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Laboratory evaluation of high-temperature sulfur removal sorbents for direct coal-fired turbines: Final report

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Jun 1987

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Research and Development Center**

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Laboratory Evaluation of High-Temperature Sulfur Removal Sorbents for Direct Coal-Fired Turbines

Final Report

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Work Performed Under Contract No.: DE-AC21-85MC22087

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ABSTRACT

Direct coal-fired turbine concepts currently being developed require substantial levels of sulfur removal from high-temperature gas streams. Calcium-based sorbents, limestones, dolomites, limes and lime hydrates, are capable of sulfur removal in direct coal-fired turbine combustor environments at temperatures up to 1200°C. Two types of desulfurizer processes are considered in this report using calcium-based sorbents: fluidized bed desulfurizers using coarse sorbent particles (300-1000 μm), and entrained desulfurizers using fine sorbent particles (1-40 μm). Small-scale laboratory tests were performed on a variety of calcium-based sorbents to determine the kinetics of sulfation and sulfidation over ranges of conditions applicable to both types of desulfurizer processes. Correlations are developed in the report for the effect of pressure, temperature, and particle size. Engineering models are also developed for both desulfurizer types that incorporate the laboratory reaction kinetics and predict potential commercial performance and performance trends. It is concluded that both desulfurizer concepts can be effective in direct coal-fired turbines, with calcium-to-sulfur molar feed ratios ranging from 1.5 to 3.0, if the correct calcium-based sorbent is selected, and if applicable design and operating conditions are identified. Both desulfurizer concepts have limitations and key development requirements, and site and fuel specific engineering assessment is required to select the best concept for a given combustor system. The influence of the desulfurizer concepts on turbine protection, through their influence on particle loading and alkali release must also be assessed.

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The authors acknowledge the outstanding test work and equipment maintenance of W. F. Kittle and C. A. Hughes, who applied much timely imagination to this program. The very reliable analytical chemistry contribution of M. L. Theodore is also noted. Finally, the guidance of Suresh C. Jain, the METC COTR, in the performance of this program and in the preparation of this report is acknowledged.

LIST OF ACRONYMS

AFBC: Atmospheric-pressure Fluidized-Bed Combustion
PFBC: Pressurized Fluidized-Bed Combustion
LIMB: Limestone Injection with Multistage Burners
CAFB: Chemically Active Fluidized Bed Process
KRW: KRW Energy Systems, Inc.
EPA: U.S. Environmental Protection Agency
CURL: Coal Utilization Research Laboratory
IEA: International Energy Agency
EER: Energy and Environmental Research Corporation
STP: Standard Temperature and Pressure

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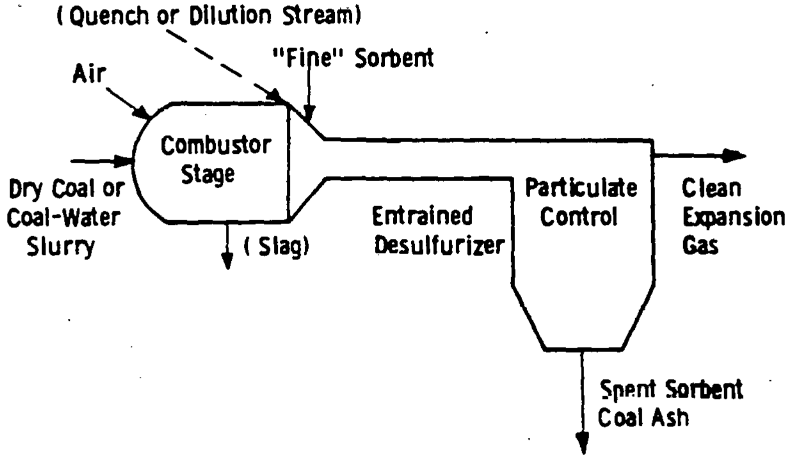
1. EXECUTIVE SUMMARY

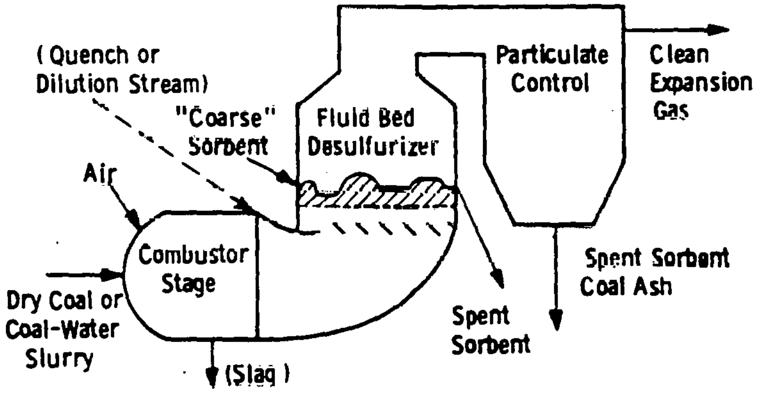
This report projects the performance and identifies the major issues in the use of calcium-based sorbents for sulfur removal in direct coal-fired turbine systems. This is accomplished by laboratory measurements of sulfur removal rates, development of kinetic correlations, and model estimates of desulfurizer behavior.

Two generic types of sulfur capture processes are of potential interest to direct coal-fired turbine systems: the fluidized bed desulfurizer, using relatively coarse sorbent particles on the order of 300 to 1000 microns in diameter, and the entrained desulfurizer, using relatively fine sorbent particles on the order of 1 to 40 microns in diameter. Both of these desulfurizers could be placed in either a rich stage (i.e., with excess fuel) of the turbine combustor to remove primarily H_2S (sulfidation), or in a lean stage (i.e., with excess air) of the combustor to remove SO_2 (sulfidation). The process concepts are illustrated in Figure 1. Primarily "external" desulfurization stages are considered in this study -- that is, stages where significant combustion does not occur and where the temperature and gas composition are relatively well defined and nearly constant throughout, as compared to "in-situ" desulfurization stages (slagging stages with sorbent injection for example) where the temperature and gas composition change radically within the stage. Indirect information, though, is provided by this program that reflects on the in-situ stage behavior.

This report is arranged in two major sections. The first section considers the fundamental kinetics and the commercial performance of coarse calcium-based sulfur sorbents in the fluidized bed desulfurizer environment. The second is devoted to the fine calcium-based sulfur sorbents in the entrained desulfurizer.



Entrained Desulfurizer Concept



Fluid Bed Desulfurizer Concept

Figure 1 — Concepts for Sulfur Removal in Direct Coal-Fired Turbines

Overall, both desulfurizer concepts can be effective in direct coal-fired turbines if the correct calcium-based sorbent is selected and if applicable design and operating conditions are identified. Both concepts have limitations and key development requirements. Site and fuel specific engineering assessment is required to select the best concept for a given combustor system.

COARSE PARTICLE, FLUIDIZED BED DESULFURIZER

Seven sorbents were selected for the testing in the coarse particle phase of the program: 2 dolomites (Plum Run, and Tymochtee), 3 limestones (Greer, Mississippi, and Vicron), and 2 dolomitic limestones (Highland, Carbon).

Thirty-six tests with the sorbents were conducted in SO_2 to determine the effect of sorbent type, sorbent particle size, and temperature on the sulfation kinetics. The experimental technique was shown to give reproducible and consistent results. The dolomites were found to degrade slightly in performance as the temperature was increased from 1000 to 1200°C; the two dolomitic limestones, Highland and Carbon, were found to improve or nearly maintain the same reactivity as the temperature was increased; and the three limestones were found to degrade extensively as the temperature was increased.

Six tests with precalcined sorbents using a procedure designed to improve sulfur removal performance in atmospheric pressure fluidized bed combustion were completed. No improvement in reactivity, or in some cases reduced reactivity, was found.

Three tests in H_2S were conducted with the coarse particles. These tests indicated the beneficial effect of increased pressure. The sulfidation rate was found to be comparable to the sulfation rate, but the ultimate extent of calcium conversion was considerably higher for sulfidation than in sulfation.

The sulfur removal kinetics were evaluated by first performing a dimensional analysis of the data collected. This analysis implies that the initial reaction period is controlled by the rate of solid phase diffusion while the subsequent period is controlled by pore diffusion. Secondly, the reaction kinetics were correlated using standard multiple regression techniques.

An engineering model of the fluidized bed desulfurizer has been developed as a tool for evaluating potential performance based on laboratory reaction kinetics. The calcium-to-sulfur feed ratio required to achieve a given level of sulfur removal efficiency was determined as a function of the sorbent type, the average particle diameter in the bed, the bed depth, the superficial gas velocity through the bed, and the bed temperature. For SO_2 removal, both dolomites tested are found to give acceptable calcium-to-sulfur ratios (from 1.8 to 3.0 depending on the particle size selected) at a temperature of 1200°C, and gas residence times in the bed of 0.5 seconds. It is expected that almost all dolomites will show this type of general acceptability. The dolomitic limestones, Highland and Carbon, were found to yield results as good as or better than the dolomites (calcium-to-sulfur molar feed ratio of 1.8 to 3.6 depending on the particle size selected) at a temperature of 1200°C. The other three limestones result in unacceptable performance at temperatures greater than 1000°C.

The commercial sulfur removal performance in H_2S is expected to be comparable to that in SO_2 removal, where at 1100°C both sorbents tested would require very acceptable sorbent feed rates (1.5 for Plum Run dolomite and 2.8 for Highland limestone) using a 0.5 second gas residence time in the fluidized bed.

FINE PARTICLE, ENTRAINED DESULFURIZER

Three sorbents were selected for testing based on their performance variation found in the coarse particle testing -- Plum Run dolomite, Highland limestone and Vicron limestone. In this experimental technique the sorbent particles are first heated to the test temperature, calcining them completely and essentially sintering their surface to a minimum and stable value. The nature of the sorbents tested, then, are categorized as "sintered" sorbents and are not directly representative of freshly calcined, high surface area sorbents.

Thirty-two tests were conducted on sulfation at temperatures of 1100 and 1200°C, pressures of 6 and 12 atmospheres, particle sizes of <400 mesh and <20 micron diameter, and gas-particle contact times of 0.75 and 1.5 seconds. The test results were found to be reproducible and it was confirmed that the sulfation rate is first-order in the SO_2 mole fraction in the gas. The relative reactivity of the sorbents is qualitatively the same as in the coarse particle testing.

A commercial lime hydrate and hydrated Vicron limestone were also tested in sulfation. Because of the sintered nature of the sorbents in these tests, the hydrated sorbents behaved almost identically to the raw limestone sorbent tests.

Eight tests were conducted to measure the sulfidation kinetics of Plum Run dolomite and Highland limestone. The tests were done at 1100°C. The sulfidation rate of Plum Run dolomite was slightly greater than the sulfation rate was under comparable conditions, but the sulfidation rate of Highland limestone was much greater than the sulfation rate. The sulfation and sulfidation kinetics were correlated with the operating conditions.

An evaluation of the commercial performance of entrained desulfurizers using calcium-based sorbents was made based on a simple entrained contactor model. The model results indicate that the calcium-to-sulfur ratio required is dependent on the sulfur removal efficiency, the SO_2 or H_2S mole fraction in the gas at the point of sorbent injection, the particle residence time in the entrained desulfurizer, and the sorbent type.

The performance of sintered sorbents were first evaluated using the kinetic correlations directly. It is concluded that sintered sorbents are probably only acceptable in cases where high sulfur coals are used, and high sulfur removal efficiencies are not required, and relatively long particle residence times are available (on the order of 1 second). Their use in a rich zone with H_2S is greatly favored over their use in a lean zone. The sintered dolomites and limestones perform comparably on a weight feed basis for SO_2 removal, but the sintered limestones perform better than the sintered dolomites on a weight feed basis for H_2S removal.

Active, high surface area sorbents were evaluated by combining the sintered sorbent kinetics with the transient surface area generated during calcination.

Projections of the performance of dolomites, limestones, and high surface area limes and lime hydrates injected into rich and lean combustor zones were developed. In general, it is found that there is no benefit from increasing the gas residence time in the entrained desulfuriser to values greater than 0.5 seconds. Low-sulfur coals require higher calcium-to-sulfur ratios than do high-sulfur coals, but the mass feed rate of sorbent is nearly independent of the coal sulfur content, depending only on the temperature, pressure, particle diameter and sulfur removal efficiency. Lower sorbent consumption can result with H_2S removal than with SO_2 removal, and higher operating pressures significantly reduces the sorbent consumption. Increasing the gas temperature from 1000 to 1100°C results in a small increase in sorbent consumption, while increasing the temperature to 1200°C results in a higher consumption.

High surface area limes and lime hydrates result in the smallest sorbent consumption and have the potential for operation with the smallest gas residence times. Limestones and dolomites are comparable for SO_2 removal on a weight feed basis, but limestones are superior to dolomites for H_2S removal. A major tradeoff exists between the sorbent consumption rate, the cost of the sorbent material (high surface area limes and lime hydrates being much more expensive than limestone and dolomites), the gas residence time in the desulfuriser, and the sorbent particle size. This can only be resolved by evaluating the design and cost of specific direct coal-fired turbine systems, and will be site and fuel sensitive in many respects.

Key questions remain as to the actual occurrence of H_2S in the rich zones (versus COS, CS_2, and SO_2), the ability to feed and disperse fine sorbent particles effectively into a hot, pressurised gas stream so that good gas-particle contacting is achieved over short residence times, and the possibility of ash-sorbent interactions and particle deposition in the combustor. The impact of potentially "sticky" particles on particulate collection devices, and the protection of turbine components (erosion, corrosion and deposition) must also be resolved.

1. INTRODUCTION

The Department of Energy (DOE), Office of Fossil Energy, is guiding and sponsoring the development of a variety of advanced power generation technologies based on the utilization of coal. One such technology is the direct coal-fired turbine, using existing gas turbine machines, or "ruggedized" versions of these machines, in series with advanced coal combustors. Applications range from locomotive transportation to electric utility power generation. Much of the development effort in the direct coal-fired turbine program is related to developing advanced coal combustors that have, combined with the characteristics of high combustion efficiency and low NOx generation, the potential for significant simultaneous removal of ash and sulfur contaminants.

The options in this technology that can be considered are many: 1) coals can be cleaned of ash and sulfur to various levels and can be fed as coal-water slurries or in dry form; 2) combustion may be performed in a staged manner going from rich to lean zones, and slagging phenomena may be incorporated to remove ash; 3) stages of particulate control may be inserted into the combustor ranging from cyclones to high-temperature filters; 4) stages of sulfur control may be inserted into the combustor either "in-situ" with the combustion stages (as in a slagging combustor with sorbent injection) or separate from the combustion phenomena (as in an "external" zone following complete combustion). Sulfur control may occur in a stage where conditions are predominantly reducing (i.e., H_2S is the major sulfur species) or in a stage that is predominantly oxidizing (i.e., SO_2 is the major sulfur species). Sorbent-gas contacting may be in a fluidized bed, using relatively coarse sorbent particles, or in an entrained bed, using relatively fine sorbent particles. Performance must achieve control levels for sulfur species and particulate that are sufficient to meet turbine protection limits and environmental regulations.

Because calcium-based sorbents are the cheapest and most highly available sulfur sorbent materials that have the potential for high-temperature, high-pressure sulfur capture, their use in direct coal-fired turbine power systems is of prime interest. The term calcium-based sorbent includes raw, untreated limestones and dolomites as well as processed forms such as limes and hydrated limes. It is known that calcium-based sorbents will be thermodynamically capable of capturing sufficient sulfur at temperatures within the range of interest to direct coal-fired turbines. Kinetically, the use of calcium-based sorbents may be limited to lower temperatures than the thermodynamic limits due to phenomena relating to sintering. The gas residence times in the desulfurizer that meet economic criteria for the power system will also define kinetic limits on calcium-based sorbents in direct coal-fired turbines. It was the major purpose of this study to determine the effect of high temperature operation on the sulfur capture potential of calcium-based sorbents.

This report considers "external" desulfurizers rather than "in-situ". The in-situ arrangements, such as slagging zones with sorbent injection, have temperatures and gas compositions that change dramatically with position, and ash-sorbent interaction may be great. External arrangements have temperatures and gas compositions that are relatively fixed throughout the desulfurizer, and little interaction between combustion and desulfurization occurs. The information presented in this report relates only indirectly to the more complex environment of in-situ desulfurization.

The report is arranged in two major sections. The first is devoted to the kinetics of "coarse" calcium-based sorbent particles (300 to 1000 microns in diameter) in sulfur dioxide and in hydrogen sulfide gases, and evaluates their performance in fluidized bed desulfurizer contactors. The second major section considers "fine" calcium-based sorbent particles (less than 40 microns in diameter), measuring their kinetics in sulfur dioxide and hydrogen sulfide gases and evaluating their commercial performance in entrained desulfurizer contactors. The program must be described as preliminary in its consideration of kinetics in that the minimum data required to propose correlations are produced. The consideration of commercial performance must be described as conceptual because the use of ideal contactor models is made to scale the laboratory kinetic data to large-scale performance estimates. Thus, performance potential, performance trends and required test directions are identified in the program.

2. COARSE CALCIUM-BASED SORBENT PARTICLE FOR SULFUR REMOVAL

Section 2 is devoted to the evaluation of coarse, calcium-based sorbents for sulfur removal from the combustion products of direct coal-fired turbines. Coarse particles are defined as having a size potentially applicable to fluidized bed desulfurizers, say in the range of 300 to 1000 microns in diameter. Background information on the use of these sorbents is extensive, based mostly on studies from fluidized bed combustion, and is presented to explain the rationale for the test effort. The test sorbent properties, the test plan, and the testing equipment and procedures are described. Test results are presented in three areas: untreated sorbent kinetic performance with sulfur dioxide; pretreated sorbent kinetic performance with sulfur dioxide; and untreated sorbent kinetic performance with hydrogen sulfide. The kinetic data is evaluated and a conceptual evaluation of fluidized bed desulfurization for direct coal-fired turbines is discussed.

2.1 BACKGROUND

Subsection 2.1 summarizes the available background information on the "sulfation" of coarse calcium-based sorbents (the conversion of calcium oxide to calcium sulfate on contact with sulfur dioxide), and on the "sulfidation" of coarse calcium-based sorbents (the conversion of calcium oxide to calcium sulfide on contact with hydrogen sulfide), to identify the existing data gaps for the use of these sorbents in direct coal-fired turbine power systems.

The thermodynamic limits for SO_2 and H_2S capture are shown in Figure 2.1 using standard thermodynamic data available in the literature. This figure plots the quantity (1-E) (1 minus the sulfur removal efficiency) times X_s (the weight fraction sulfur in the coal) as a function of the temperature of the zone of sulfur capture in the combustor system. For a 3 wt% sulfur coal and 90% sulfur removal this quantity is 0.003. A broad band is shown for H_2S capture to reflect the possible range of performance for both dry coal and coal-water slurries using either water or steam injection for quenching to the rich zone temperature. A similar band is shown for SO_2 capture, where the band width is indicative of the range of oxygen levels that might appear in the combustion products for both dry coal and for coal-water slurries. Again considering a 3 wt% sulfur coal and 90% sulfur removal, the figure indicates that efficient H_2S capture in a rich zone of a direct coal-fired turbine will be limited to temperatures less than about 1100°C, and will also be limited to relatively high sulfur coals. SO_2 removal may be limited to temperatures less than about 1200°C and will be suitable for lower sulfur coals than those for H_2S removal. These thermodynamic limits set the temperature range of concern for kinetic studies.

2.1.1 Sulfation Background

It is well known that calcium oxide (CaO) when contacted with sulfur dioxide (SO_2) at relatively high temperatures (greater than 500°C) is converted to calcium sulfate ($CaSO_4$), and this conversion is the basis for the use of calcium-based materials as sulfur sorbents in a variety of processes. Natural calcium-containing materials, limestones (primarily $CaCO_3$) and dolomites (primarily $CaCO_3 \cdot MgCO_3$) exist in the carbonate form, and on heating to their transition temperature will calcine to the oxide form:

$$CaCO_3 \Rightarrow CaO + CO_2 \quad \text{(calcined limestone or lime)} \tag{2-1}$$

$$CaCO_3 \cdot MgCO_3 \Rightarrow CaCO_3 \cdot MgO + CO_2 \text{(half-calcined dolomite)} \tag{2-2}$$

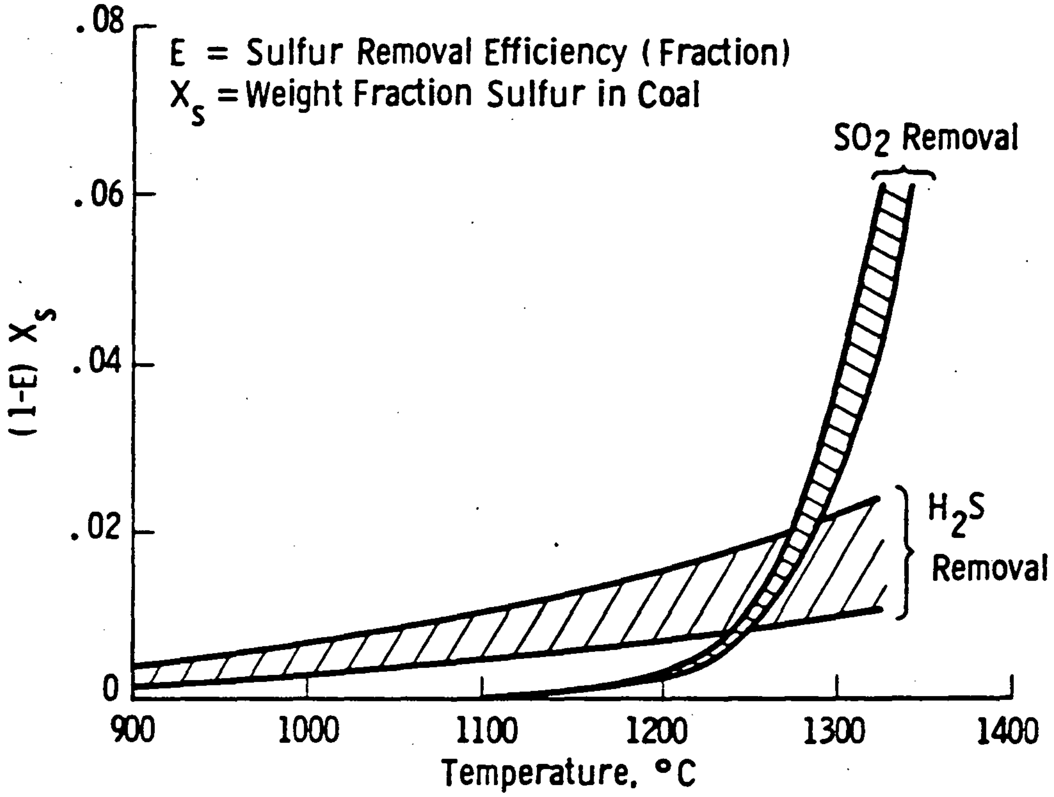


Figure 2.1 — Equilibrium SO_2 and H_2S Removal at 10 Atmospheres Pressure

$$CaCO_3 \cdot MgO \Rightarrow CaO \cdot MgO + CO_2 \quad \text{(fully-calcined dolomite)} \qquad (2\text{-}3)$$

The overall sulfation reaction is, for uncalcined sorbent

$$CaCO_3 + SO_2 + \frac{1}{2} O_2 \Rightarrow CaSO_4 + CO_2 \qquad (2\text{-}4)$$

or, for calcined sorbent

$$CaO + SO_2 + \frac{1}{2} O_2 \Rightarrow CaSO_4 \qquad (2\text{-}5)$$

While these overall reactions are known, the detailed mechanisms involved in the reaction are still speculative.

Several phenomena play an important part in the sulfation of coarse particles of calcium-based sulfur sorbents. The key ones with respect to the current topic are based on these observation

-- the temperature and gas composition during calcination impact the sulfation behavior

-- the sorbent pore and grain structure is transient (sulfate shell formation, crystal growth, sintering, interaction with coal species)

-- the sulfation rate depends on the pressure, temperature, and gas composition (sulfation rate is defined in this report as the fraction of the sorbent calcium converted to calcium sulfate per unit of time)

Much of the current understanding of these observations results from related development programs that have applied coarse, calcium-based sorbents for sulfur control at high temperatures. These include programs in atmospheric-pressure fluidized-bed combustion (AFBC), programs in pressurized fluidized-bed combustion (PFBC), and, to some extent, early programs (pre-1975) in conventional furnace sorbent injection (the LIMB process -- Limestone Injection with Multistage Burners) where relatively coarse particles were considered. These programs have generated kinetic data, correlations, and understanding of the above observations under conditions that are close to those required by the direct coal-fired turbine.

Characteristic operating conditions required for the direct coal-fired turbine and ranges of experience for the related technologies are shown in Table 2.1. Note from Table 2.1 that the coarse sorbent particle sulfation rate is slow and the particles reside in the desulfurizer for hours. This table indicates not only the complimentary areas between these technologies, but also clearly shows where gaps are found in the existing data base. The data gaps between the needed kinetic information and the existing information is seen to be specifically in the area of higher temperatures, from 1000 to 1200°C, under conditions of elevated pressure.

The major factors relating to the sulfation of coarse calcium-based sorbents for direct coal-fired turbines are the effect of temperature, the effect of pressure, the effect of sorbent type, and the effect of the gas composition. A brief discussion of the background information in each of these areas is presented.

2.1.1.1 Effect of Temperature

Several observations on coarse particle calcium-based sorbent sulfation guide this program. There are at least three interrelated phenomena that impact the overall sulfation rate and are highly temperature dependent: 1) the effect of temperature on the rate of calcination (calcination rate is defined in this report as the fraction of the sorbent calcium converted to CaO per unit of time) and the pore

Table 2.1 — Coarse Sulfation Operating Conditions and Related Experience

	Conditions For Direct Coal-Fired Turbine	Experience Fluidized-Bed Combustion	Early Experience Sorbent Injection (LIMB)
Pressure (atm)	6 to 20	1 to 20	1
Temp (°C)	up to 1200	750 to 1000	up to 1700
Particle Diameter (microns)	300 to 1000	50 to 2000	1 to 1300
Particle Residence time(hr)	5 to 50	5 to 100	up to 2
Sorbent Type	limestones, dolomites, limes	limestones, dolomites, limes	limes, hydrates, dolomites limestones,
Calcining Conditions	high-temperature with low CO_2-pressure	medium-temp with low to high CO_2-pressure	high-temperature with high CO_2-pressure

size distribution that results from calcination; 2) the sintering that occurs as a function of time due to both surface diffusion and bulk diffusion in the solid phase; and 3) reversible adsorption on the pore surfaces.

The well-known experience in atmospheric-pressure fluidized-bed combustion (AFBC) indicates that temperature is a critical parameter, and an "optimum" temperature exists, depending on the specific sorbent, at about 840°C, above which and below which the sulfation performance of the sorbent will drop significantly. This behavior has been demonstrated in both fluidized-bed combustion development units and in laboratory equipment (1-5). Several explanations have been given for this optimum temperature behavior ranging from thermodynamic influences to catalytic influences, but it has been clearly shown that the major reason is related to the pore structure that is generated in the particle when it calcines -- an optimum pore structure for sulfation is formed at the temperature where a balance exists between fine pores and large pores (6,7).

Early LIMB studies demonstrated the severe impact of high temperatures on limestone sulfation performance with fairly coarse sorbent particles (8). Sintering due to surface diffusion is sensitive to gas components that are adsorbed on the pore surfaces (CO_2, H_2O, H_2, etc). Sintering due to bulk solid-phase diffusion is sensitive to impurities in the solids. Some reversible effects of temperature on sorbent reactivity have also been observed, indicating that lowering the temperature of a saturated sorbent particle could result in further sulfation (9). Thus, irreversible sintering-type effects may not be the sole reason for loss of sorbent activity with increased temperature (10).

An optimum temperature, as observed in AFBC, is not observed in PFBC when the gas pressure is elevated above about five atmospheres, at least at temperatures up to 1000°C (11). The explanation for the difference between atmospheric-pressure and pressurized behavior is that the performance is again controlled by the physical pore structure that is developed when the sorbent is calcined, and the calcination behavior is controlled by two parameters: the temperature and the CO_2 partial-pressure. When the CO_2 partial-pressure is low, as at atmospheric pressure, the higher temperatures result in smaller pores that are less conducive to SO_2 diffusion and more conducive to sulfate layer plugging. When the CO_2 partial-pressure is high, as at elevated pressures, even higher temperatures will not generate the fine pore structure, and large, easily sulfated pores exist. This observed behavior is the basis for the precalcination scheme proposed by Westinghouse to generate higher activity calcium-based sorbents for atmospheric pressure fluidized-bed combustion (6).

These results lead to the exception that the higher temperatures representative of direct, coal-fired turbines may not hinder the use of calcium-based sorbents because of the counteracting effect of the elevated pressure. Surely a detrimental temperature effect will exist at some temperature, due to both particle sintering and because of thermodynamic limitations on the sulfation reaction leading to increased thermal decomposition. It has not been previously shown, though, if temperatures of up to 1200°C, that are thermodynamically acceptable, will be acceptable for sulfation from a kinetic standpoint.

2.1.1.2 Effect of Pressure

Another important conclusion from previous pressurized thermogravimetric balance studies is that pressures above about 6 atmospheres do not exert much influence on sulfation behavior for coarse sized particles (12). Pressurized fluidized-bed combustion testing has also demonstrated a limited pressure impact (13). The explanation for this observed behavior is based on the predominant pore diffusion rate controlling step with coarse sorbent particles.

2.1.1.3 Effect of Sorbent Type

It is observed in all of the related technologies using natural, calcium-based sorbents for high temperature sulfur control that the specific type of sorbent exerts a strong influence on the sulfation performance (14-16, 6), and selection of a specific quarry to supply a sorbent for commercial plant becomes an important issue. The chemical composition (calcium content, magnesium content, inert content, and the nature of the inert species), and the physical structure of the sorbent (grain size, pore size distribution, internal surface area, etc.) may all contribute to this diversity of behavior. The relation between these sorbent parameters and the sulfation performance is not currently understood, although the trends are generally predictable. The least understood factor is the relationship between the sorbent properties and its sensitivity to temperature.

2.1.1.4 Effect of Gas Composition

The rate of the sulfation reaction is known to be first-order in the sulfur dioxide concentration over a wide range of concentrations, so long as these are far above the equilibrium sulfur dioxide concentration at the prevailing temperature and pressure.

The effect of carbon dioxide concentration on the sorbent effectiveness is known to be through its impact on the calcination behavior and the resulting pore structure. The carbon dioxide concentration exerts less impact as the total pressure increases. Also, an important thermodynamic transition exists between the calcined and the uncalcined states of the sorbent that is influenced by the carbon dioxide concentration (reactions 1 - 3). At carbon dioxide concentrations above the equilibrium for calcium carbonate decomposition most limestones have such a low porosity that they are quite ineffective for sulfur removal. Dolomites, on the other hand, will have a significant voidage even if the calcium carbonate is not decomposed because the magnesium carbonate fraction of the dolomite calcines at a significantly lower temperature (reaction 2). Thus, half-calcined dolomites are very reactive. At the conditions of the direct coal-fired turbine full calcination is generally thermodynamically favored, so this transition will be of little concern.

The oxygen partial-pressure in the gas phase has been found to be unimportant, the reaction rate being zero-order in oxygen (11). There are some reports that the oxygen concentration is important through its interaction with SO_3 formation (18, 19), although this effect has not been demonstrated. Other major gas phase species, such as H_2O and N_2 are not expected to have any impact on the sulfation reaction at the concentrations typical to the direct coal-fired turbine, although H_2O may induce increased rates of sintering.

Trace species released from coal have been conjectured to have impacts on the sorbent behavior. While it is known that alkali salts can interact with calcium-based sorbents, when at relatively large concentrations, to increase the pore sizes (20), the sulfation results in fluidized-bed combustion tests where the sorbent particles are intimately in contact with coal ash closely correspond to the sulfation performance of sorbents in laboratory tests that have not been exposed to coal species (21, 22). Thus, at temperatures up to 1000°C, coal species interaction is an effect of limited importance.

2.1.2 Sulfidation Background

The sulfidation reaction (the conversion of calcium oxide to calcium sulfide on contact with hydrogen sulfide) for coarse particles has been studied somewhat less extensively than the sulfation reaction. The overall reaction for sorbent sulfidation is

$$CaCO_3 + H_2S \Rightarrow CaS + H_2O + CO_2 \qquad (2\text{-}6)$$

for uncalcined sorbent particles, and

$$CaO + H_2S \Rightarrow CaS + H_2O \qquad (2\text{-}7)$$

for calcined sorbent particles. As with the sulfation reaction, the mechanisms involved in the sulfidation reaction are not completely understood. The MgO component of dolomites does not sulfide to a significant extent at the conditions of interest.

Experience with the sulfidation reaction comes mainly from applications related to the gasification of fossil fuels (heavy oils and coal) and conditions have ranged from atmospheric pressure to pressures of 30 atmospheres at temperatures up to 1100°C. An application example at atmospheric pressure is the CAFB process (Chemically Active Fluidized Bed) for gasifying heavy oils and low-rank coals at atmospheric pressure to retrofit existing boilers. Limestone was used as the sulfur sorbent directly in the fluidized bed gasifier (23, 24). An application at elevated pressures is the KRW coal gasifier, used to generate low- and medium-Btu fuel for industrial uses or for combined cycle applications. Dolomites and limestones are used either directly in the gasifier or in an external fluidized bed desulfurization stage (25, 26). The major factor differentiating the existing process experience from the conditions needed in the direct coal-fired turbine application is the higher temperature level needed and the much less intimate contact between coal and sorbent particles in the direct coal-fired turbine.

A number of laboratory kinetic studies have been reported and these provide a detailed background for the effects of the major parameters (27-33). Conclusion drawn from these studies are summarized here.

2.1.2.1 Effect of Temperature

The effect of temperature on the initial reaction rate in the range of 700 to 1000°C is very limited, especially at elevated pressures, although the extent of conversion of calcium oxide to calcium sulfide tends to drop as the temperature is increased in this range. This reflects the fact that structural changes in the sorbent particle during reaction are not as important in the sulfidation reaction as they are in the sulfation reaction, and the reaction is not chemical reaction rate controlled. It is felt that the sulfidation reaction is less sensitive to sorbent pore structure and to temperature than is the sulfation reaction because of the smaller molecular volume of CaS compared to $CaSO_4$, also resulting in the extent of sorbent particle utilization being larger with the sulfidation reaction than with the sulfation reaction.

2.1.2.2 Effect of Pressure

Increasing the pressure from atmospheric to elevated levels has a dramatic impact on the rate of sulfidation, the rate being proportional to the total pressure to the 0.3 to 0.5 power depending on the specific sorbent.

2.1.2.3 Effect of Sorbent Type

Dolomites and limestones as groups are found to behave significantly different in sulfidation, although not as much differently as they do in sulfation. Likewise, the differences between specific limestone types is not as great in sulfidation as it is in sulfation. Limestones having poorer reactivity with SO_2 tend to also have poorer reactivity with H_2S. As in SO_2, uncalcined limestones are not reactive, while half-calcined dolomites are very reactive. Specific dolomite types tend to behave very similarly during sulfidation.

2.1.2.4 Effect of Gas Composition

Hydrogen, water vapor, and carbon dioxide are all found to have small influences on the rate of sulfidation in the temperature range of 700 to 1000°C, probably due to their influence on pore structure and on the rate of sintering. The sulfidation rate is found to be first order with respect to the hydrogen sulfide concentration. Other sulfur species also exist in reducing gases to a lesser extent, COS and CS_2 for example, and the rate of reaction with these species has to be studied only to a minor degree.

2.1.2.5 Other Factors

The generation of magnesium sulfide when sulfiding dolomites, especially at higher pressures, has been confirmed, but the rate of magnesium sulfide generation is much lower than calcium sulfide generation and is hindered by water vapor. The rate of calcium sulfide generation in dolomites has generally been found to be first-order with respect to the fraction of unsulfided oxide remaining (that is, the sulfidation rate is proportional to the quantity [1 - the fraction of the calcium sulfided] to the first power). The initial sulfidation rate is lower than the initial sulfation rate, all conditions being identical, but the extent of sulfidation ultimately achieved is greater than the extent of sulfation achieved. It is found that the initial reaction rate is proportional to the sorbent particle diameter to the -0.5 to -1.0 power depending on the sorbent type.

2.1.3 Modeling Background

A multitude of particle reaction models have been proposed for the sulfation and sulfidation of calcium-based sorbents, consisting of various forms of pore, grain and homogeneous models (for example, see recent reviews of particle reaction models (34, 35)) but all have an inability to predict several key factors: 1) the calcined pore/grain structure in the sorbent as a function of the calcination conditions and the raw sorbent properties; 2) the transient pore/grain structure due to crystallite growth, sintering, sulfate layer growth, crack development, impurity interactions, etc; and 3) reversible effects due to adsorption versus nonreversible effects. While modeling activities can provide conceptual pictures of the behavior of hypothesized phenomena, they are not predictive, and they cannot be extrapolated outside of their region of data fitting. For this reason, a laboratory simulation of the reaction environment to yield direct estimates of the reaction kinetics is applied in this program rather than depend on the extreme uncertainties of particle reaction model extrapolations.

2.2 SORBENT PROPERTIES

Carbonate rocks, the source of calcium-based sulfur sorbents, are composed of the mineral forms calcite ($CaCO_3$, rhombohedral), dolomite ($CaMg(CO_3)_2$) and aragonite ($CaCO_3$, orthorhombic arrangement). Various constituents may act as binding agents for the particle grains, or crystals and impurities may be mixed with the mineral grains.

Carbonate rocks have been classified into several different groups, sometimes with conflicting definitions by different authors. Calcites are very high calcium content rocks; limestones are moderately high calcium rocks; dolomites contain a high proportion of the mineral form dolomite; and dolomitic limestones contain a significant mixture of both the calcite and the dolomite mineral forms. These are the carbonate rocks most available and suitable for high temperature sulfur removal. Detailed classifications of carbonate rocks based on geological origin have been proposed in the literature (36). The definitions used in this report are: limestones contain <5 wt% $MgCO_3$; dolomitic limestones contain 5-20 wt% $MgCO_3$; and dolomites contain >20 wt% $MgCO_3$.

Other terms have also been added to modify the carbonate rock classification with respect to the nature of the impurities in the material. For example, the terms arenaceous (high in quartz), argillaceous (high in clay), carbonaceous (high in carbon), ferriferous (containing iron), or bituminous (containing organic hydrocarbons) have been used. Because of the great range of calcium-based sorbent properties existing it is important for any exploratory program to consider as large a range of sorbent types as is practical.

The type of calcium-based sorbents that are applicable for use in a fluidized bed desulfurizer are raw limestones and raw dolomites as obtained directly from quarry sources, or specially prepared calcines of limestone, or limes, (not commercially available) having pore size distributions favorable for fluidized bed sulfur capture. Commercially produced limes have no performance advantage over the use of raw limestones, and would carry with them a large cost penalty. Commercially available hydrated forms of limestone ($Ca(OH)_2$) and dolomite ($Ca(OH)_2 \cdot MgO$) are not applicable to use in fluidized bed desulfurizers because their characteristic particle size is much too small to be used in a fluidized bed.

Westinghouse has previously investigated the sulfation and sulfidation behavior of calcium-based sorbents having the following range of characteristics:

- calcium content (wt % $CaCO_3$): 40 to 99
- magnesium content (wt % $MgCO_3$): 0.5 to 50
- inert content (wt %): 0 to 40
- Al_2O_3 (wt %): up to 10
- Fe_2O_3 (wt %): up to 4
- SiO_2 (wt %): up to 15
- Na_2O (wt %): up to 1
- K_2O (wt %): up to 3
- hydrocarbon (wt %): up to 12

No general correlation of sulfation performance versus the properties has been developed, and not enough detailed information is available to attempt a comprehensive correlation.

For the test program conducted and reported on in this program a broad range of sorbent types have been selected using previous tests as the basis for selection. The sorbents selected are listed in Table 2.2. With the definitions used in this report two of the sorbents are dolomites (Plum Run and Tymochtee), two are dolomitic limestones (Highland and Carbon) and the remaining three are limestones.

Chemical analyses for calcium and magnesium were performed by EDTA titrations. Grain size has been determined by standard thin

Table 2.2 — Coarse Test Sorbent Properties

Sorbent	Composition (wt %)			Grain size	Porosity	Surface area
	Ca	Mg	Inert	(microns)	(%)	(m^2/gm)
Tymochtee dolomite	20.2	12.9	4.6	30-45	10.2	0.80
Plum Run dolomite	20.1	13.0	4.5	75-90	11.0	0.43
Highland limestone	34.1	3.8	1.5	200-250 75-90	6.5	0.70
Carbon limestone	35.1	2.6	3.2	9-27	6.2	0.43
Mississippi limestone	38.3	1.4	0.6	200-250	11.8	0.55
Greer limestone	37.8	1.0	2.0	25-40	8.6	0.47
Vicron limestone	37.8	1.5	0.3	360-730	3.2	0.03

section optical methods (ASTM E112-80 intercept procedure). Porosity and surface area has been measured using standard mercury porosimetry on a Micromeretics Autopore 9200 porosimeter. The surface areas shown in the table differ from those that would be obtained by BET methods, and they apply only to the coarse particles sizes considered. Detailed measurement results are presented in Appendix A.

All of the sorbents selected have been previously tested by Westinghouse on thermogravimetric balance equipment for use in fluidized-bed combustion applications. A standard test used for ranking the sorbents has been conducted previously on all of them except for Vicron limestone. The standard test consists of heating a 20 mg sample of the sorbent sized at 1000 to 1190 microns suspended in the thermogravimetric balance. The sample is heated to 840°C in 15% carbon dioxide/85% nitrogen at a rate of 10°C/min at atmospheric pressure. After complete calcination, about 20 minutes, a sulfation atmosphere of 0.5% SO_2, 4% O_2, and N_2 is switched on and the sample weight is recorded as a function of time. The sorbents are ranked according to their performance in this test. The ranking results are: Tymochtee, highly reactive; Plum Run, average reactivity; Highland, medium-low reactivity; Carbon, average reactivity; Mississippi, medium-high; Greer, medium-low; and Vicron, not tested, but expected to be of low reactivity. Thus, a diversity of standard sorbent rankings is also represented by the selected sorbents.

Several of the selected sorbents have also been tested in development facilities for the related technologies. Carbon limestone (or Lowellville limestone) has been extensively tested on the Babcock & Wilcox 6 ft by 6 ft atmospheric-pressure fluidized-bed combustor under EPRI sponsorship. It has also been used in some circulating fluidized-bed combustion test work. Tymochtee dolomite has been extensively tested by Exxon on a pressurized fluidized-bed combustion Miniplant under EPA sponsorship. Plum Run dolomite has been extensively tested on the CURL pressurized fluidized-bed combustion test facility and in the Grimethorpe IEA PFBC facility. Greer limestone has been a test material in many AFBC programs, including the Rivesville plant. Vicron limestone has been used in several conventional furnace injection programs.

A listing of the sorbent suppliers for these materials are shown in Appendix A.

2.3 OBJECTIVES AND TEST PLAN

The objectives of the program were to assess the potential of coarse calcium-based sorbents for use in a fluidized-bed desulfurizer for direct coal-fired turbines. The specific program objectives were to:

-- test the reactivity of a variety of coarse calcium-based sorbents at temperatures up to 1200°C and pressures up to 10 atmospheres

-- generate kinetic correlations as a function of temperature, particle size, sorbent type and pretreatment conditions

-- develop commercial design equations for the sizing and performance of fluidized bed desulfurizers

-- perform a preliminary assessment of the performance potential of calcium-based sorbents in fluidized-bed desulfurizers for direct coal-fired turbines

The following specific questions were addressed:

-- Can satisfactory sulfur reactivity be obtained in the temperature range of 1000 to 1200°C, both for SO_2 and H_2S capture? If so, for what sorbent types?

-- Does precalcination of the sorbent by previously determined methods improve the tolerance of the sorbents to high temperature?

The sets of test series were: one for SO_2 capture with raw, untreated sorbents, a second for SO_2 capture with precalcined sorbents, and a third for H_2S capture with raw sorbents. The test matrices were:

1) SO_2 capture with raw, untreated sorbents

Sorbent Types

- Tymochtee dolomite
- Plum Run dolomite
- Highland limestone
- Carbon limestone
- Mississippi limestone
- Greer limestone
- Vicron limestone

Simulation Gas Composition

- Carbon dioxide 8 mole %
- Oxygen 10 mole %
- SO_2 0.5 mole %
- Nitrogen 81.5 mole %
- Total pressure 10 atmospheres

Test Conditions

Temperature (°C)	Particle Diameter (mesh)
1000	-40 +45
	-16 +18
1200	-40 +45
	-16 +18
1100	-20 +25

2) Precalcined Sorbent Tests

Sorbent Types

Precalcination is most effective for limestones, but not for dolomites. Three limestones were selected:

- -- Vicron limestone
- -- Greer limestone
- -- Carbon limestone

Precalcination conditions

The sorbents were precalcined on a thermal gravimetric balance at conditions of 60 mole % CO_2, 950°C, and atmospheric pressure, conditions found to give nearly optimum sulfation performance in atmospheric pressure fluidized-bed combustion.

Simulation gas composition

The same composition as in the raw sorbent test sequence was used.

Test Conditions

Temperature (°C)	Particle size (mesh)
1100	-20 +25
1200	-40 +45

3) Hydrogen Sulfide Tests

These tests provided an estimate of the potential performance of the sorbents with H_2S in a rich stage of the combustor.

Sorbent Types

- -- Plum Run dolomite
- -- Highland limestone

Simulation gas composition

- CO_2 8 mole %
- H_2S 0.3 to 0.46 mole %
- balance nitrogen
- total pressure 1 to 5 atmospheres

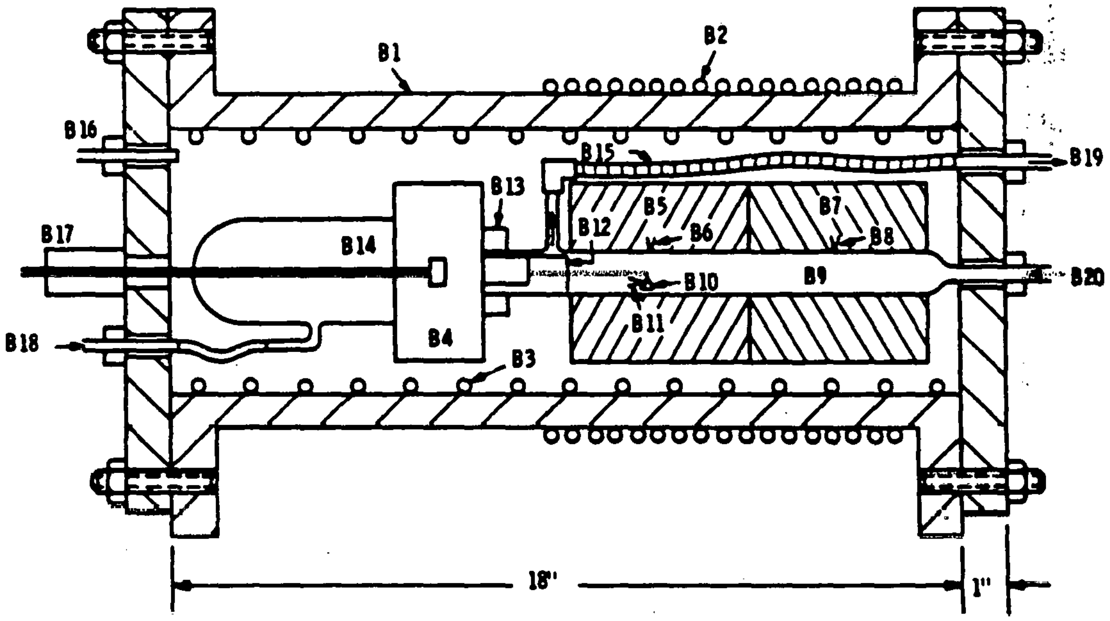
Test conditions

Temperature (°C)	Particle Size (mesh)
1100	-16 +18

2.4 TEST EQUIPMENT AND PROCEDURES

Sulfation rates were determined as a function of the sorbent utilization (fraction of the calcium oxide sulfated) from data collected on a DuPont 951 thermogravimetric balance. The thermogravimetric balance provides a direct determination of reaction rate by measuring sample weight continuously during reaction. The rates are reported in this study as the fraction of the total sample calcium being sulfated per minute.

This system has been described previously by Westinghouse (12). The balance has been adapted for operation with corrosive gases by a simple modification to gas flow paths. A baffle separates the reactant gas flow, entering through a preheater region before passing over the balance mechanism. Both reactant and purge gases exit the reaction tube on the balance side of the baffle. The reaction tube has been extended to twice the standard quartz tube length in order to accommodate two furnaces wired for parallel control. The two-furnace system has doubled the heated reactant gas zone. Several modifications have been made to the furnace materials to accommodate the higher temperature range. The balance, reaction tube, and furnaces are mounted in a stainless steel pressure shell (Figure 2.2) capable of operation to 30 atm. Gas flow rates were controlled by linear mass flow controllers (Figure 2.3).



KEY

B1	Stainless Steel Pressure Vessel
B2	External Cooling Coil
B3	Internal Cooling Coil
B4	TG Balance Housing
B5	Reaction Zone Furnace
B6	Reaction Zone Thermocouple
B7	Preheat Zone Furnace
B8	Preheat Zone Thermocouple
B9	Quartz Reaction Tube
B10	Sample Basket
B11	Sample Thermocouple
B12	Baffle Assembly
B13	Reaction Tube Retaining Ring
B14	TG Bell Jar
B15	Flexible Metal Exhaust Hose
B16	Atmospheric-Pressure Vent
B17	TG Balance Electrical Feed-through
B18	Inert Purge Gas Inlet
B19	Exhaust Gas Outlet
B20	Reaction Gas Inlet

Figure 2.2 — The Pressurized Thermogravimetric Balance Apparatus

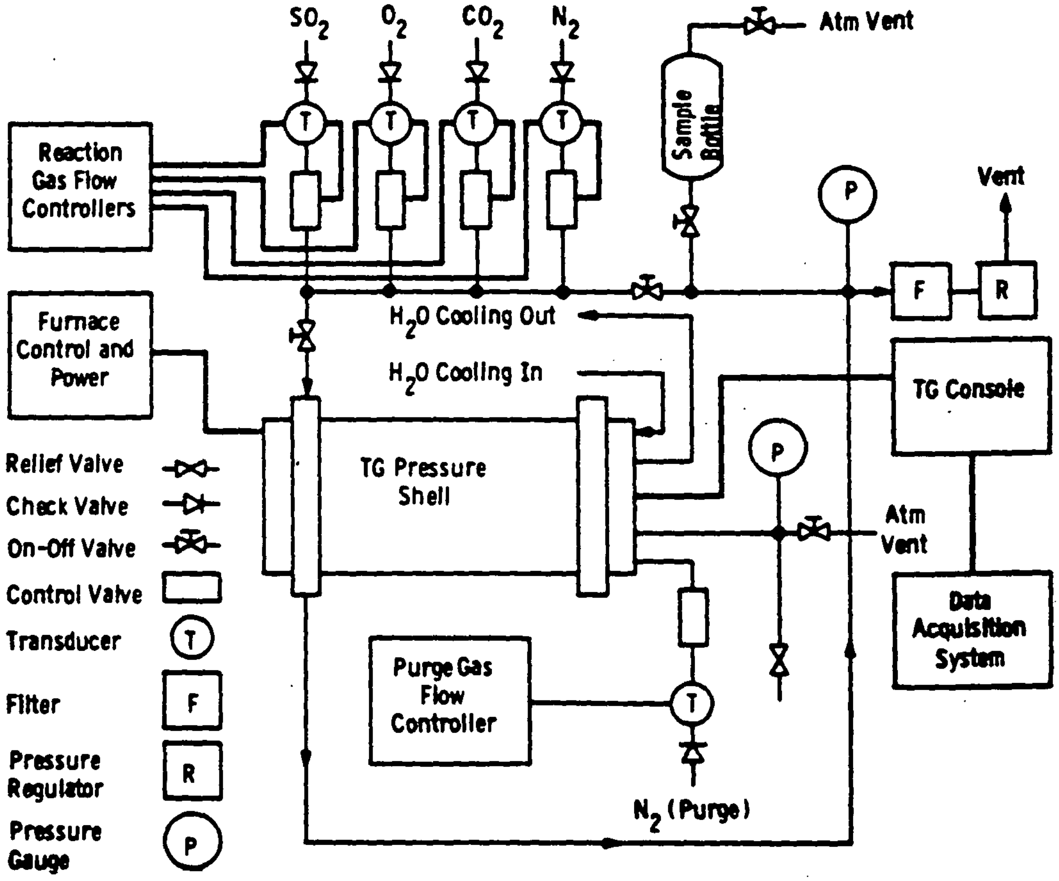


Figure 2.3 — System Diagram for the Pressurized Thermogravimetric Balance Facility

Extensive testing at pressures up to 20 atmospheres was performed on this unit as a function of several key parameters.

Experiments were run according to the following procedure:

- Sized limestone by sieving.
- Suspended a 20 mg sample in a platinum mesh basket from the balance arm; placed the thermocouple into the basket, ~1 mm from the sample.
- Pressurized the system.
- Heated the sample at a rate of 10°C/min to reaction temperature in the reactant gas, minus SO_2, flowing at a rate of 2 l/min (STP).
- After complete calcination or half-calcination as indicated by a stable sample weight, introduced SO_2 into the reactant gas mixture.
- Monitored the sample weight gain as a function of reaction time.

A reactant gas flow rate of 2 l/min (STP) was found to be necessary to exclude external mass transfer effects on the initial reaction rate. Using the initial rate data, a mass balance on the system predicted the SO_2 concentrations around the sample during the initial reaction period.

These results showed little dilution of the SO_2 concentration during initial reaction. The initial rates, however, increase with flow rate from 1 to 2 l/min. Further increasing the flow to 4 l/min have no effect on the initial reaction rate. Reactant gas flow rates of 2 l/min (STP) were used for the experimental program since the data indicate that this flow rate was sufficient to exclude mass transfer effects.

Nominal sorbent temperature was measured by a Platinum/Platinum-10% Rhodium thermocouple positioned ~ 1 mm from the sample during loading. Temperature calibrations were done using the magnetic transition point (Curie point) of iron.

The magnetic transition temperature was determined on the balance by placing a magnet over the sample. The sample was heated at 2°C/min. Upon reaching the transition temperature, the substance changes from ferromagnetic to paramagnetic (non-magnetic). An abrupt weight gain was observed due to the loss of upward magnetic force on the balance arm.

Iron's transition from ferromagnetic to paramagnetic should occur within a 5°C temperature range, reported at 770°C, with little influence from impurities. The results were fairly insensitive to flow rate and pressure. The initial detected transition occurred at 737 ± 2°C. The transition was complete at 752 ± 4°C. These results indicated that the thermocouple was reading a temperature 15 to 33°C lower than the sample temperature. Limestone experiments verified that calcination of the carbonate fraction occurred at temperatures 30°C lower than reported equilibrium decomposition temperatures. Calculations indicated that conduction of heat down the thermocouple leads did not cause much measurement error. When samples were wrapped in a platinum sheath to eliminate radiant heating, the temperature measurement remained constant. A baffle was designed to mount two thermocouples in the system, one being mounted directly in the sample to determine if this gas/solid temperature differential can be measured at reaction conditions.

2.5 UNTREATED SORBENT TEST RESULTS IN SO_2

Sulfation tests were completed with the raw sorbents to explore the effects of sorbent type, sorbent particle size, and temperature. The reproducibility of the test data was also checked. A total of 36 tests were conducted with the seven sorbent types. A listing of the run conditions, and the corresponding run numbers, are listed in Table 2.3. The complete run data summaries are presented in Appendix B. This subsection illustrates and discusses the qualitative characteristics of the data collected. The quantitative assessment of the results is made in a later section.

Table 2.3 — Run Numbers and Conditions in Untreated Sorbent Tests

Temperature: Size:	1000°C 40-45 Mesh	1000°C 16-18 Mesh	1200°C 40-45 Mesh	1200°C 16-18 Mesh	1100°C 20-25 Mesh
Sorbent:					
Tymochtee Dolomite	P437	P444	P460	P459	P452
Mississippi Lst.	P441	P448	P472	P471	P456
Greer Limestone	P440	P451/P447	P470	P469	P455
Highland Limestone	P439	P446	P468	P467	P454
Plum Run Dolomite	P438	P445	P462	P461	P453
Carbon Limestone	P442	P449	P466	P465	P458
Vicron Limestone	P443	P450	P464	P463	P457

Calcination in 10% O_2, 8% CO_2, N_2 at 2.0 L/min, 10 atm.

Sulfation in 10% O_2, 8% CO_2, 0.5% SO_2, N_2 at 2.0 L/min, 10 atm.

During the tests significant difficulty with heater burnout was experienced at the higher temperature levels of operation. Considerable modification was made to the heaters to minimize replacement frequency and near the end of the testing campaign the thermogravimetric balance operation had reached a state of only limited occurrences of burnout.

2.5.1 Data Reproducibility

It has been found in more than 2,000 previous tests on the thermogravimetric balance that reproducibility was quite good if a homogeneous sorbent sample were prepared. A replicate run using Greer limestone, a generally nonuniform sorbent, was conducted to check reproducibility in these higher than usual temperature ranges. Results, shown in Figure 2.4, are good, with the erratic shape of the rate versus fraction sulfated curve being reproduced when comparing runs P447 and P451. In this figure, and several figures to follow, the reaction rate is defined as the fraction of the total calcium in the sorbent being converted to calcium sulfate per minute of time. This rate is plotted after multiplication by 100 in the figures against the fraction of calcium converted to calcium sulfate. The rate curve shapes in most of the runs at the high temperatures of interest tend to be more erratic than those at lower temperatures (less than 1000°C) with the high temperature runs showing discontinuities where the rate may suddenly increase rather than continue the normal drop in reaction rate. This is probably due to physical structure changes such as particle expansion and crack formation that are thermally induced, but this erratic nature is reproducible and consistent. See, for example, in Figure 2.5 how the nature of the rate curve for Mississippi limestone is parallel for the two particle sizes shown in the figure, with a sudden increase in reaction rate occurring at about 20% conversion for the 16-18 mesh particles and at a larger conversion (about 25%) for the 40-45 mesh particles. It is concluded that the results are reproducible and consistent.

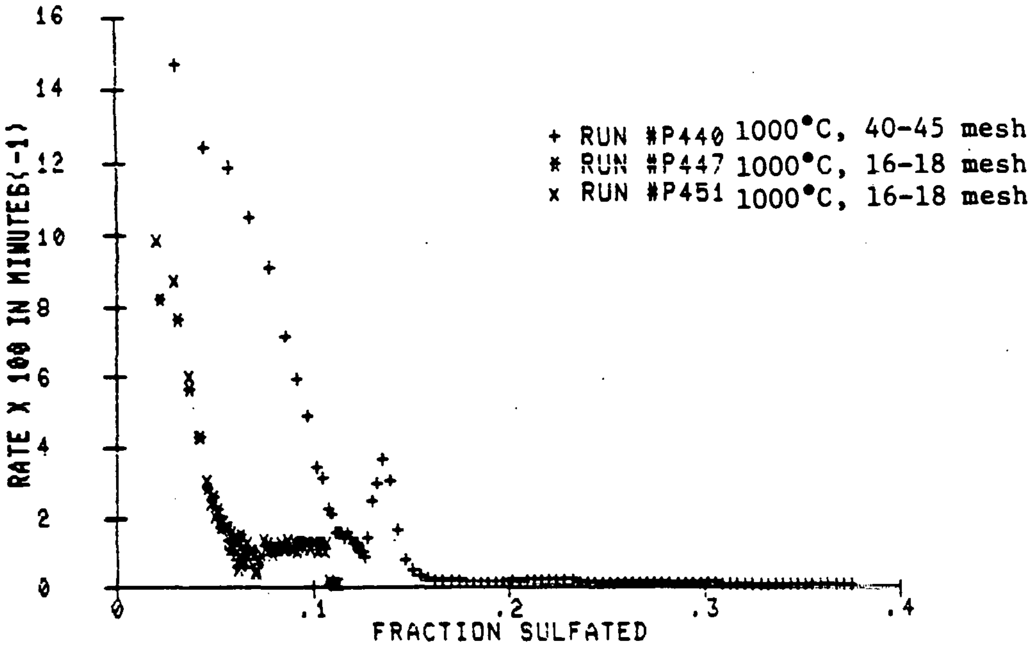


Figure 2.4 — Reproducibility of Data: Greer Limestone Runs

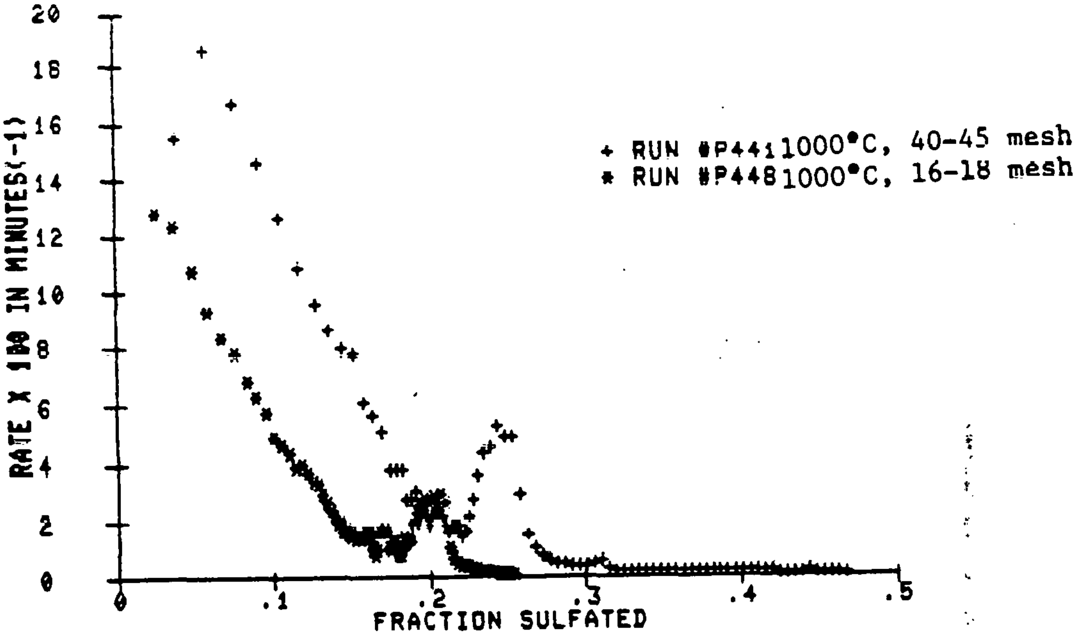


Figure 2.5 — Consistency of Data: Mississippi Limestone Runs

2.5.2 Effect of Sorbent Type

The rate curves illustrating the effect of sorbent type on performance are shown in Figures 2.6 through 2.9. Comparisons are similar at temperatures of both 1000 and 1200°C. While the two dolomites have very similar behavior at 1000°C with their rate curve almost coincident (Figure 2.6), their behavior differs significantly at 1200°C with the Plum Run rate falling below the Tymochtee rate at intermediate conversions. This means that even though the dolomites behave very similarly at 1000°C, there are thermally induced differences that only appear at the higher temperature, and these differences appear mainly during the intermediate conversion of the sorbents with their rates being similar for greater than 50% conversion to calcium sulfate.

Note that both dolomites achieve calcium utilizations greater than 100% at 1000°C. This is consistent with previous testing at elevated pressure and indicates that either one or all of the following are occurring: 1) impurities in the sorbent are reacting with sulfur (iron, sodium, potassium, etc have the potential to form stable sulfates); 2) the magnesium component is entering into the sulfation reaction (magnesium oxide is known to sulfate at these conditions although the magnesium content of dolomites has only been found in past investigations to form traces of sulfate species); or 3) complex Mg-Ca-S-O components are being generated (39).

The five limestones show a large variation in sulfation performance at both 1000 and 1200°C. Ranking of the sorbent reactivity at 1000°C based on the extent of conversion of the sorbents when the rate is 2% per minute is Carbon > Highland > Mississippi > Greer > Vicron. The ranking of the limestones change in going from 1000 to 1200°C, becoming Highland > Carbon > Mississippi = Greer > Vicron. As has been found in all previous testing on coarse calcium particle sulfation, the impact of the sorbent type is critical to the performance. Note that the two dolomitic limestones (Highland and Carbon) rank higher than the other three limestones.

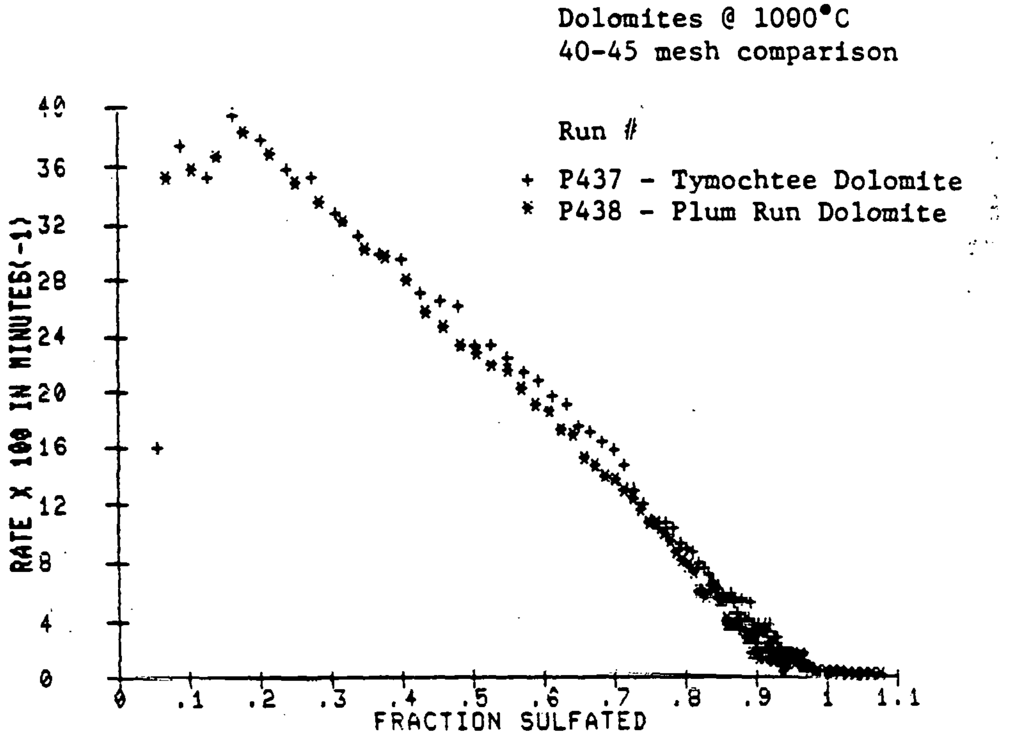


Figure 2.6 — Comparison of 40-45 Mesh Dolomites at 1000°C

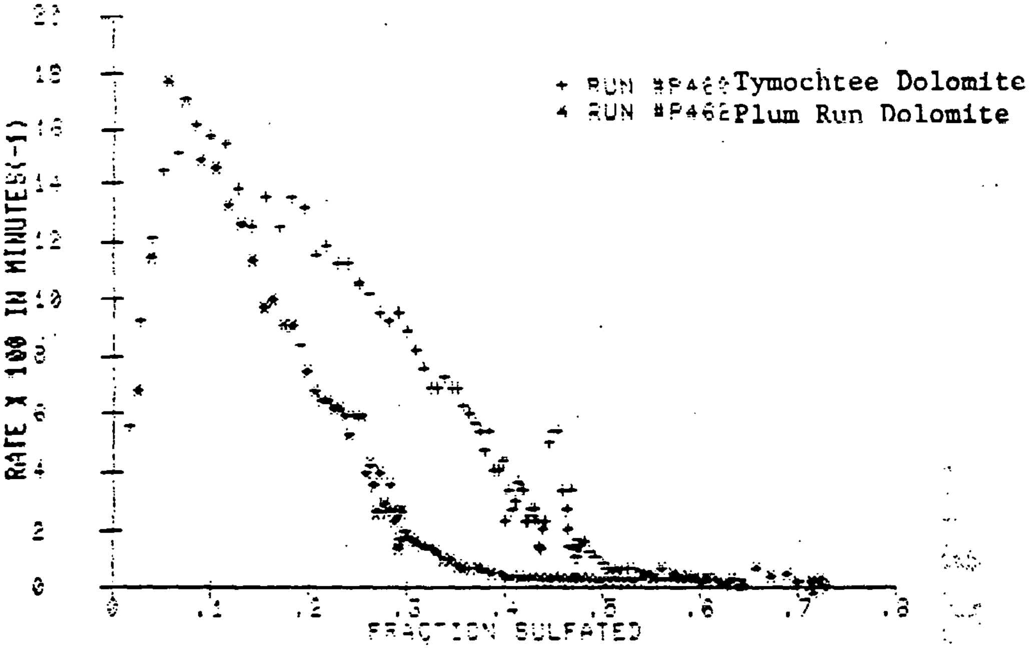


Figure 2.7 — Comparison on 40-45 Mesh Dolomites at 1200°C

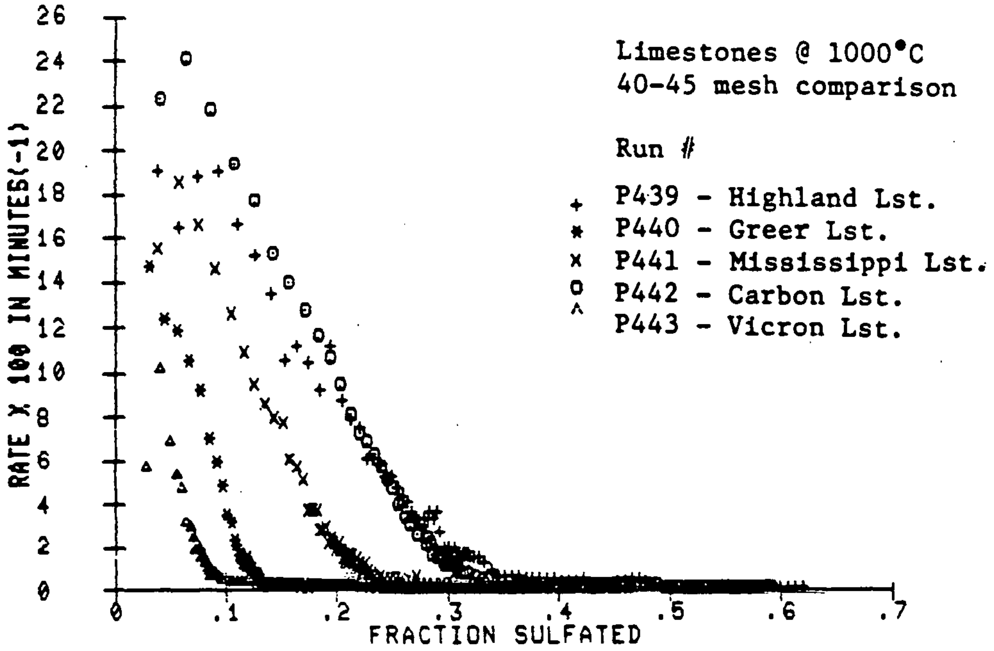


Figure 2.8 — Comparison of 40-45 Mesh Limestones at 1000°C

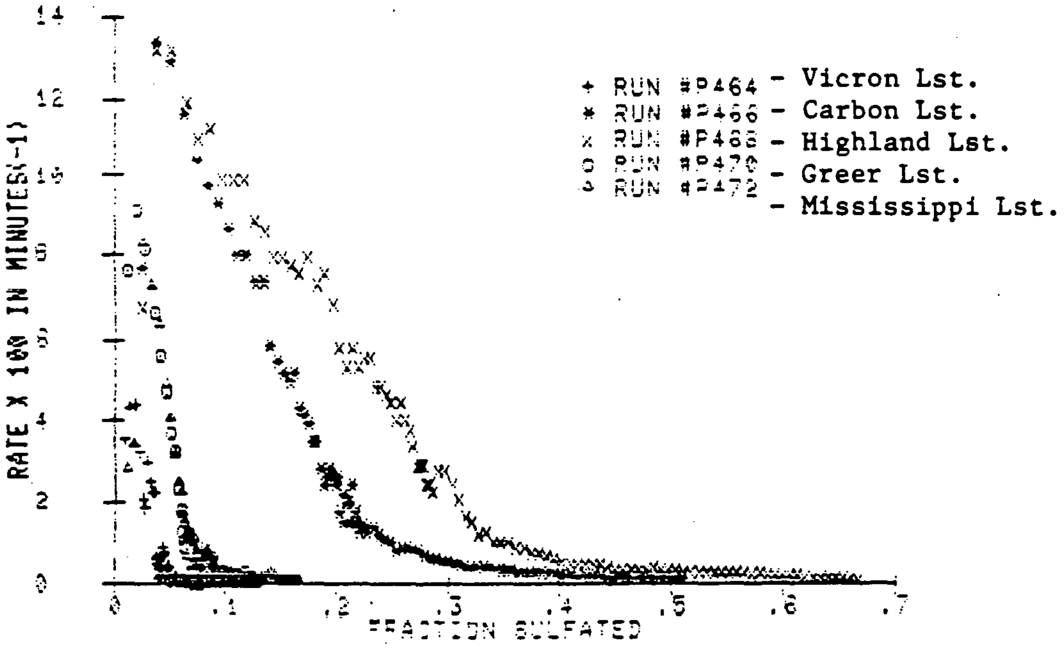


Figure 2.9 — Comparison of 40-45 Mesh Limestones at 1200°C

2.5.3 Effect of Particle Size

The effect of particle size is illustrated in Figures 2.10 through 2.16 for a temperature of 1000°C. There is a clear and consistent rate reduction in the sulfation rate as the particle size is increased, and this trend holds also at 1200°C. For example, the two dolomites shown in Figures 2.10 and 2.11 have relatively smooth rate curves showing complete calcium sulfation for both particle sizes. The larger 16-18 mesh particles have a considerably smaller rate (at 20% calcium sulfation the rate is about 20% per minute) than the 40-45 mesh particles (at 20% calcium sulfation the rate is about 40% per minute). This trend agrees with previous testing and modeling expectations. Note that the initial reaction rate is difficult to obtain from the rate curves because the reactor induction period covers up the initial reaction results.

The limestone rate results in Figures 2.12 through 2.16 show the same trend of reduced rate with increased particle diameter and indicate much less than 100% final calcium conversion is obtained. Again, each limestone behaves differently. In addition, the limestones, other than Highland, all show discontinuous behavior where the reaction rate increases suddenly at an intermediate level of conversion. While the mechanism for this feature of increasing reaction rate has not been determined, it is a reproducible occurrence.

2.5.4 Effect of Temperature

The effect of temperature is illustrated in Figures 2.17 through 2.23. Comparisons in the rate curves at 1000 and 1200°C are made for each sorbent at particle sizes of 40-45 mesh. The behavior with respect to temperature is mixed, with some sorbents being reduced in performance, some being only slightly impacted, and some being improved. These trends are fairly consistent between the two particle sizes tested. The two dolomites (Figures 2.17 and 2.18) behave similarly, with the Plum Run being slightly more sensitive to temperature (at 20% calcium sulfation the rate is about 8% per minute) than the Tymochtee dolomite (at 20% calcium sulfation the rate is about 14% per minute).

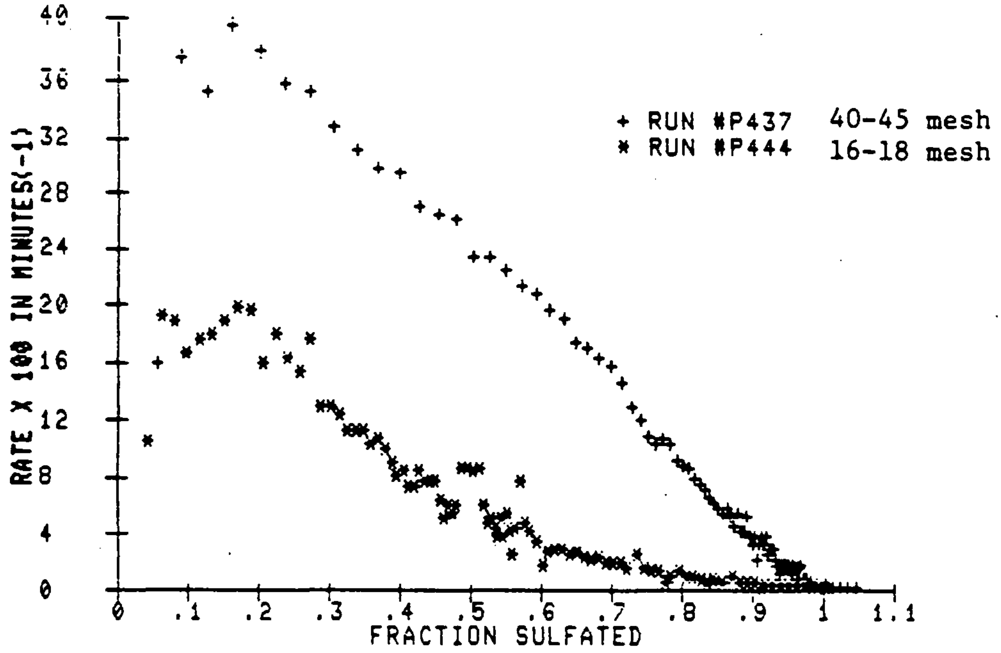


Figure 2.10 — Effect of Particle Size for Tymochtee Dolomite at 1000°C

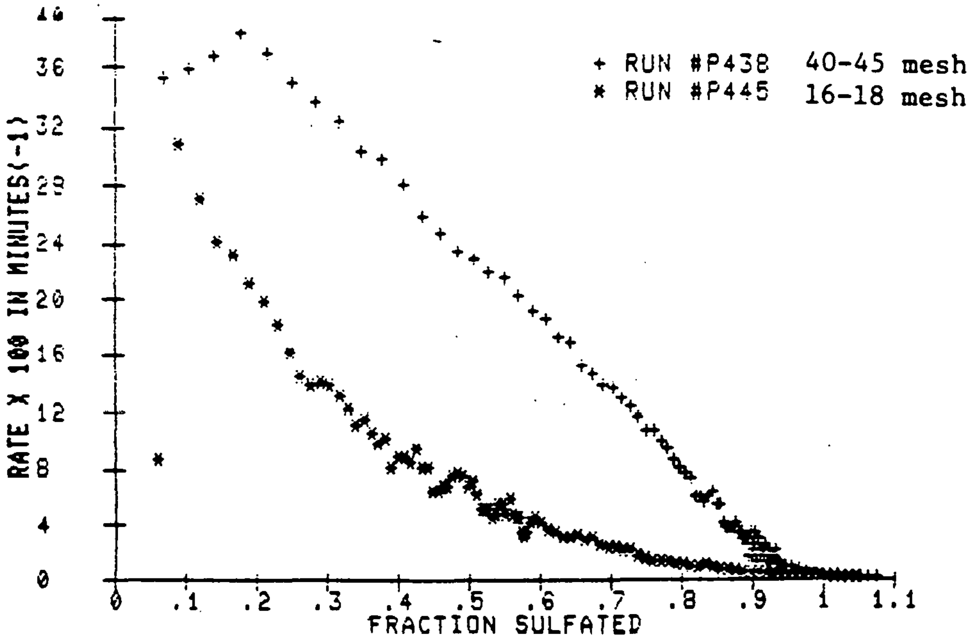


Figure 2.11 — Effect of Particle Size for Plum Run Dolomite at 1000°C

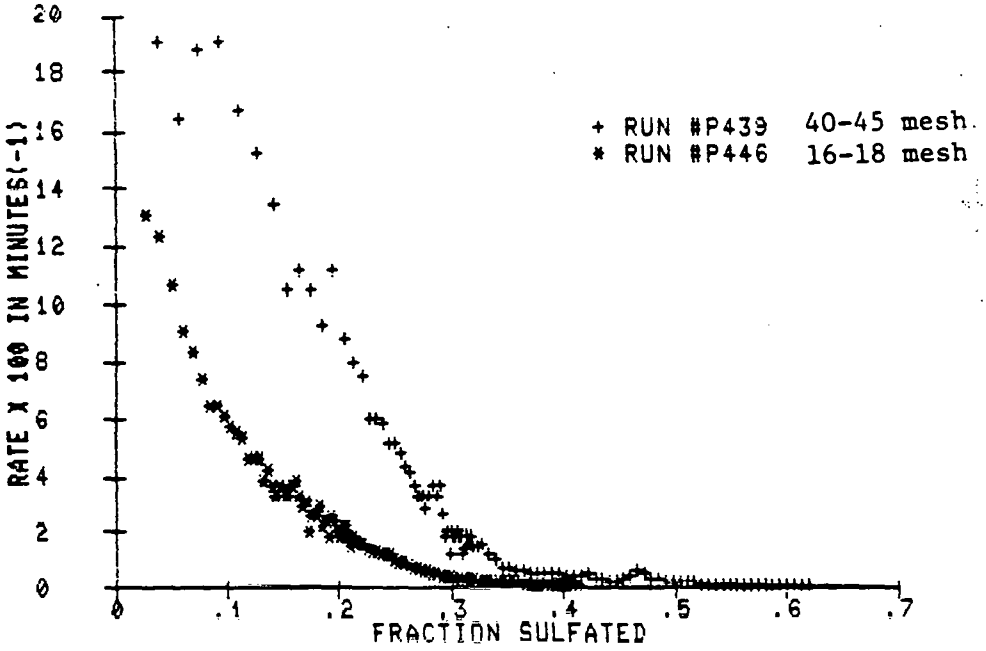


Figure 2.12 — Effect of Particle Size for Highland Limestone at 1000°C

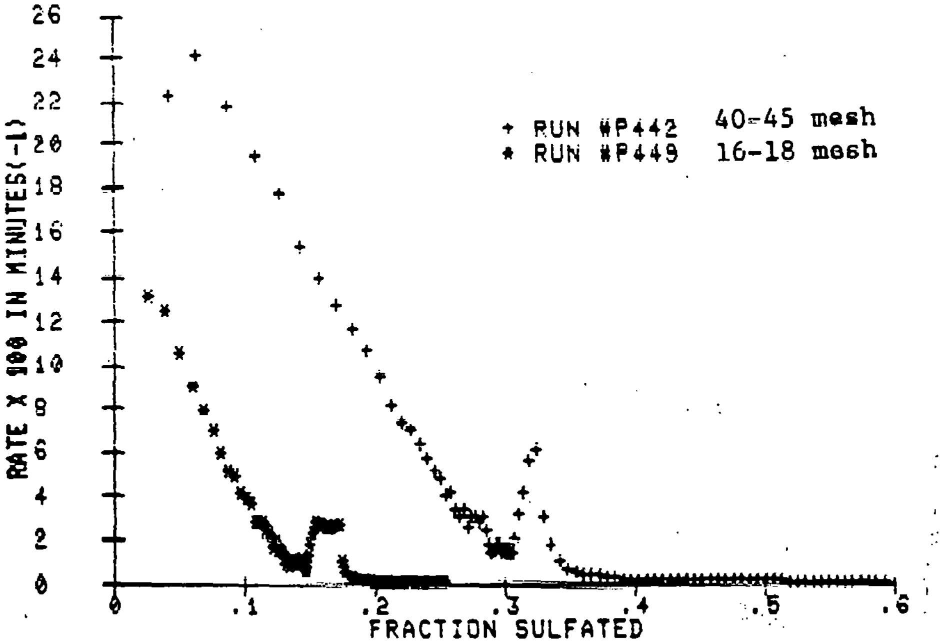


Figure 2.13 — Effect of Particle Size for Carbon Limestone at 1000°C

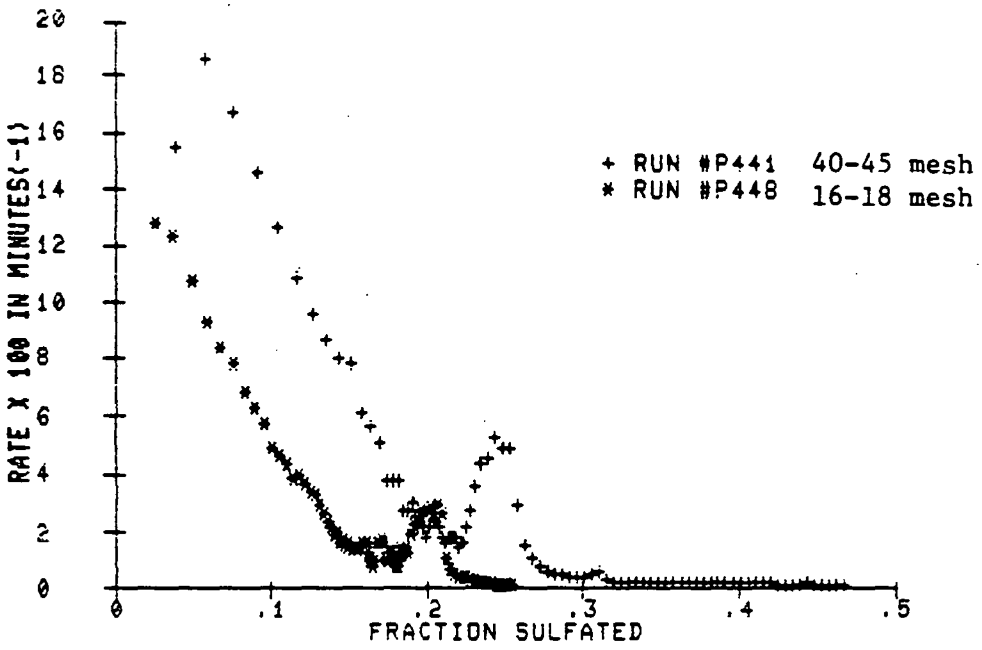


Figure 2.14 — Effect of Particle Size for Mississippi Limestone for 1000°C

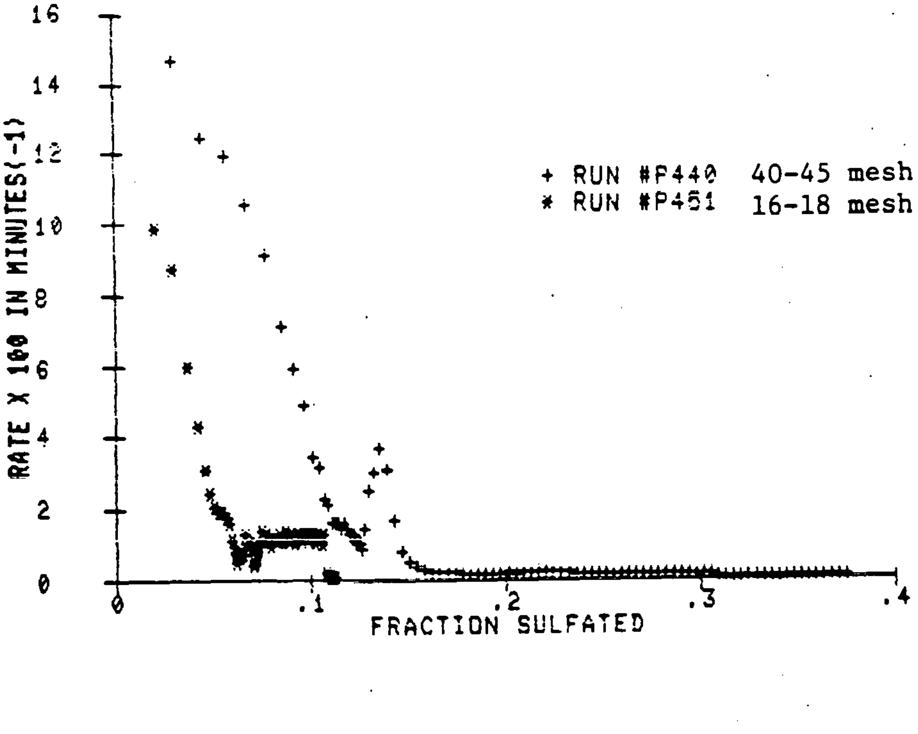


Figure 2.15 — Effect of Particle Size for Greer Limestone at 1000°C

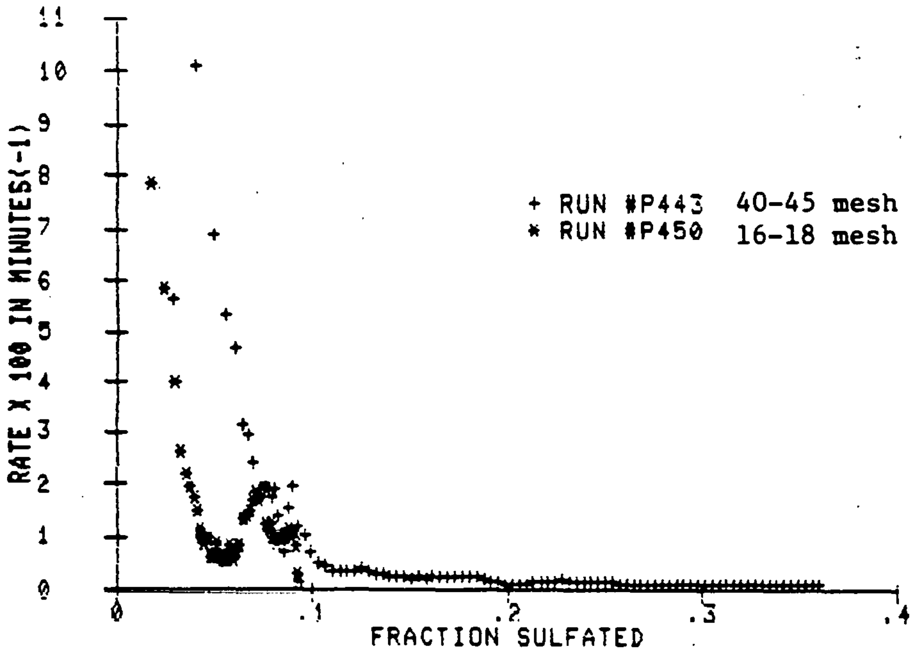


Figure 2.16 — Effect of Particle Size for Vicron Limestone at 1000°C

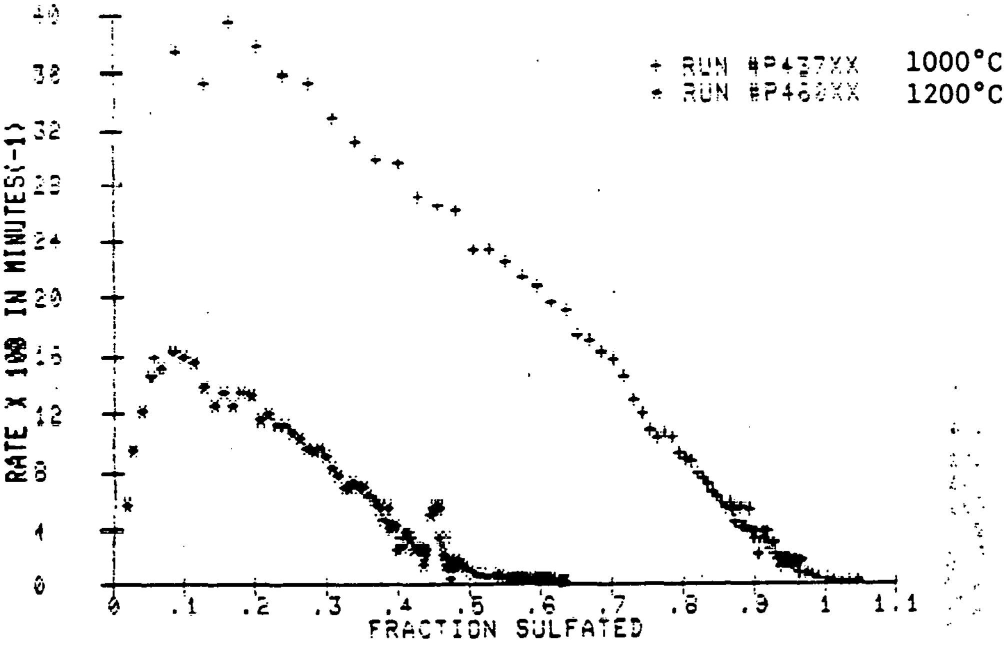


Figure 2.17 — Effect of Temperature for 40-45 Mesh Tymochtee Dolomite

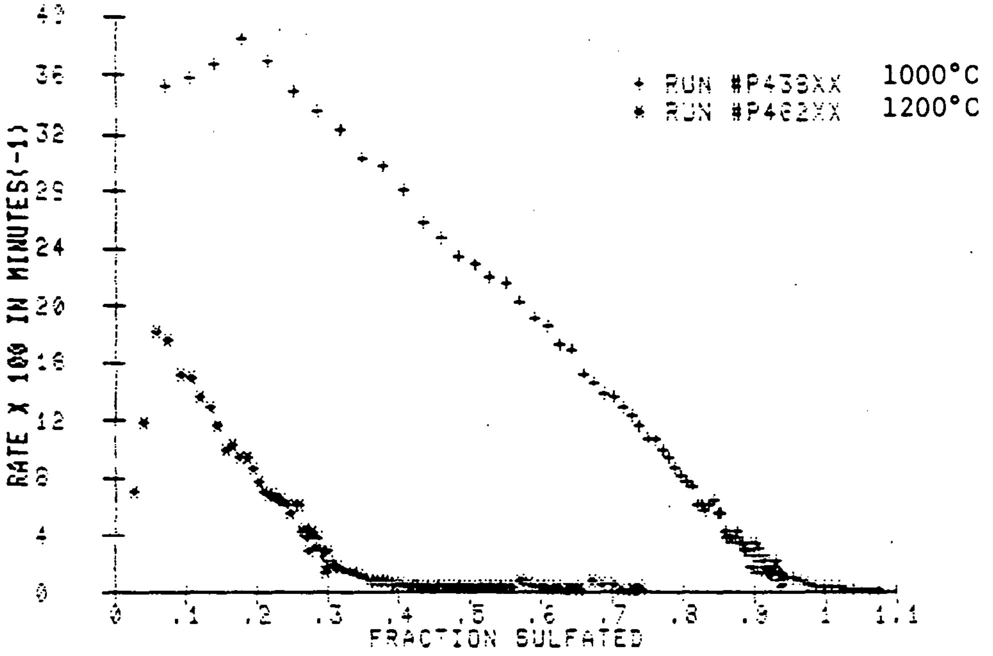


Figure 2.18 — Effect of Temperature for 40-45 Mesh
Plum Run Dolomite

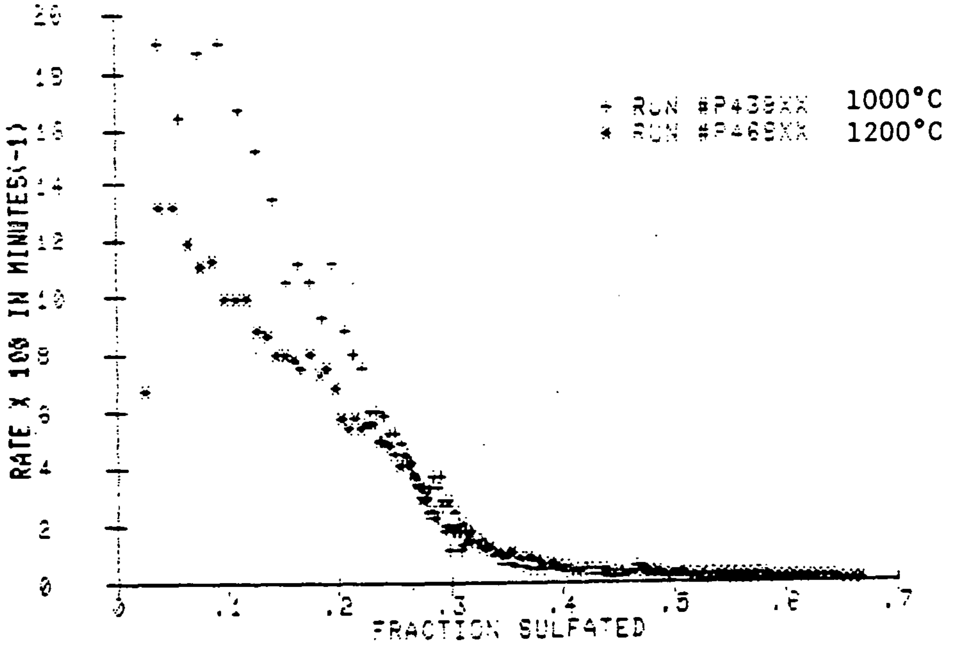


Figure 2.19 — Effect of Temperature for 40-45 Mesh
Highland Limestone

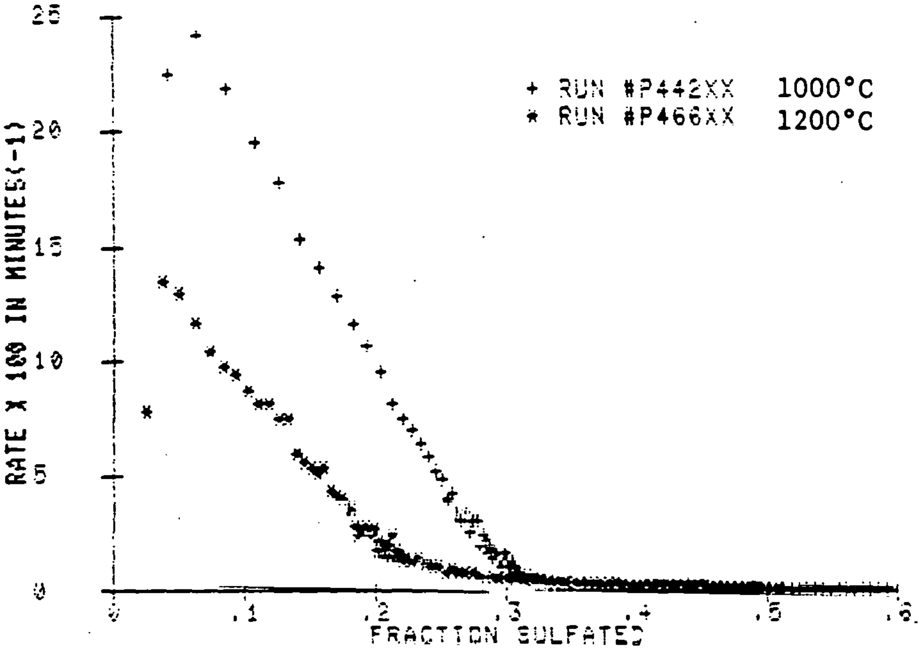


Figure 2.20 — Effect of Temperature for 40-45 Mesh Carbon Limestone

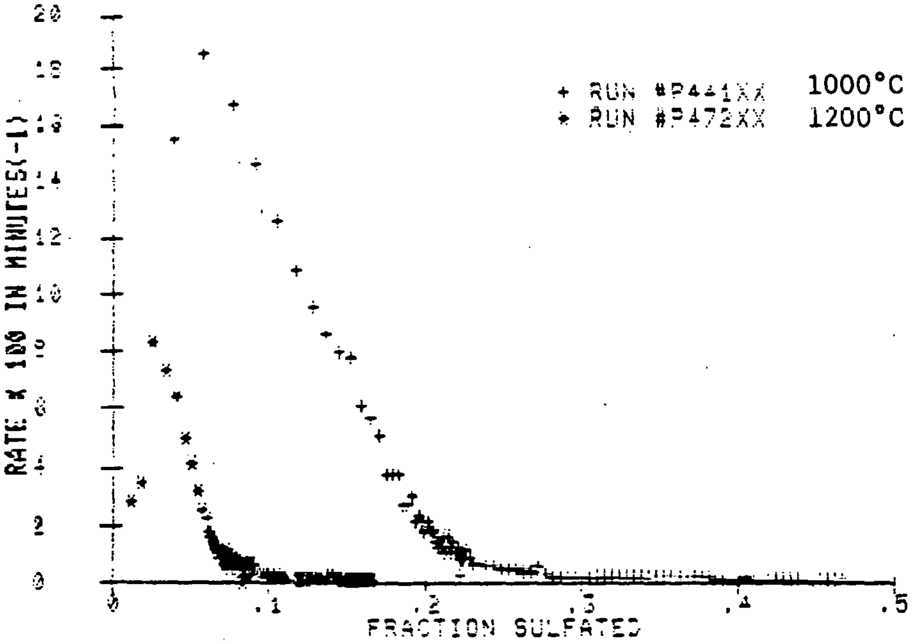


Figure 2.21 — Effect of Temperature for 40-45 Mesh Mississippi Limestone

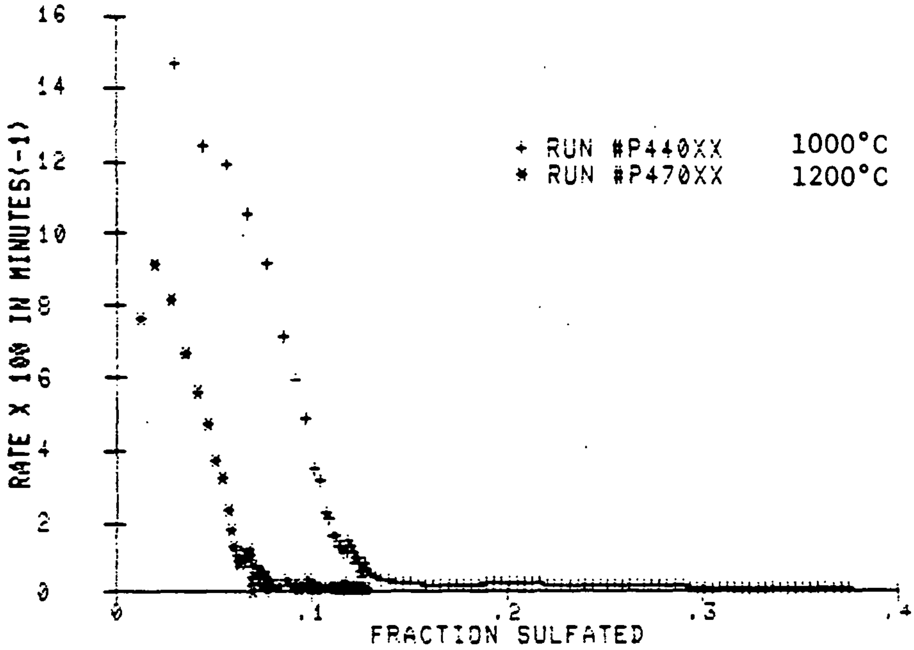


Figure 2.22 — Effect of Temperature for 40-45 Mesh Greer Limestone

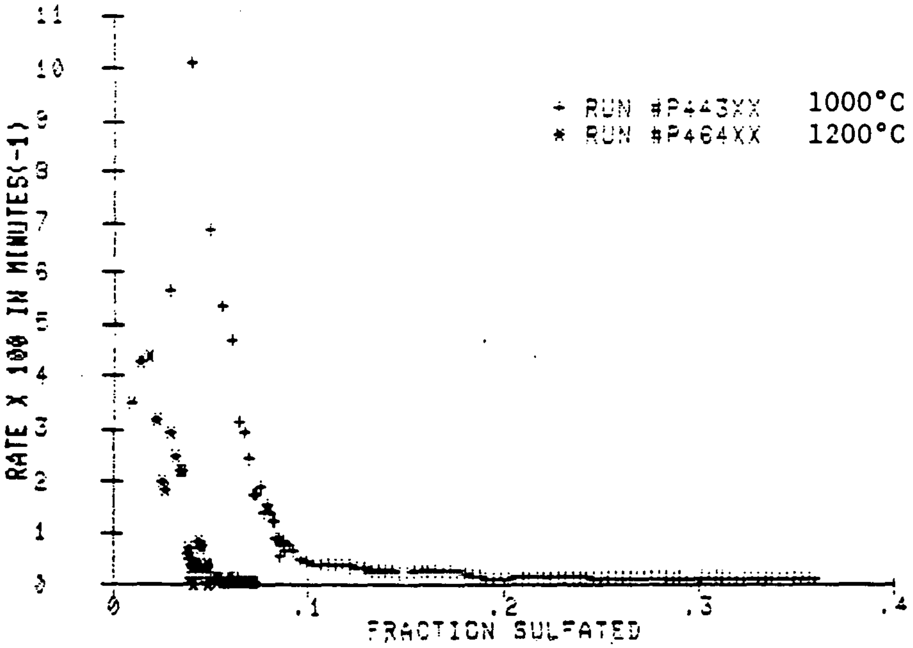


Figure 2.23 — Effect of Temperature for 40-45 Mesh Vicron Limestone

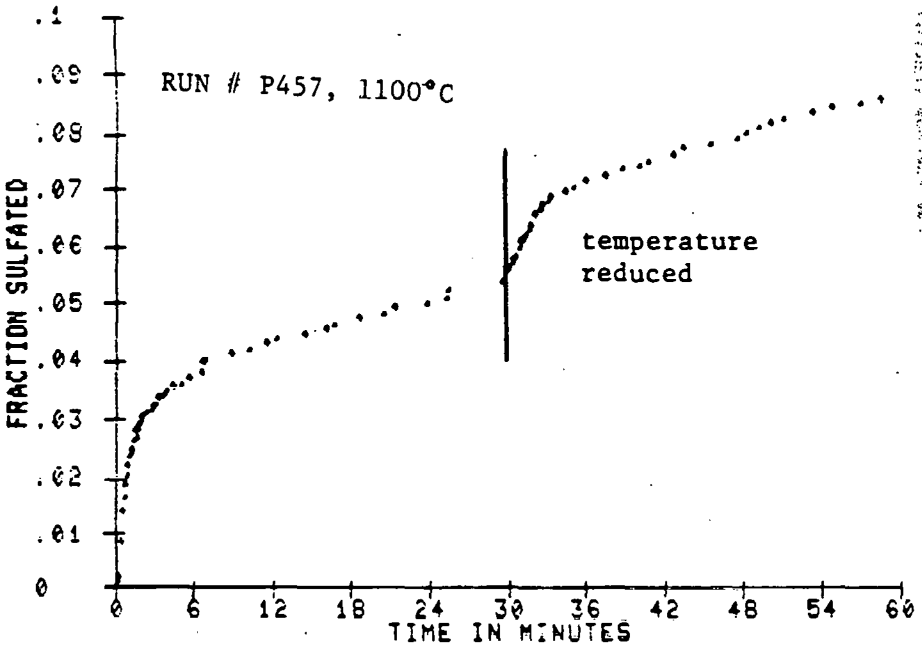


Figure 2.24 — Vicron Limestone Reversible Temperature Effect

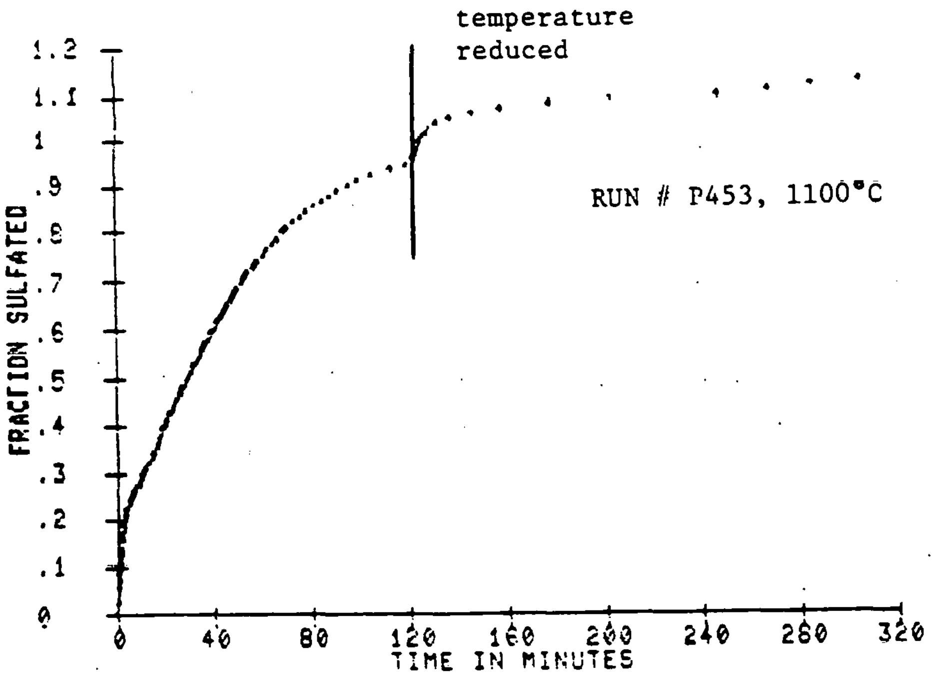


Figure 2.25 — Plum Run Dolomite Reversible Temperature Effect

Highland limestone (Figure 2.19), a dolomitic limestone, shows a slight reduction in conversion rate at calcium sulfation levels less than 20%, but the final extent of conversion is increased slightly as the temperature is increased. The coarser 16-18 mesh Highland limestone shows a little less sensitivity to increased temperature than do the 40-45 mesh particles. Carbon limestone of the 40-45 mesh size (Figure 2.20), the other dolomitic limestone, shows a significant decrease in sulfation rate when the temperature is increased. On the other hand, the coarser 16-18 mesh Carbon limestone shows a significant increase in sulfation rate as the temperature is increased from 1000 to 1200°C. The other three limestones all show a significant reduction in sulfation rate with increased temperature not only for the 40-45 mesh sizes considered in Figure 2.21 through 2.23, but also for the 16-18 mesh sizes not shown.

Another factor found with respect to the effect of temperature is that a reversible effect exists. Once a sample has approached a saturated condition at a high temperature it will be further sulfated if its temperature is reduced. This behavior is illustrated in Figure 2.24 and 2.25 for Vicron limestone and for Plum Run dolomite. In Figure 2.24 the Vicron limestone sample was heated at 1100°C and had reached a low sulfation rate after about 30 minutes. The temperature was then reduced to about 1000°C and the sulfation level then increased. Similarly, in Figure 2.25, Plum Run dolomite was sulfated at 1100°C for about 130 minutes to a conversion level of about 90% where the reaction rate became very small. When the temperature was reduced to about 1000°C the sulfation rate increased and the conversion jumped to about 110%. This behavior is of great interest in understanding the nature of high temperatures on calcium-based sorbent sulfation because it has previously been assumed that all of the high temperature behavior was due to irreversible sintering effects such that once a sorbent was exposed to high temperatures its reactivity would be permanently reduced.

2.5.5 Overall Qualitative Behavior

Many characteristics may be selected to depict the sorbent sulfation performance. One characteristic is the extent of calcium sulfation when the sulfation rate has dropped to some low value, such as 0.1% calcium sulfation per minute and is a quantity that might be considered the final or saturation sulfation level of the sorbent. This characteristic is listed in Table 2.4 for all of the coarse particle tests. The numbers in Table 2.4 are characteristic of the effects of sorbent type, particle size and temperature. The table indicates that Carbon limestone, a dolomitic limestone, performance nominally improves with increased temperature, as does Highland limestone, the other dolomitic limestone, while the other sorbents performance decrease with increasing temperature. While the characteristic is an indicator of the relative performance of the sorbent, it is not quantitative and should not be used to project the fluidized bed desulfurizer performance. As will be seen the integrated, quantitative performance, taking into account the total shape of the sulfation rate curve, may be significantly different from the values in Table 2.4. On the other hand, the relative ranking of the sorbents will not change.

Other qualitative observations made were 1) Highland limestone, Carbon limestone and Mississippi limestone all showed a tendency to "pop", or spontaneously explode into smaller particles when heated to about 400°C; and 2) some agglomeration of the sorbent particles and sticking to the platinum pan was found at 1200°C, especially for the smallest particle size of 40-45 mesh, and most strongly with Highland limestone. The popping phenomena is quite common with limestones and is likely to result from the breaking of hydrate bonds that occur at this temperature or the transition from the aragonite crystal to the calcite crystal. Calcination does not occur until a much higher temperature is reached and so does not contribute to popping. The agglomeration is likely to be due to sintering and low melting impurity interactions.

Table 2.4 — Characteristic Sorbent Performance

Sorbent	Particle Size (mesh)	Fraction Sulfated Temperature (°C)		
		1000	1100	1200
Tymochtee dolomite	-40+45	1.03		0.65
	-20+25		0.90	
	-16+18	<1.0		0.52
Plum Run dolomite	-40+45	1.07		0.63
	-20+25		0.95	
	-16=18	1.04		0.41
Mississippi limestone	-40+45	0.41		0.11
	-20+25		0.15	
	-16+18	0.24		0.10
Carbon limestone	-40+45	0.51		0.51
	-20+25		0.18	
	-16+18	0.19		0.33
Greer limestone	-40+45	0.28		0.08
	-20+25		0.08	
	-16+18	0.09		0.07
Highland limestone	-40+45	0.52		0.65
	-20+25		0.66	
	-16+18	0.37		0.36
Vicron limestone	-40+45	0.15		0.05
	-20+25		0.05	
	-16+18	<0.09		0.03

2.6 PRETREATED SORBENT TEST RESULTS IN SO_2

Coarse sorbent particles were pretreated by precalcination using a technique that has been shown to improve the reactivity of calcium-based sorbents used for atmospheric-pressure fluidized-bed combustion. The precalcination technique also showed a tendency to reduce the extent of sulfation performance lost as the sulfation temperature was increased at atmospheric pressure.

The test sorbents, Vicron limestone, Greer limestone, and Carbon limestone were precalcined at 950°C, in 60% carbon dioxide, and at atmospheric pressure. Two sizes were tested, 20-25 mesh, with sulfation at 1100°C, and 40-45 mesh, with sulfation at 1200°C. The sulfation rate curve for the untreated and pretreated sorbents are compared in Figures 2.26 through 2.31. There is no improvement in performance upon precalcination with any of the sorbents tested. In fact, Carbon limestone shows lower sulfation rate after precalcination than it does when it is used in the raw condition (Figures 2.28 and 2.31). The normal sorbent calcination that occurs when operating at high pressure and high temperature apparently yields the same type (or even better) of sorbent pore structure as does the precalcination procedure, so little change in sulfation performance is found.

2.7 TESTS RESULTS WITH HYDROGEN SULFIDE

Tests with hydrogen sulfide in the pressurized thermogravimetric balance were found to result in a severe operating problem: elemental sulfur would form within the back-pressure controller, making the pressure and gas flow very erratic such that data could not be collected. During the test program several attempts to correct this problem were made. Finally, an after-burner was placed downstream of the balance, but upstream of the back-pressure controller to convert the hydrogen sulfide to sulfur dioxide. This conversion permitted successful test operation.

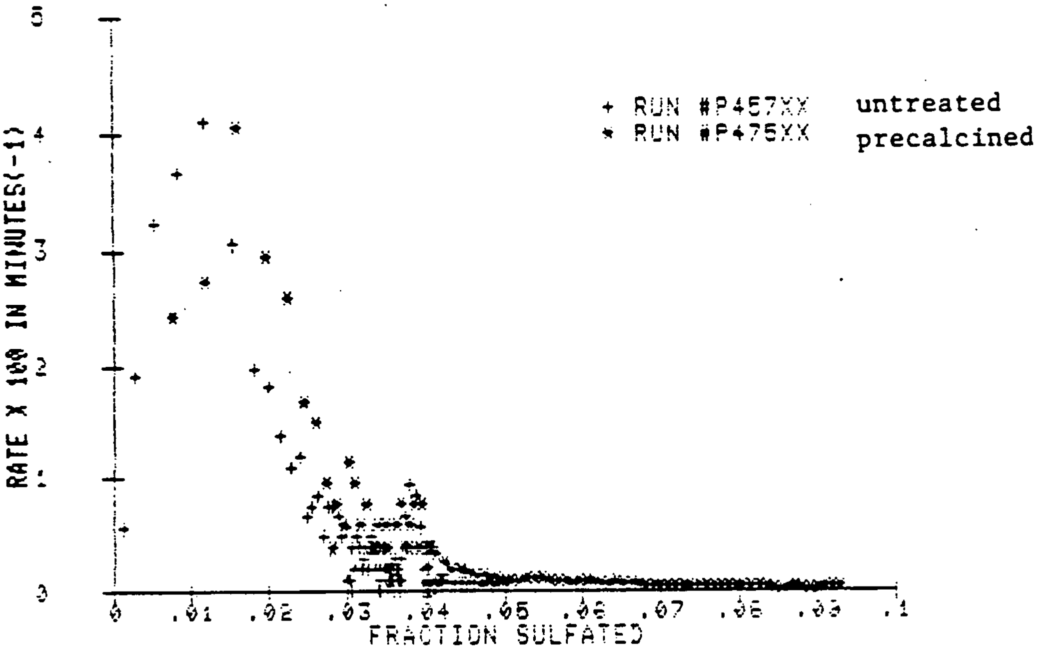


Figure 2.26 — Precalcination Performance With Vicron Limestone: 20-25 Mesh, 1100°C

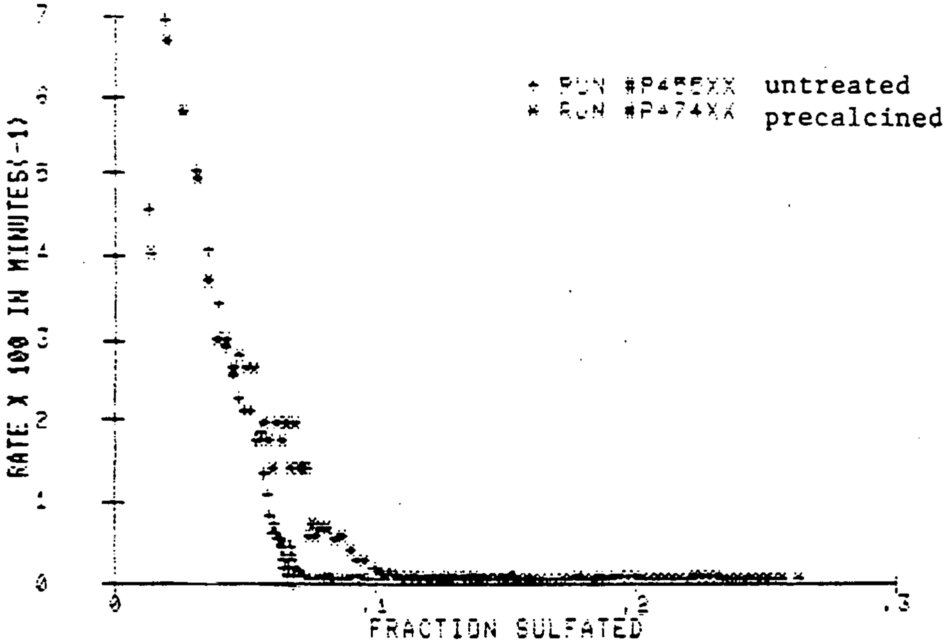


Figure 2.27 — Precalcination Performance With Greer Limestone: 20-25 Mesh, 1100°C

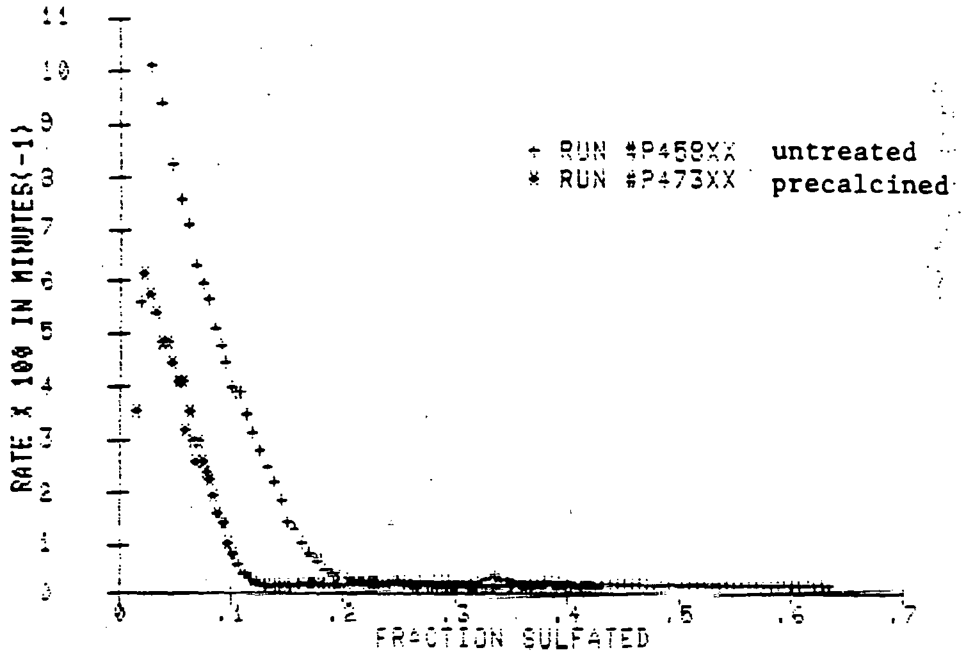


Figure 2.28 — Precalcination Performance With Carbon Limestone: 20-25 Mesh, 1100°C

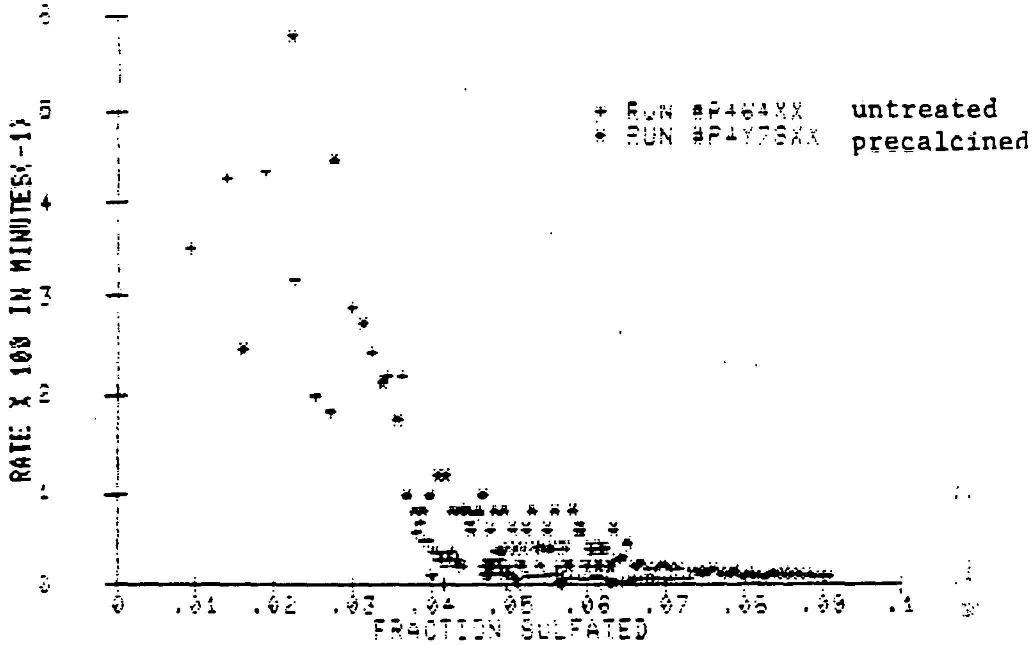


Figure 2.29 — Precalcination Performance With Vicron Limestone: 40-45 Mesh, 1200°C

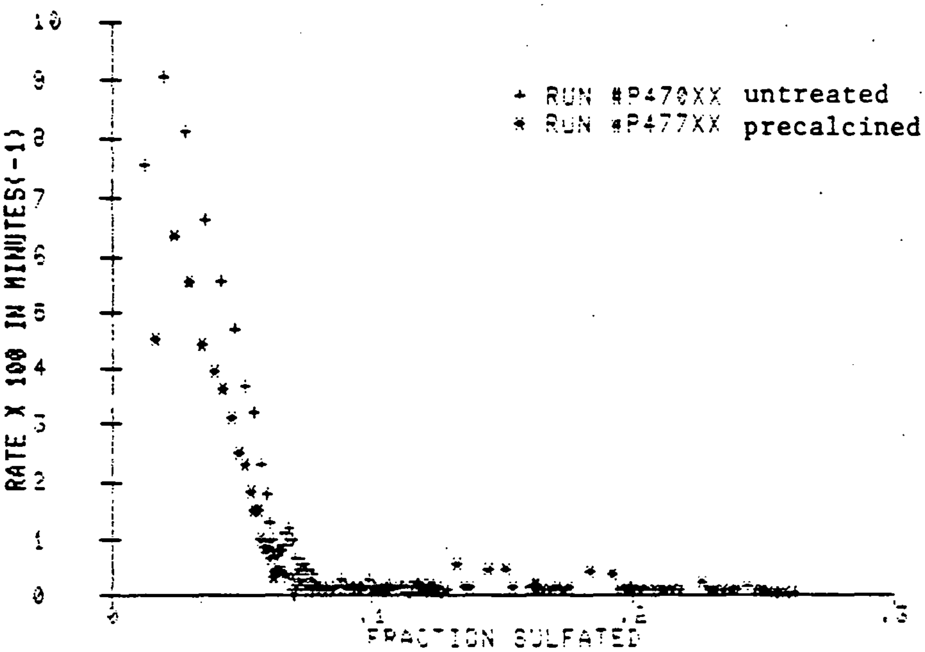


Figure 2.30 — Precalcination Performance With Greer Limestone: 40-45 Mesh, 1200°C

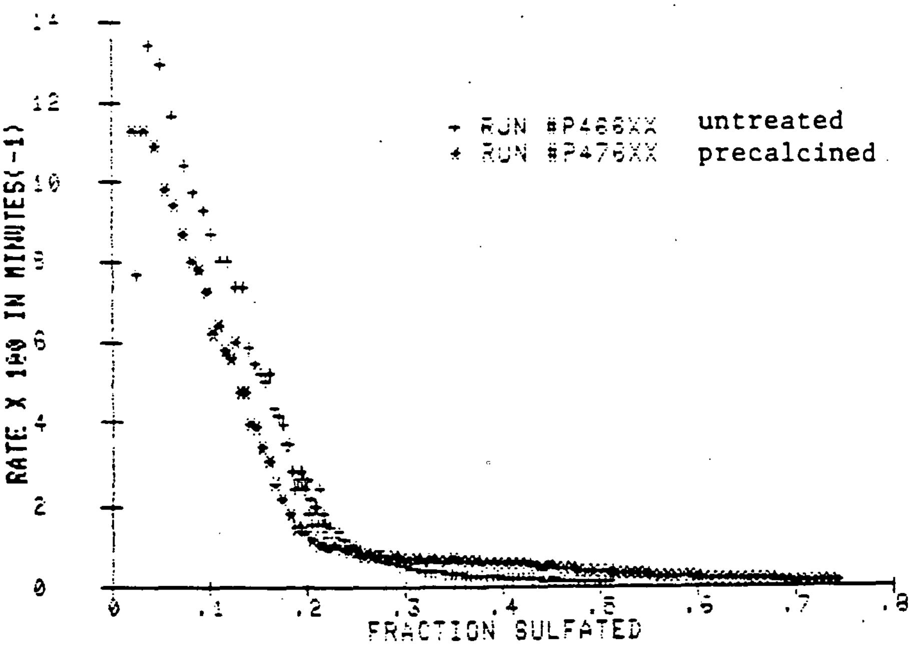


Figure 2.31 — Precalcination Performance With Carbon Limestone: 40-45 Mesh, 1200°C

Limited testing of coarse sorbent particles was conducted to supplement the existing data base. The effect of temperature was the major parameter of interest, and runs only at 1100°C were completed to determine the reaction kinetics at this high temperature. Two tests were performed at atmospheric pressure, 1100°C, and with 0.3 mole % hydrogen sulfide, using Plum Run dolomite and Highland limestone. Then, a single test was completed with Plum Run dolomite at 5 atmospheres pressure and 1100°C with 0.46 mole % hydrogen sulfide. A comparison of the test results in H_2S and in SO_2 under similar conditions is made in Table 2.5, all for a particle size of 16-18 mesh. The detailed test results for the H_2S tests and for the sulfation tests made for comparison are compiled in Appendix B4.

Table 2.5 — H_2S Test Results and Comparison With Sulfation

Sorbent	H_2S mole%	SO_2 mole%	Pressure (atm)	Maximum Calcium conversion(%)	Initial Rate % / minute
Plum Run	0.3	---	1	0.95	3.1
Plum Run	0.46	---	5	1.20	11.1
Plum Run	---	0.1	5	0.60	3.9
Highland	0.3	---	1	0.50	1.5
Highland	---	0.1	5	0.50	1.6

The values in the table indicate first that sulfidation of the Plum Run dolomite at 1100°C will proceed to higher calcium conversion than does sulfation of Plum Run dolomite. The dolomite test indicates that significant MgS is generated, although this occurs at a very slow rate. Water vapor in the gas would essentially eliminate MgS formation at these conditions. Also, sulfidation of Highland limestone leads to calcium conversion comparable to that obtained on sulfation. A comparison of the values in the table and the sulfidation rate curves for Plum Run dolomite at 1 atmosphere and 5 atmospheres pressure (compiled in Appendix B4) shows that the sulfidation rate at 5 atmospheres pressure is much greater than it is at 1 atmosphere pressure, increasing at a power of the pressure of about 0.53. Also, the initial sulfidation rate is lower than the initial sulfation rate by a factor of about 0.6 to 0.7 for both the limestone and dolomite tested under comparable conditions of pressure and H_2S and SO_2 concentration.

These limited results show that hydrogen sulfide removal is comparable in effectiveness to sulfur dioxide removal at 1100°C. Further testing and use of the existing data base on coarse sorbent particle sulfidation is needed to make significant quantitative conclusions.

2.8 EVALUATION OF SULFUR REMOVAL KINETICS

In this section the test results described are evaluated to generate quantitative correlations of reaction kinetics behavior. First, the controlling reaction resistances are evaluated using dimensional analysis. Secondly, empirical rate correlations are developed for the sulfation and sulfidation reactions.

2.8.1 Dimensional Analysis of Controlling Resistances

A valuable technique to gain perspective on the controlling resistances in the reaction kinetics studied is to apply dimensional analysis. Such an analysis has been conducted and the details of the development are reported in Appendix C. A summary of the results of the dimensional modeling are shown in Table 2.6, showing the impact of particle size, pressure, temperature, and internal particle structure on the reaction rate for two key cases: reaction rate control by gas diffusion into the pores of the sorbent particle, and reaction rate control by solid diffusion in the sorbent particle grains. The case of chemical reaction control is not considered since it is unlikely to control for the coarse particle sizes studied. The dimensional analysis leads to the conclusion that the reaction rate should be first order in the SO_2 (or H_2S) concentration, as has been observed consistently for coarse particle sulfation (or sulfidation) in many previous investigations.

The thermogravimetric data collected has been analyzed with respect to the dimensional analysis performed. For example, according to Table 2.6 (the column for solid diffusion control and the item "particle size") the sulfation rate, $d\alpha/dt$, should be independent of particle size if it is controlled by the rate of solid diffusion and should be only a function of time, so a plot of the rate versus time data for the 400 and 1000 micron particle runs at 1000°C should indicate the possibility of solid diffusion control if no particle size dependency is shown. Such plots are shown for each of the seven sorbent tested in Figures 2.32 through 2.38, suggesting that solid diffusion may control in the early stages of the reaction where the rate curves are close together and particle size has little impact. Note that in these plots, the logarithm to the base 10 of the sulfation rate multiplied by 100 is shown.

Similarly, from Table 2.6 a plot of (the reaction rate times the particle diameter squared) versus (the time over the particle diameter squared) will indicate the existence of pore diffusion control. From Appendix C it is equivalent to plotting (the reaction rate times the particle diameter squared) versus (the fraction sulfated). This type of plot in Figures 2.39 through 2.45 for the 400 and 1000 micron sizes of all seven sorbent tested suggests that pore diffusion may control in the latter stages of the reaction for most of the sorbents. Pore diffusion control appears to be initiated after about 60 to 70% calcium sulfation for the dolomites in Figures 2.39 and 2.40. Pore diffusion control begins in the limestones at conversions ranging from about 5% up to about 30% depending on the specific limestone.

Table 2.6 — Dimensional Analysis Results

	Pore Diffusion Control	Solid Diffusion Control
Particle Size	1)[a] $d\ \alpha_1/dt\ \Phi\ R_o^2 = f\ \{t/R_o^2\}$	$d\ \alpha_1/dt = f\ \{t\}$
	2)[b] $= f\ \{t/R_o^2,\ R_p/R_o\}$	
Pressure	1) $d\ \alpha_1/dt = f\ \{t/P\}$	$d\ \alpha_1/dt = P\ f\ \{t\}$
	2) $= P\ f\ \{t\}$	
Temperature	1) $d\ \alpha_1/dt = T^{.8}\ f\ \{t\ T^{1.8}\}$	$d\ \alpha_1/dt = \exp[-(E_a+E_s)/T]/T$ $x\ f\ \{t\ \exp(-E_x/T),\ k_s\}$
	2) $d\ \alpha_1/dt = T^{-.5}\ f\ \{t\ T^{.5},\ k_s\}$	
Internal Structure	1) $d\ \alpha_1/dt = 1/(m_r(1-\epsilon_o-\epsilon_{io}))$ $x\ f\ \{t.\ ,_r,_p\}$	$d\ \alpha_1/dt = 1/(\Phi_g\ R_{go}^2)$ $x\ f\ \{t/R_{go}^2,\ m_r/m_p\}$
	2) $d\ \alpha_1/dt = 1/(m_r(1-\epsilon_o-\epsilon_{io}))$ $x\ f\ \{t,\ R_{po}/R_o,\ m_r/m_p\}$	

a - Case 1 under pore diffusion control is for molecular diffusion in the pores.

b - Case 2 under pore diffusion control is for Knudsen diffusion in the pores.

Table 2-6 (Continued)

Nomenclature is as follows:

α_1 = the fraction of the sorbent calcium reacted
t = the time
Φ = the particle sphericity
Φ_g = the grain average sphericity
R_o = the equivalent radius of the particle
R_{go} = the equivalent radius of the grain
R_p = the average pore radius
P = the gas pressure
T = the absolute temperature
E_s = the activation energy for the solid diffusion
E_a = the activation energy for the adsorption of SO_2
k_s = the particle sintering rate constant
m_r = the molar density of the solid reactant species
m_p = the molar density of the solid product species
ϵ_o = the initial calcine porosity
ϵ_{io} = the initial volume fraction of inerts in the particle

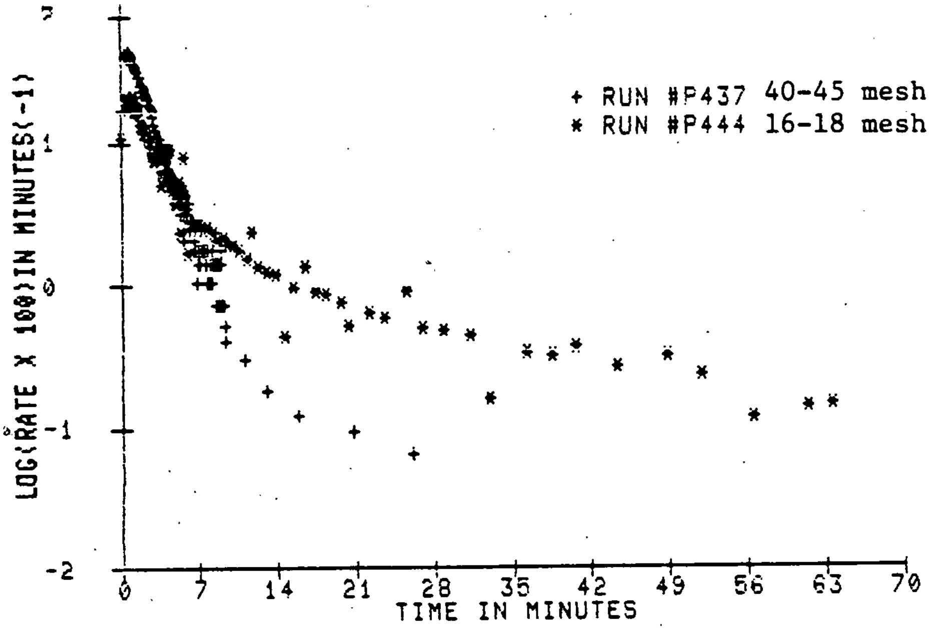


Figure 2.32 — Solid Diffusion Control for Tymochtee Dolomite at 1000°C

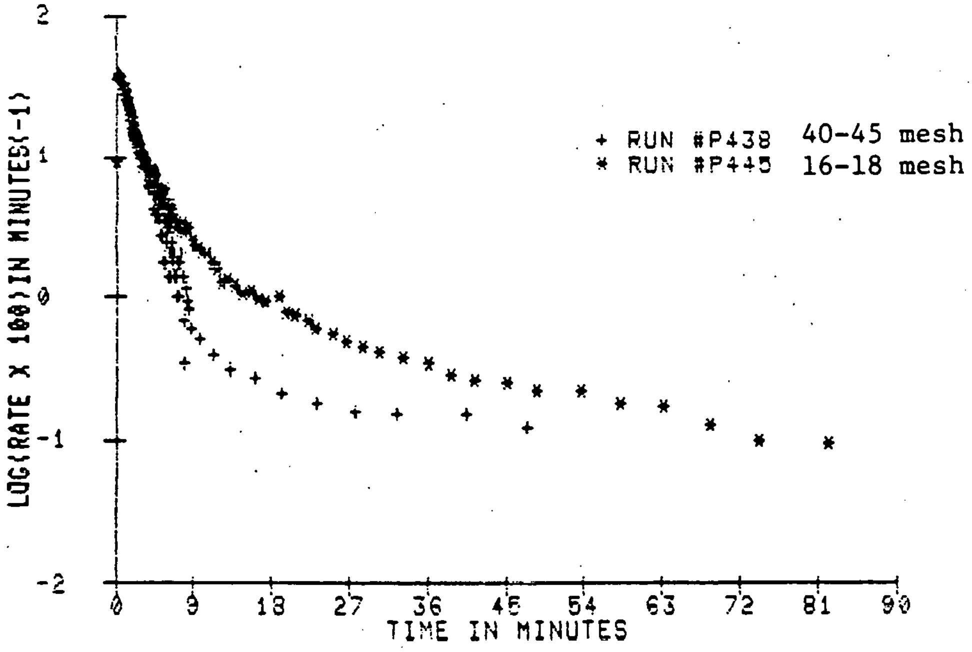


Figure 2.33 — Solid Diffusion Control for Plum Run Dolomite at 1000°C

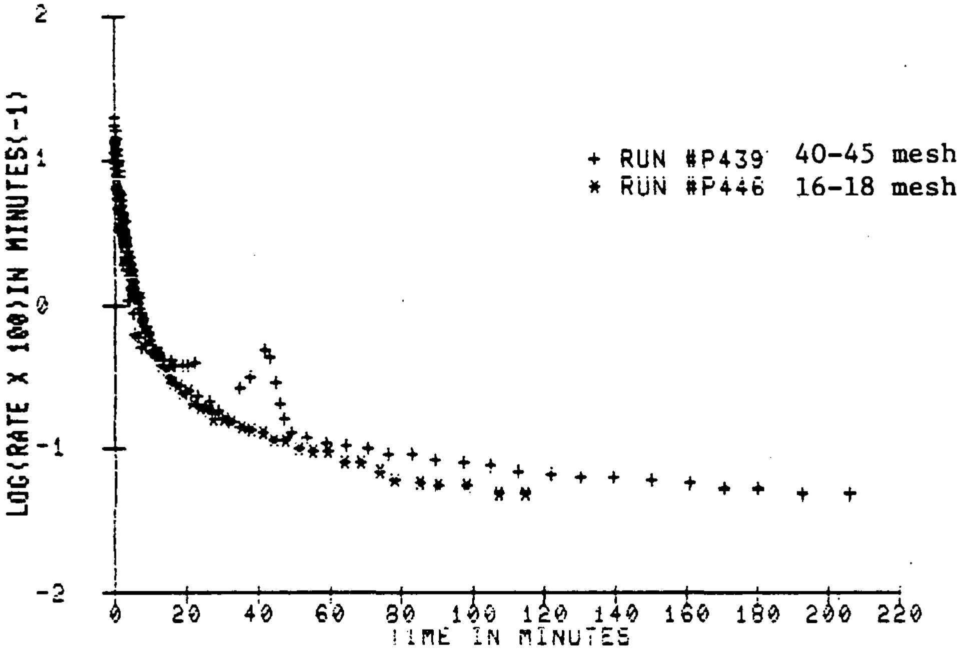


Figure 2.34 — Solid Diffusion Control for Highland Limestone at 1000°C

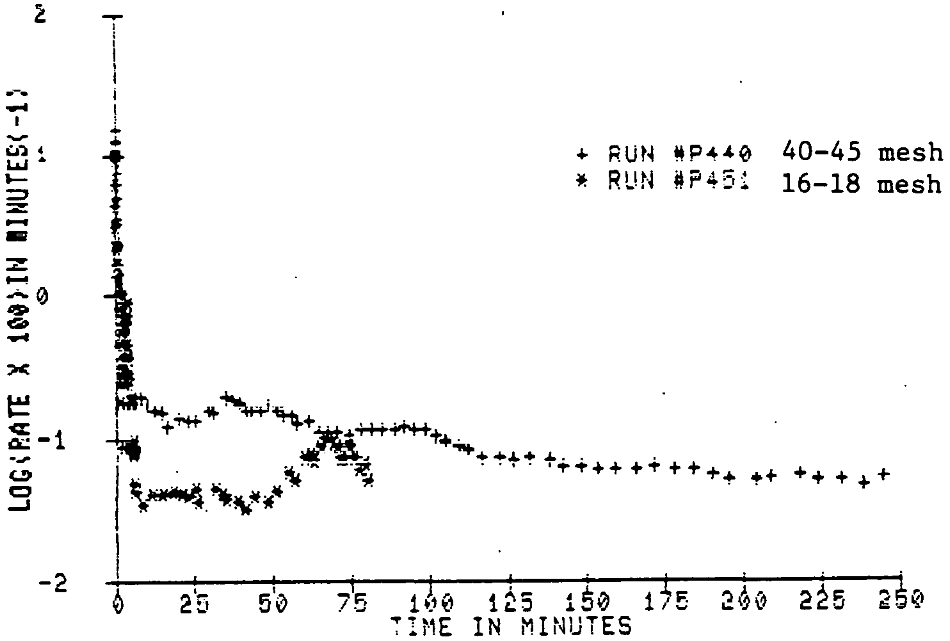


Figure 2.35 — Solid Diffusion Control for Greer Limestone at 1000°C

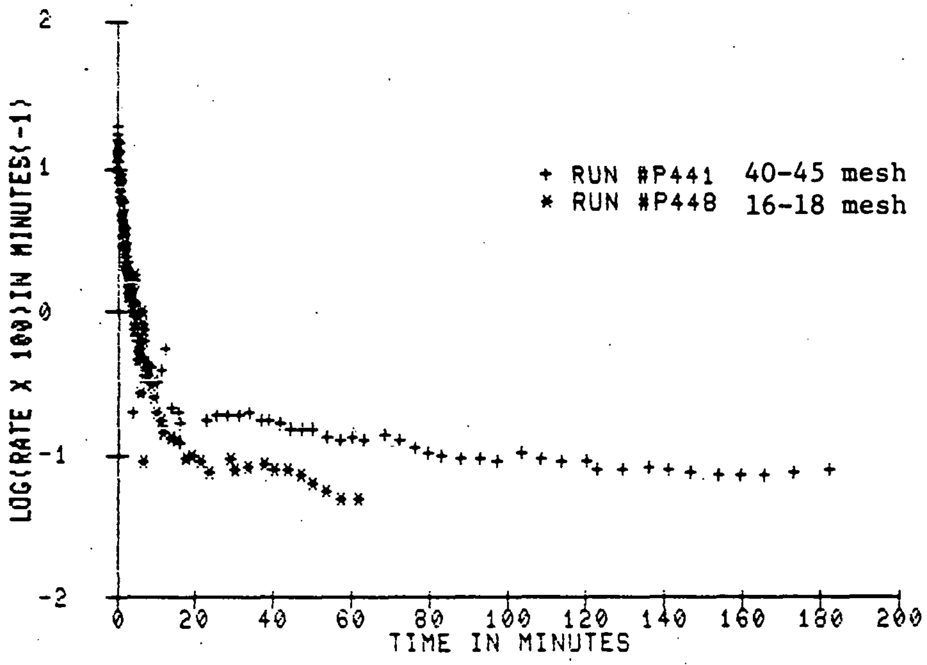


Figure 2.36 — Solid Diffusion Control for Mississippi Limestone at 1000°C

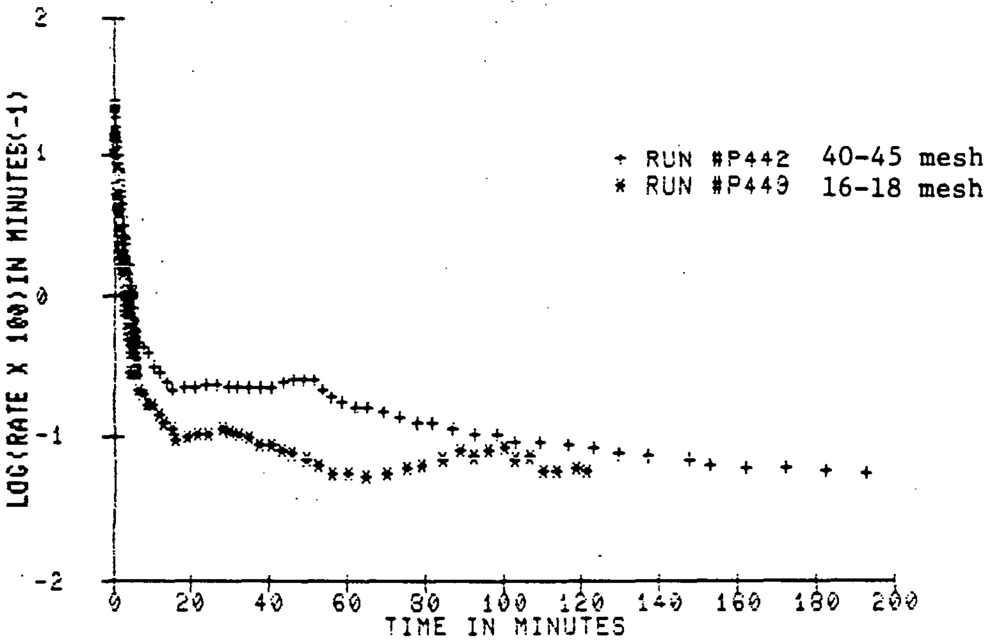


Figure 2.37 — Solid Diffusion Control for Carbon Limestone at 1000°C

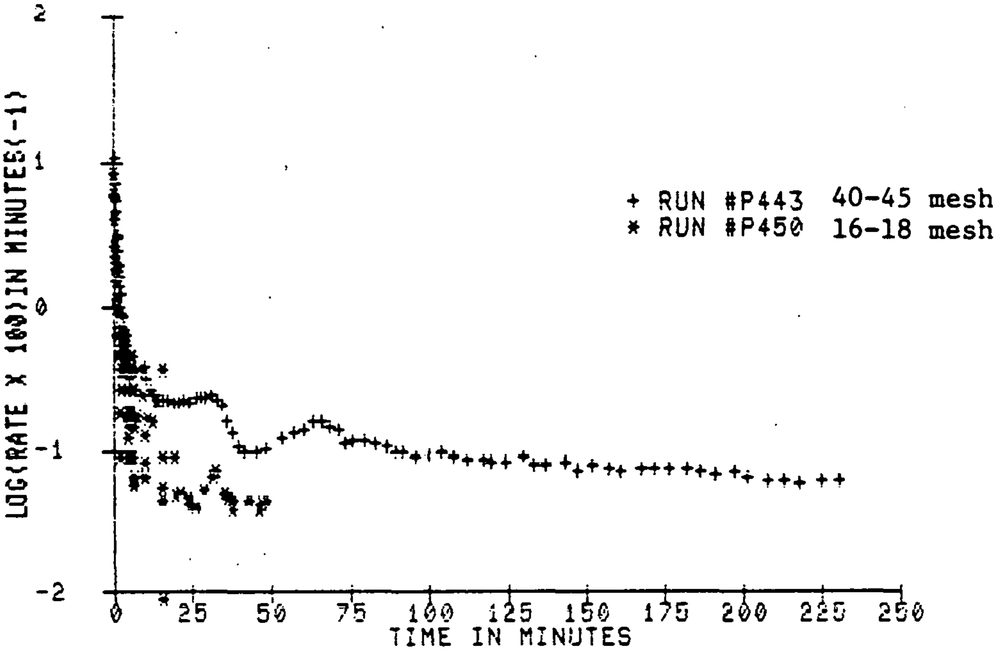


Figure 2.38 — Solid Diffusion Control for Vicron Limestone at 1000°C

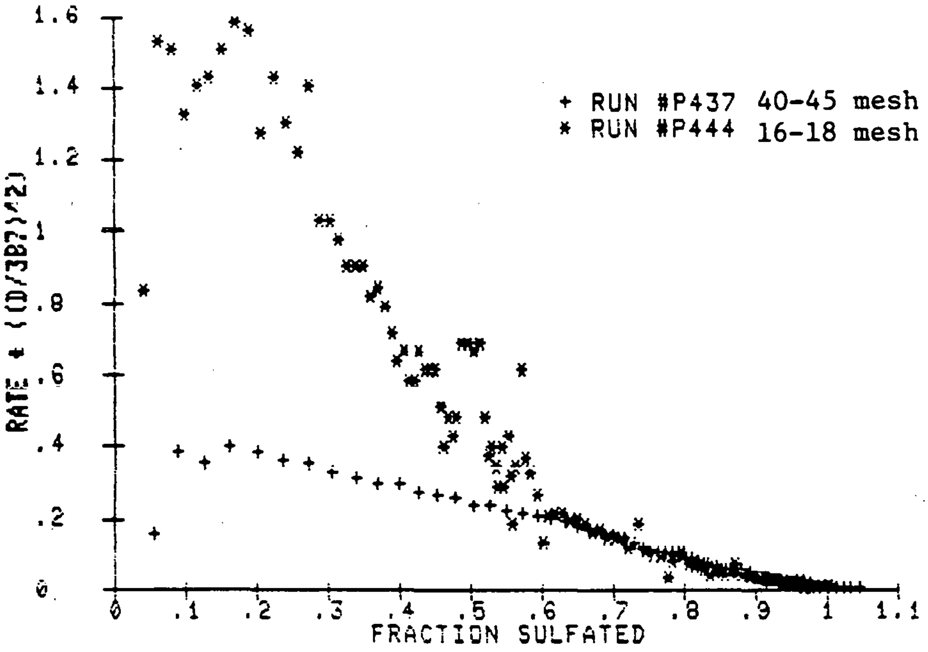


Figure 2.39 — Pore Diffusion Control for Tymochtee Dolomite at 1000°C

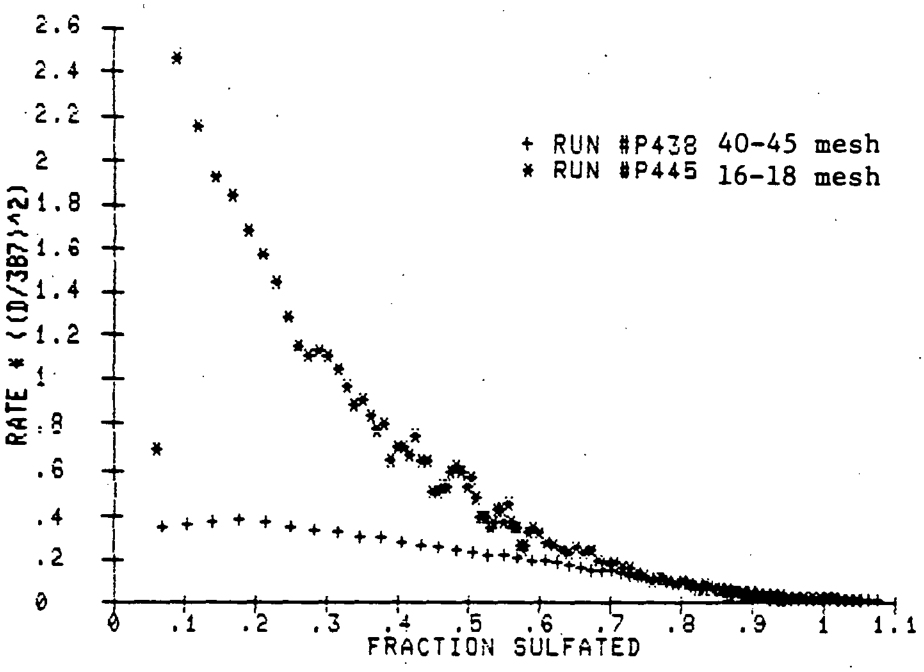


Figure 2.40 — Pore Diffusion Control for Plum Run Dolomite at 1000°C

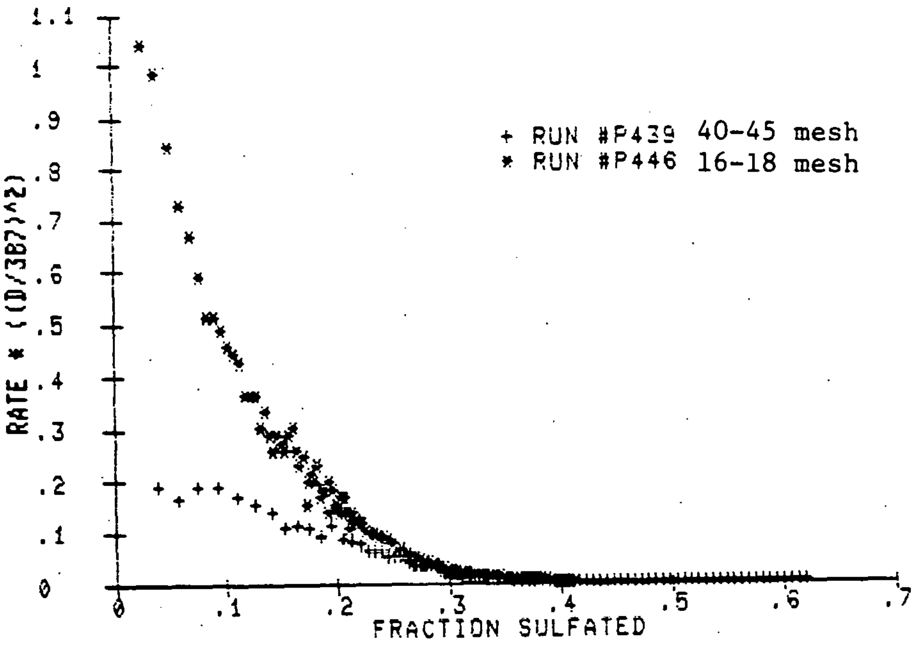


Figure 2.41 — Pore Diffusion Control for Highland Limestone for 1000°C

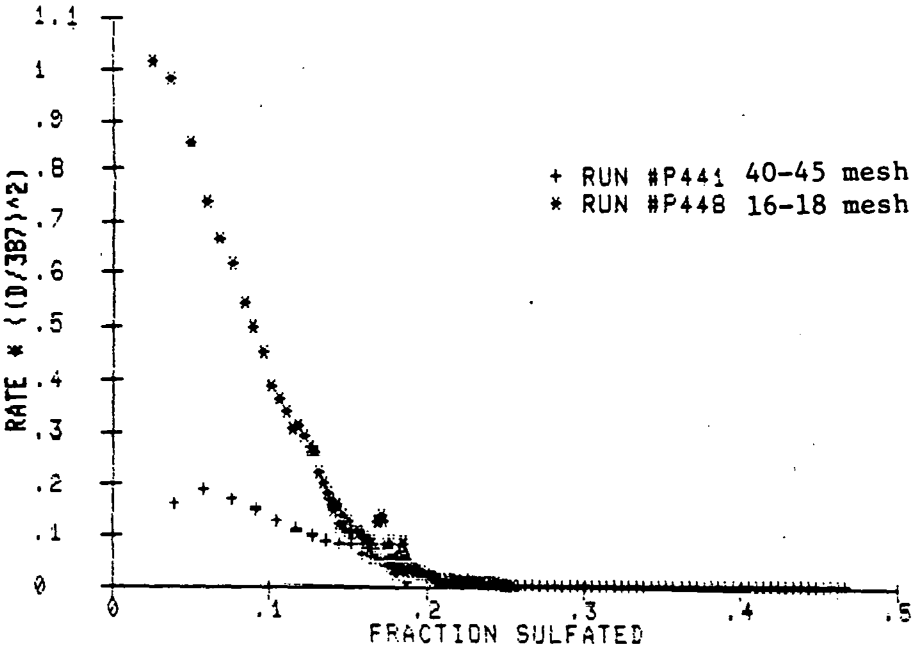


Figure 2.42 — Pore Diffusion Control for Greer Limestone for 1000°C

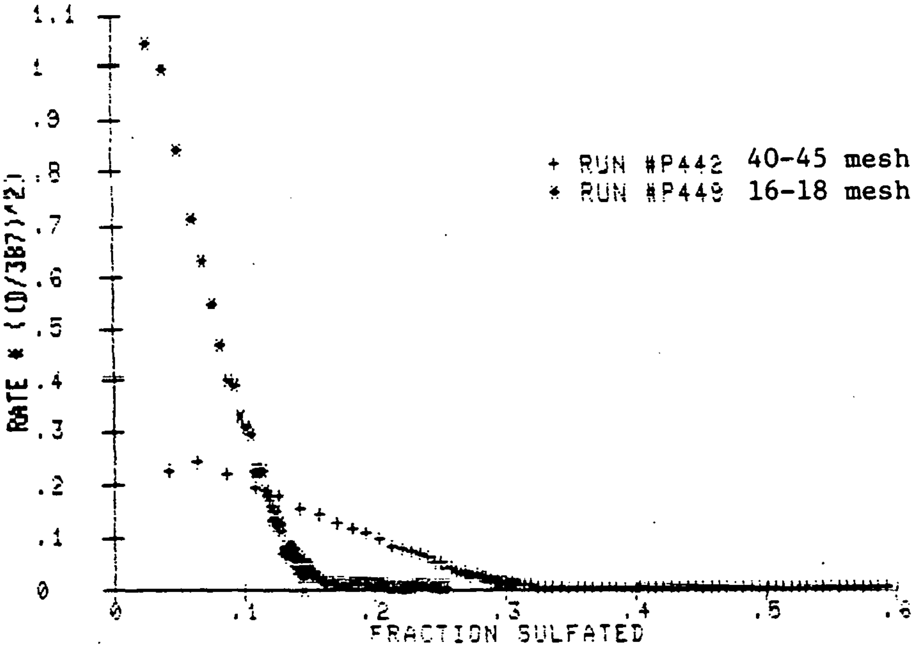


Figure 2.43 — Pore Diffusion Control for Mississippi Limestone for 1000°C

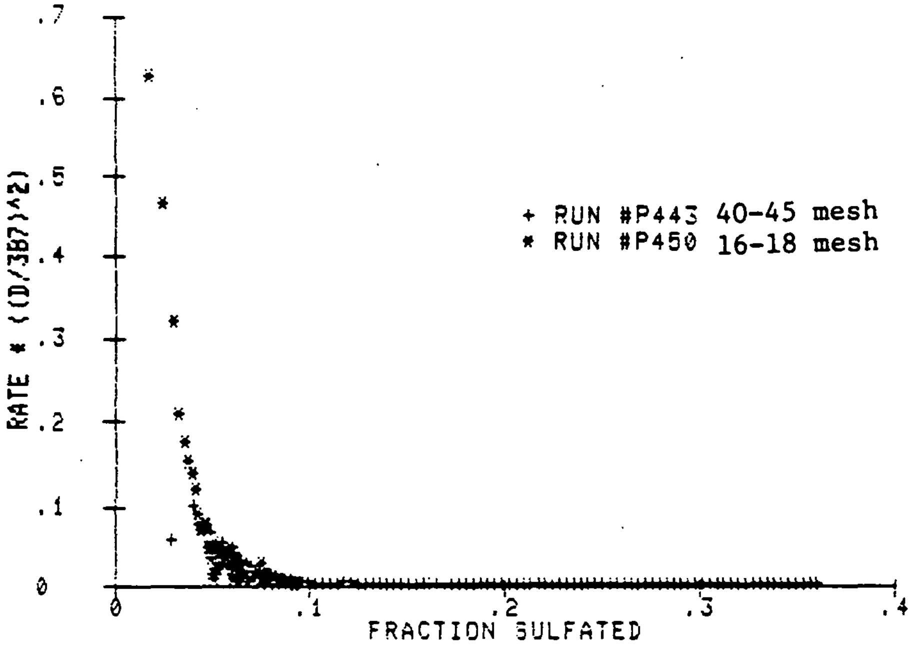


Figure 2.44 — Pore Diffusion Control for Carbon Limestone for 1000°C

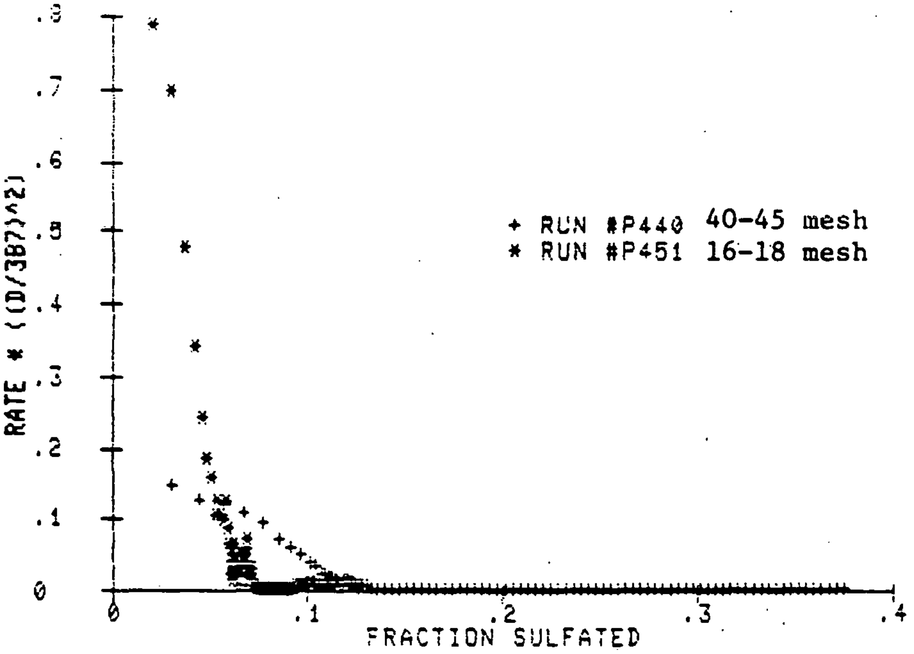


Figure 2.45 — Pore Diffusion Control for Vicron Limestone fcr 1000°C

This behavior trend seems to be confirmed by earlier testing of the effect of pressure on the sulfation rate for Plum Run dolomite (12), again following the dimensional analysis presented in Table 2.6, and it is concluded that solid phase diffusion control in the early stage of conversion and pore diffusion control in the late stages of conversion are probable mechanisms.

While this type of analysis provides insights into the reaction mechanisms, it has certainly not been fully developed to consider phenomena such as adsorption. Further evaluation of sulfation rate data using this type of analysis is needed.

2.8.2 Empirical Rate Correlation for Untreated Sorbent Sulfation

The rate data was subjected to statistical analysis using the empirical model suggested by the shape of the rate curves:

$$d\,\alpha/dt = k\,(1 - \alpha)^{m} \tag{2-8}$$

where α is the fraction of the calcium sulfated, t is the time, k is an empirical reaction constant, and m is an empirical reaction order constant. Plotting the sulfation rate data in the form of

$$\mathrm{Ln}(d\alpha/dt) \quad \text{versus} \quad \mathrm{Ln}(1 - \alpha) \tag{2-9}$$

should yield a straight line having slope m. The sulfation rate data is found to actually plot as three straight lines segments for all of the runs performed rather than the ideal single line, and it is believed that this is because the reaction controlling resistance changes as the level of sulfation increases, as was shown in the previous section using dimensional analysis. Note that a higher value of the reaction order m means that the sorbent has a lower reaction rate for the same fractional conversion to calcium sulfate.

A typical rate curve in this form is shown in Figure 2.46. This curve for Carbon limestone of 20-25 mesh size shows line segment 1

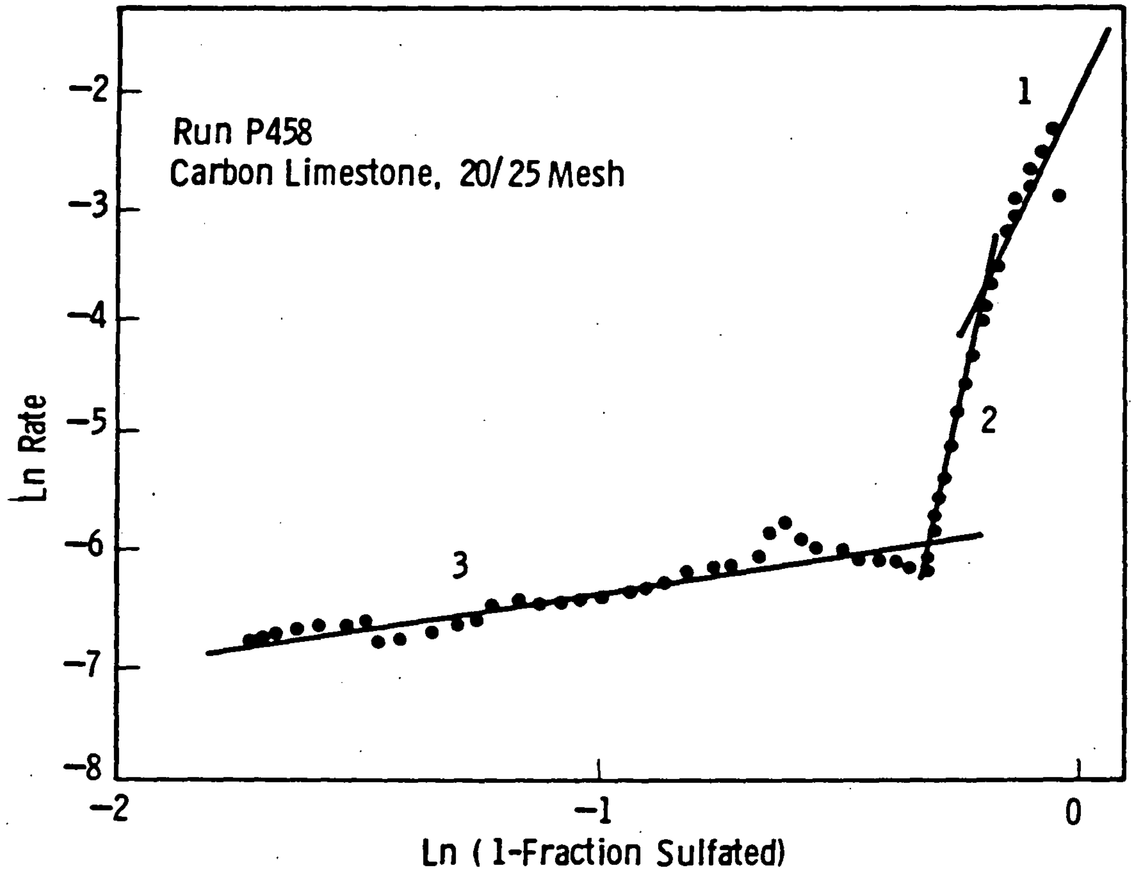


Figure 2.46 — Empirical Fit of Rate Expression to Rate Data: Three Straight Line Segments

extending from $\mathrm{Ln}(1-\alpha) = 0$ to about -0.15 (equivalent to the fraction of calcium sulfated extending from $\alpha = 0$ to 0.14). The line segment 2 extends from $\mathrm{Ln}(1-\alpha) = -0.15$ to about -0.22 (equivalent to calcium sulfation extending from 0.14 to 0.20) and line segment 3 extends beyond 0.22 calcium sulfation. A tabulation of the value of α at each of the two intersection points of the three line segments; the initial sulfation rate (equal to the rate constant k for the first line segment); the rate constant, k, for the second and third line segments; and the reaction order, m, for each of the three line segments are shown in Table 2.7 for all of the untreated sorbent tests conducted.

Examination of the data in Table 2.7 and of the rate curves compiled in Appendix B.1 shows several things:

1) The behavior is similar for five of the seven sorbents, a loss of reactivity is seen as the temperature is increased, while the two that increase in reactivity, Highland and Carbon limestones, show behavior trends that strongly contrast. This can be seen in Table 2.7 by noting that the values of m in all of the line segments increase as the temperature is increased (for equal values of the particle size) for the sorbents Tymochtee, Plum Run, Greer, Mississippi, and Vicron, while the value of m drops as the temperature is increased for Highland and Carbon limestones. This behavior is seen qualitatively in Figures 2.22 through 2.28 as has been described earlier.

2) All seven of the sorbents have initial sulfation rates that display the same behavior trends, with the initial sulfation rate decreasing as the temperature is increased from 1000 to 1200°C. This is clearly seen in Table 2.7 by comparing the initial reaction rate for each sorbent for equal particle sizes. This is more difficult to discern from the actual rate graphs.

3) The data suggests that, at least for the five sorbents with decreasing reactivity as the temperature is increased, there is a similarity in behavior such that:

-- the reaction rate at each of the two intersection points is constant relative to the initial reaction rate, or R_o/R_1 is a constant and R_o/R_2 is a constant, where R_o is the initial reaction rate, R_1 is the reaction rate at the first intersection point in the curve, and R_2 is the rate at the second intersection point in the rate curve.

-- the points of intersection are related by the ratio $(1 - \alpha_1)/(1 - \alpha_2)$ being constant, where α_1 is the fractional calcium conversion at the first intersection point and α_2 is the fractional calcium conversion at the second intersection point in the rate curve.

Thus, the only factors that need to be correlated are the ratios R_o/R_1, R_o/R_2, and $(1-\alpha_1)/(1-\alpha_2)$, the initial reaction rate R_o, and the quantity α_1.

The parameters involved are the sorbent characteristics:

the mass fraction calcium carbonate, X_{CaCO_3}

the mass fraction magnesium carbonate, X_{MgCO_3}

the inert mass fraction, X_{inert}

the pore surface area, A (m^2/gm)

the average pore diameter, d_p (microns)

the average porosity, ϵ_p

and the average grain size, d_g (microns)

and the operating parameters:

the particle diameter, D (microns)

and the temperature, T (°C)

Table 2.7 — Correlation of Coarse Particle Reaction Kinetics

Sorbent	Run Number	Particle Diameter, Microns	Temperature, °C	Calcium Fraction Sulfated at First Intersection	Calcium Fraction Sulfated at Second Intersection	Initial Reaction Rate, min^{-1}	Second Segment k	Third Segment k	First Segment m	Second Segment m	Third Segment m
Tymochtee Dolomite	P437	387	1000	0.71	0.935	0.511	0.836	1.22	1.00	1.40	1.54
	P444	1095	1000	0.55	0.89	0.383	0.206	0.027	2.40	1.63	0.718
	P452	774	1100	0.18	0.49	0.162	0.264	0.009	2.96	5.43	0.48
	P460	387	1200	0.35	0.59	0.261	2.58	0.005	2.65	7.97	1.03
	P459	1095	1200	0.217	0.45	0.182	0.688	0.609	3.25	8.69	8.49
Plum Run Dolomite	P438	387	1000	0.62	0.88	0.562	0.840	0.400	1.18	1.60	1.34
	P445	1095	1000	0.33	0.83	0.383	0.278	0.031	2.77	1.98	0.746
	P453	774	1100	0.15	0.23	0.147	1.08	0.013	4.92	17.2	0.572
	P462	387	1200	0.25	0.429	0.287	1.41	0.003	5.32	10.8	0.287
	P461	1095	1200	0.185	0.523	0.261	1.79	0.082	6.57	15.9	8.10
Highland Limestone	P439	387	1000	0.233	0.35	0.285	3.44	0.030	5.51	14.9	3.94
	P446	1095	1000	0.19	0.31	0.178	0.407	0.367	9.12	13.0	12.7
	P454	774	1100	0.18	0.34	0.133	0.242	0.007	7.17	10.1	1.80
	P468	387	1200	0.238	0.48	0.162	0.597	0.011	3.19	7.99	1.99
	P467	1095	1200	0.138	0.27	0.147	0.452	0.029	9.11	16.3	7.89
Greer Limestone	P440	387	1000	0.0875	0.138	0.261	54.0	0.010	16.4	68.7	11.1
	P451/447	1095	1000	0.045	0.063	0.300	4.07	0.043	49.4	102.1	32.4
	P455	774	1100	0.068	0.081	0.18	276.0	0.003	41.0	145.2	12.5
	P470	387	1200	0.056	2.084	0.214	37.2	0.002	32.9	122.5	12.1
	P469	1095	1200	0.043	0.073	0.22	18.4	0.001	43.8	144.5	15.3
Mississippi Limestone	P441	387	1000	0.154	0.28	0.383	3.27	.011	9.14	21.9	4.80
	P448	1095	1000	0.095	0.222	0.261	0.479	3.23	14.3	20.4	28.0
	P456	774	1100	0.060	0.125	2.16	0.271	1.05	21.2	29.7	39.9
	P472	387	1200	0.051	0.115	0.178	1.29	2.005	23.8	61.8	16.8
	P471	1095	1200	0.058	0.096	0.18	6.81	0.002	32.3	93.2	16.2
Carbon Limestone	P442	387	1000	0.218	0.34	0.422	14.6	0.014	5.85	20.2	3.65
	P449	1095	1000	0.09	0.19	0.261	1.25	0.047	14.4	31.0	15.5
	P458	774	1100	0.14	0.20	0.18	4.78	0.003	11.4	33.1	1.01
	P466	387	1200	0.145	0.34	0.237	0.549	0.009	7.51	12.8	3.20
	P465	1095	1200	0.15	0.31	0.147	0.798	0.004	7.28	17.3	3.81
Vicron Limestone	P443	387	1000	0.069	0.11	0.516	2.41	0.003	32.0	60.4	3.28
	P450	1095	1000	0.024	0.05	0.20	0.539	0.029	44.4	85.2	28.4
	P457	774	1100	0.0185	0.037	0.26	0.085	0.026	140.1	80.5	49.6
	P464	387	1200	0.0375	0.054	0.162	13.5	0.005	66.0	180.8	42.3
	P463	1095	1200	0.015	0.034	0.152	0.788	0.014	116.8	225.7	110.8

The mass fraction of $CaCO_3$, $MgCO_3$ and inerts sum to unity, so the mass fraction of $CaCO_3$ can be eliminated as a parameter. The average pore diameter is directly related to the porosity and the surface area through the mercury porosimeter measurements and calculations, so it may also be eliminated. Also, for the seven sorbents studied, it is found that the porosity correlates very well with the sorbent composition, grain size and surface area by

$$\epsilon_p = 1.977\ (A)^{0.43}\ (d_g)^{0.46}\ (X_{inert})^{0.46}\ (X_{MgCO_3})^{-0.19} \qquad (2\text{-}10)$$

with the standard error of this correlation being about 20%. Then, the porosity of the sorbent may also be eliminated as a parameter in the evaluation.

Six parameters remain: X_{MgCO_3}, X_{inert}, A, d_g, D, and T.

The quantities proposed to be constant, R_o/R_1 , R_o/R_2, and $(1-\alpha_1)/(1-\alpha_2)$ have been calculated from the test data as reported in Table 2.7, and statistically evaluated for all of the tests completed using standard statistical methods to see if they are indeed approximately constant. The results are as follows:

R_o/R_1:

sample average -- 5.34
standard deviation -- 3.51
median -- 4.21
95% confidence limits -- 4.14 to 6.55

R_o/R_2:

sample average -- 129
standard deviation -- 140
median -- 75
95% confidence limits -- 81 to 177

$(1 - \alpha_1)/(1 - \alpha_2)$:

sample average -- 0.80
standard deviation -- 0.22
median -- 0.85
95% confidence limits -- 0.72 to 0.88

While these ratios show a significant variation, they draw the test results very close together considering the extremely wide variation in sorbent behavior observed. Errors arise from several major sources: sorbent sample not representative or homogeneous, thermogravimetric balance measurement errors, rate data evaluation errors, and model errors. Considering the potential magnitude of the errors, the proposed similarity of the rate curves is a good method to bring the data together in a more uniform description.

The initial reaction rate (expressed as the fraction of calcium sulfated per minute in a gas containing 0.5% SO_2 by volume) may be correlated against the parameters for all of the seven sorbents tested since all seven displayed the same trends. In the correlation below, generated by standard multiple regression techniques, each parameter is shown divided by its mean value for the 36 runs.

$$R_o/0.2506 = 0.0385\ (X_{MgCO_3})/17.8)^{-.0075}\ (X_{inert}/2.55)^{0.215}$$

$$(A/0.486)^{-0.0338}\ (d_g/145)^{0.107}\ (D/748)^{-0.277}$$

$$\exp[4799/(T + 273)] \qquad (2\text{-}11)$$

The standard error for this correlation is about 31%. Obviously, the parameters X_{MgC03}, A, and d_g are of little significance. The initial rate increases as the inert fraction in the sorbent increases, as the particle diameter decreases, and as the temperature decreases, in the range of conditions tested. The small influence of particle diameter is consistent with a predominant solid phase diffusion control in the initial reaction rate.

In a similar manner the calcium conversion at the point of the first intersect in the rate curve, α_1, may be correlated with the parameters for the five sorbents that displayed a reduced reactivity with increasing temperature (Tymochtee, Plum Run, Mississippi, Greer and Vicron), all of these showing a reduced value of α_1 as the temperature was increased.

$$\alpha_1 = 0.00196 \ (X_{MgCO_3})/20.5)^{0.639} \ (X_{inert}/2.5)^{-0.079} \ (A/.45)^{0.376} \ (d_g/184)^{-0.062} \ (D/748)^{-0.517} \ \exp[5990/(T + 273)] \tag{2-12}$$

The standard error in this correlation is about 36%. The parameters X_{inert}, and d_g are not significant. The value of α_1 increases as X_{MgC03} increases, as the term A increases, as D decreases, and as the temperature decreases. The larger the value of α_1 is, the larger is the overall reactivity of the sorbent.

The value of α_1 for the two sorbents tested that display increased reactivity with increased temperature, Highland and Carbon limestones, increases as the temperature increases, although it follows the same trends in X_{inert}, A, and D as for the other five sorbents. The explanation for the behavior of these two sorbents is not found in the values of the chemical and physical properties of the sorbents measured and reported in Table 2.2 and the fact that they are both dolomitic limestones may or may not be significant. Some other chemical/physical properties as yet not known may explain these results. At this point the only clues are found in the fact that Carbon limestone shows a tendency to "pop", or spontaneously explode when reaching the temperature of about 400°C, probably due to the breakage of hydrate bonds or the transition from aragonite to calcite crystals since this is the temperature of $Ca(OH)_2$ decomposition and aragonite transition. Thus, the crystal structure of Carbon limestone is probably altered when this occurs, giving more favorable performance. Also, previous tests at atmospheric pressure with Carbon limestone show that it is more reactive when it is shock calcined than when it is slowly calcined, contrary to most sorbents that show little or no difference. These two factors, popping and shock activation, may be empirical indicators of sorbents that will perform well at high temperatures.

Highland limestone also shows a tendency to pop, consistent with its improved performance at higher temperatures. Its shock calcination behavior has not been tested. One other sorbent, Mississippi limestone, also shows the popping behavior, but is not increased in activity as the temperature is increased, so this factor alone is not sufficient to indicate the activation at increased temperatures.

It must also be pointed out that the reversible temperature effect found with all of the sorbents, was also found with Carbon and Highland limestones -- that is, when Carbon and Highland limestones approached saturation, a drop in the temperature would increase the reaction rate and the extent of sulfation, although the increase was not as significant as with the other five sorbents.

Other explanations for the behavior of Carbon limestone and Highland limestone may be hypothesized based on thermal sintering influences on the pore size distributions, impurity interactions with the possible formation of liquid phases, improvements in the solid phase diffusion coefficient, etc. All of these are speculative phenomena and would require detailed testing.

2.8.3 Analysis of Rate Data for Sorbent Sulfidation

The rate data for the sulfidation tests with hydrogen sulfide, though not as extensive as the tests with sulfur dioxide, also reveal some important factors. First, it is assumed that the reaction rate is first-order in the H_2S partial pressure from previous studies. Then, from the two runs with Plum Run dolomite in H_2S at pressures of 1 and 5 atmospheres (runs P484 and P481 shown in Appendix B4) it can be determined that the reaction rate is proportional to the 0.5 power of

$$d\alpha/dt = k\ (1 - \alpha\ )\ Y\ \ P^{0.5} \tag{2-13}$$

the total pressure. The reaction is also found to be about first-order in the calcium fraction reacted over at least the first 70% of conversion, so the rate expression becomes for dolomites where Y is the volume fraction of H_2S in the gas and P is the total gas pressure. For Highland limestone (run P485 in Appendix B4, page B-184) the rate expression is roughly

$$d\alpha/dt = k\ (\ 1 - \alpha\ )^{5}\ Y\ \ P^{0.5} \tag{2-14}$$

The initial reaction rates with H_2S are slightly lower than with SO_2. For identical conditions of pressure, temperature and concentration the initial rate of reaction with H_2S is about 70% of the initial rate with SO_2 with both Plum Run dolomite and with Highland limestone. On the other hand, the extent of calcium conversion tends to be considerably greater with H_2S than with SO_2 because, as is expected, the rate of reaction falls off less rapidly as conversion is increased.

2.9 EVALUATION OF THE FLUIDIZED-BED DESULFURIZER

An engineering model of the fluidized-bed desulfurizer has been developed based on previous Westinghouse sulfur removal modeling for fluidized bed combustion systems (21, 37, 38). The model, described in detail in Appendix D, is based mainly on the following set of assumptions:

-- The reaction kinetics in the fluidized-bed desulfurizer may be scaled using the laboratory measured kinetics for the specific temperature, particle size, and sorbent.

-- Significant sorbent particle attrition or agglomeration does not occur in the fluidized-bed desulfurizer.

-- The fluidized bed behaves either in a large particle mode having high rates of gas flow through the slow bubbles in the bed, or it behaves as a turbulent fluidized bed having high particle streaming and good gas-particle contacting.

-- The temperature is uniform in the fluidized bed and the sorbent particles are perfectly mixed within the bed.

These assumptions apply best to the situations of very coarse particles, where bubble are predominantly of the slow type, or for turbulent fluidization, where gas-solids mixing is very uniform.

The model developed uses the thermogravimetric kinetic data reported and evaluated earlier (the kinetic characteristics in Table 2.7) to generate performance estimates for the commercial desulfurizer. The integrated kinetic information will describe the behavior of the specific sorbents tested as a function of the major desulfurizer operating and design parameters: the temperature, the superficial velocity, the bed depth, and the bed particle size. Note that for fluidized bed desulfurizers the sulfur removal performance is independent of the sulfur content of the coal (so long as the equilibrium SO_2 or H_2S concentration in the gas is always far exceeded). This is due to the well mixed nature of particles in the fluidized bed. The performance factors of interest are

-- the calcium-to-sulfur ratio required to achieve a specified sulfur removal efficiency; 90% sulfur removal is assumed as the requirement in this evaluation since it corresponds to the New Source Performance Standard for large utility boilers.

-- the mass of sorbent fed per mass of sulfur fed in the combustion products to achieve the specified sulfur removal efficiency; since the sorbent mass per unit of calcium may differ significantly between the sorbents considered this factor relates more closely to the economic impact of the purchased sorbent.

-- the gas residence time required in the desulfurizer, or the ratio of the bed depth (H) to the gas superficial velocity (U); this factor relates to the size of the desulfurizer and the pressure drop across the desulfurizer.

-- the energy consumption resulting from the sensible heat loss in the waste sorbent and in calcining and sulfating the sorbent; this factor is small if calcium-to-sulfur ratios as low as about 2 can be used (the exothermic sulfation reaction almost balances the endothermic calcination reaction) and if heat recovery from the solid waste is incorporated into the plant design.

The following Figures (Figure 2.47 through 2.53) show the calculated calcium-to-sulfur ratio (moles of calcium fed per mole of sulfur fed) for SO_2 removal as a function of the temperature, particle size and the quantity [gas residence time in the bed (H/U) multiplied by the quantity (1 minus the bed bubble volume fraction) times (1 minus the emulsion phase voidage fraction)] for each of the seven sorbents tested. The points shown on the curves are calculated points. Typically the quantity $(1-\delta)(1-\epsilon)$ will be about 0.35 depending on the fluidization velocity and sorbent particle size. The performance variation is very large between the sorbents and the implications on the desulfurizer design and operating conditions are related directly to the figures. Obviously it is economically desirable to operate with a shallow bed so that the desulfurizer is compact and so pressure drops are small, to operate with high gas velocities to minimize the desulfurizer diameter, and to use small calcium-to-sulfur ratios to minimize operating cost and waste disposal.

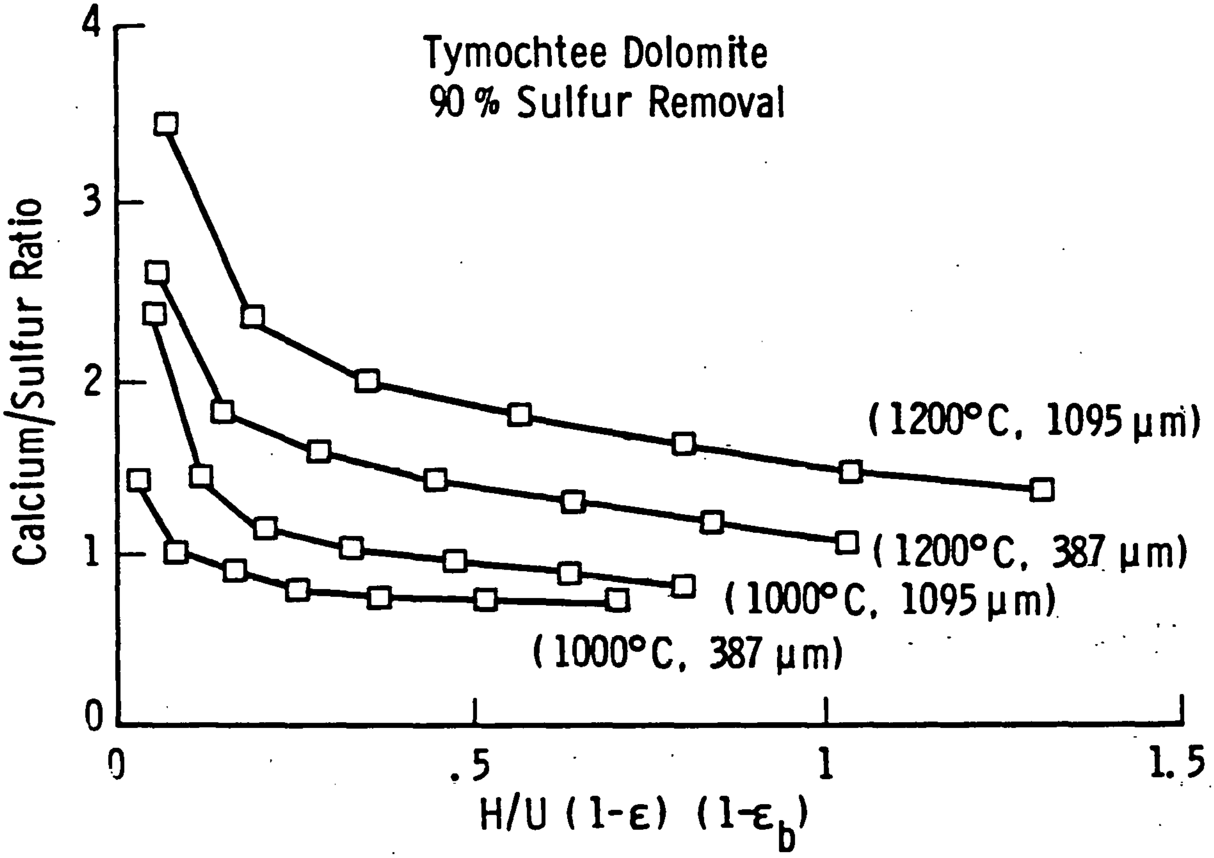


Figure 2.47 — Fluid Bed Desulfurizer Performance Using Tymochtee Dolomite

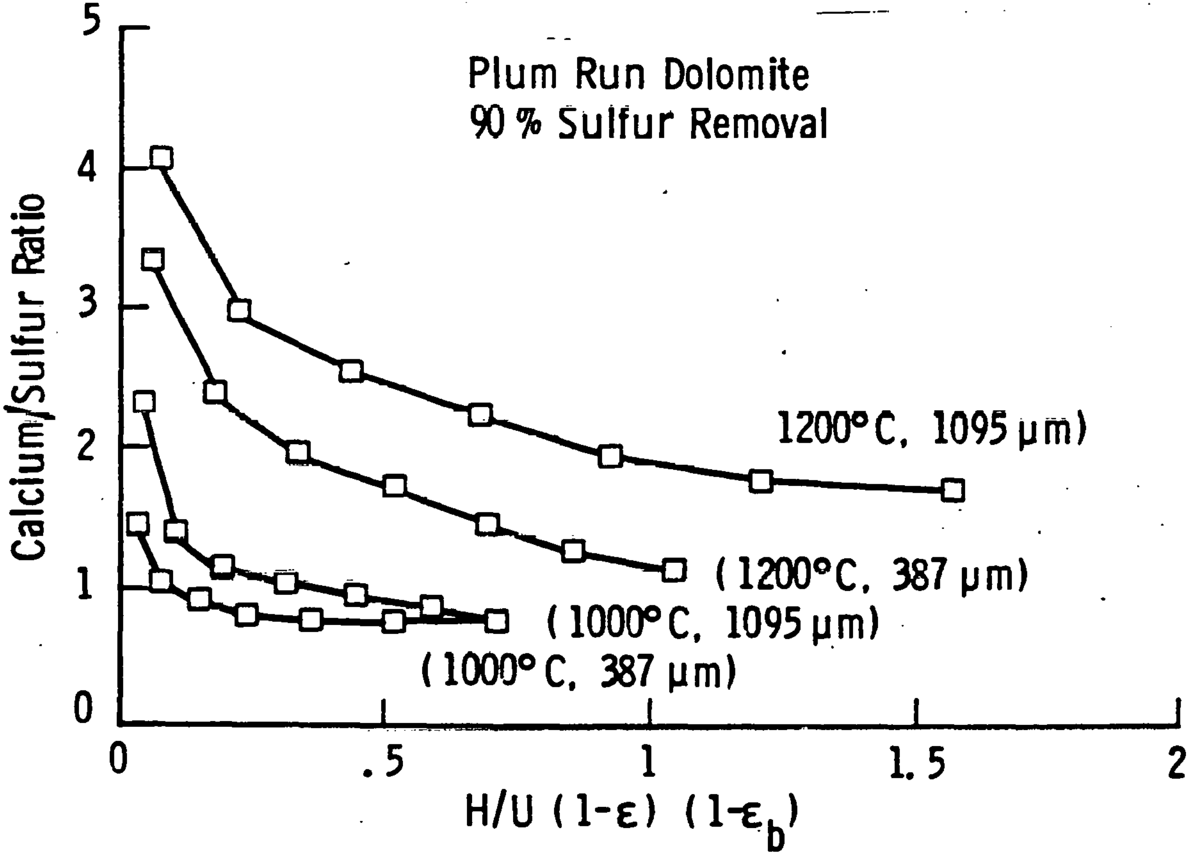


Figure 2.48 — Fluid Bed Desulfurizer Performance Using Plum Run Dolomite

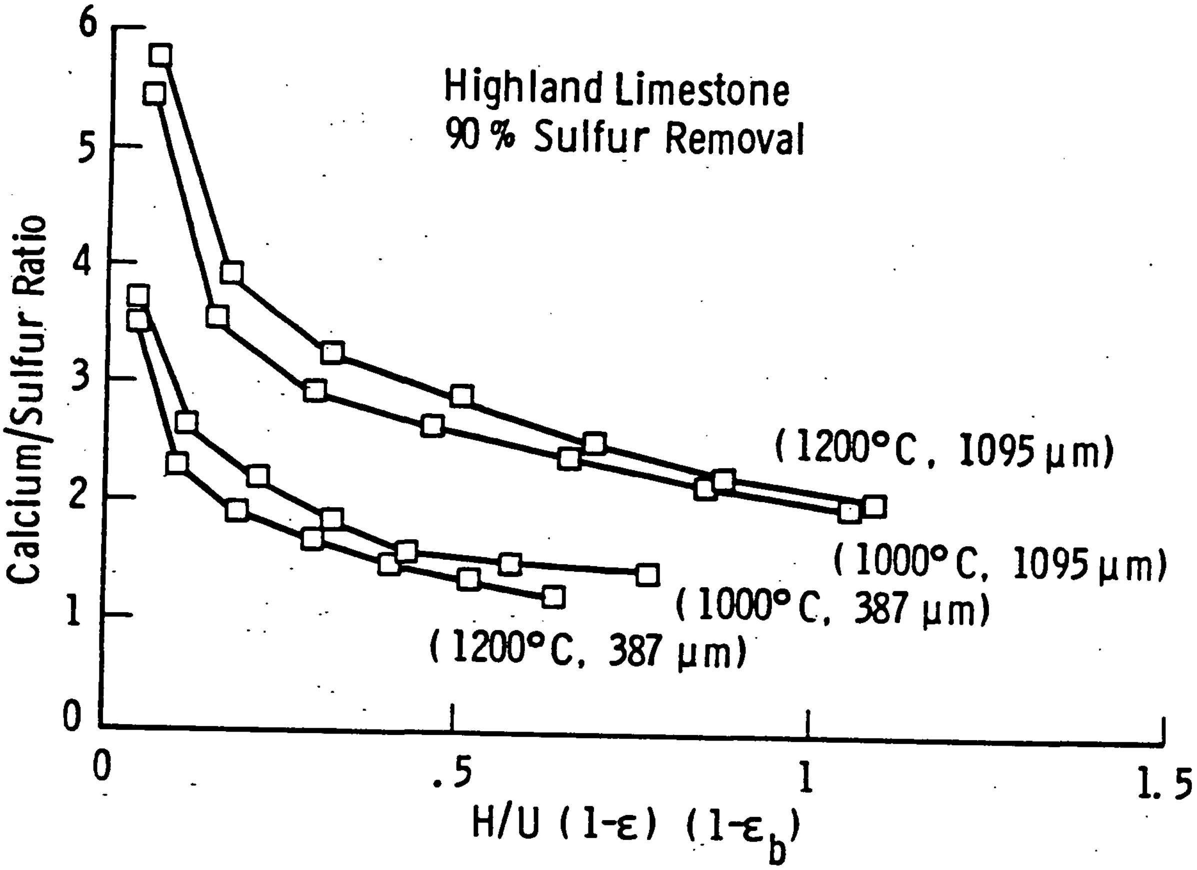


Figure 2.49 — Fluid Bed Desulfurizer Performance Using Highland Limestone

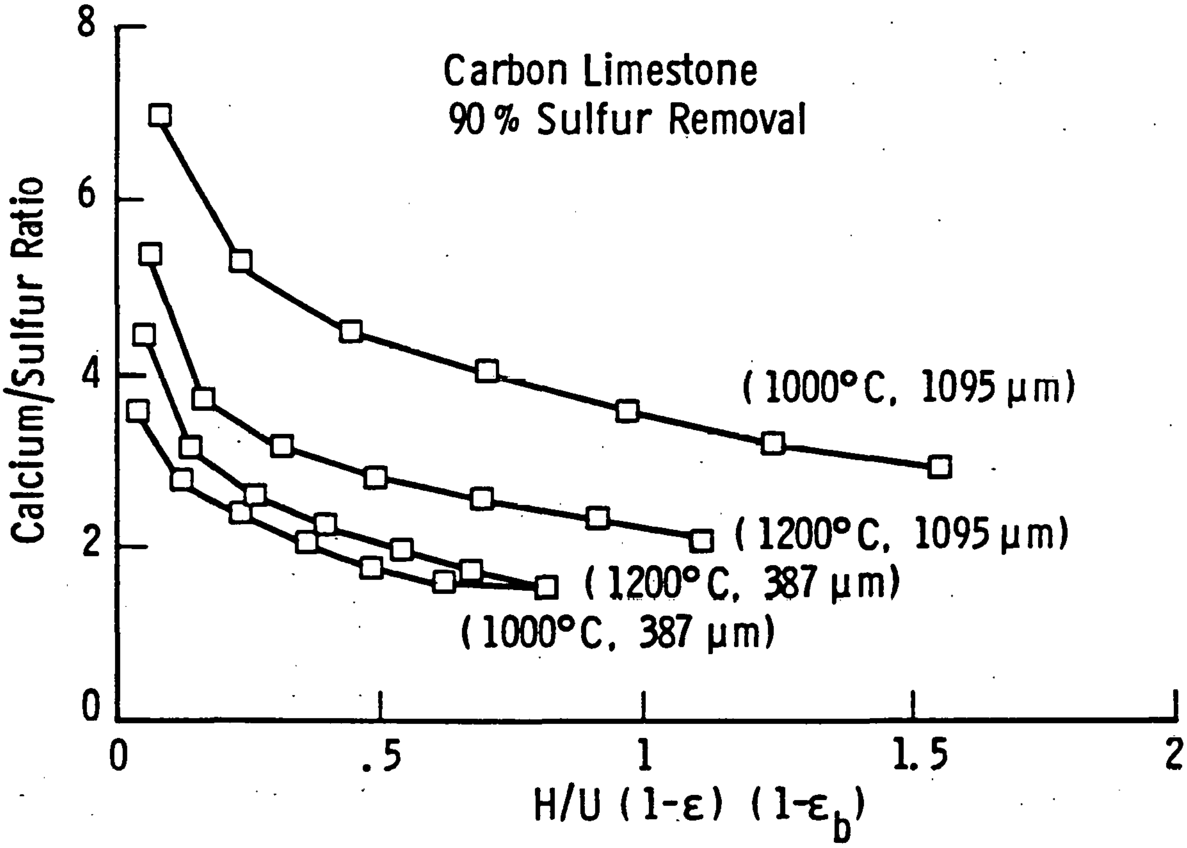


Figure 2.50 — Fluid Bed Desulfurizer Performance Using Carbon Limestone

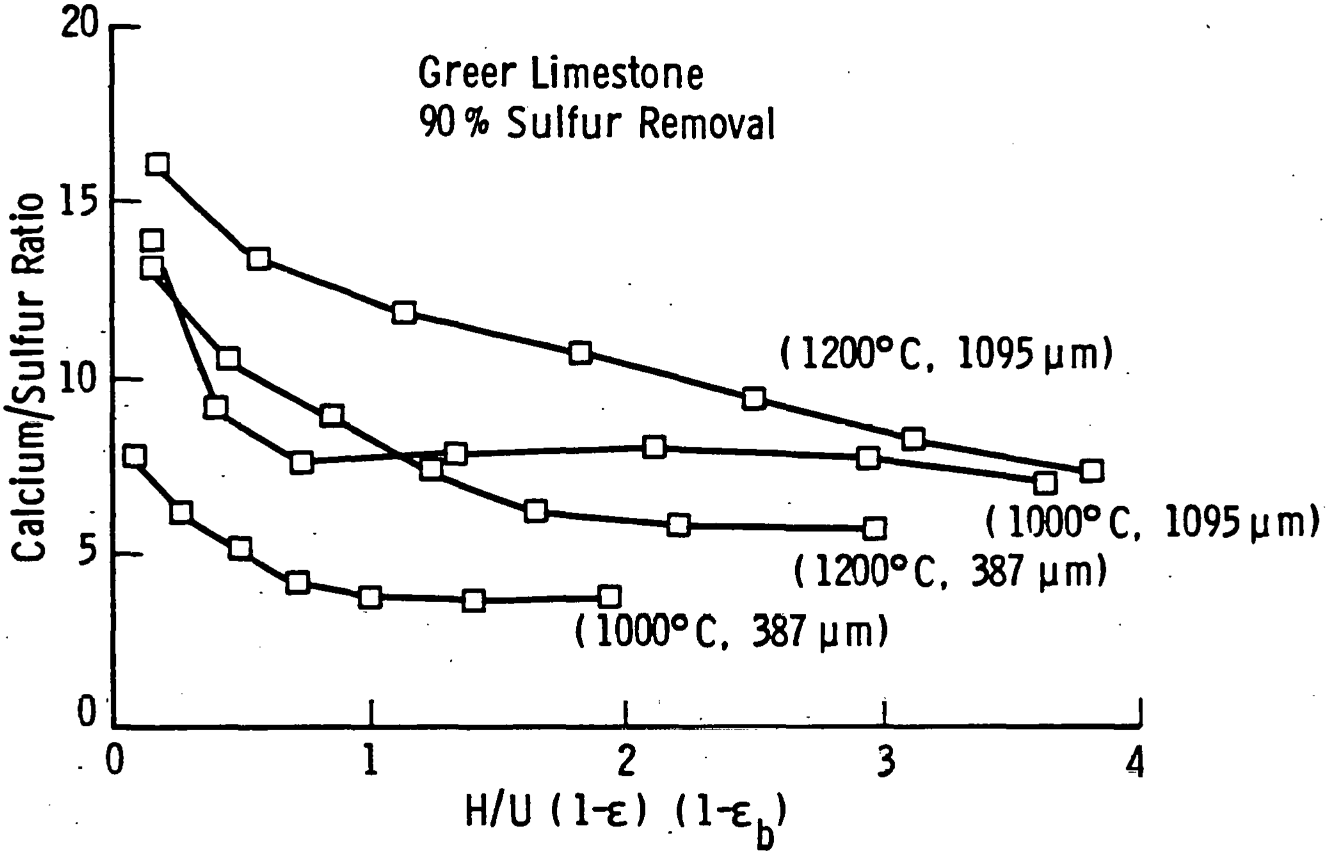


Figure 2.51 — Fluid Bed Desulfurizer Performance Using Greer Limestone

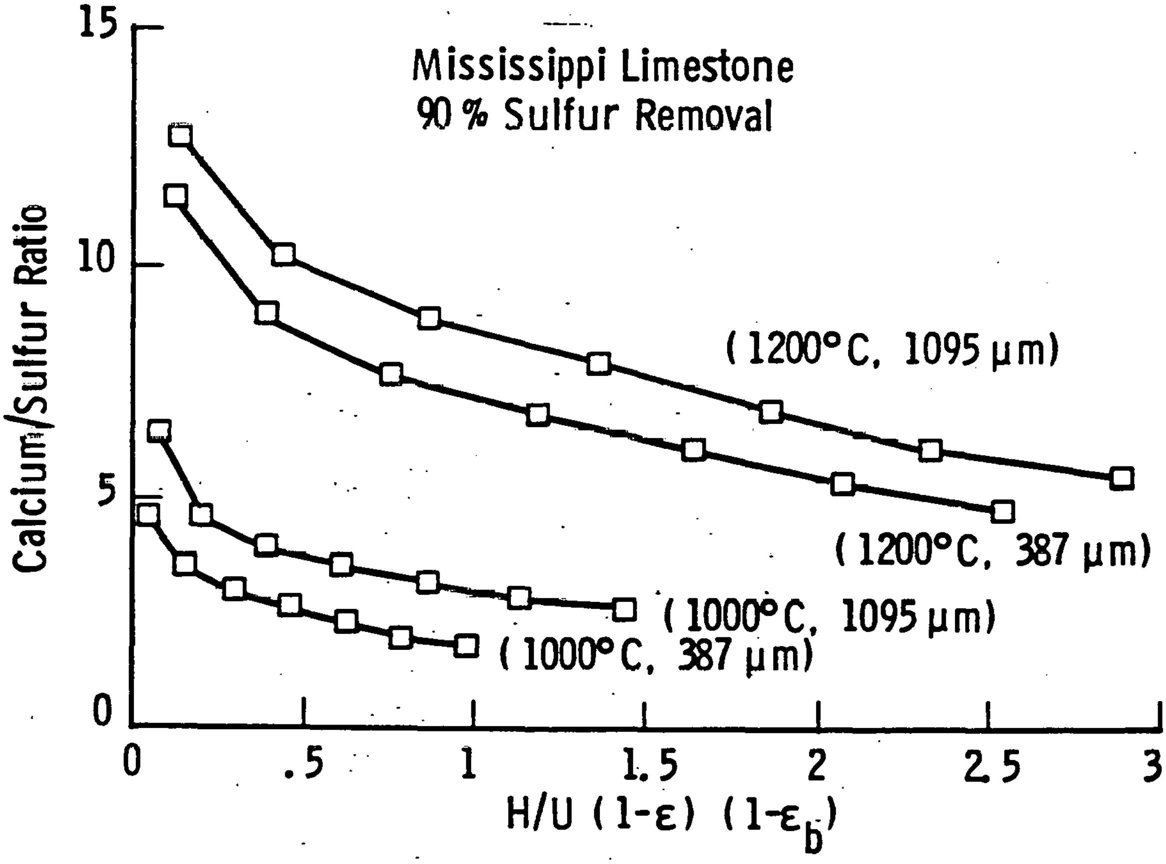


Figure 2.52 — Fluid Bed Desulfurizer Performance Using Mississippi Limestone

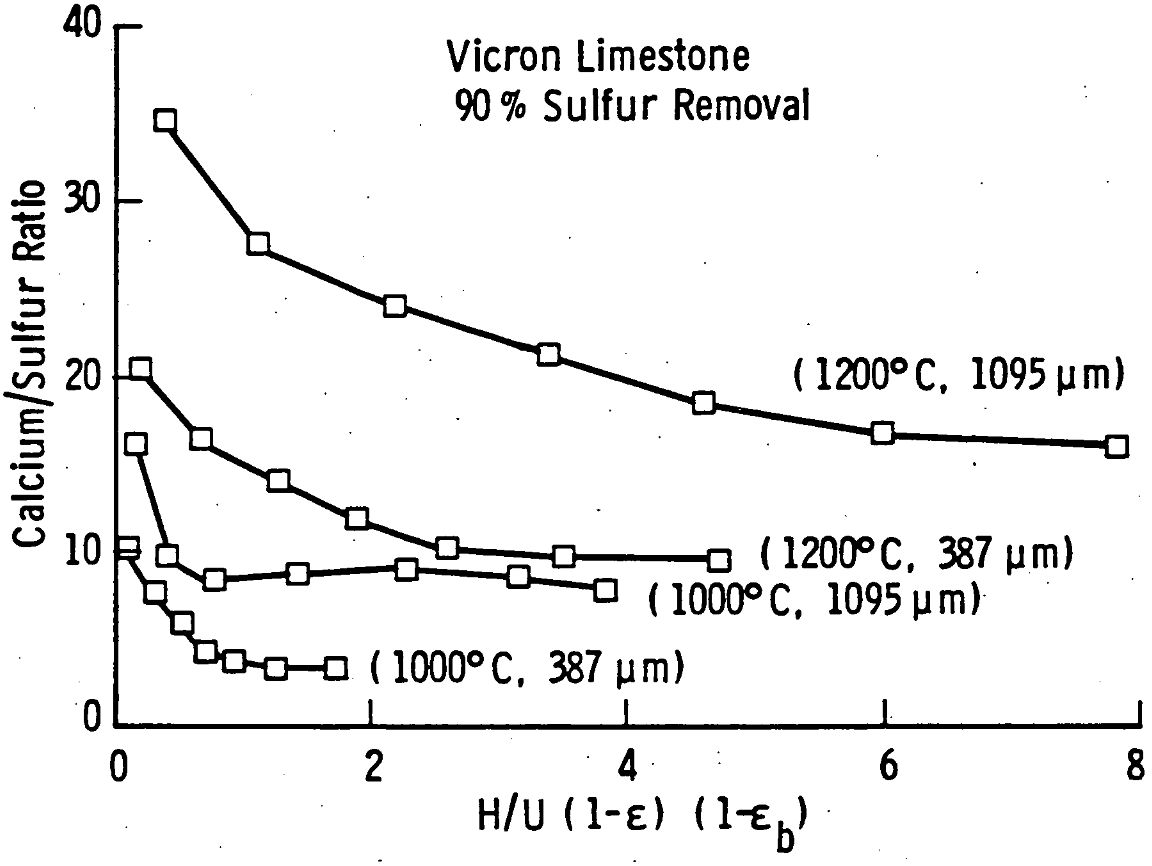


Figure 2.53 — Fluid Bed Desulfurizer Performance Using Vicron Limestone

For a specific gas residence time, H/U, of one-half second in the bed, the following tabulation, Table 2.8, of calcium-to-sulfur ratios and sorbent mass to sulfur mass ratios result. Note that a typical value of the gas residence time, H/U, in pressurized fluidized bed combustion would be about 2 to 3 seconds or even greater in some designs. The obvious detrimental effect of temperature on some of the sorbents, and the limited temperature effect on other sorbent is apparent from the figures and Table 2.8: dolomites will be suitable sorbent even at temperatures as high as 1200°C, although not as good as at 1000°C; limestones having the characteristics of Highland and Carbon will be very good sorbents at temperatures as high as 1200°C, even better than the dolomites on a weight basis; limestones having the characteristics of Greer, Mississippi, and Vicron will be unacceptable for use at temperatures even as great as 1000°C. The kinetic data for sorbent sulfidation for Plum Run dolomite and Highland limestone has been used to estimate the performance of a fluidized bed desulfurizer for H_2S removal. At the bed temperature of 1100°C and with a particle diameter of 1095 microns, Plum Run dolomite would require a calcium-to-sulfur ratio of about 1.5 to remove 90% of the H_2S for the same conditions as those in Table 2.8. Highland limestone would require a calcium-to-sulfur ratio of about 2.6 at these same conditions. Both of the sorbents would perform in H_2S removal about the same as they do in SO_2 (with the exception of the differing equilibrium constraints).

Statistical evaluation of the calcium-to-sulfur results for SO_2 removal for the five sorbents that were found to decrease in performance as the temperature was increased (Plum Run, Tymochtee, Greer, Mississippi, and Vicron) results in the following correlation of the calcium-to-sulfur ratio for a gas residence time of one second, a sulfur removal efficiency of 90%, all at a pressure of 10 atmospheres:

$$Ca/S = 1613\ (X_{MgCO_3})^{-0.666}\ (X_{inert})^{-0.073}\ (A)^{-0.443}\ (d_g)^{-0.20}\ (D)^{0.342}\ \exp[-8331/(T + 273)] \qquad (2\text{-}15)$$

Table 2.8 — Sorbent Consumption for 90% Sulfur Removal

Basis: $H/U\ (1-\epsilon)(1-\delta) = 0.175$ sec; $H/U = 0.5$ sec

	Calcium/Sulfur Molar Ratio				Sorbent Mass/Coal Mass (3 wt % sulfur in coal)			
Dp (μm)	387	1095	387	1095	387	1095	387	1095
T (°C)	1000		1200		1000		1200	
Tymochtee Dolomite	1.0	1.2	1.8	2.4	0.19	0.22	0.34	0.45
Plum Run Dolomite	1.0	1.2	2.3	3.0	0.19	0.22	0.42	0.55
Highland	2.1	3.2	1.8	3.6	0.24	0.37	0.21	0.41
Greer	7.0	13.5	13.0	16.0	0.70	1.35	1.30	1.60
Mississippi	3.2	4.6	10.5	12.4	0.32	0.46	1.05	1.24
Carbon	2.3	5.5	2.7	3.5	0.24	0.58	0.28	0.37
Vicron	10.0	16.0	21.0	38.0	1.0	1.6	2.1	3.8

The standard error of this correlation is about 18%. Increased magnesium content, increased surface area, and, surprisingly, increased grain size, all contribute to a reduction in the sorbent consumption. As is expected, decreased particle diameter and decreased temperature contribute to reduced sorbent consumption. Thus, sorbents for high temperature application having high magnesium content, high surface area, and large grain size should be selected. Designs using small particles sizes (as small as 300 microns) should be used; for example, a circulating fluidized bed rather than a bubbling fluidized bed may provide improved performance.

The two dolomitic limestone sorbents that yield improved performance with increased temperature (Highland and Carbon) show the following statistical behavior for SO_2 removal:

Highland limestone fits a particle diameter to the 0.56 power, while showing very little temperature effect. With a standard error of about 11%, the calcium-to-sulfur ratio for a one second gas residence time in the bed is given by

$$Ca/S = 0.0589\ (D)^{0.56}\ \exp[30/(T + 273)] \qquad (2\text{-}16)$$

Carbon limestone shows a particle diameter power very nearly the same, 0.55, with a higher temperature sensitivity:

$$Ca/S = 0.0245\ (D)^{0.55}\ \exp[1699/(T + 273)] \qquad (2\text{-}17)$$

Major factors in the economic balance for the power plant are: 1) the sulfur content of the coal and the required sulfur removal efficiency, 2) the delivered cost of sorbent to the plant, and 3) the cost of solid waste disposal. Comprehensive cost models of direct coal-fired power plants are not available, but based on fluidized-bed combustion studies it is likely that calcium-to-sulfur ratios of less than 2.0 would be acceptable for dolomites and less than 3.5 for limestones. This also assumes delivered sorbent costs of less than about $20/ton. On this basis, Tymochtee dolomite and Plum Run dolomite could be economically used at temperatures up to 1200°C if particle sizes of less than 400 microns and $H/U\ (1-\epsilon)(1-\epsilon_b)$ greater than 0.2 were used. Highland limestone could be economically used at temperatures up to 1200°C with shallower beds or beds having higher velocities than those suitable for the dolomites. Carbon limestone would also be acceptable at temperatures up to 1200°C for a wide range of operating conditions. None of the other sorbents would be expected to be economically suitable for operation in a fluidized bed desulfurizer at temperatures greater than 1000°C. The disposal cost of residue from SO_2 removal will be lower than the residue from H_2S removal because the sulfided form of calcium is environmently unacceptable for direct disposal and required further processing.

The pressure drop through the fluidized bed desulfurizer will be on the order of about 10 kPa per meter of bed depth. At ten atmospheres pressure an acceptable pressure drop through the desulfurizer system would be about 0.3 atmospheres. Assuming a distributor pressure drop of about 20% of the bed pressure drop, the bed depth could then be up to about 3 meters. Obviously, the gas residence time in the bed is the critical parameter with respect to sulfur removal. Shallow beds could be used if operated at low velocity. For example, with a gas residence time of 0.3 seconds and a velocity of 0.7 m/s, the bed depth would be about 0.2 meters, but the vessel would be very large in cross-section. The deep bed design, with a gas residence time of 1 second, could operate at velocities up to 3 m/s resulting in compact vessel cross-section.

Optimization of the plant economics with respect to the desulfurizer vessel is needed, but many degrees of freedom exist to achieve minimum cost. Contrary to the difficulties of feeding coal in fluidized-bed combustion systems, the sorbent need not be fed in a well distributed manner, but may be fed at only a few points in the vessel. Factors such as sorbent agglomeration, attrition, and elutriation, as well as the distribution of hot gas to the base of the fluidized bed desulfurizer will also influence the choice of operating conditions.

3. FINE CALCIUM-BASED SORBENT PARTICLE FOR SULFUR REMOVAL

Section 3 is devoted to the evaluation of fine, calcium-based sorbents for sulfur removal from the combustion products of direct coal-fired turbines. Fine particles are defined here as having diameters less than about 40 microns, suitable for injection into and entrainment by the hot combustion gases. Background information is reviewed and the key data needs are identified. The test plan, test equipment and procedures are described, using a dispersed particle reactor to simulate the entrained particle environment. Tests that measure the kinetics of sulfation and sulfidation of "sintered", low surface area sorbent particles were conducted -- these are representative of the behavior of sorbents that have been exposed to very high flame temperatures when injected into the combustor or to the behavior of commercial limes. The kinetics of sulfidation and sulfation are evaluated and correlated for the sintered, low surface area sorbents. A conceptual commercial evaluation of sulfur removal performance in entrained desulfurizers using the sintered sorbents is performed based on these measured kinetics. Finally, the kinetics of sulfidation and sulfation of the sintered sorbents is scaled to that expected for active, freshly calcined sorbents having high, but transient surface areas. The commercial performance of these active sorbents is projected.

3.1 BACKGROUND

The data base for the kinetics of the sulfation and sulfidation of fine calcium-based sorbent particles is very limited, especially in the area of elevated pressures, when compared to the coarse particle data base. The following discussion summarizes what has previously been reported in the literature, most of which comes from research directed toward sorbent injection into conventional furnaces at atmospheric pressure.

3.1.1 Effect of Calcined Sorbent Surface Area

The reaction rate of sulfation or sulfidation is observed to be sensitive to the initial surface area of the calcined sorbent. Increased calcined surface area increases the reaction rate and the extent of conversion that can be obtained. Borgwardt, et al, have reported on laboratory studies for both sulfation and sulfidation and have concluded that the reaction rate is proportional to the initial calcined surface area squared (40, 41). Examination of their data shows that they have considered rates for exposure times greater than about 3 seconds that do not apply to the exposure times characteristic of entrained desulfurizers -- the rate has dropped significantly for these long residence times, and exposure times less than 1 second are actually of interest. If the initial reaction rates are estimated from the Borgardt data, it is seen that the reaction rate is roughly proportional to the calcined surface area to the first-power, consistent with the observations of several other investigators (42-47).

These investigators present data on the rate of calcination and surface area development for limestones, dolomites, and lime hydrates.

3.1.2 Effect of Temperature

In the temperature range of interest to direct coal-fired turbines it is known that the surface area of sorbent particles is a strong function of time, changing very quickly during exposure. This transient surface area behavior has been measured by several investigators (42, 46-49). The surface area passes through three stages of development: 1) A sudden surface area increase as the sorbent calcines, 2) a simultaneous surface reduction catalyzed by the presence of H_2O or CO_2 during the calcination process, and 3) a slower thermal sintering of the particle following complete calcination. Higher temperatures increase the rate of calcination while also increasing the rate of thermal and catalytic sintering.

Hydrated limes calcine much more quickly than do limestones or dolomites. The effect of temperature on the sulfation reaction itself seems to be overshadowed by the impact of the temperature on the initial calcined surface area.

3.1.3 Effect of Pressure

The effect of pressure on the calcination rate of fine sorbent particles has not been previously measured. It is expected based on coarse particle testing that higher pressures will reduce the rate of sorbent calcination and will increase the rate of sorbent sintering, resulting in lower surface areas of calcined particles. Simons, et al (50) measured the rate of sulfation of fine sorbent particles over a range of pressures and concluded that the "intrinsic" reaction rate is directly proportional to the total pressure, but the intrinsic reaction rate has little to do with overall sorbent reaction performance. Their testing was conducted in a packed bed requiring relatively long particle exposure to high temperature before sulfation.

3.1.4 Effect of Sorbent Type

Several classes of calcium-based sorbents may be applicable for use in entrained desulfurizers: raw limestones and raw dolomites having fine grinds; calcitic hydrates ($Ca(OH)_2$) having characteristic sizes of about 2 to 5 microns; dolomitic hydrates ($Ca(OH)_2 \cdot MgO$) or dihydrates ($Ca(OH)_2 \cdot Mg(OH)_2$) having characteristic particle sizes of about 2 to 5 microns; commercial limes (CaO) or specially produced high surface area limes (not commercially available) as fine grinds. Significant differences between the sulfation performance of limestones, dolomites, hydrated limes, hydrated dolomites and limes have been noted. Within each class the differences are quite minor compared to the differences found for coarse particles, and this is a result of the small particle size and the relatively small pore diffusion resistances. The major factors for differences in sorbent types seems to relate simply to the surface area and particle size while impurities may also have an influence on the variations observed. The order of reactivity found is usually hydrated dolomite > hydrated lime > dolomite > lime > limestone with characteristic surface areas of these materials being: limestones and dolomites about 1 to 5 m^2/gm; calcitic and dolomitic hydrates about 10 to 30 m^2/gm; commercial limes about 1 to 5 m^2/gm; and specially prepared limes about 20 to 50 m^2/gm.

Borgwardt, et al (49) concludes that the rate of sorbent calcination is directly proportional to the initial surface area of the raw sorbent, which may lead to a variation in the resulting calcine surface area for different sorbent types. The treatment of sorbents with additives of various types has indicated some improvement in reactivity, though this is a secondary effect that may well not be applicable for use in direct coal-fired turbines.

3.1.5 Effect of Gas Composition

The sulfation and sulfidation reactions have been found to be first-order in the SO_2 or the H_2S mole fraction by most investigators. Borgwardt (51), for example, found the rate of sulfation of uncalcined limestone particles to be first-order in the H_2S mole fraction. No impact of the oxygen level in the gas has been reported for the sulfation reaction and it is assumed that the sulfation reaction is zero-order in O_2, just as has been found for coarse particles. H_2O and CO_2 catalyze the loss of surface area, and H_2O has a strong effect on the equilibrium H_2S level in sulfidation. The reported technique for producing lime sorbents having very high surface areas is to calcine them at a moderate temperature under conditions that will minimize the CO_2 content in the surrounding gas (49).

Borgwardt (40) has reported that the sulfation reaction rate is proportional to the 0.67 power of the SO_2 mole fraction in the gas, but again, these are for sulfation rates that occur after longer exposure times than is characteristic of entrained desulfurizer, and it is concluded that the measurement do not represent the behavior of the initial high sulfation rate period.

3.2 OBJECTIVES AND TEST PLAN

The objectives of the fine particle testing and evaluation were to assess the potential of fine calcium-based sorbents for use in an entrained gas-particle contactor for direct coal-fired turbines. The specific objectives were to:

-- test the reactivity of a range of calcium-based sorbents at temperatures up to 1200°C and pressures up to 12 atmospheres

-- generate kinetic correlations as a function of temperature, particle size and sorbent type

-- develop commercial design equations for the sizing and performance of entrained desulfurization

-- perform a preliminary assessment of the performance potential of calcium-based sorbents in entrained desulfurizers for direct coal-fired turbines

The effect of pressure on the reaction kinetics was the major consideration. Two major test series were conducted for the sulfur dioxide reaction and for the hydrogen sulfide reaction. The test matrices were:

1) SO_2 capture
Sorbent types
-- Plum Run dolomite
-- Highland limestone
-- Vicron limestone

- hydrated Vicron limestone
- a commercial lime hydrate

Simulation Gas Composition

- Carbon dioxide 8 mole %
- Oxygen 10 mole %
- SO_2 0.5 mole %
- Nitrogen 81.5 mole %

Test Conditions

Seven tests were conducted for each of the raw sorbents and two for each of the hydrated sorbents. For the raw sorbents:

Temperature(°C)	Pressure(atm)	Particle size	Contact Time(sec)
1100	6	<400 mesh	0.75 and 1.5
1100	12	<20 microns	0.75 and 1.5
1100	6	<400 mesh	0.75
1200	6	<20 microns	0.75 and 1.5

The particle sizes tested were in the range of 5 to 25 microns (mass mean diameters), and these are typical of the grinds that can be commercially achieved, as well as being representative of sizes previously tested in conventional furnace injection programs.

Some additional tests were also conducted to test the reproducibility of the results and to test the order of reaction with SO_2. A total of 33 tests were completed. The raw sorbent types were selected, based on their coarse particle test behavior, because of their wide variation in performance. The hydrated sorbents tests were conducted at 1100°C and at pressures of 6 and 12 atmospheres with a contact time of 0.75 seconds.

These test matrices provided the minimum information required to develop preliminary reaction kinetics correlations.

2) H_2S Capture

Sorbent types

- Plum Run dolomite
- Highland limestone

Gas composition

-- Hydrogen sulfide 0.5 mole %

-- Nitrogen 99.5 mole %

Test conditions

Four tests were conducted with each sorbent:

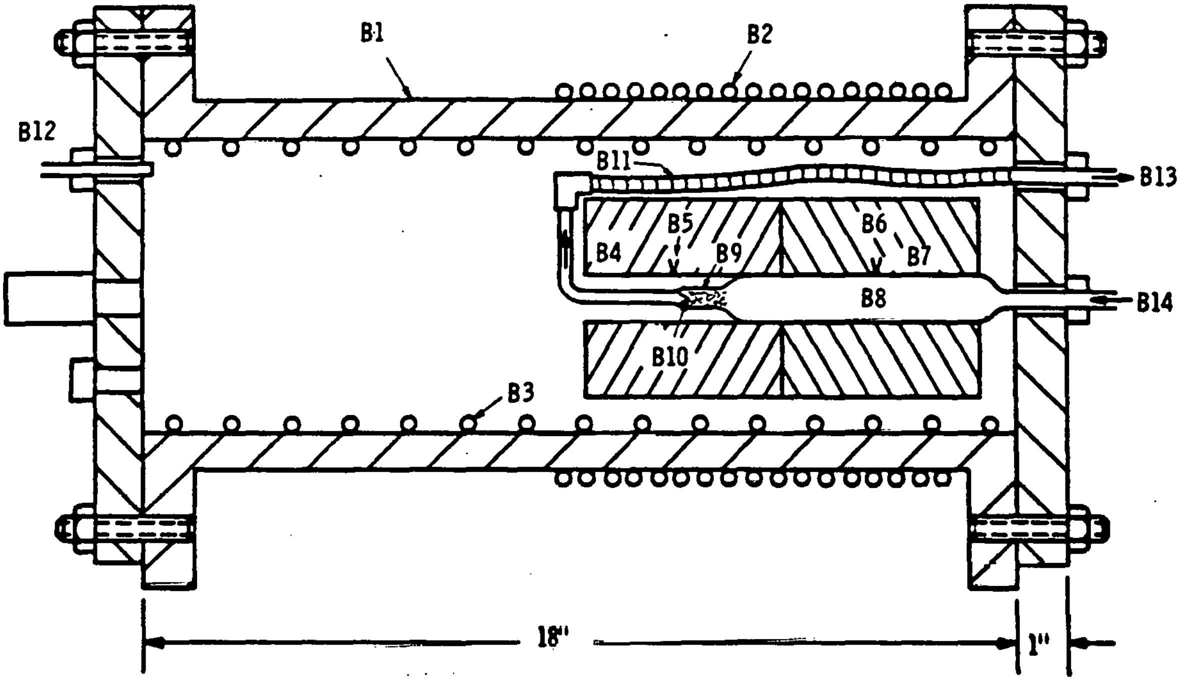
Temperature(°C)	Pressure(atm)	Particle Size	Contact Time(sec)
1100	6	<400 mesh	0.75
1100	6	<20 microns	0.75
1100	12	<400 mesh	0.75
1100	12	<20 microns	0.75

Again, these tests provided the minimum information needed to produce preliminary kinetic expressions. The two raw sorbents were selected to represent the general classes of dolomites and limestones. Under sulfidation conditions using fine particles, little variation between different limestones or between different dolomites is expected based on the background data review.

3.3 DISPERSED PARTICLE REACTOR TEST EQUIPMENT AND PROCEDURES

All of the fine particle tests were conducted on a "dispersed particle" reactor. In this reactor the particles are first dispersed within a quartz wool matrix, stirring the 20 mg sample of sorbent particles continuously into the wool mechanically for 20 minutes to ensure uniform dispersion of the particles onto the quartz filaments. The wool is placed within a quartz tube that is necked down from a 20 mm inner diameter to a 3 mm inner diameter to provide sufficient gas velocity to minimize mass transfer resistance at the particle surface. The quartz tube containing the wool plug sits horizontally within a pressure shell as shown in Figure 3.1. The quartz tube is surrounded by electric heaters that bring the sample and reaction gases up to the desired temperature. The pressure shell is the shell used to house the thermogravimetric balance for the coarse particle testing.

The system flow diagram is shown in Figure 3.2 and differs for the system diagram for the thermogravimetric balance in only one



KEY TO DISPERSED REACTOR FIGURE

B1	Stainless Steel Pressure Vessel	B8	Quartz Reaction Tube
B2	External Cooling Coil	B9	Sample Basket
B3	Internal Cooling Coil	B10	Sample Thermocouple
B4	Reaction Zone Furnace	B11	Flexible Metal Exhaust Hose
B5	Reaction Zone Thermocouple	B12	Atmospheric Pressure Vent
B6	Preheat Zone Furnace	B13	Exhaust Gas Outlet
B7	Preheat Zone Thermocouple	B14	Reaction Gas Inlet

Figure 3.1 — Dispersed Particle Reactor Apparatus

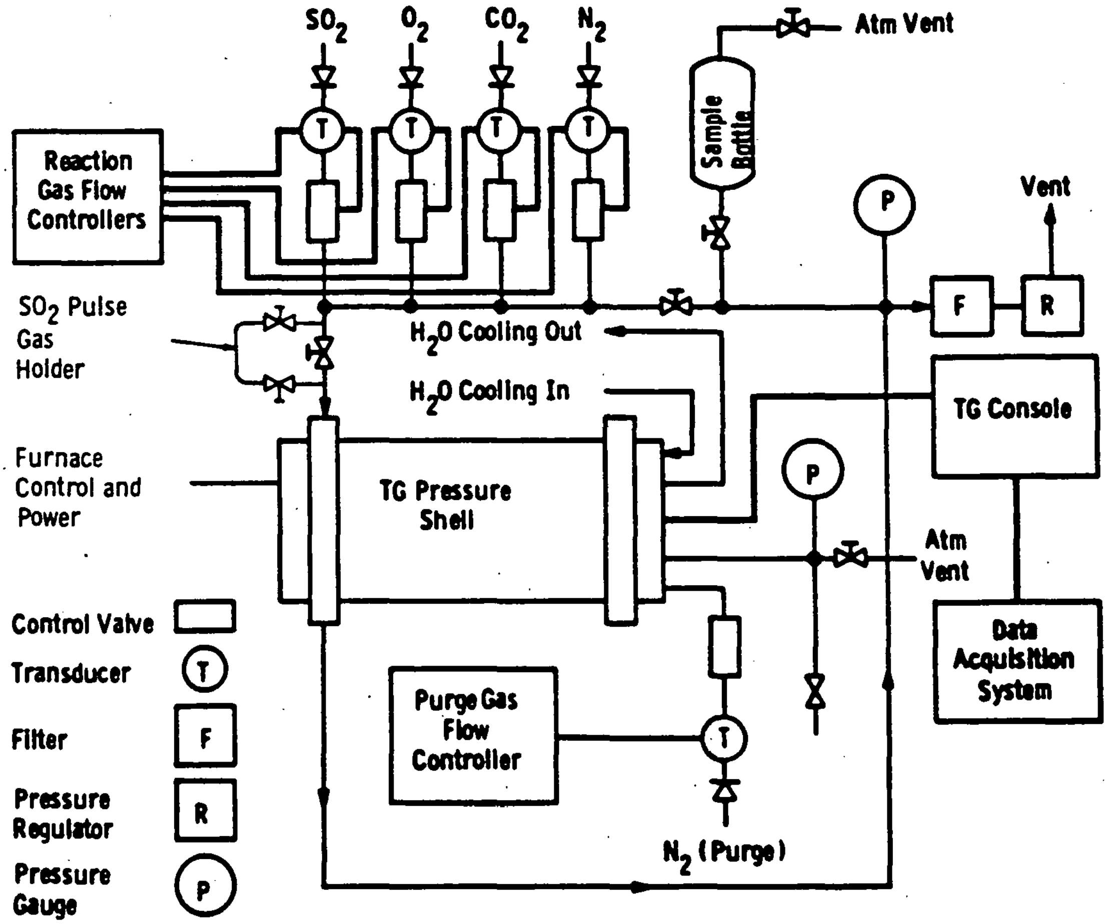


Figure 3.2 — System Diagram for the Dispersed Particle Reactor Facility

respect. The reaction gas (premixed SO_2 or H_2S) is contained within a small reservoir having a carefully measured volume that will provide a specified contact time between the reaction gas and the sorbent particles when the control valves are switched. In operation the sample is dispersed within the wool matrix, the wool plug is placed into the quartz tube constriction, the quartz tube is placed within the pressure vessel, the system is pressurized and the flow of inert nitrogen, CO_2 and oxygen is started through the sorbent sample. The sample and inert gas are slowly heated up to the reaction temperature desired. Once at temperature, the reaction gas reservoir valves are switched sending the flow of reaction gas through the quartz tube to contact the sorbent particles for the prescribed time. Following the test the system is cooled down, the wool plug is removed and the reacted sorbent particles are analyzed for calcium and sulfur content. This analysis then provides the conversion of CaO to $CaSO_4$ or CaS.

This technique is analogous to a method developed and used by Borgwardt at EPA (40, 51) for atmospheric pressure testing of fine sorbent particles. The analytical procedures for $CaSO_4$ and CaS used by Borgwardt were also used in this program.

The potential concerns with this technique are:

1) The sample must be preheated to the reaction temperature before sulfation or sulfidation is initiated. Thus, the important calcination rate is not included as part of the kinetic measurement. Fortunately, at the temperatures of interest to coal-fired turbines the time required for calcination is very small.

2) Because the sample is preheated and held at high temperature for a relatively long time (on the order of 0.5 hours) the sorbent samples will have surface areas very close to their minimum value. Thus, the test results really represent the behavior of minimal surface area sorbents, or "sintered" sorbent. The sintered sorbent kinetics must be scaled to higher surface areas to determine the performance of active, freshly injected and calcined particle.

3) Significant dispersion of the reactant gas in the feed system occurs before the reaction gas reaches the sorbent particles, so the concentration of the SO_2 or H_2S is lower than the specified test value. Fortunately, because the reaction rate is first-order in the sulfur species concentration, the product of the SO_2 (or H_2S) concentration and the contact time determines the conversion. When the reaction gas is diluted the contact time increases in inverse proportion to the drop in concentration so that the product of concentration and contact time is always fixed. Dispersion only influences the test results if the concentration is reduced to values near or below the equilibrium SO_2 or H_2S level. This will be discussed in the evaluation of the test results to demonstrate this behavior.

4) Some of the sorbent particles are entrained out of the quartz wool and are lost from the product chemical analysis. This is not really a concern because the evaluation procedure measures the calcium and sulfur in the product sample collected and does not depend on a material balance on the sample initially placed in the wool matrix. On the other hand, if the entrainment loss represents particles of a predominantly small or large size then the test results would be confused because the size distribution of the particles analyzed would not correspond to the size distribution dispersed in the initial wool plug.

3.4 TEST RESULTS IN SULFUR DIOXIDE

The test results for the 32 tests conducted in SO_2 are listed in Table 3.1. The average particle diameter listed is the mass-mean.

Several tests were done in duplicate to test reproducibility: Runs 1 and 2 showed reproducibility for Plum Run dolomite of about 96% while Runs 15 and 18 showed reproducibility of only 85%. Runs 3 and 7 showed reproducibility for Vicron limestone of about 90%. It is concluded that the experimental technique yields reproducible results. The analytical step for Run 14 indicated a loss of sample may have occurred during analysis, and indeed the result in Run 14 is

Table 3.1 — Fine Particle Sulfation Test Results

Run No.	Sorbent	Average diameter (microns)	Temperature (°C)	Pressure (atm)	Contact time (sec)	% Sulfated
1	Plum Run	25.8	1100	6	1.5	55.94
2	Plum Run	25.8	1100	6	1.5	60.85
3	Vicron	12.7	1100	6	1.5	28.86
4	Highland	13.5	1100	6	1.5	30.12
5	Plum Run	25.8	1200	6	1.5	40.47
6	Highland	13.5	1200	6	1.5	21.94
7	Vicron	12.7	1100	6	1.5	23.88
8	Plum Run	25.8	1100	6	0.75	26.90
9	Vicron	12.7	1100	6	0.75	16.91
10	Highland	13.5	1200	6	0.75	2.86 [a]
11	Vicron	12.7	1200	6	0.75	2.92 [a]
12	Plum Run	25.8	1200	6	0.75	2.08 [a]
13	Highland	13.5	1100	6	0.75	14.19
14	Vicron	12.7	1200	6	1.5	42.04 [b]
15	Plum Run	25.8	1100	12	0.75	33.60
16	Highland	13.5	1100	12	0.75	16.83
17	Vicron	12.7	1100	12	0.75	20.45
18	Plum Run	25.8	1100	12	0.75	45.07
19	Highland	13.5	1100	12	1.5	37.71
20	Vicron	12.7	1100	12	1.5	34.72
21	Plum Run	25.8	1100	12	1.5	74.22
22	Highland	6.8	1100	6	0.75	18.73
23	Plum Run	9.8	1100	6	0.75	42.05
24	Vicron	8.5	1100	6	0.75	22.28
25	Commercial hydrate	---	1100	6	0.75	13.05
26	Vicron hydrate	---	1100	6	0.75	12.45

Table 3.1 (continued)

27	Commercial hydrate	---	1100	12	0.75	18.69
28	Vicron hydrate	---	1100	12	0.75	14.24
29	Highland	13.5	1100	12	0.75	39.83 c
30	Plum Run	25.8	1100	12	1.5	89.79 c
31	Vicron	12.7	1100	6	1.5	29.88
32	Vicron	12.7	1200	6	1.5	13.18

a -- tests where the SO_2 level dropped below equilibrium

c -- tests conducted with 1 mole % SO_2 rather than 0.5 mole %

b -- test result rejected and repeated

inconsistent with the other runs, so this run was repeated in Run 32. Run 14 was thus rejected.

Run 29 was performed to test the first-order behavior of the reaction rate with respect to the SO_2 concentration. The test conditions are identical with those of Run 19, except Run 19 has a contact time of 1.5 seconds in 0.5 mole % SO_2 while Run 29 has a contact time of 0.75 seconds in 1 mole % SO_2. If the reaction rate is first-order in the SO_2 concentration then the sulfation level resulting from these two tests should have been the same. The sulfation levels were only 5% different and it is concluded that the rate is first-order in SO_2.

Run 30 was performed specifically to determine the curvature in the sulfation versus time plot, and this is seen in the data plots that follow. A clear indication of the extent of dispersion of the reaction gas when it was injected into the reactor tube is seen in the three runs at 1200°C and 0.75 second contact time, Runs 10, 11, and 12. In these runs the dispersion must have dropped the SO_2 concentration in the gas contacting the sorbent to a level near or below the equilibrium SO_2 level. These tests used the smallest reactant gas reservoir of the test series, resulting in the greatest reactant gas dispersion in the inert carrier gas, while being at the temperature having the highest SO_2 equilibrium level (about 350 ppm) -- thus, very little sulfation could proceed. These three runs provide no kinetic information, but they do provide information about the operating limits of operation of the dispersed reactor due to gas dispersion.

The sulfation data for Plum Run dolomite is shown graphically in Figure 3.3. The figure shows linear behavior in the degree of sulfation with time (curves 1 and 2), and indicates improved sulfation as the pressure is increased and as the particle diameter is reduced. Increased temperature from 1100 to 1200°C results in reduced sulfation. Note the point run with 1 mole % SO_2 with a 1.5 second contact time is shown in the figure as being equivalent to a 0.5 mole % SO_2 test with a 3.0 second contact time, and this shows that a large degree of curvature occurs when the sulfation level exceeds about 80% conversion.

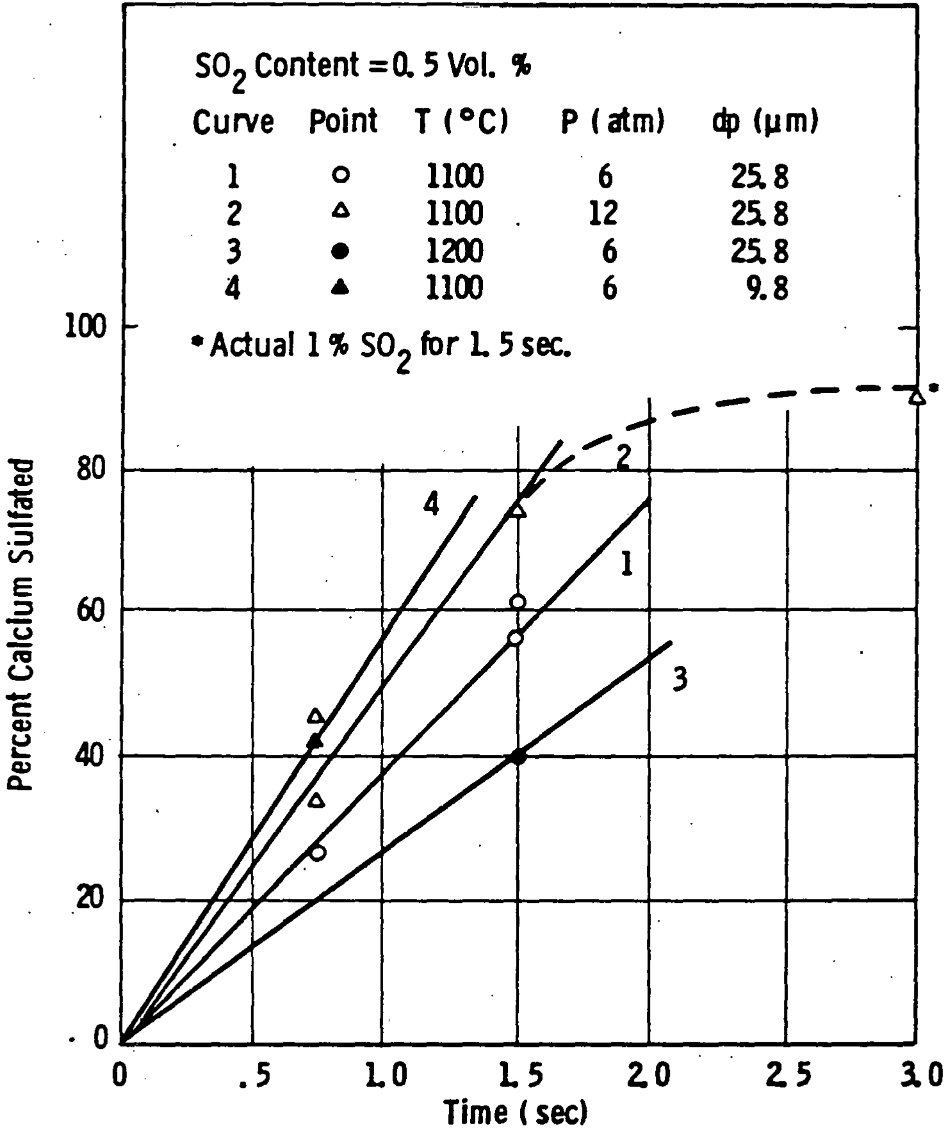


Figure 3.3 — Fine Particle Sulfation Results for Plum Run Dolomite

A similar plot of sulfation level versus time is shown in Figure 3.4 for Highland limestone. The results have the same trends as for Plum Run dolomite, although the conversion levels are much lower. Linear behavior with time is shown, improved sulfation with increased pressure and reduced particle size, and reduced sulfation with increased temperature is shown. Figure 3.5 illustrates the test results for Vicron limestone. The results are very similar to those for Highland limestone, except that 1) the Vicron limestone appears more sensitive to temperature, with the sulfation level decreasing more as the temperature is increased, and 2) there is a definite, though small degree of curvature in the sulfation data (curves 1 and 2 as shown by the dashed lines).

It is interesting to note that there is a parallel here between the results obtained in the coarse particle testing. The Plum Run dolomite showed the highest level of sulfation of the three sorbents and the Vicron limestone was the most sensitive to temperature (see Table 2.8). Comparing the initial reaction rates in Table 2.7 for the coarse particles also shows a strong parallel between the coarse and fine particle results. The similarity between Highland and Vicron limestones also is consistent with previous fine particle test results reported at atmospheric pressure that indicate limestones on the whole do not behave much differently from one another at these small particle sizes.

Figure 3.6 presents the graphic results for the Vicron hydrate and the commercial hydrate. The two hydrates behave very similarly to each other as well as being close to the results for the Highland limestone and the Vicron limestone. The lack of improvement in the sulfation performance relative to the limestones results from the test procedure that exposes the sorbent to high temperatures for long times prior to sulfation, thus sintering the sorbents severely. It is concluded that hydrates exposed to high temperature will loose surface area to a level of the raw limestone and will behave no better than limestones or limes exposed to high temperatures. The behavior shown in Figure 3.6 does not correspond to that of a fresh hydrate injected into

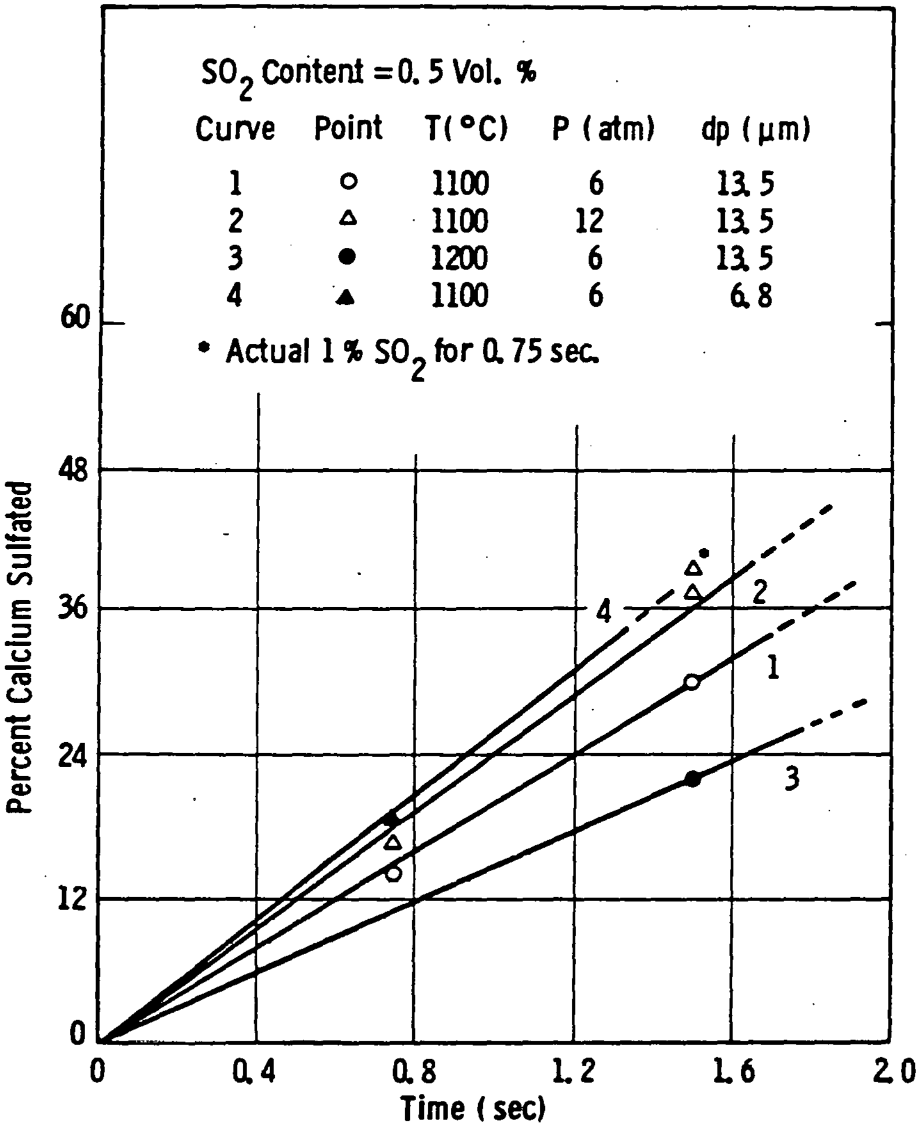


Figure 3.4 — Fine Particle Sulfation Results for Highland Limestone

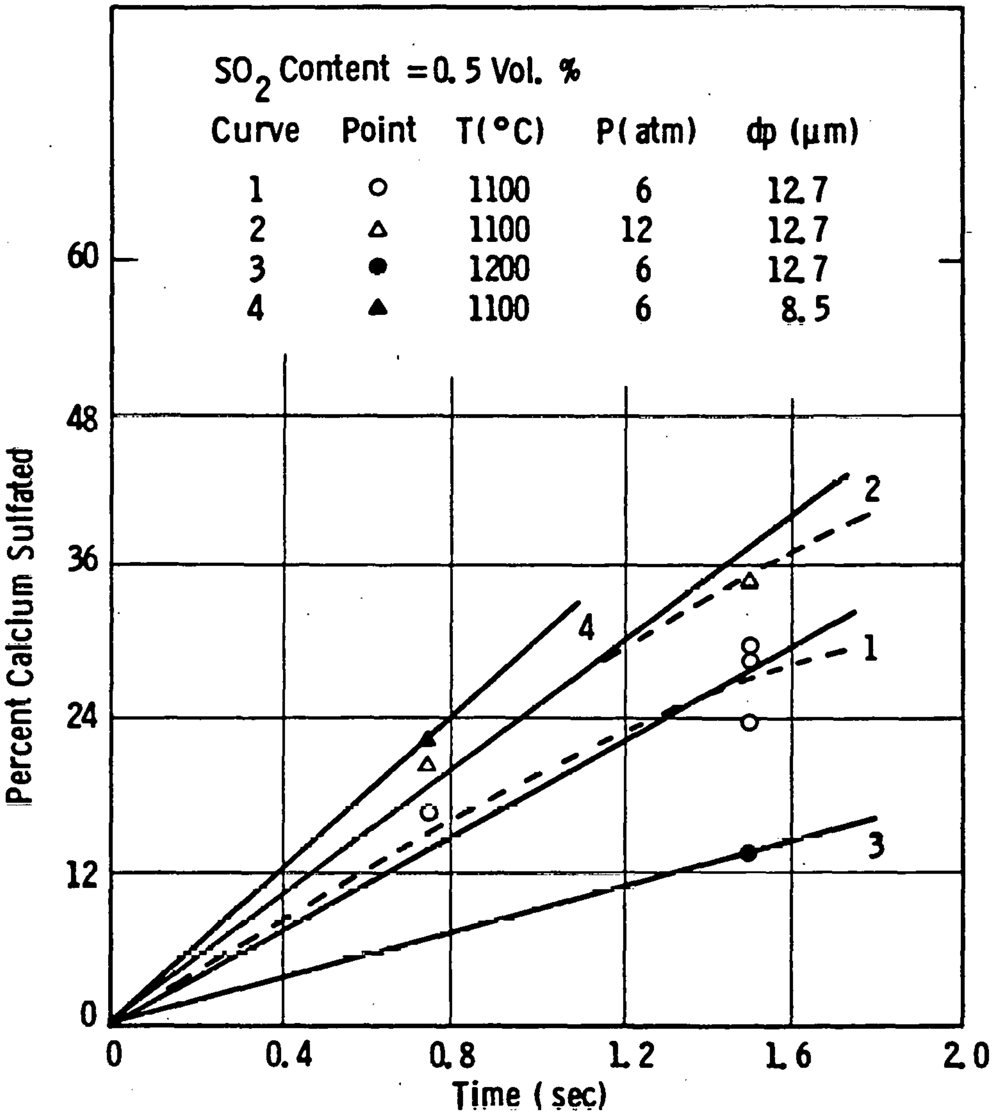


Figure 3.5 — Fine Particle Sulfation Results for Vicron Limestone

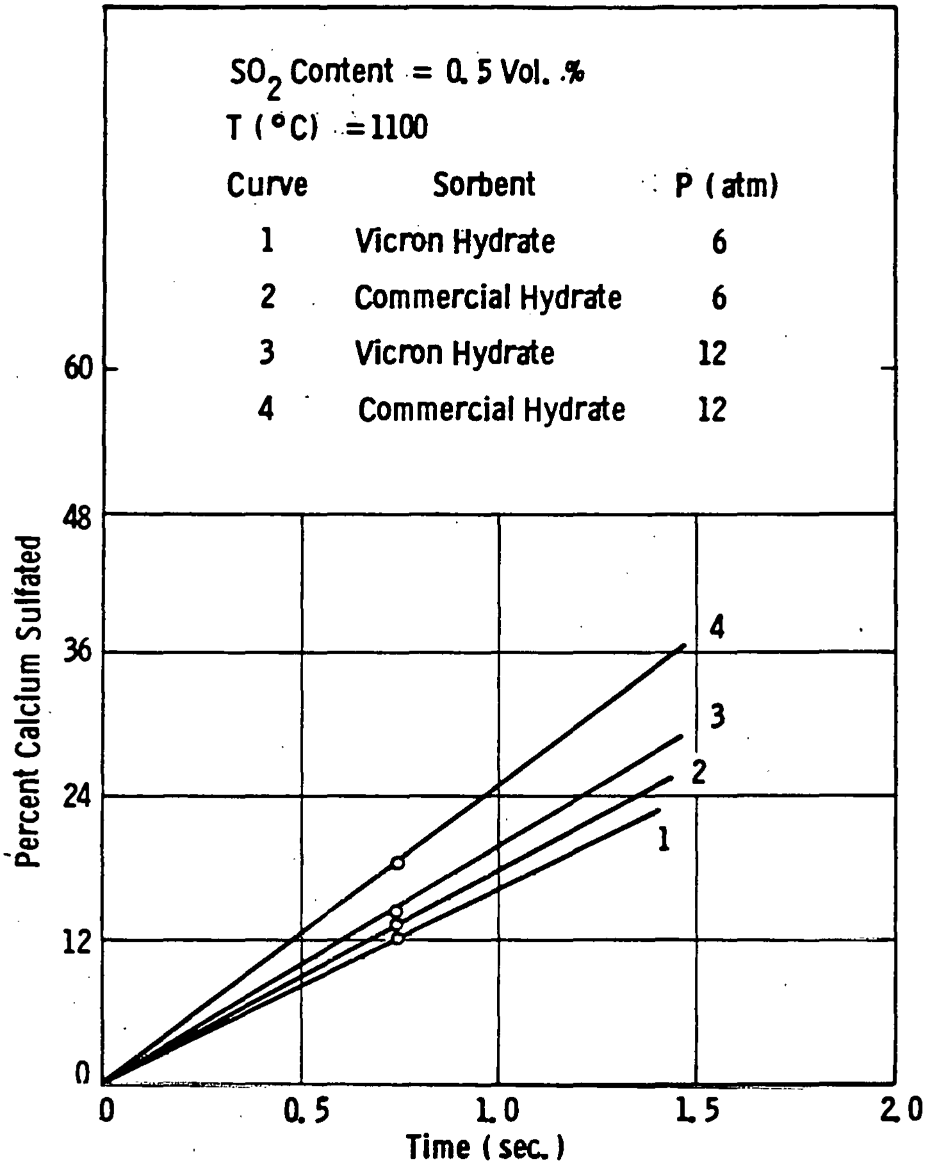


Figure 3.6 — Fine Particle Sulfation Results for Calcium Hydrates

a high temperature SO_2 gas. The behavior shown in the figure is probably similar to that of a commercial lime produced in a rotary kiln and having characteristically low surface areas.

3.5 TEST RESULTS IN HYDROGEN SULFIDE

The test results for the eight runs performed with H_2S are shown in Table 3.2.

Table 3.2 - Fine Particle Test Results in H_2S

Run No.	Sorbent	Particle Size (microns)	Temperature (°C)	Pressure (atm)	Contact time (sec)	% Sulfidation
33	Plum Run	25.8	1100	6	0.75	39.96
34	Plum Run	9.8	1100	6	0.75	43.26
35	Highland	13.5	1100	6	0.75	25.26
36	Highland	6.8	1100	6	0.75	29.72
37	Plum Run	25.8	1100	12	0.75	46.56
38	Plum Run	9.8	1100	12	0.75	49.72
39	Highland	13.5	1100	12	0.75	37.11
40	Highland	6.8	1100	12	0.75	43.47

Trends shown in the data are 1) increased sulfidation occurs with increased pressure; 2) increased sulfidation occurs with decreased particle size; and 3) higher sulfidation levels occur for the dolomite than for the limestone. Comparing the results for sulfidation with those for sulfation in Table 3.1 indicates that slightly higher sulfidation levels occur in the same contact time for Plum Run dolomite than are obtained for sulfation. Greatly higher sulfidation levels occur at the same conditions for Highland limestone than occur with sulfation. This is consistent with expectations, and based on the observed low sensitivity of sulfidation to sorbent type it is expected that the behavior shown here is characteristic of all dolomites and all limestones. Again, these results represent the behavior of low surface area, sintered sorbents.

3.6 EVALUATION OF SULFUR REMOVAL KINETICS

The test data accumulated in Tables 3.1 and 3.2 may be correlated using standard multiple regression analysis. This leads to quantitative descriptions of the qualitative trends demonstrated by the data.

3.6.1 Sulfation Data Correlation

The general form assumed for the correlation is

$$\alpha = k_o \ (d_p)^a \ (P)^b \ (t)^c \ Y \qquad (3\text{-}1)$$

where α is the fraction of the calcium sulfated, k_o is the reaction rate constant, d_p is the mass-mean particle diameter in microns, P is the total pressure in atmospheres, t is the time in seconds, and Y is the mole fraction SO_2 in the gas. The terms a, b, and c are empirical constants. The correlation results are as follows:

Plum Run Dolomite

Range of correlation: dp = 9.8 to 25.8 microns; P = 6 to 12 atmospheres; maximum sulfation level about 85 %.; temperature 1100°C

$$\alpha = 133 \ (d_p)^{-.42} \ (P)^{.44} \ (t)^{1.03} \ Y \qquad (3\text{-}2)$$

The limited curvature with time implies that the rate of reaction, R = $d\alpha/dt$, is given by

$$R = 133\ (d_p)^{-.42}\ (P)^{.44}\ Y = k\ Y \tag{3-3}$$

where R is the sulfation rate expressed as the fraction of the sorbent calcium sulfated per second. The limited temperature data collected, while not sufficient for statistical analysis, indicates that the rate constant is related roughly to the temperature by

$$k_o = 0.6 \exp \{7417/(T+ 273)\} \tag{3 4}$$

where T is the temperature in °C. This is quite close to the activation-term of about 6300 found for 387 micron Plum Run dolomite in the coarse particle testing, giving some confidence in the constants in Equation 3-4.

Highland Limestone

Range of correlation: dp = 6.8 to 13.5 microns; P = 6 to 12 atmospheres; maximum sulfation level about 50 %.; temperature 1100°C

$$\alpha = 70\ (d_p)^{-.43}\ (P)^{.29}\ (t)^{1.13}\ Y \tag{3 5}$$

The limited curvature with time implies that the rate of reaction is given by

$$R = 70\ (d_p)^{-.43}\ (P)^{.29}\ Y = k\ Y \tag{3-6}$$

where R is the sulfation rate expressed as the fraction of the sorbent calcium sulfated per second. Again, temperature data collected is too limited for statistical analysis, but indicates that the rate constant is given roughly by

$$k_o = 0.66 \exp \{6411/(T+273)\} \tag{3-7}$$

where T is the temperature in °C. This is close to the activation energy-term found for the Highland limestone initial reaction rate of 387 micron particles in the coarse particle testing.

Vicron Limestone

Range of correlation: dp = 8.5 to 12.7 microns; P = 6 to 12 atmospheres; maximum sulfation level about 40%.; temperature 1100°C

$$\alpha = 145\ (d_p)^{-.72}\ (P)^{.31}\ (t)^{.72}\ Y \tag{3-8}$$

While there is a slight curvature with time, this may be linearized and the implied rate of reaction is given by

$$R = 113\ (d_p)^{-.72}\ (P)^{.31}\ Y = k\ Y \tag{3-9}$$

where R is the sulfation rate expressed as the fraction of the sorbent calcium sulfated per second. The limited temperature data collected indicates that the rate constant is given roughly by

$$k_o = 0.0041 \exp \{14018/(T+273)\} \tag{3-10}$$

where T is the temperature in °C. The 14018 is a much higher activation energy-term than that found for the initial reaction rate in coarse particle Vicron limestone testing, and the observed fine particle behavior is suspected of inaccuracy in this case. Overall, it is concluded that the Highland and Vicron limestones behave almost identically in their sulfation kinetics at these fine particle sizes.

3.6.2 Sulfidation Data Correlation

Here it is assumed that the sulfidation extent increases linearly with time for Plum Run dolomite and Highland limestone, since this behavior was found for sulfation. The same general form for the rate equation is assumed:

$$R = k_o \ (d_p)^a \ (P)^b \ Y = k \ Y \tag{3-11}$$

where R is now the sulfidation rate, in fraction of the calcium sulfided per second, and Y is the mole fraction of H_2S in the gas.

Plum Run Dolomite

Limits of the correlation: dp = 9.8 to 25.8 microns; pressure = 6 to 12 atmospheres; temperature 1100°C; maximum level of sulfidation about 90%.

$$R = 93.5 \ (d_p)^{-.08} \ (P)^{.21} \ Y \tag{3-12}$$

No data was collected on the effect of temperature in this program, but based on coarse particle testing it is likely that the rate will decrease slightly in the temperature range of 1000 to 1200°C, much as for sulfation. Note the very small effect of particle diameter on the sulfidation rate, indicating small diffusion resistance, and the small effect of pressure relative to the pressure influence in sulfation.

Highland Limestone

Limits of the correlation: dp = 6.8 to 13.5 microns; pressure = 6 to 12 atmospheres; temperature 1100°C; maximum level of sulfidation about 70%.

$$R = 46.1 \ (d_p)^{-.23} \ (P)^{.55} \ Y \tag{3-13}$$

Again, no data was collected on the effect of temperature in this program, but based on coarse particle testing it is likely that the rate will decrease slightly in the temperature range of 1000 to 1200°C, much as for sulfation. A smaller effect of particle diameter and a larger effect of pressure is seen for sulfidation that was seen for sulfation in Equation 3.6.

3.7 EVALUATION OF ENTRAINED DESULFURIZERS FOR DIRECT COAL-FIRED TURBINES

In this section the commercial performance of entrained desulfurization for direct coal-fired turbines is estimated based on the kinetic correlations developed in the previous section. In contrast to the fluidized bed desulfurizer evaluation in section 2.9 for coarse calcium-based sorbents, the sulfur removal performance of the entrained desulfurizer is sensitive to the sulfur content of the coal and the combustion excess air (or the resulting SO_2 or H_2S concentration in the gas). Thus, specific scenarios for the coal sulfur content and the combustion excess air must be proposed to see what the sensitivity is. Also, the correlations developed are for the low surface area, sintered sorbent particles, and these must be scaled to the performance of freshly calcined sorbents.

3.7.1 Combustor Operation and Coal Scenarios

The entrained desulfurizer is characterized by the equation for the sulfur removal performance developed in Appendix D:

$$Ca/S = [\ -\ln(1-E)\ ] \ / \{\ H/(U - U_s)\ k\ Y_o\ \} \tag{3-14}$$

The gas phase SO_2 or H_2S mole fraction at the point of sorbent introduction, Y_o, appears explicitly in the equation, showing that the calcium-to-sulfur feed ratio required for a given sulfur removal efficiency is inversely proportional to Y_o. The value of Y_o in a turbine combustor depends upon the sulfur content of the coal, whether the coal is fed dry or in slurry form, and on the combustion conditions at the point of sorbent injection -- that is, on the degree of excess or substoichiometric air at the point of injection and on the degree of quenching by water or steam injection at that point. For example, a high-sulfur bituminous coal (4 wt % sulfur) if fed as dry coal will produce a combustion product containing about 1600 to 1700 ppm SO_2 at a temperature of 1100 to 1200°C, respectively. The SO_2 content of the gas will be roughly proportional to the sulfur content of the coal, so that a 1 wt % sulfur bituminous coal will yield an SO_2 content of 400 to 425 ppm. Corresponding oxygen and carbon dioxide contents would be about 10 mole % and 8 mole %, respectively.

On the other hand, if a 4 wt % sulfur bituminous coal is partially combusted in an initial stage of the combustor and quenched to a temperature of 1100°C it will produce a gas having a predominantly H_2S content of about 6200 ppm, with a water content on the order of 32 mole %. Again, the H_2S content will be roughly proportional to the sulfur content of the bituminous coal. This increase in the H_2S content of the gas relative to the previous SO_2 case provides a large potential for improved sulfur removal.

This behavior results from the assumption that the gas and sorbent flow cocurrently through the entrained desulfurizer effectively in plug flow. Any degree of backmixing of gas and particles will tend to reduce the dependency of the sulfur removal on the inlet sulfur content of the gas. Certain combustor designs, such as generally in slaggers where significant backmixing will occur, will result in lower dependence on coal sulfur content and combustion conditions, but this dependence will not be removed entirely.

The next factor influencing the sulfur removal performance is the required sulfur removal efficiency, E. The sulfur removal requirements for direct coal-fired turbines are not yet defined and will depend on the size of the facility (electric utility large scale applications will have standards differing from smaller industrial cogeneration applications, which will also differ from even smaller transportation applications). Even if the New Source Performance Standard for large utility applications is applied there is uncertainty.

If a high-sulfur bituminous coal is fired the required sulfur removal would be 90% with this standard, while a low-sulfur coal would only require about 70% removal. A partially cleaned coal, say with 50% sulfur removed during slurry preparation, would only require about 80% sulfur removal with the utility standard. Standards of sulfur removal may also vary significantly with the specific location of the plant. The impact on the sorbent consumption is large. For a given coal sulfur content, if the sulfur removal efficiency is reduced from 90% to 60% then the required Ca/S ratio, according to equation 3.14, is reduced by a factor of 2.5 if the combustion conditions are the same in both cases. Thus, these two factors, Y_o and E, have a large impact on the sorbent consumption rate even without considering the kinetics of specific calcium-based sorbents or the specific combustor conditions.

For the combustion conditions at the point of sorbent injection fixed (fixed temperature, excess or substoichiometric air level, and quench gas level); fixed calcium-based sorbent type and size; and fixed combustor design (fixed value of H/U, etc), the calcium-to-sulfur ratio required to achieve a given sulfur removal efficiency is proportional to the quantity $[-\mathrm{Ln}(1-E)/X_s]$ according to Equation 3-14, but the sorbent mass feed rate is independent of the coal sulfur content, being directly proportional to the quantity $[-\mathrm{Ln}(1-E)]$. Contrast this to the fluidized bed desulfurizer where the calcium-to-sulfur ratio for a given sulfur removal efficiency is independent of the coal sulfur content, and the sorbent mass feed rate is directly proportional to the coal sulfur content.

The quantity U_s is the gas-particle slip velocity, so $H/(U-U_s)$ is the particle residence time in the desulfurizer.

3.7.2 Sintered Sorbent Performance in SO_2 and H_2S

The sorbent testing performed and the kinetics developed are for low-surface area sorbents that have been highly sintered prior to sulfur exposure. The surface areas of these sorbents are at a low and stable level that does not change during the coarse of the test. According to equation 3.14 the Ca/S ratio for these sorbent depends on the factors:

- the sulfur removal efficiency required
- the particle residence time in the desulfurizer stage, $H/(U-U_s)$
- the particle kinetic constant k, itself a function of temperature, pressure, sorbent type, and particle diameter
- the content of SO_2 or H_2S in the gas at the point of injection of the sorbent into the gas stream, Y_o

The performance of the sorbents tested can be expressed in the form

$$Ca/S \ \ H/(U-U_s) \ \ Y_o(ppm) \quad \text{versus (mass-mean sorbent particle diameter)}$$

to simplify the consideration of specific conditions. This is done in Figures 3.7 and 3.8 for sintered Plum Run dolomite and sintered Highland and Vicron limestones. Highland and Vicron limestones behave very similarly as seen from the previous rate comparisons. Each figure shows the effect of pressure at 10 and 20 atmospheres and the effect of SO_2 and H_2S gases all at a temperature of 1100°C and with a sulfur removal efficiency of 80%. Note that the figures extrapolate beyond the pressure range and particle size range of the testing. The figures are applied by selecting a representative gas SO_2 or H_2S content for the specific coal sulfur content and combustion conditions of interest, a particle residence time, and a particle mass-mean diameter, from which the required Ca/S ratio can then be taken directly. In the figure for Plum Run dolomite, for example, with a 10 atmosphere pressure and a 4 micron diameter sorbent size, the quantity Ca/S $H/(U-U_s)$ Y_o is equal to about 8000 in an SO_2 gas. If the SO_2 content of the gas were 1600 ppm and the particle residence time were 1.0 second then the required Ca/S ratio would be 5.0. Increasing the pressure to 20 atmospheres would reduce the Ca/S ratio to about 3.75 based on the pressure factor in Equation 3.3. On the other hand, in an H_sS gas, at 10 atmospheres pressure and with 4 micron particle size the quantity Ca/S $H/(U-U_s)$ Y_o is equal to about 12000. If the H_2S content of the gas were 6200 ppm and the particle residence time were 1.0 second the required Ca/S ratio

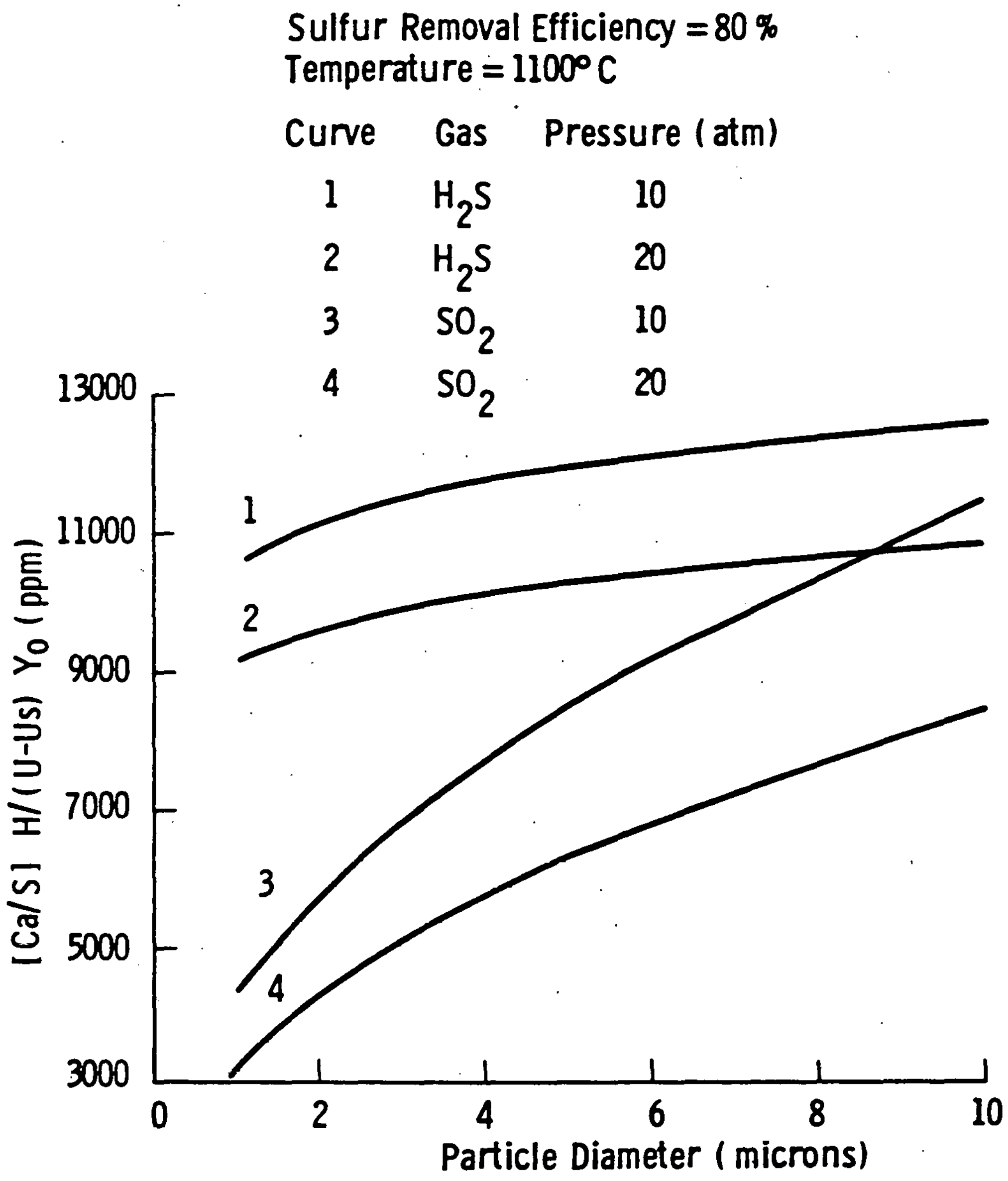


Figure 3.7 — Sintered Highland and Vicron Limestones Removal Performance in SO_2 and H_2S

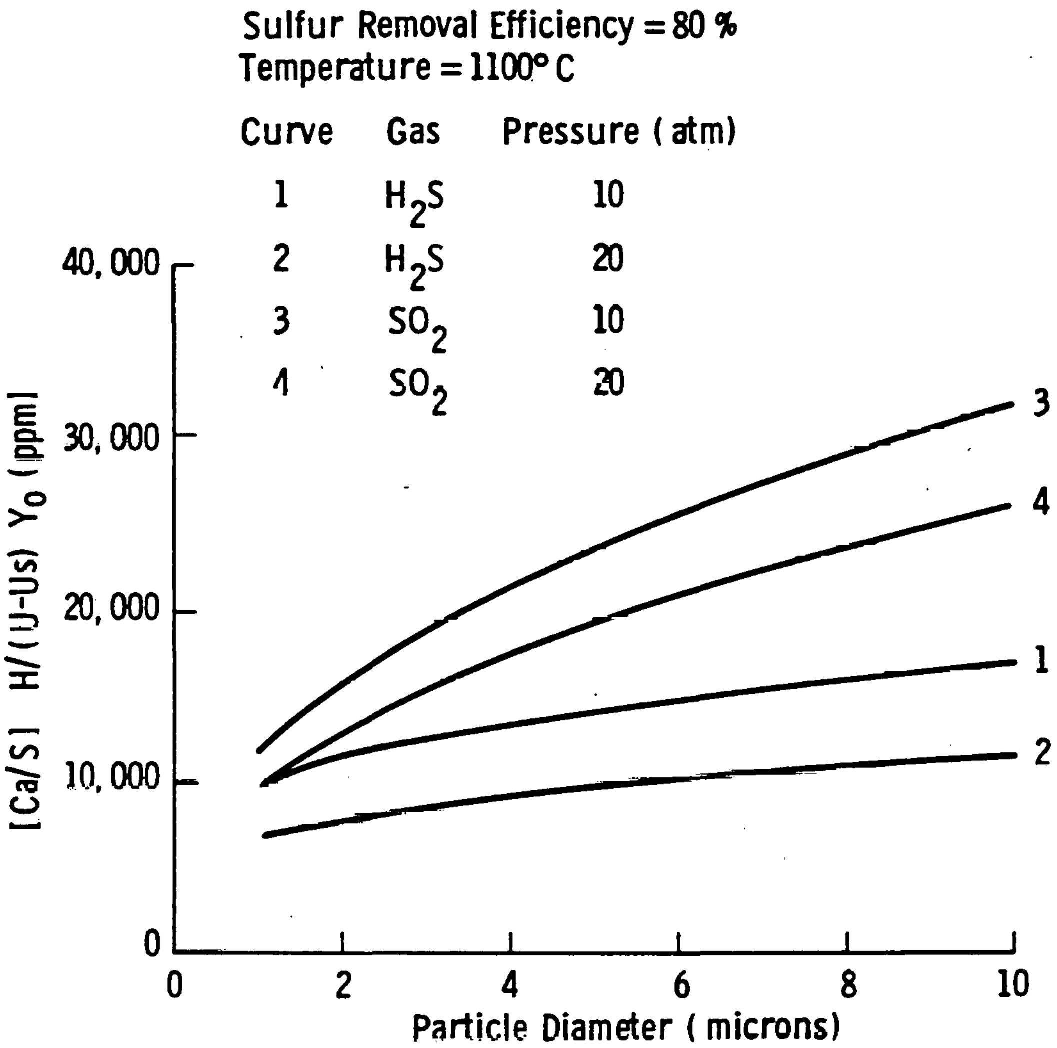


Figure 3.8 — Sintered Plum Run Dolomite Removal Performance in SO_2 and H_2S

would be about 2.0. Increasing the pressure to 20 atmospheres would decrease the Ca/S ratio to about 1.6 based on the pressure factor in Equation 3.12.

Figure 3.8 for sintered Highland and Vicron limestones indicates that in SO_2 the sintered limestones perform worse than the sintered dolomite. For the same hypothetical conditions as assumed above for Plum Run dolomite in SO_2, the required Ca/S ratio would be about 13 at 10 atmospheres pressure and about 10.8 at 20 atmospheres. On the other hand, the sintered limestones compare favorably to the performance of sintered dolomite in H_2S. At the same conditions hypothesized for sintered Plum Run dolomite in H_2S, the sintered limestones require a Ca/S ratio of about 2.3 at 10 atmospheres pressure and 1.5 at 20 atmospheres.

The following conclusions are reached for the sintered sorbents based on these two figures:

- The sintered, low surface area sorbents are representative of sorbents injected into a very hot zone of a direct coal-fired turbine combustor (greater than 1500°C) before removing sulfur in a cooler combustor zone. The sintered limestones are also representative of typical commercial limes produced in high-temperature rotary kilns.
- The performance of the sintered sorbents (that is, the Ca/S ratio required to achieve the needed sulfur removal) is probably acceptable only for high sulfur coals, for cases where high sulfur removal efficiency is not required, and for combustor systems where the gas residence time can be on the order of 1 second. Their use would be more commercially acceptable in an H_2S gas than in an SO_2 zone of the combustor.
- The sintered dolomite performs better than the sintered limestones in SO_2 gases on a Ca/S ratio basis, but on a feed weight basis the limestones and dolomites are comparable.
- The sintered dolomite performs better in H_2S than in SO_2 gases, but only because of the potentially higher content of H_2S in the gas. On the other hand, much larger dolomite particles may be used in

an H_2S gas than in an SO_2 gas since the kinetics in H_2S are less sensitive to particle diameter.

- The sintered limestones perform much better in H_2S than in SO_2 because of both improved kinetics and higher potential H_2S concentrations compared to SO_2 concentrations. Again, much larger limestone particles may be used in H_2S than in SO_2. While the sintered limestones and sintered dolomite are comparable in Ca/S ratio in H_2S, the limestones are much superior to dolomite on a feed weight basis.

3.7.3 Active, High-Surface Area Sorbent Performance

The objective of this section is to scale the sintered sorbent kinetics and performance results to estimate the potential performance of high surface area, freshly calcined calcium-based sorbents. This is done using available information from the literature on the behavior of the sorbent surface area with time, temperature and gas composition. There is significant uncertainty in the scaling procedure and the results provide only perspective on the potential performance of active, high surface area sorbents. Confirmation of many of the assumptions made is needed in controlled experiments as well as in small-scale integrated combustor testing.

The rate constant k in equation 3.14 is observed to be directly proportional to the surface area of the sorbent particle. For the sintered sorbents tested this surface area is a minimal value that is also stable with time, but for freshly calcined sorbents the surface area may be much larger as well as being a function of time, temperature and gas composition. The rate constant k for the sintered sorbents is given by

$$k = k_o \ (d_p)^a \ (P)^b \ e^{E/T} \qquad (3\text{-}15)$$

where values for k_o, a, b and E have been estimated and reported in the previous sections. For the active, high-surface area sorbents the rate constant is expressed as

$$k = k_o \ (S/S_o) \ (d_p)^a \ (P)^b \ e^{E/T} \qquad (3\text{-}16)$$

The additional term (S/S_o) is the ratio of the sorbent surface area over the surface area reached on sintering. This ratio is expected to be a function of the sorbent particle diameter, the gas temperature, the pressure, the composition of the gas (mainly the carbon dioxide and water vapor content), and the time of exposure of the sorbent, but is not expected to be a strong function of the sorbent type.

The mathematical form of the ratio is expected to be

$$(S/S_o) = (S_*/S_o)\ \alpha_c\ \eta_d + 1 \tag{3-17}$$

where (S_*/S_o) is the ratio of the maximum surface area that would be achieved on instantaneous calcination of the sorbent in a gas free of carbon dioxide and water vapor divided by the sintered sorbent surface area. α_c is the fraction of the calcium carbonate or calcium hydroxide calcined to calcium oxide, and η_d is a factor representing the degradation of the surface area due to sintering phenomena. It is assumed in Equation 3.17 that the sintered sorbent surface area is very close to the initial surface area of the uncalcined, raw sorbent.

The term (S_*/S_o) is observed to be a function of particle diameter. Data reported by EPA(41) and EER(42) on the calcination of fine sorbents at atmospheric pressure has been compiled and correlated to suggest that

$$(S_*/S_o) = 80\ (d_p)^{-.44} \tag{3-18}$$

This relation indicates that 1 micron diameter particles of limestone or dolomite will have an ultimate surface area of 80 times the sintered surface area if they are shock calcined without CO_2 or H_2O being present.

The calcination term, α_c, has a form

$$\alpha_c = 1 - \text{exo}\ \{-K_c\ (t)^{m_c}\ (1-P_C/P_e)\} \tag{3-19}$$

where K_c is a calcination rate constant, t is the exposure time, m_c is an empirical constant, P_C is the partial pressure of CO_2 in the gas and P_e is the equilibrium partial pressure of CO_2 at the gas temperature. The form is suggested by the reported calcination evaluations of Borgwardt (49) and Ulerich (6). From Borgwardt's work it is also expected that

$$K_c = A_c S_o \exp \{-E_c/(T + 273)\} \tag{3-20}$$

where A_c and E_c are empirical constants, and S_o is the initial limestone or dolomite surface area in the uncalcined state.

The data of EPA (41, 49) and EER (42) have been compiled and correlated using standard multiple regression techniques to determine the calcination factors m_c, A_c and E_c in Equations 3.19 and 3.20. The EER data was collected on an actual entrained combustor using 11 micron Vicron limestone (S_o = 0.9 m^2/gm), while the EPA data was collected on a dispersed-fixed bed simulation of an entrained reactor using 10 micron Fredonia limestone (S_o = 0.9 m^2/gm). The range of temperatures in the EPA testing was up to a maximum of 1000°C with particle exposure times of 0.1 to 0.7 seconds. The EER data considered a temperature range of 1360 to 1830°C at particle residence times up to 0.15 seconds.

The EPA and EER data correlations compare favorably for the factor m_c, but the predicted calcination constant is larger from the EPA data than it is from the EER data by a factor of about ten at 1200°C. This is because the particle heatup time becomes a significant portion of the total calcination time at the higher temperature range used by EER, according to the assessment of EER. The 0.5 value for m_c is representative of a diffusion-controlled reaction.

	EPA data	EER data
m_c	0.5	0.45
A_c	136,240	81
E_c	13,330	5790
K_c (1200°C)	16.0	1.6

The particle sintering rate factor, η_d, is expected to depend on thermal sintering and sintering that is catalyzed by the presence of CO_2 and H_2O in the gas. Again, EPA and EER provide data on the sintering of limestone at atmospheric pressure (41, 42). The EPA data is at temperatures up to 1000°C with 1 micron limestone particles, while the EER data is at much higher temperatures with 11 micron limestone particles. The form used to fit the data is a product of exponential quantities, the first representing thermal sintering in a gas free of CO_2 and water vapor, and the second representing the catalytic contribution of CO_2 (no data on the effect of water vapor on sintering is available):

$$\eta_d = \exp\left\{ - K_t(t)^{m_t} \right\} \exp\left\{ - K_C \, (P_C)^m \, (t)^r \right\} \qquad (3\text{-}21)$$

The results of the correlation are, for $K_t = A_t \exp[-E_t/\{T+273\}]$ and $K_c = A_c \exp[-E_c/\{T+273\}]$;

	EPA	EER
A_t	51	222
E_t	8781	8822
m_t	0.48	0.30
A_C	12	
E_C	3665	
r	0.31	
m	0.39	

The results are quite similar considering the differences in test technique and test conditions, but the EER data tends to show greater degradation of surface area with time. Again, the value of m_t suggests a diffusion-controlled reaction.

The relative surface area factor, S/S_o from Equation 3.17, is illustrated in Figure 3.9 for limestone and dolomite sorbents for

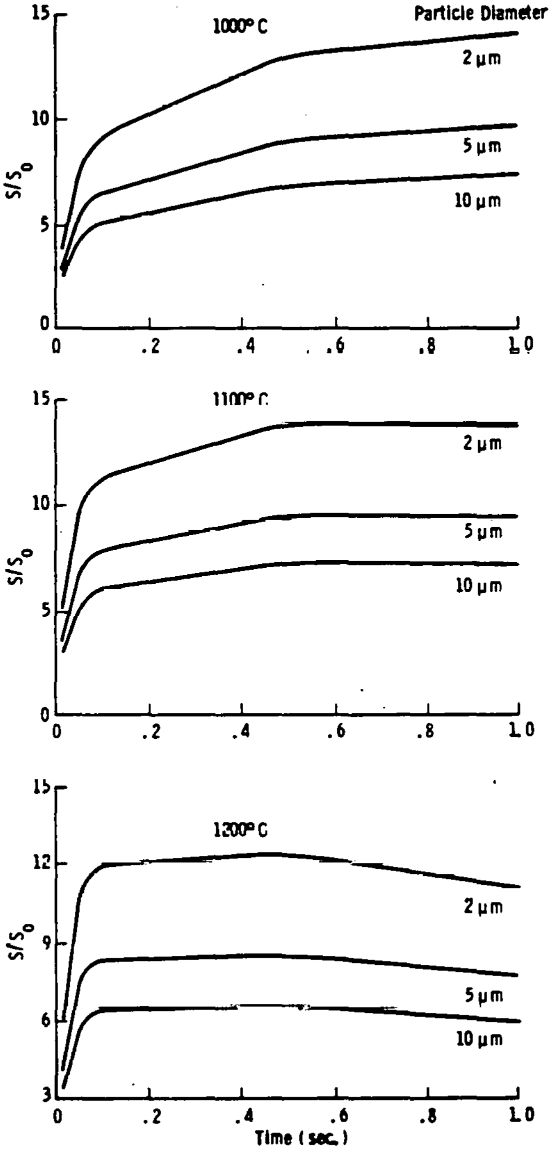


Figure 3.9 — Relative Surface Area of Limestones and Dolomites

temperatures of 1000, 1100, and 1200°C with particle diameters of 2, 5 and 10 microns diameter. The correlations forms from EER are used, along with the constants based on the EPA data for the catalytic sintering rate. At the moderate temperature of 1000°C the surface area is 5 to 15 times the sintered sorbent surface area within the range of times of interest. At the higher temperatures the surface area reaches a peak value early and begins to drop.

Figure 3.10 illustrates the relative surface area of a 2 micron high-surface area lime particle or a calcium hydroxide particle (S/S_*) (assuming very fast calcination of the hydrate) when injected into gases at temperatures of 1000, 1100 and 1200°C. In this figure the correlation for the sintering of surface, Equation 3.17, was used assuming the initial fraction of calcination is unity, so in these cases the surface area continuously decreases with time.

The scaling of the sintered sorbent kinetics to high-surface area sorbent was done using Equation 3.16. Specific combustor conditions and coal sulfur contents must now be included in the estimates because of the dependency of surface area on exposure time. Plum Run dolomite performance is illustrated in Figure 3.11 for the effect of coal sulfur content and particle diameter on the performance in SO_2, Figure 3.12 for the effect of temperature, and Figure 3.13 for the performance in H_2S. It is expected that these results for Plum Run dolomite may be generalized to most dolomites because of the limited sensitivity of performance due to changes in dolomite type reported in the literature.

In Figure 3.11 Plum Run dolomite particle sizes of 2 and 5 microns are considered at a temperature of 1100°C and a pressure of 10 atmospheres. Two specific conditions are included in the figure, a 1 wt % sulfur coal requiring 70% sulfur removal, and a 4 wt % sulfur coal requiring 90 % sulfur removal. The particle residence time ranges from 0.2 to 1 second. The following conclusions can be drawn from the figure:

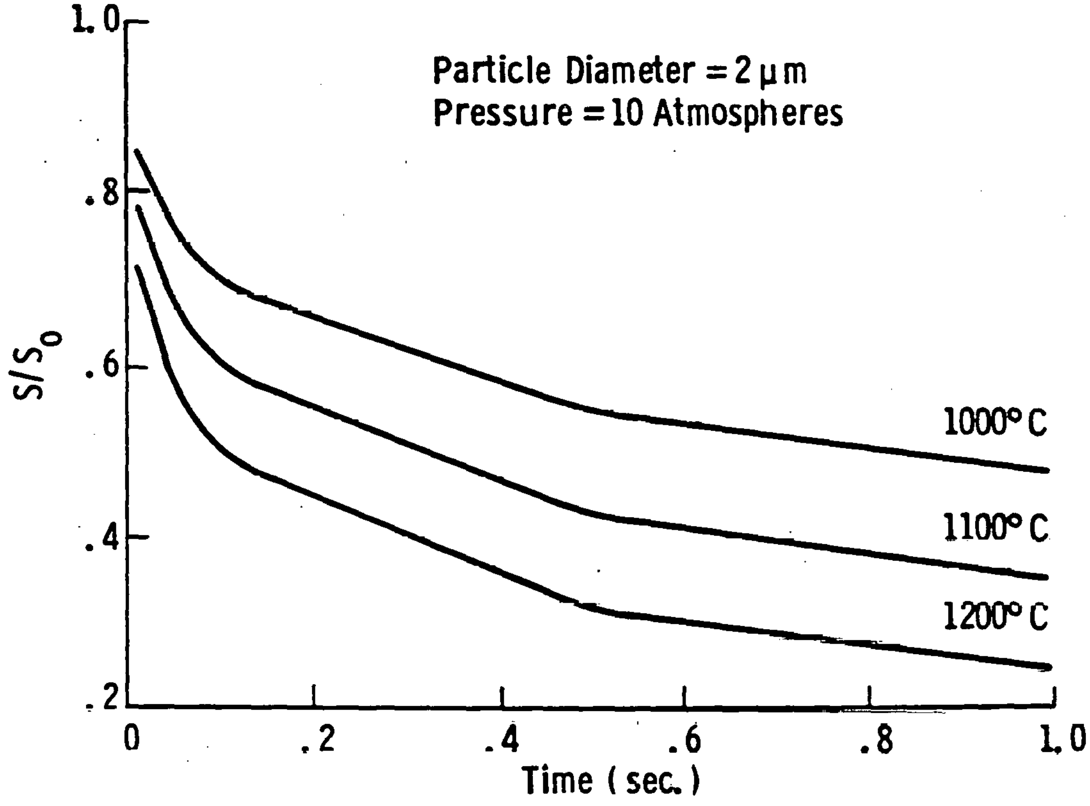
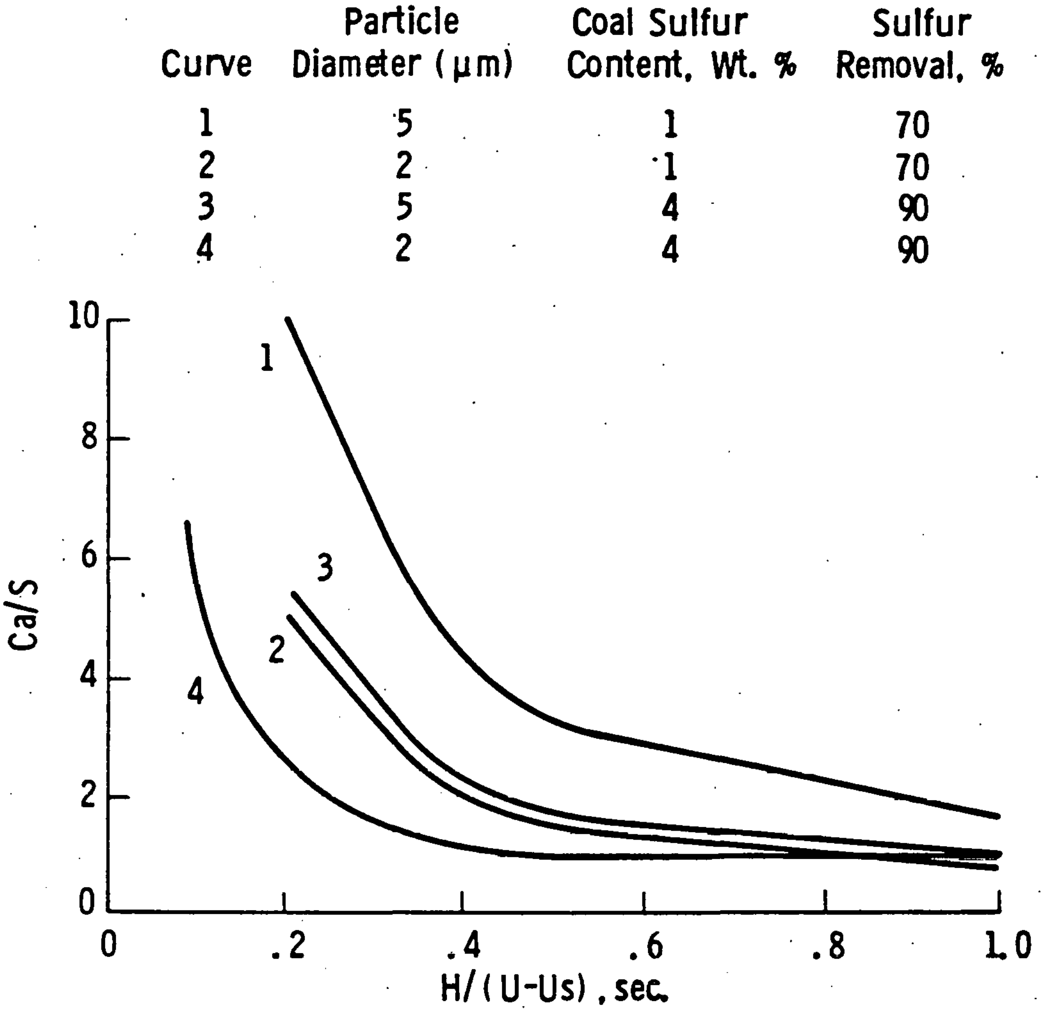


Figure 3.10 — Relative Surface Area (S/S*) of Limes and Hydrates



Curve	Particle Diameter (μm)	Coal Sulfur Content, Wt. %	Sulfur Removal, %
1	5	1	70
2	2	1	70
3	5	4	90
4	2	4	90

Figure 3.11 — Plum Run Dolomite SO_2 Removal Performance at 1100°C and 10 atmospheres pressure

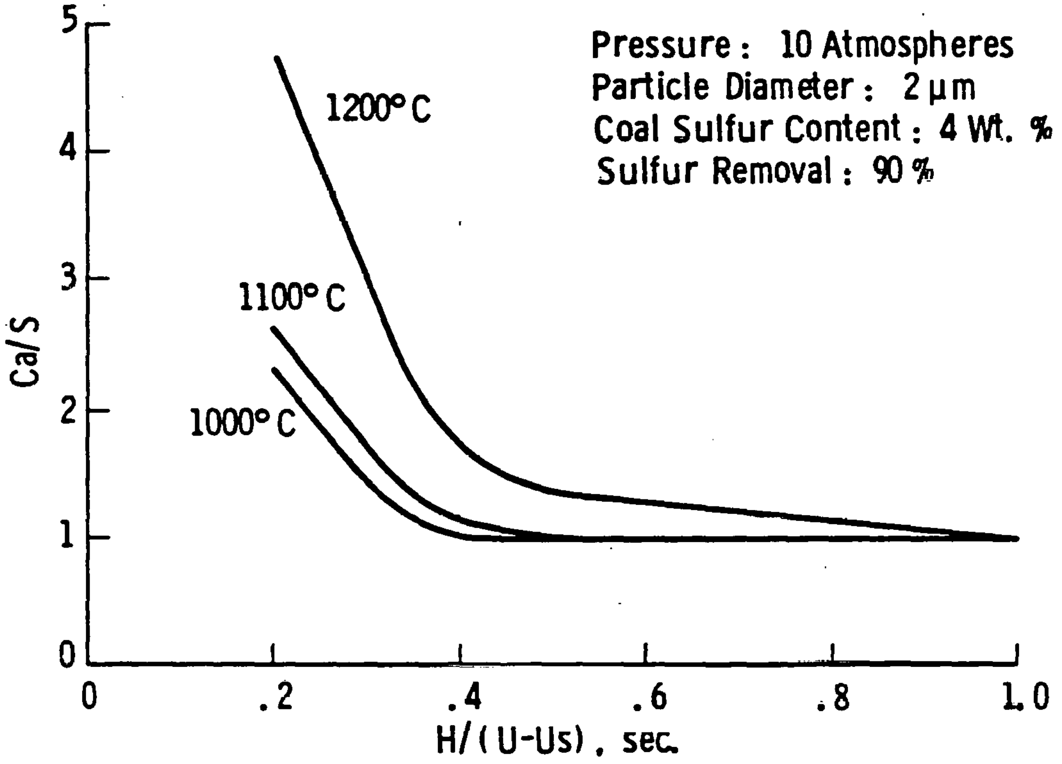


Figure 3.12 — Plum Run Dolomite SO_2 Removal Performance: Effect of Temperature

Curve	Particle Diameter (μm)	Coal Sulfur Content, Wt. %	Sulfur Removal, %
1	5	1	70
2	2	1	70
3	5	4	90
4	2	4	90

Figure 3.13 — Plum Run Dolomite H_2S Removal Performance: 1100°C and 10 Atmospheres Pressure

- There is little benefit in performance from increasing the gas residence time above 0.5 seconds.
- Low sulfur coals will require small dolomite particle diameters on the order of 2 microns for acceptable sorbent consumption rates
- The performance looks promising with high sulfur coals in that Ca/S ratios of less than 2 can probably achieve 90% sulfur removal
- There is a tradeoff between Ca/S ratio, gas residence time, and particle diameter for all of the cases pictured that can only be resolved by considering operating cost, equipment cost, and operability
- Increasing the pressure will reduce the sorbent consumption by about the pressure to the 0.44 power

The effect of temperature on Plum Run dolomite sulfur removal in SO_2 is illustrated in Figure 3.12. Only the high sulfur case is considered with a particle diameter of 2 microns. Increasing the temperature to 1200°C is costly in terms of sorbent consumption, while little difference is expected between 1000 and 1100°C performance.

H_2S removal in dolomite is illustrated in Figure 3.13 for high and low sulfur coal cases. Performance is significantly better than in SO_2 mainly because of the higher H_2S contents of the gas. The following conclusions have been drawn:

- Gas residence time greater than 0.5 seconds has no benefit for reduced sorbent consumption
- Ca/S ratios less than 2 can achieve acceptable sulfur removal for low sulfur coals using gas residence times as small as 0.35 seconds
- Ca/S ratios less than 1.5 can achieve acceptable sulfur removal for high sulfur coals using gas residence times as small as 0.3 seconds.
- Relatively large dolomite particles, up to about 25 microns, could be used for H_2S removal with little increase in the required sulfur removal efficiency because of the low

sensitivity of H_2S removal to particle size in H_2S. This may permit the use of cyclones for dolomite removal.

- Increasing the pressure reduces the dolomite consumption rate only by about pressure to the 0.2 power

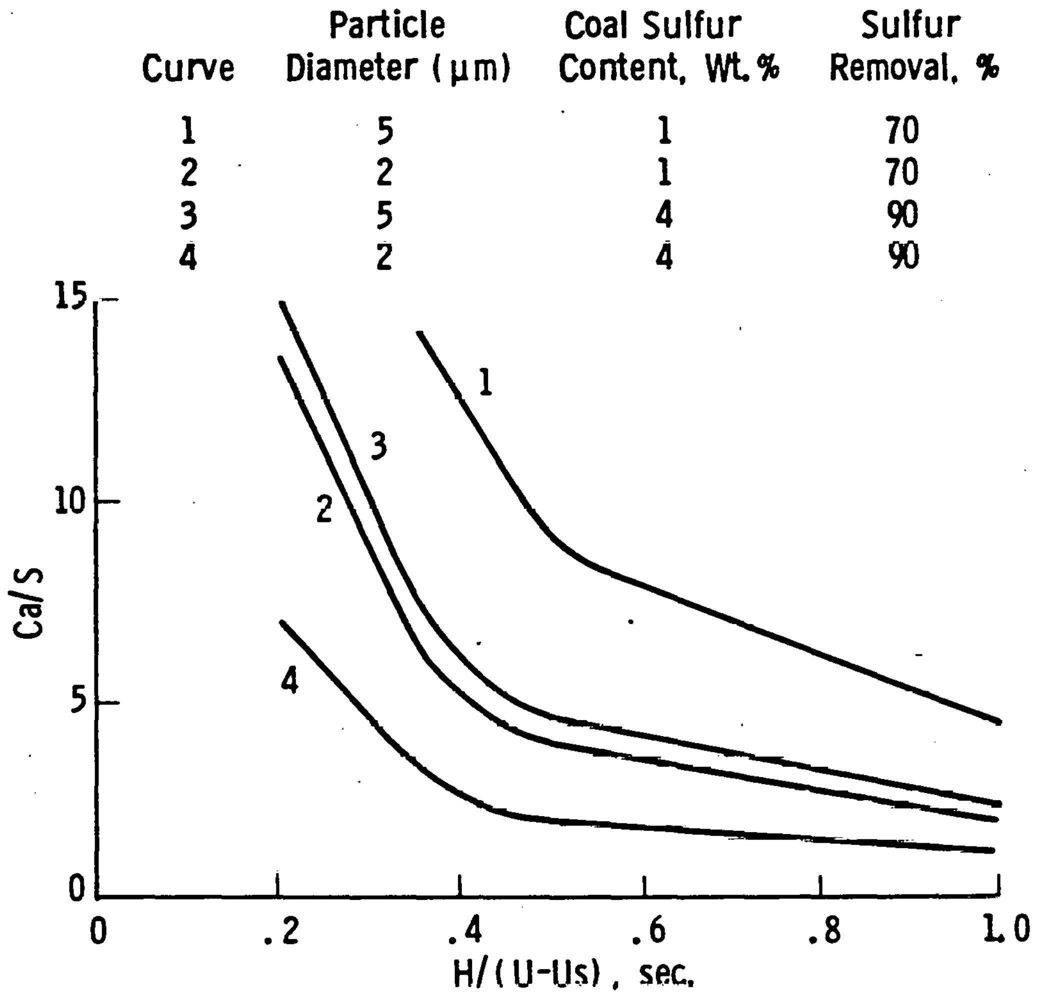
Results for Highland limestone and Vicron limestone are shown in Figures 3.14 through 3.16. Again, as with the dolomites, it is expected that these results will generally represent limestones of most types within a reasonable band of variation. Figure 3.14 shows the results for limestone sulfur removal in SO_2 as a function of particle diameter, coal sulfur content, and gas residence time. The temperature is 1100°C and the pressure is 10 atmospheres. Analogous to the conclusion for dolomites, the following conclusions are drawn:

- Little benefit is gained from gas residence times greater than 0.5 seconds
- Use of small limestone particles, less than 2 microns diameter is probably needed for acceptable performance and gas residence times will probably need to be greater than 0.4 seconds
- Increasing the pressure will reduce the sorbent consumption by about the pressure to the 0.3 power

The effect of temperature on limestone SO_2 removal shown in Figure 3.15 is quite the same as for dolomite SO_2 removal. A significant increase in sorbent consumption is found when going to 1200°C, while reducing the temperature from 1100 to 1000°C reduces the sorbent consumption only slightly.

H_2S removal by limestone is pictured in Figure 3.17 and shows that results comparable to dolomite H_2S removal on a Ca/S basis is obtained. This means that limestone H_2S removal is superior to dolomite on a weight basis. Also,

- Gas residence times less than 0.4 seconds will be acceptable
- Ca/S ratios less than 1.5 may be expected with high sulfur coals



Curve	Particle Diameter (μm)	Coal Sulfur Content, Wt.%	Sulfur Removal, %
1	5	1	70
2	2	1	70
3	5	4	90
4	2	4	90

Figure 3.14 — Highland and Vicson Limestones SO_2 removal performance at 1100°C, 10 atmospheres pressure

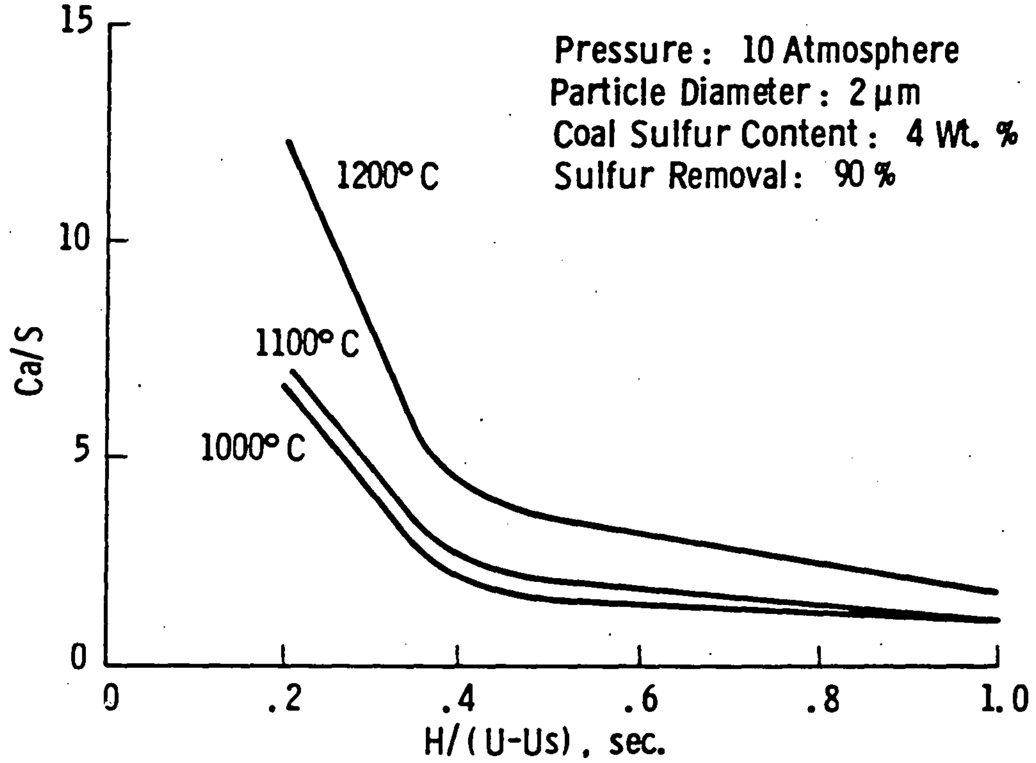
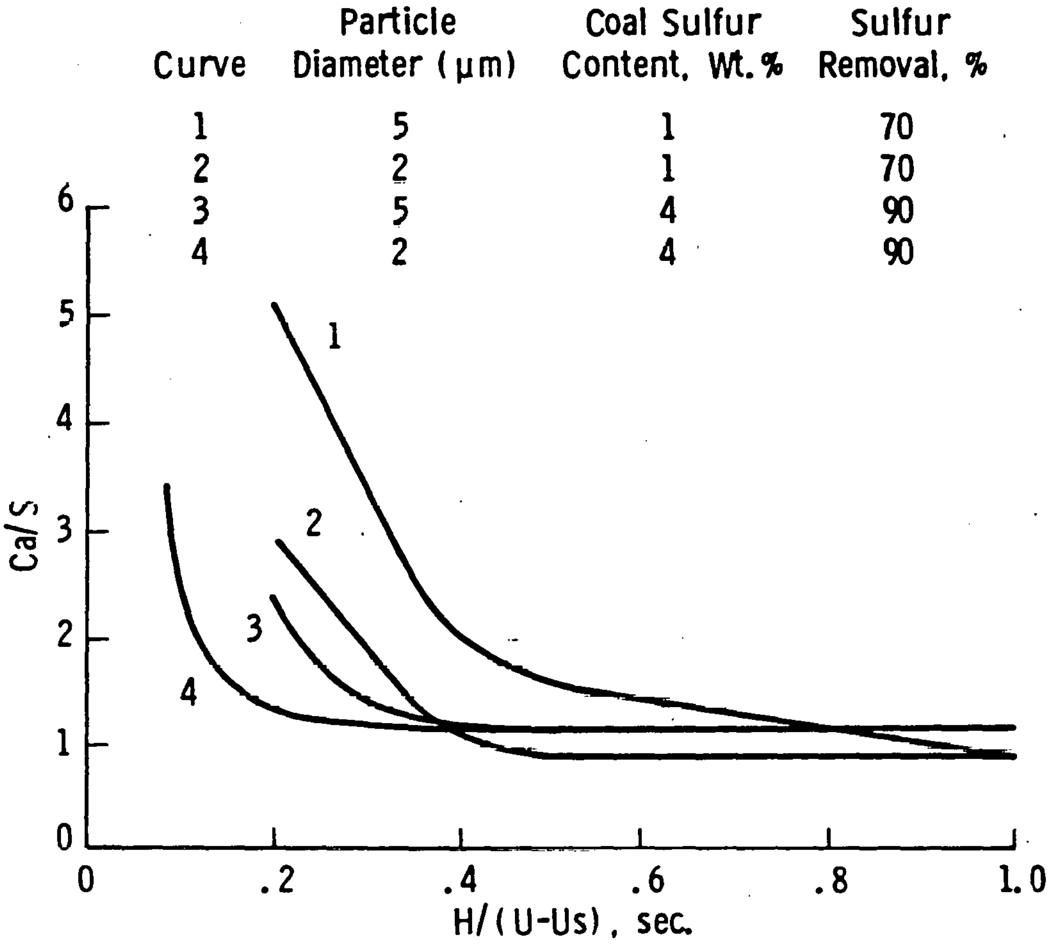


Figure 3.15 — Highland and Vicson Limestones SO_2 removal performance: effect of temperature



Curve	Particle Diameter (μm)	Coal Sulfur Content, Wt.%	Sulfur Removal, %
1	5	1	70
2	2	1	70
3	5	4	90
4	2	4	90

Figure 3.16 — Highland and Vicson Limestones H_2S removal performance at 1100°C and 10 atmospheres pressure

Curve	Particle Diameter (μm)	Coal Sulfur Content, Wt.%	Sulfur Removal, %
1	5	1	70
2	2	1	70
3	5	4	90
4	2	4	90

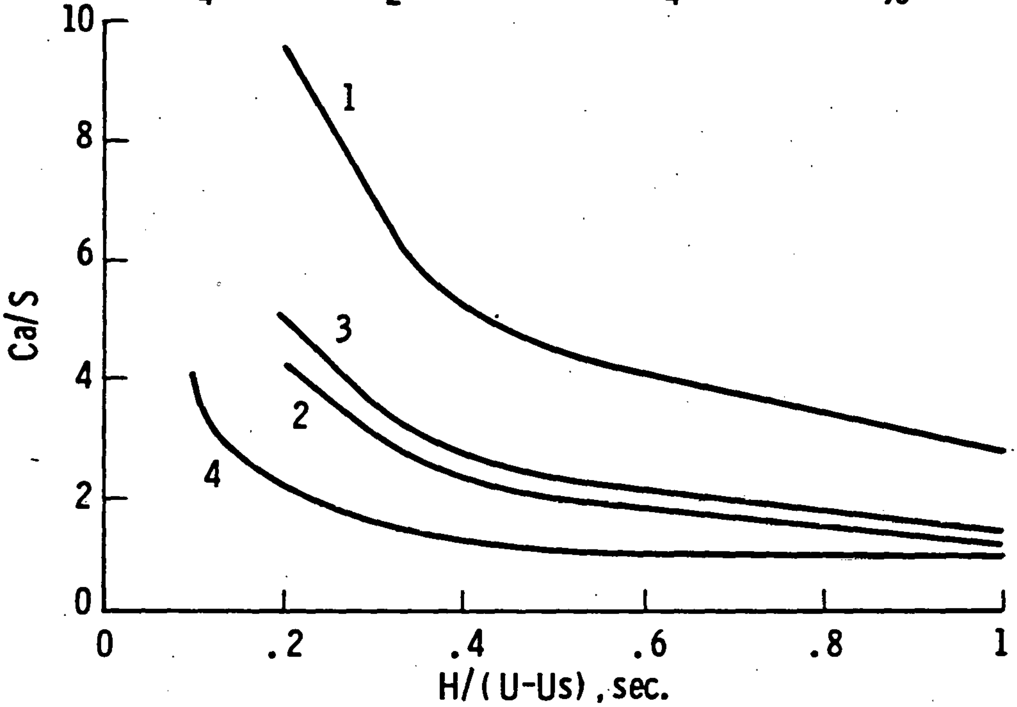


Figure 3.17 — High-surface area lime or hydrate SO_2 removal performance at 1100°C and 10 atmospheres pressure

- Fairly large limestone particles could be used for H_2S removal if long gas residence times are acceptable
- Increasing the pressure reduces the sorbent consumption by the 0.55 power.

The use of high surface area limes or calcium hydroxides is illustrated in Figures 3.17 through 3.19 on the same basis as previously discussed for limestones and dolomites. Lime or calcium hydroxide behaves much the same as dolomite does in SO_2 on the basis of Ca/S ratio. On a weight basis the lime or calcium hydroxide will be superior to dolomite by a factor of about 2. In H_2S the lime or calcium hydroxide is superior to dolomite and limestone and permit the use of gas residence times less than 0.3 seconds with Ca/S ratios less than 1.5. The tradeoff that exists is between the relatively high cost of high surface area lime (not commercially available) or hydrated limes (commercially available) and the relatively low cost of limestone and dolomite.

While the potential performance in H_2S for dolomites, limestones, high-sulfur area limes or calcium hydroxides appears excellent, the existence of H_2S in substoichiometric zones of combustors is not necessarily the predominant species and significant COS and SO_2 may also exist in these zones. Also, with lower sulfur coals in zones where water vapor content is high, equilibrium may limit the extent of sulfur removal possible, as is demonstrated in Figure 2.1. Another limiting factor may arise from the interaction of coal ash with the calcium-based sorbents (42). Fortunately, in direct coal-fired turbines the temperatures are moderate compared to conventional furnace injection situations. Also, most cases consider the use of moderately cleaned coals having relatively low ash content, so the problem of ash interaction may not be a critical problem. The injection of fine sorbents uniformly into a hot gas stream to achieve good gas-solid contacting over short residence times is a key consideration in the development of effective entrained desulfurizers.

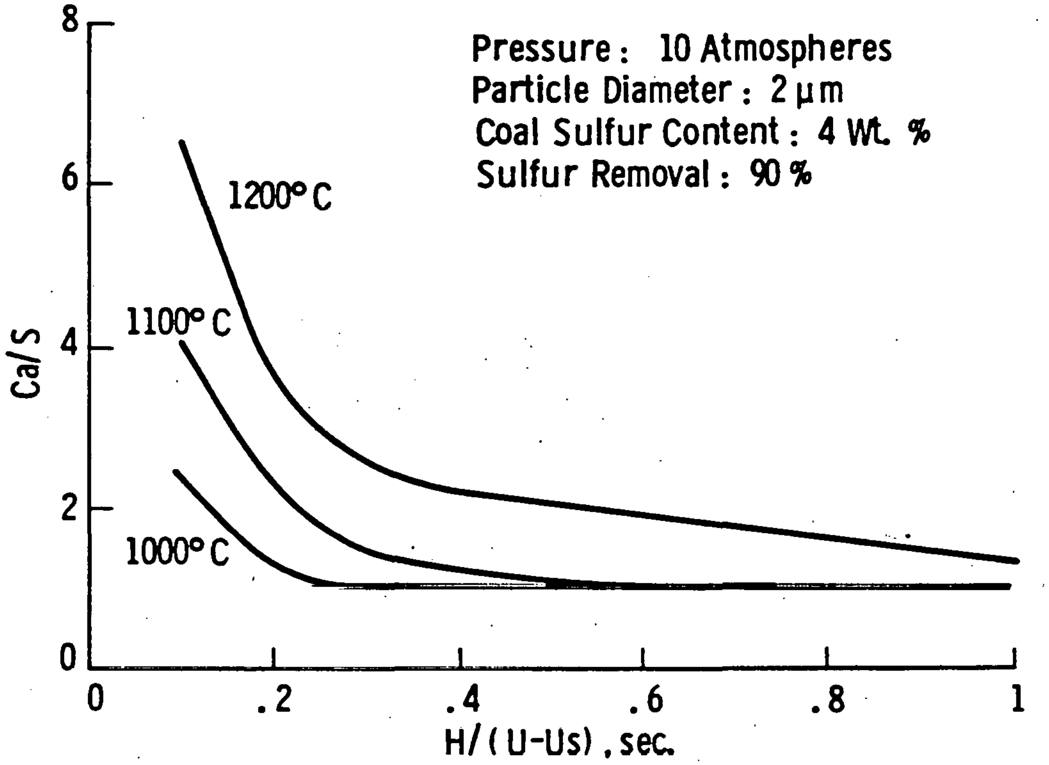


Figure 3.18 — High-surface area lime or hydrate SO_2 removal performance: effect of temperature

Curve	Particle Diameter(μm)	Coal Sulfur Content, Wt.%	Sulfur Removal, %
1	5	1	70
2	2	1	70
3	5	4	90
4	2	4	90

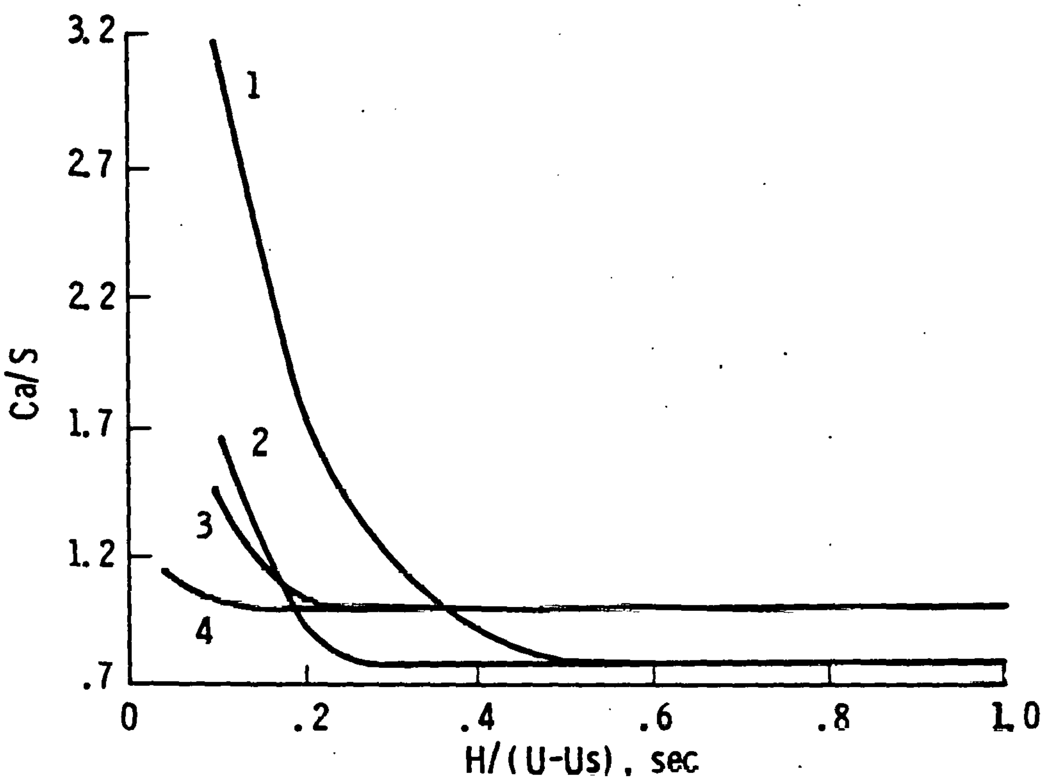


Figure 3.19 — High-surface area lime or hydrate H_2S removal performance at 1100°C and 10^2 atmospheres pressure

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have been extracted from the results presented:

Overall Conclusions

- Both fluidized bed and entrained desulfurizers using calcium-based sorbents have the potential to be used effectively for sulfur emissions control (SO_2 or H_2S removal) in direct coal-fired turbine systems at temperatures as high as 1200°C. Integration of the total system design with the sulfur removal components is required to optimize the sulfur removal performance.
- Thermodynamic equilibrium may limit both the capture of SO_2 and H_2S, depending on the pressure, temperature, sulfur content of the coal and the combustion conditions (concentration of oxygen and of water vapor). The temperature limit for SO_2 removal is about 1200°C, while the limit for H_2S removal is about 1100°C, within the range of behavior for dry coal or coal-water slurries expected.
- The overall sulfur removal performance of fluidized bed and entrained desulfurizers may be quite comparable depending on the specific conditions. Fluidized bed desulfurizers can achieve high SO_2 removal efficiency at lower calcium-to-sulfur ratios than entrained desulfurizers because of the nature of gas-particle mixing in these two contactors. The advantage increases for fluid bed desulfurization as the coal sulfur content decreases. Entrained desulfurizers are more effective for H_2S removal with high-sulfur coals (>3 wt %) than are fluidized bed desulfurizers, but the advantage

switches for low-sulfur coals (< 2 wt %). Some comparative sorbent consumption rates are shown below for the specific case of a 4 wt % sulfur coal, at 1100°C, 10 atmospheres pressure, achieving 90% sulfur removal in the desulfurizer. Shown in the tabulations are the mass of sorbent that must be fed to the desulfurizer per unit mass of coal. All of the fluidized bed desulfurizer cases use a 0.5 second gas residence time in the bed, while for the entrained desulfurizers a particle residence time in the desulfurizer is selected for each case that is representative of the capabilities of the specific sorbent.

Fluidized Bed Desulfurizer

1100°C; 10 atm; 90 % sulfur removal efficiency; 0.5 second gas residence time in the bed; 387 micron particle diameter; 4 wt % sulfur in coal:

Mass sorbent feed per mass coal

sorbent type	For SO_2 removal	For H_2S removal
dolomite	0.27-0.32	0.25
limestone	0.23-0.26	0.25

Entrained Desulfurizer

1100°C; 10 atm; 90 % sulfur removal efficiency; 5 micron particle diameter; 4 wt% sulfur coal:

	Mass sorbent feed per mass coal			
sorbent type	For SO_2 removal		For H_2S removal	
	time (sec)		time (sec)	
sintered dolomite	1.0	2.03	1.0	0.39
sinter. limestone	1.0	2.32	1.0	0.37
commercial lime	1.0	1.30	1.0	0.21
dolomite	0.5	0.32	0.3	0.25
limestone	0.5	0.55	0.3	0.17
active lime	0.5	0.15	0.3	0.07
hydrated lime	0.5	0.15	0.3	0.07

Note that the fluidized bed desulfurizer sorbent mass feed rates will be directly proportional to coal sulfur content while the entrained desulfurizer sorbent mass feed rates will be independent of the coal sulfur content.

- A much larger range of sorbents will potentially provide acceptable sulfur removal with entrained desulfurizers (most dolomites, most limestones, all high surface area limes and lime hydrates) than will with fluidized bed desulfurizers (most dolomites, selected limestones).

Fluidized Bed Desulfurizers

- The Ca/S ratio required for a given sulfur removal efficiency in a fluidized bed desulfurizer is not effected by the coal sulfur content, while the sorbent feed rate is directly proportional to the coal sulfur content. Controlling factors are the sorbent type, the sorbent particle size, the bed voidage, the bed depth, and the bed temperature. The calcium-to-sulfur ratio is sensitive to the sulfur removal efficiency. SO_2 removal is not influenced by pressure, while the calcium-to-sulfur ratio for a given

H_2S removal efficiency is reduced as the pressure is increased.

- Calcium-based sorbents can be identified that are effective at temperatures as high as 1200°C. Dolomites will, in general, be acceptable sorbents, while some limestones, possibly dolomitic limestones, will be very good sorbents, and many limestones will be very poor. The variation in sorbent performance widens as the temperature is increased.
- Pretreating calcium-based sorbents by precalcination provides no sulfur removal performance advantages for the direct coal-fired turbine
- With a gas residence time of 0.5 seconds in the fluidized bed desulfurizer, and an SO_2 removal efficiency of 90 %, the Ca/S ratio will be less than about 2.0 with dolomites and less than 3.0 with selected limestones at temperatures as high as 1200°C. The sulfur removal performance in H_2S is quite comparable or better than it is with SO_2 removal, except for a lower temperature requirement due to equilibrium.
- The major concerns with fluidized bed desulfurizers are sorbent particle agglomeration and defluidization, sorbent-ash interaction, hot gas distribution and distributor design, relatively high pressure drops, and relatively small velocities requiring relatively large vessel diameters.
- Commercial performance estimates (Figures 2.47-2.53), and correlations have been developed showing the relation between the sulfur removal performance and the sorbent properties (Equation 2-15). Better sulfur removal is promoted by sorbents having higher magnesium content, higher surface area, and larger grain size, and additional properties such as spontaneous sorbent popping or activation on shock calcination may be additional indicators of excellent performance potential.

- Correlations for the initial reaction rate (Equation 2-11), and the sulfation (Equation 2-8) and sulfidation (Equations 2-13 and 2-14) kinetics have been developed. The sulfation reaction appears to be controlled initially by solid phase diffusion, followed by pore diffusion control.
- Further laboratory testing should be conducted to explain the observed, reproducible discontinuity in the sulfation curves, appearing to be related to particle expansion and crack formation, and the reversible temperature effect behavior, appearing to be related to adsorption phenomena.
- Bench-scale fluidized bed testing should be conducted to look at the problem of sorbent agglomeration and defluidization, as well as the possible consequences of sorbent-ash interaction.
- Engineering studies should be performed to evaluate the integrated process design and economics of fluidized bed desulfurizers in direct coal-fired turbine systems so that acceptable design and operating conditions can be identified.

Entrained Desulfurizers

- The Ca/S ratio required for a given sulfur removal efficiency in an entrained desulfurizer having generally cocurrent plug flow of gases and sorbent particles is inversely proportional to the coal sulfur content, while the sorbent feed rate is not effected by the coal sulfur content (Equation 3.14). Combustors having some backmixing will have less Ca/S ratio dependency on the coal sulfur content. Controlling factors are the sorbent type, the sorbent particle size, the temperature, the pressure, the gas-particle contact time, and the sulfur species mole fraction in the gas (SO_2 or H_2S), or equivalently, the coal sulfur content and the combustion conditions. Increased-pressure reduces the calcium-to-sulfur ratio for SO_2 removal by the pressure to the 0.29 to 0.44 power. Similar pressure sensitivity is observed for H_2S removal.

- A wide range of acceptable calcium-based sulfur sorbents exists for entrained desulfurization at temperatures as high as 1200°C, with the sorbent performance variation being quite small. Dolomites and high surface area limes and lime hydrates provide the best performance in SO_2 removal, while limestones are probably best (on a weight and cost basis) for H_2S removal. Highly sintered limestones, dolomites (i.e., those exposed to very high flame temperatures prior to desulfurization) and commercial limes (i.e., those produced in typical rotary kilns) are probably only feasible for use with H_2S removal with high sulfur coals and where long residence times are available.
- Correlations of the sulfation kinetics (Equation 3-1) and the sulfidation kinetics (Equation 3-11) have been developed. The greatest uncertainty lies in the transient nature of the sorbent particle surface area. Preliminary correlations for the surface area have been developed from data reported in the literature at atmospheric pressure (Equation 3-17). The sintering rate of sorbents in the high water vapor content characteristic of direct coal-fired turbines has not been accounted for and could result in reduced sulfur removal performance relative to that estimated here.
- The major concerns with entrained desulfurizers are sorbent injection, distribution and mixing, as well as sorbent ash interaction, and sorbent particle deposition on the combustor boundaries.
- Laboratory tests should be conducted to determine the calcination rates and surface area history in high temperature, high pressure gases containing CO_2 and water

vapor representative of direct coal-fired turbines. The scaled sorbent reaction kinetics generated in this study using a dispersed particle reactor should be confirmed in an entrained reactor test unit.

- Engineering design studies should be conducted to evaluate the integrated economics and performance of direct coal-fired turbine systems to determine what gas-particle contact times and what sorbent feed rates are acceptable, and to select design and operating conditions. The compact design philosophy used for conventional turbine combustors may not be appropriate or required for coal-fired systems.

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APPENDIX A

SORBENT PROPERTIES AND SUPPLIES

Table 1

SORBENT COMPOSITIONS

SAMPLE	% CALCIUM	% MAGNESIUM	AVERAGE Ca	AVERAGE Mg
TYMOCHTEE DOLOMITE	20.38	12.60		
	20.04	13.13	20.21	12.87
PLUM RUN DOLOMITE	20.44	12.16		
(GF & LT LEDGES)	19.68	13.87	20.06	13.01
GREER LIMESTONE	37.96	.73		
	37.92	1.21		
	37.59	.96		
	37.51	.84	37.75	.94
CANAAN DOLOMITE	21.20	12.37		
	20.82	12.87	21.01	12.62
HIGHLAND LIMESTONE	34.06	3.87		
(HD-2)	34.07	3.65	34.07	3.76
MISSISSIPPI LIMESTONE	38.52	1.42		
	38.01	1.30	38.26	1.36
CARBON LIMESTONE	34.85	2.52		
	35.30	2.62	35.08	2.57
VICRON LIMESTONE	37.61	1.66		
LUCERNE VALLEY, CALIF.	38.00	1.31	37.81	1.49
VICRON LIMESTONE	36.90	2.38		
ADAMS, MASS.	36.81	1.65	36.86	2.02

Table 2

SORBENT SUPPLIERS

SAMPLE	SOURCE	CONTACT
CANAAN DOLOMITE	PFIZER MINERALS.PIGMENTS AND METALS DIVISION P.O. BOX 667 CANAAN.CT. 06018	JOHN GUNTHER (203) 824-5435
GREER LIMESTONE	GERMANY VALLEY LIMESTONE CO. GREER BUILDING MORGANTOWN. W.V. 26505	RONNIE VANCE (304) 567-2141
MISSISSIPPI LIMESTONE	MISSISSIPPI LIME CO. ST. GENEVIEVE. MO. 63670	MR. BAIERLEIN (618) 465-7741
CARBON LIMESTONE	SME INDUSTRIES INC. P.O. BOX 5250 POLAND. OHIO 44514	BRENT EDWARDS (216) 536-6275
TYMOCHTEE DOLOMITE	C.E. DUFF AND SON 9042 S.R. 117 HUNTSVILLE. OHIO 43324	DWIGHT GRANTZ (513) 686-2488
PLUM RUN DOLOMITE (GF & LT LEDGES)	DAVON INC. PLUM RUN STONE DIVISION 848 PLUM RUN ROAD PEEBLES. OHIO 45660	CRAIG MORGAN (513) 393-4211
HIGHLAND LIMESTONE (HD-2 LIMESTONE)	DAVON INC. HIGHLAND STONE DIVISION 4281 ROUSH ROAD HILLSBORO. OHIO	CRAIG MORGAN (513) 393-4211
SILICA PLANT DOLOMITIC LIMESTONE (LS-4 DOLOMITIC LST.)	FRANCE STONE CO. P.O. BOX 1928 TOLEDO. OHIO 43603	(419) 241-4101
	FRANCE STONE LABORATORIES P.O. BOX 49 WATERVILLE. OHIO 43566	BRUCE MASON V.P. PROPERTY & PRODUCT DEVELOPMENT (419) 878-9600

Table 4

MERCURY POROSIMETRY RESULTS

SAMPLE	TOTAL INTRUSION VOLUME CC/G	TOTAL PORE AREA M2/G	BULK DENSITY G/CC	APPARENT SKELETAL DENSITY G/CC
TYMOCHTEE DOLOMITE	.0407	.7937	2.4965	2.7785
MISSISSIPPI LIMESTONE	.0493	.5474	2.3848	2.7027
GREER LIMESTONE	.0348	.4693	2.4605	2.6910
PLUM RUN DOLOMITE (GF & LT LEDGES)	.0425	.4300	2.5890	2.9095
HIGHLAND LIMESTONE (HD-2)	.0250	.7041	2.6137	2.7965
VICRON LIMESTONE LUCERNE VALLEY, CALIF.	.0123	.0318	2.6296	2.7174
CANAAN DOLOMITE	.0075	.0237	2.8032	2.8635
VICRON LIMESTONE ADAMS, MASS.	.0099	.0290	2.6399	2.7111
CARBON LIMESTONE	.0241	.4255	2.5801	2.7508

Sample	Total Intrusion Volume cc/g	Total Pore Area m²/g	Bulk Density g/cc	Apparent (Skeletal) Density g/cc	
1 Tymochtee Dolomite	0.0407	0.7937	2.4965	2.7785	
2 Mississippi Limestone	0.0493	0.5474	2.3848	2.7027	
3 Greer Limestone	0.0348	0.4693	2.4605	2.6910	
4 Rum Run Dolomite GF-LT Ledges	0.0425	0.4300	2.5890	2.9095	
5 Highland (HD-2) Limestone	0.0250	0.7041	2.6137	2.7965	
6 Vicron Limestone Lucerne Valley, Calif.	0.0123	0.0318	2.6296	2.7174	
7 Canaan Dolomite	0.0075	0.0237	2.8032	2.8635	
8 Vicron Limestone Adams, Mass.	0.0099	0.0290	2.6399	2.7111	
9 Carbon Limestone	0.0241	0.4255	2.5801	2.7508	

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                    MICROMERITICS AUTO-PORE 9200 V2.01                         PAGE 1

HITEMP-SORBENT                                                          LP 9:14:24 8/16/85
CANAAN DOLOMITE: 16/18 MESH UNCALCINED                                  HP 9:38:24 8/16/85
PNTR NUMBER  +385

   LP EQUILIBRATION =   +15.0000 SEC         PNTR CONSTANT =  +10.7900 MICRO-L/
   HP EQUILIBRATION =   +10.0000 SEC                 THETA = +130.0000
      SAMPLE WEIGHT =    +5.0000 G                   GAMMA = +485.0000 DYNES/CM
        PNTR WEIGHT =   +74.9400 G        INITIAL PRESSURE =   +0.9011 PSIA
 PNTR+SAMPLE WEIGHT =   +79.9400 G           PORE DIAMETER = +196.1730 MICRO-M
PNTR+SAMPLE+MERCURY =  +130.7900 G         MERCURY DENSITY =  +13.5335 G/CC
        PNTR VOLUME =    +5.5410 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =    +0.0075 CC/G
               TOTAL PORE AREA =    +0.0237 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =  +119.0450 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =    +0.1096 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =    +1.2659 MICROMETERS
                  BULK DENSITY =    +2.8032 G/CC
   APPARENT (SKELETAL) DENSITY =    +2.8635 G/CC

% CAPILLARY =   +9.7822 ****
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                    MICROMERITICS AUTO-PORE 9200 V2.01

HITEMP-SORBENT                                                  LP 9:14:24 8/16/85
CANAAN DOLOMITE: 16/18 MESH UNCALCINED                          HP 9:38:24 8/16/85
PNTR NUMBER  +385

  PRESSURE        PORE        INTRUSION      PORE         MEAN
    PSIA        DIAMETER       VOLUME       SURFACE      DIAMETER           DV
                 MICRO-M        CC/G        SQ-M/G        MICRO-M

      +5.0      +35.4843      +0.0050      +0.0002      +115.8290       +0.0050
      +9.9      +17.7814      +0.0056      +0.0003       +26.6328       +0.0006
     +14.6      +12.0767      +0.0059      +0.0003       +14.9291       +0.0002
     +19.9       +8.8743      +0.0060      +0.0004       +10.4755       +0.0002
     +39.7       +4.4519      +0.0061      +0.0004        +6.6631       +0.0001
     +60.0       +2.9462      +0.0062      +0.0005        +3.6990       +0.0001
     +80.0       +2.2096      +0.0063      +0.0007        +2.5779       +0.0001
    +100.4       +1.7613      +0.0064      +0.0009        +1.9855       +0.0001
    +118.8       +1.4876      +0.0064      +0.0009        +1.6244       +0.0000
    +150.5       +1.1742      +0.0064      +0.0011        +1.3309       +0.0001
    +201.2       +0.8784      +0.0066      +0.0017        +1.0263       +0.0002
    +252.0       +0.7014      +0.0067      +0.0023        +0.7899       +0.0001
    +298.9       +0.5914      +0.0068      +0.0027        +0.6464       +0.0001
    +353.6       +0.4999      +0.0068      +0.0031        +0.5457       +0.0001
    +400.5       +0.4414      +0.0069      +0.0036        +0.4707       +0.0001
    +455.2       +0.3883      +0.0069      +0.0037        +0.4149       +0.0000
    +503.1       +0.3514      +0.0070      +0.0043        +0.3699       +0.0001
    +600.7       +0.2943      +0.0070      +0.0044        +0.3228       +0.0000
    +697.4       +0.2535      +0.0070      +0.0053        +0.2739       +0.0001
    +799.0       +0.2212      +0.0071      +0.0064        +0.2373       +0.0001
    +895.7       +0.1973      +0.0072      +0.0076        +0.2093       +0.0001
    +997.3       +0.1772      +0.0072      +0.0078        +0.1873       +0.0000
   +1104.8       +0.1600      +0.0072      +0.0093        +0.1686       +0.0001
   +1206.3       +0.1465      +0.0072      +0.0095        +0.1533       +0.0000
   +1307.0       +0.1353      +0.0073      +0.0097        +0.1409       +0.0000
   +1411.5       +0.1252      +0.0073      +0.0100        +0.1302       +0.0000
   +1501.3       +0.1177      +0.0073      +0.0119        +0.1215       +0.0001
   +1607.8       +0.1099      +0.0073      +0.0119        +0.1138       +0.0000
   +1691.8       +0.1045      +0.0073      +0.0124        +0.1072       +0.0000
   +1803.2       +0.0980      +0.0073      +0.0127        +0.1013       +0.0000
   +2004.4       +0.0882      +0.0074      +0.0132        +0.0931       +0.0000
   +2200.7       +0.0803      +0.0074      +0.0137        +0.0843       +0.0000
   +2397.1       +0.0737      +0.0074      +0.0170        +0.0770       +0.0001
   +2593.1       +0.0682      +0.0074      +0.0175        +0.0710       +0.0000
   +2814.7       +0.0628      +0.0074      +0.0181        +0.0655       +0.0000
   +2995.5       +0.0590      +0.0075      +0.0186        +0.0609       +0.0000
   +3189.0       +0.0554      +0.0075      +0.0191        +0.0572       +0.0000
   +3398.8       +0.0520      +0.0075      +0.0196        +0.0537       +0.0000
   +3588.5       +0.0493      +0.0075      +0.0196        +0.0506       +0.0000
   +3800.0       +0.0465      +0.0075      +0.0207        +0.0479       +0.0000
   +3993.8       +0.0443      +0.0075      +0.0212        +0.0454       +0.0000
   +4500.4       +0.0393      +0.0075      +0.0225        +0.0418       +0.0000
   +5007.1       +0.0353      +0.0075      +0.0238        +0.0373       +0.0000
   +5498.9       +0.0321      +0.0075      +0.0238        +0.0337       +0.0000
   +5990.6       +0.0295      +0.0075      +0.0238        +0.0308       +0.0000
   +6527.1       +0.0271      +0.0075      +0.0238        +0.0283       +0.0000
   +6989.1       +0.0253      +0.0075      +0.0238        +0.0262       +0.0000
   +7525.5       +0.0235      +0.0075      +0.0238        +0.0244       +0.0000
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               MICROMERITICS AUTO-PORE 9200 V2.01                PAGE 3

HITEMP-SORBENT                                              LP 9:14:24 8/16/85
CANAAN DOLOMITE; 16/18 MESH UNCALCINED                      HP 9:38:24 8/16/85
PNTR NUMBER  +385

  PRESSURE       PORE        INTRUSION      PORE         MEAN
    PSIA       DIAMETER       VOLUME       SURFACE     DIAMETER          DV
                MICRO-M        CC/G        SQ-M/G       MICRO-M

   +7987.5     +0.0221      +0.0075      +0.0238      +0.0228        +0.000
   +8956.1     +0.0197      +0.0075      +0.0238      +0.0209        +0.000
   +9954.6     +0.0178      +0.0075      +0.0238      +0.0187        +0.000
  +10953.0     +0.0161      +0.0075      +0.0238      +0.0169        +0.000
  +11996.2     +0.0147      +0.0075      +0.0238      +0.0154        +0.000
  +12964.8     +0.0136      +0.0075      +0.0238      +0.0142        +0.000
  +13948.3     +0.0127      +0.0075      +0.0238      +0.0132        +0.000
  +14946.8     +0.0118      +0.0075      +0.0238      +0.0123        +0.000
  +15930.3     +0.0111      +0.0075      +0.0238      +0.0115        +0.000
  +17077.8     +0.0104      +0.0075      +0.0238      +0.0107        +0.000
  +18150.7     +0.0097      +0.0075      +0.0238      +0.0100        +0.000
  +19149.2     +0.0092      +0.0075      +0.0238      +0.0095        +0.000
  +20132.7     +0.0088      +0.0075      +0.0238      +0.0090        +0.000
  +24961.0     +0.0071      +0.0075      +0.0238      +0.0079        +0.000
  +29923.3     +0.0059      +0.0075      +0.0238      +0.0065        +0.000
  +35154.0     +0.0050      +0.0075      +0.0238      +0.0055        +0.000
  +40205.8     +0.0044      +0.0075      +0.0238      +0.0047        +0.000
  +45138.4     +0.0039      +0.0075      +0.0238      +0.0042        +0.000
  +50056.0     +0.0035      +0.0075      +0.0238      +0.0037        +0.000
  +54884.3     +0.0032      +0.0075      +0.0238      +0.0034        +0.000
  +59787.1     +0.0030      +0.0075      +0.0238      +0.0031        +0.000
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HITEMP-SORBENT                                          LP 9:14:24 8/16/85
CANAAN DOLOMITE: 16/18 MESH UNCALCINED                  HP 9:38:24 8/16/85
PNTR NUMBER  +385
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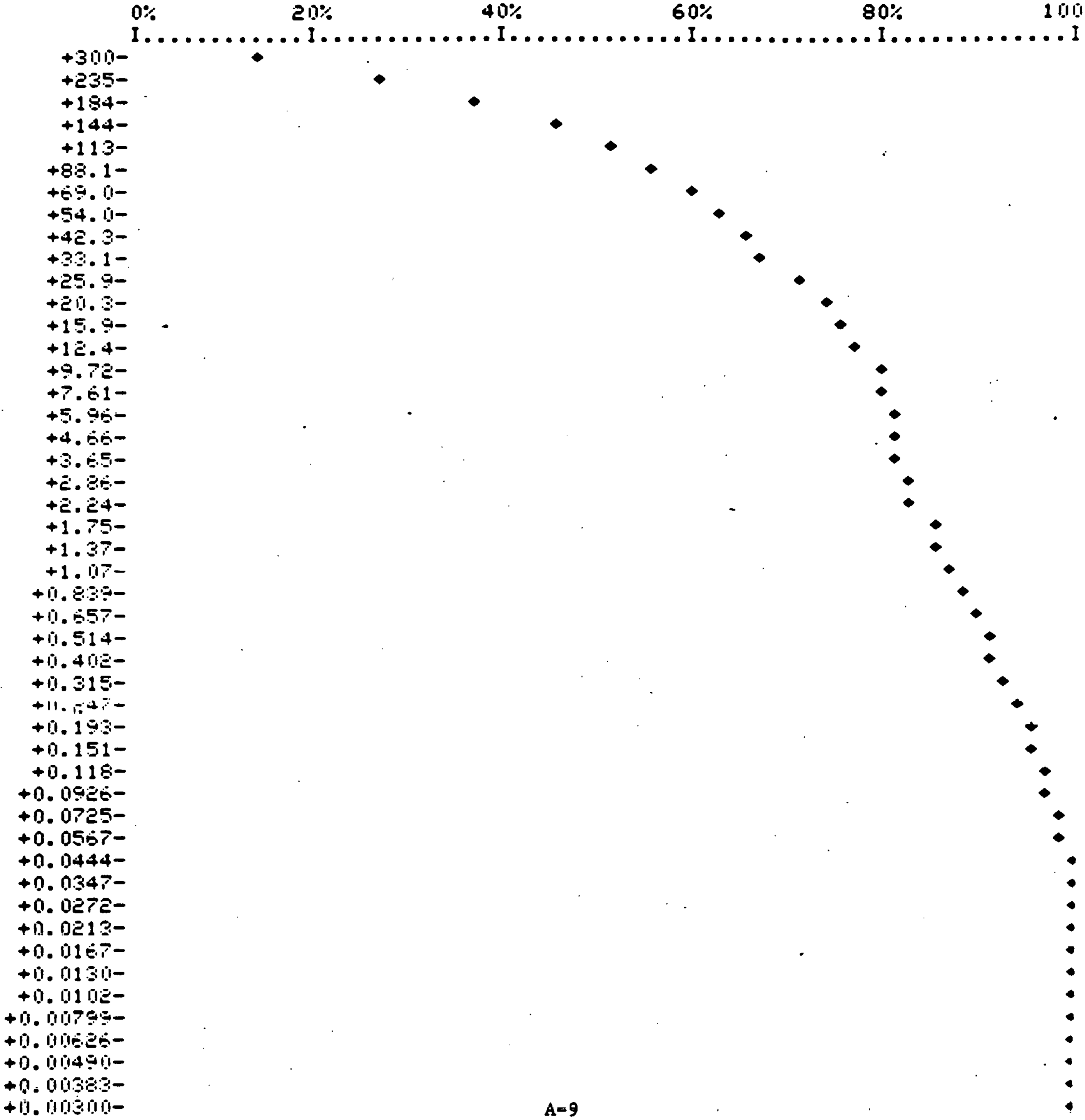
CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
100% = +0.0075



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                    MICROMERITICS AUTO-PORE 9200 V2.01                        PAGE 5

HITEMP-SORBENT                                                    LP 9:14:24 8/16/85
CANAAN DOLOMITE: 16/18 MESH UNCALCINED                            HP 9:38:24 8/16/85
PNTR NUMBER  +385

                 CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
                                     100% =     +0.0237

         0%          20%           40%           60%           80%         1
         I............I.............I.............I.............I.............
    +300-◆
    +235-◆
    +184-◆
    +144-◆
    +113-◆
   +88.1-◆
   +69.0-◆
   +54.0-◆
   +42.3-◆
   +33.1-◆
   +25.9-◆
   +20.3-◆
   +15.9-◆
   +12.4-◆
   +9.72-◆
   +7.61-◆
   +5.96-◆
   +4.66-◆
   +3.65-◆
   +2.86-◆
   +2.24- ◆
   +1.75- ◆
   +1.37-  ◆
   +1.07-   ◆
  +0.839-    ◆
  +0.657-      ◆
  +0.514-        ◆
  +0.402-          ◆
  +0.315-            ◆
  +0.247-               ◆
  +0.193-                     ◆
  +0.151-                           ◆
  +0.118-                                  ◆
 +0.0926-                                     ◆
 +0.0725-                                                 ◆
 +0.0567-                                                       ◆
 +0.0444-                                                             ◆
 +0.0347-
 +0.0272-
 +0.0213-
 +0.0167-
 +0.0130-
 +0.0102-
+0.00799-
+0.00626-
+0.00490-
+0.00383-
+0.00300-
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                       MICROMERITICS AUTO-PORE 9200 V2.01                PAGE 6

HITEMP-SORBENT                                                  LP 9:14:24 8/16/85
CANAAN DOLOMITE: 16/18 MESH UNCALCINED                          HP 9:38:24 8/16/85
PNTR NUMBER  +385

                DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                                    100% = +0.490555E-002

         0%          20%           40%           60%           80%            10
         I............I.............I.............I.............I..............I
    +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆.
   +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +15.9-◆◆◆◆◆◆◆
   +12.4-◆◆◆
   +9.72-◆◆
   +7.61-◆◆
   +5.96-◆◆
   +4.66-◆◆
   +3.65-◆
   +2.86-◆
   +2.24-◆◆
   +1.75-◆
   +1.37-◆
   +1.07-◆
  +0.839-◆◆
  +0.657-◆
  +0.514-◆
  +0.402-◆
  +0.315-◆
  +0.247-◆
  +0.193-◆
  +0.151-◆
  +0.118-◆
 +0.0926-◆
 +0.0725-◆
 +0.0567-◆
 +0.0444-◆
 +0.0347-◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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                    MICROMERITICS AUTO-PORE 9200 V2.01                  PAGE 7

HITEMP-SORBENT                                                  LP 9:14:24 8/16/85
CANAAN DOLOMITE: 16/18 MESH UNCALCINED                          HP 9:38:24 8/16/85
PNTR NUMBER   +385


            DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                                100% = +0.262426E-002

         0%          20%          40%          60%          80%          10
         I............I............I............I............I.............
    +300-◆
    +235-◆
    +184-◆
    +144-◆◆
    +113-◆◆
   +88.1-◆◆
   +69.0-◆◆
   +54.0-◆◆
   +42.3-◆◆◆
   +33.1-◆◆◆
   +25.9-◆◆◆
   +20.3-◆◆◆
   +15.9-◆◆
   +12.4-◆◆
   +9.72-◆◆
   +7.61-◆◆
   +5.96-◆◆
   +4.66-◆◆
   +3.65-◆◆
   +2.86-◆◆
   +2.24-◆◆◆◆
   +1.75-◆◆◆◆◆◆
   +1.37-◆◆
   +1.07-◆◆◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆◆◆◆◆◆◆◆
  +0.402-◆◆◆◆◆
  +0.315-◆◆◆◆◆◆◆◆
  +0.247-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.193-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.151-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.118-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0926-◆◆◆◆◆◆◆◆◆◆◆
 +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0444-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0347-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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                 MICROMERITICS AUTO-PORE 9200 V2.01                    PAGE 1

HITEMP-SORBENT                                                 LP 11:34:48 8/26/85
CARBON LIMESTONE (8/85) 16-18 MESH                             HP 12:57:19 8/26/85
PNTR NUMBER  +388

   LP EQUILIBRATION =   +15.0000 SEC       PNTR CONSTANT =   +10.7900 MICRO-L/F
   HP EQUILIBRATION =   +10.0000 SEC               THETA =  +130.0000
      SAMPLE WEIGHT =    +3.5300 G                 GAMMA =  +485.0000 DYNES/CM
        PNTR WEIGHT =   +77.3400 G      INITIAL PRESSURE =    +0.9451 PSIA
 PNTR+SAMPLE WEIGHT =   +80.8700 G         PORE DIAMETER =  +187.0490 MICRO-M
PNTR+SAMPLE+MERCURY =  +108.5300 G      MERCURY DENSITY =    +13.5335 G/CC
        PNTR VOLUME =    +3.4120 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =     +0.0241 CC/G
               TOTAL PORE AREA =     +0.4255 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =    +13.7645 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =     +0.0217 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =     +0.2261 MICROMETERS
                  BULK DENSITY =     +2.5801 G/CC
   APPARENT (SKELETAL) DENSITY =     +2.7508 G/CC

% CAPILLARY =  +22.1120 ****
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HITEMP-SORBENT                                                      LP 11:34:48 8/26/85
CARBON LIMESTONE (8/85) 16-18 MESH                                  HP 12:57:19 8/26/85
PNTR NUMBER  +388

  PRESSURE       PORE        INTRUSION      PORE         MEAN
    PSIA       DIAMETER       VOLUME       SURFACE     DIAMETER          DV
                MICRO-M        CC/G         SQ-M/G      MICRO-M

      +5.0     +35.4322      +0.0057      +0.0002    +111.2400      +0.0057
      +9.9     +17.8208      +0.0115      +0.0011     +26.6265      +0.0057
     +14.6     +12.0949      +0.0122      +0.0013     +14.9578      +0.0007
     +19.9      +8.8613      +0.0128      +0.0015     +10.4781      +0.0005
     +38.8      +4.5527      +0.0137      +0.0020      +6.7070      +0.0009
     +58.4      +3.0275      +0.0142      +0.0025      +3.7901      +0.0005
     +78.8      +2.2446      +0.0147      +0.0033      +2.6361      +0.0005
     +98.6      +1.7927      +0.0151      +0.0042      +2.0186      +0.0005
    +120.8      +1.4633      +0.0156      +0.0053      +1.6280      +0.0005
    +148.9      +1.1875      +0.0163      +0.0074      +1.3254      +0.0007
    +198.8      +0.8890      +0.0176      +0.0126      +1.0382      +0.0014
    +252.2      +0.7010      +0.0182      +0.0156      +0.7950      +0.0006
    +301.8      +0.5857      +0.0189      +0.0199      +0.6433      +0.0007
    +355.6      +0.4972      +0.0192      +0.0221      +0.5414      +0.0003
    +403.4      +0.4382      +0.0194      +0.0241      +0.4677      +0.0002
    +454.2      +0.3892      +0.0197      +0.0264      +0.4137      +0.0002
    +504.0      +0.3507      +0.0198      +0.0281      +0.3699      +0.0002
    +602.7      +0.2933      +0.0202      +0.0329      +0.3220      +0.0004
    +701.3      +0.2520      +0.0205      +0.0364      +0.2727      +0.0002
    +803.9      +0.2199      +0.0206      +0.0392      +0.2360      +0.0002
    +897.7      +0.1969      +0.0208      +0.0423      +0.2084      +0.0002
    +994.4      +0.1778      +0.0210      +0.0458      +0.1873      +0.0002
   +1113.6      +0.1587      +0.0211      +0.0497      +0.1683      +0.0002
   +1216.1      +0.1454      +0.0212      +0.0520      +0.1521      +0.0001
   +1315.7      +0.1344      +0.0214      +0.0566      +0.1399      +0.0002
   +1414.4      +0.1250      +0.0215      +0.0592      +0.1297      +0.0001
   +1512.1      +0.1169      +0.0215      +0.0620      +0.1209      +0.0001
   +1611.7      +0.1097      +0.0216      +0.0650      +0.1133      +0.0001
   +1712.3      +0.1032      +0.0217      +0.0681      +0.1065      +0.0001
   +1812.0      +0.0976      +0.0218      +0.0715      +0.1004      +0.0001
   +2008.3      +0.0880      +0.0219      +0.0754      +0.0928      +0.0001
   +2204.6      +0.0802      +0.0220      +0.0797      +0.0841      +0.0001
   +2403.9      +0.0735      +0.0221      +0.0843      +0.0769      +0.0001
   +2596.7      +0.0681      +0.0221      +0.0892      +0.0708      +0.0001
   +2787.4      +0.0634      +0.0222      +0.0945      +0.0657      +0.0001
   +3011.9      +0.0587      +0.0223      +0.1002      +0.0611      +0.0001
   +3190.2      +0.0554      +0.0224      +0.1062      +0.0570      +0.0001
   +3386.3      +0.0522      +0.0225      +0.1124      +0.0538      +0.0001
   +3606.9      +0.0490      +0.0225      +0.1133      +0.0506      +0.0000
   +3800.0      +0.0465      +0.0226      +0.1203      +0.0478      +0.0001
   +3993.8      +0.0443      +0.0226      +0.1210      +0.0454      +0.0000
   +4515.3      +0.0391      +0.0228      +0.1372      +0.0417      +0.0002
   +5007.1      +0.0353      +0.0229      +0.1469      +0.0372      +0.0001
   +5513.8      +0.0321      +0.0229      +0.1576      +0.0337      +0.0001
   +6020.4      +0.0294      +0.0230      +0.1690      +0.0307      +0.0001
   +6542.0      +0.0270      +0.0231      +0.1812      +0.0282      +0.0001
   +7018.9      +0.0252      +0.0232      +0.1942      +0.0261      +0.0001
   +7540.4      +0.0234      +0.0232      +0.1957      +0.0243      +0.0000
```

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HITEMP-SORBENT                                                LP 11:34:48 8/26/85
CARBON LIMESTONE (8/85) 16-18 MESH                            HP 12:57:19 8/26/85
PNTR NUMBER  +388

  PRESSURE      PORE        INTRUSION      PORE         MEAN
    PSIA      DIAMETER       VOLUME       SURFACE     DIAMETER          DV
              MICRO-M         CC/G        SQ-M/G      MICRO-M

   +8017.3    +0.0220       +0.0233      +0.2102      +0.0227        +0.0001
   +8985.9    +0.0197       +0.0234      +0.2272      +0.0209        +0.0001
   +9984.4    +0.0177       +0.0235      +0.2617      +0.0187        +0.0002
  +10953.0    +0.0161       +0.0236      +0.2817      +0.0169        +0.0001
  +11981.3    +0.0148       +0.0236      +0.2840      +0.0154        +0.0000
  +12949.9    +0.0137       +0.0238      +0.3280      +0.0142        +0.0002
  +13948.3    +0.0127       +0.0238      +0.3300      +0.0132        +0.0000
  +14946.8    +0.0118       +0.0239      +0.3561      +0.0123        +0.0001
  +15930.3    +0.0111       +0.0240      +0.3838      +0.0115        +0.0001
  +17122.5    +0.0103       +0.0240      +0.3857      +0.0107        +0.0000
  +18165.6    +0.0097       +0.0240      +0.3871      +0.0100        +0.0000
  +18910.7    +0.0093       +0.0240      +0.4194      +0.0095        +0.0001
  +20102.9    +0.0088       +0.0240      +0.4209      +0.0091        +0.0000
  +24975.9    +0.0071       +0.0241      +0.4256      +0.0079        +0.0000
  +29953.1    +0.0059       +0.0241      +0.4256      +0.0065        +0.0000
  +35288.1    +0.0050       +0.0241      +0.4256      +0.0055        +0.0000
  +40414.4    +0.0044       +0.0241      +0.4256      +0.0047        +0.0000
  +45332.1    +0.0039       +0.0241      +0.4256      +0.0041        +0.0000
  +50324.3    +0.0035       +0.0241      +0.4256      +0.0037        +0.0000
  +55107.8    +0.0032       +0.0241      +0.4256      +0.0034        +0.0000
  +59906.3    +0.0030       +0.0241      +0.4256      +0.0031        +0.0000
```

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HITEMP-SORBENT                                    LP 11:34:48 8/26/8
CARBON LIMESTONE (8/85) 16-18 MESH                HP 12:57:19 8/26/8
PNTR NUMBER  +388
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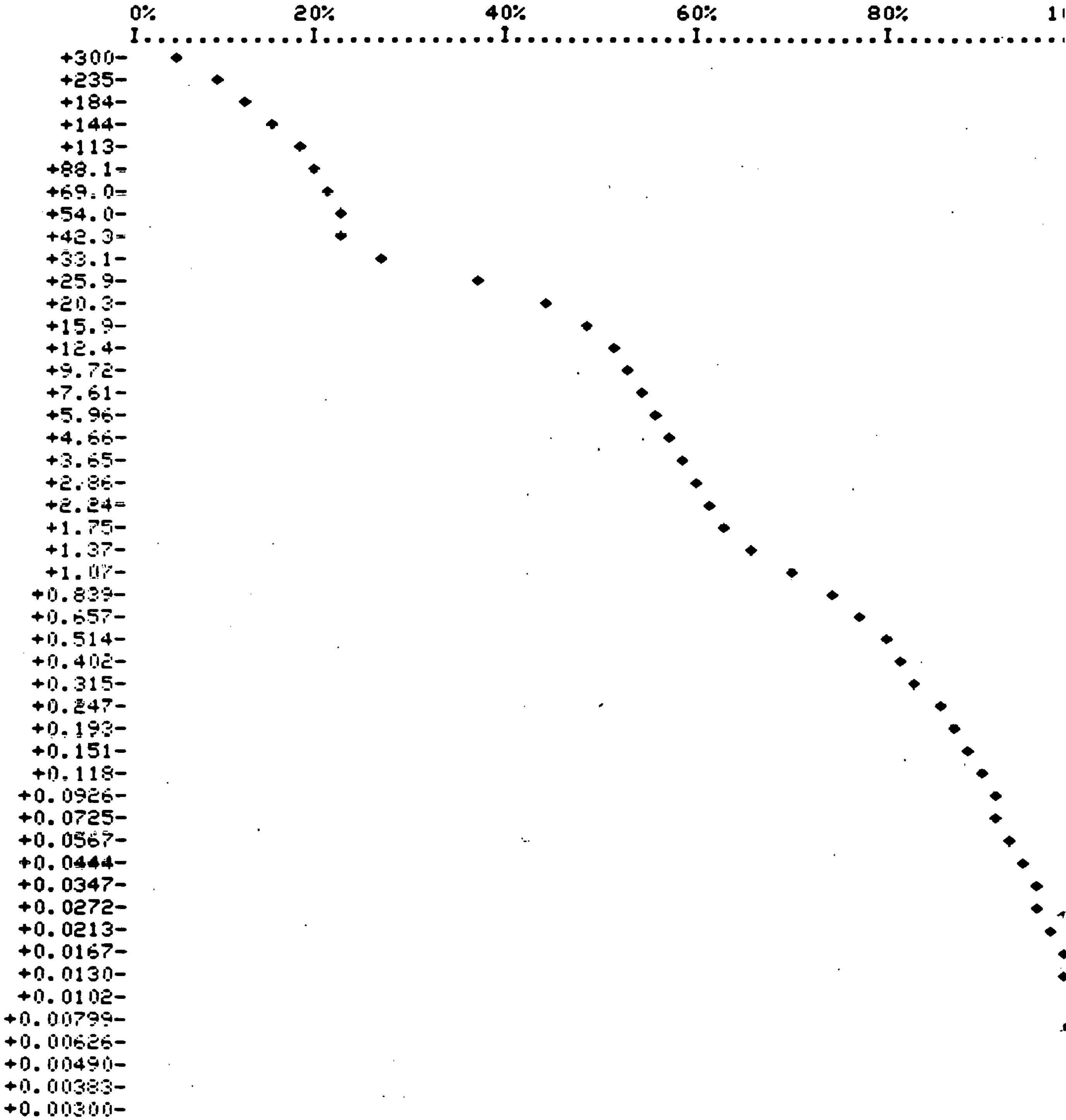
          CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
                         100% =      +0.0241
```



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                    MICROMERITICS AUTO-PORE 9200 V2.01                  PAGE 5

HITEMP-SORBENT                                                LP 11:34:48 8/26/85
CARBON LIMESTONE (8/85) 16-18 MESH                            HP 12:57:19 8/26/85
PNTR NUMBER  +388

               CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
                             100% =     +0.4255

         0%         20%          40%          60%          80%          10
         I............I............I............I............I............I
    +300-◆
    +235-◆
    +184-◆
    +144-◆
    +113-◆
   +88.1-◆
   +69.0-◆
   +54.0-◆
   +42.3-◆
   +33.1-◆
   +25.9-◆
   +20.3-◆
   +15.9-◆
   +12.4-◆
   +9.72-◆
   +7.61-◆
   +5.96-◆
   +4.66-◆
   +3.65-◆
   +2.86-◆
   +2.24-◆
   +1.75-◆
   +1.37-◆
   +1.07- ◆
  +0.839- ◆
  +0.657-  ◆
  +0.514-   ◆
  +0.402-   ◆
  +0.315-    ◆
  +0.247-     ◆
  +0.193-      ◆
  +0.151-       ◆
  +0.118-         ◆
 +0.0926-           ◆
 +0.0725-             ◆
 +0.0567-                ◆
 +0.0444-                  ◆
 +0.0347-                      ◆
 +0.0272-                            ◆
 +0.0213-                                ◆
 +0.0167-                                          ◆
 +0.0130-                                                  ◆
 +0.0102-                                                          ◆
+0.00799-                                                                 ◆
+0.00626-                                                                 ◆
+0.00490-                                                                 ◆
+0.00383-                                                                 ◆
+0.00300-                                                                 ◆
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                MICROMERITICS AUTO-PORE 9200 V2.01                  PAGE 6

HITEMP-SORBENT                                                 LP 11:34:48 8/26/8
CARBON LIMESTONE (8/85) 16-18 MESH                             HP 12:57:19 8/26/8
PNTR NUMBER  +388

                 DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                                 100% = +0.574866E-002

               0%          20%           40%           60%           80%           1
               I............I.............I.............I.............I............
          +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
          +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
          +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
          +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
          +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +15.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +12.4-◆◆◆◆◆◆◆◆◆◆◆◆◆
         +9.72-◆◆◆◆◆◆◆
         +7.61-◆◆◆◆◆◆◆◆
         +5.96-◆◆◆◆◆◆◆◆◆◆
         +4.66-◆◆◆◆◆◆◆◆◆◆◆
         +3.65-◆◆◆◆◆◆◆◆
         +2.86-◆◆◆◆◆◆
         +2.24-◆◆◆◆◆◆
         +1.75-◆◆◆◆◆◆
         +1.37-◆◆◆◆◆◆
         +1.07=◆◆◆◆◆◆◆◆◆◆◆
        +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.657-◆◆◆◆◆◆◆◆
        +0.514-◆◆◆◆◆
        +0.402-◆◆◆
        +0.316-◆◆◆◆
        +0.247-◆◆◆
        +0.193-◆◆
        +0.151-◆
        +0.118-◆
       +0.0926-◆
       +0.0725-◆
       +0.0567-◆
       +0.0444-◆
       +0.0347-◆
       +0.0272-◆
       +0.0213-◆
       +0.0167-◆
       +0.0130-◆
       +0.0102-◆
      +0.00799-◆
      +0.00626-◆
      +0.00490-◆
      +0.00383-◆
      +0.00300-◆
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                MICROMERITICS AUTO-PORE 9200 V2.01                      PAGE 7

HITEMP-SORBENT                                                  LP 11:34:48 8/26/8
CARBON LIMESTONE (8/85) 16-18 MESH                              HP 12:57:19 8/26/85
PNTR NUMBER  +388

            DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                                100% = +0.248392E-001

         0%           20%           40%           60%           80%           10
         I.............I.............I.............I.............I.............
    +300-◆
    +235-◆
    +184-◆
    +144-◆
    +113-◆
   +88.1-◆
   +69.0-◆
   +54.0-◆
   +42.3-◆
   +33.1-◆
   +25.9-◆
   +20.3-◆◆
   +15.9-◆◆
   +12.4-◆
   +9.72-◆
   +7.61-◆
   +5.96-◆
   +4.66-◆◆
   +3.65-◆
   +2.86-◆◆
   +2.24-◆◆
   +1.75-◆◆◆
   +1.37-◆◆◆◆
   +1.07-◆◆◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆◆◆◆
  +0.402-◆◆◆◆◆◆
  +0.315-◆◆◆◆◆◆◆◆◆◆
  +0.247-◆◆◆◆◆◆◆◆◆◆
  +0.193-◆◆◆◆◆◆◆◆◆
  +0.151-◆◆◆◆◆◆◆◆
  +0.118-◆◆◆◆◆◆◆◆
 +0.0926-◆◆◆◆◆◆◆◆◆◆
 +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0444-◆◆◆
 +0.0347-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0272-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0213-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0167-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0130-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0102-◆◆◆◆◆
+0.00799-◆◆◆◆◆◆◆◆
+0.00626-◆◆◆◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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                  MICROMERITICS AUTO-PORE 9200 V2.01                             PAGE 1

HITEMP-SORBENT                                                              LP 9:14:24 8/16/85
HIGHLAND (HD-2) LIMESTONE; 16/18 MESH UNCALCINED                            HP 11:18:58 8/16/85
PNTR NUMBER  +382

   LP EQUILIBRATION =   +15.0000 SEC          PNTR CONSTANT =   +10.7900 MICRO-L/P
   HP EQUILIBRATION =   +10.0000 SEC                  THETA =  +130.0000
      SAMPLE WEIGHT =    +4.0000 G                    GAMMA =  +465.0000 DYNES/CM
        PNTR WEIGHT =   +76.3700 G         INITIAL PRESSURE =    +0.9011 PSIA
 PNTR+SAMPLE WEIGHT =   +80.3700 G            PORE DIAMETER =  +196.1730 MICRO-M
PNTR+SAMPLE+MERCURY =  +111.8300 G         MERCURY DENSITY =   +13.5335 G/CC
        PNTR VOLUME =    +3.8550 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =    +0.0250 CC/G
               TOTAL PORE AREA =    +0.7041 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =    +1.1082 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =    +0.0277 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =    +0.1421 MICROMETERS
                  BULK DENSITY =    +2.6137 G/CC
   APPARENT (SKELETAL) DENSITY =    +2.7965 G/CC

% CAPILLARY =  +26.0546
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                MICROMERITICS AUTO-PORE 9200 V2.01                     PAGE 2

HITEMP-SORBENT                                                 LP 9:14:24 8/16/85
HIGHLAND (HD-2) LIMESTONE: 16/18 MESH UNCALCINED               HP 11:18:58 8/16/85
PNTR NUMBER  +387

  PRESSURE      PORE        INTRUSION      PORE        MEAN
    PSIA       DIAMETER      VOLUME       SURFACE     DIAMETER         DV
               MICRO-M        CC/G         SQ-M/G      MICRO-M

      +5.0    +35.4843      +0.0074      +0.0003    +115.8290      +0.0074
      +9.9    +17.7814      +0.0090      +0.0005     +26.6328      +0.0015
     +14.6    +12.0767      +0.0097      +0.0007     +14.9291      +0.0007
     +19.9     +8.8743      +0.0101      +0.0009     +10.4755      +0.0005
     +38.6     +4.5786      +0.0104      +0.0010      +6.7265      +0.0003
     +58.5     +3.0237      +0.0107      +0.0014      +3.8012      +0.0003
     +79.3     +2.2301      +0.0111      +0.0020      +2.6269      +0.0004
    +100.7     +1.7549      +0.0115      +0.0026      +1.9925      +0.0[illegible]
    +118.4     +1.4932      +0.0117      +0.0033      +1.6240      +0.0[illegible]
    +148.6     +1.1898      +0.0121      +0.0045      +1.3415      +0.0[illegible]
    +200.5     +0.8817      +0.0135      +0.0099      +1.0358      +0.0014
    +249.1     +0.7097      +0.0149      +0.0169      +0.7957      +0.0014
    +303.8     +0.5819      +0.0155      +0.0202      +0.6458      +0.0005
    +351.6     +0.5027      +0.0159      +0.0236      +0.5423      +0.0005
    +404.4     +0.4371      +0.0163      +0.0271      +0.4699      +0.0004
    +454.2     +0.3892      +0.0167      +0.0310      +0.4132      +0.0004
    +506.0     +0.3494      +0.0171      +0.0346      +0.3693      +0.0003
    +599.8     +0.2947      +0.0176      +0.0413      +0.3221      +0.0005
    +702.3     +0.2517      +0.0181      +0.0483      +0.2732      +0.0005
    +802.0     +0.2204      +0.0185      +0.0552      +0.2361      +0.0004
    +902.6     +0.1959      +0.0188      +0.0605      +0.2081      +0.0003
    +997.3     +0.1772      +0.0191      +0.0678      +0.1866      +0.0003
   +1110.6     +0.1592      +0.0194      +0.0744      +0.1682      +0.0003
   +1204.4     +0.1468      +0.0196      +0.0798      +0.1530      +0.0002
   +1312.8     +0.1347      +0.0199      +0.0876      +0.1407      +0.0003
   +1406.6     +0.1257      +0.0201      +0.0939      +0.1302      +0.0002
   +1495.5     +0.1182      +0.0202      +0.0985      +0.1219      +0.00[illegible]
   +1609.8     +0.1098      +0.0204      +0.1058      +0.1140      +0.0[illegible]
   +1699.6     +0.1040      +0.0206      +0.1110      +0.1069      +0.[illegible]
   +1805.1     +0.0979      +0.0208      +0.1192      +0.1010      +0.0[illegible]
   +1997.6     +0.0885      +0.0210      +0.1283      +0.0932      +0.0002
   +2200.7     +0.0803      +0.0213      +0.1414      +0.0844      +0.0003
   +2397.1     +0.0737      +0.0215      +0.1523      +0.0770      +0.0002
   +2598.9     +0.0680      +0.0216      +0.1604      +0.0709      +0.0001
   +2786.0     +0.0634      +0.0218      +0.1731      +0.0657      +0.0002
   +2987.0     +0.0592      +0.0220      +0.1824      +0.0613      +0.0001
   +3199.3     +0.0553      +0.0222      +0.1969      +0.0572      +0.0002
   +3400.8     +0.0520      +0.0223      +0.2074      +0.0536      +0.0001
   +3584.5     +0.0493      +0.0224      +0.2184      +0.0506      +0.0001
   +3814.9     +0.0463      +0.0225      +0.2247      +0.0478      +0.0001
   +3993.8     +0.0443      +0.0226      +0.2311      +0.0453      +0.0001
   +4500.4     +0.0393      +0.0229      +0.2642      +0.0418      +0.0003
   +5022.0     +0.0352      +0.0232      +0.2871      +0.0372      +0.0002
   +5513.8     +0.0321      +0.0234      +0.3121      +0.0336      +0.0002
   +6020.4     +0.0294      +0.0235      +0.3307      +0.0307      +0.0001
   +6512.2     +0.0271      +0.0237      +0.3601      +0.0283      +0.0002
   +7033.8     +0.0251      +0.0239      +0.3817      +0.0261      +0.0001
   +7540.4     +0.0234      +0.0239      +0.3939      +0.0243      +0.0001
```

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                  MICROMERITICS AUTO-PORE 9200 V2.01                      PAGE 3

HITEMP-SORBENT                                                    LP 9:14:24 8/16/85
HIGHLAND (HD-2) LIMESTONE: 16/18 MESH UNCALCINED                  HP 11:18:58 8/16/85
PNTR NUMBER  +387

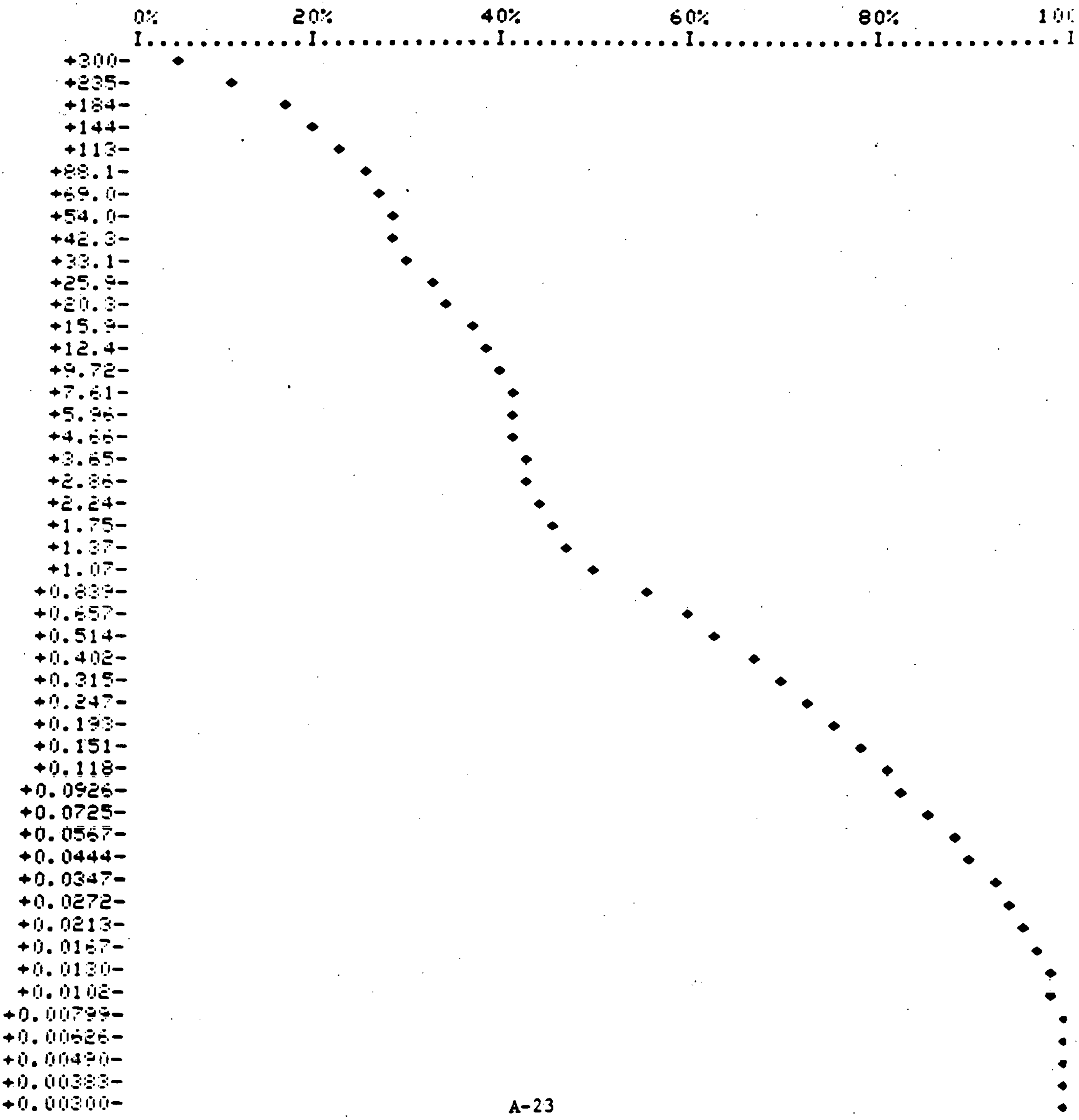
  PRESSURE       PORE         INTRUSION      PORE         MEAN
    PSIA       DIAMETER        VOLUME       SURFACE     DIAMETER            DV
                MICRO-M         CC/G        SQ-M/G       MICRO-M

   +8002.4      +0.0221       +0.0241      +0.4182      +0.0228        +0.0001
   +8956.1      +0.0197       +0.0242      +0.4458      +0.0209        +0.0001
   +9984.4      +0.0177       +0.0244      +0.4762      +0.0187        +0.0001
  +10953.0      +0.0161       +0.0245      +0.5094      +0.0169        +0.0001
  +11996.2      +0.0147       +0.0246      +0.5285      +0.0154        +0.0001
  +12964.8      +0.0136       +0.0246      +0.5489      +0.0142        +0.0001
  +13948.3      +0.0127       +0.0247      +0.5706      +0.0132        +0.0001
  +14944.8      +0.0118       +0.0248      +0.5937      +0.0123        +0.0001
  +15960.1      +0.0111       +0.0248      +0.5952      +0.0115        +0.0000
  +17092.7      +0.0103       +0.0248      +0.5967      +0.0107        +0.0000
  +18150.7      +0.0097       +0.0249      +0.6243      +0.0100        +0.0001
  +19164.1      +0.0092       +0.0249      +0.6255      +0.0095        +0.0000
  +19909.2      +0.0089       +0.0249      +0.6554      +0.0091        +0.0001
  +24961.0      +0.0071       +0.0249      +0.6597      +0.0080        +0.0000
  +29923.3      +0.0059       +0.0250      +0.7029      +0.0065        +0.0001
  +35273.2      +0.0050       +0.0250      +0.7042      +0.0055        +0.0000
  +40354.8      +0.0044       +0.0250      +0.7042      +0.0047        +0.0000
  +45242.7      +0.0039       +0.0250      +0.7042      +0.0041        +0.0000
  +50175.2      +0.0035       +0.0250      +0.7042      +0.0037        +0.0000
  +54943.9      +0.0032       +0.0250      +0.7042      +0.0034        +0.0000
  +59831.8      +0.0030       +0.0250      +0.7042      +0.0031        +0.0000
```

HITEMP-SORBENT
HIGHLAND (HD-2) LIMESTONE: 16/18 MESH UNCALCINED
PNTR NUMBER +387

LP 9:14:24 8/16/
HP 11:18:58 8/16

CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
100% = +0.0250



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                     MICROMERITICS AUTO-PORE 9200 V2.01                     PAGE 5

HITEMP-SORBENT                                                    LP 9:14:24 8/16/85
HIGHLAND (HD-2) LIMESTONE; 16/18 MESH UNCALCINED                  HP 11:18:58 8/16/8
PNTR NUMBER  +387

            CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
                                100% =     +0.7041

         0%         20%         40%         60%         80%         1
         I............I............I............I............I............
     +300-◆
     +235-◆
     +184-◆
     +144-◆
     +113-◆
    +88.1-◆
    +69.0-◆
    +54.0-◆
    +42.3-◆
    +33.1-◆
    +25.9-◆
    +20.3-◆
    +15.9-◆
    +12.4-◆
    +9.72-◆
    +7.61-◆
    +5.96-◆
    +4.66-◆
    +3.65-◆
    +2.86-◆
    +2.24-◆
    +1.75-◆
    +1.37-◆
    +1.07-◆
   +0.839-◆
   +0.657- ◆
   +0.514- ◆
   +0.402-  ◆
   +0.315-   ◆
   +0.247-    ◆
   +0.193-     ◆
   +0.151-       ◆
   +0.118-         ◆
  +0.0926-           ◆
  +0.0725-             ◆
  +0.0567-                 ◆
  +0.0444-                     ◆
  +0.0347-                           ◆
  +0.0272-                                 ◆
  +0.0213-                                        ◆
  +0.0167-                                              ◆
  +0.0130-                                                    ◆
  +0.0102-                                                        ◆
 +0.00799-                                                             ◆
 +0.00626-
 +0.00490-
 +0.00383-
 +0.00300-
```

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HITEMP-SORBENT                                                      LP 9:14:24 8/16/85
HIGHLAND (HD-2) LIMESTONE: 16/18 MESH UNCALCINED                    HP 11:18:58 8/16/8
PNTR NUMBER  +387

              DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                                   100% = +0.729359E-002

         0%          20%           40%           60%           80%          10
         I............I.............I.............I.............I.............I
    +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆.
   +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +15.9-◆◆◆◆◆◆◆◆◆◆◆◆
   +12.4-◆◆◆◆◆◆◆
   +9.72-◆◆◆◆◆
   +7.61-◆◆◆◆
   +5.96-◆◆◆
   +4.66-◆◆
   +3.65-◆◆◆
   +2.86-◆◆◆
   +2.24-◆◆◆◆
   +1.75-◆◆◆
   +1.37-◆◆◆
   +1.07-◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆◆
  +0.402-◆◆◆◆
  +0.315-◆◆◆◆
  +0.247-◆◆◆◆
  +0.193-◆◆◆
  +0.151-◆◆
  +0.118-◆
 +0.0926-◆◆
 +0.0725-◆◆
 +0.0567-◆◆
 +0.0444-◆
 +0.0347-◆◆
 +0.0272-◆◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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HITEMP-SORBENT                                                      LP 9:14:24 8/16/85
HIGHLAND (HD-2) LIMESTONE; 16/18 MESH UNCALCINED                    HP 11:18:58 8/16/8
PNTR NUMBER  +387

            DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                                100% = +0.322794E-001

         0%          20%          40%          60%          80%          1
         I............I............I............I............I............
    +300-*
    +235-*
    +184-*
    +144-*
    +113-*
   +88.1-*
   +69.0-*
   +54.0-*
   +42.3-*
   +33.1-*
   +25.9-*
   +20.3-*
   +15.9-*
   +12.4-*
   +9.72-*
   +7.61-*
   +5.96-*
   +4.66-*
   +3.65-*
   +2.86-*
   +2.24-*
   +1.75-*
   +1.37-**
   +1.07-******
  +0.839-*************
  +0.657-************
  +0.514-*******
  +0.402-********
  +0.315-************
  +0.247-***************
  +0.193-************
  +0.151-*************
  +0.118-**********
 +0.0926-*******************
 +0.0725-**********************
 +0.0567-***************************
 +0.0444-**************
 +0.0347-**************************************************
 +0.0272-***************************************************************
 +0.0213-*******************************************************
 +0.0167-********************************************************************
 +0.0130-**********************************************
 +0.0102-****************
+0.00799-*************************************
+0.00626-********************************************************************
+0.00490-**
+0.00383-*
+0.00300-*
```

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                        MICROMERITICS AUTO-PORE 9200 V2.01                         PAGE 1

HITEMP-SORBENT                                                               LP 11:1:11 8/16/85
MISSISSIPPI LIMESTONE; 16/18 MESH UNCALCINED                                 HP 11:18:58 8/16/85
PNTR NUMBER  +381

   LP EQUILIBRATION =   +15.0000 SEC         PNTR CONSTANT =   +10.7900 MICRO-L/P
   HP EQUILIBRATION =   +10.0000 SEC                 THETA =  +130.0000
      SAMPLE WEIGHT =    +4.0000 G                   GAMMA =  +485.0000 DYNES/CM
        PNTR WEIGHT =   +74.1900 G        INITIAL PRESSURE =    +0.9158 PSIA
 PNTR+SAMPLE WEIGHT =   +78.1900 G           PORE DIAMETER =  +193.0350 MICRO-M
PNTR+SAMPLE+MERCURY =  +130.4800 G        MERCURY DENSITY =   +13.5335 G/CC
        PNTR VOLUME =    +5.5410 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =     +0.0493 CC/G
               TOTAL PORE AREA =     +0.5474 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =     +1.7166 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =     +0.0834 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =     +0.3603 MICROMETERS
                  BULK DENSITY =     +2.3848 G/CC
   APPARENT (SKELETAL) DENSITY =     +2.7027 G/CC

% CAPILLARY =  +51.3645
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                   MICROMERITICS AUTO-PORE 9200 V2.01                        PAGE 2

HITEMP-SORBENT                                                      LP 11:1:11 8/16/85
MISSISSIPPI LIMESTONE; 16/18 MESH UNCALCINED                        HP 11:18:58 8/16/85
PNTR NUMBER  +381

  PRESSURE        PORE        INTRUSION      PORE          MEAN
    PSIA        DIAMETER       VOLUME       SURFACE      DIAMETER           DV
                MICRO-M        CC/G         SQ-M/G       MICRO-M

      +5.0      +35.4843      +0.0086      +0.0003     +114.2590        +0.0086
     +10.0      +17.7422      +0.0116      +0.0008      +26.6132        +0.0030
     +14.6      +12.0707      +0.0132      +0.0012      +14.9064        +0.0016
     +19.9       +8.8711      +0.0144      +0.0016      +10.4709        +0.0011
     +38.6       +4.5786      +0.0156      +0.0023       +6.7248        +0.0012
     +58.5       +3.0237      +0.0179      +0.0048       +3.8012        +0.0024
     +79.3       +2.2301      +0.0212      +0.0099       +2.6269        +0.0033
    +100.7       +1.7549      +0.0243      +0.0161       +1.9925        +0.0031
    +118.4       +1.4932      +0.0265      +0.0214       +1.6240        +0.0022
    +148.6       +1.1898      +0.0294      +0.0299       +1.3415        +0.0028
    +200.5       +0.8817      +0.0335      +0.0460       +1.0358        +0.0042
    +249.1       +0.7097      +0.0356      +0.0566       +0.7957        +0.0021
    +303.8       +0.5819      +0.0364      +0.0612       +0.6458        +0.0007
    +351.6       +0.5027      +0.0370      +0.0661       +0.5423        +0.0007
    +404.4       +0.4371      +0.0376      +0.0712       +0.4699        +0.0006
    +454.2       +0.3892      +0.0382      +0.0764       +0.4132        +0.0005
    +506.0       +0.3494      +0.0387      +0.0822       +0.3693        +0.0005
    +599.8       +0.2947      +0.0395      +0.0921       +0.3221        +0.0008
    +702.3       +0.2517      +0.0402      +0.1030       +0.2732        +0.0007
    +802.0       +0.2204      +0.0408      +0.1132       +0.2361        +0.0006
    +902.6       +0.1959      +0.0415      +0.1261       +0.2081        +0.0007
    +997.3       +0.1772      +0.0420      +0.1362       +0.1866        +0.0005
   +1110.6       +0.1592      +0.0425      +0.1491       +0.1682        +0.0005
   +1204.4       +0.1468      +0.0429      +0.1596       +0.1530        +0.0004
   +1312.8       +0.1347      +0.0434      +0.1731       +0.1407        +0.0005
   +1406.6       +0.1257      +0.0437      +0.1835       +0.1302        +0.0003
   +1495.5       +0.1182      +0.0441      +0.1967       +0.1219        +0.0004
   +1609.8       +0.1098      +0.0445      +0.2086       +0.1140        +0.0003
   +1699.6       +0.1040      +0.0448      +0.2212       +0.1069        +0.0003
   +1805.1       +0.0979      +0.0452      +0.2346       +0.1010        +0.0003
   +1997.6       +0.0885      +0.0457      +0.2578       +0.0932        +0.0005
   +2200.7       +0.08[illegible]      +0.0462      +0.2834       +0.0844        +0.0005
   +2397.1       +0.0737      +0.0467      +0.3046       +0.0770        +0.0004
   +2598.9       +0.0680      +0.0470      +0.3239       +0.0709        +0.0003
   +2786.0       +0.0634      +0.0473      +0.3405       +0.0657        +0.0003
   +2987.0       +0.0592      +0.0475      +0.3584       +0.0613        +0.0003
   +3199.3       +0.0553      +0.0478      +0.3775       +0.0572        +0.000
   +3400.8       +0.0520      +0.0480      +0.3880       +0.0536        +0.000
   +3584.5       +0.0493      +0.0482      +0.4042       +0.0506        +0.000
   +3814.9       +0.0463      +0.0483      +0.4160       +0.0478        +0.000
   +3993.8       +0.0443      +0.0484      +0.4282       +0.0453        +0.000
   +4500.4       +0.0393      +0.0487      +0.4488       +0.0418        +0.000
   +5022.0       +0.0352      +0.0489      +0.4717       +0.0372        +0.000
   +5513.8       +0.0321      +0.0490      +0.4888       +0.0336        +0.000
   +6020.4       +0.0294      +0.0490      +0.4903       +0.0307        +0.000
   +6512.2       +0.0271      +0.0491      +0.5010       +0.0283        +0.000
   +7033.8       +0.0251      +0.0492      +0.5125       +0.0261        +0.000
   +7540.4       +0.0234      +0.0492      +0.5139       +0.0243        +0.000
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                       MICROMERITICS AUTO-PORE 9200 V2.01                        PAGE 3

                                                                    LP 11:1:11 8/16/85
HITEMP-SORBENT                                                      HP 11:18:58 8/16/85
MISSISSIPPI LIMESTONE: 16/18 MESH UNCALCINED
PNTR NUMBER  +381

  PRESSURE        PORE        INTRUSION      PORE         MEAN
    PSIA        DIAMETER       VOLUME       SURFACE      DIAMETER          DV
                MICRO-M         CC/G        SQ-M/G       MICRO-M

   +8002.4      +0.0221       +0.0492      +0.5151      +0.0228      +0.0000
   +8956.1      +0.0197       +0.0492      +0.5174      +0.0209      +0.0000
   +9984.4      +0.0177       +0.0492      +0.5197      +0.0187      +0.0000
  +10953.0      +0.0161       +0.0492      +0.5218      +0.0169      +0.0000
  +11996.2      +0.0147       +0.0492      +0.5238      +0.0154      +0.0000
  +12964.8      +0.0136       +0.0493      +0.5442      +0.0142      +0.0001
  +13948.3      +0.0127       +0.0493      +0.5442      +0.0132      +0.0000
  +14946.8      +0.0118       +0.0493      +0.5475      +0.0123      +0.0000
  +15960.1      +0.0111       +0.0493      +0.5475      +0.0115      +0.0000
  +17092.7      +0.0103       +0.0493      +0.5475      +0.0107      +0.0000
  +18150.7      +0.0097       +0.0493      +0.5475      +0.0100      +0.0000
  +19164.1      +0.0092       +0.0493      +0.5475      +0.0095      +0.0000
  +19909.2      +0.0089       +0.0493      +0.5475      +0.0091      +0.0000
  +24961.0      +0.0071       +0.0493      +0.5475      +0.0080      +0.0000
  +29923.3      +0.0059       +0.0493      +0.5475      +0.0065      +0.0000
  +35273.2      +0.0050       +0.0493      +0.5475      +0.0055      +0.0000
  +40354.8      +0.0044       +0.0493      +0.5475      +0.0047      +0.0000
  +45242.7      +0.0039       +0.0493      +0.5475      +0.0041      +0.0000
  +50175.2      +0.0035       +0.0493      +0.5475      +0.0037      +0.0000
  +54943.9      +0.0032       +0.0493      +0.5475      +0.0034      +0.0000
  +59831.8      +0.0030       +0.0493      +0.5475      +0.0031      +0.0000
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                    MICROMERITICS AUTO-PORE 9200 V2.01                     PAGE 4

HITEMP-SORBENT                                                  LP 11:1:11 8/16/85
MISSISSIPPI LIMESTONE: 16/18 MESH UNCALCINED                    HP 11:18:58 8/16/85
PNTR NUMBER  +381
```
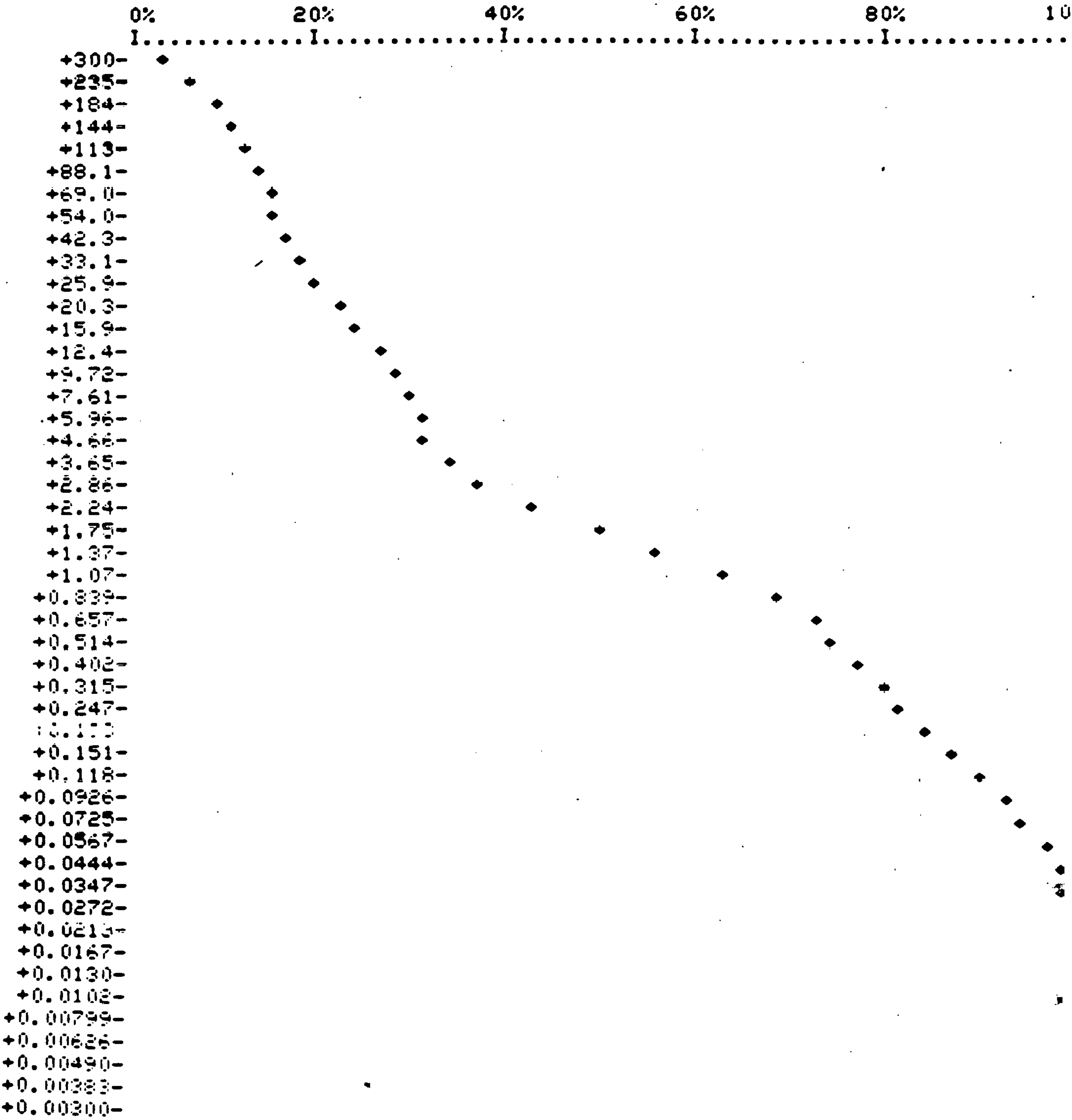

CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
100% = +0.0493



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HITEMP-SORBENT                                        LP 11:1:11 8/16/85
MISSISSIPPI LIMESTONE: 16/18 MESH UNCALCINED          HP 11:18:58 8/16/85
PNTR NUMBER   +381

              CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
                                   100% =     +0.5474

         0%         20%          40%          60%          80%          100%
         I............I............I............I............I............I
    +300-◆
    +235-◆
    +184-◆
    +144-◆
    +113-◆
   +88.1-◆
   +69.0-◆
   +54.0-◆
   +42.3-◆
   +33.1-◆
   +25.9-◆
   +20.3-◆
   +15.9-◆
   +12.4-◆
   +9.72-◆
   +7.61-◆
   +5.96-◆
   +4.66-◆
   +3.65-◆
   +2.86-◆
   +2.24-◆
   +1.75- ◆
   +1.37-  ◆
   +1.07-    ◆
  +0.839-     ◆
  +0.657-      ◆
  +0.514-       ◆
  +0.402-         ◆
  +0.315-          ◆
  +0.247-           ◆
  +0.193-              ◆
  +0.151-                  ◆
  +0.118-                       ◆
 +0.0926-                             ◆
 +0.0725-                                    ◆
 +0.0567-                                           ◆
 +0.0444-                                                   ◆
 +0.0347-                                                         ◆
 +0.0272-                                                           ◆
 +0.0213-                                                             ◆
 +0.0167-                                                              ◆
 +0.0130-                                                                 ◆
 +0.0102-                                                                 ◆
+0.00799-                                                                 ◆
+0.00626-                                                                 ◆
+0.00490-                                                                 ◆
+0.00383-                                                                 ◆
+0.00300-                                                                 ◆
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HITEMP-SORBENT                                            LP 11:1:11 8/16/85
MISSISSIPPI LIMESTONE; 16/18 MESH UNCALCINED              HP 11:18:58 8/16/85
PNTR NUMBER   +381

              DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                                 100% = +0.839070E-002

         0%          20%           40%           60%           80%          10
         I............I.............I.............I.............I.............
    +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +15.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +12.4-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +9.72-◆◆◆◆◆◆◆◆◆◆◆
   +7.61-◆◆◆◆◆◆◆◆◆◆
   +5.96-◆◆◆◆◆◆◆◆◆◆
   +4.66-◆◆◆◆◆◆◆◆◆◆
   +3.65-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +2.86-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +2.24-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.75-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.37-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.07-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆◆◆
  +0.402-◆◆◆◆◆
  +0.315-◆◆◆◆◆◆
  +0.247-◆◆◆◆◆◆
  +0.193-◆◆◆◆◆
  +0.151-◆◆◆◆
  +0.118-◆◆◆
 +0.0926-◆◆◆◆
 +0.0725-◆◆◆
 +0.0567-◆◆
 +0.0444-◆
 +0.0347-◆◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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HITEMP-SORBENT                                             LP 11:1:11 8/16/85
MISSISSIPPI LIMESTONE; 16/18 MESH UNCALCINED               HP 11:18:58 8/16/85
PNTP NUMBER  +381

          DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                           100% = +0.220400E-001

         0%           20%           40%           60%           80%           10
         I.............I.............I.............I.............I.............
    +300-◆
    +235-◆
    +184-◆
    +144-◆
    +113-◆
   +88.1-◆
   +69.0-◆
   +54.0-◆
   +42.3-◆
   +33.1-◆
   +25.9-◆
   +20.3-◆
   +15.9-◆
   +12.4-◆
   +9.72-◆
   +7.61-◆◆
   +5.96-◆◆
   +4.66-◆◆
   +3.65-◆◆◆◆◆◆
   +2.86-◆◆◆◆◆◆◆◆◆◆
   +2.24-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.75-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.37-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.07-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.402-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.315-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.247-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.193-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.151-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.118-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0926-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0444-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0347-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0272-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0213-◆◆◆◆◆
 +0.0167-◆◆◆◆◆◆◆
 +0.0130-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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                  MICROMERITICS AUTO-PORE 9200 V2.01                   PAGE 1

HITEMP-SORBENT                                              LP 11:25:48 8/15/85
GREER LIMESTONE; 16/18 MESH UNCALCINED                      HP 11:59:34 8/15/85
PNTR NUMBER  +382

   LP EQUILIBRATION =   +15.0000 SEC        PNTR CONSTANT =   +10.7900 MICRO-L/
   HP EQUILIBRATION =   +10.0000 SEC                THETA = +130.0000
      SAMPLE WEIGHT =    +4.0100 G                  GAMMA =  +485.0000 DYNES/CM
        PNTR WEIGHT =   +77.2000 G       INITIAL PRESSURE =    +0.9524 PSIA
 PNTR+SAMPLE WEIGHT =   +81.2100 G          PORE DIAMETER =  +185.6100 MICRO-M
PNTR+SAMPLE+MERCURY =  +105.3300 G        MERCURY DENSITY =   +13.5335 G/CC
        PNTR VOLUME =    +3.4120 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =    +0.0348 CC/G
               TOTAL PORE AREA =    +0.4693 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =    +2.5948 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =    +0.0285 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =    +0.2967 MICROMETERS
                  BULK DENSITY =    +2.4605 G/CC
   APPARENT (SKELETAL) DENSITY =    +2.6910 G/CC

% CAPILLARY =  +36.3562
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                 MICROMERITICS AUTO-PORE 9200 V2.01                     PAGE 2

HITEMP-SORBENT                                                  LP 11:25:48 8/15/85
GREER LIMESTONE; 16/18 MESH UNCALCINED                          HP 11:59:34 8/15/85
PNTR NUMBER  +382

 PRESSURE      PORE      INTRUSION      PORE        MEAN
   PSIA      DIAMETER     VOLUME      SURFACE     DIAMETER          DV
             MICRO-M       CC/G        SQ-M/G      MICRO-M

     +5.0    +35.6416    +0.0116     +0.0004    +110.6260        +0.0116
     +9.9    +17.7683    +0.0141     +0.0008     +26.7049        +0.0025
    +14.6    +12.0888    +0.0151     +0.0011     +14.9286        +0.0010
    +19.9     +8.8678    +0.0158     +0.0014     +10.4783        +0.0008
    +39.3     +4.4934    +0.0164     +0.0017      +6.6806        +0.0006
    +58.5     +3.0199    +0.0171     +0.0024      +3.7566        +0.0007
    +79.8     +2.2157    +0.0177     +0.0034      +2.6178        +0.0007
    +99.6     +1.7742    +0.0183     +0.0046      +1.9950        +0.0006
   +119.6     +1.4776    +0.0190     +0.0062      +1.6259        +0.0007
   +150.2     +1.1770    +0.0204     +0.0106      +1.3273        +0.0015
   +201.2     +0.8786    +0.0255     +0.0303      +1.0278        +0.0051
   +252.0     +0.7014    +0.0279     +0.0423      +0.7900        +0.0024
   +303.8     +0.5819    +0.0285     +0.0465      +0.6417        +0.0007
   +350.7     +0.5041    +0.0290     +0.0499      +0.5430        +0.0005
   +401.5     +0.4403    +0.0294     +0.0533      +0.4722        +0.0004
   +454.2     +0.3892    +0.0297     +0.0566      +0.4147        +0.0003
   +498.2     +0.3548    +0.0299     +0.0588      +0.3720        +0.0002
   +600.7     +0.2943    +0.0304     +0.0646      +0.3246        +0.0005
   +701.3     +0.2520    +0.0307     +0.0687      +0.2732        +0.0003
   +800.0     +0.2210    +0.0310     +0.0733      +0.2365        +0.0003
   +897.7     +0.1969    +0.0312     +0.0773      +0.2089        +0.0002
   +997.3     +0.1772    +0.0313     +0.0804      +0.1871        +0.0001
  +1094.0     +0.1616    +0.0315     +0.0838      +0.1694        +0.0001
  +1202.4     +0.1470    +0.0316     +0.0875      +0.1543        +0.0001
  +1301.1     +0.1359    +0.0317     +0.0914      +0.1414        +0.0001
  +1400.7     +0.1262    +0.0318     +0.0937      +0.1310        +0.0001
  +1507.2     +0.1173    +0.0320     +0.0984      +0.1217        +0.0001
  +1603.9     +0.1102    +0.0320     +0.1010      +0.1137        +0.0001
  +1704.5     +0.1037    +0.0321     +0.1037      +0.1070        +0.0001
  +1802.2     +0.0981    +0.0323     +0.1093      +0.1009        +0.0001
  +1989.7     +0,0888    +0.0323     +0.1127      +0.0935        +0.0001
  +2189.0     +0.0808    +0.0324     +0.1164      +0.0848        +0.0001
  +2391.2     +0.0739    +0.0326     +0.1239      +0.0773        +0.0001
  +2619.3     +0.0675    +0.0326     +0.1246      +0.0707        +0.0000
  +2797.1     +0.0632    +0.0326     +0.1293      +0.0653        +0.0001
  +2991.7     +0.0591    +0.0327     +0.1342      +0.0611        +0.0001
  +3185.3     +0.0555    +0.0328     +0.1394      +0.0573        +0.0001
  +3396.0     +0.0521    +0.0329     +0.1450      +0.0538        +0.0001
  +3582.8     +0.0493    +0.0329     +0.1457      +0.0507        +0.0000
  +3814.9     +0.0463    +0.0330     +0.1519      +0.0478        +0.0001
  +3993.8     +0.0443    +0.0330     +0.1525      +0.0453        +0.0000
  +4485.5     +0.0394    +0.0331     +0.1666      +0.0418        +0.0001
  +4992.2     +0.0354    +0.0333     +0.1823      +0.0374        +0.0001
  +5498.9     +0.0321    +0.0334     +0.1994      +0.0338        +0.0001
  +6005.5     +0.0294    +0.0336     +0.2265      +0.0308        +0.0002
  +6497.3     +0.0272    +0.0337     +0.2464      +0.0283        +0.0001
  +7004.0     +0.0252    +0.0340     +0.2779      +0.0262        +0.0002
  +7495.7     +0.0236    +0.0340     +0.2900      +0.0244        +0.0001
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HITEMP-SORBENT                                                LP 11:25:48 8/15/85
GREER LIMESTONE: 16/18 MESH UNCALCINED                        HP 11:59:34 8/15/85
PNTR NUMBER   +382

  PRESSURE        PORE        INTRUSION       PORE          MEAN
    PSIA        DIAMETER       VOLUME       SURFACE       DIAMETER          DV
                 MICRO-M        CC/G         SQ-M/G        MICRO-M

   +8002.4      +0.0221       +0.0342      +0.3143       +0.0228         +0.0001
   +9015.8      +0.0196       +0.0344      +0.3545       +0.0209         +0.0002
  +10014.2      +0.0177       +0.0345      +0.3850       +0.0186         +0.0001
  +10953.0      +0.0161       +0.0346      +0.4025       +0.0169         +0.0001
  +11981.3      +0.0148       +0.0347      +0.4216       +0.0154         +0.0001
  +12964.8      +0.0136       +0.0347      +0.4234       +0.0142         +0.0000
  +13978.1      +0.0126       +0.0347      +0.4251       +0.0131         +0.0000
  +14931.9      +0.0118       +0.0348      +0.4695       +0.0122         +0.0001
  +15915.4      +0.0111       +0.0348      +0.4695       +0.0115         +0.0000
  +17062.9      +0.0104       +0.0348      +0.4695       +0.0107         +0.0000
  +18135.8      +0.0097       +0.0348      +0.4695       +0.0101         +0.0000
  +19134.2      +0.0092       +0.0348      +0.4695       +0.0095         +0.0000
  +20102.9      +0.0088       +0.0348      +0.4695       +0.0090         +0.0000
  +24901.4      +0.0071       +0.0348      +0.4695       +0.0079         +0.0000
  +29878.6      +0.0059       +0.0348      +0.4695       +0.0065         +0.0000
  +34960.3      +0.0051       +0.0348      +0.4695       +0.0055         +0.0000
  +40161.1      +0.0044       +0.0348      +0.4695       +0.0047         +0.0000
  +45078.8      +0.0039       +0.0348      +0.4695       +0.0042         +0.0000
  +49966.6      +0.0035       +0.0348      +0.4695       +0.0037         +0.0000
  +54780.0      +0.0032       +0.0348      +0.4695       +0.0034         +0.0000
  +59712.6      +0.0030       +0.0348      +0.4695       +0.0031         +0.0000
```

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                 MICROMERITICS AUTO-PORE 9200 V2.01                 PAGE 4

HITEMP-SORBENT                                            LP 11:25:48 8/15/85
GREER LIMESTONE: 16/18 MESH UNCALCINED                    HP 11:59:34 8/15/85
PNTR NUMBER  +382

           CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
                          100% =     +0.0348
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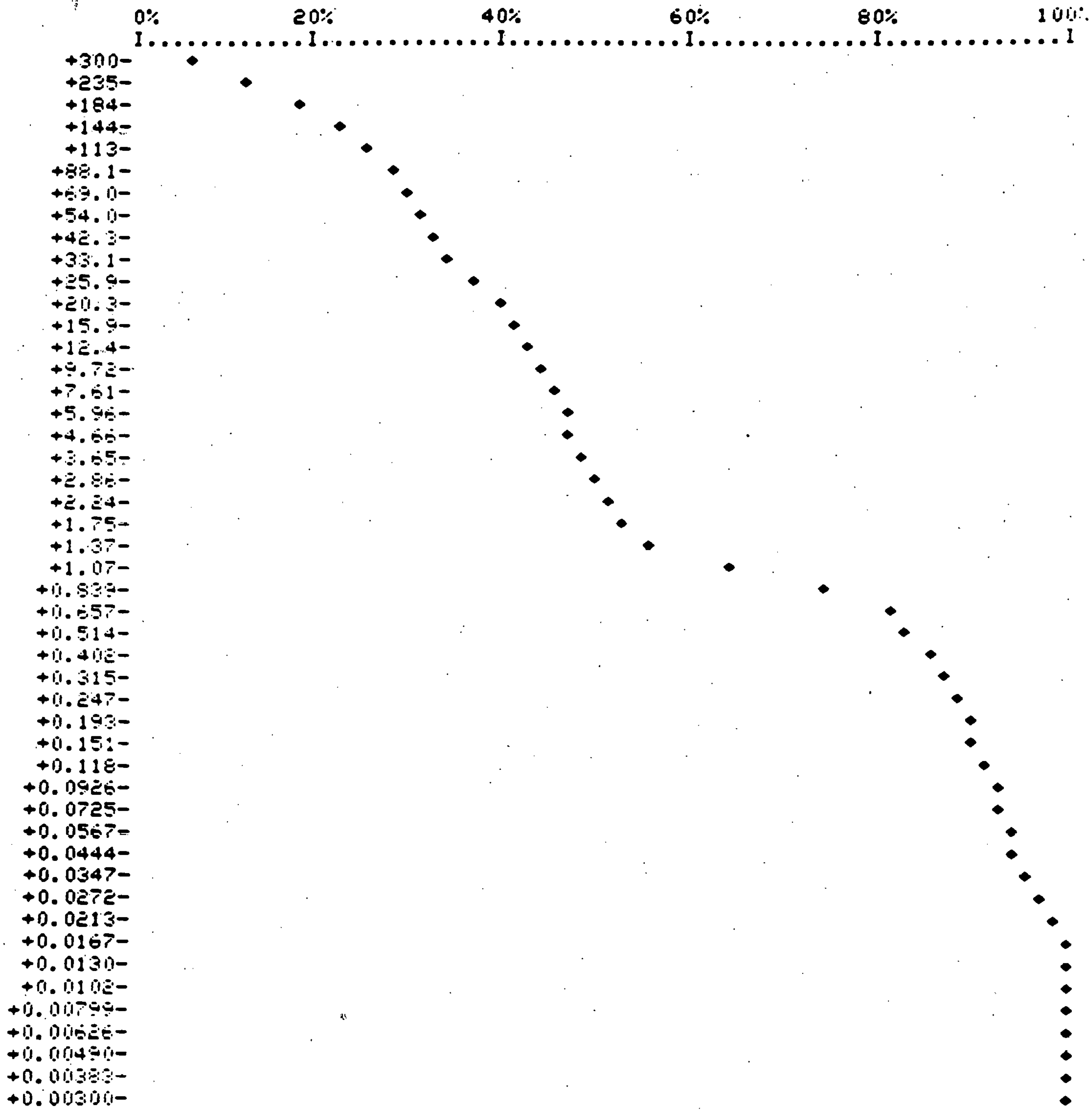

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HITEMP-SORBENT                                        LP 11:25:48 8/15/85
GREER LIMESTONE: 16/18 MESH UNCALCINED                HP 11:59:34 8/15/85
PNTR NUMBER  +382
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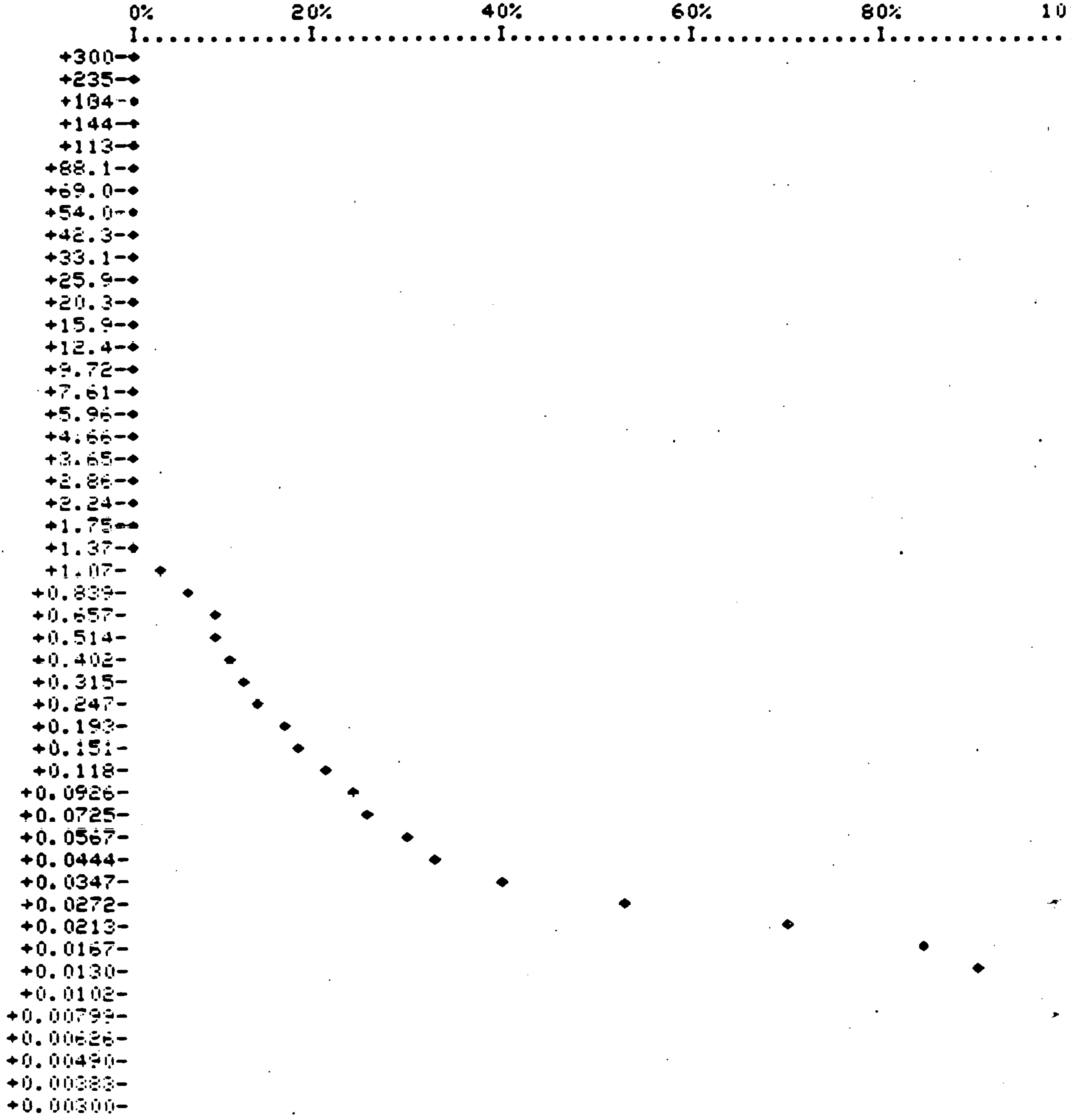
CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
100% = +0.4693



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                    MICROMERITICS AUTO-PORE 9200 V2.01                    PAGE 6

HITEMP-SORBENT                                               LP 11:25:48 8/15/85
GREER LIMESTONE: 16/18 MESH UNCALCINED                       HP 11:59:34 8/15/85
PNTR NUMBER  +382

             DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                                100% = +0.113364E-001

         0%          20%           40%           60%           80%          100%
         I............I.............I.............I.............I.............I
    +300-+++++++++++++++
    +235-+++++++++++++++++++++++++++++
    +184-++++++++++++++++++++++++++++++++++++++++
    +144-++++++++++++++++++++++++++++++++++++++++++++++++
    +113-+++++++++++++++++++++++++++++++++++++++++++++++++++++++
   +88.1-++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   +69.0-++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   +54.0-+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   +42.3-++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   +33.1-+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   +25.9-+++++++++++++++++++++++++++++++++++++++++
   +20.3-+++++++++++++++++++++++
   +15.9-++++++++++++
   +12.4-+++++++
   +9.72-+++++
   +7.61-++++
   +5.96-++++
   +4.66-+++
   +3.65-++++
   +2.86-++++
   +2.24-++++
   +1.75-++++
   +1.37-++++++
   +1.07-+++++++++++++++++
  +0.839-++++++++++++++++++++++++++++
  +0.657-+++++++++++
  +0.514-+++
  +0.402-++
  +0.315-++
  +0.247-++
  +0.193-+
  +0.151-+
  +0.118-+
 +0.0926-+
 +0.0725-+
 +0.0567-+
 +0.0444-+
 +0.0347-+
 +0.0272-+
 +0.0213-+
 +0.0167-+
 +0.0130-+
 +0.0102-+
+0.00799-+
+0.00626-+
+0.00490-+
+0.00383-+
+0.00300-+
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                 MICROMERITICS AUTO-PORE 9200 V2.01

HITEMP-SORBENT                                          LP 11:25:48 8/15/85
GREER LIMESTONE: 16/18 MESH UNCALCINED                  HP 11:59:34 8/15/85
PNTR NUMBER  +382

            DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                              100% = +0.294610E-001

         0%          20%           40%           60%           80%           10
         I............I.............I.............I.............I.............I
     +300-◆
     +235-◆
     +184-◆
     +144-◆
     +113-◆
    +88.1-◆
    +69.0-◆
    +54.0-◆
    +42.3-◆
    +33.1-◆
    +25.9-◆
    +20.3-◆
    +15.9-◆
    +12.4-◆
    +9.72-◆
    +7.61-◆
    +5.96-◆
    +4.66-◆
    +3.65-◆
    +2.86-◆◆
    +2.24-◆◆
    +1.75-◆◆◆
    +1.37-◆◆◆◆◆◆
    +1.07-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.514-◆◆◆◆◆◆◆◆
   +0.402-◆◆◆◆◆◆◆◆
   +0.315-◆◆◆◆◆◆◆◆◆◆◆
   +0.247-◆◆◆◆◆◆◆◆◆◆
   +0.193-◆◆◆◆◆◆◆◆◆
   +0.151-◆◆◆◆◆◆◆◆◆
   +0.118-◆◆◆◆◆◆◆◆◆◆
  +0.0926-◆◆◆◆◆◆◆◆◆◆
  +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆
  +0.0444-◆◆
  +0.0347-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆o
  +0.0272-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.0213-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.0167-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.0130-◆◆◆◆
  +0.0102-◆
 +0.00799-◆
 +0.00626-◆
 +0.00490-◆
 +0.00383-◆
 +0.00300-◆
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                  MICROMERITICS AUTO-PORE 9200 V2.01                       PAGE 1

HITEMP-SORBENT                                                   LP 11:25:48 8/15/85
PLUM RUN DOLOMITE (GR&LT LEDGE):  16/18 MESH UNC                 HP 13:14:19 8/15/85
PNTR NUMBER  +383

   LP EQUILIBRATION =   +15.0000 SEC        PNTR CONSTANT =   +10.7900 MICRO-L/
   HP EQUILIBRATION =   +10.0000 SEC                THETA =  +130.0000
      SAMPLE WEIGHT =    +4.0100 G                  GAMMA =  +485.0000 DYNES/CM
        PNTR WEIGHT =   +75.9400 G       INITIAL PRESSURE =    +0.9524 PSIA
 PNTR+SAMPLE WEIGHT =   +79.9500 G          PORE DIAMETER =  +185.6100 MICRO-M
PNTR+SAMPLE+MERCURY =  +111.1600 G        MERCURY DENSITY =   +13.5335 G/CC
        PNTR VOLUME =    +3.8550 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =     +0.0425 CC/G
               TOTAL PORE AREA =     +0.4300 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =    +14.4043 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =     +0.0408 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =     +0.3958 MICROMETERS
                  BULK DENSITY =     +2.5890 G/CC
   APPARENT (SKELETAL) DENSITY =     +2.9095 G/CC

% CAPILLARY =  +44.4326
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                 MICROMERITICS AUTO-PORE 9200 V2.01                          PAGE 2

HITEMP-SORBENT                                                    LP 11:25:48 8/15/85
PLUM RUN DOLOMITE (GF&LT LEDGE): 16/18 MESH UNC                   HP 13:14:19 8/15/85
PNTR NUMBER  +383

  PRESSURE       PORE       INTRUSION      PORE         MEAN
    PSIA       DIAMETER      VOLUME       SURFACE     DIAMETER          DV
               MICRO-M        CC/G        SQ-M/G      MICRO-M

      +5.0    +35.6416      +0.0172      +0.0006    +110.6260       +0.0172
      +9.9    +17.7683      +0.0199      +0.0010     +26.7049       +0.0028
     +14.6    +12.0888      +0.0222      +0.0017     +14.9286       +0.0023
     +19.9     +8.8678      +0.0241      +0.0024     +10.4783       +0.0019
     +40.0     +4.4193      +0.0256      +0.0033      +6.6436       +0.0015
     +59.0     +2.9937      +0.0276      +0.0054      +3.7065       +0.0020
     +79.0     +2.2383      +0.0290      +0.0075      +2.6160       +0.0014
     +99.9     +1.7703      +0.0299      +0.0094      +2.0043       +0.0009
    +121.3     +1.4571      +0.0306      +0.0112      +1.6137       +0.0007
    +150.3     +1.1765      +0.0316      +0.0140      +1.3168       +0.0009
    +200.3     +0.8626      +0.0335      +0.0217      +1.0295       +0.0020
    +248.1     +0.7125      +0.0348      +0.0280      +0.7975       +0.0013
    +303.8     +0.5819      +0.0353      +0.0313      +0.6472       +0.0005
    +353.6     +0.4999      +0.0357      +0.0343      +0.5409       +0.0004
    +398.5     +0.4436      +0.0361      +0.0371      +0.4717       +0.0003
    +449.3     +0.3934      +0.0363      +0.0397      +0.4185       +0.0003
    +498.2     +0.3548      +0.0366      +0.0426      +0.3741       +0.0003
    +601.7     +0.2938      +0.0371      +0.0484      +0.3243       +0.0005
    +699.4     +0.2528      +0.0375      +0.0544      +0.2733       +0.0004
    +798.0     +0.2215      +0.0378      +0.0602      +0.2371       +0.0003
    +900.6     +0.1963      +0.0381      +0.0654      +0.2089       +0.0003
    +996.3     +0.1774      +0.0384      +0.0713      +0.1869       +0.0003
   +1107.7     +0.1596      +0.0386      +0.0763      +0.1685       +0.0002
   +1207.3     +0.1464      +0.0388      +0.0817      +0.1530       +0.0002
   +1309.9     +0.1350      +0.0389      +0.0857      +0.1407       +0.0001
   +1402.7     +0.1260      +0.0391      +0.0920      +0.1305       +0.0002
   +1500.4     +0.1178      +0.0392      +0.0945      +0.1219       +0.0001
   +1599.0     +0.1105      +0.0394      +0.1017      +0.1142       +0.0002
   +1698.7     +0.1041      +0.0395      +0.1044      +0.1073       +0.0001
   +1793.4     +0.0986      +0.0396      +0.1099      +0.1013       +0.0001
   +1995.6     +0.0886      +0.0398      +0.1190      +0.0936       +0.0002
   +2189.0     +0.0808      +0.0401      +0.1289      +0.0847       +0.0002
   +2387.3     +0.0740      +0.0403      +0.1398      +0.0774       +0.0002
   +2615.9     +0.0676      +0.0403      +0.1442      +0.0708       +0.0001
   +2797.6     +0.0632      +0.0405      +0.1529      +0.0654       +0.0001
   +2989.2     +0.0591      +0.0406      +0.1621      +0.0612       +0.0001
   +3198.6     +0.0553      +0.0408      +0.1720      +0.0572       +0.0001
   +3386.8     +0.0522      +0.0409      +0.1824      +0.0537       +0.0001
   +3594.6     +0.0492      +0.0410      +0.1883      +0.0507       +0.0001
   +3829.8     +0.0462      +0.0411      +0.1946      +0.0477       +0.0001
   +3993.8     +0.0443      +0.0411      +0.2009      +0.0452       +0.0001
   +4485.5     +0.0394      +0.0413      +0.2214      +0.0418       +0.0002
   +4992.2     +0.0354      +0.0416      +0.2440      +0.0374       +0.0002
   +5484.0     +0.0322      +0.0416      +0.2533      +0.0338       +0.0001
   +5990.6     +0.0295      +0.0418      +0.2803      +0.0309       +0.0002
   +6512.2     +0.0271      +0.0419      +0.2911      +0.0283       +0.0001
   +7004.0     +0.0252      +0.0421      +0.3125      +0.0262       +0.0001
   +7510.6     +0.0235      +0.0421      +0.3138      +0.0244       +0.0000
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                 MICROMERITICS AUTO-PORE 9200 V2.01                       PAGE 3

HITEMP-SORBENT                                                    LP 11:25:48 8/15/85
PLUM RUN DOLOMITE (GF&LT LEDGE):  16/12 MESH UNC                  HP 13:14:19 8/15/8
PNTR NUMBER  +383

   PRESSURE        PORE        INTRUSION       PORE          MEAN
     PSIA        DIAMETER       VOLUME       SURFACE       DIAMETER           DV
                  MICRO-M        CC/G         SQ-M/G        MICRO-M

    +8002.4      +0.0221       +0.0421       +0.3266       +0.0228       +0.0001
    +9000.8      +0.0196       +0.0423       +0.3542       +0.0209       +0.0001
    +9999.3      +0.0177       +0.0423       +0.3565       +0.0187       +0.0000
   +10982.8      +0.0161       +0.0424       +0.3741       +0.0169       +0.0001
   +11981.3      +0.0148       +0.0424       +0.3761       +0.0154       +0.0000
   +12949.9      +0.0137       +0.0424       +0.3963       +0.0142       +0.0001
   +13963.2      +0.0127       +0.0425       +0.4180       +0.0132       +0.0001
   +14961.7      +0.0118       +0.0425       +0.4180       +0.0122       +0.0000
   +15960.1      +0.0111       +0.0425       +0.4212       +0.0114       +0.000
   +17048.0      +0.0104       +0.0425       +0.4227       +0.0107       +0.00
   +18076.2      +0.0098       +0.0425       +0.4240       +0.0101       +0.0
   +19059.7      +0.0093       +0.0425       +0.4251       +0.0095       +0.00
   +20073.1      +0.0088       +0.0425       +0.4262       +0.0090       +0.0000
   +24871.5      +0.0071       +0.0425       +0.4303       +0.0080       +0.0000
   +29968.1      +0.0059       +0.0425       +0.4303       +0.0065       +0.0000
   +35079.5      +0.0050       +0.0425       +0.4303       +0.0055       +0.0000
   +39892.8      +0.0044       +0.0425       +0.4303       +0.0047       +0.0000
   +44825.4      +0.0039       +0.0425       +0.4303       +0.0042       +0.0000
   +49936.8      +0.0035       +0.0425       +0.4303       +0.0037       +0.0000
   +54884.3      +0.0032       +0.0425       +0.4303       +0.0034       +0.0000
   +59787.1      +0.0030       +0.0425       +0.4303       +0.0031       +0.0000
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HITEMP-SORBENT                                                   LP 11:25:48 8/15/85
PLUM RUN DOLOMITE (GF&LT LEDGE):  16/18 MESH UNC                 HP 13:14:19 8/15/85
PNTR NUMBER  +383
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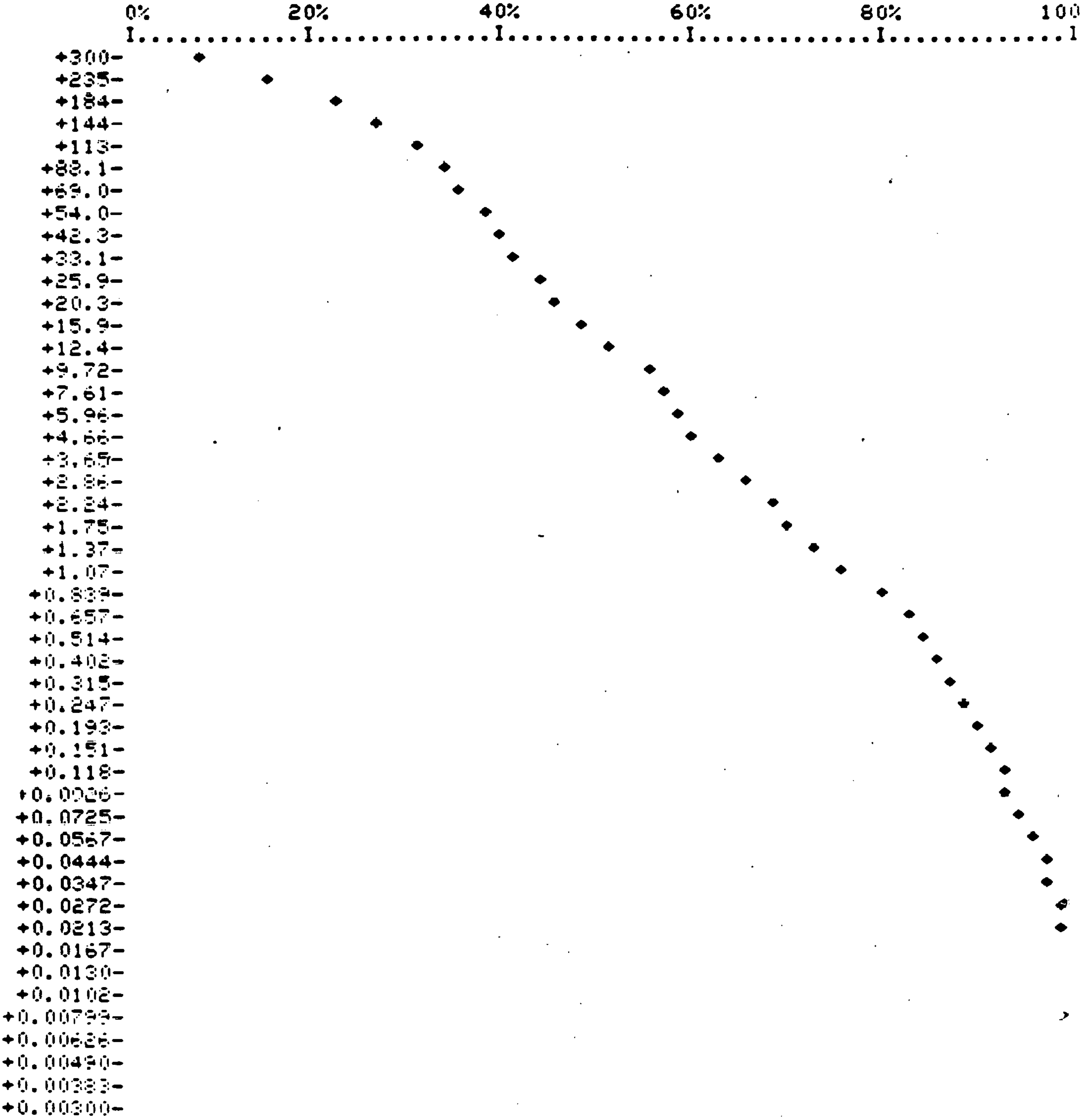
CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
100% =   +0.0425



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HITEMP-SORBENT                                              LP 11:25:48 8/15/85
PLUM RUN DOLOMITE (GF&LT LEDGE);  16/18 MESH UNC            HP 13:14:19 8/15/
PNTR NUMBER   +383

              CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
                                 100% =      +0.4300
```

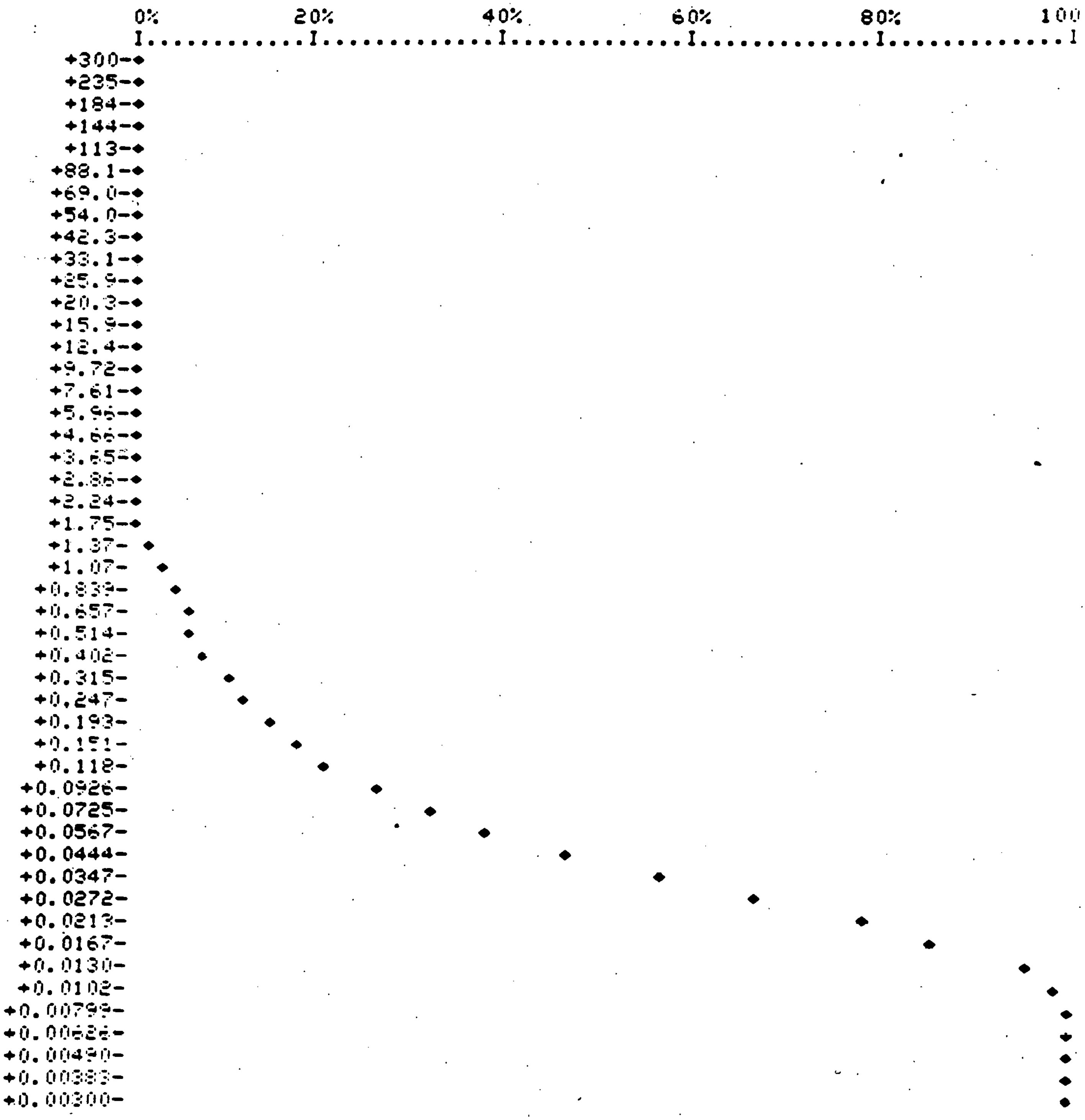

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                  MICROMERITICS AUTO-PORE 9200 V2.01                  PAGE 6

HITEMP-SORBENT                                             LP 11:25:48 8/15/85
PLUM RUN DOLOMITE (GF&LT LEDGE);  16/18 MESH UNC           HP 13:14:19 8/15/85
PNTR NUMBER  +383

             DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                                  100% = +0.168108E-001

         0%          20%           40%           60%           80%          10
         I............I.............I.............I.............I.............
    +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +15.9-◆◆◆◆◆◆◆◆◆◆◆
   +12.4-◆◆◆◆◆◆◆◆◆◆
   +9.72-◆◆◆◆◆◆◆◆
   +7.61-◆◆◆◆◆◆◆
   +5.96-◆◆◆◆◆◆◆
   +4.66-◆◆◆◆◆◆
   +3.65-◆◆◆◆◆◆◆
   +2.86-◆◆◆◆◆◆◆◆
   +2.24-◆◆◆◆◆◆
   +1.75-◆◆◆◆
   +1.37-◆◆◆
   +1.07-◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆
  +0.657-◆◆◆◆
  +0.514-◆◆
  +0.402-◆
  +0.315-◆◆
  +0.247-◆◆
  +0.193-◆
  +0.151-◆
  +0.118-◆
 +0.0926-◆
 +0.0725-◆
 +0.0567-◆
 +0.0444-◆
 +0.0347-◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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HITEMP-SORBENT                                               LP 11:25:48 8/15/85
PLUM RUN DOLOMITE (GF&LT LEDGE):  16/18 MESH UNC             HP 13:14:19 8/15/85
PNTR NUMBER  +383

            DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                                  100% = +0.211478E-001

                0%           20%           40%           60%           80%           100%
                I.............I.............I.............I.............I.............I
           +300-◆
           +235-◆
           +184-◆
           +144-◆
           +113-◆
          +88.1-◆
          +69.0-◆
          +54.0-◆
          +42.3-◆
          +33.1-◆
          +25.9-◆
          +20.3-◆
          +15.9-◆◆
          +12.4-◆◆
          +9.72-◆◆
          +7.61-◆◆◆
          +5.96-◆◆◆
          +4.66-◆◆◆
          +3.65-◆◆◆◆◆
          +2.86-◆◆◆◆◆◆◆
          +2.24-◆◆◆◆◆◆◆
          +1.75-◆◆◆◆◆◆
          +1.37-◆◆◆◆◆◆◆
          +1.07-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +0.514-◆◆◆◆◆◆◆◆◆◆
         +0.402-◆◆◆◆◆◆◆◆◆
         +0.315-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +0.247-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +0.193-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +0.151-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
         +0.118-◆◆◆◆◆◆◆◆◆
        +0.0926-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0444-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0347-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0272-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0213-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0167-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0130-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
        +0.0102-◆◆◆◆◆
       +0.00799-◆◆◆◆◆◆◆◆
       +0.00626-◆◆◆◆
       +0.00490-◆
       +0.00383-◆
       +0.00300-◆
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                    MICROMERITICS AUTO-PORE 9200 V2.01                          PAGE 1

HITEMP-SORBENT                                                          LP 11:25:48 8/15/85
TYMOCHTEE DOLOMITE: 16/18 MESH UNCALCINED                               HP 11:59:34 8/15/85
PNTR NUMBER  +380

   LP EQUILIBRATION =   +15.0000 SEC         PNTR CONSTANT =  +10.7900 MICRO-L/
   HP EQUILIBRATION =   +10.0000 SEC                 THETA = +130.0000
      SAMPLE WEIGHT =    +5.0100 G                   GAMMA = +485.0000 DYNES/CM
        PNTR WEIGHT =   +74.1600 G        INITIAL PRESSURE =   +0.9524 PSIA
 PNTR+SAMPLE WEIGHT =   +79.1700 G           PORE DIAMETER = +185.6100 MICRO-M
PNTR+SAMPLE+MERCURY =  +127.0000 G         MERCURY DENSITY =  +13.5335 G/CC
        PNTR VOLUME =    +5.5410 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =     +0.0407 CC/G
               TOTAL PORE AREA =     +0.7937 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =     +1.8787 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =     +0.0320 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =     +0.2049 MICROMETERS
                  BULK DENSITY =     +2.4965 G/CC
   APPARENT (SKELETAL) DENSITY =     +2.7785 G/CC

% CAPILLARY =  +53.0477
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                    MICROMERITICS AUTO-PORE 9200 V2.01                      PAGE 2

HITEMP-SORBENT                                                   LP 11:25:48 8/15/8
TYMOCHTEE DOLOMITE: 16/18 MESH UNCALCINED                        HP 11:59:34 8/15/8
PNTR NUMBER  +380

  PRESSURE       PORE       INTRUSION      PORE        MEAN
    PSIA       DIAMETER      VOLUME      SURFACE     DIAMETER            DV
               MICRO-M        CC/G        SQ-M/G      MICRO-M

      +5.0    +35.6416      +0.0116     +0.0004    +110.6260         +0.0116
      +9.9    +17.7683      +0.0137     +0.0007     +26.7049         +0.0022
     +14.6    +12.0888      +0.0146     +0.0010     +14.9286         +0.0009
     +19.9     +8.8678      +0.0161     +0.0015     +10.4783         +0.0015
     +39.3     +4.4934      +0.0167     +0.0019      +6.6806         +0.0006
     +58.5     +3.0199      +0.0181     +0.0034      +3.7566         +0.0014
     +79.8     +2.2157      +0.0195     +0.0055      +2.6178         +0.0014
     +99.6     +1.7742      +0.0206     +0.0078      +1.9950         +0.0011
    +119.6     +1.4776      +0.0216     +0.0102      +1.6259         +0.0010
    +150.2     +1.1770      +0.0229     +0.0140      +1.3273         +0.0013
    +201.2     +0.8786      +0.0259     +0.0259      +1.0278         +0.0031
    +252.0     +0.7014      +0.0280     +0.0364      +0.7900         +0.0021
    +303.8     +0.5819      +0.0287     +0.0410      +0.6417         +0.0007
    +350.7     +0.5041      +0.0294     +0.0457      +0.5430         +0.0006
    +401.5     +0.4403      +0.0299     +0.0506      +0.4722         +0.0006
    +454.2     +0.3892      +0.0305     +0.0558      +0.4147         +0.0005
    +498.2     +0.3548      +0.0308     +0.0598      +0.3720         +0.0004
    +600.7     +0.2943      +0.0316     +0.0697      +0.3246         +0.0008
    +701.3     +0.2520      +0.0323     +0.0791      +0.2732         +0.0006
    +800.0     +0.2210      +0.0328     +0.0881      +0.2365         +0.0005
    +897.7     +0.1969      +0.0333     +0.0964      +0.2089         +0.0004
    +997.3     +0.1772      +0.0337     +0.1056      +0.1871         +0.0004
   +1094.0     +0.1616      +0.0340     +0.1132      +0.1694         +0.0003
   +1202.4     +0.1470      +0.0344     +0.1230      +0.1543         +0.0004
   +1301.1     +0.1359      +0.0347     +0.1306      +0.1414         +0.0003
   +1400.7     +0.1262      +0.0349     +0.1389      +0.1310         +0.0003
   +1507.2     +0.1173      +0.0352     +0.1478      +0.1217         +0.0003
   +1603.9     +0.1102      +0.0354     +0.1554      +0.1137         +0.0002
   +1704.5     +0.1037      +0.0356     +0.1616      +0.1070         +0.0002
   +1802.2     +0.0981      +0.0358     +0.1702      +0.1009         +0.0002
   +1989.7     +0.0888      +0.0361     +0.1841      +0.0935         +0.0003
   +2189.0     +0.0808      +0.0365     +0.1996      +0.0848         +0.0003
   +2391.2     +0.0739      +0.0367     +0.2137      +0.0773         +0.0003
   +2619.3     +0.0675      +0.0369     +0.2262      +0.0707         +0.0002
   +2797.1     +0.0632      +0.0372     +0.2395      +0.0653         +0.0002
   +2991.7     +0.0591      +0.0374     +0.2538      +0.0611         +0.0002
   +3185.3     +0.0555      +0.0375     +0.2654      +0.0573         +0.0002
   +3396.0     +0.0521      +0.0378     +0.2816      +0.0538         +0.0002
   +3582.8     +0.0493      +0.0379     +0.2945      +0.0507         +0.0002
   +3814.9     +0.0463      +0.0380     +0.2995      +0.0478         +0.0001
   +3993.8     +0.0443      +0.0382     +0.3139      +0.0453         +0.0002
   +4485.5     +0.0394      +0.0384     +0.3403      +0.0418         +0.0003
   +4992.2     +0.0354      +0.0387     +0.3697      +0.0374         +0.0003
   +5498.9     +0.0321      +0.0389     +0.3959      +0.0338         +0.0002
   +6005.5     +0.0294      +0.0391     +0.4244      +0.0308         +0.0002
   +6497.3     +0.0272      +0.0393     +0.4478      +0.0283         +0.0002
   +7004.0     +0.0252      +0.0394     +0.4649      +0.0262         +0.0001
   +7495.7     +0.0236      +0.0396     +0.4912      +0.0244         +0.0002
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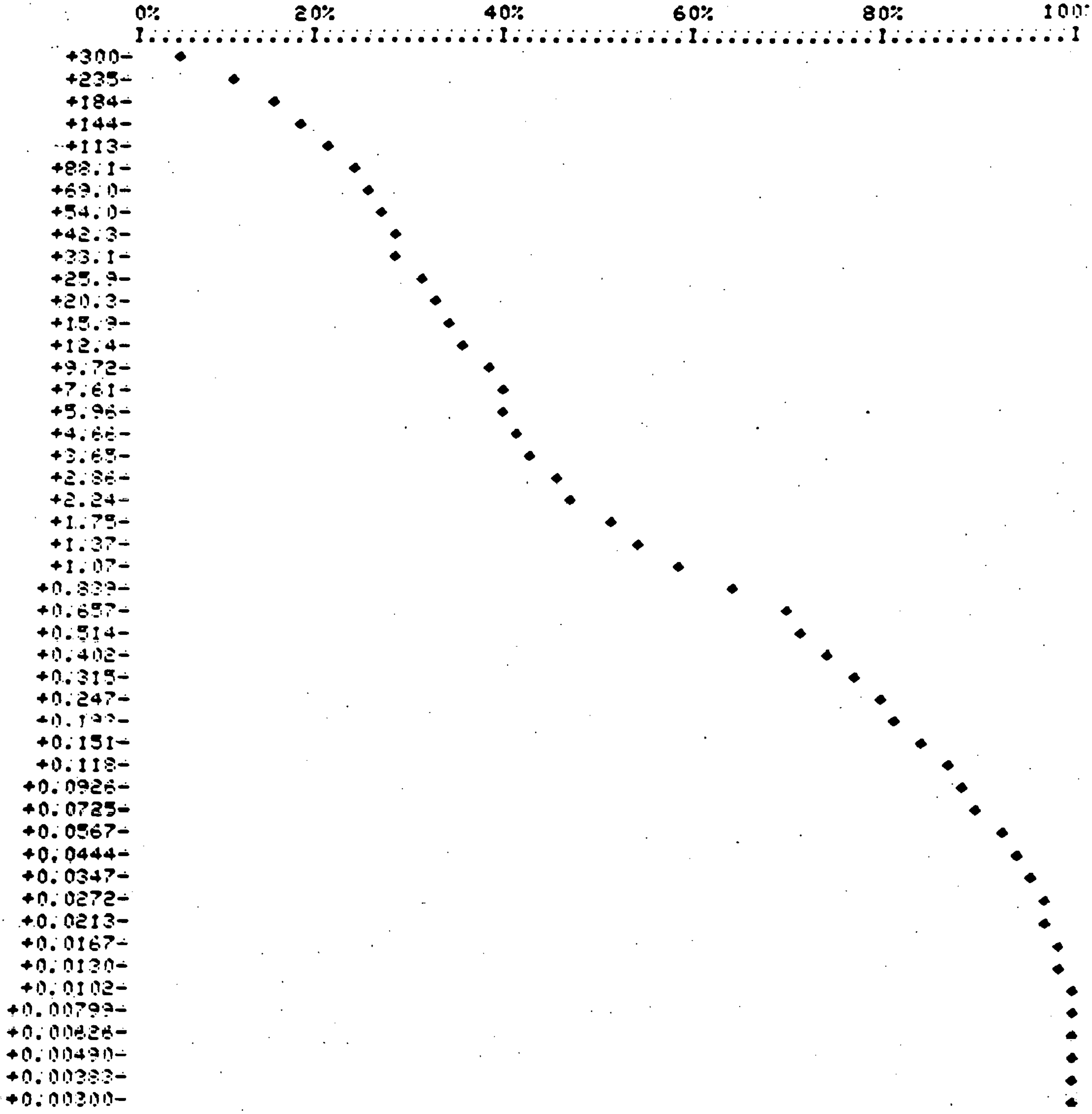
HITEMP-SORBENT LP 11:25:42 8/15/85
TYMOCHTEE DOLOMITE: 16/18 MESH UNCALCINED HP 11:59:34 8/15/85
PNTR NUMBER +380

PRESSURE PSIA	PORE DIAMETER MICRO-M	INTRUSION VOLUME CC/G	PORE SURFACE SQ-M/G	MEAN DIAMETER MICRO-M	DV
+8002.4	+0.0221	+0.0396	+0.4929	+0.0228	+0.0000
+9015.8	+0.0196	+0.0398	+0.5352	+0.0208	+0.0002
+10014.2	+0.0177	+0.0400	+0.5709	+0.0186	+0.0002
+10953.0	+0.0161	+0.0401	+0.5974	+0.0169	+0.0001
+11981.3	+0.0148	+0.0402	+0.6262	+0.0154	+0.0001
+12964.8	+0.0136	+0.0403	+0.6425	+0.0142	+0.0001
+13978.1	+0.0126	+0.0404	+0.6759	+0.0131	+0.0001
+14931.9	+0.0118	+0.0404	+0.6943	+0.0122	+0.0001
+15915.4	+0.0111	+0.0404	+0.6954	+0.0115	+0.0000
+17062.9	+0.0104	+0.0405	+0.7359	+0.0107	+0.0001
+18135.8	+0.0097	+0.0405	+0.7369	+0.0101	+0.0000
+19134.2	+0.0092	+0.0405	+0.7379	+0.0095	+0.0000
+20102.9	+0.0088	+0.0406	+0.7620	+0.0090	+0.0001
+24901.4	+0.0071	+0.0407	+0.7918	+0.0079	+0.0001
+29878.6	+0.0059	+0.0407	+0.7939	+0.0065	+0.0000
+34960.3	+0.0051	+0.0407	+0.7939	+0.0055	+0.0000
+40161.1	+0.0044	+0.0407	+0.7939	+0.0047	+0.0000
+45078.8	+0.0039	+0.0407	+0.7939	+0.0042	+0.0000
+49966.6	+0.0035	+0.0407	+0.7939	+0.0037	+0.0000
+54780.0	+0.0032	+0.0407	+0.7939	+0.0034	+0.0000
+59712.8	+0.0030	+0.0407	+0.7939	+0.0031	+0.0000

HITEMP-SORBENT
TYMOCHTEE DOLOMITE; 16/12 MESH UNCALCINED
PNTR NUMBER +380

LP 11:25:48 8/15/85
HP 11:59:34 8/15/85

CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
100% = +0.0407



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HITEMP-SORBENT                                           LP 11:25:48 8/15/85
TYMOCHTEE DOLOMITE: 16/18 MESH UNCALCINED                HP 11:59:34 8/15/85
PNTR NUMBER  +380
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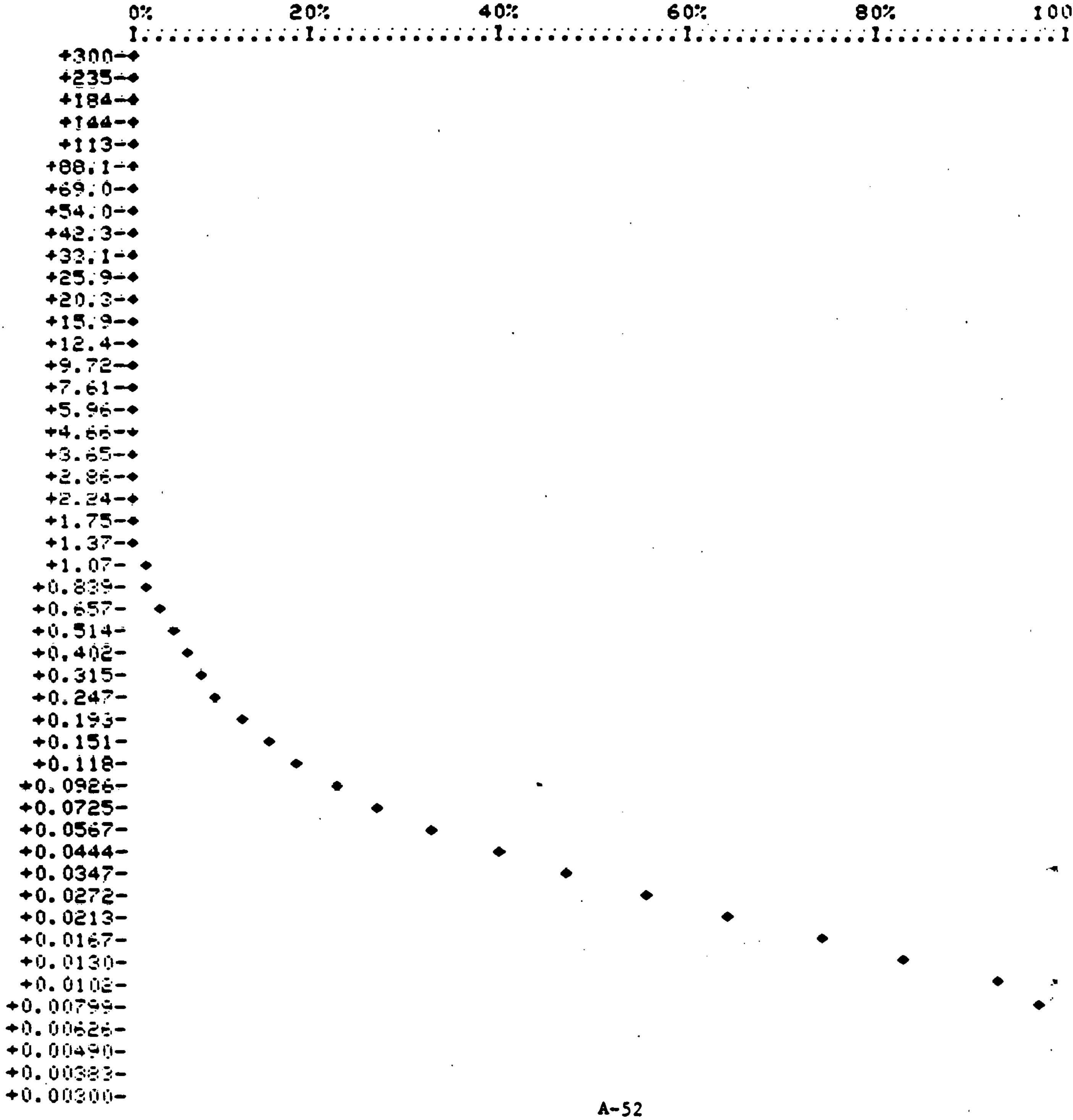
CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
100% = +0.7937



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HITEMP-SORBENT                                               LP 11:25:48 8/15/85
TYMOCHTEE DOLOMITE; 16/18 MESH UNCALCINED                    HP 11:59:34 8/15/85
PNTR NUMBER  +380

             DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                              100% = +0.113418E-001

        0%           20%           40%           60%           80%          100%
        I.............I.............I.............I.............I.............I
    +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +15.9-◆◆◆◆◆◆◆◆◆◆◆
   +12.4-◆◆◆◆◆◆
   +9.72-◆◆◆◆◆◆◆◆
   +7.61-◆◆◆◆◆◆◆◆
   +5.96-◆◆◆◆◆
   +4.66-◆◆◆◆
   +3.65-◆◆◆◆◆◆
   +2.86-◆◆◆◆◆◆◆◆◆
   +2.24-◆◆◆◆◆◆◆◆◆
   +1.75-◆◆◆◆◆◆◆
   +1.37-◆◆◆◆◆◆◆
   +1.07-◆◆◆◆◆◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆
  +0.402-◆◆◆
  +0.315-◆◆◆◆
  +0.247-◆◆◆◆
  +0.197-◆◆◆
  +0.151-◆◆
  +0.118-◆◆
 +0.0926-◆◆
 +0.0725-◆◆
 +0.0567-◆
 +0.0444-◆
 +0.0347-◆◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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                    MICROMERITICS AUTO-PORE 9200 V2.01                        PAGE 7

     HITEMP-SORBENT                                                      LP 11:25:48 8/15/85
     TYMOCHTEE DOLOMITE: 16/18 MESH UNCALCINED                           HP 11:59:34 8/15/85
     PNTR NUMBER   +380

                DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                                     100% = +0.307924E-001

                0%           20%          40%          60%          80%          10
                I............I............I............I............I............
      +300-◆
      +235-◆
      +184-◆
      +144-◆
      +113-◆
     +88.1-◆
     +69.0-◆
     +54.0-◆
     +42.3-◆
     +33.1-◆
     +25.9-◆
     +20.3-◆
     +15.9-◆
     +12.4-◆
     +9.72-◆
     +7.61-◆
     +5.96-◆
     +4.66-◆
     +3.65-◆◆
     +2.86-◆◆◆◆
     +2.24-◆◆◆◆◆
     +1.75-◆◆◆◆◆
     +1.37-◆◆◆◆◆◆◆
     +1.07-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +0.514-◆◆◆◆◆◆◆◆◆◆◆
    +0.402-◆◆◆◆◆◆◆◆◆◆◆◆
    +0.315-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +0.247-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +0.193-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +0.151-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +0.118-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0926-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0444-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0347-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0272-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0213-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0167-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0130-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +0.0102-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.00799-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.00626-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.00490-◆
  +0.00383-◆
  +0.00300-◆
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                    MICROMERITICS AUTO-PORE 9200 V2.01                           PAGE 1

HITEMP-SORBENT                                                          LP 9:14:24 8/16/85
VICRON LST.,LUCERNE VALLEY,CA.; 16/18 MESH UNCAL                        HP 9:38:24 8/16/85
PNTR NUMBER  +386

   LP EQUILIBRATION =   +15.0000 SEC         PNTR CONSTANT =   +10.7900 MICRO-L/PF
   HP EQUILIBRATION =   +10.0000 SEC                 THETA =  +130.0000
      SAMPLE WEIGHT =    +4.0000 G                   GAMMA =  +485.0000 DYNES/CM
        PNTR WEIGHT =   +76.9800 G        INITIAL PRESSURE =    +0.9011 PSIA
 PNTR+SAMPLE WEIGHT =   +80.9800 G           PORE DIAMETER =  +196.1730 MICRO-M
PNTR+SAMPLE+MERCURY =  +106.5700 G         MERCURY DENSITY =   +13.5335 G/CC
        PNTR VOLUME =    +3.4120 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =     +0.0123 CC/G
               TOTAL PORE AREA =     +0.0318 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =    +64.1763 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =     +0.1870 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =     +1.5434 MICROMETERS
                  BULK DENSITY =     +2.6296 G/CC
   APPARENT (SKELETAL) DENSITY =     +2.7174 G/CC

% CAPILLARY =  +12.7993 ****
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HITEMP-SORBENT                                                          LP 9:14:24 8/16/85
VICRON LST.,LUCERNE VALLEY,CA.; 16/18 MESH UNCAL                        HP 9:38:24 8/16/85
PNTR NUMBER  +386

 PRESSURE       PORE        INTRUSION       PORE          MEAN
   PSIA       DIAMETER       VOLUME       SURFACE       DIAMETER           DV
               MICRO-M        CC/G         SQ-M/G        MICRO-M

     +5.0     +35.4843      +0.0067      +0.0002      +115.8290        +0.0067
     +9.9     +17.7814      +0.0080      +0.0004       +26.6328        +0.0013
    +14.6     +12.0767      +0.0086      +0.0006       +14.9291        +0.0005
    +19.9      +8.8743      +0.0089      +0.0007       +10.4755        +0.0003
    +39.7      +4.4519      +0.0093      +0.0009        +6.6631        +0.0004
    +60.0      +2.9462      +0.0095      +0.0012        +3.6990        +0.0003
    +80.0      +2.2096      +0.0098      +0.0016        +2.5779        +0.0003
   +100.4      +1.7613      +0.0100      +0.0020        +1.9855        +0.0002
   +118.8      +1.4876      +0.0101      +0.0024        +1.6244        +0.0001
   +150.5      +1.1742      +0.0103      +0.0030        +1.3309        +0.0002
   +201.2      +0.8784      +0.0108      +0.0048        +1.0263        +0.0005
   +252.0      +0.7014      +0.0112      +0.0065        +0.7899        +0.0003
   +298.9      +0.5914      +0.0113      +0.0074        +0.6464        +0.0001
   +353.6      +0.4999      +0.0114      +0.0079        +0.5457        +0.0001
   +400.5      +0.4414      +0.0114      +0.0086        +0.4707        +0.0001
   +455.2      +0.3883      +0.0115      +0.0093        +0.4149        +0.0001
   +503.1      +0.3514      +0.0116      +0.0101        +0.3699        +0.0001
   +600.7      +0.2943      +0.0116      +0.0102        +0.3228        +0.0000
   +697.4      +0.2535      +0.0118      +0.0124        +0.2739        +0.0001
   +799.0      +0.2212      +0.0118      +0.0137        +0.2373        +0.0001
   +895.7      +0.1973      +0.0119      +0.0152        +0.2093        +0.0001
   +997.3      +0.1772      +0.0120      +0.0168        +0.1873        +0.0001
  +1104.8      +0.1600      +0.0120      +0.0171        +0.1686        +0.0000
  +1206.3      +0.1465      +0.0120      +0.0171        +0.1533        +0.0000
  +1307.0      +0.1353      +0.0120      +0.0177        +0.1409        +0.0000
  +1411.5      +0.1252      +0.0120      +0.0180        +0.1302        +0.0000
  +1501.3      +0.1177      +0.0120      +0.0183        +0.1215        +0.0000
  +1607.8      +0.1099      +0.0121      +0.0209        +0.1138        +0.0001
  +1691.8      +0.1045      +0.0121      +0.0212        +0.1072        +0.000
  +1803.2      +0.0980      +0.0121      +0.0215        +0.1013        +0.000
  +2004.4      +0.0882      +0.0121      +0.0222        +0.0931        +0.000
  +2200.7      +0.0803      +0.0122      +0.0228        +0.0843        +0.000
  +2397.1      +0.0737      +0.0122      +0.0234        +0.0770        +0.000
  +2593.1      +0.0682      +0.0122      +0.0241        +0.0710        +0.000
  +2814.7      +0.0628      +0.0122      +0.0248        +0.0655        +0.000
  +2995.5      +0.0590      +0.0122      +0.0254        +0.0609        +0.000
  +3189.0      +0.0554      +0.0122      +0.0261        +0.0572        +0.000
  +3398.8      +0.0520      +0.0123      +0.0317        +0.0537        +0.000
  +3588.5      +0.0493      +0.0123      +0.0317        +0.0506        +0.000
  +3800.0      +0.0465      +0.0123      +0.0317        +0.0479        +0.000
  +3993.8      +0.0443      +0.0123      +0.0317        +0.0454        +0.000
  +4500.4      +0.0393      +0.0123      +0.0317        +0.0418        +0.000
  +5007.1      +0.0353      +0.0123      +0.0317        +0.0373        +0.000
  +5498.9      +0.0321      +0.0123      +0.0319        +0.0337        +0.000
  +5990.6      +0.0295      +0.0123      +0.0319        +0.0308        +0.000
  +6527.1      +0.0271      +0.0123      +0.0319        +0.0283        +0.000
  +6989.1      +0.0253      +0.0123      +0.0319        +0.0262        +0.000
  +7525.5      +0.0235      +0.0123      +0.0319        +0.0244        +0.000
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HITEMP-SORBENT                                                          LP 9:14:24 8/16/85
VICRON LST.,LUCERNE VALLEY,CA.; 16/18 MESH UNCAL                        HP 9:38:24 8/16/85
PNTR NUMBER  +386

   PRESSURE        PORE        INTRUSION       PORE          MEAN
     PSIA        DIAMETER       VOLUME        SURFACE       DIAMETER              DV
                  MICRO-M        CC/G         SQ-M/G        MICRO-M

    +7987.5      +0.0221       +0.0123       +0.0319       +0.0228          +0.0000
    +8956.1      +0.0197       +0.0123       +0.0319       +0.0209          +0.0000
    +9954.6      +0.0178       +0.0123       +0.0319       +0.0187          +0.0000
   +10953.0      +0.0161       +0.0123       +0.0319       +0.0169          +0.0000
   +11996.2      +0.0147       +0.0123       +0.0319       +0.0154          +0.0000
   +12964.8      +0.0136       +0.0123       +0.0319       +0.0142          +0.0000
   +13948.3      +0.0127       +0.0123       +0.0319       +0.0132          +0.0000
   +14946.8      +0.0118       +0.0123       +0.0319       +0.0123          +0.0000
   +15930.3      +0.0111       +0.0123       +0.0319       +0.0115          +0.0000
   +17077.8      +0.0104       +0.0123       +0.0319       +0.0107          +0.0000
   +18150.7      +0.0097       +0.0123       +0.0319       +0.0100          +0.0000
   +19149.2      +0.0092       +0.0123       +0.0319       +0.0095          +0.0000
   +20132.7      +0.0088       +0.0123       +0.0319       +0.0090          +0.0000
   +24961.0      +0.0071       +0.0123       +0.0319       +0.0079          +0.0000
   +29923.3      +0.0059       +0.0123       +0.0319       +0.0065          +0.0000
   +35154.0      +0.0050       +0.0123       +0.0319       +0.0055          +0.0000
   +40205.8      +0.0044       +0.0123       +0.0319       +0.0047          +0.0000
   +45138.4      +0.0039       +0.0123       +0.0319       +0.0042          +0.0000
   +50056.0      +0.0035       +0.0123       +0.0319       +0.0037          +0.0000
   +54884.3      +0.0032       +0.0123       +0.0319       +0.0034          +0.0000
   +59787.1      +0.0030       +0.0123       +0.0319       +0.0031          +0.0000
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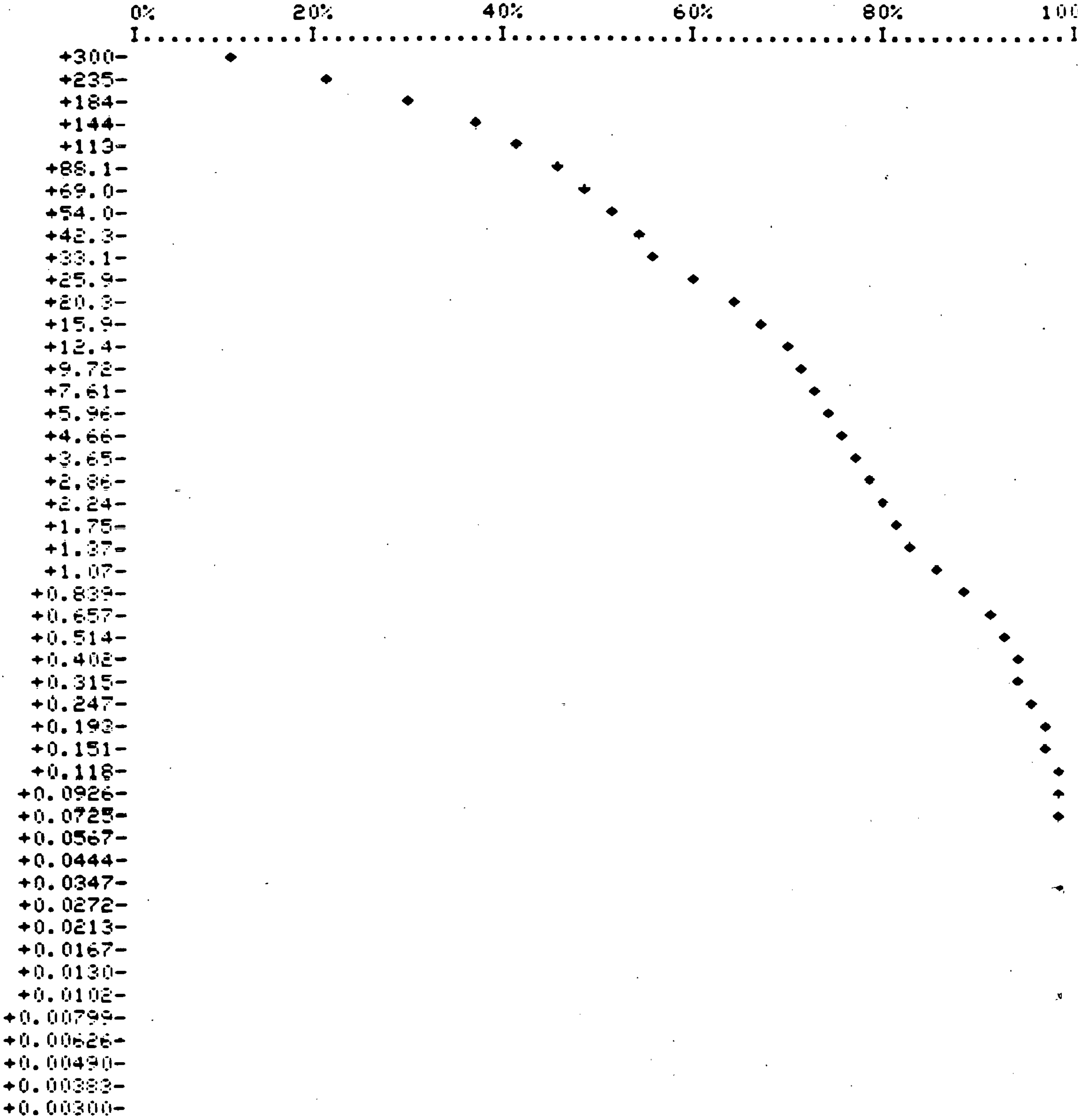
HITEMP-SORBENT
VICRON LST.,LUCERNE VALLEY,CA.: 16/18 MESH UNCAL
PNTR NUMBER +386

LP 9:14:24 8/16/85
HP 9:38:24 8/16/85

CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
100% = +0.0123



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HITEMP-SORBENT                                                LP 9:14:24 8/16/85
VICRON LTD.,LUCERNE VALLEY,CA.; 16/18 MESH UNCAL              HP 9:38:24 8/16/85
PNTR NUMBER  +386

              CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
                                   100% =     +0.0318

          0%          20%           40%           60%           80%          100%
          I............I.............I.............I.............I.............I
     +300-◆
     +235-◆
     +184-◆
     +144-◆
     +113-◆
    +88.1-◆
    +69.0-◆
    +54.0-◆
    +42.3-◆
    +33.1-◆
    +25.9-◆
    +20.3-◆
    +15.9-◆
    +12.4-◆
    +9.72-◆
    +7.61-◆
    +5.96- ◆
    +4.66- ◆
    +3.65- ◆
    +2.86-  ◆
    +2.24-  ◆
    +1.75-   ◆
    +1.37-    ◆
    +1.07-       ◆
   +0.839-          ◆
   +0.657-              ◆
   +0.514-                ◆
   +0.402-                   ◆
   +0.315-                     ◆
   +0.247-                           ◆
   +0.193-                                 ◆
   +0.151-                                    ◆
   +0.118-                                       ◆
  +0.0926-                                               ◆
  +0.0725-                                                   ◆
  +0.0567-                                                        ◆
  +0.0444-                                                                    ◆
  +0.0347-                                                                     ◆
  +0.0272-                                                                     ◆
  +0.0213-                                                                     ◆
  +0.0167-                                                                     ◆
  +0.0130-                                                                     ◆
  +0.0102-                                                                     ◆
 +0.00799-                                                                     ◆
 +0.00626-                                                                     ◆
 +0.00490-                                                                     ◆
 +0.00383-                                                                     ◆
 +0.00300-                                                                     ◆
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                  MICROMERITICS AUTO-PORE 9200 V2.01                     PAGE 6

HITEMP-SORBENT                                                LP 9:14:24 8/16/85
VICRON LST.,LUCERNE VALLEY,CA.; 16/18 MESH UNCAL              HP 9:38:24 8/16/85
PNTR NUMBER  +386


              DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                               100% = +0.658369E-002

          0%           20%           40%           60%           80%           10
          I.............I.............I.............I.............I.............
     +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +15.9-◆◆◆◆◆◆◆◆◆◆◆
    +12.4-◆◆◆◆◆◆
    +9.72-◆◆◆◆
    +7.61-◆◆◆◆
    +5.96-◆◆◆◆
    +4.66-◆◆◆◆
    +3.65-◆◆◆
    +2.86-◆◆◆
    +2.24-◆◆◆
    +1.75-◆◆
    +1.37-◆◆
    +1.07-◆◆◆
   +0.839-◆◆◆◆◆
   +0.657-◆◆◆
   +0.514-◆
   +0.402-◆
   +0.315-◆
   +0.247-◆
   +0.193-◆
   +0.151-◆
   +0.118-◆
  +0.0926-◆
  +0.0725-◆
  +0.0567-◆
  +0.0444-◆
  +0.0347-◆
  +0.0272-◆
  +0.0213-◆
  +0.0167-◆
  +0.0130-◆
  +0.0102-◆
 +0.00799-◆
 +0.00626-◆
 +0.00490-◆
 +0.00383-◆
 +0.00300-◆
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HITEMP-SORBENT                                              LP 9:14:24 8/16/85
VICRON LST.,LUCERNE VALLEY,CA.; 16/18 MESH UNCAL            HP 9:38:24 8/16/85
PNTR NUMBER  +386

             DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                                   100% = +0.194853E-002

         0%            20%           40%           60%           80%          100%
         I.............I.............I.............I.............I.............I
    +300-◆
    +235-◆◆
    +184-◆◆◆
    +144-◆◆◆
    +113-◆◆◆◆
   +88.1-◆◆◆◆
   +69.0-◆◆◆◆
   +54.0-◆◆◆◆
   +42.3-◆◆◆◆◆
   +33.1-◆◆◆◆◆
   +25.9-◆◆◆◆◆◆
   +20.3-◆◆◆◆◆◆◆
   +15.9-◆◆◆◆◆◆
   +12.4-◆◆◆◆◆
   +9.72-◆◆◆◆◆
   +7.61-◆◆◆◆◆◆
   +5.96-◆◆◆◆◆◆◆
   +4.66-◆◆◆◆◆◆◆◆
   +3.65-◆◆◆◆◆◆◆◆◆
   +2.86-◆◆◆◆◆◆◆◆◆◆◆
   +2.24-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.75-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.37-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.07-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.402-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.315-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.247-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.193-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.151-◆◆◆
  +0.118-◆◆◆◆◆◆◆◆◆◆
 +0.0926-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0444-◆
 +0.0347-◆◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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                 MICROMERITICS AUTO-PORE 9200 V2.01                    PAGE 1

HITEMP-SORBENT                                                  LP 11:34:48 8/26/8
VICRON LST. ADAMS MASS. (8/85) 16-18 MESH                       HP 12:57:19 8/26/8
PNTR NUMBER  +387

   LP EQUILIBRATION =   +15.0000 SEC       PNTR CONSTANT =   +10.7900 MICRO-L/
   HP EQUILIBRATION =   +10.0000 SEC               THETA =  +130.0000
      SAMPLE WEIGHT =    +6.0800 G                 GAMMA =  +485.0000 DYNES/C
        PNTR WEIGHT =   +74.0600 G      INITIAL PRESSURE =    +0.9451 PSIA
 PNTR+SAMPLE WEIGHT =   +80.1400 G         PORE DIAMETER =  +187.0490 MICRO-M
PNTR+SAMPLE+MERCURY =  +123.9600 G       MERCURY DENSITY =   +13.5335 G/CC
        PNTR VOLUME =    +5.5410 CC


INTRUSION (PRESSURIZATION) DATA SUMMARY

        TOTAL INTRUSION VOLUME =    +0.0099 CC/G
               TOTAL PORE AREA =    +0.0290 SQ-M/G
MEDIAN PORE DIAMETER  (VOLUME) =   +26.8138 MICROMETERS
MEDIAN PORE DIAMETER  (AREA)   =    +0.1545 MICROMETERS
  AVERAGE PORE DIAMETER (4V/A) =    +1.3715 MICROMETERS
                  BULK DENSITY =    +2.6399 G/CC
   APPARENT (SKELETAL) DENSITY =    +2.7111 G/CC

% CAPILLARY =  +15.7443 ****
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                MICROMERITICS AUTO-PORE 9200 V2.01                          PAGE 2

HITEMP-SORBENT                                                        LP 11:34:48 8/26/85
VICRON LST. ADAMS MASS. (8/85) 16-18 MESH                             HP 12:57:19 8/26/8
PNTR NUMBER  +387

  PRESSURE       PORE        INTRUSION      PORE         MEAN
    PSIA       DIAMETER       VOLUME       SURFACE     DIAMETER           DV
                MICRO-M        CC/G        SQ-M/G       MICRO-M

       +5.0    +35.4322      +0.0044      +0.0002     +111.2400        +0.0044
       +9.9    +17.8208      +0.0056      +0.0003      +26.6265        +0.0012
      +14.6    +12.0949      +0.0061      +0.0005      +14.9578        +0.0005
      +19.9     +8.8613      +0.0065      +0.0006      +10.4781        +0.0004
      +38.8     +4.5527      +0.0070      +0.0009       +6.7070        +0.0004
      +58.4     +3.0275      +0.0074      +0.0013       +3.7901        +0.0
      +78.8     +2.2446      +0.0077      +0.0018       +2.6361        +0.
      +98.6     +1.7927      +0.0079      +0.0022       +2.0186        +0.
     +120.8     +1.4633      +0.0081      +0.0027       +1.6280        +0.0
     +148.9     +1.1875      +0.0084      +0.0035       +1.3254        +0.0003
     +198.8     +0.8890      +0.0088      +0.0052       +1.0382        +0.0004
     +252.2     +0.7010      +0.0089      +0.0059       +0.7950        +0.0001
     +301.8     +0.5857      +0.0091      +0.0070       +0.6433        +0.0002
     +355.6     +0.4972      +0.0092      +0.0077       +0.5414        +0.0001
     +403.4     +0.4382      +0.0093      +0.0081       +0.4677        +0.0000
     +454.2     +0.3892      +0.0093      +0.0086       +0.4137        +0.0000
     +504.0     +0.3507      +0.0094      +0.0091       +0.3699        +0.0000
     +602.7     +0.2933      +0.0094      +0.0098       +0.3220        +0.0001
     +701.3     +0.2520      +0.0095      +0.0112       +0.2727        +0.0001
     +803.9     +0.2199      +0.0096      +0.0121       +0.2360        +0.0001
     +897.7     +0.1969      +0.0096      +0.0122       +0.2084        +0.0000
     +994.4     +0.1778      +0.0096      +0.0133       +0.1873        +0.0001
    +1113.6     +0.1587      +0.0097      +0.0145       +0.1683        +0.0001
    +1216.1     +0.1454      +0.0097      +0.0147       +0.1521        +0.00
    +1315.7     +0.1344      +0.0097      +0.0149       +0.1399        +0.0
    +1414.4     +0.1250      +0.0097      +0.0164       +0.1297        +0.0
    +1512.1     +0.1169      +0.0097      +0.0166       +0.1209        +0.000
    +1611.7     +0.1097      +0.0097      +0.0168       +0.1133        +0.0000
    +1712.3     +0.1032      +0.0097      +0.0170       +0.1065        +0.0000
    +1812.0     +0.0976      +0.0098      +0.0189       +0.1004        +0.0000
    +2008.3     +0.0880      +0.0098      +0.0194       +0.0928        +0.0000
    +2204.6     +0.0802      +0.0098      +0.0198       +0.0841        +0.0000
    +2403.9     +0.0735      +0.0099      +0.0225       +0.0769        +0.0001
    +2596.7     +0.0681      +0.0099      +0.0229       +0.0708        +0.0000
    +2787.4     +0.0634      +0.0099      +0.0233       +0.0657        +0.0000
    +3011.9     +0.0587      +0.0099      +0.0238       +0.0611        +0.0000
    +3190.2     +0.0554      +0.0099      +0.0242       +0.0570        +0.0000
    +3386.3     +0.0522      +0.0099      +0.0246       +0.0538        +0.0000
    +3606.9     +0.0490      +0.0099      +0.0251       +0.0506        +0.0000
    +3800.0     +0.0465      +0.0099      +0.0255       +0.0478        +0.0000
    +3993.8     +0.0443      +0.0099      +0.0259       +0.0454        +0.0000
    +4515.3     +0.0391      +0.0099      +0.0270       +0.0417        +0.0000
    +5007.1     +0.0353      +0.0099      +0.0281       +0.0372        +0.0000
    +5513.8     +0.0321      +0.0099      +0.0291       +0.0337        +0.0000
    +6020.4     +0.0294      +0.0099      +0.0291       +0.0307        +0.0000
    +6542.0     +0.0270      +0.0099      +0.0291       +0.0282        +0.0000
    +7018.9     +0.0252      +0.0099      +0.0291       +0.0261        +0.0000
    +7540.4     +0.0234      +0.0099      +0.0291       +0.0243        +0.0000
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HITEMP-SORBENT                                                   LP 11:34:48 8/26/8
VICRON LST. ADAMS MASS. (8/85) 16-18 MESH                        HP 12:57:19 8/26/8
PNTR NUMBER  +387

 PRESSURE      PORE       INTRUSION      PORE         MEAN
   PSIA      DIAMETER      VOLUME      SURFACE      DIAMETER          DV
              MICRO-M       CC/G        SQ-M/G       MICRO-M

  +8017.3     +0.0220      +0.0099     +0.0291      +0.0227         +0.000
  +8985.9     +0.0197      +0.0099     +0.0291      +0.0209         +0.000
  +9984.4     +0.0177      +0.0099     +0.0291      +0.0187         +0.000
 +10953.0     +0.0161      +0.0099     +0.0291      +0.0169         +0.000
 +11981.3     +0.0148      +0.0099     +0.0291      +0.0154         +0.000
 +12949.9     +0.0137      +0.0099     +0.0291      +0.0142         +0.000
 +13948.3     +0.0127      +0.0099     +0.0291      +0.0132         +0.000
 +14946.8     +0.0118      +0.0099     +0.0291      +0.0123         +0.000
 +15930.3     +0.0111      +0.0099     +0.0291      +0.0115         +0.000
 +17122.5     +0.0103      +0.0099     +0.0291      +0.0107         +0.000
 +18165.6     +0.0097      +0.0099     +0.0291      +0.0100         +0.000
 +18910.7     +0.0093      +0.0099     +0.0291      +0.0095         +0.000
 +20102.9     +0.0088      +0.0099     +0.0291      +0.0091         +0.000
 +24975.9     +0.0071      +0.0099     +0.0291      +0.0079         +0.000
 +29953.1     +0.0059      +0.0099     +0.0291      +0.0065         +0.000
 +35288.1     +0.0050      +0.0099     +0.0291      +0.0055         +0.000
 +40414.4     +0.0044      +0.0099     +0.0291      +0.0047         +0.000
 +45332.1     +0.0039      +0.0099     +0.0291      +0.0041         +0.000
 +50324.3     +0.0035      +0.0099     +0.0291      +0.0037         +0.000
 +55107.8     +0.0032      +0.0099     +0.0291      +0.0034         +0.000
 +59906.3     +0.0030      +0.0099     +0.0291      +0.0031         +0.000
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HITEMP-SORBENT                                          LP 11:34:48 8/26/85
VICRON LST. ADAMS MASS. (8/85) 16-18 MESH               HP 12:57:19 8/26/85
PNTR NUMBER  +387
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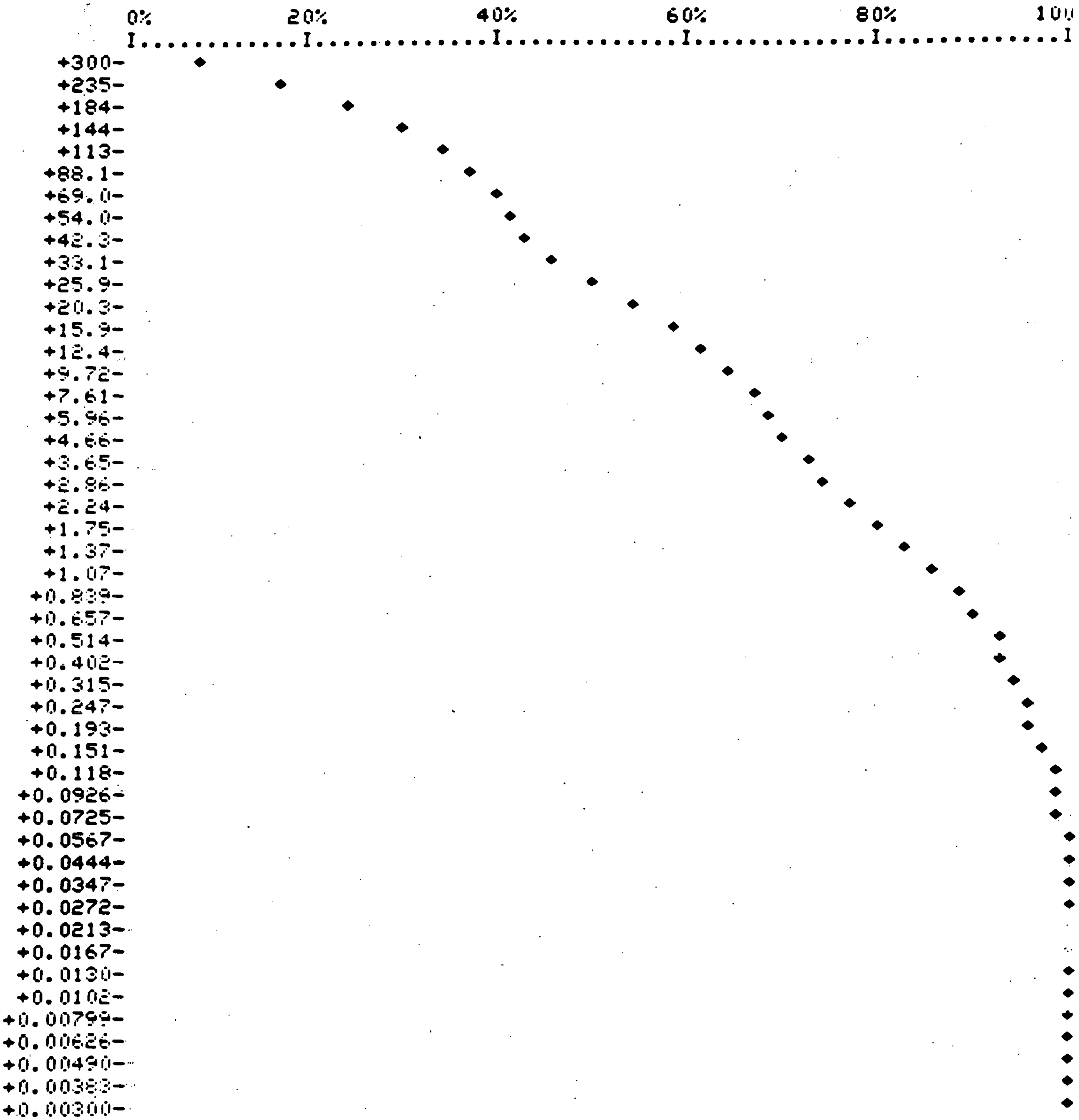
CUMULATIVE PORE VOLUME (CC/G) VS. PORE DIAMETER
100% = +0.0099



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                    MICROMERITICS AUTO-PORE 9200 V2.01                          PAGE 5

HITEMP-SORBENT                                                    LP 11:34:48 8/26/85
VICRON LST. ADAMS MASS. (8/85) 16-18 MESH                         HP 12:57:19 8/26/85
PNTR NUMBER  +387


                   CUMULATIVE SURFACE AREA (M2/G) VS. PORE DIAMETER
                                       100% =     +0.0290

         0%           20%           40%           60%           80%           10
         I.............I.............I.............I.............I.............
    +300-◆
    +235-◆
    +184-◆
    +144-◆
    +113-◆
   +88.1-◆
   +69.0-◆
   +54.0-◆
   +42.3-◆
   +33.1-◆
   +25.9-◆
   +20.3-◆
   +15.9-◆
   +12.4-◆
   +9.72-◆
   +7.61- ◆
   +5.96- ◆
   +4.66- ◆
   +3.65-  ◆
   +2.86-  ◆
   +2.24-   ◆
   +1.75-    ◆
   +1.37-      ◆
   +1.07-          ◆
  +0.839-             ◆
  +0.657-               ◆
  +0.514-                  ◆
  +0.402-                    ◆
  +0.315-                       ◆
  +0.247-                           ◆
  +0.193-                              ◆
  +0.151-                                   ◆
  +0.118-                                        ◆
 +0.0926-                                              ◆
 +0.0725-                                                      ◆
 +0.0567-                                                          ◆
 +0.0444-                                                              ◆
 +0.0347-                                                                    ◆
 +0.0272-
 +0.0213-
 +0.0167-
 +0.0130-
 +0.0102-
+0.00799-
+0.00626-
+0.00490-
+0.00383-
+0.00300-
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HITEMP-SORBENT                                              LP 11:34:48 8/26/85
VICRON LST. ADAMS MASS. (8/85) 16-18 MESH                   HP 12:57:19 8/26/85
PNTR NUMBER  +387

              DIFFERENTIAL VOLUME (CC/G-MICRO-M) VS. PORE DIAMETER
                              100% = +0.428826E-002

         0%          20%           40%           60%           80%          100
         I............I.............I.............I.............I.............I
    +300-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +235-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +184-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +144-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
    +113-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +88.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +69.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +54.0-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +42.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +33.1-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +25.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +20.3-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +15.9-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +12.4-◆◆◆◆◆◆◆◆◆
   +9.72-◆◆◆◆◆◆◆
   +7.61-◆◆◆◆◆◆◆
   +5.96-◆◆◆◆◆◆◆
   +4.66-◆◆◆◆◆◆◆
   +3.65-◆◆◆◆◆◆◆
   +2.86-◆◆◆◆◆◆
   +2.24-◆◆◆◆◆
   +1.75-◆◆◆◆
   +1.37-◆◆◆◆
   +1.07-◆◆◆◆◆
  +0.839-◆◆◆◆◆◆
  +0.657-◆◆
  +0.514-◆◆
  +0.402-◆
  +0.315-◆
  +0.247-◆
  +0.193-◆
  +0.151-◆
  +0.118-◆
 +0.0926-◆
 +0.0725-◆
 +0.0567-◆
 +0.0444-◆
 +0.0347-◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
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HITEMP-SORBENT                                              LP 11:34:48 8/26/8
VICRON LST. ADAMS MASS. (8/85) 16-18 MESH                   HP 12:57:19 8/26/8
PNTR NUMBER  +387

           DIFFERENTIAL SURFACE AREA (M2/G-MICRO-M) VS. DIAMETER
                              100% = +0.224178E-002

         0%           20%           40%           60%           80%           1
         I............I.............I.............I.............I............
    +300-◆
    +235-◆
    +184-◆◆
    +144-◆◆
    +113-◆◆
   +88.1-◆◆
   +69.0-◆◆
   +54.0-◆◆◆
   +42.3-◆◆◆
   +33.1-◆◆◆
   +25.9-◆◆◆◆
   +20.3-◆◆◆◆◆
   +15.9-◆◆◆◆◆
   +12.4-◆◆◆◆
   +9.72-◆◆◆◆◆
   +7.61-◆◆◆◆◆◆
   +5.96-◆◆◆◆◆◆◆
   +4.66-◆◆◆◆◆◆◆◆
   +3.65-◆◆◆◆◆◆◆◆◆◆◆
   +2.86-◆◆◆◆◆◆◆◆◆◆◆◆◆
   +2.24-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.75-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.37-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
   +1.07-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.839-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.657-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.514-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.402-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.315-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.247-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.193-◆◆◆◆◆◆◆◆◆◆
  +0.151-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  +0.118-◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0926-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0725-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0567-◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0444-◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0347-◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 +0.0272-◆
 +0.0213-◆
 +0.0167-◆
 +0.0130-◆
 +0.0102-◆
+0.00799-◆
+0.00626-◆
+0.00490-◆
+0.00383-◆
+0.00300-◆
```

APPENDIX B

COARSE SORBENT THERMOGRAVIMETRIC BALANCE DATA

B1: Run Summaries
B2: Untreated Sorbents in SO_2
B3: Pretreated Sorbents in SO_2
B4: Untreated Sorbents in H_2S

APPENDIX B1

RUN SUMMARIES

Table Key:

Orig. wt. = original weight of test sample
Final wt. calc. = final weight of sample after calcination
Weight loss = weight lost on calcination
Solid = % of sample remaining after calcination
Volit = % of sample volatile
CA = implied weight of calcium in sample
MG = implied weight of magnesium in sample
FX. CA. = wt. fraction calcium in sample
FX. MG. = wt. fraction magnesium in sample

RUN NO.	STONE	ORIG. WT. (mg.)	FINAL WT. CALC.	WEIGHT LOSS (mg.)	% SOLID	% VOLIT.	mg. CA.	mg. MG.	FX. CA.	FX. MG.
P437	TYMOCHTEE	18.36	10.24	8.12	55.77	44.23	3.71	2.36	.2021	.1287
P438	PLUM RUN	19.02	10.04	8.98	52.79	47.21	3.82	2.48	.2006	.1302
P439	HIGHLAND	17.26	10.26	7.00	59.44	40.56	5.88	.65	.3407	.0376
P440	GREER	19.32	10.88	8.44	56.31	43.69	7.29	.18	.3775	.0094
P441	MISSISSIPPI	16.94	9.50	7.44	56.08	43.92	6.48	.23	.3827	.0136
P442	CARBON	18.24	10.32	7.92	56.58	43.42	6.40	.47	.3508	.0257
P443	VICRON	19.34	10.64	8.70	55.02	44.98	7.31	.29	.3781	.0149
P444	TYMOCHTEE	18.82	10.46	8.36	55.58	44.42	3.80	2.42	.2021	.1287
P445	PLUM RUN	18.76	9.84	8.92	52.45	47.55	3.76	2.44	.2006	.1302
P446	HIGHLAND	19.50	11.08	8.42	56.82	43.18	6.64	.73	.3407	.0376
P447	GREER	17.92	9.90	8.02	55.25	44.75	6.76	.17	.3775	.0094
P448	MISSISSIPPI	18.56	10.20	8.36	54.96	45.04	7.10	.25	.3827	.0136
P449	CARBON	19.28	11.20	8.08	58.09	41.91	6.76	.50	.3508	.0257
P450	VICRON	19.10	10.52	8.58	55.08	44.92	7.22	.28	.3781	.0149
P451	GREER	19.30	11.08	8.22	57.41	42.59	7.29	.18	.3775	.0094
P452	TYMOCHTEE	19.34	10.40	8.94	53.77	46.23	3.91	2.49	.2021	.1287
P453	PLUM RUN	19.06	9.82	9.24	51.52	48.48	3.82	2.48	.2006	.1302
P454	HIGHLAND	17.16	9.66	7.50	56.29	43.71	5.85	.65	.3407	.0376
P455	GREER	18.88	10.24	8.64	54.24	45.76	7.13	.18	.3775	.0094
P456	MISSISSIPPI	15.84	8.32	7.52	52.53	47.47	6.06	.22	.3827	.0136
P457	VICRON	18.60	10.00	8.60	53.76	46.24	7.03	.28	.3781	.0149
P458	CARBON	18.44	10.62	7.82	57.59	42.41	6.47	.47	.3508	.0257
P459	TYMOCHTEE	19.26	9.94	9.32	51.61	48.39	3.89	2.48	.2021	.1287
P460	TYMOCHTEE	18.90	10.10	8.80	53.44	46.56	3.82	2.43	.2021	.1287
P461	PLUM RUN	17.82	8.88	8.94	49.83	50.17	3.57	2.32	.2006	.1302
P462	PLUM RUN	19.04	9.84	9.20	51.68	48.32	3.82	2.48	.2006	.1302
P463	VICRON	18.00	9.70	8.30	53.89	46.11	6.81	.27	.3781	.0149
P464	VICRON	18.40	9.84	8.56	53.48	46.52	6.96	.27	.3781	.0149
P465	CARBON	18.54	10.58	7.96	57.07	42.93	6.50	.48	.3508	.0257
P466	CARBON	16.60	9.56	7.04	57.59	42.41	5.82	.43	.3508	.0257
P467	HIGHLAND	17.40	9.42	7.98	54.14	45.86	5.93	.65	.3407	.0376
P468	HIGHLAND	16.78	9.80	6.98	58.40	41.60	5.72	.63	.3407	.0376
P469	GREER	19.70	10.40	9.30	52.79	47.21	7.44	.19	.3775	.0094
P470	GREER	18.90	10.26	8.64	54.29	45.71	7.13	.18	.3775	.0094
P471	MISSISSIPPI	14.92	7.70	7.22	51.61	48.39	5.71	.20	.3827	.0136
P472	MISSISSIPPI	17.84	9.50	8.34	53.25	46.75	6.83	.24	.3827	.0136

SAMPLE NO.	STONE	ORIGINAL WT. (mg.)	FINAL WT. CALC.	WEIGHT LOSS (mg.)	PERCENT SOLIDS	PERCENT VOLATILES	TEMP. C	MESH SIZE
P437	TYMOCHTEE	18.36	10.24	8.12	55.77	44.23	1000	40/45
P444	TYMOCHTEE	18.82	10.46	8.36	55.58	44.42	1000	16/18
P452	TYMOCHTEE	19.34	10.40	8.94	53.77	46.23	1100	20/25
P459	TYMOCHTEE	19.26	9.94	9.32	51.61	48.39	1200	16/18
P460	TYMOCHTEE	18.90	10.10	8.80	53.44	46.56	1200	40/45
P440	GREER	19.32	10.88	8.44	56.31	43.69	1000	40/45
P447	GREER	17.92	9.90	8.02	55.25	44.75	1000	16/18
P451	GREER	19.30	11.08	8.22	57.41	42.59	1000	16/18
P455	GREER	18.88	10.24	8.64	54.24	45.76	1100	20/25
P469	GREER	19.70	10.40	9.30	52.79	47.21	1200	16/18
P470	GREER	18.90	10.26	8.64	54.29	45.71	1200	40/45
P443	VICRON	19.34	10.64	8.70	55.02	44.98	1000	40/45
P450	VICRON	19.10	10.52	8.58	55.08	44.92	1000	16/18
P457	VICRON	18.60	10.00	8.60	53.76	46.24	1100	20/25
P463	VICRON	18.00	9.70	8.30	53.89	46.11	1200	16/18
P464	VICRON	18.40	9.84	8.56	53.48	46.52	1200	40/45
P438	PLUM RUN	19.02	10.04	8.98	52.79	47.21	1000	40/45
P445	PLUM RUN	18.76	9.84	8.92	52.45	47.55	1000	16/18
P453	PLUM RUN	19.06	9.82	9.24	51.52	48.48	1100	20/25
P461	PLUM RUN	17.82	8.88	8.94	49.83	50.17	1200	16/18
P462	PLUM RUN	19.04	9.84	9.20	51.68	48.32	1200	40/45
P439	HIGHLAND	17.26	10.26	7.00	59.44	40.56	1000	40/45
P446	HIGHLAND	19.50	11.08	8.42	56.82	43.18	1000	16/18
P454*	HIGHLAND	17.16	9.66	7.50	56.29	43.71	1100	20/25
P467*	HIGHLAND	17.40	9.42	7.98	54.14	45.86	1200	16/18
P468*	HIGHLAND	16.78	9.80	6.98	58.40	41.60	1200	40/45
P441*	MISSISSIPPI	16.94	9.50	7.44	56.08	43.92	1000	40/45
P448*	MISSISSIPPI	18.56	10.20	8.36	54.96	45.04	1000	16/18
P456*	MISSISSIPPI	15.84	8.32	7.52	52.53	47.47	1100	20/25
P471*	MISSISSIPPI	14.92	7.70	7.22	51.61	48.39	1200	16/18
P472*	MISSISSIPPI	17.84	9.50	8.34	53.25	46.75	1200	40/45
P442	CARBON	18.24	10.32	7.92	56.58	43.42	1000	40/45
P449	CARBON	19.28	11.20	8.08	58.09	41.91	1000	16/18
P458	CARBON	18.44	10.62	7.82	57.59	42.41	1100	20/25
P465	CARBON	18.54	10.58	7.96	57.07	42.93	1200	16/18
P466*	CARBON	16.60	9.56	7.04	57.59	42.41	1200	40/45

* POPPING STONE - RESULTS IN SOME ORIGINAL WEIGHT LOSS FROM TG PAN

WEIGHT DATA IS TAKEN FROM THE TG CHARTS
LIST SHOWS SAMPLE VARIABILITY OVER THE PARTICLE SIZE RANGE
AND OVER THE COURSE OF THE SCHEDULED TG RUNS.

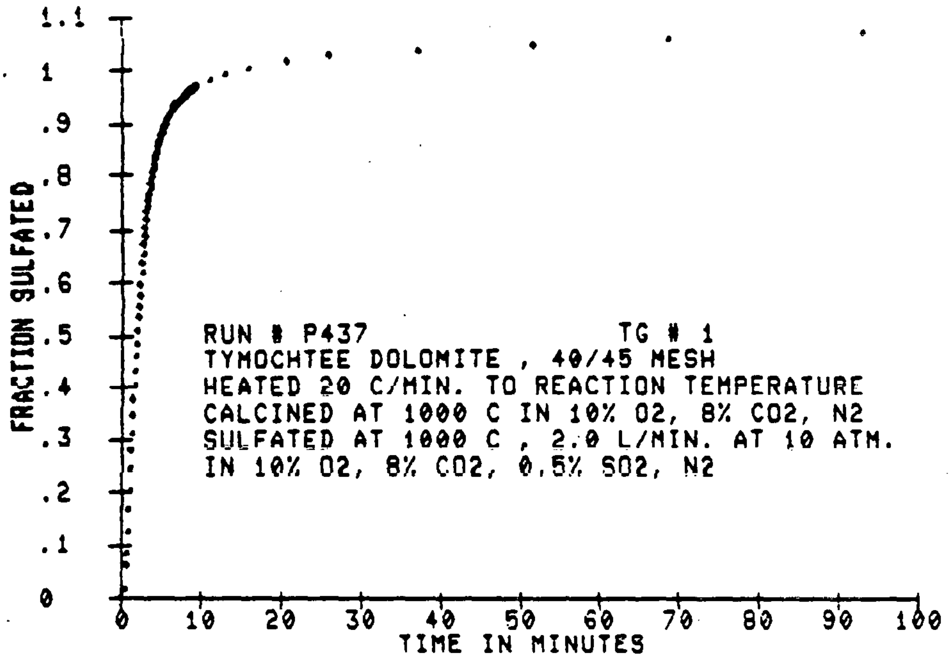
THE 40/45 MESH PARTICLE SIZES HAVE A TENDENCY TO CLUMP TOGETHER AND ADHERE TO THE PLATINUM PAN AT 1200 C. THE HIGHLAND LIMESTONE (HD-2) IS PARTICULARLY DIFFICULT TO REMOVE FROM THE TG PAN.

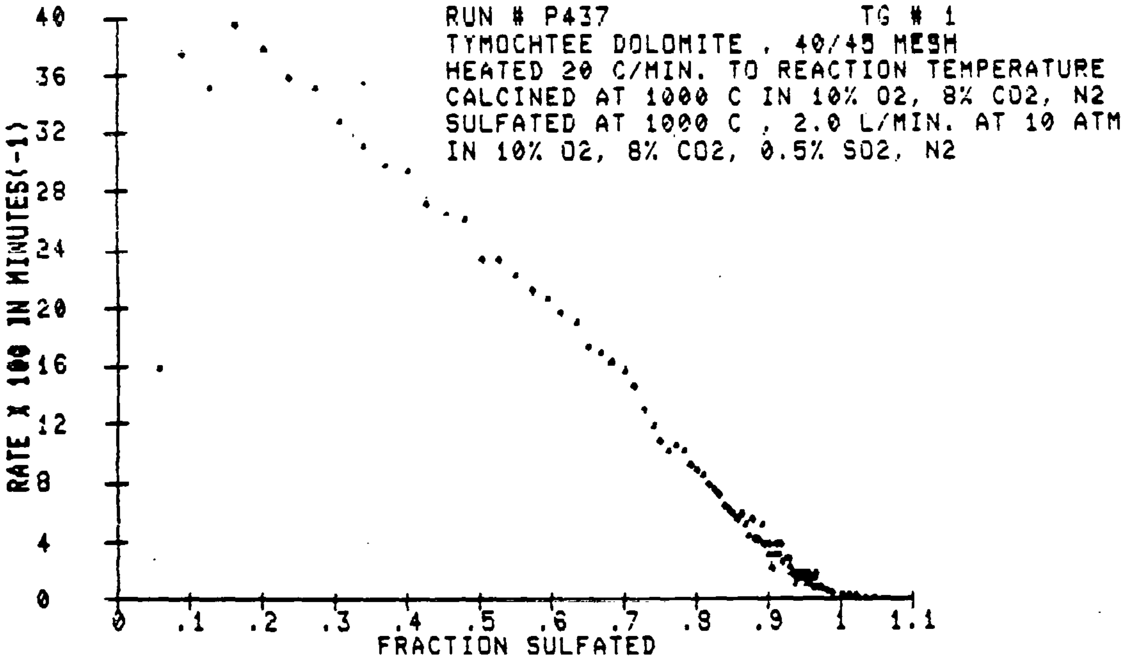
APPENDIX B2

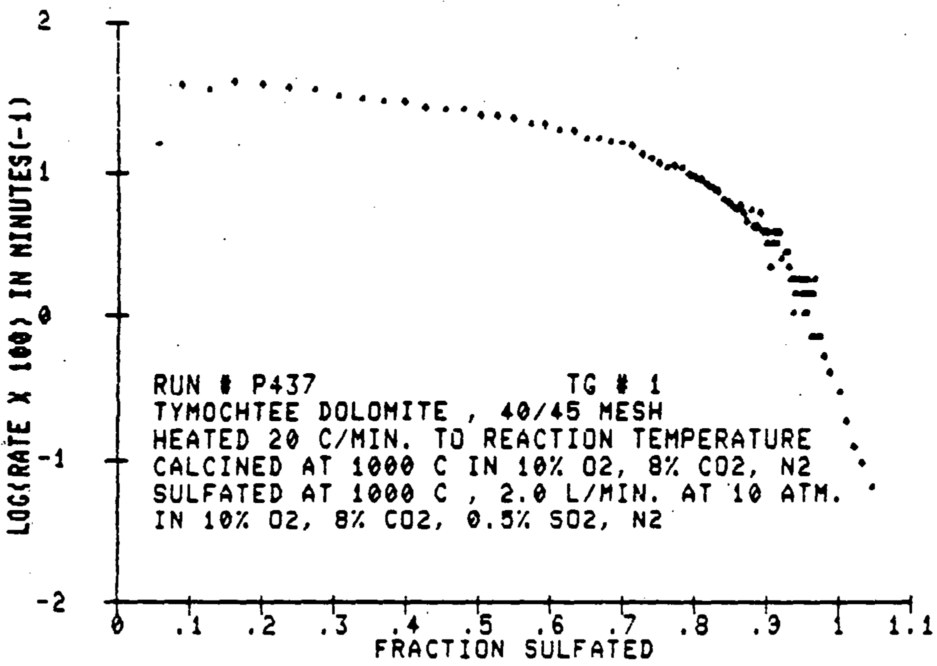
UNTREATED SORBENTS IN SO_2

Each run presents plot of

- fraction calcium sulfated versus time
- sulfation rate (fraction sulfated per minute) x 100 versus fraction sulfated
- Log_{10} {sulfation rate x 100} versus fraction sulfated
- tabulation of fraction calcium sulfated versus time
- tabulation of sulfation rate (fraction calcium sulfated per minute) versus time


FRACTION SULFATED
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
10
20
30
40
50
60
70
80
90
100
TIME IN MINUTES
RUN # P437 TG # 1
TYMOCHTEE DOLOMITE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
40
36
32
28
24
20
16
12
8
4
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
FRACTION SULFATED
RUN # P437 TG # 1
TYMOCHTEE DOLOMITE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2

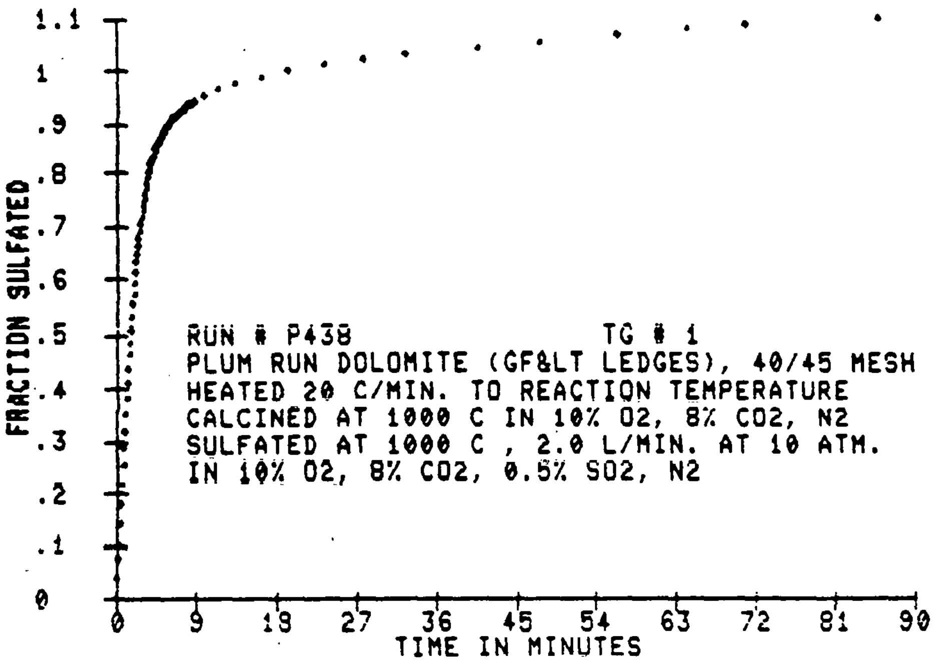

2
1
0
-1
-2
LOG(RATE X 100) IN MINUTES(-1)
RUN # P437 TG # 1
TYMOCHTEE DOLOMITE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
FRACTION SULFATED

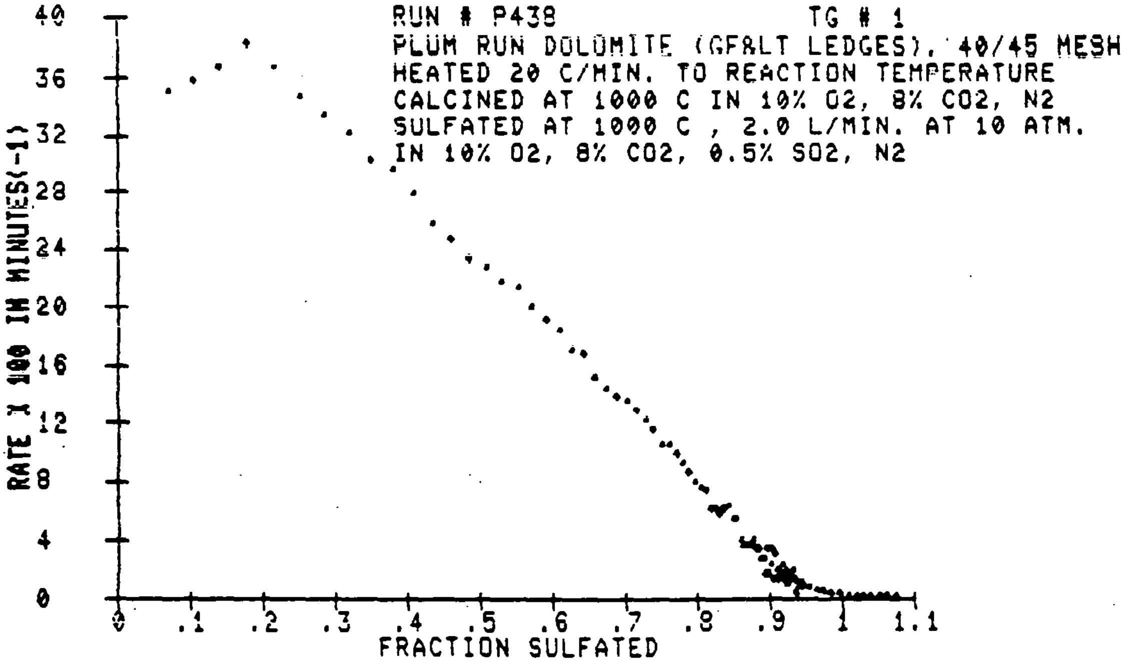
RUN # P437 TEMPERATURE = (1001.56 +/- 0.01) C

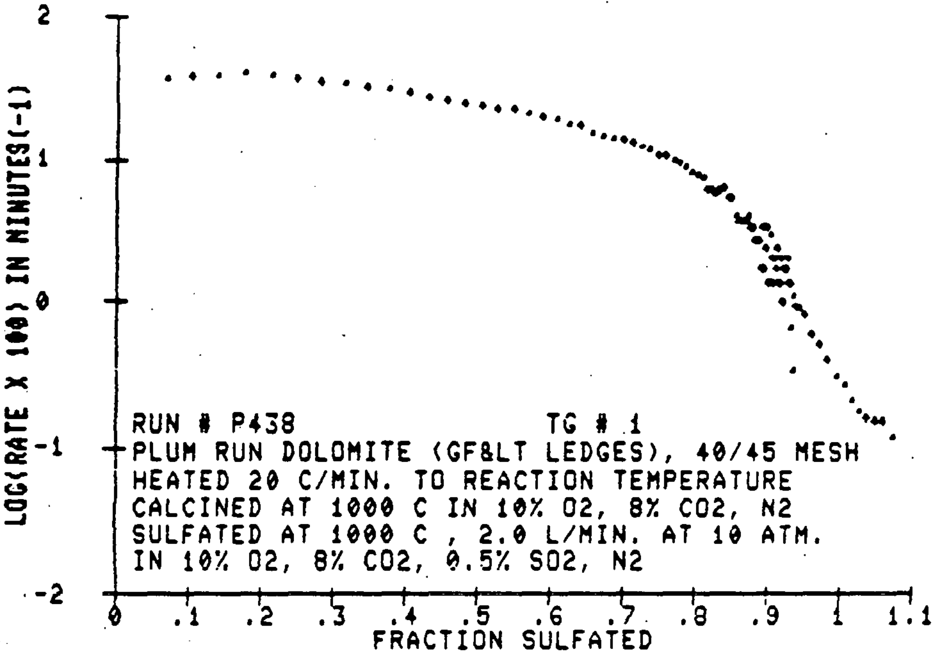
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.8932	5.40
0.0162	0.50	0.8959	5.50
0.0607	0.60	0.9026	5.60
0.0836	0.70	0.9053	5.70
0.1255	0.80	0.9053	5.80
0.1660	0.90	0.9107	5.90
0.2010	1.00	0.9107	6.00
0.2415	1.10	0.9174	6.10
0.2766	1.20	0.9201	6.20
0.3090	1.30	0.9228	6.30
0.3413	1.40	0.9255	6.40
0.3724	1.50	0.9269	6.50
0.4007	1.60	0.9309	6.60
0.4377	1.70	0.9336	6.70
0.4587	1.80	0.9363	6.80
0.4803	1.90	0.9350	6.90
0.5059	2.00	0.9377	7.00
0.5316	2.10	0.9404	7.10
0.5518	2.20	0.9404	7.20
0.5734	2.30	0.9417	7.30
0.5950	2.40	0.9431	7.40
0.6166	2.50	0.9458	7.50
0.6341	2.60	0.9471	7.60
0.6517	2.70	0.9485	7.70
0.6705	2.80	0.9498	7.80
0.6854	2.90	0.9525	7.90
0.7016	3.00	0.9525	8.00
0.7164	3.10	0.9552	8.10
0.7326	3.20	0.9539	8.20
0.7434	3.30	0.9566	8.30
0.7528	3.40	0.9579	8.40
0.7636	3.50	0.9593	8.50
0.7758	3.60	0.9606	8.60
0.7839	3.70	0.9620	8.70
0.7947	3.80	0.9633	8.80
0.8041	3.90	0.9647	8.90
0.8122	4.00	0.9633	9.00
0.8190	4.10	0.9674	9.10
0.8284	4.20	0.9660	9.20
0.8351	4.30	0.9701	9.30
0.8419	4.40	0.9701	9.40
0.8473	4.50	0.9809	11.10
0.8540	4.60	0.9917	13.00
0.8594	4.70	1.0025	15.80
0.8648	4.80	1.0132	20.70
0.8689	4.90	1.0240	26.10
0.8770	5.00	1.0348	37.30
0.8797	5.10	1.0456	51.60
0.8824	5.20	1.0578	68.60
0.8905	5.30	1.0672	93.00

RUN # P437

RATE	FRACTION	RATE	FRACTION
0.15683	0.0572	0.05059	0.8929
0.37438	0.0904	0.03711	0.8975
0.35082	0.1274	0.03035	0.9005
0.39461	0.1635	0.03710	0.9040
0.37781	0.2021	0.02024	0.9069
0.35751	0.2388	0.03035	0.9099
0.35077	0.2739	0.03711	0.9129
0.32721	0.3082	0.03035	0.9164
0.31030	0.3400	0.03710	0.9193
0.29685	0.3702	0.02361	0.9226
0.29343	0.4002	0.02698	0.9253
0.26982	0.4280	0.02699	0.9280
0.26312	0.4547	0.02698	0.9307
0.25970	0.4809	0.02024	0.9326
0.23276	0.5057	0.01687	0.9347
0.23272	0.5286	0.01686	0.9366
0.22260	0.5515	0.01012	0.9380
0.21252	0.5737	0.01686	0.9390
0.20574	0.5942	0.01349	0.9407
0.19565	0.6142	0.01349	0.9423
0.18888	0.6336	0.01686	0.9436
0.17201	0.6517	0.01687	0.9452
0.16866	0.6687	0.01686	0.9469
0.16189	0.6851	0.01686	0.9488
0.15517	0.7013	0.01349	0.9501
0.14503	0.7159	0.01686	0.9517
0.12817	0.7294	0.01012	0.9528
0.11807	0.7418	0.01012	0.9541
0.10793	0.7537	0.01349	0.9552
0.10120	0.7639	0.01012	0.9566
0.10456	0.7742	0.01686	0.9577
0.10118	0.7844	0.01349	0.9593
0.09108	0.7941	0.01349	0.9606
0.08769	0.8028	0.01349	0.9620
0.08433	0.8117	0.00675	0.9628
0.07757	0.8198	0.01349	0.9641
0.07420	0.8273	0.00675	0.9649
0.07084	0.8343	0.01349	0.9663
0.06408	0.8414	0.01686	0.9674
0.06072	0.8476	0.00675	0.9709
0.05734	0.8535	0.00675	0.9757
0.05396	0.8589	0.00498	0.9830
0.05735	0.8648	0.00382	0.9917
0.05059	0.8700	0.00288	1.0025
0.04385	0.8745	0.00178	1.0132
0.05396	0.8797	0.00121	1.0240
0.04047	0.8845	0.00093	1.0351
0.04048	0.8883	0.00065	1.0459


FRACTION SULFATED
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
9
18
27
36
45
54
63
72
81
90
TIME IN MINUTES
RUN # P438 TG # 1
PLUM RUN DOLOMITE (GF&LT LEDGES), 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
40
36
32
28
24
20
16
12
8
4
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
FRACTION SULFATED
RUN # P438 TG # 1
PLUM RUN DOLOMITE (GF&LT LEDGES), 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2



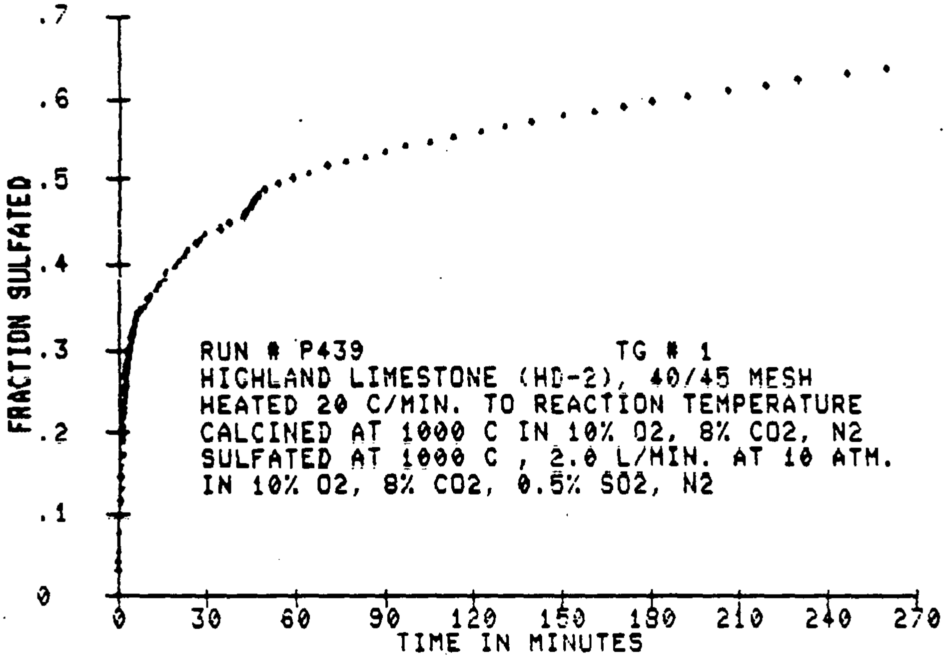
RUN # P438 TG # 1
PLUM RUN DOLOMITE (GF&LT LEDGES), 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

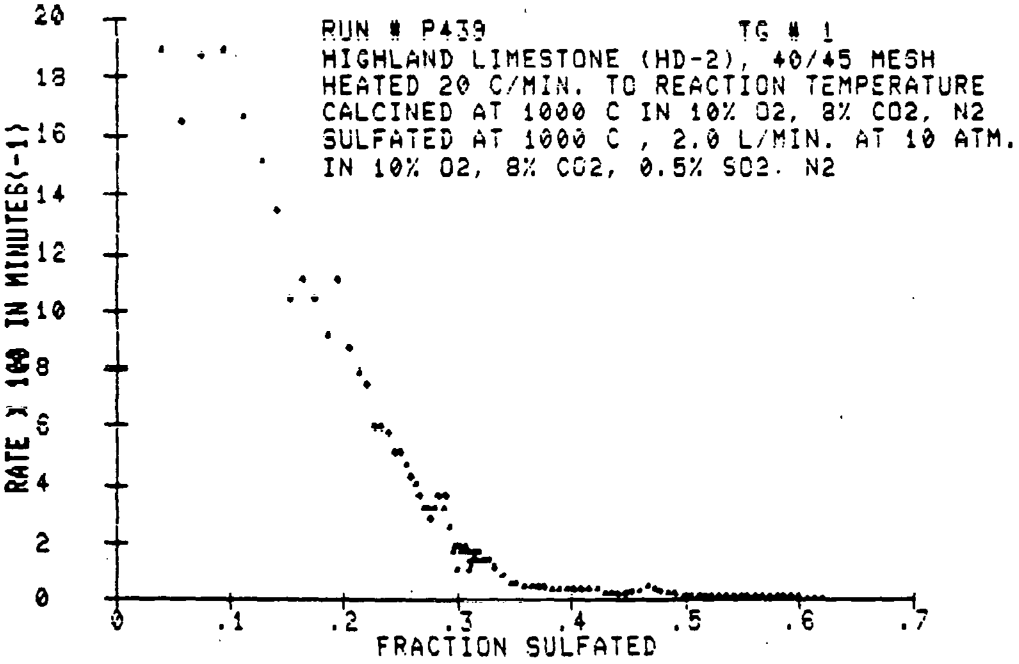
```
RUN # P438        TEMPERATURE = (1000.74 +/-  0.04 ) C

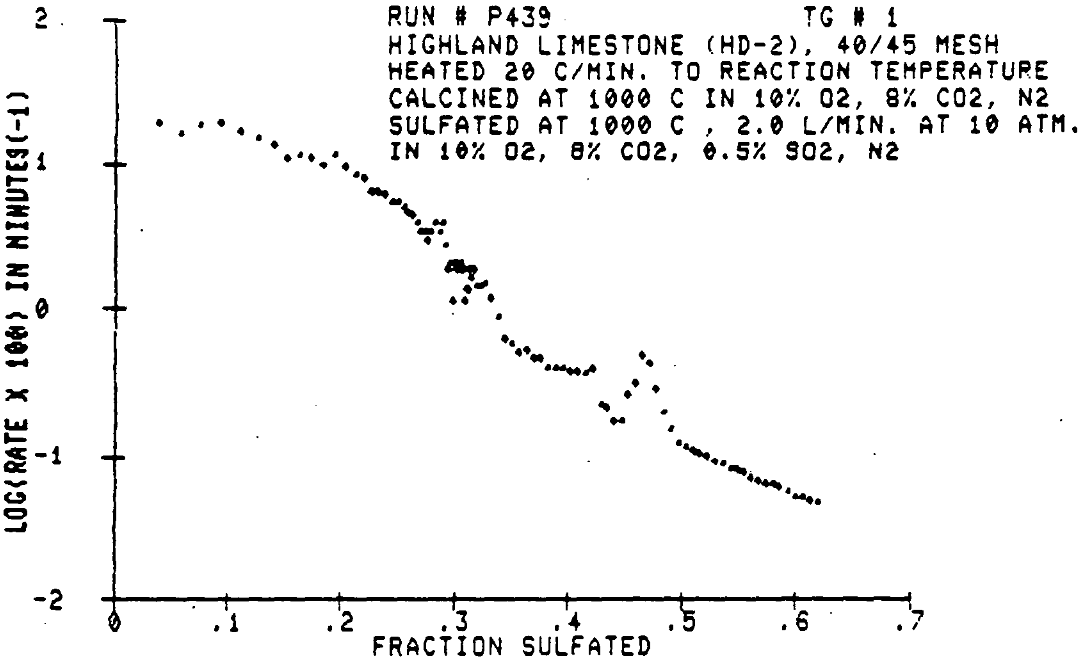
FRACTION           TIME              FRACTION          TIME
0.0000              0.00              0.8726               5.00
0.0354              0.10              0.8778               5.10
0.0695              0.20              0.8804               5.20
0.0997              0.30              0.8844               5.30
0.1404              0.40              0.8857               5.40
0.1784              0.50              0.8909               5.50
0.2165              0.60              0.8909               5.60
0.2532              0.70              0.8949               5.70
0.2874              0.80              0.8962               5.80
0.3175              0.90              0.8975               5.90
0.3503              1.00              0.9040               6.00
0.3818              1.10              0.9014               6.10
0.4081              1.20              0.9054               6.20
0.4356              1.30              0.9106               6.30
0.4619              1.40              0.9093               6.40
0.4842              1.50              0.9132               6.50
0.5065              1.60              0.9132               6.60
0.5288              1.70              0.9159               6.70
0.5524              1.80              0.9172               6.80
0.5708              1.90              0.9198               6.90
0.5918              2.00              0.9224               7.00
0.6088              2.10              0.9211               7.10
0.6285              2.20              0.9250               7.20
0.6442              2.30              0.9250               7.30
0.6600              2.40              0.9264               7.40
0.6757              2.50              0.9277               7.50
0.6889              2.60              0.9290               7.60
0.7020              2.70              0.9316               7.70
0.7151              2.80              0.9329               7.80
0.7295              2.90              0.9355               7.90
0.7400              3.00              0.9368               8.00
0.7505              3.10              0.9368               8.10
0.7610              3.20              0.9382               8.20
0.7715              3.30              0.9382               8.30
0.7820              3.40              0.9382               8.40
0.7899              3.50              0.9434               8.70
0.7978              3.60              0.9526               9.80
0.8056              3.70              0.9657              11.40
0.8135              3.80              0.9762              13.20
0.8201              3.90              0.9867              16.10
0.8266              4.00              0.9985              19.20
0.8293              4.10              1.0103              23.20
0.8371              4.20              1.0195              27.70
0.8424              4.30              1.0300              32.50
0.8502              4.40              1.0418              40.50
0.8542              4.50              1.0523              47.50
0.8581              4.60              1.0641              56.40
0.8634              4.70              1.0772              64.20
0.8660              4.80              1.0864              70.90
0.8686              4.90              1.0969              85.90
```

RUN # P438

RATE	FRACTION	RATE	FRACTION
0.35097	0.0690	0.03608	0.8731
0.35758	0.1047	0.03937	0.8768
0.36737	0.1409	0.03280	0.8802
0.38377	0.1777	0.03281	0.8838
0.36743	0.2152	0.02624	0.8865
0.34769	0.2506	0.02624	0.8893
0.33462	0.2850	0.02624	0.8917
0.32145	0.3181	0.01640	0.8941
0.30177	0.3490	0.03281	0.8967
0.29525	0.3787	0.01640	0.8988
0.27881	0.4075	0.02296	0.9009
0.25589	0.4343	0.03281	0.9038
0.24601	0.4592	0.01312	0.9061
0.23289	0.4834	0.02953	0.9080
0.22636	0.5067	0.01968	0.9103
0.21649	0.5285	0.01312	0.9124
0.21324	0.5500	0.01968	0.9138
0.20009	0.5705	0.01640	0.9159
0.19024	0.5905	0.02296	0.9177
0.18371	0.6088	0.01312	0.9193
0.17056	0.6267	0.01968	0.9211
0.16731	0.6435	0.01312	0.9227
0.15088	0.6595	0.00984	0.9240
0.14432	0.6742	0.01640	0.9250
0.13778	0.6883	0.00984	0.9266
0.13448	0.7022	0.01640	0.9279
0.12794	0.7151	0.01640	0.9295
0.12136	0.7274	0.01968	0.9313
0.11480	0.7392	0.01968	0.9332
0.10498	0.7505	0.01312	0.9347
0.10496	0.7610	0.01312	0.9361
0.09842	0.7710	0.00656	0.9371
0.09184	0.7804	0.00328	0.9376
0.08528	0.7894	0.01093	0.9389
0.07873	0.7978	0.00902	0.9421
0.07544	0.8054	0.00889	0.9476
0.07217	0.8127	0.00793	0.9552
0.05904	0.8190	0.00585	0.9649
0.05904	0.8253	0.00489	0.9759
0.05577	0.8311	0.00378	0.9875
0.05904	0.8371	0.00299	0.9983
0.06233	0.8426	0.00264	1.0090
0.05248	0.8484	0.00203	1.0200
0.05248	0.8537	0.00173	1.0308
0.03937	0.8584	0.00155	1.0416
0.03608	0.8621	0.00149	1.0531
0.03609	0.8657	0.00147	1.0644
0.03608	0.8697	0.00116	1.0754


RUN # P439 TG # 1
HIGHLAND LIMESTONE (HD-2), 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
0
.1
.2
.3
.4
.5
.6
.7
TIME IN MINUTES
0
30
60
90
120
150
180
210
240
270


RUN # P439 TG # 1
HIGHLAND LIMESTONE (HD-2), 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2· N2
RATE X 100 IN MINUTES(-1)
0
2
4
6
8
10
12
14
16
18
20
FRACTION SULFATED
0
.1
.2
.3
.4
.5
.6
.7

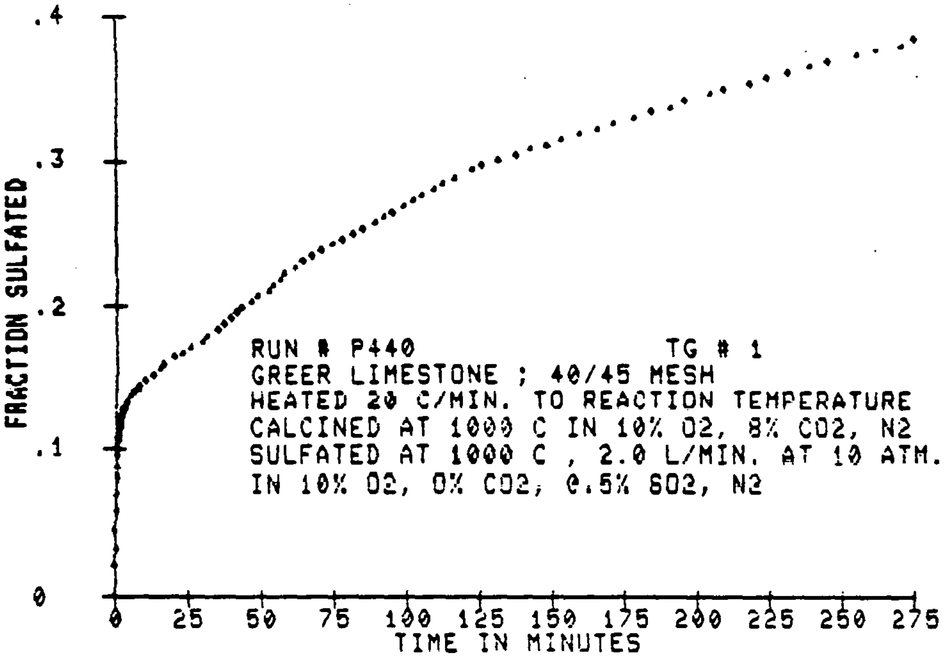

RUN # P439
TG # 1
HIGHLAND LIMESTONE (HD-2), 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
FRACTION SULFATED

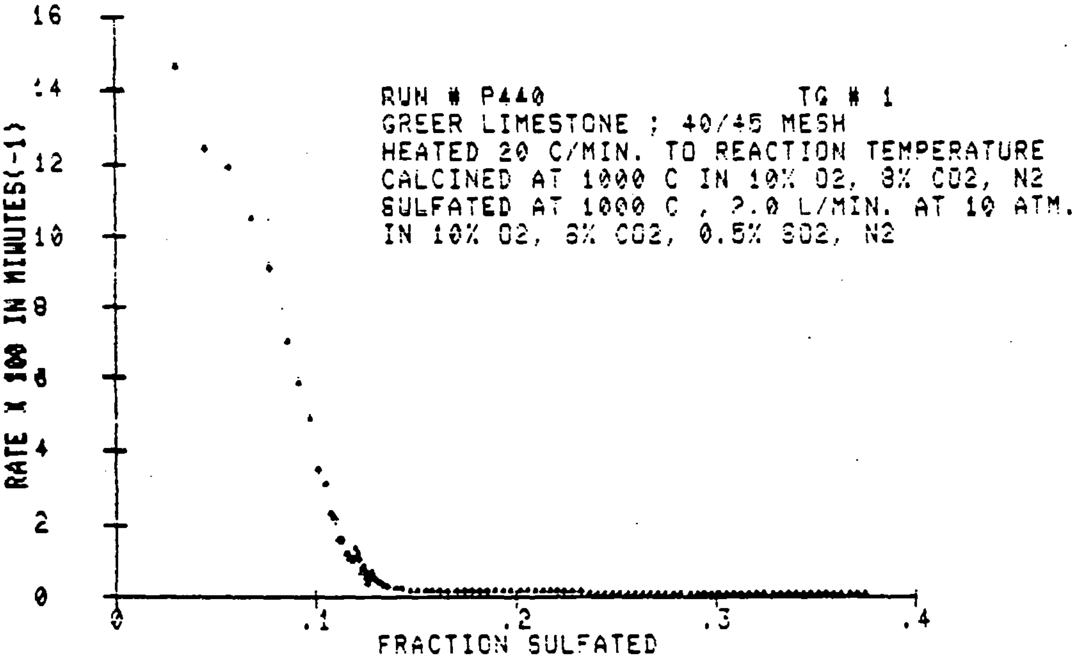
```
RUN # P439       TEMPERATURE = (1002.54 +/-  0.01 ) C

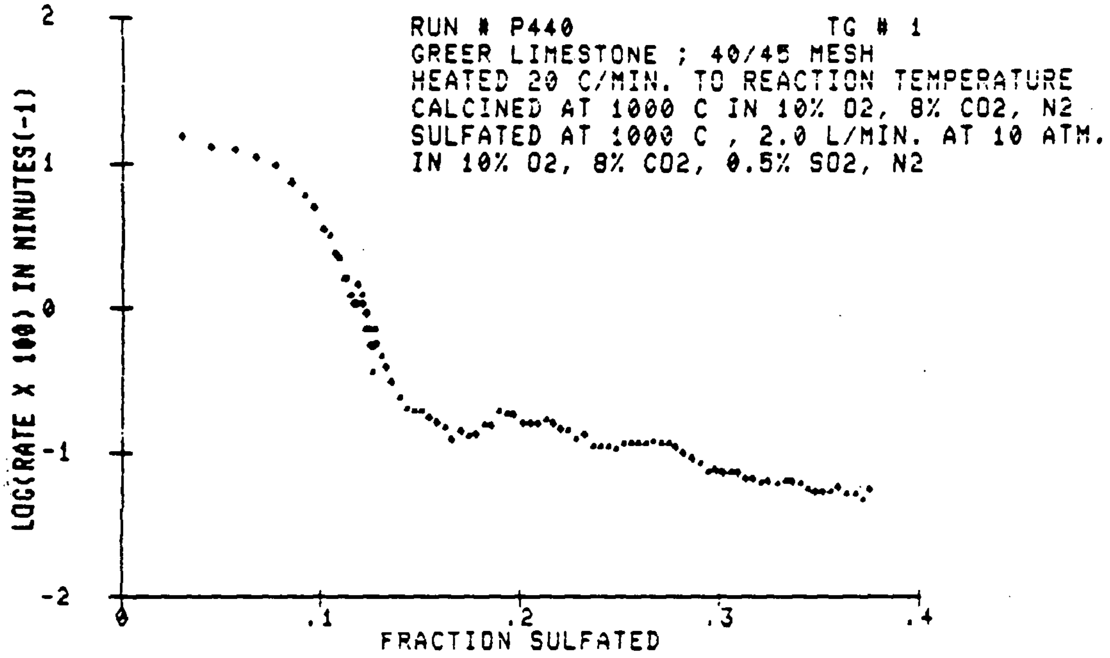
FRACTION          TIME             FRACTION          TIME
0.0000               0.00            0.3201              5.00
0.0281               0.10            0.3252              5.40
0.0392               0.20            0.3320              5.80
0.0528               0.30            0.3388              6.40
0.0758               0.40            0.3456              7.30
0.0936               0.50            0.3507              8.40
0.1141               0.60            0.3576             10.00
0.1286               0.70            0.3635             10.70
0.1422               0.80            0.3703             12.30
0.1541               0.90            0.3763             13.40
0.1677               1.00            0.3831             15.60
0.1703               1.10            0.3891             16.30
0.1864               1.20            0.3959             18.90
0.1958               1.30            0.4018             20.00
0.2043               1.40            0.4086             22.20
0.2145               1.50            0.4146             23.30
0.2213               1.60            0.4231             26.40
0.2273               1.70            0.4282             27.40
0.2341               1.80            0.4350             29.10
0.2384               1.90            0.4401             34.70
0.2452               2.00            0.4470             37.80
0.2503               2.10            0.4531             42.00
0.2545               2.20            0.4593             43.30
0.2588               2.30            0.4660             44.70
0.2639               2.40            0.4721             46.00
0.2673               2.50            0.4783             47.30
0.2707               2.60            0.4853             49.50
0.2733               2.70            0.4912             53.70
0.2767               2.80            0.4980             59.10
0.2801               2.90            0.5040             64.30
0.2818               3.00            0.5108             70.60
0.2860               3.10            0.5168             76.30
0.2912               3.20            0.5236             83.20
0.2929               3.30            0.5295             89.50
0.2963               3.40            0.5363             97.10
0.2963               3.50            0.5423            104.90
0.2980               3.60            0.5491            112.60
0.3005               3.70            0.5551            121.90
0.3005               3.80            0.5619            130.10
0.3039               3.90            0.5678            139.40
0.3048               4.00            0.5747            150.20
0.3073               4.10            0.5806            160.85
0.3082               4.20            0.5874            170.45
0.3107               4.30            0.5934            180.05
0.3116               4.40            0.6002            192.65
0.3116               4.50            0.6061            206.15
0.3133               4.60            0.6130            219.35
0.3158               4.70            0.6189            229.85
0.3184               4.80            0.6266            246.65
0.3175               4.90            0.6317            260.15
```

```
RUN # P439

RATE                 FRACTION             RATE                 FRACTION
0.18944              0.0392               0.01362              0.3227
0.16387              0.0579               0.01419              0.3267
0.18731              0.0751               0.01110              0.3324
0.18941              0.0930               0.00851              0.3385
0.16600              0.1108               0.00608              0.3450
0.15113              0.1265               0.00574              0.3513
0.13408              0.1413               0.00494              0.3576
0.10430              0.1526               0.00511              0.3637
0.11067              0.1641               0.00456              0.3702
0.10428              0.1749               0.00456              0.3765
0.09153              0.1849               0.00387              0.3829
0.11067              0.1943               0.00387              0.3892
0.08727              0.2045               0.00387              0.3957
0.07874              0.2127               0.00365              0.4020
0.07449              0.2203               0.00363              0.4088
0.05960              0.2271               0.00357              0.4153
0.05959              0.2333               0.00382              0.4219
0.05747              0.2391               0.00224              0.4282
0.05108              0.2445               0.00209              0.4347
0.05108              0.2494               0.00170              0.4407
0.04683              0.2545               0.00171              0.4469
0.04256              0.2590               0.00258              0.4531
0.04044              0.2631               0.00307              0.4595
0.03618              0.2668               0.00477              0.4658
0.03192              0.2704               0.00419              0.4722
0.03193              0.2736               0.00281              0.4786
0.02767              0.2765               0.00198              0.4850
0.03193              0.2796               0.00151              0.4914
0.03618              0.2832               0.00121              0.4979
0.03192              0.2864               0.00113              0.5042
0.03619              0.2896               0.00106              0.5106
0.02554              0.2925               0.00101              0.5169
0.01703              0.2949               0.00096              0.5234
0.01915              0.2968               0.00089              0.5297
0.01064              0.2983               0.00087              0.5362
0.01916              0.2998               0.00079              0.5425
0.01703              0.3015               0.00077              0.5489
0.01703              0.3034               0.00074              0.5552
0.01915              0.3049               0.00068              0.5617
0.01703              0.3070               0.00066              0.5680
0.01703              0.3085               0.00063              0.5745
0.01064              0.3099               0.00063              0.5808
0.01277              0.3111               0.00060              0.5872
0.01277              0.3126               0.00056              0.5935
0.01703              0.3141               0.00052              0.6000
0.01490              0.3153               0.00051              0.6063
0.01703              0.3170               0.00049              0.6130
0.01338              0.3194               0.00047              0.6193
```


FRACTION SULFATED
.4
.3
.2
.1
0
0
25
50
75
100
125
150
175
200
225
250
275
TIME IN MINUTES
RUN # P440 TG # 1
GREER LIMESTONE ; 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 0% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
16
14
12
10
8
6
4
2
0
0
.1
.2
.3
.4
FRACTION SULFATED
RUN # P440 TG # 1
GREER LIMESTONE ; 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 0% CO2, 0.5% SO2, N2

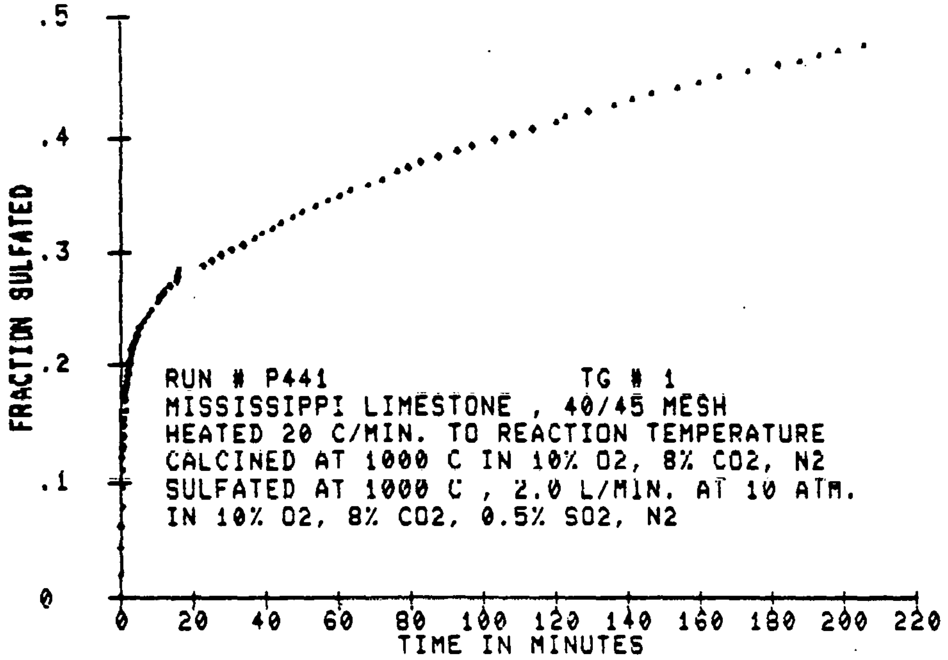

RUN # P440 TG # 1
GREER LIMESTONE ; 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
FRACTION SULFATED

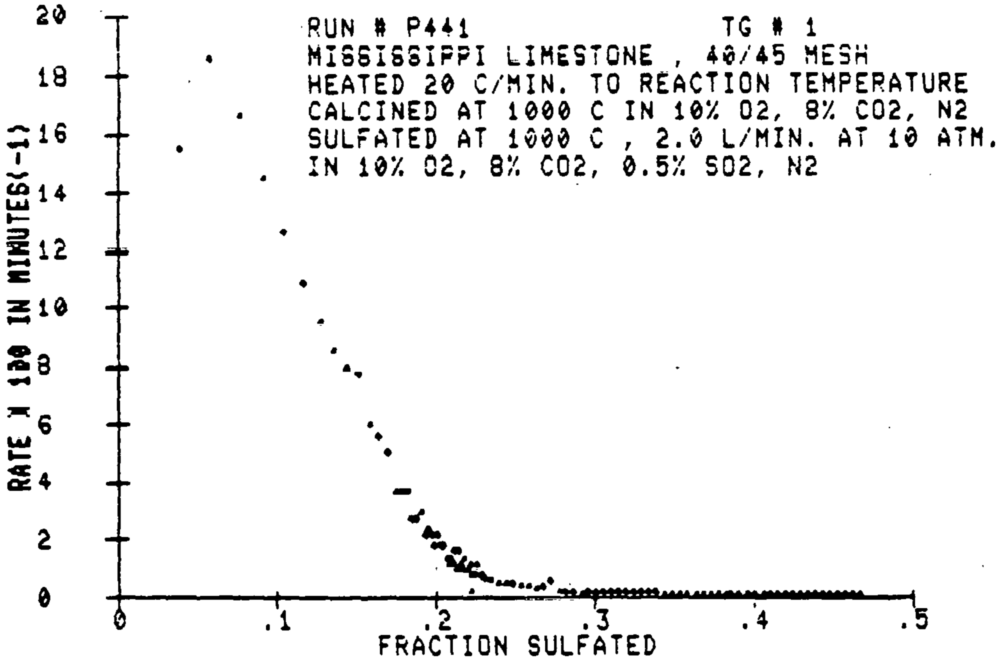
```
RUN # P440        TEMPERATURE = (1001.58 +/-  0.00 ) C

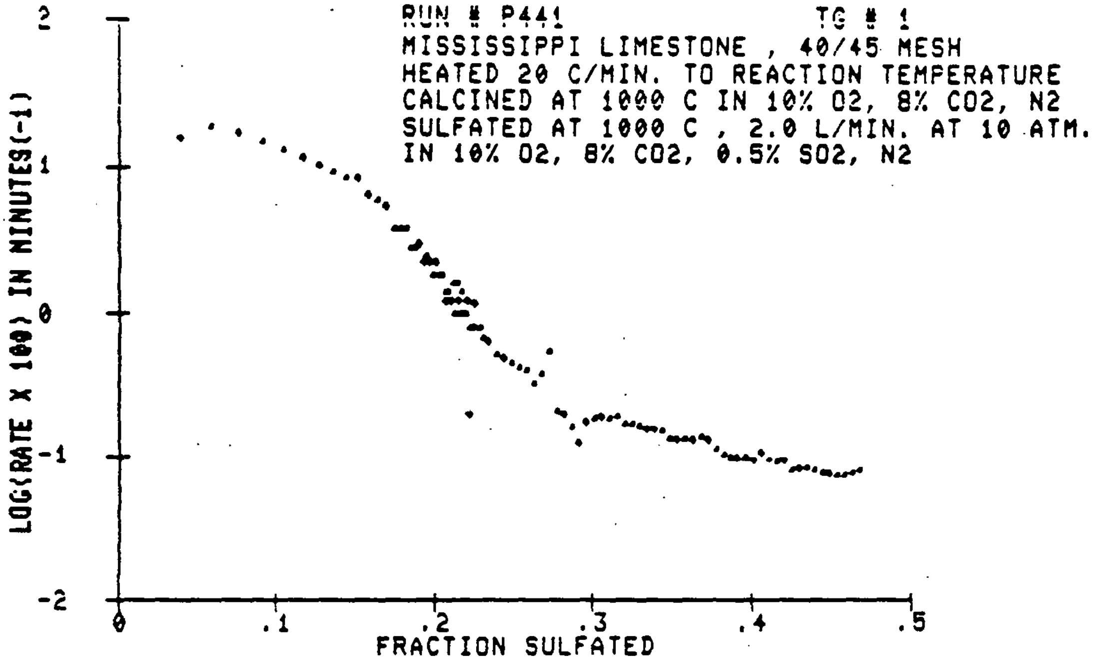
FRACTION          TIME           FRACTION         TIME
0.0000             0.00           0.1936            41.40
0.0206             0.10           0.1977            43.20
0.0323             0.20           0.2018            46.20
0.0439             0.30           0.2052            48.40
0.0583             0.40           0.2094            51.60
0.0700             0.50           0.2135            53.40
0.0796             0.60           0.2169            56.00
0.0858             0.70           0.2203            57.60
0.0947             0.80           0.2245            61.40
0.0982             0.90           0.2293            64.40
0.1030             1.00           0.2327            67.40
0.1050             1.10           0.2361            70.40
0.1085             1.20           0.2409            74.00
0.1105             1.30           0.2437            77.80
0.1119             1.40           0.2478            81.40
0.1133             1.50           0.2512            84.40
0.1146             1.60           0.2560            88.60
0.1167             1.70           0.2595            91.80
0.1167             1.80           0.2629            95.00
0.1181             1.90           0.2670            98.60
0.1188             2.00           0.2711           102.00
0.1208             2.10           0.2746           104.80
0.1222             2.20           0.2787           109.00
0.1229             2.30           0.2821           112.20
0.1229             2.40           0.2862           116.40
0.1236             2.50           0.2910           122.00
0.1256             2.60           0.2938           126.00
0.1263             2.70           0.2979           131.40
0.1256             2.80           0.3020           137.80
0.1256             2.90           0.3061           142.20
0.1270             3.00           0.3096           148.20
0.1277             3.10           0.3137           153.00
0.1277             3.20           0.3171           159.00
0.1290             3.40           0.3212           165.40
0.1318             3.90           0.3247           171.00
0.1366             5.10           0.3288           177.80
0.1393             6.40           0.3329           184.00
0.1435             8.30           0.3363           190.20
0.1469            10.40           0.3405           195.40
0.1510            12.50           0.3453           204.00
0.1551            14.90           0.3480           208.80
0.1586            16.30           0.3521           218.20
0.1634            20.20           0.3556           223.80
0.1668            22.80           0.3597           231.20
0.1702            25.20           0.3638           238.20
0.1744            29.40           0.3672           244.60
0.1778            30.80           0.3714           254.60
0.1826            35.20           0.3755           261.40
0.1860            37.40           0.3789           270.00
0.1895            39.40           0.3837           274.60
```

```
RUN # P440

RATE           FRACTION      RATE           FRACTION
0.14586        0.0310        0.00179        0.1937
0.12355        0.0450        0.00175        0.1976
0.11842        0.0568        0.00155        0.2015
0.10467        0.0675        0.00155        0.2055
0.09096        0.0777        0.00154        0.2094
0.07035        0.0857        0.00164        0.2131
0.05834        0.0923        0.00154        0.2169
0.04305        0.0973        0.00144        0.2209
0.03432        0.1019        0.00138        0.2247
0.03089        0.1050        0.00123        0.2286
0.02231        0.1078        0.00131        0.2327
0.02059        0.1098        0.00108        0.2365
0.01545        0.1117        0.00108        0.2402
0.01544        0.1134        0.00108        0.2440
0.01201        0.1146        0.00103        0.2479
0.01201        0.1159        0.00113        0.2516
0.01030        0.1170        0.00111        0.2555
0.01030        0.1182        0.00111        0.2593
0.01373        0.1193        0.00113        0.2633
0.01201        0.1205        0.00116        0.2670
0.01030        0.1215        0.00113        0.2709
0.00686        0.1225        0.00111        0.2747
0.00858        0.1234        0.00105        0.2785
0.00858        0.1242        0.00096        0.2825
0.00686        0.1248        0.00089        0.2864
0.00515        0.1253        0.00082        0.2902
0.00343        0.1260        0.00074        0.2942
0.00343        0.1264        0.00075        0.2982
0.00515        0.1267        0.00071        0.3019
0.00686        0.1274        0.00073        0.3059
0.00534        0.1286        0.00071        0.3097
0.00446        0.1306        0.00065        0.3136
0.00365        0.1329        0.00066        0.3173
0.00294        0.1360        0.00061        0.3211
0.00232        0.1396        0.00063        0.3250
0.00195        0.1435        0.00061        0.3288
0.00186        0.1472        0.00065        0.3326
0.00189        0.1510        0.00063        0.3368
0.00168        0.1550        0.00061        0.3406
0.00153        0.1590        0.00056        0.3444
0.00147        0.1628        0.00053        0.3483
0.00121        0.1667        0.00053        0.3521
0.00136        0.1705        0.00054        0.3558
0.00127        0.1744        0.00057        0.3597
0.00129        0.1782        0.00051        0.3635
0.00151        0.1820        0.00052        0.3675
0.00149        0.1859        0.00047        0.3714
0.00189        0.1899        0.00055        0.3753
```


.5
.4
.3
.2
.1
0
FRACTION SULFATED
RUN # P441 TG # 1
MISSISSIPPI LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0 20 40 60 80 100 120 140 160 180 200 220
TIME IN MINUTES


20
18
16
14
12
10
8
6
4
2
0
RATE X 100 IN MINUTES(-1)
RUN # P441 TG # 1
MISSISSIPPI LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0 .1 .2 .3 .4 .5
FRACTION SULFATED

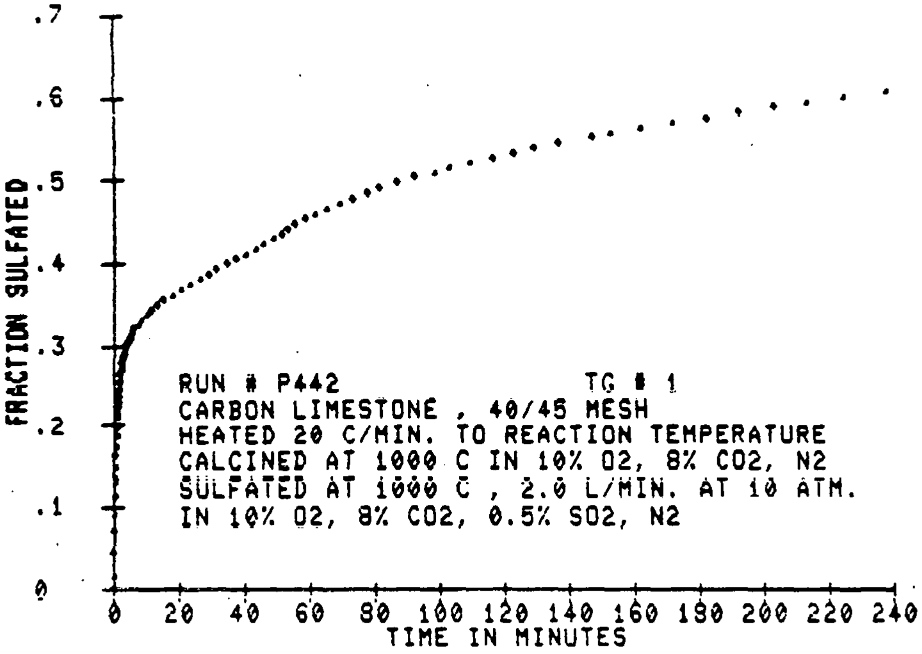

RUN # P441 TG # 1
MISSISSIPPI LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
FRACTION SULFATED

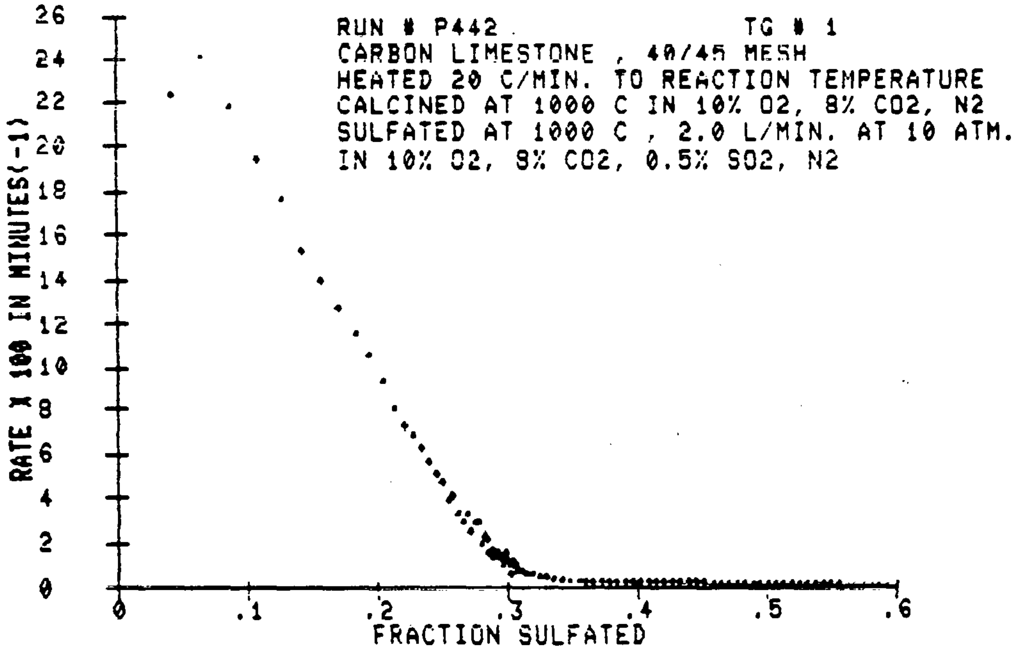
```
RUN # P441       TEMPERATURE = (1001.33 +/-  0.00 ) C

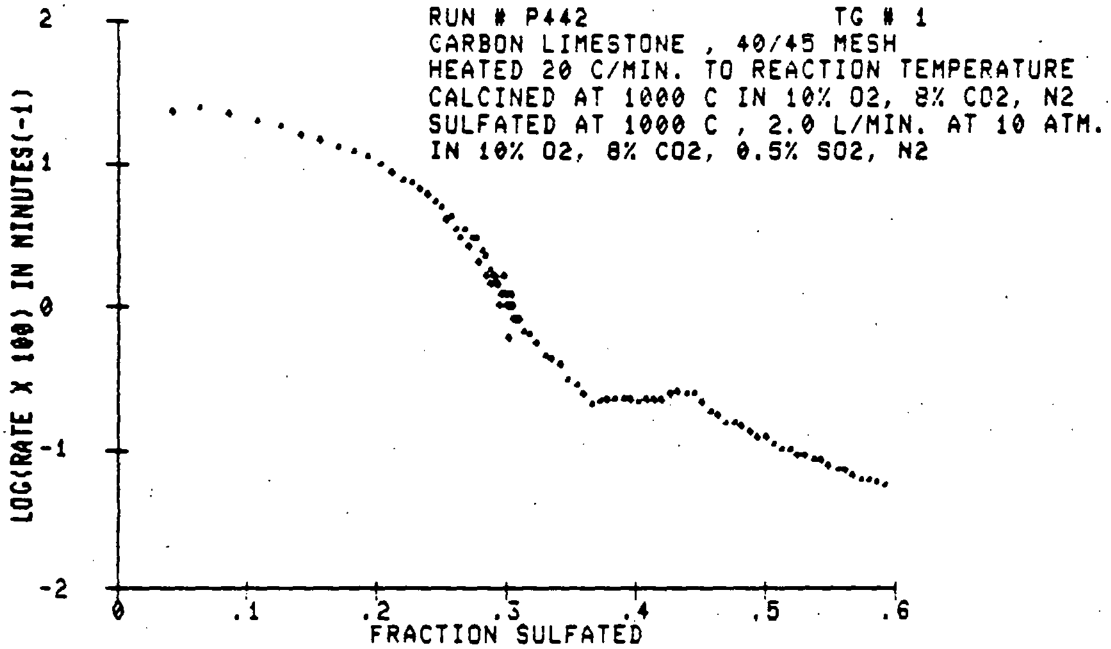

FRACTION        TIME               FRACTION        TIME
0.0000             0.00             0.2432              7.60
0.0193             0.20             0.2479              8.70
0.0417             0.30             0.2548             10.20
0.0602             0.40             0.2579             11.00
0.0772             0.50             0.2626             12.30
0.0934             0.60             0.2680             13.90
0.1081             0.70             0.2718             15.60
0.1181             0.80             0.2765             16.00
0.1274             0.90             0.2826             16.15
0.1367             1.00             0.2865             23.05
0.1459             1.10             0.2911             25.75
0.1521             1.20             0.2958             28.30
0.1591             1.30             0.3004             31.15
0.1676             1.40             0.3050             34.00
0.1699             1.50             0.3112             37.00
0.1745             1.60             0.3151             38.80
0.1792             1.70             0.3197             41.95
0.1822             1.80             0.3243             44.35
0.1846             1.90             0.3290             47.65
0.1892             2.00             0.3336             50.05
0.1900             2.10             0.3390             54.10
0.1931             2.20             0.3436             57.40
0.1961             2.30             0.3483             60.55
0.1977             2.40             0.3529             63.40
0.1992             2.50             0.3575             68.65
0.2015             2.60             0.3622             72.40
0.2031             2.70             0.3683             76.45
0.2062             2.80             0.3730             79.60
0.2062             2.90             0.3768             83.20
0.2085             3.00             0.3815             88.00
0.2085             3.10             0.3861             92.95
0.2108             3.20             0.3907             97.45
0.2116             3.30             0.3961            103.60
0.2131             3.40             0.4008            108.70
0.2147             3.50             0.4054            113.80
0.2147             3.60             0.4108            120.10
0.2178             3.70             0.4155            122.80
0.2178             3.80             0.4193            129.40
0.2185             3.90             0.4247            136.30
0.2201             4.00             0.4294            141.25
0.2216             4.10             0.4340            146.95
0.2216             4.20             0.4386            154.00
0.2232             4.30             0.4433            159.70
0.2232             4.40             0.4479            165.70
0.2224             4.50             0.4533            173.35
0.2247             4.60             0.4587            182.20
0.2263             4.70             0.4626            187.60
0.2263             4.80             0.4672            193.15
0.2301             5.20             0.4718            198.55
0.2340             5.80             0.4765            205.45
0.2386             6.60
```

RUN # P441

RATE	FRACTION	RATE	FRACTION
0.15444	0.0397	0.00474	0.2437
0.18532	0.0584	0.00439	0.2485
0.16604	0.0761	0.00411	0.2533
0.14478	0.0914	0.00386	0.2582
0.12550	0.1049	0.00315	0.2630
0.10810	0.1168	0.00371	0.2673
0.09459	0.1273	0.00522	0.2723
0.08495	0.1361	0.00203	0.2771
0.07915	0.1443	0.00190	0.2817
0.07723	0.1523	0.00157	0.2865
0.05984	0.1589	0.00118	0.2913
0.05598	0.1646	0.00169	0.2958
0.05020	0.1700	0.00178	0.3007
0.03668	0.1747	0.00184	0.3055
0.03668	0.1781	0.00179	0.3103
0.03668	0.1819	0.00187	0.3151
0.02703	0.1850	0.00167	0.3199
0.02703	0.1878	0.00165	0.3243
0.02896	0.1906	0.00159	0.3291
0.02124	0.1932	0.00148	0.3339
0.02317	0.1952	0.00150	0.3387
0.02123	0.1975	0.00145	0.3435
0.01738	0.1995	0.00127	0.3483
0.02123	0.2015	0.00124	0.3529
0.01738	0.2032	0.00126	0.3578
0.01737	0.2051	0.00124	0.3628
0.01351	0.2065	0.00133	0.3676
0.01158	0.2080	0.00124	0.3724
0.01351	0.2091	0.00108	0.3772
0.01158	0.2105	0.00100	0.3816
0.01544	0.2117	0.00095	0.3863
0.00965	0.2130	0.00093	0.3911
0.01545	0.2144	0.00093	0.3958
0.01158	0.2156	0.00089	0.4008
0.00965	0.2167	0.00101	0.4057
0.01351	0.2178	0.00090	0.4104
0.00965	0.2192	0.00086	0.4151
0.00965	0.2199	0.00088	0.4199
0.01158	0.2210	0.00077	0.4246
0.00772	0.2219	0.00078	0.4292
0.00193	0.2224	0.00079	0.4340
0.00772	0.2230	0.00076	0.4386
0.00772	0.2239	0.00073	0.4434
0.00772	0.2246	0.00071	0.4484
0.01103	0.2260	0.00069	0.4531
0.00772	0.2283	0.00070	0.4579
0.00650	0.2310	0.00074	0.4627
0.00607	0.2344	0.00076	0.4673
0.00507	0.2388		


RUN # P442 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
0
.1
.2
.3
.4
.5
.6
.7
0
20
40
60
80
100
120
140
160
180
200
220
240
TIME IN MINUTES


RUN # P442 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
.1
.2
.3
.4
.5
.6
FRACTION SULFATED

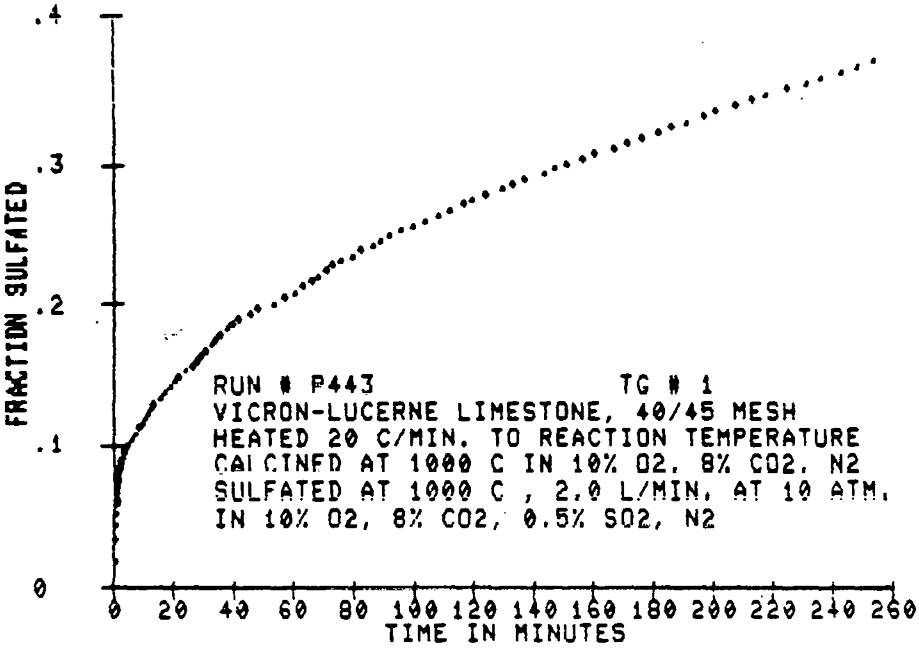

RUN # P442 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
FRACTION SULFATED

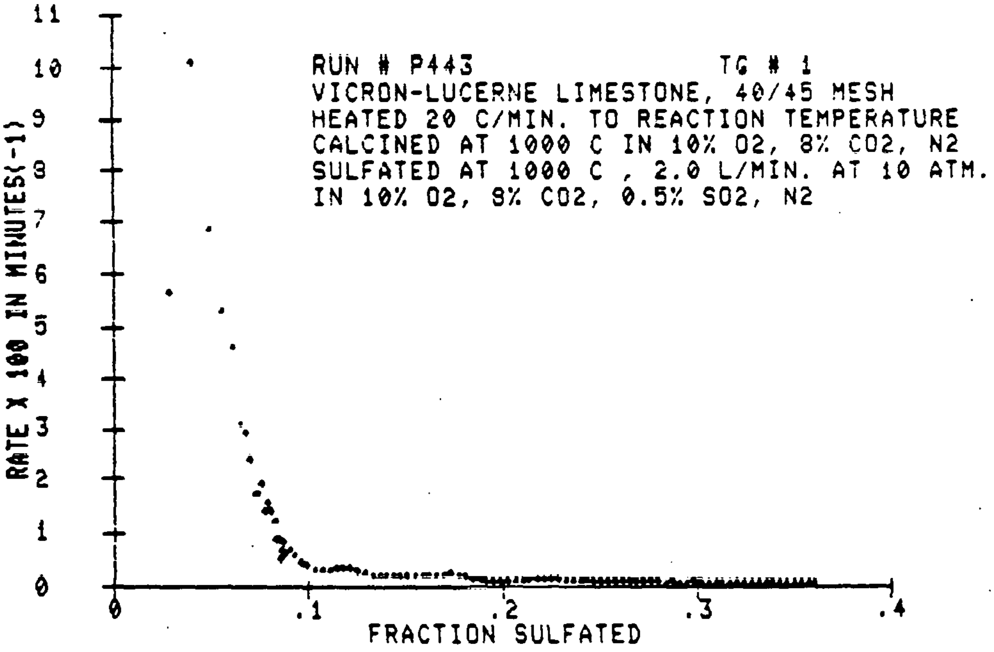
```
RUN # P442        TEMPERATURE = (1002.13 +/-   0.01 ) C

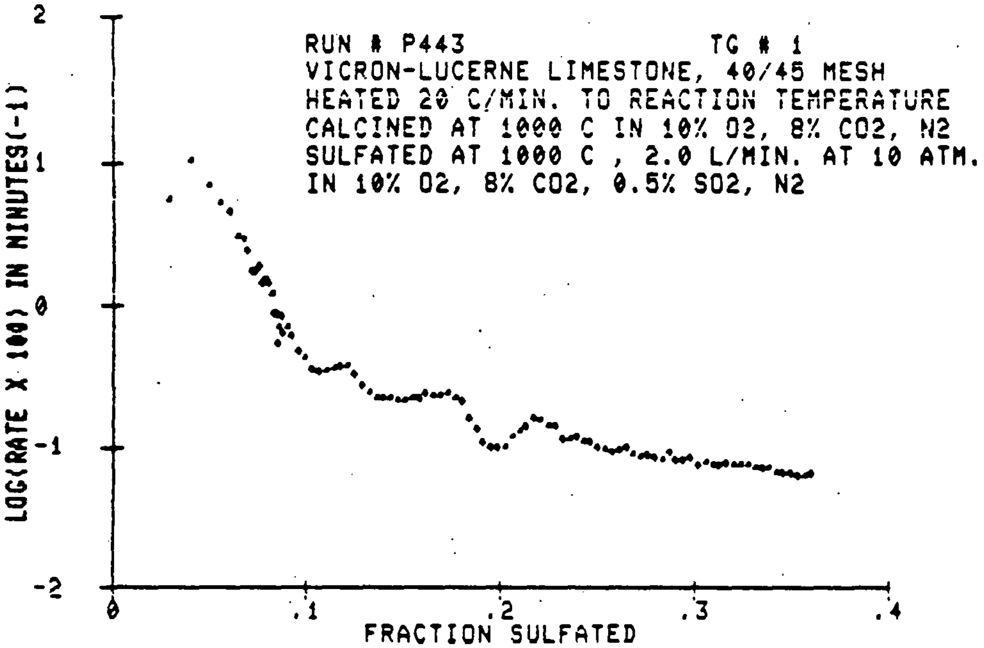

FRACTION          TIME              FRACTION          TIME
0.0000              0.00             0.3083             5.00
0.0141              0.10             0.3122             5.50
0.0415              0.20             0.3184             6.20
0.0673              0.30             0.3239             7.40
0.0892              0.40             0.3302             8.50
0.1103              0.50             0.3364            10.00
0.1283              0.60             0.3419            11.50
0.1447              0.70             0.3482            13.30
0.1596              0.80             0.3552            15.00
0.1713              0.90             0.3607            18.00
0.1839              1.00             0.3669            20.60
0.1956              1.10             0.3724            23.50
0.2058              1.20             0.3787            26.40
0.2136              1.30             0.3849            29.30
0.2214              1.40             0.3912            31.80
0.2277              1.50             0.3975            34.70
0.2347              1.60             0.4037            37.70
0.2410              1.70             0.4092            40.30
0.2465              1.80             0.4155            43.20
0.2504              1.90             0.4217            45.90
0.2551              2.00             0.4280            48.70
0.2598              2.10             0.4334            51.40
0.2621              2.20             0.4397            53.50
0.2668              2.30             0.4460            55.70
0.2684              2.40             0.4522            58.70
0.2715              2.50             0.4585            61.80
0.2754              2.60             0.4640            65.00
0.2770              2.70             0.4702            69.30
0.2801              2.80             0.4765            73.20
0.2832              2.90             0.4827            77.90
0.2832              3.00             0.4890            81.70
0.2864              3.10             0.4953            87.00
0.2887              3.20             0.5015            92.50
0.2895              3.30             0.5070            98.20
0.2903              3.40             0.5140           102.85
0.2918              3.50             0.5195           109.45
0.2950              3.60             0.5250           116.50
0.2957              3.70             0.5312           122.80
0.2957              3.80             0.5375           129.40
0.2973              3.90             0.5438           137.05
0.2989              4.00             0.5508           147.70
0.3004              4.10             0.5555           152.95
0.3020              4.20             0.5618           162.10
0.3020              4.30             0.5680           172.00
0.3028              4.40             0.5743           182.35
0.3044              4.50             0.5805           192.55
0.3044              4.60             0.5860           203.35
0.3059              4.70             0.5923           213.55
0.3075              4.80             0.5985           224.95
0.3075              4.90             0.6048           237.85
```

RUN # P442

RATE	FRACTION	RATE	FRACTION
0.22297	0.0424	0.00782	0.3108
0.24061	0.0645	0.00657	0.3141
0.21710	0.0873	0.00626	0.3186
0.19363	0.1080	0.00539	0.3242
0.17606	0.1264	0.00443	0.3302
0.15256	0.1429	0.00411	0.3361
0.13889	0.1576	0.00385	0.3424
0.12713	0.1710	0.00303	0.3485
0.11540	0.1832	0.00275	0.3546
0.10563	0.1940	0.00238	0.3607
0.09388	0.2040	0.00206	0.3668
0.08020	0.2128	0.00215	0.3727
0.07237	0.2206	0.00217	0.3788
0.06846	0.2277	0.00224	0.3849
0.06260	0.2343	0.00222	0.3912
0.05672	0.2400	0.00220	0.3973
0.05086	0.2455	0.00213	0.4034
0.04694	0.2505	0.00217	0.4095
0.03912	0.2547	0.00220	0.4156
0.04108	0.2588	0.00219	0.4216
0.03325	0.2624	0.00235	0.4277
0.02934	0.2657	0.00247	0.4338
0.03325	0.2688	0.00243	0.4399
0.02543	0.2718	0.00241	0.4460
0.02934	0.2745	0.00211	0.4521
0.02934	0.2774	0.00178	0.4582
0.01956	0.2798	0.00167	0.4643
0.02347	0.2820	0.00151	0.4704
0.02151	0.2843	0.00150	0.4765
0.01565	0.2862	0.00141	0.4827
0.01760	0.2876	0.00130	0.4890
0.01369	0.2893	0.00119	0.4951
0.01565	0.2911	0.00118	0.5014
0.01565	0.2925	0.00108	0.5075
0.01369	0.2937	0.00098	0.5134
0.01369	0.2951	0.00099	0.5194
0.00978	0.2965	0.00088	0.5255
0.01174	0.2976	0.00088	0.5314
0.01565	0.2989	0.00083	0.5377
0.01174	0.3001	0.00080	0.5438
0.00978	0.3012	0.00074	0.5499
0.00978	0.3023	0.00069	0.5560
0.00587	0.3031	0.00068	0.5621
0.00978	0.3039	0.00063	0.5680
0.01174	0.3050	0.00059	0.5741
0.00782	0.3059	0.00058	0.5802
0.00978	0.3067	0.00057	0.5863
0.00782	0.3083	0.00054	0.5924


FRACTION SULFATED
.4
.3
.2
.1
0
RUN # P443 TG # 1
VICRON-LUCERNE LIMESTONE, 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0 20 40 60 80 100 120 140 160 180 200 220 240 260
TIME IN MINUTES


RATE X 100 IN MINUTES(-1)
11
10
9
8
7
6
5
4
3
2
1
0
RUN # P443 TG # 1
VICRON-LUCERNE LIMESTONE, 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0 .1 .2 .3 .4
FRACTION SULFATED

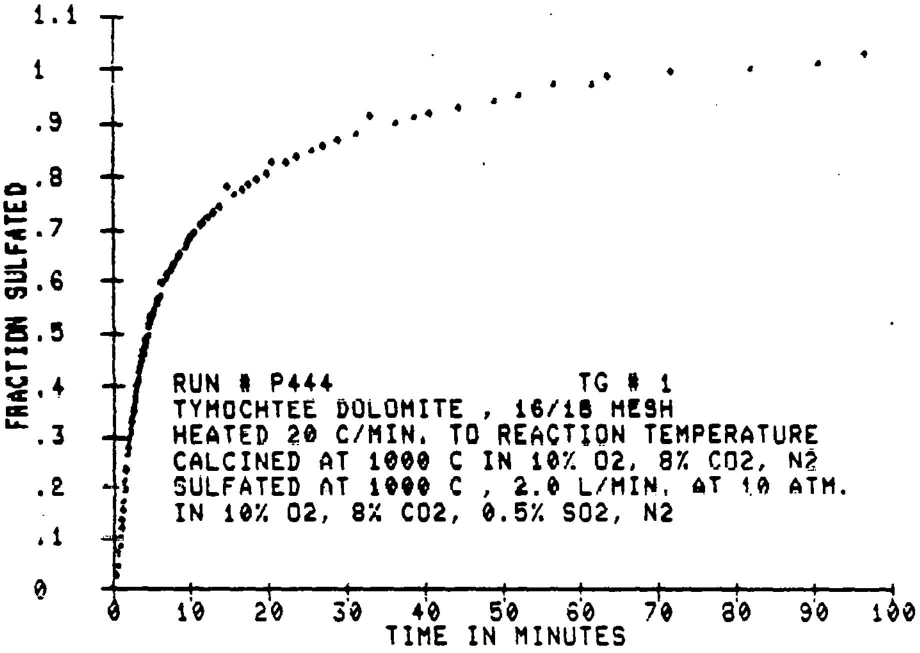

RUN # P443 TG # 1
VICRON-LUCERNE LIMESTONE, 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
FRACTION SULFATED

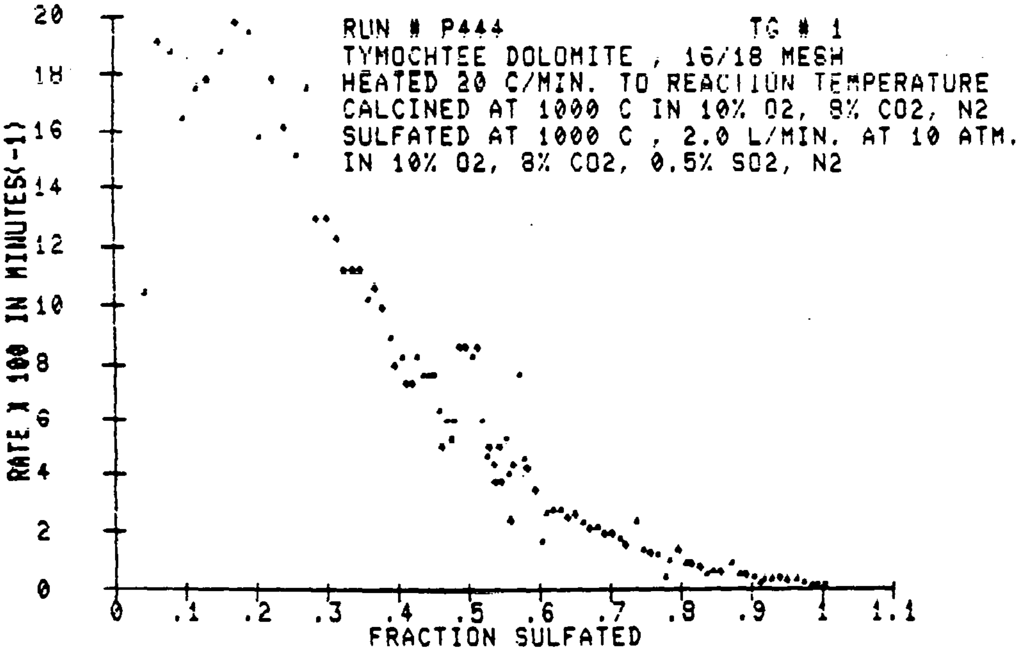
```
RUN # P443       TEMPERATURE = (1001.23 +/-  0.01 ) C

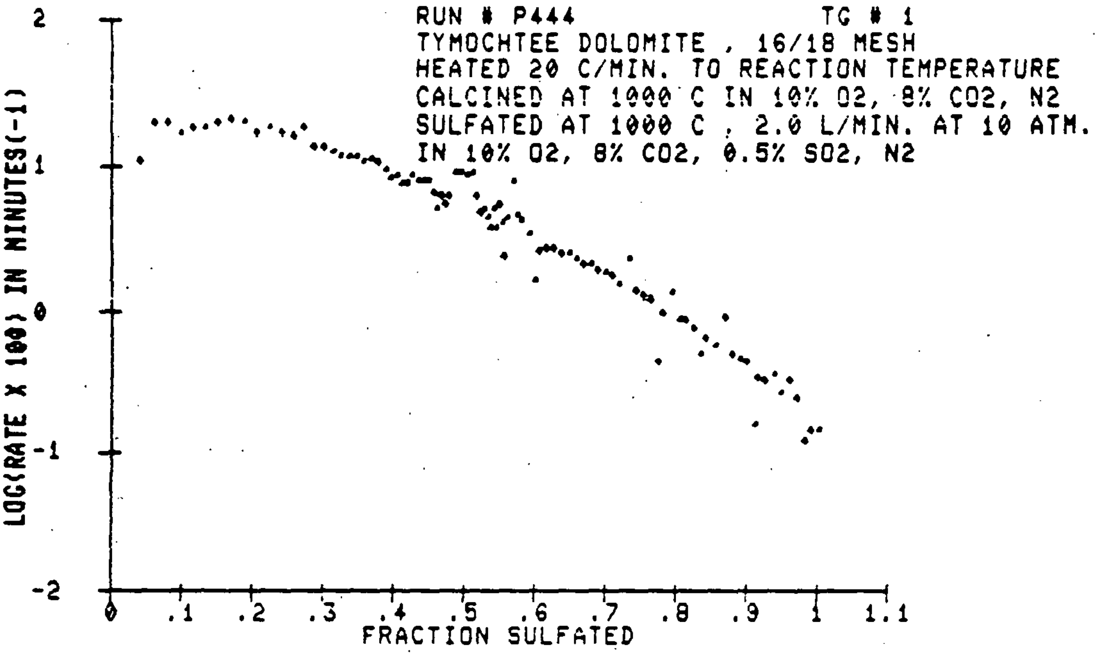
FRACTION         TIME            FRACTION         TIME
0.0000             0.00           0.1876            41.50
0.0178             0.60           0.1917            45.40
0.0335             0.70           0.1951            48.10
0.0438             0.80           0.1985            53.30
0.0507             0.90           0.2026            57.20
0.0582             1.00           0.2061            60.30
0.0609             1.10           0.2102            63.30
0.0650             1.20           0.2136            66.10
0.0691             1.30           0.2170            68.40
0.0705             1.40           0.2211            71.40
0.0726             1.50           0.2252            73.00
0.0746             1.60           0.2280            75.60
0.0760             1.70           0.2321            79.30
0.0774             1.80           0.2362            82.40
0.0801             1.90           0.2396            86.20
0.0801             2.00           0.2430            89.10
0.0822             2.10           0.2465            91.85
0.0828             2.20           0.2506            95.75
0.0849             2.30           0.2540            99.95
0.0849             2.40           0.2574           103.85
0.0856             2.50           0.2615           107.90
0.0863             2.60           0.2649           111.95
0.0869             2.70           0.2697           117.05
0.0876             2.80           0.2725           119.60
0.0897             3.00           0.2759           124.40
0.0924             3.60           0.2800           129.95
0.0965             4.10           0.2834           133.25
0.0993             4.80           0.2869           137.30
0.1034             6.00           0.2910           143.30
0.1068             7.10           0.2951           147.05
0.1116             8.60           0.2978           151.55
0.1143             9.50           0.3019           156.80
0.1178            10.40           0.3053           160.85
0.1219            11.50           0.3094           167.30
0.1253            12.50           0.3129           171.50
0.1287            13.50           0.3163           176.45
0.1328            15.30           0.3204           181.85
0.1362            17.00           0.3238           186.50
0.1403            19.00           0.3272           191.15
0.1438            20.60           0.3314           197.15
0.1472            22.00           0.3348           201.35
0.1513            24.10           0.3389           207.95
0.1547            26.10           0.3423           213.35
0.1581            27.60           0.3457           217.85
0.1623            29.10           0.3498           225.05
0.1657            31.00           0.3533           231.05
0.1698            32.70           0.3567           236.00
0.1732            34.30           0.3608           242.90
0.1766            35.60           0.3642           248.45
0.1814            37.70           0.3676           253.85
0.1842            39.50
```

```
RUN # P443

RATE               FRACTION           RATE               FRACTION
0.05629            0.0292             0.00132            0.1880
0.10098            0.0408             0.00104            0.1914
0.06846            0.0494             0.00096            0.1951
0.05306            0.0557             0.00096            0.1988
0.04621            0.0608             0.00099            0.2025
0.03081            0.0648             0.00118            0.2062
0.02909            0.0676             0.00128            0.2099
0.02396            0.0704             0.00136            0.2136
0.01712            0.0726             0.00155            0.2174
0.01711            0.0742             0.00151            0.2210
0.01883            0.0761             0.00138            0.2247
0.01369            0.0776             0.00137            0.2285
0.01540            0.0791             0.00109            0.2322
0.01369            0.0805             0.00112            0.2358
0.01198            0.0820             0.00115            0.2395
0.01198            0.0830             0.00108            0.2432
0.00856            0.0841             0.00105            0.2467
0.00856            0.0849             0.00097            0.2503
0.00514            0.0857             0.00094            0.2540
0.00685            0.0863             0.00089            0.2577
0.00822            0.0872             0.00092            0.2615
0.00616            0.0886             0.00096            0.2652
0.00685            0.0906             0.00087            0.2689
0.00582            0.0931             0.00084            0.2726
0.00456            0.0963             0.00085            0.2763
0.00411            0.0997             0.00081            0.2797
0.00335            0.1035             0.00080            0.2834
0.00320            0.1071             0.00088            0.2873
0.00327            0.1108             0.00079            0.2908
0.00342            0.1145             0.00077            0.2945
0.00351            0.1182             0.00082            0.2982
0.00359            0.1216             0.00071            0.3019
0.00307            0.1253             0.00075            0.3055
0.00261            0.1290             0.00073            0.3092
0.00232            0.1327             0.00072            0.3129
0.00212            0.1364             0.00075            0.3166
0.00215            0.1401             0.00073            0.3201
0.00212            0.1438             0.00073            0.3238
0.00202            0.1475             0.00074            0.3275
0.00205            0.1510             0.00070            0.3312
0.00212            0.1547             0.00068            0.3349
0.00208            0.1584             0.00069            0.3386
0.00228            0.1621             0.00064            0.3423
0.00225            0.1658             0.00062            0.3460
0.00221            0.1695             0.00063            0.3496
0.00235            0.1733             0.00060            0.3533
0.00211            0.1770             0.00061            0.3570
0.00200            0.1806             0.00063            0.3605
0.00154            0.1843
```


RUN # P444 TG # 1
TYMOCHTEE DOLOMITE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
TIME IN MINUTES
0
10
20
30
40
50
60
70
80
90
100


RUN # P444 TG # 1
TYMOCHTEE DOLOMITE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
0
2
4
6
8
10
12
14
16
18
20
FRACTION SULFATED
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1

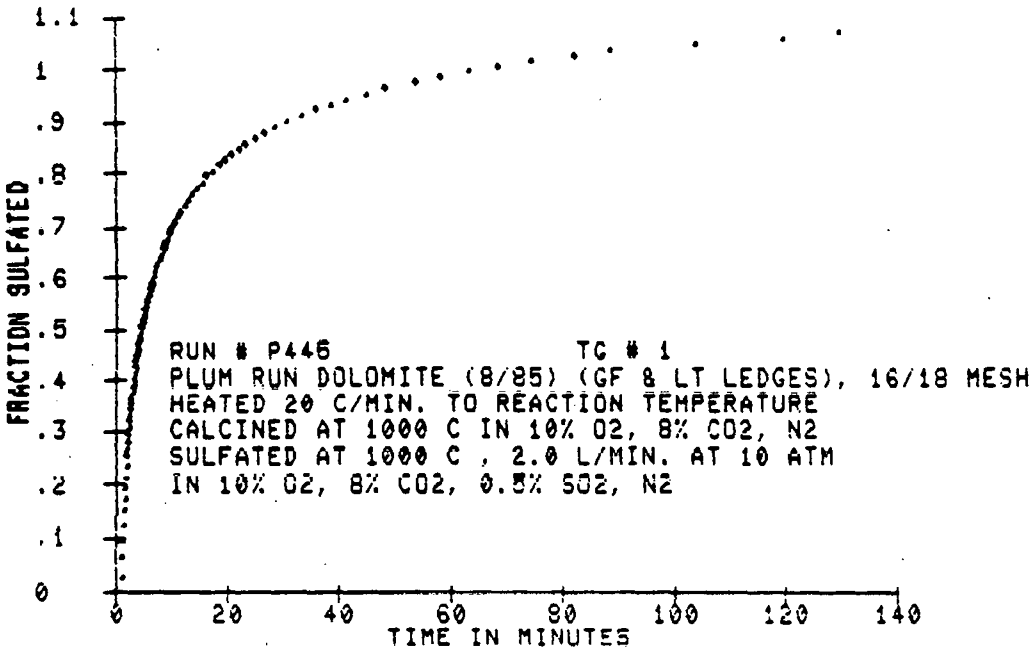

RUN # P444 TG # 1
TYMOCHTEE DOLOMITE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
FRACTION SULFATED

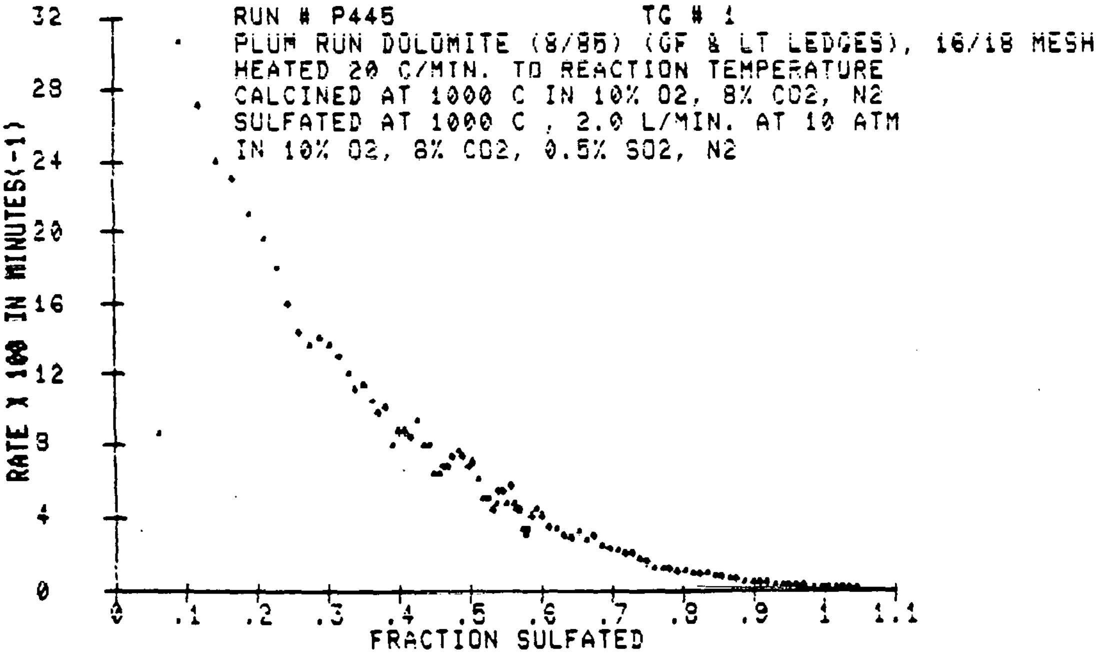
RUN # P444 TEMPERATURE = (999.89 +/- 0.02) C

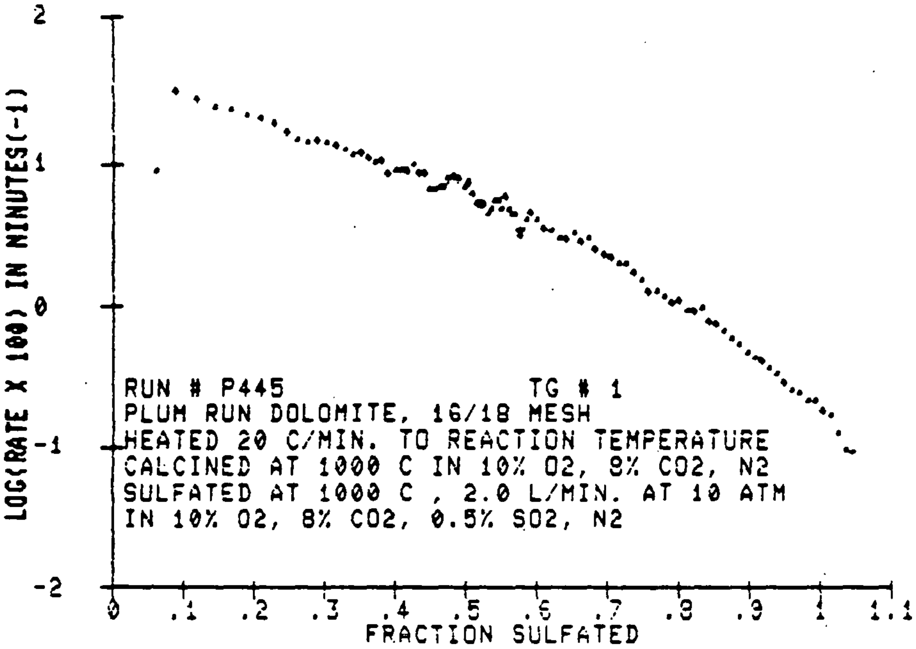
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.5541	5.40
0.0237	0.50	0.5541	5.50
0.0421	0.60	0.5660	5.60
0.0658	0.70	0.5620	5.70
0.0829	0.80	0.5633	5.80
0.1000	0.90	0.5712	5.90
0.1171	1.00	0.5962	6.00
0.1316	1.10	0.5936	6.40
0.1527	1.20	0.6002	6.70
0.1711	1.30	0.6081	7.00
0.1922	1.40	0.6186	7.40
0.2106	1.50	0.6393	7.80
0.2303	1.60	0.6423	8.30
0.2343	1.70	0.6502	8.60
0.2632	1.80	0.6621	9.20
0.2751	1.90	0.6713	9.50
0.2909	2.00	0.6805	10.00
0.3040	2.10	0.6910	10.60
0.3146	2.20	0.7055	11.30
0.3264	2.30	0.7121	11.70
0.3396	2.40	0.7226	12.30
0.3488	2.50	0.7318	13.00
0.3593	2.60	0.7423	13.80
0.3712	2.70	0.7779	14.60
0.3804	2.80	0.7647	15.50
0.3909	2.90	0.7739	16.50
0.3988	3.00	0.7845	17.40
0.4067	3.10	0.7937	18.40
0.4120	3.20	0.8042	19.70
0.4238	3.30	0.8239	20.40
0.4278	3.40	0.8253	22.20
0.4357	3.50	0.8358	23.50
0.4449	3.60	0.8463	25.50
0.4541	3.70	0.8555	27.00
0.4580	3.80	0.8661	28.90
0.4659	3.90	0.8779	31.20
0.4699	4.00	0.9108	33.00
0.4738	4.10	0.8990	36.20
0.4817	4.20	0.9082	38.50
0.4870	4.30	0.9174	40.70
0.4936	4.40	0.9279	44.40
0.5081	4.50	0.9398	48.90
0.5160	4.60	0.9490	51.90
0.5199	4.70	0.9714	56.50
0.5278	4.80	0.9714	61.40
0.5318	4.90	0.9845	63.60
0.5344	5.00	0.9937	71.60
0.5396	5.10	1.0003	81.90
0.5449	5.20	1.0109	90.60
0.5462	5.30	1.0306	96.60

RUN # P444

RATE	FRACTION	RATE	FRACTION
0.10365	0.0429	0.05265	0.5531
0.19084	0.0629	0.03949	0.5565
0.18758	0.0816	0.02303	0.5599
0.16452	0.0995	0.04277	0.5633
0.17441	0.1169	0.07569	0.5718
0.17768	0.1345	0.04513	0.5773
0.18755	0.1529	0.04095	0.5849
0.19745	0.1716	0.03350	0.5939
0.19413	0.1914	0.01598	0.6034
0.15796	0.2077	0.02538	0.6099
0.17768	0.2261	0.02632	0.6197
0.16123	0.2427	0.02632	0.6297
0.15138	0.2588	0.02413	0.6405
0.17439	0.2735	0.02478	0.6510
0.12834	0.2896	0.02245	0.6613
0.12832	0.3022	0.02040	0.6710
0.12174	0.3151	0.02068	0.6821
0.11189	0.3267	0.01855	0.6921
0.11187	0.3377	0.01831	0.7023
0.11189	0.3491	0.01700	0.7126
0.10200	0.3599	0.01474	0.7229
0.10529	0.3701	0.02269	0.7373
0.09873	0.3801	0.01316	0.7479
0.08884	0.3896	0.01203	0.7581
0.07898	0.3978	0.01170	0.7687
0.08226	0.4064	0.00416	0.7789
0.07239	0.4138	0.00940	0.7842
0.07240	0.4212	0.01282	0.7960
0.08226	0.4288	0.00850	0.8063
0.07569	0.4372	0.00826	0.8166
0.07568	0.4441	0.00726	0.8271
0.07568	0.4517	0.00479	0.8374
0.06253	0.4586	0.00609	0.8458
0.04936	0.4644	0.00547	0.8563
0.05924	0.4699	0.00860	0.8713
0.05265	0.4757	0.00472	0.8819
0.05923	0.4812	0.00439	0.8924
0.08556	0.4883	0.00416	0.9027
0.08555	0.4973	0.00150	0.9127
0.08227	0.5049	0.00321	0.9185
0.08555	0.5131	0.00304	0.9285
0.05923	0.5207	0.00342	0.9411
0.04607	0.5260	0.00256	0.9519
0.04936	0.5307	0.00304	0.9632
0.04278	0.5357	0.00227	0.9740
0.03619	0.5394	0.00114	0.9843
0.04936	0.5439	0.00135	0.9922
0.03620	0.5478	0.00140	1.0040


RUN # P445 TC # 1
PLUM RUN DOLOMITE (8/85) (GF & LT LEDGES), 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
0
20
40
60
80
100
120
140
TIME IN MINUTES


RUN # P445 TC # 1
PLUM RUN DOLOMITE (8/85) (GF & LT LEDGES), 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
0
4
8
12
16
20
24
28
32
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
FRACTION SULFATED

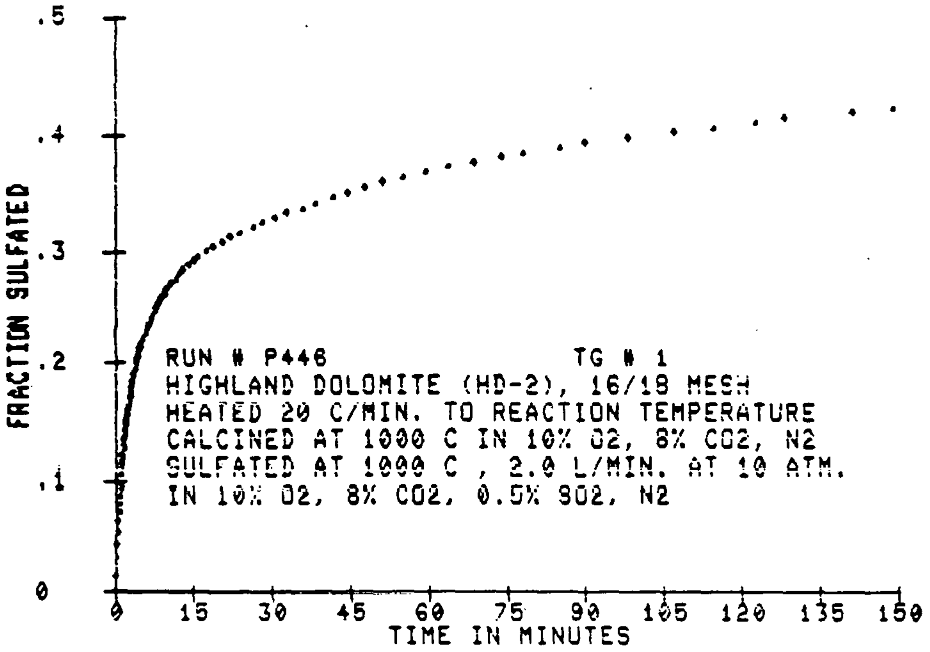

LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
RUN # P445
TG # 1
PLUM RUN DOLOMITE, 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
FRACTION SULFATED

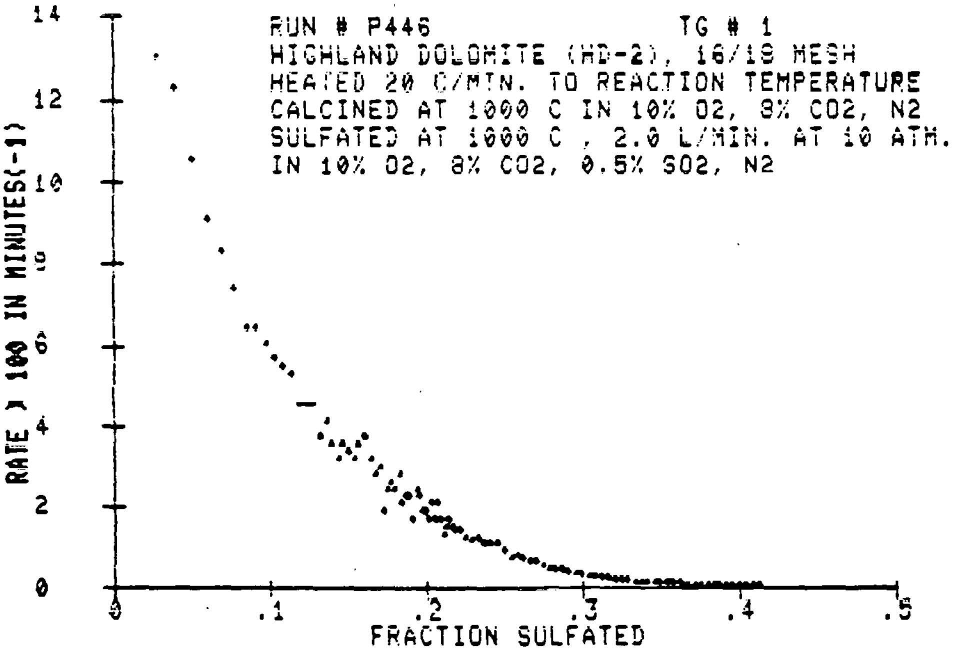
```
RUN # P445       TEMPERATURE = (1001.23 +/-  0.01 ) C

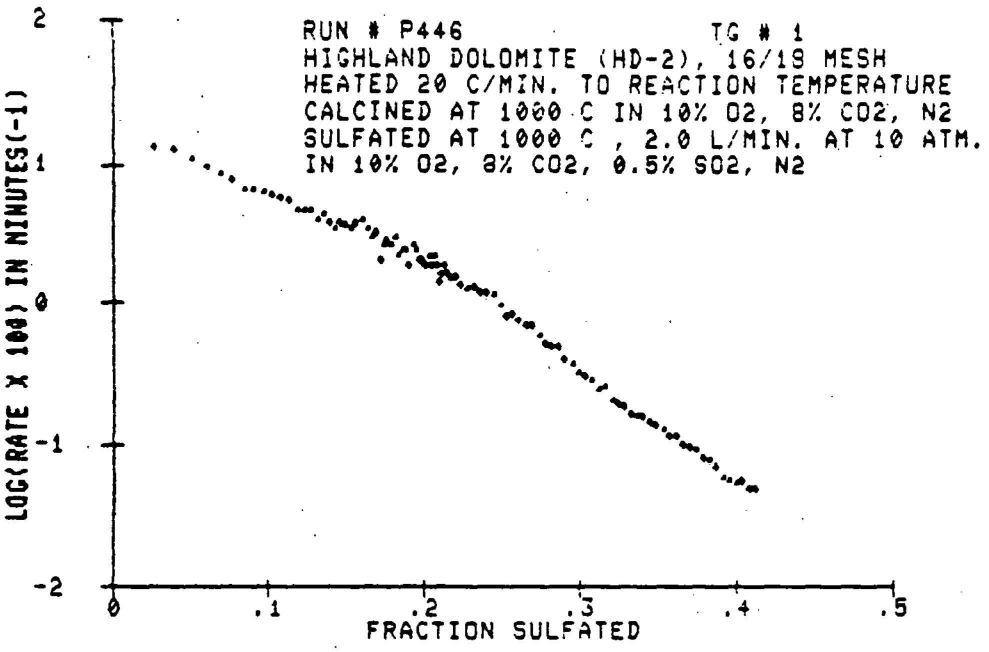
FRACTION          TIME            FRACTION          TIME
0.0000             0.00            0.5760             6.10
0.0266             1.10            0.5773             6.20
0.0639             1.20            0.5800             6.30
0.0945             1.30            0.5827             6.40
0.1197             1.40            0.5893             6.50
0.1490             1.50            0.6013             6.80
0.1716             1.60            0.6106             7.00
0.1902             1.70            0.6226             7.40
0.2115             1.80            0.6332             7.80
0.2328             1.90            0.6412             8.00
0.2501             2.00            0.6545             8.50
0.2621             2.10            0.6651             8.90
0.2754             2.20            0.6745             9.10
0.2900             2.30            0.6851             9.60
0.3046             2.40            0.6957             9.90
0.3179             2.50            0.7064            10.60
0.3299             2.60            0.7184            11.10
0.3419             2.70            0.7277            11.60
0.3525             2.80            0.7396            12.20
0.3618             2.90            0.7503            12.90
0.3751             3.00            0.7609            13.70
0.3831             3.10            0.7702            14.50
0.3911             3.20            0.7809            15.60
0.4018             3.30            0.7942            16.40
0.4071             3.40            0.8022            17.30
0.4177             3.50            0.8141            16.80
0.4257             3.60            0.8248            19.70
0.4350             3.70            0.8341            20.70
0.4443             3.80            0.8461            22.20
0.4496             3.90            0.8554            23.10
0.4576             4.00            0.8660            25.10
0.4603             4.10            0.8767            26.60
0.4696             4.20            0.8873            28.50
0.4762             4.30            0.8980            30.50
0.4842             4.40            0.9086            33.20
0.4895             4.50            0.9206            36.00
0.5002             4.60            0.9299            38.60
0.5055             4.70            0.9405            41.30
0.5108             4.80            0.9512            45.00
0.5175             4.90            0.9618            48.50
0.5241             5.00            0.9724            53.60
0.5255             5.10            0.9831            58.20
0.5308             5.20            0.9951            63.20
0.5374             5.30            1.0044            68.60
0.5414             5.40            1.0164            74.30
0.5441             5.50            1.0257            82.30
0.5521             5.60            1.0363            88.40
0.5587             5.70            1.0469           103.80
0.5601             5.80            1.0589           119.50
0.5667             5.90            1.0682           129.60
0.5707             6.00
```

RUN # P445

RATE	FRACTION
0.08552	0.0609
0.30595	0.0907
0.26941	0.1197
0.23944	0.1450
0.22946	0.1684
0.20954	0.1910
0.19621	0.2113
0.17961	0.2293
0.15963	0.2464
0.14300	0.2621
0.13637	0.2764
0.13967	0.2900
0.13637	0.3036
0.12970	0.3169
0.11972	0.3294
0.10976	0.3408
0.11307	0.3523
0.10311	0.3629
0.09644	0.3727
0.09977	0.3826
0.07983	0.3916
0.08646	0.4002
0.08649	0.4087
0.08314	0.4174
0.09312	0.4260
0.07983	0.4345
0.07981	0.4425
0.06319	0.4494
0.06319	0.4563
0.06651	0.4627
0.06652	0.4696
0.07316	0.4760
0.07650	0.4840
0.07316	0.4911
0.06651	0.4981
0.06985	0.5047
0.05986	0.5116
0.04989	0.5167
0.04988	0.5217
0.04988	0.5271
0.04324	0.5319
0.04656	0.5358
0.05322	0.5412
0.05321	0.5468
0.04656	0.5513
0.05654	0.5563
0.04656	0.5617
0.04324	0.5664
0.04323	0.5702
RATE	FRACTION
0.03326	0.5742
0.02993	0.5773
0.03326	0.5811
0.03991	0.5861
0.04371	0.5928
0.03991	0.6013
0.03377	0.6114
0.03326	0.6218
0.02927	0.6324
0.02838	0.6433
0.03172	0.6537
0.02744	0.6641
0.02946	0.6750
0.02426	0.6854
0.02195	0.6960
0.02128	0.7067
0.01909	0.7176
0.01909	0.7285
0.01637	0.7394
0.01468	0.7498
0.01213	0.7604
0.01254	0.7713
0.01146	0.7817
0.01021	0.7923
0.01071	0.8032
0.00928	0.8139
0.00896	0.8243
0.00959	0.8349
0.00764	0.8453
0.00722	0.8556
0.00655	0.8663
0.00575	0.8767
0.00526	0.8873
0.00467	0.8982
0.00421	0.9089
0.00394	0.9195
0.00361	0.9301
0.00330	0.9408
0.00284	0.9512
0.00252	0.9618
0.00241	0.9727
0.00212	0.9834
0.00212	0.9943
0.00177	1.0049
0.00164	1.0156
0.00121	1.0259
0.00094	1.0368
0.00090	1.0472


RUN # P446 TG # 1
HIGHLAND DOLOMITE (HD-2), 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.5
.4
.3
.2
.1
0
0
15
30
45
60
75
90
105
120
135
150
TIME IN MINUTES


RUN # P446 TG # 1
HIGHLAND DOLOMITE (HD-2), 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
14
12
10
8
6
4
2
0
0
.1
.2
.3
.4
.5
FRACTION SULFATED

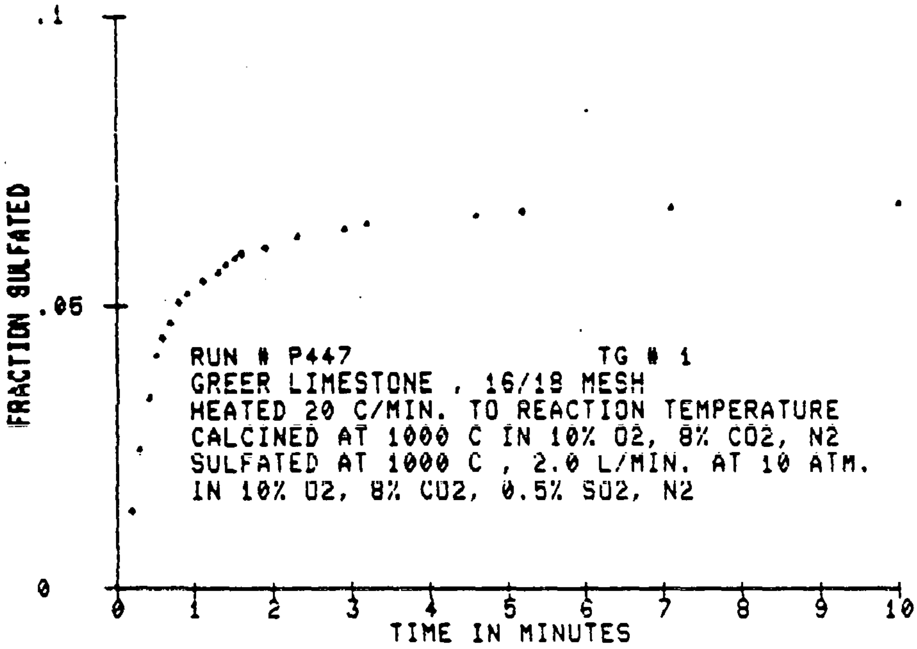

RUN # P446
TG # 1
HIGHLAND DOLOMITE (HD-2), 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
FRACTION SULFATED

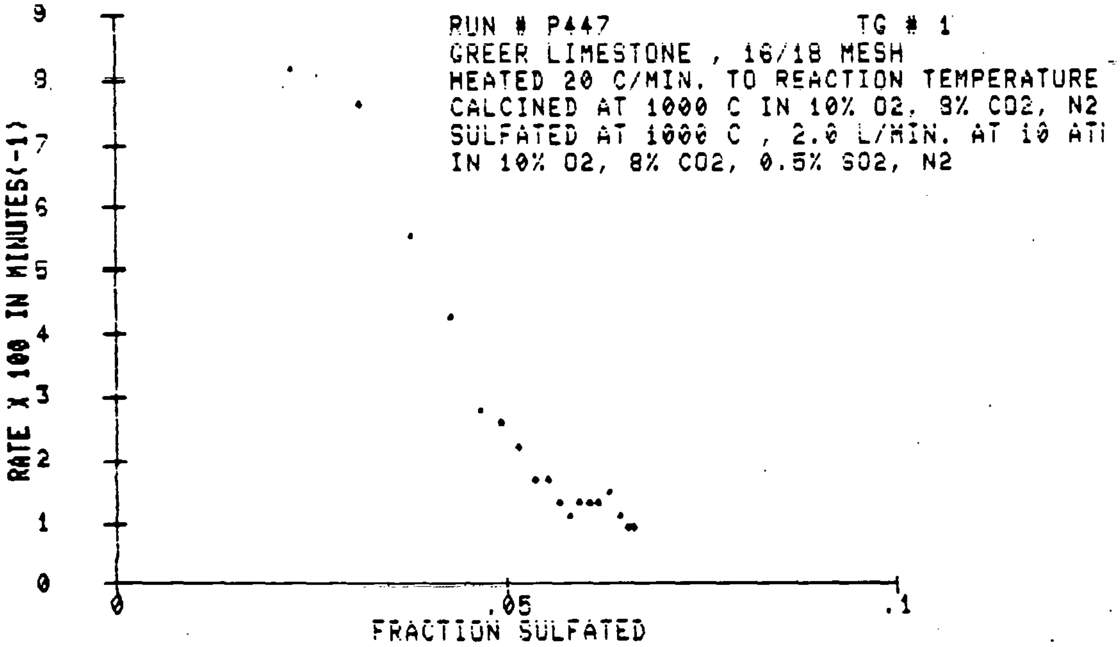
RUN # P446 TEMPERATURE = (1006.15 +/- 0.03) C

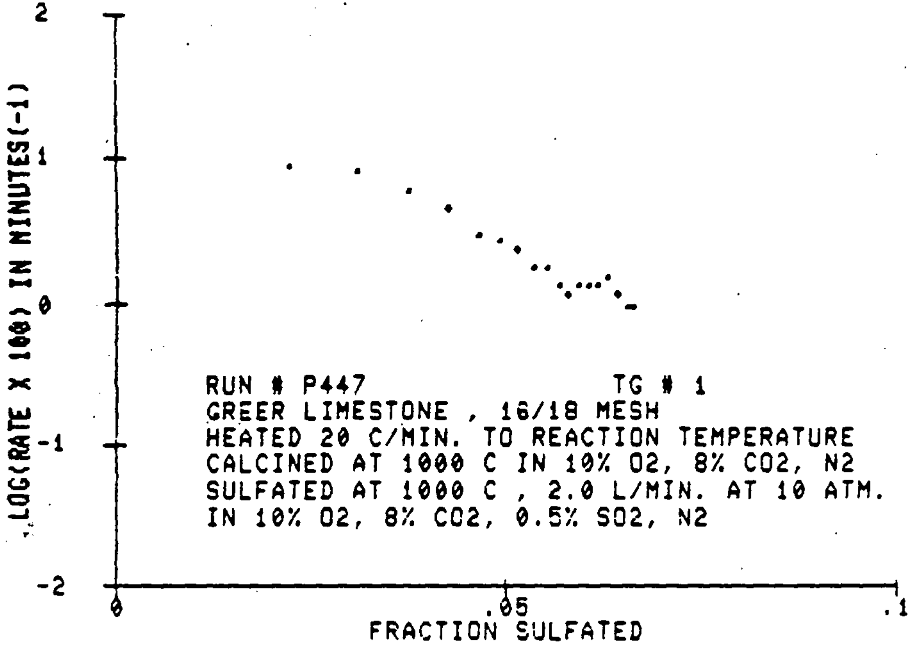
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.2170	5.10
0.0136	0.10	0.2193	5.30
0.0286	0.20	0.2246	5.70
0.0414	0.30	0.2291	6.00
0.0520	0.40	0.2321	6.30
0.0625	0.50	0.2359	6.70
0.0708	0.60	0.2404	7.00
0.0776	0.70	0.2457	7.50
0.0851	0.80	0.2487	7.80
0.0919	0.90	0.2532	8.30
0.0965	1.00	0.2577	8.90
0.1032	1.10	0.2607	9.50
0.1093	1.20	0.2652	9.90
0.1145	1.30	0.2698	10.70
0.1183	1.40	0.2735	11.40
0.1243	1.50	0.2781	12.20
0.1273	1.60	0.2818	13.90
0.1326	1.70	0.2863	14.20
0.1364	1.80	0.2909	15.20
0.1394	1.90	0.2946	15.90
0.1439	2.00	0.2992	17.60
0.1469	2.10	0.3029	19.00
0.1492	2.20	0.3074	20.70
0.1537	2.30	0.3120	22.00
0.1575	2.40	0.3157	23.80
0.1598	2.50	0.3203	26.40
0.1635	2.60	0.3248	27.90
0.1688	2.70	0.3285	30.50
0.1703	2.80	0.3323	32.80
0.1711	2.90	0.3368	35.80
0.1756	3.00	0.3406	38.20
0.1763	3.10	0.3451	41.50
0.1801	3.20	0.3496	44.40
0.1816	3.30	0.3534	47.90
0.1854	3.40	0.3579	51.40
0.1876	3.50	0.3617	55.00
0.1884	3.60	0.3662	59.50
0.1906	3.70	0.3707	63.80
0.1944	3.80	0.3745	68.50
0.1944	3.90	0.3790	73.90
0.1982	4.00	0.3828	78.00
0.1997	4.10	0.3873	85.10
0.2019	4.20	0.3911	90.30
0.2019	4.30	0.3956	98.30
0.2050	4.40	0.4001	107.20
0.2080	4.50	0.4039	114.70
0.2087	4.60	0.4084	122.60
0.2102	4.70	0.4122	128.20
0.2117	4.80	0.4167	141.30
0.2133	4.90	0.4205	149.10
0.2148	5.00		

RUN # P446

RATE	FRACTION	RATE	FRACTION
0.12998	0.0271	0.01413	0.2178
0.12246	0.0396	0.01432	0.2209
0.10549	0.0511	0.01256	0.2244
0.09043	0.0609	0.01184	0.2282
0.08288	0.0696	0.01217	0.2324
0.07347	0.0776	0.01105	0.2366
0.06406	0.0844	0.01105	0.2405
0.06405	0.0909	0.01083	0.2447
0.06029	0.0972	0.00912	0.2491
0.05651	0.1031	0.00754	0.2532
0.05463	0.1084	0.00789	0.2571
0.05275	0.1139	0.00691	0.2613
0.04521	0.1188	0.00633	0.2654
0.04522	0.1234	0.00642	0.2695
0.04521	0.1278	0.00553	0.2737
0.03767	0.1320	0.00474	0.2779
0.04145	0.1359	0.00456	0.2821
0.03579	0.1399	0.00448	0.2863
0.03203	0.1432	0.00369	0.2906
0.03579	0.1466	0.00345	0.2948
0.03391	0.1503	0.00301	0.2990
0.03203	0.1534	0.00284	0.3032
0.03579	0.1567	0.00267	0.3074
0.03768	0.1607	0.00234	0.3117
0.03202	0.1640	0.00241	0.3160
0.02826	0.1667	0.00195	0.3203
0.03014	0.1698	0.00184	0.3243
0.01884	0.1724	0.00176	0.3285
0.02449	0.1747	0.00154	0.3326
0.02637	0.1769	0.00151	0.3367
0.02449	0.1798	0.00149	0.3409
0.02826	0.1822	0.00137	0.3451
0.02072	0.1846	0.00131	0.3493
0.02261	0.1867	0.00123	0.3536
0.02260	0.1893	0.00110	0.3578
0.01695	0.1911	0.00109	0.3620
0.02449	0.1932	0.00097	0.3662
0.02260	0.1955	0.00092	0.3704
0.01884	0.1977	0.00090	0.3747
0.01884	0.1992	0.00078	0.3789
0.01695	0.2013	0.00076	0.3829
0.02072	0.2033	0.00068	0.3872
0.01695	0.2051	0.00059	0.3914
0.02072	0.2068	0.00056	0.3956
0.01695	0.2087	0.00054	0.3998
0.01319	0.2104	0.00055	0.4040
0.01507	0.2117	0.00049	0.4083
0.01695	0.2134	0.00048	0.4123
0.01507	0.2152		


.1
.05
0
FRACTION SULFATED
RUN # P447 TG # 1
GREER LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
1
2
3
4
5
6
7
8
9
10
TIME IN MINUTES


9
8
7
6
5
4
3
2
1
0
RATE X 100 IN MINUTES(-1)
RUN # P447 TG # 1
GREER LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 AT
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
.05
.1
FRACTION SULFATED

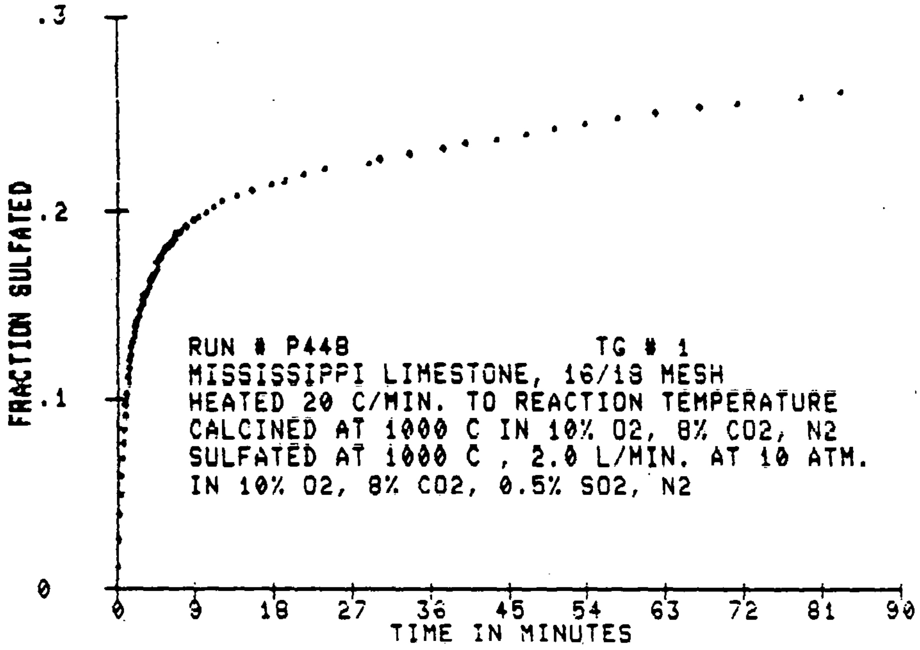

2
1
0
-1
-2
LOG(RATE X 100) IN MINUTES(-1)
RUN # P447 TG # 1
GREER LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
.05
.1
FRACTION SULFATED

RUN # P447

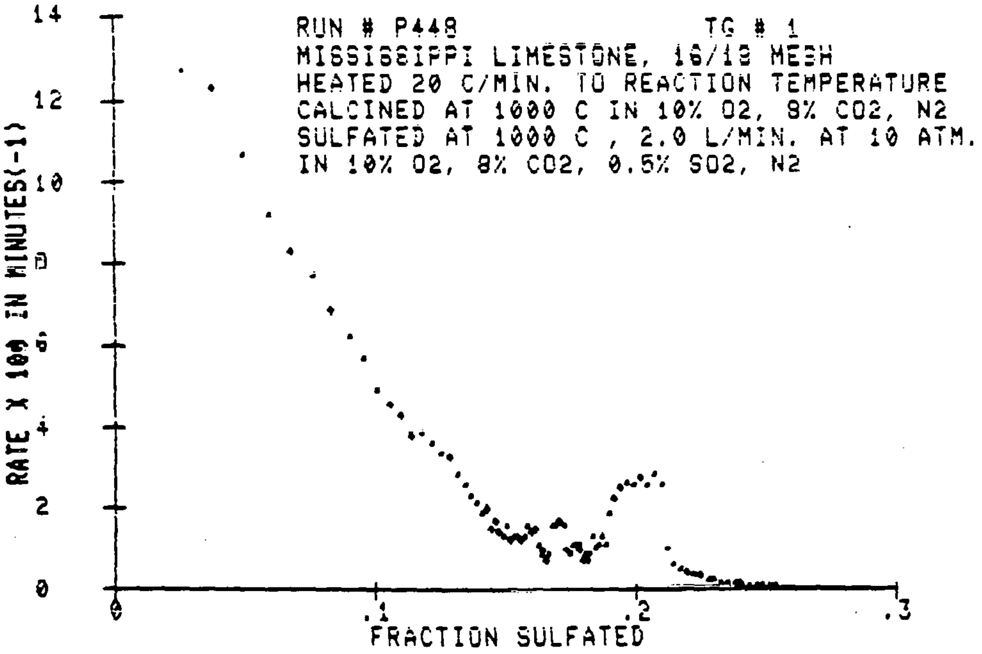
RATE	FRACTION	RATE	FRACTION
0.08140	0.0223	0.01295	0.0568
0.07586	0.0311	0.01110	0.0580
0.05550	0.0377	0.01295	0.0594
0.04255	0.0429	0.01295	0.0607
0.03775	0.0466	0.01295	0.0619
0.02590	0.0493	0.01480	0.0632
0.02220	0.0517	0.01110	0.0645
0.01665	0.0537	0.00925	0.0656
0.01665	0.0554	0.00925	0.0665

```
RUN # P447      TEMPERATURE = (1003.42 +/-  0.00 ) C

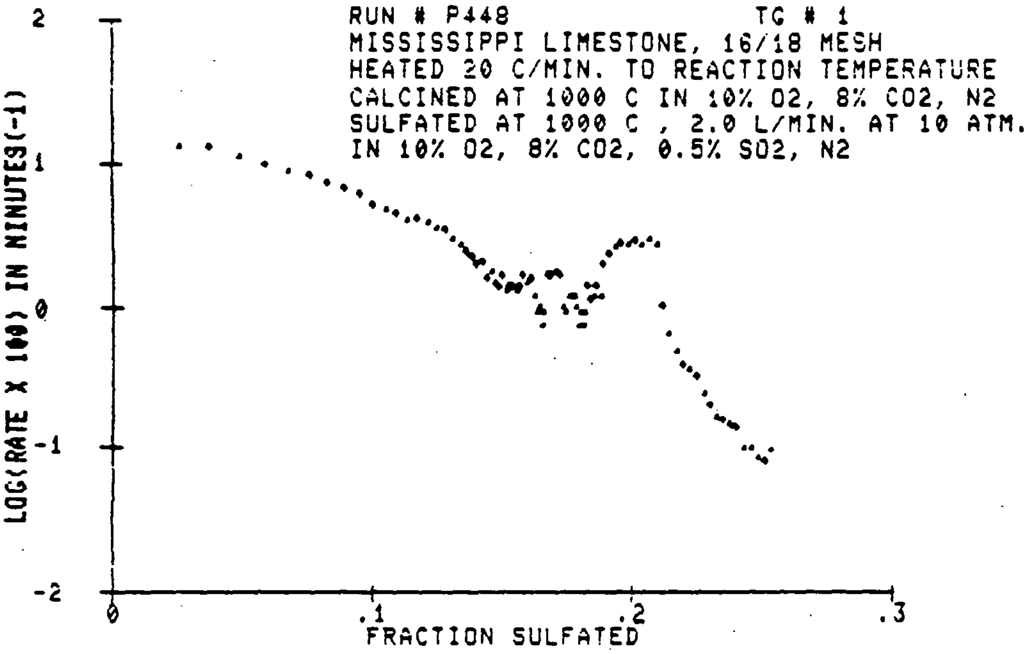
FRACTION        TIME          FRACTION        TIME
0.0000            0.00         0.0570            1.40
0.0133            0.20         0.0585            1.50
0.0244            0.30         0.0592            1.60
0.0333            0.40         0.0599            1.90
0.0407            0.50         0.0622            2.30
0.0437            0.60         0.0636            2.90
0.0466            0.70         0.0644            3.20
0.0503            0.80         0.0659            4.60
0.0518            0.90         0.0666            5.20
0.0540            1.10         0.0673            7.10
0.0555            1.30         0.0681           10.00
```



.3
.2
.1
0
FRACTION SULFATED
0
9
18
27
36
45
54
63
72
81
90
TIME IN MINUTES
RUN # P448 TG # 1
MISSISSIPPI LIMESTONE, 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2



14
12
10
8
6
4
2
0
RATE X 100 IN MINUTES(-1)
0
.1
.2
.3
FRACTION SULFATED
RUN # P448 TG # 1
MISSISSIPPI LIMESTONE, 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

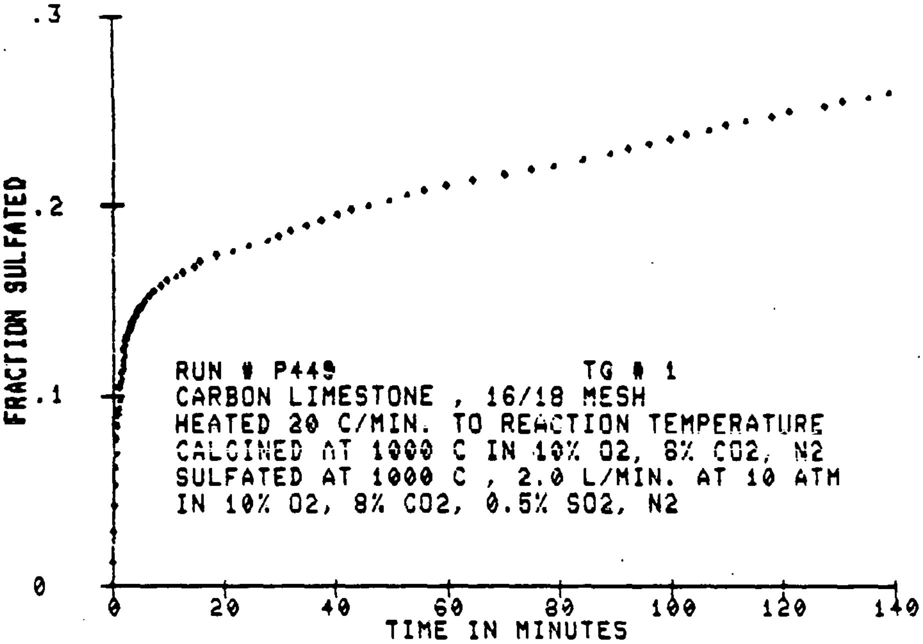

RUN # P448 TG # 1
MISSISSIPPI LIMESTONE, 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
FRACTION SULFATED

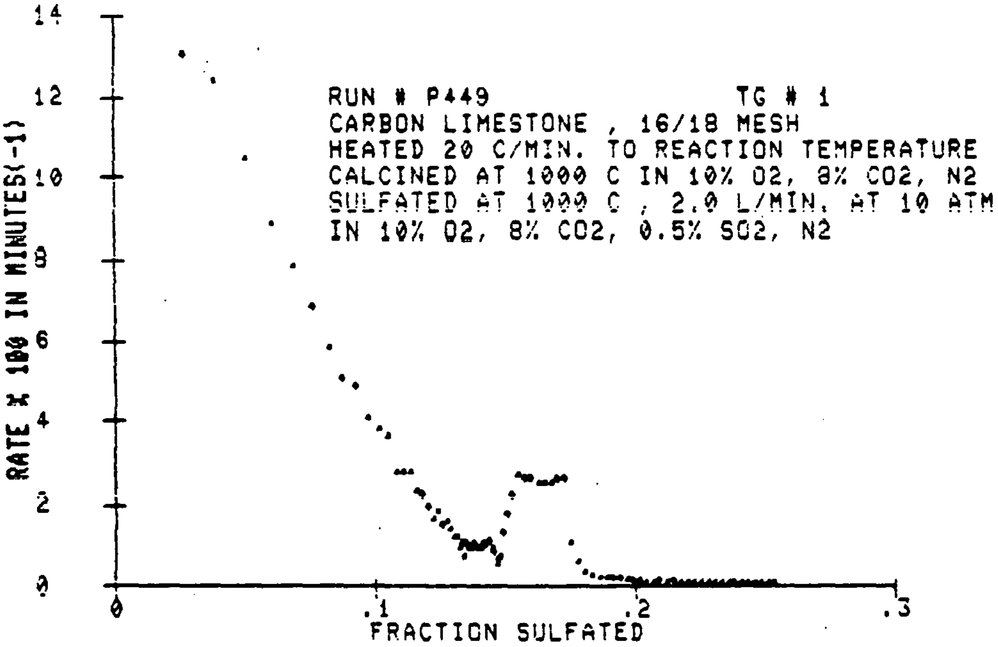
```
RUN # P448       TEMPERATURE = (1001.65 +/-  0.02 ) C

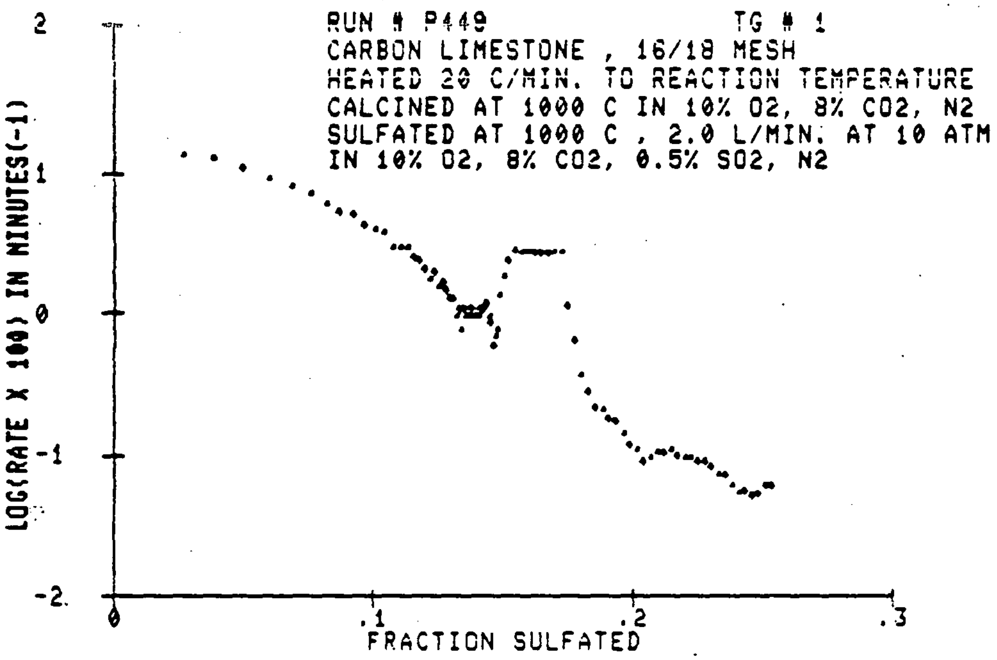
FRACTION        TIME            FRACTION        TIME
0.0000          0.00            0.1716          4.60
0.0113          0.10            0.1730          4.70
0.0264          0.20            0.1737          4.80
0.0402          0.30            0.1744          4.90
0.0507          0.40            0.1755          5.00
0.0603          0.50            0.1766          5.10
0.0691          0.60            0.1783          5.30
0.0768          0.70            0.1790          5.50
0.0839          0.80            0.1801          5.70
0.0909          0.90            0.1804          5.80
0.0962          1.00            0.1811          5.90
0.1015          1.10            0.1825          6.20
0.1064          1.20            0.1829          6.30
0.1103          1.30            0.1840          6.50
0.1143          1.40            0.1864          6.60
0.1184          1.50            0.1868          6.80
0.1216          1.60            0.1875          7.10
0.1258          1.70            0.1892          7.20
0.1286          1.80            0.1910          7.90
0.1318          1.90            0.1942          8.70
0.1346          2.00            0.1963          9.30
0.1371          2.10            0.1991         10.10
0.1388          2.20            0.2016         11.00
0.1410          2.30            0.2044         12.00
0.1431          2.40            0.2072         13.70
0.1445          2.50            0.2093         15.40
0.1466          2.60            0.2129         17.70
0.1470          2.70            0.2146         19.20
0.1498          2.80            0.2171         21.40
0.1501          2.90            0.2199         23.80
0.1519          3.00            0.2231         28.90
0.1533          3.10            0.2252         30.30
0.1547          3.20            0.2277         33.70
0.1554          3.30            0.2301         37.60
0.1572          3.40            0.2333         40.20
0.1582          3.50            0.2334         43.60
0.1600          3.60            0.2382         47.00
0.1618          3.80            0.2407         50.20
0.1628          3.90            0.2439         53.70
0.1642          4.00            0.2463         57.50
0.1646          4.10            0.2488         61.90
0.1653          4.20            0.2513         67.00
0.1667          4.30            0.2537         71.40
0.1670          4.40            0.2566         78.60
0.1681          4.50            0.2590         83.30
```

RUN # P448

RATE	FRACTION	RATE	FRACTION
0.12686	0.0257	0.01674	0.1707
0.12247	0.0378	0.01586	0.1722
0.10660	0.0493	0.00969	0.1737
0.09163	0.0594	0.00881	0.1747
0.08281	0.0682	0.01145	0.1757
0.07664	0.0762	0.01145	0.1768
0.06784	0.0834	0.01145	0.1779
0.06167	0.0899	0.00969	0.1789
0.05639	0.0958	0.00705	0.1798
0.04845	0.1011	0.00881	0.1806
0.04493	0.1057	0.00705	0.1814
0.04229	0.1102	0.00881	0.1822
0.03788	0.1142	0.01321	0.1834
0.03877	0.1181	0.01057	0.1845
0.03612	0.1217	0.01145	0.1855
0.03348	0.1252	0.01322	0.1868
0.03260	0.1285	0.01145	0.1882
0.02819	0.1316	0.01850	0.1897
0.02555	0.1342	0.02203	0.1916
0.02291	0.1367	0.02467	0.1940
0.02114	0.1389	0.02643	0.1964
0.01850	0.1409	0.02555	0.1991
0.01938	0.1429	0.02731	0.2017
0.01498	0.1444	0.02555	0.2043
0.01674	0.1462	0.02819	0.2071
0.01410	0.1476	0.02555	0.2097
0.01322	0.1491	0.00987	0.2122
0.01586	0.1504	0.00622	0.2148
0.01234	0.1520	0.00465	0.2175
0.01321	0.1531	0.00365	0.2200
0.01321	0.1545	0.00341	0.2226
0.01234	0.1558	0.00310	0.2252
0.01321	0.1571	0.00232	0.2279
0.01586	0.1585	0.00193	0.2303
0.01410	0.1600	0.00158	0.2329
0.01498	0.1614	0.00147	0.2355
0.01145	0.1627	0.00137	0.2383
0.00881	0.1637	0.00130	0.2409
0.00969	0.1647	0.00094	0.2436
0.00705	0.1656	0.00095	0.2462
0.00881	0.1663	0.00080	0.2488
0.01586	0.1677	0.00074	0.2513
0.01586	0.1693	0.00090	0.2539


.3
.2
.1
0
FRACTION SULFATED
0
20
40
60
80
100
120
140
TIME IN MINUTES
RUN # P449 TG # 1
CARBON LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2


14
12
10
8
6
4
2
0
RATE X 100 IN MINUTES(-1)
0
.1
.2
.3
FRACTION SULFATED
RUN # P449 TG # 1
CARBON LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2


RUN # P449
TG # 1
CARBON LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2.
0
.1
.2
.3
FRACTION SULFATED

```
RUN # P449        TEMPERATURE = (1002.51 +/-  0.05 ) C

FRACTION          TIME            FRACTION         TIME
0.0000            0.00             0.1488            5.50
0.0122            0.10             0.1495            5.70
0.0278            0.20             0.1525            6.40
0.0415            0.30             0.1547            7.20
0.0522            0.40             0.1577            8.50
0.0618            0.50             0.1603            9.70
0.0696            0.60             0.1628           11.40
0.0770            0.70             0.1651           12.60
0.0836            0.80             0.1677           14.80
0.0892            0.90             0.1702           15.90
0.0929            1.00             0.1728           18.80
0.0970            1.10             0.1754           21.40
0.1029            1.20             0.1780           24.20
0.1055            1.30             0.1810           27.70
0.1081            1.40             0.1832           29.70
0.1114            1.50             0.1858           31.90
0.1140            1.60             0.1887           34.80
0.1166            1.70             0.1913           37.40
0.1192            1.80             0.1943           40.40
0.1207            1.90             0.1969           42.90
0.1229            2.00             0.1991           45.80
0.1244            2.10             0.2017           49.50
0.1258            2.20             0.2043           52.50
0.1281            2.30             0.2069           55.70
0.1288            2.40             0.2095           59.90
0.1306            2.50             0.2121           64.50
0.1314            2.60             0.2150           70.00
0.1329            2.80             0.2176           75.00
0.1336            2.90             0.2198           78.80
0.1343            3.00             0.2224           84.30
0.1355            3.10             0.2254           89.00
0.1358            3.20             0.2280           92.30
0.1377            3.30             0.2306           96.00
0.1380            3.40             0.2332          100.20
0.1392            3.50             0.2359          102.70
0.1399            3.70             0.2383          106.70
0.1414            3.80             0.2413          110.00
0.1417            4.00             0.2439          113.40
0.1429            4.10             0.2461          118.20
0.1440            4.40             0.2487          121.20
0.1454            4.60             0.2513          127.60
0.1462            4.90             0.2539          130.90
0.1466            5.10             0.2565          135.30
0.1473            5.20             0.2591          139.00
0.1477            5.40
```

```
RUN # P449

RATE                FRACTION            RATE                FRACTION
0.13047             0.0267              0.01295             0.1491
0.12398             0.0391              0.01758             0.1506
0.10456             0.0506              0.02221             0.1526
0.08882             0.0604              0.02683             0.1549
0.07864             0.0688              0.02591             0.1576
0.06847             0.0762              0.02591             0.1601
0.05829             0.0825              0.02498             0.1627
0.04997             0.0879              0.02498             0.1652
0.04811             0.0931              0.02498             0.1677
0.04071             0.0975              0.02591             0.1702
0.03794             0.1013              0.02591             0.1728
0.03608             0.1050              0.01073             0.1755
0.02776             0.1084              0.00610             0.1781
0.02776             0.1111              0.00357             0.1807
0.02776             0.1138              0.00268             0.1833
0.02313             0.1164              0.00207             0.1860
0.02220             0.1187              0.00206             0.1887
0.01943             0.1207              0.00176             0.1914
0.01665             0.1226              0.00167             0.1941
0.01850             0.1244              0.00140             0.1967
0.01481             0.1260              0.00114             0.1993
0.01573             0.1275              0.00106             0.2018
0.01388             0.1289              0.00088             0.2043
0.01203             0.1303              0.00095             0.2069
0.01203             0.1315              0.00102             0.2095
0.00925             0.1326              0.00101             0.2122
0.01018             0.1335              0.00107             0.2148
0.00740             0.1344              0.00097             0.2174
0.01018             0.1354              0.00094             0.2201
0.00925             0.1363              0.00094             0.2227
0.00925             0.1372              0.00089             0.2252
0.01018             0.1381              0.00089             0.2279
0.00925             0.1392              0.00081             0.2306
0.00925             0.1400              0.00073             0.2332
0.00925             0.1410              0.00072             0.2358
0.01018             0.1420              0.00061             0.2385
0.01018             0.1431              0.00054             0.2411
0.01110             0.1440              0.00055             0.2437
0.00925             0.1450              0.00050             0.2463
0.00833             0.1459              0.00053             0.2488
0.00555             0.1466              0.00060             0.2513
0.00648             0.1473              0.00060             0.2539
0.00740             0.1480
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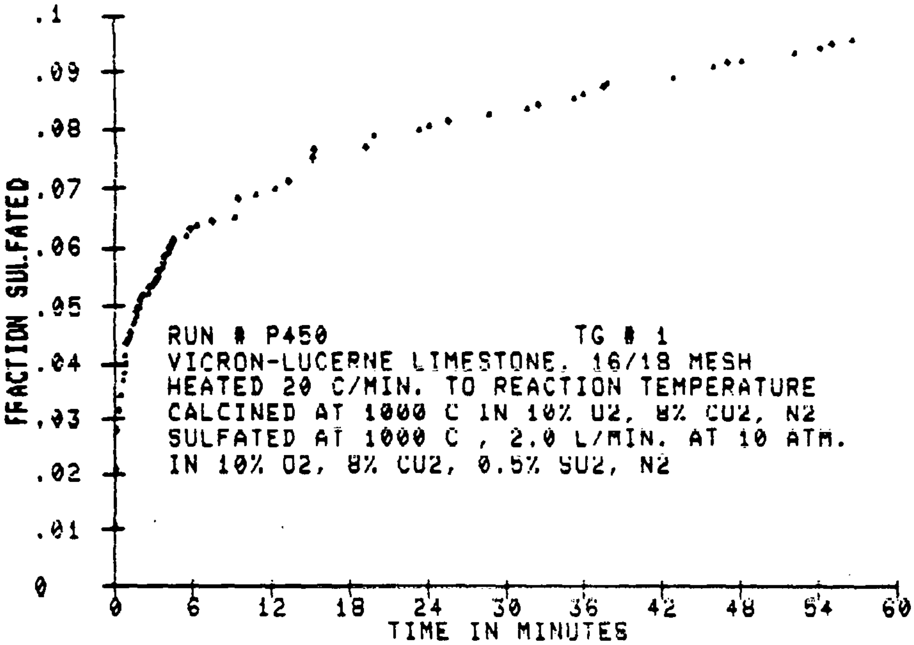
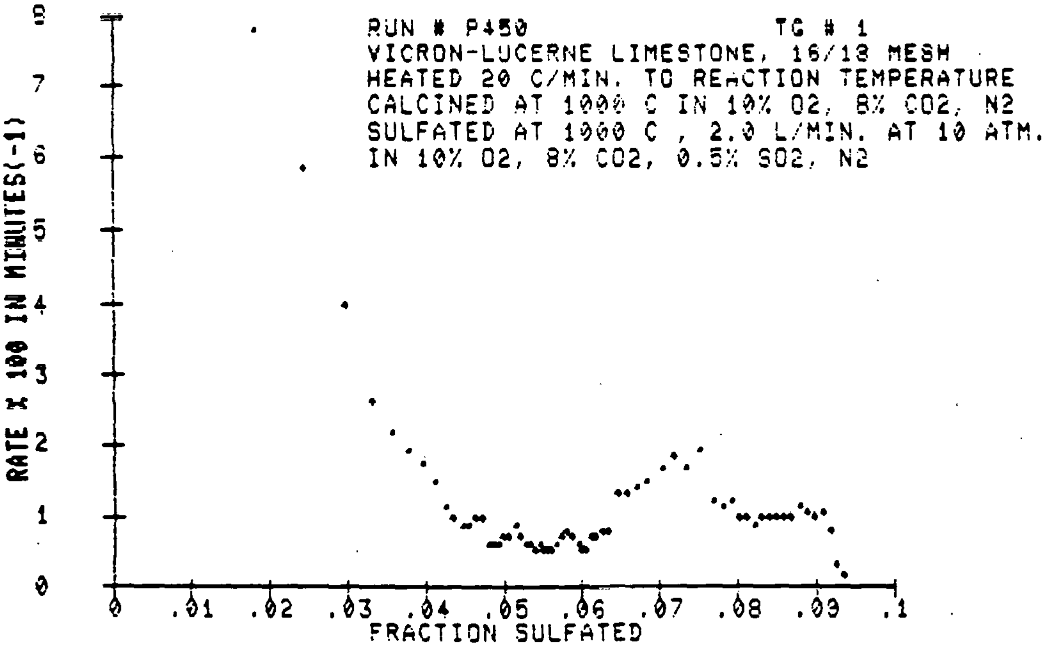
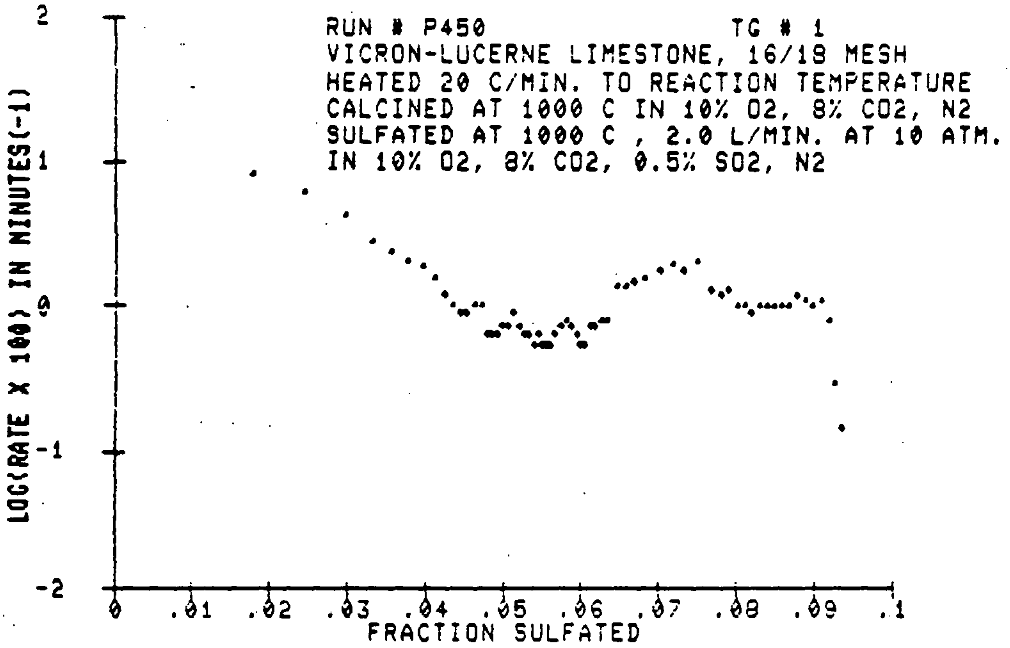

FRACTION SULFATED
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
RUN # P450 TG # 1
VICRON-LUCERNE LIMESTONE, 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
6
12
18
24
30
36
42
48
54
60
TIME IN MINUTES

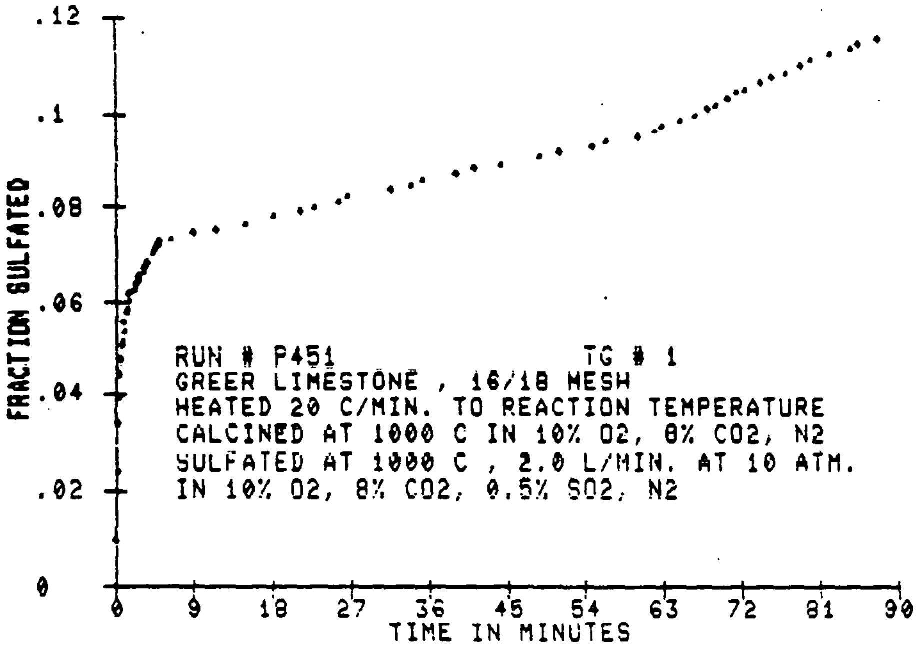

RATE X 100 IN MINUTES(-1)
8
7
6
5
4
3
2
1
0
RUN # P450 TG # 1
VICRON-LUCERNE LIMESTONE, 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED

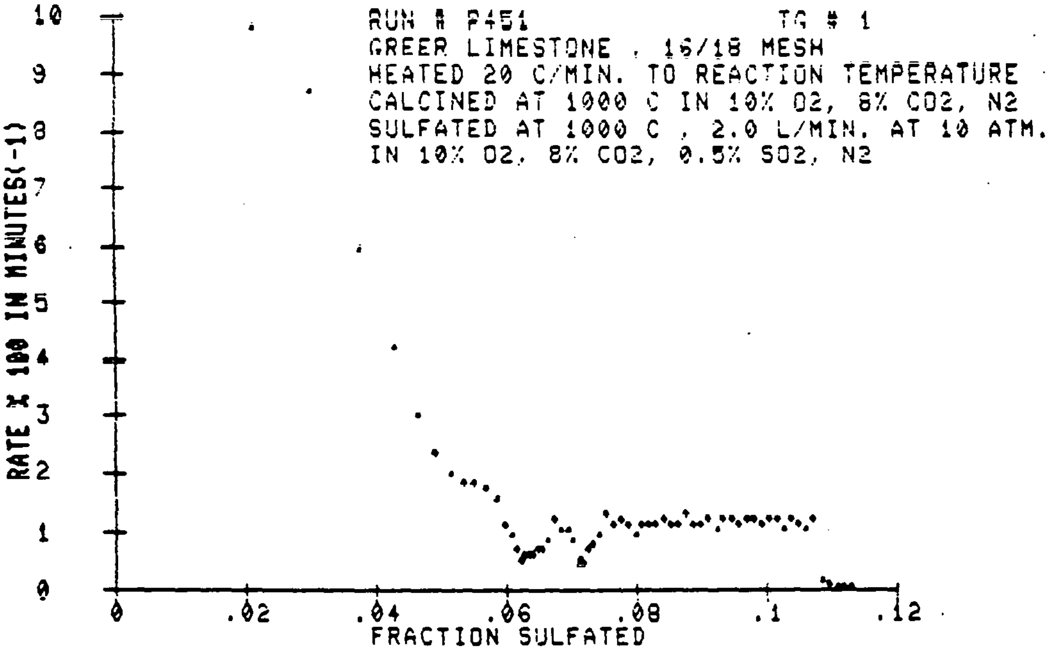

RUN # P450 TG # 1
VICRON-LUCERNE LIMESTONE, 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED

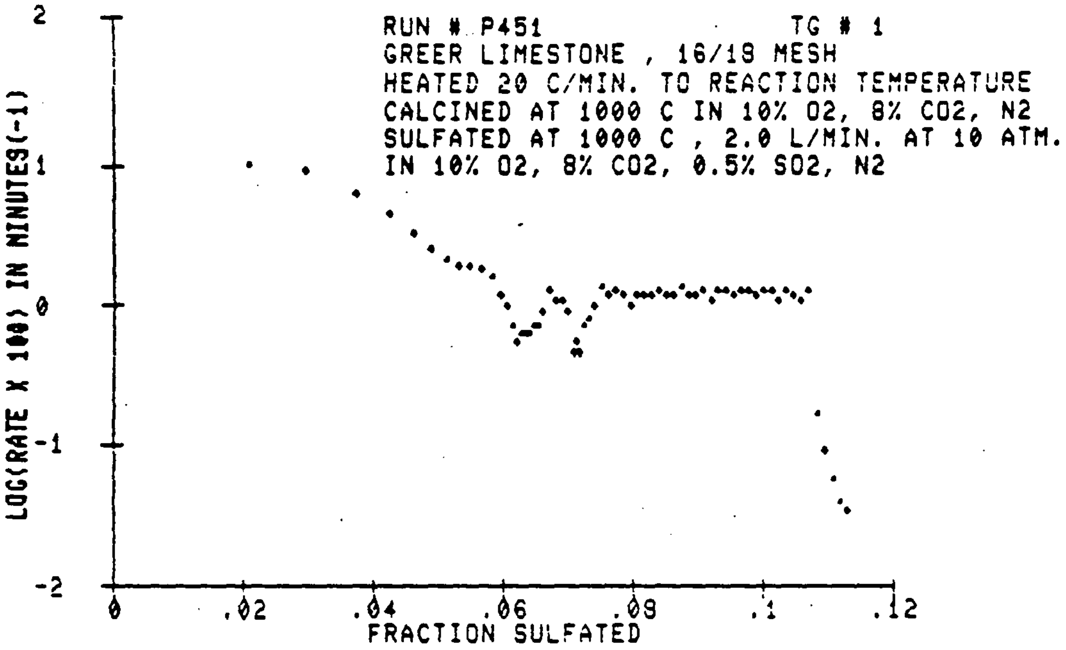
RUN # P450 TEMPERATURE = (1002.12 +/- 0.01) C

FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.0600	4.40
0.0104	0.10	0.0607	4.50
0.0205	0.20	0.0610	4.60
0.0274	0.30	0.0617	5.50
0.0312	0.40	0.0627	5.80
0.0336	0.50	0.0634	6.30
0.0364	0.60	0.0641	7.50
0.0378	0.70	0.0648	9.10
0.0399	0.80	0.0679	9.50
0.0412	0.90	0.0686	10.70
0.0433	1.00	0.0697	12.20
0.0437	1.10	0.0707	13.40
0.0444	1.20	0.0745	15.20
0.0451	1.30	0.0759	15.30
0.0468	1.40	0.0763	19.30
0.0471	1.50	0.0783	19.90
0.0482	1.60	0.0794	23.00
0.0485	1.70	0.0804	24.00
0.0492	1.80	0.0811	25.60
0.0496	1.90	0.0821	28.70
0.0506	2.00	0.0832	31.70
0.0516	2.20	0.0839	32.50
0.0520	2.60	0.0849	35.30
0.0530	2.70	0.0860	36.00
0.0534	2.90	0.0870	37.50
0.0541	3.10	0.0877	37.80
0.0544	3.20	0.0887	42.90
0.0551	3.30	0.0905	46.00
0.0558	3.40	0.0912	47.10
0.0562	3.50	0.0915	48.10
0.0565	3.70	0.0929	52.20
0.0572	3.80	0.0936	54.30
0.0582	3.90	0.0946	55.20
0.0589	4.20	0.0953	56.60
0.0596	4.30		

```
RUN # P450


RATE               FRACTION           RATE               FRACTION
0.07799            0.0179             0.00520            0.0600
0.05805            0.0246             0.00520            0.0606
0.03986            0.0298             0.00693            0.0612
0.02600            0.0333             0.00693            0.0619
0.02166            0.0358             0.00780            0.0626
0.01907            0.0378             0.00780            0.0634
0.01733            0.0397             0.01300            0.0646
0.01473            0.0412             0.01300            0.0658
0.01127            0.0425             0.01386            0.0670
0.00953            0.0435             0.01473            0.0684
0.00867            0.0446             0.01647            0.0703
0.00866            0.0454             0.01820            0.0719
0.00953            0.0463             0.01647            0.0734
0.00953            0.0472             0.01906            0.0751
0.00607            0.0480             0.01213            0.0769
0.00607            0.0486             0.01127            0.0781
0.00607            0.0493             0.01213            0.0791
0.00693            0.0500             0.00953            0.0803
0.00693            0.0506             0.00953            0.0812
0.00866            0.0514             0.00866            0.0821
0.00693            0.0521             0.00953            0.0830
0.00607            0.0528             0.00953            0.0840
0.00607            0.0534             0.00953            0.0850
0.00520            0.0540             0.00953            0.0859
0.00607            0.0546             0.00953            0.0869
0.00520            0.0551             0.01127            0.0880
0.00520            0.0556             0.01040            0.0890
0.00520            0.0562             0.00953            0.0899
0.00607            0.0568             0.01040            0.0910
0.00693            0.0574             0.00780            0.0919
0.00780            0.0581             0.00289            0.0928
0.00693            0.0588             0.00141            0.0936
0.00607            0.0595
```


.12
.1
.08
.06
.04
.02
0
FRACTION SULFATED
0
9
18
27
36
45
54
63
72
81
90
TIME IN MINUTES
RUN # P451 TG # 1
GREER LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

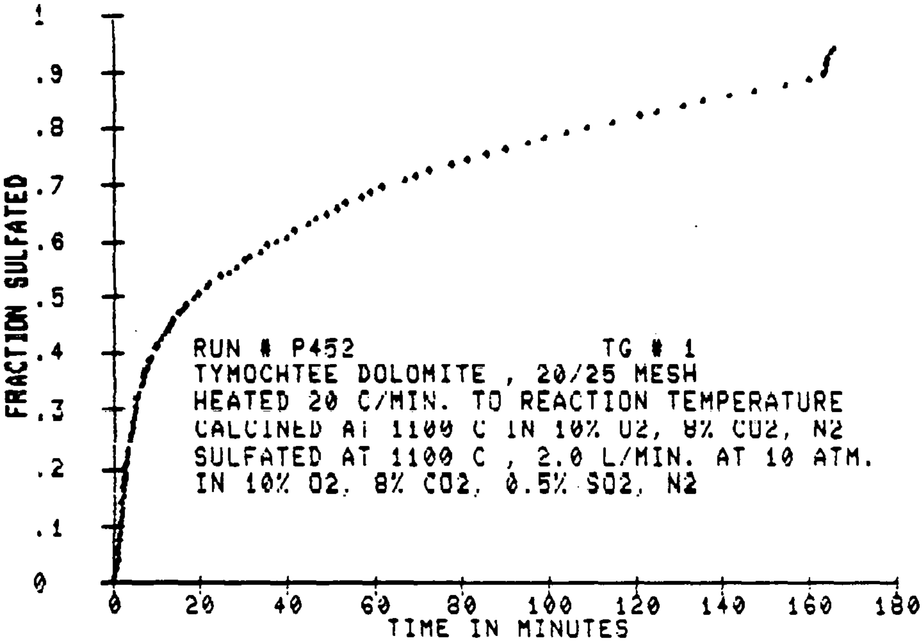

10
9
8
7
6
5
4
3
2
1
0
RATE X 100 IN MINUTES(-1)
0
.02
.04
.06
.08
.1
.12
FRACTION SULFATED
RUN # P451 TG # 1
GREER LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RUN # P451 TG # 1
GREER LIMESTONE , 16/18 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1000 C IN 10% O2, 8% CO2, N2
SULFATED AT 1000 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.02
.04
.06
.08
.1
.12
FRACTION SULFATED

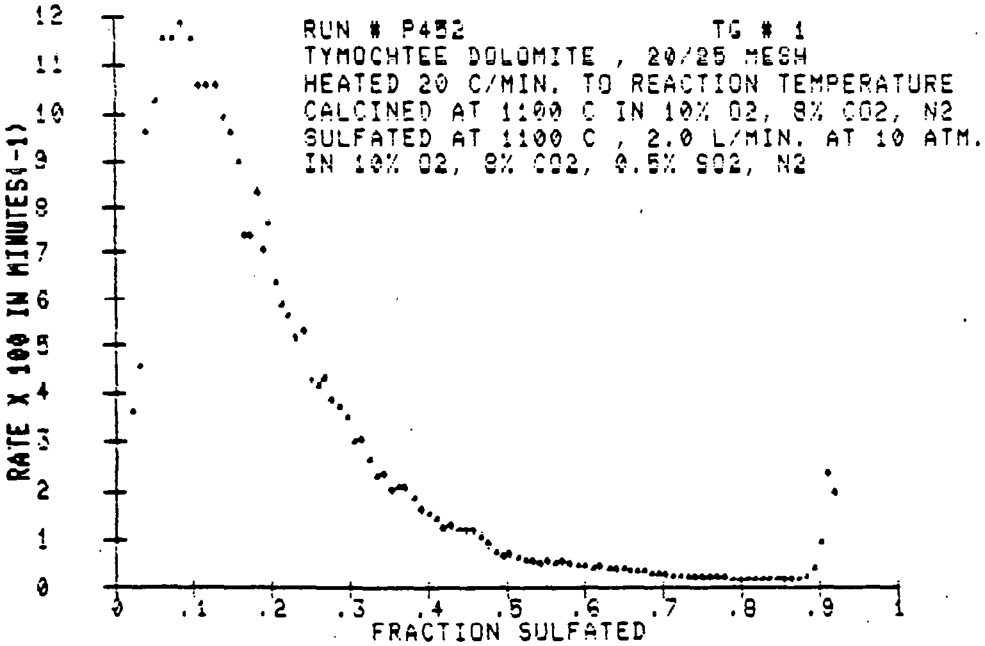
```
RUN # P451       TEMPERATURE = (1003.31 +/-  0.01 ) C

FRACTION        TIME            FRACTION        TIME
0.0000            0.00          0.0780           18.00
0.0093            0.10          0.0787           21.30
0.0237            0.20          0.0797           22.80
0.0333            0.30          0.0807           25.50
0.0392            0.40          0.0818           26.50
0.0440            0.50          0.0831           31.70
0.0474            0.60          0.0842           33.90
0.0502            0.70          0.0852           35.20
0.0512            0.80          0.0866           39.20
0.0533            0.90          0.0876           41.20
0.0553            1.00          0.0886           44.30
0.0574            1.20          0.0904           48.70
0.0584            1.30          0.0910           51.00
0.0601            1.40          0.0921           54.80
0.0615            1.50          0.0934           56.40
0.0618            1.80          0.0945           60.00
0.0622            2.10          0.0959           61.90
0.0629            2.20          0.0969           62.80
0.0636            2.30          0.0979           64.90
0.0642            2.50          0.0993           66.50
0.0646            2.60          0.1007           68.10
0.0653            2.70          0.1014           69.00
0.0663            3.20          0.1027           70.40
0.0670            3.40          0.1041           71.30
0.0680            3.60          0.1048           72.30
0.0701            4.10          0.1062           74.30
0.0704            4.30          0.1072           75.50
0.0711            4.60          0.1082           76.90
0.0715            4.70          0.1096           78.90
0.0718            4.80          0.1110           79.90
0.0725            5.00          0.1120           82.00
0.0728            6.30          0.1130           84.50
0.0742            8.90          0.1141           85.50
0.0749           11.50          0.1151           87.70
0.0763           14.70
```

RUN # P451

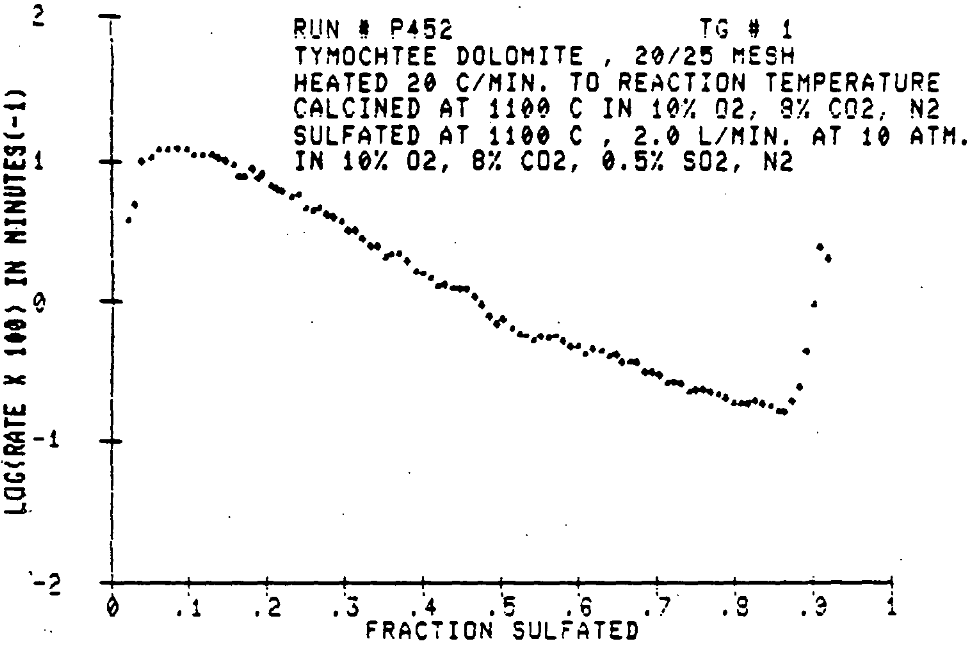
RATE	FRACTION	RATE	FRACTION
0.09791	0.0211	0.01202	0.0775
0.08674	0.0299	0.01117	0.0787
0.05927	0.0375	0.00945	0.0798
0.04208	0.0428	0.01117	0.0808
0.03006	0.0464	0.01117	0.0819
0.02319	0.0492	0.01117	0.0830
0.01975	0.0515	0.01203	0.0842
0.01804	0.0535	0.01117	0.0853
0.01804	0.0551	0.01117	0.0864
0.01718	0.0569	0.01288	0.0877
0.01546	0.0585	0.01117	0.0888
0.01117	0.0598	0.01117	0.0899
0.00945	0.0608	0.01202	0.0911
0.00687	0.0617	0.01031	0.0923
0.00515	0.0624	0.01203	0.0934
0.00601	0.0629	0.01202	0.0945
0.00601	0.0635	0.01117	0.0957
0.00601	0.0641	0.01202	0.0969
0.00687	0.0648	0.01202	0.0981
0.00687	0.0655	0.01117	0.0992
0.00859	0.0662	0.01202	0.1004
0.01202	0.0673	0.01203	0.1016
0.01031	0.0684	0.01031	0.1027
0.01031	0.0693	0.01202	0.1038
0.00859	0.0702	0.01117	0.1050
0.00429	0.0710	0.01031	0.1061
0.00515	0.0715	0.01203	0.1072
0.00429	0.0719	0.00166	0.1084
0.00687	0.0726	0.00089	0.1096
0.00773	0.0732	0.00057	0.1108
0.00945	0.0741	0.00038	0.1119
0.01288	0.0752	0.00033	0.1130
0.01117	0.0764		



RUN # P452 TG # 1
TYMOCHTEE DOLOMITE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2



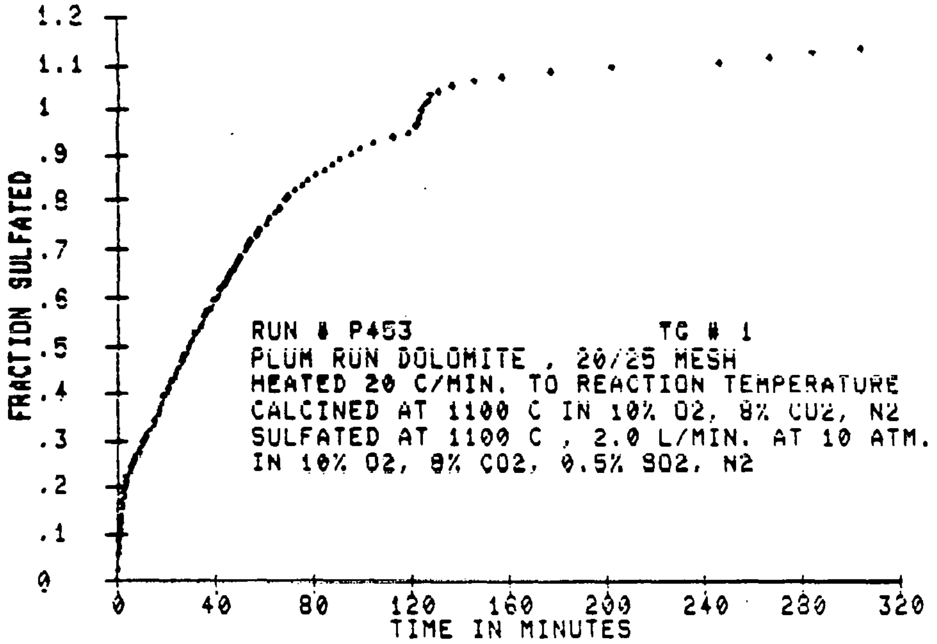
RUN # P452 TG # 1
TYMOCHTEE DOLOMITE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

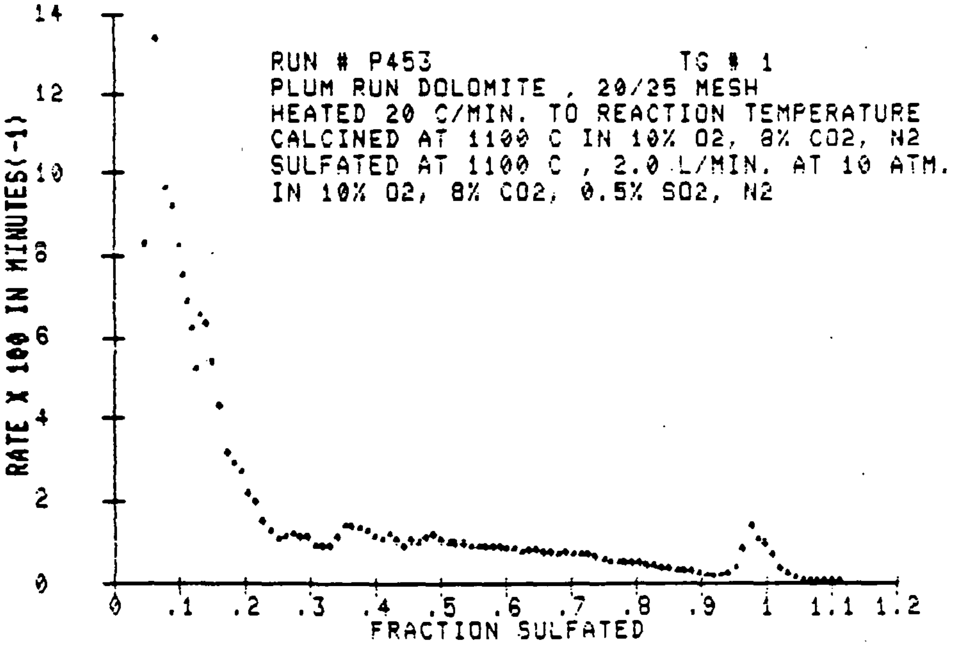

RUN # P452
TG # 1
TYMOCHTEE DOLOMITE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
FRACTION SULFATED

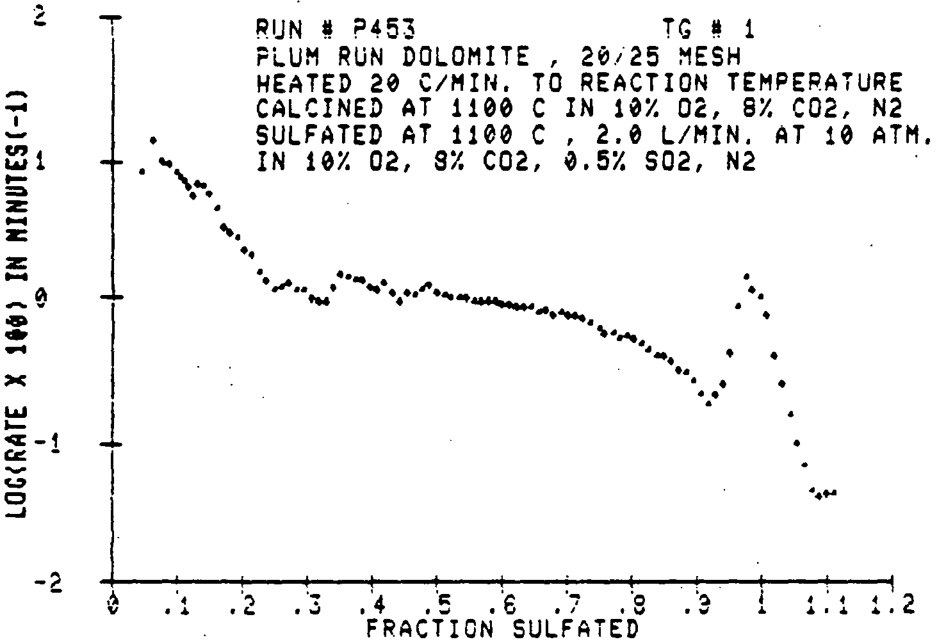
```
RUN # P452        TEMPERATURE = (1091.50 +/-  2.84 ) C


FRACTION            TIME                FRACTION            TIME
0.0000                 0.00               0.4765               15.70
0.0102                 0.30               0.4842               16.80
0.0231                 0.90               0.4944               18.20
0.0320                 1.00               0.5034               19.60
0.0397                 1.10               0.5136               21.30
0.0512                 1.20               0.5226               22.10
0.0615                 1.30               0.5341               24.60
0.0730                 1.40               0.5418               26.30
0.0858                 1.50               0.5508               28.00
0.0973                 1.60               0.5623               30.00
0.1089                 1.70               0.5700               31.30
0.1191                 1.80               0.5802               33.60
0.1281                 1.90               0.5917               35.40
0.1396                 2.00               0.5981               37.30
0.1511                 2.10               0.6084               39.80
0.1588                 2.20               0.6186               41.90
0.1665                 2.30               0.6302               44.80
0.1755                 2.40               0.6391               46.70
0.1806                 2.50               0.6481               49.20
0.1883                 2.60               0.6571               51.80
0.1998                 2.70               0.6647               53.40
0.2037                 2.80               0.6750               57.00
0.2113                 2.90               0.6840               59.20
0.2203                 3.10               0.6929               62.00
0.2293                 3.20               0.7045               67.00
0.2434                 3.50               0.7121               69.70
0.2523                 3.70               0.7224               72.90
0.2574                 3.80               0.7314               77.80
0.2677                 4.10               0.7403               81.30
0.2767                 4.30               0.7506               85.80
0.2869                 4.50               0.7595               90.30
0.2959                 4.80               0.7698               95.40
0.3048                 5.10               0.7787               99.00
0.3151                 5.40               0.7890              104.30
0.3228                 5.70               0.7980              109.00
0.3381                 6.20               0.8069              114.60
0.3420                 6.50               0.8184              121.20
0.3522                 7.00               0.8261              125.10
0.3625                 7.40               0.8364              131.00
0.3702                 7.80               0.8453              135.50
0.3817                 8.40               0.8543              141.70
0.3894                 8.80               0.8646              147.50
0.4035                 9.60               0.8735              154.50
0.4086                10.20               0.8838              160.35
0.4201                10.90               0.8940              163.25
0.4304                11.70               0.9017              163.65
0.4368                12.30               0.9132              164.10
0.4470                13.20               0.9209              164.40
0.4560                13.90               0.9324              165.00
0.4688                15.00               0.9427              165.75
```

RUN # P452

RATE	FRACTION	RATE	FRACTION
0.03610	0.0210	0.00894	0.4760
0.04554	0.0313	0.00752	0.4854
0.09607	0.0415	0.00663	0.4944
0.10246	0.0515	0.00725	0.5036
0.11527	0.0622	0.00620	0.5136
0.11529	0.0738	0.00574	0.5231
0.11847	0.0853	0.00554	0.5326
0.11529	0.0968	0.00503	0.5423
0.10566	0.1078	0.00535	0.5518
0.10566	0.1186	0.00526	0.5610
0.10568	0.1294	0.00554	0.5710
0.09926	0.1394	0.00491	0.5805
0.09607	0.1488	0.00452	0.5897
0.08965	0.1583	0.00463	0.5994
0.07364	0.1665	0.00409	0.6094
0.07365	0.1739	0.00436	0.6189
0.08325	0.1821	0.00422	0.6289
0.07045	0.1896	0.00388	0.6386
0.07684	0.1967	0.00402	0.6478
0.06404	0.2047	0.00348	0.6568
0.05892	0.2129	0.00359	0.6658
0.05672	0.2216	0.00352	0.6747
0.05123	0.2313	0.00292	0.6842
0.05306	0.2405	0.00292	0.6937
0.04270	0.2500	0.00280	0.7032
0.04163	0.2595	0.00243	0.7127
0.04323	0.2682	0.00251	0.7221
0.03842	0.2769	0.00239	0.7314
0.03714	0.2864	0.00213	0.7408
0.03493	0.2959	0.00218	0.7503
0.02989	0.3051	0.00217	0.7598
0.03019	0.3153	0.00208	0.7695
0.02653	0.3246	0.00205	0.7790
0.02322	0.3340	0.00193	0.7885
0.02336	0.3435	0.00179	0.7982
0.02001	0.3530	0.00179	0.8077
0.02090	0.3617	0.00175	0.8172
0.02064	0.3712	0.00184	0.8266
0.01863	0.3814	0.00175	0.8361
0.01601	0.3907	0.00172	0.8453
0.01537	0.4006	0.00158	0.8548
0.01413	0.4104	0.00155	0.8643
0.01233	0.4199	0.00183	0.8740
0.01281	0.4286	0.00230	0.8835
0.01195	0.4380	0.00414	0.8932
0.01164	0.4478	0.00917	0.9027
0.01168	0.4570	0.02329	0.9125
0.01032	0.4665	0.01952	0.9222


RUN # P453 TG # 1
PLUM RUN DOLOMITE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
TIME IN MINUTES
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
1.2
0
40
80
120
160
200
240
280
320

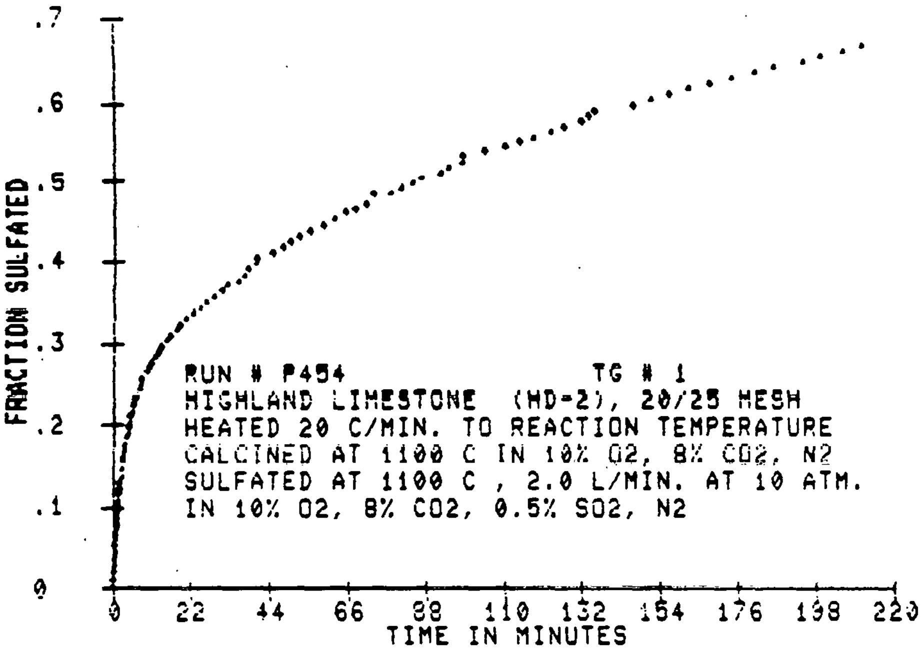

RUN # P453 TG # 1
PLUM RUN DOLOMITE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
FRACTION SULFATED
0
2
4
6
8
10
12
14
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
1.2

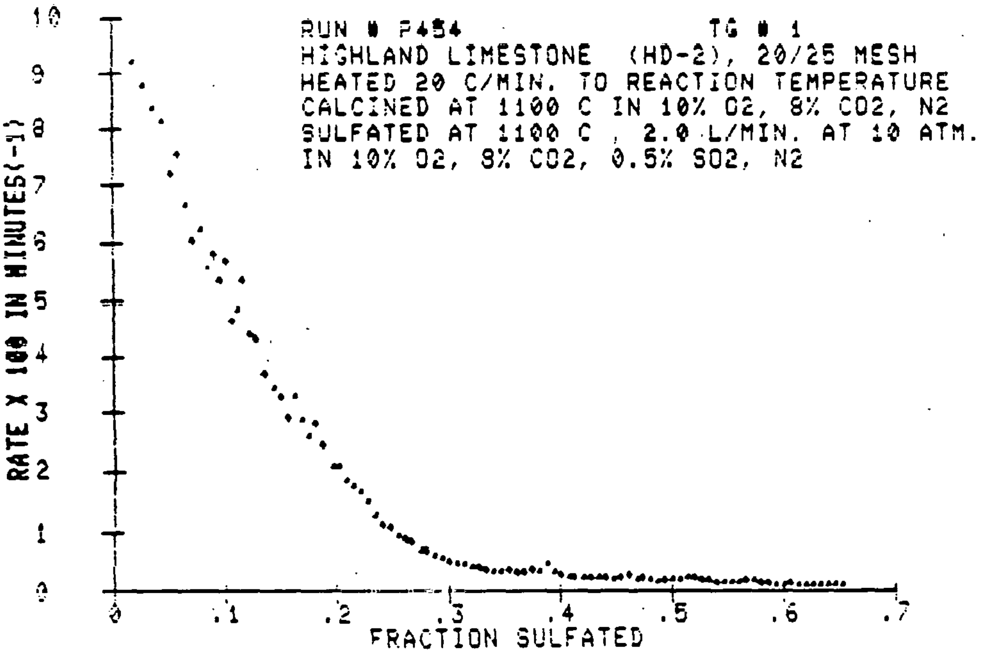

RUN # P453 TG # 1
PLUM RUN DOLOMITE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
1.2
FRACTION SULFATED

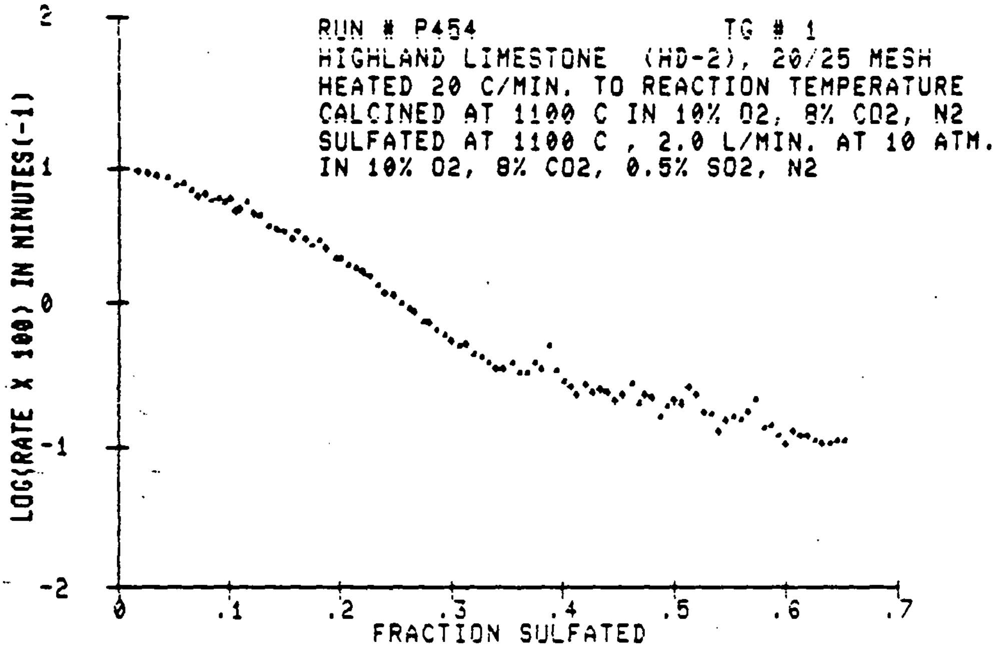
```
RUN # P453      TEMPERATURE = (1080.75 +/-  1.73 ) C

FRACTION         TIME          FRACTION        TIME
0.0000           0.00           0.5787        37.90
0.0236           0.60           0.5918        39.30
0.0537           0.75           0.6010        40.40
0.0694           0.90           0.6141        41.80
0.0825           1.00           0.6246        43.20
0.0903           1.10           0.6363        44.50
0.0969           1.20           0.6468        46.00
0.1061           1.30           0.6599        47.30
0.1152           1.40           0.6704        48.60
0.1205           1.50           0.6809        50.20
0.1244           1.60           0.6940        52.00
0.1309           1.70           0.7031        53.20
0.1362           1.80           0.7149        54.40
0.1532           2.00           0.7267        56.50
0.1624           2.20           0.7372        57.90
0.1741           2.50           0.7516        60.20
0.1833           2.90           0.7620        61.70
0.1938           3.30           0.7725        64.20
0.2056           3.70           0.7830        66.40
0.2174           4.10           0.7974        68.60
0.2304           5.10           0.8053        70.20
0.2383           5.60           0.8170        72.70
0.2501           6.70           0.8288        75.60
0.2619           7.60           0.8393        77.70
0.2737           9.10           0.8524        81.20
0.2881          10.00           0.8629        84.40
0.2959          10.50           0.8733        87.30
0.3077          11.80           0.8851        90.90
0.2195          13.30           0.8969        95.70
0.3313          14.60           0.9074        99.10
0.3404          15.50           0.9192       104.50
0.3535          16.90           0.9323       112.80
0.3640          17.30           0.9414       119.20
0.3771          17.90           0.9558       122.40
0.3902          19.20           0.9650       123.00
0.3990          20.30           0.9755       123.60
0.4085          20.80           0.9886       124.80
0.4229          22.00           1.0017       125.80
0.4321          23.10           1.0095       127.20
0.4439          24.10           1.0213       128.40
0.4543          25.30           1.0331       131.00
0.4674          27.00           1.0436       136.80
0.4805          27.80           1.0553       145.60
0.4884          28.50           1.0671       157.20
0.5002          29.50           1.0776       177.40
0.5107          30.70           1.0894       202.20
0.5237          32.00           1.1012       246.60
0.5342          33.10           1.1116       266.80
0.5447          34.10           1.1234       284.40
0.5591          35.70           1.1339       304.80
0.5696          36.90
```

RUN # P453

RATE	FRACTION	RATE	FRACTION
0.08249	0.0458	0.00891	0.5800
0.13356	0.0639	0.00909	0.5910
0.09602	0.0786	0.00865	0.6020
0.09166	0.0890	0.00856	0.6136
0.08183	0.0982	0.00818	0.6246
0.07528	0.1058	0.00833	0.6363
0.06875	0.1126	0.00849	0.6476
0.06219	0.1194	0.00781	0.6589
0.05238	0.1254	0.00786	0.6704
0.06547	0.1330	0.00732	0.6817
0.06328	0.1414	0.00768	0.6927
0.05401	0.1514	0.00727	0.7039
0.04235	0.1618	0.00732	0.7152
0.03122	0.1734	0.00692	0.7267
0.02881	0.1838	0.00646	0.7385
0.02701	0.1948	0.00595	0.7500
0.02143	0.2061	0.00539	0.7613
0.01936	0.2171	0.00546	0.7733
0.01484	0.2284	0.00508	0.7840
0.01272	0.2396	0.00524	0.7950
0.01080	0.2509	0.00498	0.8063
0.01131	0.2624	0.00460	0.8176
0.01206	0.2739	0.00429	0.8286
0.01091	0.2854	0.00392	0.8401
0.01091	0.2970	0.00380	0.8513
0.00939	0.3085	0.00347	0.8626
0.00890	0.3190	0.00307	0.8741
0.00899	0.3305	0.00303	0.8851
0.01113	0.3417	0.00266	0.8964
0.01339	0.3533	0.00215	0.9082
0.01345	0.3650	0.00189	0.9194
0.01309	0.3766	0.00208	0.9312
0.01272	0.3876	0.00248	0.9427
0.01118	0.3994	0.00400	0.9540
0.01074	0.4104	0.00842	0.9653
0.01206	0.4211	0.01348	0.9772
0.01018	0.4324	0.01060	0.9880
0.00890	0.4441	0.00955	0.9993
0.01031	0.4557	0.00718	1.0108
0.01012	0.4669	0.00381	1.0218
0.01091	0.4782	0.00249	1.0326
0.01168	0.4894	0.00159	1.0441
0.01029	0.5007	0.00096	1.0553
0.00996	0.5114	0.00070	1.0666
0.00968	0.5227	0.00045	1.0781
0.00969	0.5345	0.00041	1.0894
0.00935	0.5463	0.00043	1.1007
0.00927	0.5573	0.00043	1.1119
0.00906	0.5688		


RUN # P454 TG # 1
HIGHLAND LIMESTONE (HD-2), 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.7
.6
.5
.4
.3
.2
.1
0
0
22
44
66
88
110
132
154
176
198
220
TIME IN MINUTES

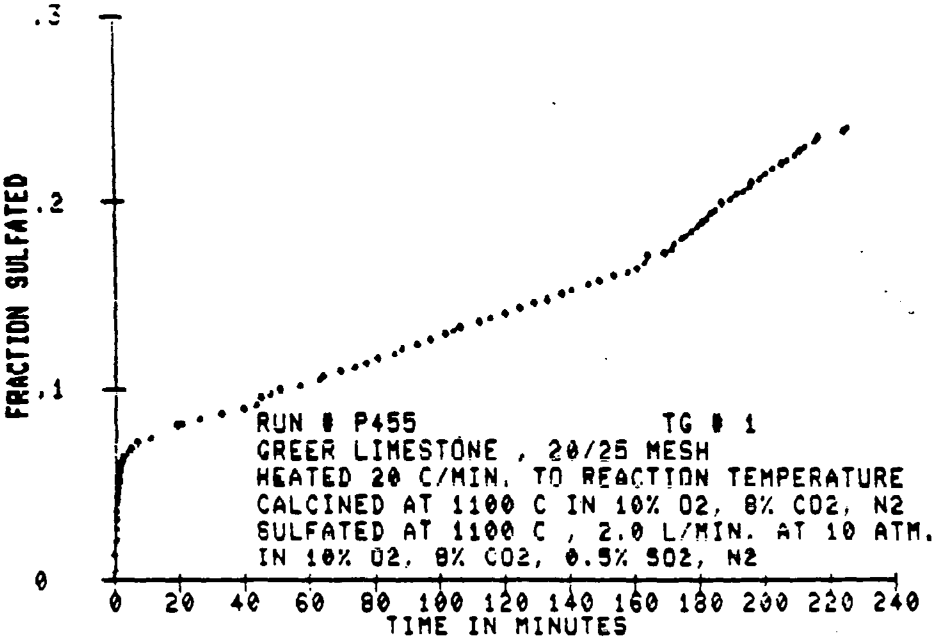

RUN # P454 TG # 1
HIGHLAND LIMESTONE (HD-2), 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
10
9
8
7
6
5
4
3
2
1
0
0
.1
.2
.3
.4
.5
.6
.7
FRACTION SULFATED

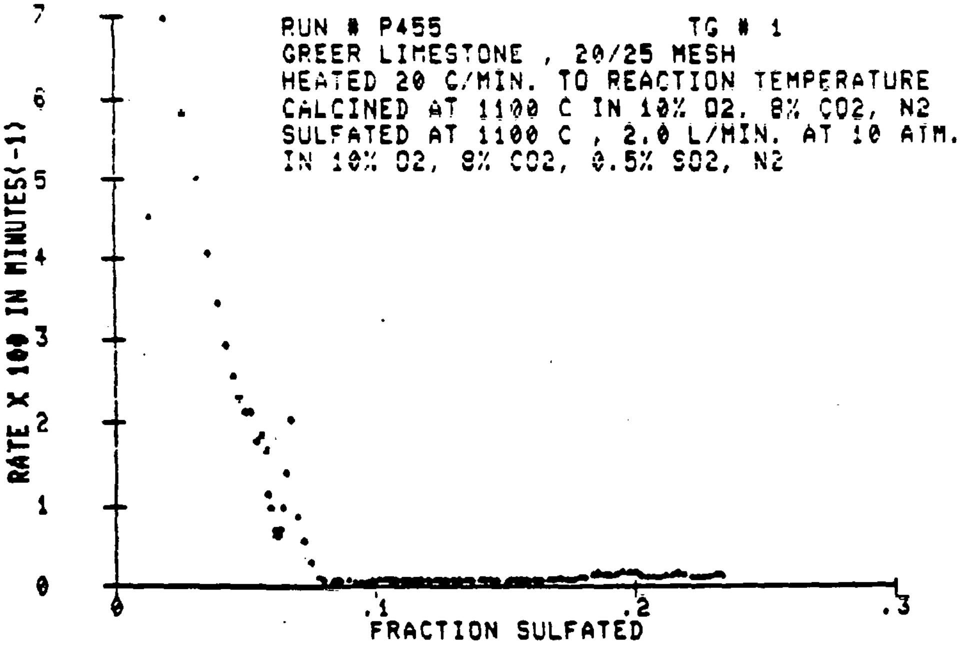

RUN # P454 TG # 1
HIGHLAND LIMESTONE (HD-2), 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
FRACTION SULFATED

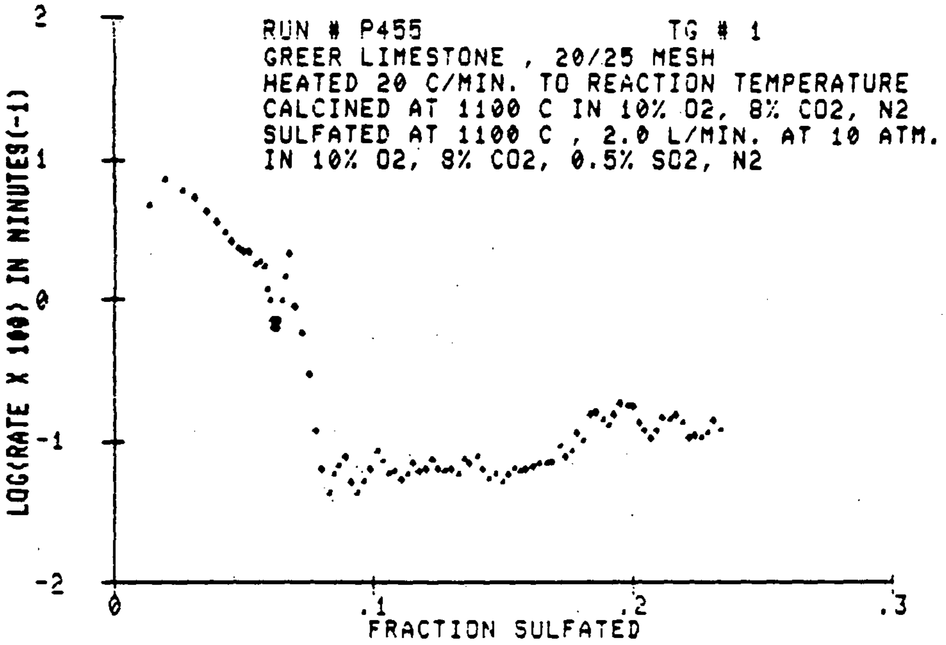
```
RUN # P454       TEMPERATURE = (1100.36 +/-  0.00 ) C


FRACTION          TIME              FRACTION          TIME
0.0000             0.00              0.3399            24.20
0.0090             0.10              0.3468            26.20
0.0184             0.20              0.3536            28.10
0.0273             0.30              0.3609            30.60
0.0368             0.40              0.3691            32.00
0.0441             0.50              0.3733            34.70
0.0518             0.60              0.3802            36.60
0.0604             0.70              0.3870            37.60
0.0655             0.80              0.3956            39.85
0.0741             0.90              0.3999            40.15
0.0784             1.00              0.4067            44.65
0.0843             1.10              0.4144            47.50
0.0903             1.20              0.4204            49.90
0.0963             1.30              0.4264            52.30
0.1015             1.40              0.4333            55.00
0.1058             1.50              0.4401            58.90
0.1130             1.60              0.4487            61.75
0.1147             1.70              0.4555            65.05
0.1207             1.80              0.4598            68.20
0.1272             1.90              0.4667            71.20
0.1349             2.10              0.4787            73.00
0.1447             2.40              0.4804            77.80
0.1537             2.70              0.4864            80.50
0.1580             2.80              0.4932            83.95
0.1610             2.90              0.5001            86.65
0.1678             3.20              0.5069            91.90
0.1734             3.30              0.5138            94.15
0.1837             3.70              0.5198            97.90
0.1867             3.90              0.5283            98.05
0.1957             4.20              0.5343           104.50
0.1999             4.40              0.5403           110.05
0.2085             4.90              0.5472           114.40
0.2136             5.20              0.5532           118.15
0.2214             5.50              0.5617           123.10
0.2273             6.00              0.5669           126.70
0.2333             6.40              0.5737           131.80
0.2423             7.10              0.5797           134.05
0.2483             7.70              0.5874           135.55
0.2535             8.30              0.5934           146.50
0.2600             9.20              0.6011           151.45
0.2672             9.70              0.6063           156.70
0.2740            10.60              0.6140           161.95
0.2809            11.60              0.6200           167.95
0.2869            12.50              0.6268           173.80
0.2937            13.50              0.6337           180.70
0.3010            14.90              0.6397           186.10
0.3066            16.10              0.6465           194.50
0.3134            17.70              0.6534           199.45
0.3198            18.90              0.6602           205.45
0.3280            20.40              0.6662           210.85
0.3335            22.40
```

RUN # P454

RATE	FRACTION	RATE	FRACTION
0.09205	0.0184	0.00334	0.3404
0.08778	0.0272	0.00334	0.3470
0.08348	0.0358	0.00373	0.3541
0.08136	0.0442	0.00312	0.3608
0.07171	0.0517	0.00312	0.3674
0.07492	0.0592	0.00373	0.3741
0.06637	0.0660	0.00338	0.3811
0.05994	0.0725	0.00487	0.3872
0.06209	0.0785	0.00330	0.3939
0.05566	0.0847	0.00277	0.4007
0.05780	0.0902	0.00247	0.4074
0.05352	0.0956	0.00218	0.4136
0.05673	0.1014	0.00256	0.4203
0.04603	0.1063	0.00225	0.4269
0.04316	0.1111	0.00238	0.4338
0.05352	0.1163	0.00228	0.4408
0.04367	0.1221	0.00201	0.4475
0.04281	0.1284	0.00216	0.4542
0.03663	0.1362	0.00266	0.4619
0.03425	0.1437	0.00195	0.4682
0.03265	0.1505	0.00216	0.4744
0.02890	0.1570	0.00208	0.4811
0.03282	0.1628	0.00157	0.4877
0.02854	0.1688	0.00188	0.4934
0.02569	0.1745	0.00201	0.5001
0.02783	0.1814	0.00190	0.5068
0.02413	0.1879	0.00248	0.5138
0.02069	0.1949	0.00217	0.5206
0.02075	0.2009	0.00167	0.5273
0.01835	0.2073	0.00166	0.5340
0.01739	0.2142	0.00124	0.5407
0.01656	0.2209	0.00147	0.5473
0.01510	0.2277	0.00159	0.5539
0.01284	0.2346	0.00153	0.5605
0.01117	0.2410	0.00167	0.5670
0.01070	0.2482	0.00206	0.5739
0.00955	0.2549	0.00134	0.5802
0.00886	0.2613	0.00139	0.5871
0.00830	0.2678	0.00117	0.5936
0.00714	0.2744	0.00101	0.6004
0.00699	0.2805	0.00124	0.6069
0.00627	0.2873	0.00115	0.6136
0.00571	0.2939	0.00114	0.6201
0.00510	0.3003	0.00106	0.6268
0.00484	0.3069	0.00100	0.6333
0.00490	0.3137	0.00103	0.6400
0.00428	0.3203	0.00107	0.6467
0.00408	0.3269	0.00107	0.6532
0.00369	0.3336		


RUN # P455 TG # 1
GREER LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.3
.2
.1
0
0
20
40
60
80
100
120
140
160
180
200
220
240
TIME IN MINUTES

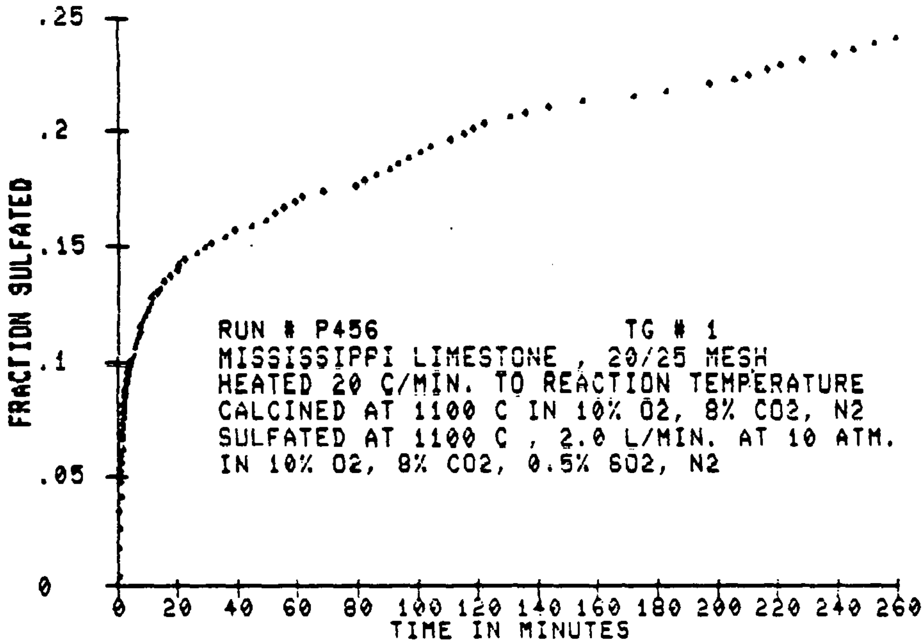

RUN # P455 TG # 1
GREER LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
7
6
5
4
3
2
1
0
0
.1
.2
.3
FRACTION SULFATED

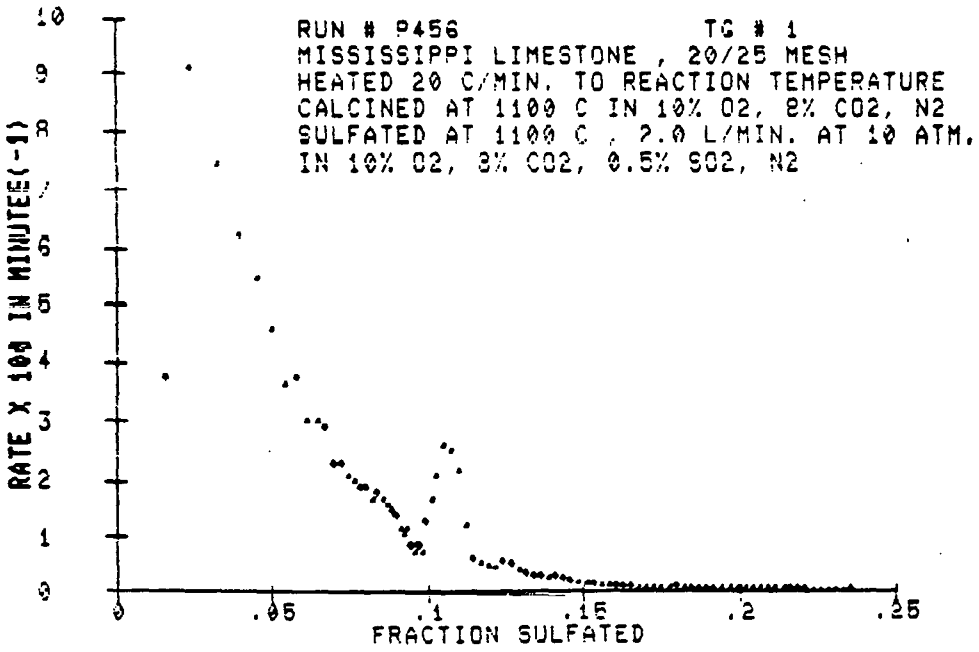

RUN # P455 TG # 1
GREER LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
FRACTION SULFATED

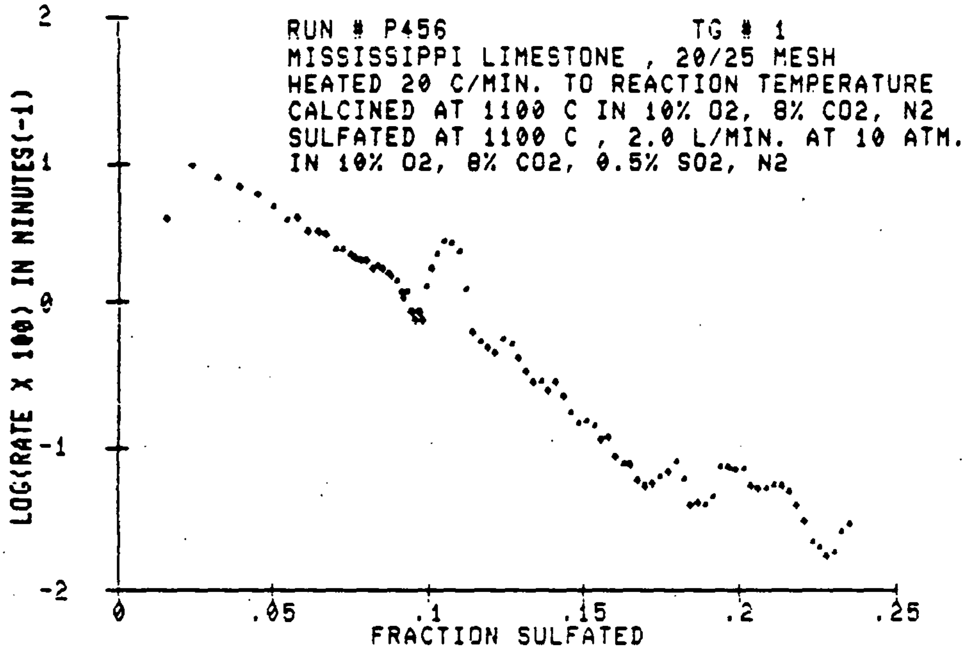
```
RUN # P455       TEMPERATURE = (1067.72 +/-  1.68 ) C

FRACTION         TIME           FRACTION         TIME
0.0000            0.00          0.1254            97.40
0.0046            0.30          0.1282           102.20
0.0137            0.40          0.1303           104.30
0.0211            0.50          0.1324           106.40
0.0270            0.60          0.1352           112.40
0.0323            0.70          0.1373           115.70
0.0369            0.80          0.1398           120.20
0.0411            0.90          0.1422           124.85
0.0432            1.00          0.1454           129.35
0.0460            1.10          0.1468           133.25
0.0485            1.20          0.1493           138.05
0.0513            1.30          0.1517           140.90
0.0523            1.40          0.1542           145.55
0.0544            1.50          0.1566           149.15
0.0569            1.60          0.1591           153.65
0.0583            1.70          0.1612           157.85
0.0597            1.80          0.1637           161.15
0.0611            2.00          0.1665           163.55
0.0615            2.10          0.1703           164.90
0.0622            2.20          0.1717           169.70
0.0625            2.30          0.1735           171.80
0.0636            2.40          0.1767           172.55
0.0643            2.60          0.1791           174.95
0.0646            2.70          0.1805           176.15
0.0653            2.80          0.1833           178.10
0.0674            3.70          0.1855           179.60
0.0699            5.10          0.1886           181.55
0.0727            6.90          0.1904           182.60
0.0748           10.80          0.1932           183.65
0.0808           19.30          0.1949           185.30
0.0815           19.40          0.1981           187.40
0.0818           20.70          0.2002           189.65
0.0843           26.20          0.2030           191.60
0.0867           32.90          0.2048           194.00
0.0892           39.60          0.2072           195.65
0.0917           43.20          0.2093           196.55
0.0945           45.40          0.2118           198.65
0.0966           48.05          0.2142           200.60
0.0987           51.05          0.2170           203.00
0.1011           57.20          0.2192           206.00
0.1036           62.75          0.2216           207.65
0.1061           64.25          0.2241           209.75
0.1085           69.65          0.2265           211.40
0.1110           73.85          0.2286           212.90
0.1131           77.30          0.2311           216.05
0.1155           81.20          0.2336           217.70
0.1180           86.00          0.2360           225.05
0.1205           88.25          0.2385           226.10
0.1229           93.50
```

RUN # P455

RATE	FRACTION	RATE	FRACTION
0.04507	0.0133	0.00061	0.1255
0.06936	0.0197	0.00059	0.1278
0.05795	0.0262	0.00061	0.1303
0.05005	0.0317	0.00057	0.1327
0.04039	0.0361	0.00074	0.1350
0.03425	0.0399	0.00066	0.1374
0.02897	0.0431	0.00075	0.1400
0.02546	0.0460	0.00060	0.1423
0.02283	0.0483	0.00051	0.1447
0.02107	0.0505	0.00056	0.1471
0.02107	0.0527	0.00050	0.1495
0.01756	0.0546	0.00055	0.1517
0.01844	0.0563	0.00061	0.1542
0.01668	0.0581	0.00059	0.1566
0.01141	0.0595	0.00060	0.1590
0.00966	0.0605	0.00063	0.1614
0.00702	0.0614	0.00066	0.1642
0.00615	0.0622	0.00068	0.1667
0.00702	0.0628	0.00068	0.1691
0.00615	0.0634	0.00091	0.1717
0.00702	0.0641	0.00074	0.1743
0.00966	0.0650	0.00082	0.1763
0.01405	0.0663	0.00109	0.1786
0.02020	0.0680	0.00098	0.1812
0.00862	0.0700	0.00147	0.1836
0.00556	0.0731	0.00156	0.1859
0.00283	0.0759	0.00139	0.1884
0.00116	0.0783	0.00128	0.1907
0.00061	0.0806	0.00147	0.1930
0.00042	0.0830	0.00177	0.1953
0.00056	0.0847	0.00173	0.1979
0.00064	0.0867	0.00168	0.2002
0.00075	0.0893	0.00130	0.2026
0.00049	0.0917	0.00115	0.2049
0.00042	0.0941	0.00101	0.2072
0.00049	0.0965	0.00115	0.2095
0.00060	0.0989	0.00143	0.2119
0.00083	0.1012	0.00139	0.2143
0.00070	0.1036	0.00149	0.2168
0.00057	0.1061	0.00134	0.2192
0.00059	0.1085	0.00100	0.2217
0.00051	0.1108	0.00105	0.2240
0.00057	0.1132	0.00104	0.2264
0.00065	0.1156	0.00113	0.2288
0.00058	0.1180	0.00137	0.2312
0.00060	0.1205	0.00117	0.2336
0.00071	0.1230		


FRACTION SULFATED
.25
.2
.15
.1
.05
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
TIME IN MINUTES
RUN # P456 TG # 1
MISSISSIPPI LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

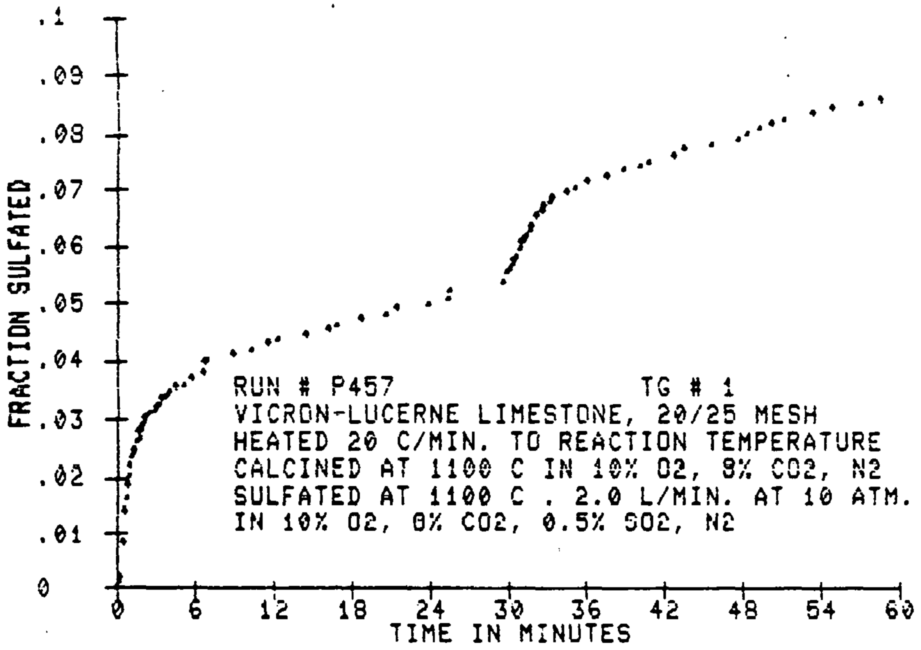

RATE X 100 IN MINUTES(-1)
10
9
8
7
6
5
4
3
2
1
0
0
.05
.1
.15
.2
.25
FRACTION SULFATED
RUN # P456 TG # 1
MISSISSIPPI LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

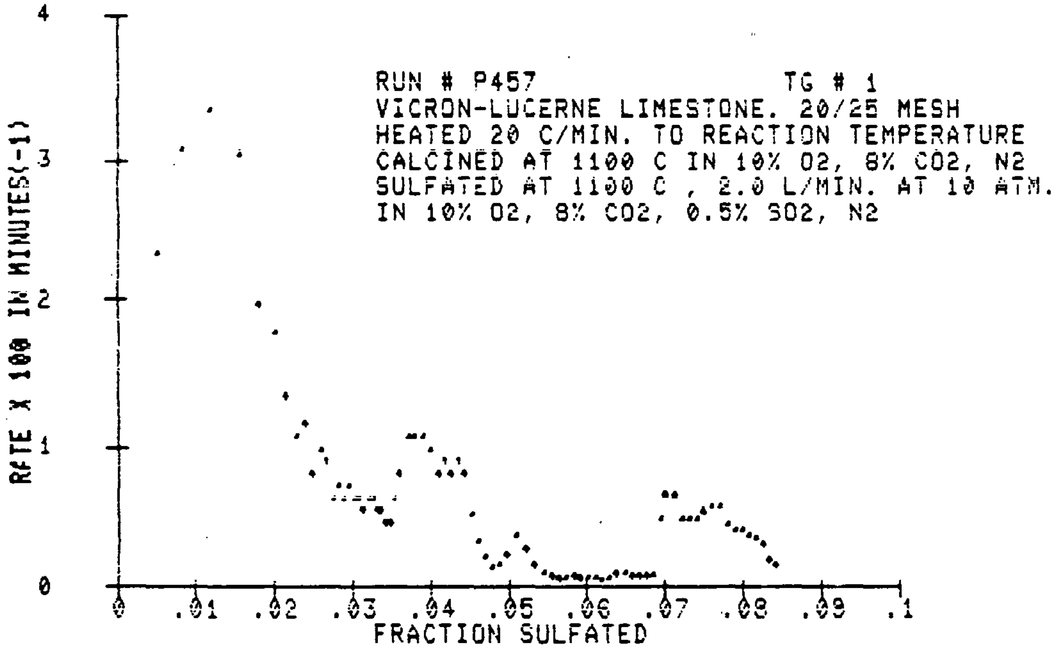

RUN # P456 TG # 1
MISSISSIPPI LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.05
.1
.15
.2
.25
FRACTION SULFATED

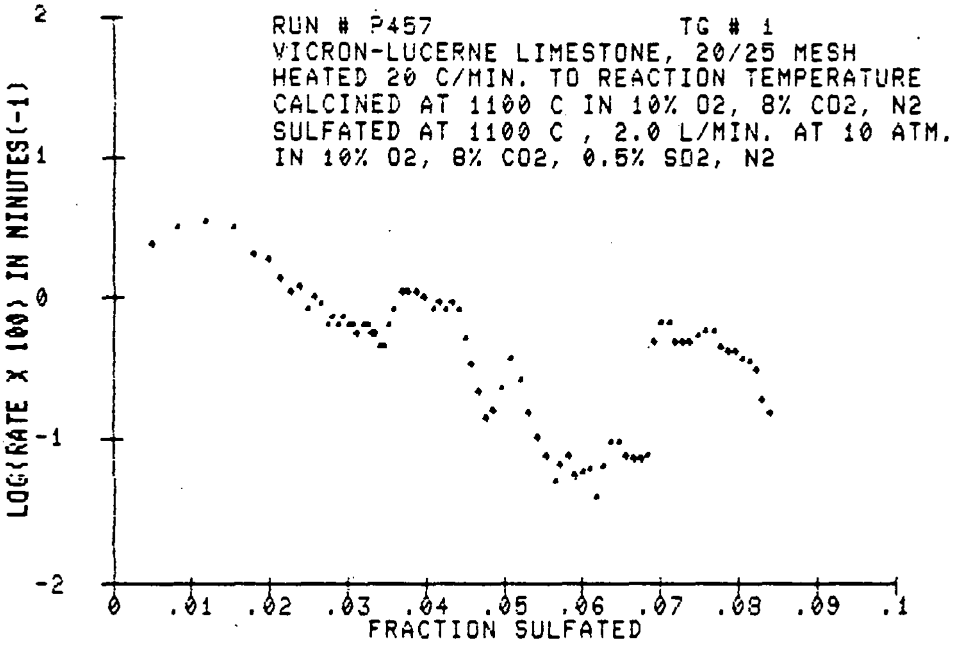
```
RUN # P456       TEMPERATURE = (1066.11 +/-  1.66 ) C

FRACTION        TIME            FRACTION        TIME
0.0000            0.00           0.1288           13.20
0.0037            0.60           0.1309           14.00
0.0165            0.70           0.1338           15.70
0.0260            0.80           0.1359           17.30
0.0334            0.90           0.1383           19.70
0.0401            1.00           0.1408           20.30
0.0462            1.10           0.1433           22.60
0.0508            1.20           0.1462           26.40
0.0553            1.30           0.1482           28.80
0.0582            1.40           0.1503           31.50
0.0607            1.50           0.1528           35.50
0.0657            1.60           0.1557           39.20
0.0673            1.70           0.1577           44.40
0.0702            1.80           0.1602           49.50
0.0723            1.90           0.1631           52.60
0.0747            2.00           0.1652           55.40
0.0764            2.10           0.1676           59.45
0.0785            2.20           0.1697           62.00
0.0801            2.30           0.1722           68.60
0.0822            2.40           0.1747           79.55
0.0838            2.50           0.1771           82.70
0.0851            2.60           0.1796           85.70
0.0871            2.70           0.1821           90.50
0.0888            2.90           0.1846           93.20
0.0900            3.00           0.1866           96.65
0.0908            3.10           0.1891          100.85
0.0925            3.30           0.1916          104.00
0.0933            3.60           0.1941          111.05
0.0941            3.70           0.1966          115.55
0.0954            3.80           0.1990          118.25
0.0958            3.90           0.2015          122.30
0.0966            4.00           0.2044          130.55
0.0970            4.20           0.2060          135.95
0.0987            4.30           0.2085          140.45
0.0991            4.40           0.2110          154.70
0.0995            4.50           0.2135          172.10
0.1020            5.10           0.2160          182.75
0.1053            5.90           0.2188          197.75
0.1074            6.40           0.2209          205.85
0.1098            6.70           0.2234          210.35
0.1119            7.40           0.2259          216.80
0.1140            7.70           0.2279          221.15
0.1169            8.20           0.2304          228.95
0.1189            9.20           0.2329          239.75
0.1218           10.20           0.2354          245.75
0.1239           11.20           0.2378          252.35
0.1268           11.80           0.2403          259.70
```

RUN # P456

RATE	FRACTION	RATE	FRACTION
0.03716	0.0159	0.00396	0.1288
0.09084	0.0239	0.00324	0.1312
0.07433	0.0325	0.00271	0.1335
0.06193	0.0393	0.00275	0.1359
0.05471	0.0452	0.00237	0.1384
0.04543	0.0501	0.00272	0.1409
0.03613	0.0543	0.00220	0.1434
0.03717	0.0581	0.00173	0.1458
0.02994	0.0614	0.00146	0.1482
0.02994	0.0644	0.00151	0.1506
0.02891	0.0672	0.00138	0.1529
0.02271	0.0700	0.00109	0.1553
0.02271	0.0722	0.00113	0.1579
0.02064	0.0744	0.00085	0.1604
0.01961	0.0764	0.00077	0.1628
0.01858	0.0784	0.00074	0.1652
0.01858	0.0802	0.00058	0.1676
0.01652	0.0819	0.00053	0.1699
0.01755	0.0837	0.00056	0.1723
0.01652	0.0854	0.00061	0.1747
0.01549	0.0870	0.00066	0.1771
0.01445	0.0884	0.00079	0.1796
0.01342	0.0899	0.00059	0.1820
0.01135	0.0911	0.00039	0.1844
0.01032	0.0922	0.00041	0.1868
0.01136	0.0932	0.00040	0.1892
0.00826	0.0942	0.00045	0.1916
0.00826	0.0951	0.00073	0.1941
0.00723	0.0958	0.00071	0.1966
0.00826	0.0967	0.00068	0.1991
0.00826	0.0974	0.00070	0.2015
0.00723	0.0982	0.00053	0.2039
0.01239	0.0993	0.00050	0.2063
0.01652	0.1009	0.00052	0.2087
0.02064	0.1027	0.00054	0.2110
0.02581	0.1048	0.00053	0.2136
0.02477	0.1073	0.00049	0.2160
0.02169	0.1097	0.00039	0.2185
0.01187	0.1120	0.00031	0.2210
0.00606	0.1143	0.00022	0.2234
0.00522	0.1167	0.00020	0.2257
0.00472	0.1191	0.00017	0.2281
0.00431	0.1216	0.00019	0.2305
0.00551	0.1240	0.00026	0.2329
0.00505	0.1264	0.00029	0.2354


FRACTION SULFATED
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
0
6
12
18
24
30
36
42
48
54
60
TIME IN MINUTES
RUN # P457 TG # 1
VICRON-LUCERNE LIMESTONE, 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C . 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
4
3
2
1
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED
RUN # P457 TG # 1
VICRON-LUCERNE LIMESTONE. 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

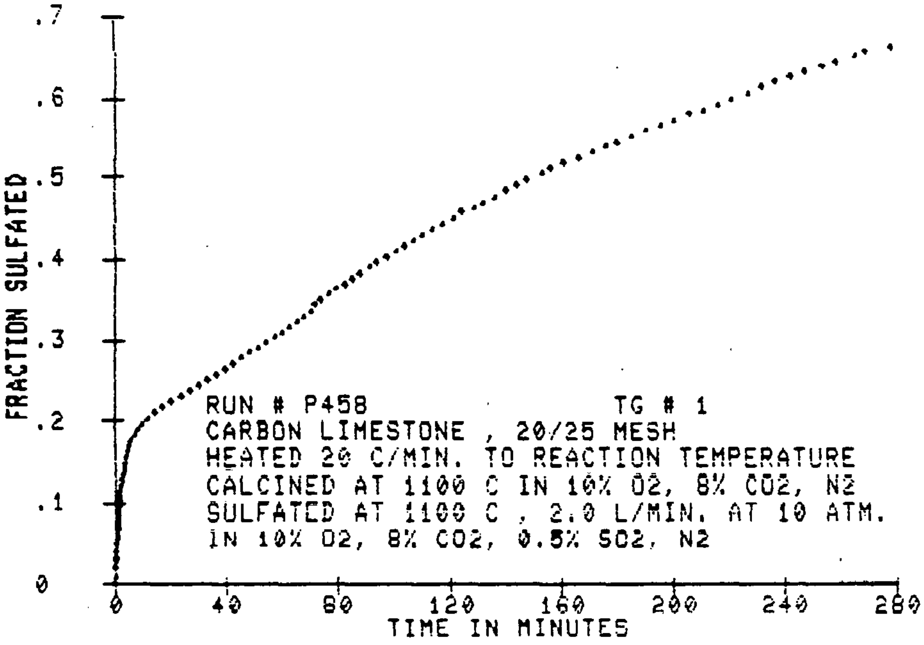

RUN # P457 TG # 1
VICRON-LUCERNE LIMESTONE, 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED

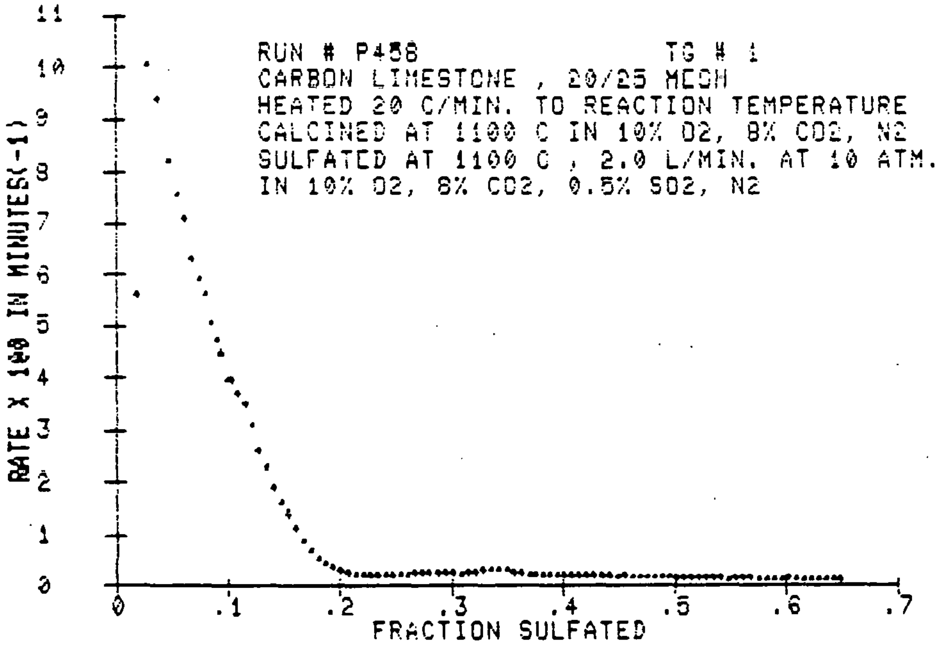
RUN # P457 TEMPERATURE = (895.21 +/- 4.54) C

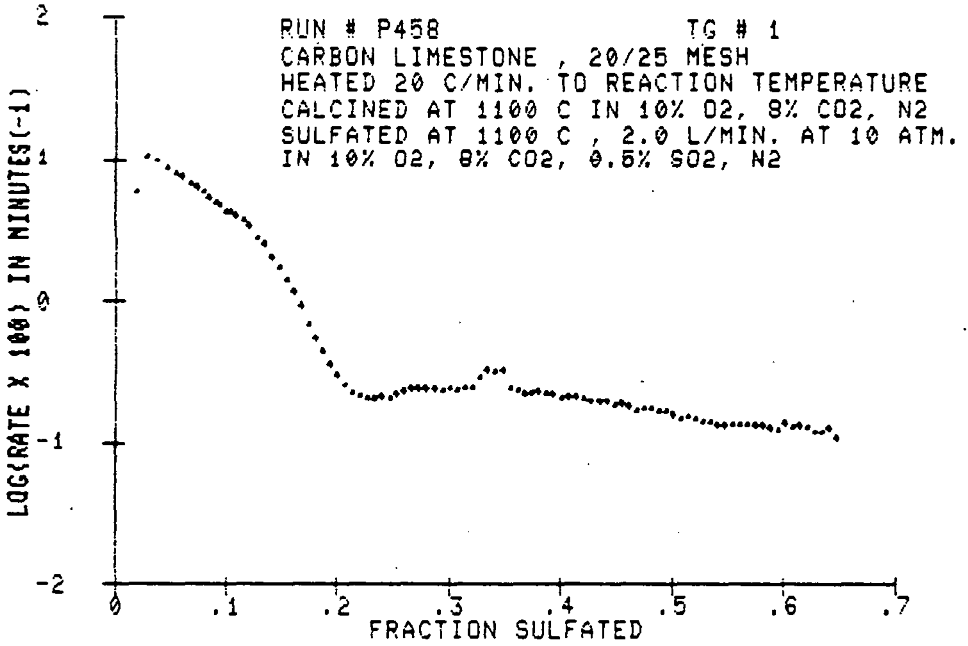
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.0477	20.50
0.0011	0.20	0.0488	21.40
0.0018	0.30	0.0495	23.80
0.0082	0.50	0.0505	25.30
0.0139	0.60	0.0520	25.45
0.0164	0.70	0.0534	29.50
0.0185	0.80	0.0552	29.80
0.0203	0.90	0.0555	30.10
0.0217	1.00	0.0566	30.25
0.0235	1.10	0.0573	30.40
0.0238	1.20	0.0580	30.55
0.0246	1.30	0.0594	30.85
0.0263	1.40	0.0605	31.00
0.0267	1.60	0.0609	31.15
0.0278	1.70	0.0616	31.30
0.0281	1.80	0.0626	31.60
0.0288	1.90	0.0634	31.75
0.0295	2.00	0.0651	32.05
0.0303	2.10	0.0662	32.50
0.0310	2.30	0.0669	32.65
0.0313	2.80	0.0676	33.10
0.0320	3.00	0.0683	33.40
0.0324	3.10	0.0694	34.45
0.0335	3.40	0.0701	35.05
0.0338	3.60	0.0712	36.10
0.0342	3.80	0.0723	37.60
0.0345	3.90	0.0733	38.80
0.0352	4.50	0.0737	40.00
0.0356	5.00	0.0747	40.75
0.0367	5.70	0.0758	42.70
0.0377	6.70	0.0772	43.45
0.0395	6.80	0.0779	45.55
0.0399	6.90	0.0790	47.50
0.0409	8.95	0.0797	48.25
0.0416	10.15	0.0808	49.15
0.0427	11.50	0.0815	50.20
0.0434	12.25	0.0822	51.10
0.0441	14.50	0.0833	53.35
0.0452	16.15	0.0844	54.85
0.0459	16.75	0.0851	56.95
0.0470	18.70	0.0858	58.60

RUN # P457

RATE	FRACTION	RATE	FRACTION
0.02313	0.0050	0.00137	0.0478
0.03061	0.0083	0.00155	0.0487
0.03346	0.0117	0.00225	0.0497
0.03025	0.0154	0.00356	0.0508
0.01958	0.0182	0.00253	0.0521
0.01780	0.0201	0.00149	0.0533
0.01335	0.0216	0.00101	0.0545
0.01068	0.0228	0.00075	0.0556
0.01157	0.0240	0.00051	0.0565
0.00801	0.0250	0.00065	0.0574
0.00979	0.0258	0.00075	0.0584
0.00890	0.0267	0.00055	0.0592
0.00623	0.0275	0.00059	0.0601
0.00712	0.0282	0.00061	0.0610
0.00623	0.0289	0.00040	0.0618
0.00712	0.0295	0.00065	0.0627
0.00623	0.0302	0.00093	0.0638
0.00623	0.0308	0.00095	0.0649
0.00534	0.0314	0.00075	0.0658
0.00623	0.0320	0.00071	0.0668
0.00623	0.0326	0.00071	0.0677
0.00534	0.0332	0.00076	0.0685
0.00534	0.0337	0.00475	0.0693
0.00445	0.0342	0.00652	0.0703
0.00445	0.0347	0.00653	0.0713
0.00623	0.0352	0.00475	0.0721
0.00801	0.0359	0.00475	0.0730
0.01068	0.0369	0.00475	0.0740
0.01068	0.0379	0.00522	0.0750
0.01068	0.0389	0.00569	0.0759
0.00979	0.0399	0.00569	0.0770
0.00801	0.0409	0.00435	0.0779
0.00890	0.0417	0.00395	0.0789
0.00801	0.0426	0.00395	0.0798
0.00890	0.0434	0.00356	0.0807
0.00801	0.0443	0.00339	0.0815
0.00508	0.0451	0.00297	0.0824
0.00324	0.0460	0.00183	0.0833
0.00209	0.0469	0.00148	0.0841


FRACTION SULFATED
.7
.6
.5
.4
.3
.2
.1
0
0
40
80
120
160
200
240
280
TIME IN MINUTES
RUN # P458 TG # 1
CARBON LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
11
10
9
8
7
6
5
4
3
2
1
0
0
.1
.2
.3
.4
.5
.6
.7
FRACTION SULFATED
RUN # P458 TG # 1
CARBON LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

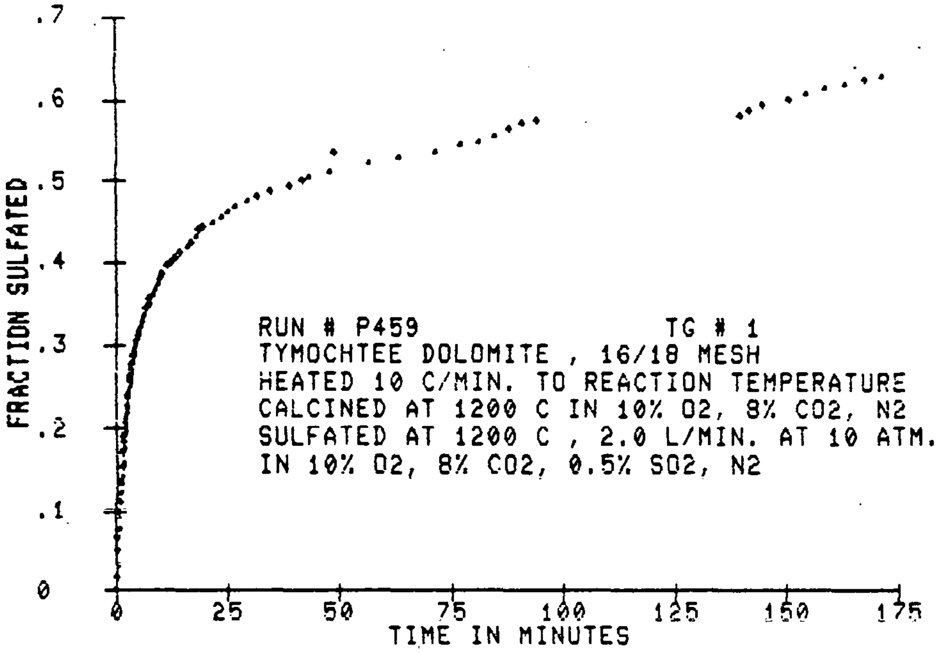

RUN # P458 TG # 1
CARBON LIMESTONE , 20/25 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 10% O2, 8% CO2, N2
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
FRACTION SULFATED

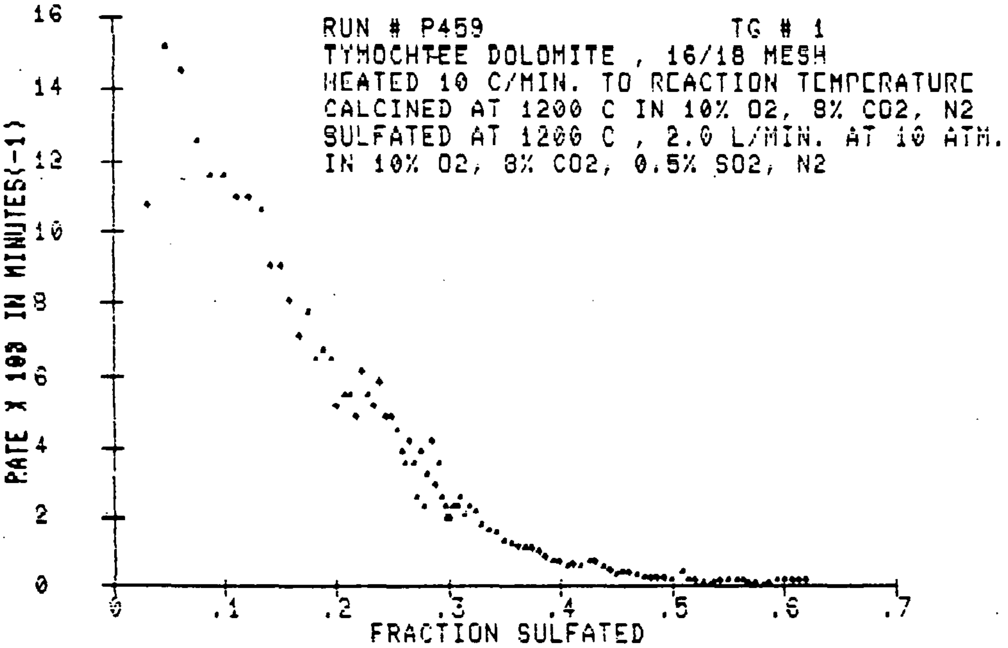
RUN # P458 TEMPERATURE = (1099.70 +/- 0.99) C

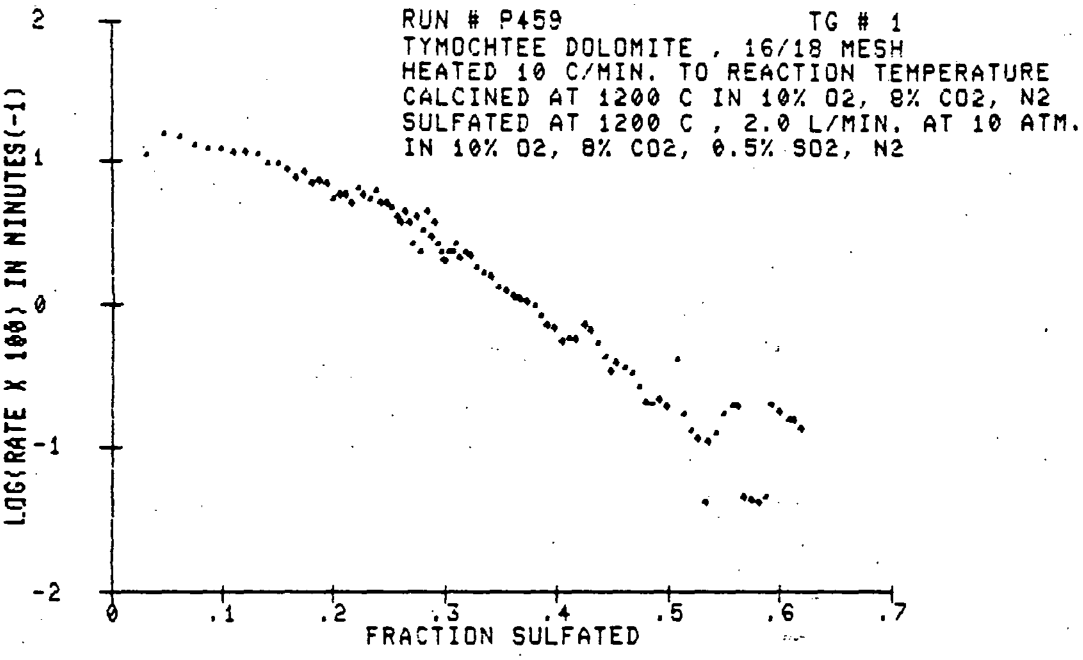
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.3343	70.50
0.0074	0.40	0.3425	71.80
0.0182	0.50	0.3486	74.05
0.0294	0.60	0.3564	76.75
0.0391	0.70	0.3626	79.30
0.0476	0.80	0.3680	82.30
0.0557	0.90	0.3750	85.30
0.0623	1.00	0.3812	88.00
0.0693	1.10	0.3889	91.00
0.0758	1.20	0.3943	93.85
0.0809	1.30	0.4013	97.15
0.0859	1.40	0.4082	100.30
0.0917	1.50	0.4144	103.60
0.0960	1.60	0.4214	106.90
0.0998	1.70	0.4284	110.20
0.1037	1.80	0.4353	113.65
0.1076	1.90	0.4415	117.70
0.1157	2.10	0.4485	121.00
0.1219	2.30	0.4554	124.30
0.1281	2.50	0.4616	128.35
0.1354	2.80	0.4670	131.95
0.1416	3.10	0.4748	136.00
0.1474	3.40	0.4818	140.35
0.1544	3.90	0.4887	144.10
0.1610	4.40	0.4949	147.55
0.1676	5.00	0.5027	152.95
0.1741	5.80	0.5081	156.40
0.1811	6.90	0.5150	161.15
0.1877	8.30	0.5220	166.15
0.1939	9.90	0.5297	170.95
0.2008	11.90	0.5359	175.75
0.2078	14.50	0.5414	179.95
0.2140	17.30	0.5483	184.95
0.2206	20.40	0.5553	190.35
0.2275	24.00	0.5615	195.35
0.2349	27.10	0.5684	200.15
0.2407	30.30	0.5762	205.95
0.2473	33.70	0.5824	210.55
0.2542	36.80	0.5886	216.15
0.2608	39.80	0.5955	220.95
0.2674	42.60	0.6017	226.55
0.2744	45.50	0.6087	232.15
0.2809	48.00	0.6164	236.55
0.2875	51.10	0.6226	242.15
0.2945	53.90	0.6298	247.55
0.3014	56.80	0.6358	253.55
0.3076	59.40	0.6420	258.35
0.3142	62.10	0.6497	265.35
0.3208	65.30	0.6559	269.35
0.3278	67.60	0.6621	278.55

RUN # P455

RATE	FRACTION	RATE	FRACTION
0.05583	0.0188	0.00318	0.3348
0.10062	0.0283	0.00313	0.3419
0.09383	0.0380	0.00321	0.3489
0.08224	0.0468	0.00243	0.3556
0.07545	0.0548	0.00234	0.3621
0.07062	0.0621	0.00220	0.3686
0.06289	0.0688	0.00225	0.3751
0.05901	0.0748	0.00228	0.3815
0.05611	0.0807	0.00222	0.3881
0.05030	0.0861	0.00220	0.3948
0.04740	0.0909	0.00203	0.4014
0.04450	0.0954	0.00208	0.4079
0.03966	0.0998	0.00208	0.4147
0.03947	0.1046	0.00203	0.4216
0.03676	0.1097	0.00192	0.4282
0.03483	0.1154	0.00192	0.4350
0.03096	0.1217	0.00192	0.4418
0.02593	0.1285	0.00179	0.4485
0.02322	0.1349	0.00185	0.4550
0.01879	0.1414	0.00175	0.4616
0.01596	0.1480	0.00164	0.4683
0.01365	0.1544	0.00172	0.4750
0.01113	0.1609	0.00174	0.4816
0.00890	0.1676	0.00164	0.4886
0.00685	0.1743	0.00164	0.4952
0.00537	0.1809	0.00154	0.5019
0.00438	0.1875	0.00146	0.5085
0.00351	0.1943	0.00150	0.5155
0.00292	0.2008	0.00144	0.5222
0.00254	0.2074	0.00140	0.5288
0.00221	0.2141	0.00140	0.5355
0.00215	0.2210	0.00132	0.5421
0.00205	0.2275	0.00130	0.5485
0.00201	0.2342	0.00134	0.5550
0.00209	0.2409	0.00133	0.5619
0.00204	0.2476	0.00134	0.5687
0.00217	0.2541	0.00130	0.5754
0.00230	0.2608	0.00130	0.5822
0.00238	0.2675	0.00124	0.5889
0.00236	0.2742	0.00122	0.5954
0.00240	0.2809	0.00137	0.6022
0.00240	0.2877	0.00128	0.6090
0.00234	0.2944	0.00129	0.6156
0.00243	0.3011	0.00127	0.6225
0.00231	0.3077	0.00117	0.6291
0.00244	0.3144	0.00117	0.6358
0.00241	0.3209	0.00124	0.6424
0.00291	0.3279	0.00105	0.6491


RUN # P459 TG # 1
TYMOCHTEE DOLOMITE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.7
.6
.5
.4
.3
.2
.1
0
0
25
50
75
100
125
150
175
TIME IN MINUTES


RUN # P459 TG # 1
TYMOCHTEE DOLOMITE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
16
14
12
10
8
6
4
2
0
0
.1
.2
.3
.4
.5
.6
.7
FRACTION SULFATED

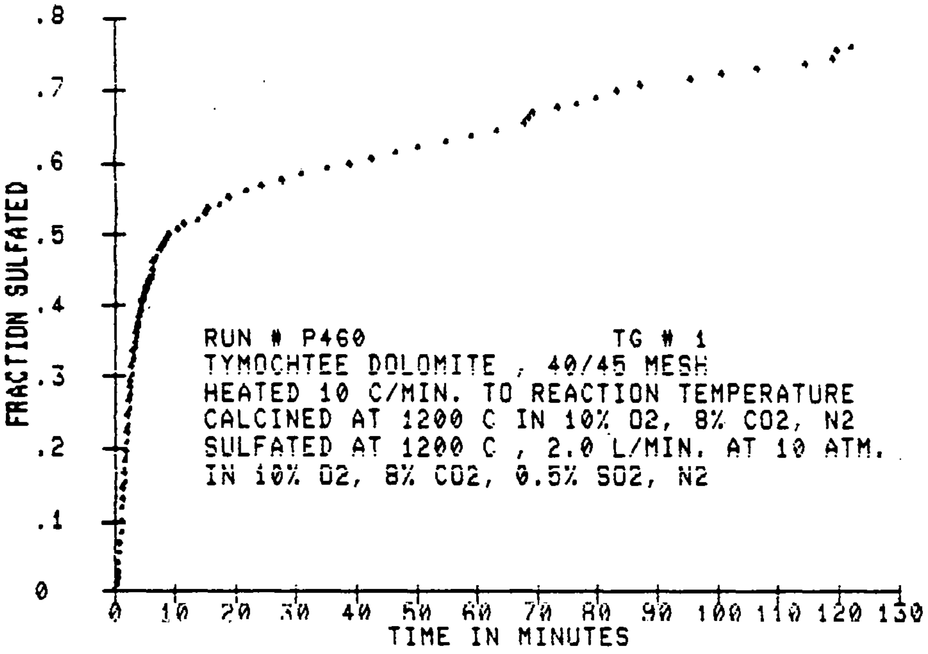

RUN # P459
TG # 1
TYMOCHTEE DOLOMITE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
FRACTION SULFATED

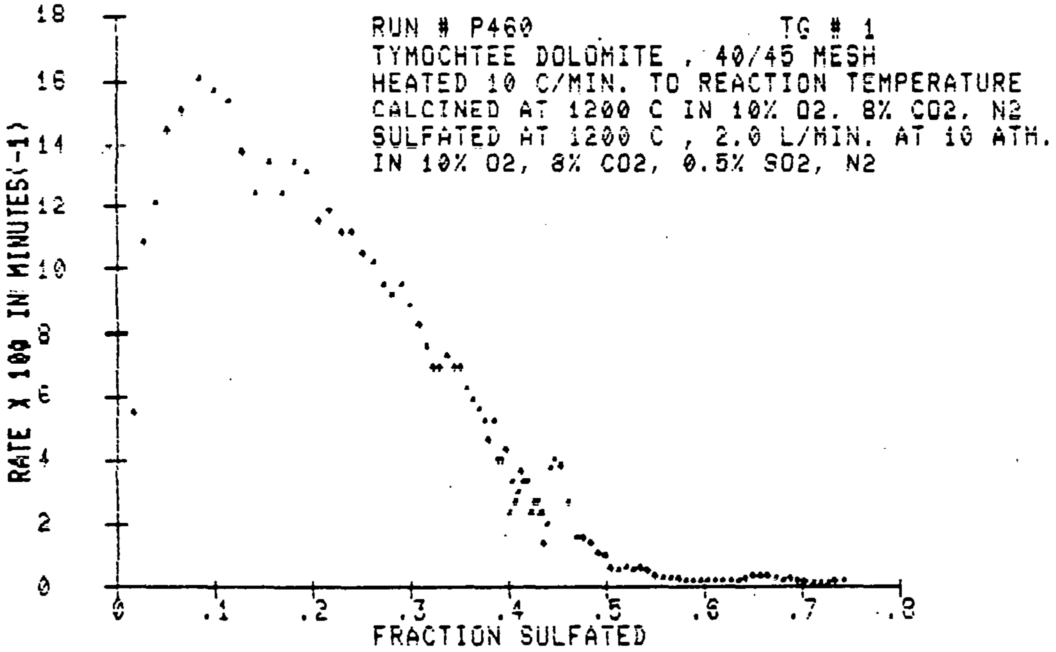
RUN # P459 TEMPERATURE = (1177.25 +/- 1.76) C

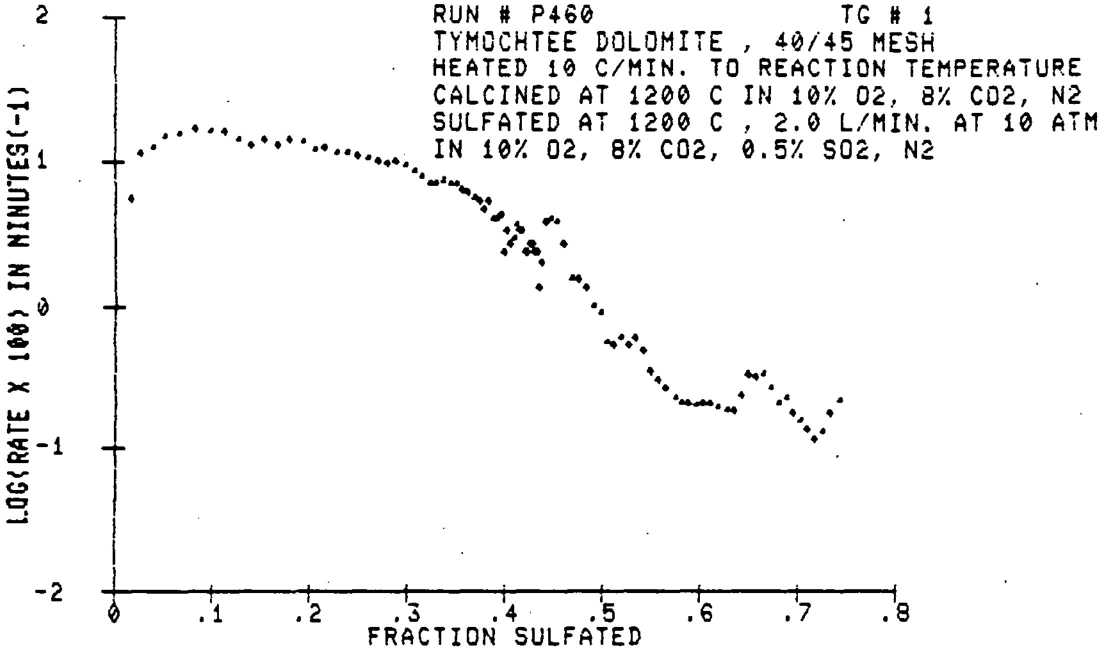
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.3215	5.60
0.0154	0.30	0.3280	5.80
0.0309	0.40	0.3344	6.20
0.0476	0.50	0.3421	6.70
0.0643	0.60	0.3485	7.30
0.0759	0.70	0.3550	7.60
0.0887	0.80	0.3601	8.20
0.0977	0.90	0.3666	8.70
0.1106	1.00	0.3730	9.50
0.1222	1.10	0.3794	9.90
0.1325	1.20	0.3846	10.60
0.1415	1.30	0.3936	11.50
0.1531	1.40	0.3974	12.50
0.1582	1.50	0.4038	13.40
0.1685	1.60	0.4103	14.50
0.1736	1.70	0.4180	16.00
0.1813	1.80	0.4231	17.00
0.1891	1.90	0.4309	18.20
0.1942	2.00	0.4399	18.80
0.2006	2.10	0.4424	19.80
0.2071	2.20	0.4476	21.60
0.2096	2.30	0.4540	23.60
0.2161	2.40	0.4604	24.90
0.2225	2.50	0.4682	26.60
0.2264	2.60	0.4746	29.20
0.2341	2.70	0.4797	31.50
0.2379	2.80	0.4862	34.70
0.2431	2.90	0.4926	38.80
0.2495	3.00	0.4990	41.80
0.2534	3.10	0.5042	43.10
0.2572	3.20	0.5106	48.00
0.2611	3.30	0.5338	49.00
0.2649	3.40	0.5235	56.60
0.2675	3.50	0.5299	63.30
0.2739	3.60	0.5363	71.50
0.2752	3.70	0.5453	77.20
0.2752	3.80	0.5492	81.10
0.2830	3.90	0.5556	84.55
0.2830	4.00	0.5633	88.00
0.2881	4.10	0.5710	90.85
0.2920	4.20	0.5736	94.30
0.2945	4.30	0.5801	139.90
0.2971	4.40	0.5865	142.15
0.2984	4.50	0.5929	144.85
0.3010	4.60	0.5993	150.85
0.3022	4.70	0.6083	154.75
0.3048	4.80	0.6148	158.80
0.3074	4.90	0.6212	163.45
0.3100	5.00	0.6251	168.10
0.3112	5.10	0.6302	171.70
0.3177	5.30		

RUN # P459

RATE	FRACTION	RATE	FRACTION
0.10718	0.0316	0.02105	0.3226
0.15111	0.0468	0.01745	0.3287
0.14468	0.0615	0.01589	0.3349
0.12541	0.0749	0.01501	0.3416
0.11575	0.0875	0.01286	0.3480
0.11576	0.0990	0.01222	0.3545
0.10932	0.1104	0.01111	0.3606
0.10932	0.1209	0.01062	0.3668
0.10612	0.1320	0.01018	0.3727
0.09002	0.1415	0.00965	0.3794
0.09004	0.1507	0.00815	0.3856
0.08038	0.1590	0.00698	0.3918
0.07073	0.1669	0.00660	0.3979
0.07718	0.1741	0.00543	0.4046
0.06430	0.1813	0.00572	0.4105
0.06753	0.1878	0.00563	0.4172
0.06430	0.1945	0.00688	0.4244
0.05144	0.2001	0.00643	0.4309
0.05467	0.2055	0.00531	0.4368
0.05466	0.2112	0.00429	0.4429
0.04823	0.2163	0.00337	0.4489
0.06109	0.2217	0.00378	0.4545
0.05466	0.2274	0.00355	0.4610
0.05145	0.2328	0.00326	0.4674
0.05787	0.2382	0.00262	0.4738
0.04823	0.2436	0.00200	0.4802
0.04823	0.2482	0.00194	0.4864
0.04501	0.2529	0.00211	0.4923
0.03859	0.2572	0.00184	0.4985
0.03537	0.2608	0.00403	0.5080
0.04180	0.2649	0.00165	0.5142
0.03537	0.2685	0.00127	0.5204
0.02572	0.2714	0.00109	0.5268
0.03859	0.2750	0.00041	0.5338
0.02251	0.2781	0.00105	0.5368
0.03216	0.2809	0.00121	0.5433
0.04180	0.2842	0.00164	0.5500
0.02894	0.2881	0.00188	0.5569
0.03537	0.2909	0.00185	0.5626
0.02572	0.2940	0.00044	0.5687
0.02251	0.2966	0.00043	0.5749
0.01929	0.2986	0.00040	0.5808
0.01929	0.3007	0.00045	0.5865
0.02251	0.3028	0.00191	0.5934
0.02251	0.3051	0.00170	0.6004
0.02251	0.3071	0.00152	0.6073
0.02572	0.3102	0.00149	0.6137
0.02021	0.3136	0.00129	0.6199
0.02251	0.3177		


FRACTION SULFATED
.8
.7
.6
.5
.4
.3
.2
.1
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130
TIME IN MINUTES
RUN # P460 TG # 1
TYMOCHTEE DOLOMITE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
18
16
14
12
10
8
6
4
2
0
0 .1 .2 .3 .4 .5 .6 .7 .8
FRACTION SULFATED
RUN # P460 TG # 1
TYMOCHTEE DOLOMITE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RUN # P460 TG # 1
TYMOCHTEE DOLOMITE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
FRACTION SULFATED

RUN # P460 TEMPERATURE = (1183.87 +/- 2.08) C

FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.4246	5.30
0.0092	0.40	0.4260	5.40
0.0183	0.50	0.4286	5.50
0.0249	0.60	0.4325	5.60
0.0380	0.70	0.4351	5.70
0.0524	0.80	0.4351	5.80
0.0668	0.90	0.4378	5.90
0.0826	1.00	0.4378	6.00
0.0983	1.10	0.4469	6.30
0.1166	1.20	0.4574	6.40
0.1298	1.30	0.4613	6.50
0.1442	1.40	0.4679	6.80
0.1533	1.50	0.4758	7.40
0.1665	1.60	0.4836	8.10
0.1835	1.70	0.4915	8.50
0.1940	1.80	0.4980	9.10
0.2071	1.90	0.5059	10.40
0.2189	2.00	0.5138	11.50
0.2294	2.10	0.5203	13.70
0.2412	2.20	0.5282	15.00
0.2516	2.30	0.5361	15.40
0.2634	2.40	0.5426	17.10
0.2713	2.50	0.5505	18.90
0.2818	2.60	0.5596	21.60
0.2897	2.70	0.5662	24.30
0.3001	2.80	0.5741	27.80
0.3093	2.90	0.5819	31.00
0.3172	3.00	0.5898	35.20
0.3224	3.10	0.5963	39.10
0.3303	3.20	0.6042	42.80
0.3368	3.30	0.6121	46.40
0.3447	3.40	0.6199	50.10
0.3513	3.50	0.6278	54.70
0.3578	3.60	0.6344	58.90
0.3644	3.70	0.6422	63.20
0.3696	3.80	0.6514	67.90
0.3748	3.90	0.6593	68.60
0.3801	4.00	0.6671	69.20
0.3853	4.10	0.6737	73.50
0.3880	4.20	0.6802	76.50
0.3958	4.30	0.6881	79.60
0.3958	4.40	0.6960	83.20
0.4011	4.50	0.7038	87.00
0.4050	4.60	0.7117	95.30
0.4050	4.70	0.7195	100.50
0.4089	4.80	0.7261	106.40
0.4115	4.90	0.7340	114.70
0.4168	5.00	0.7418	119.00
0.4194	5.10	0.7523	119.90
0.4220	5.20	0.7589	121.90

```
RUN # P460


RATE                FRACTION            RATE                FRACTION
0.05430             0.0181              0.02294             0.4241
0.10814             0.0286              0.02621             0.4267
0.12123             0.0401              0.02621             0.4294
0.14418             0.0529              0.02294             0.4315
0.15072             0.0676              0.02293             0.4338
0.16054             0.0834              0.01311             0.4357
0.15729             0.0988              0.01966             0.4385
0.15399             0.1143              0.03713             0.4430
0.13763             0.1284              0.03932             0.4482
0.12450             0.1421              0.03768             0.4543
0.13433             0.1554              0.02621             0.4619
0.12452             0.1683              0.01542             0.4692
0.13433             0.1809              0.01507             0.4760
0.13108             0.1940              0.01311             0.4834
0.11467             0.2066              0.01005             0.4910
0.11795             0.2181              0.00887             0.4986
0.11142             0.2296              0.00555             0.5059
0.11140             0.2409              0.00511             0.5132
0.10486             0.2514              0.00603             0.5208
0.10157             0.2619              0.00515             0.5282
0.09502             0.2716              0.00580             0.5355
0.09175             0.2813              0.00477             0.5434
0.09502             0.2904              0.00339             0.5510
0.08848             0.2996              0.00294             0.5586
0.08191             0.3077              0.00260             0.5665
0.07536             0.3159              0.00222             0.5743
0.06881             0.3232              0.00204             0.5817
0.06880             0.3303              0.00201             0.5893
0.07209             0.3371              0.00196             0.5969
0.06880             0.3442              0.00202             0.6045
0.06880             0.3510              0.00202             0.6121
0.06226             0.3575              0.00187             0.6197
0.05898             0.3636              0.00179             0.6273
0.05571             0.3693              0.00178             0.6351
0.05242             0.3748              0.00226             0.6430
0.04587             0.3796              0.00318             0.6509
0.05243             0.3848              0.00305             0.6587
0.03932             0.3890              0.00331             0.6663
0.03932             0.3932              0.00262             0.6737
0.04259             0.3971              0.00206             0.6810
0.02293             0.4005              0.00223             0.6883
0.03277             0.4032              0.00167             0.6960
0.02621             0.4063              0.00151             0.7038
0.02949             0.4094              0.00130             0.7114
0.03604             0.4123              0.00109             0.7190
0.03276             0.4157              0.00127             0.7266
0.03277             0.4189              0.00169             0.7347
0.02293             0.4218              0.00211             0.7426
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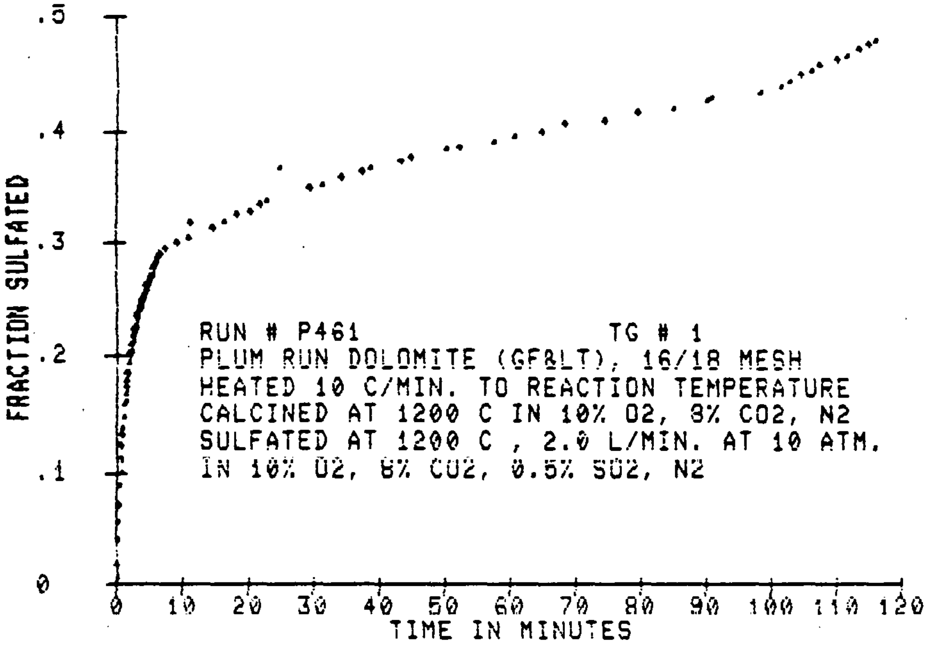
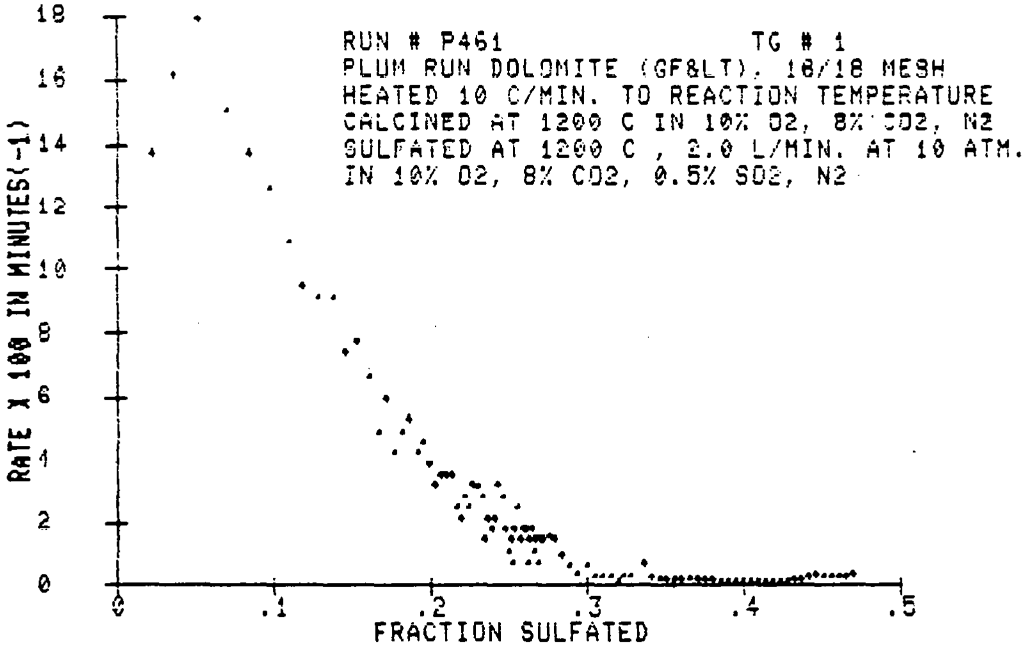
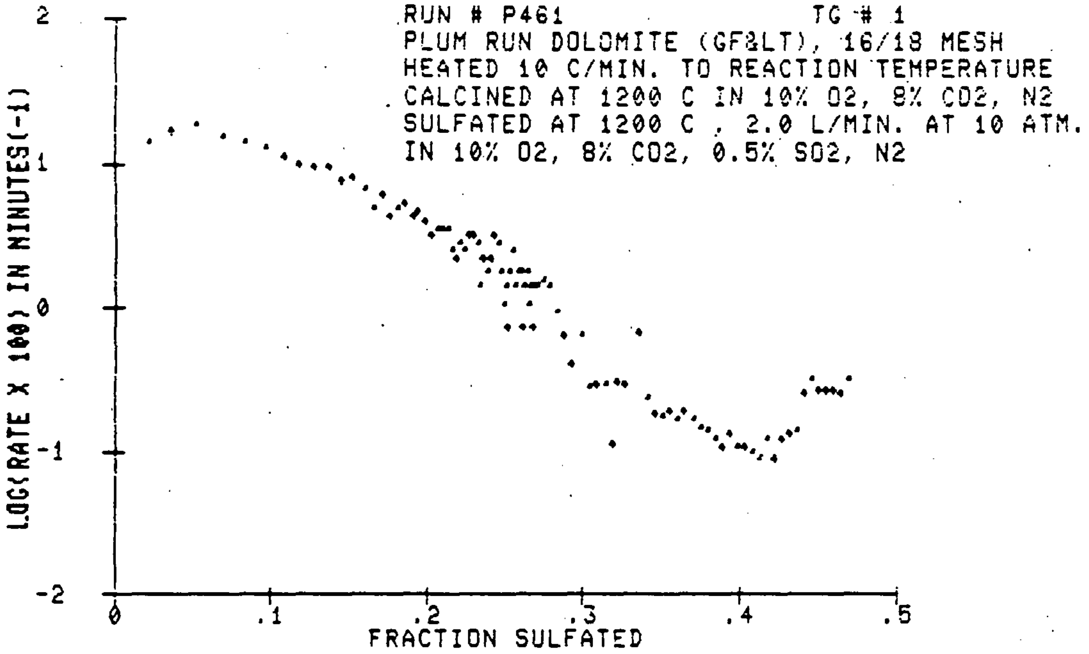

.5
.4
.3
.2
.1
0
FRACTION SULFATED
0 10 20 30 40 50 60 70 80 90 100 110 120
TIME IN MINUTES
RUN # P461 TG # 1
PLUM RUN DOLOMITE (GF&LT), 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


18
16
14
12
10
8
6
4
2
0
RATE X 100 IN MINUTES(-1)
0 .1 .2 .3 .4 .5
FRACTION SULFATED
RUN # P461 TG # 1
PLUM RUN DOLOMITE (GF&LT), 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

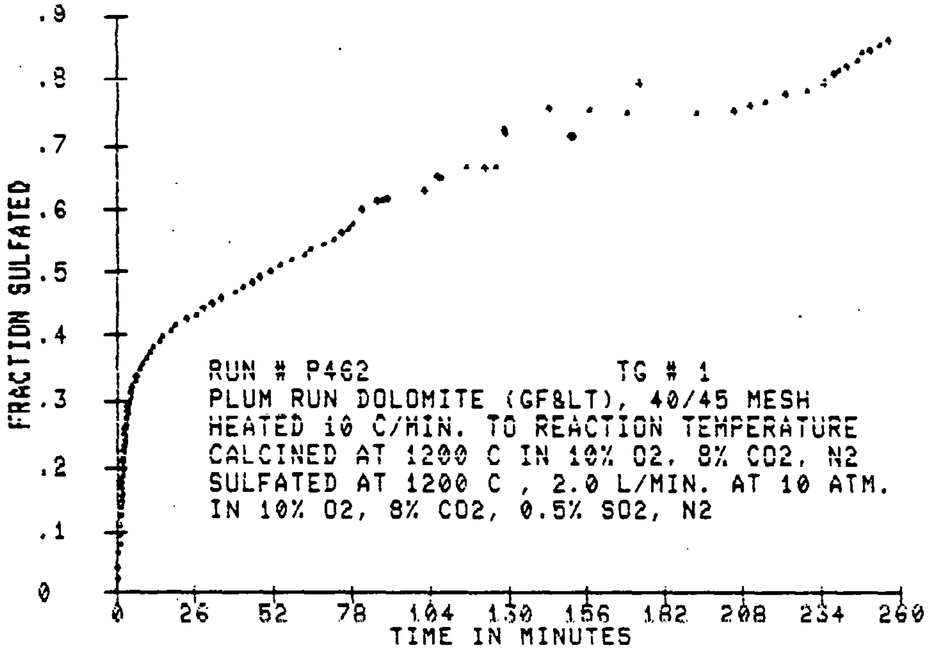

RUN # P461 TG # 1
PLUM RUN DOLOMITE (GF&LT), 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
FRACTION SULFATED

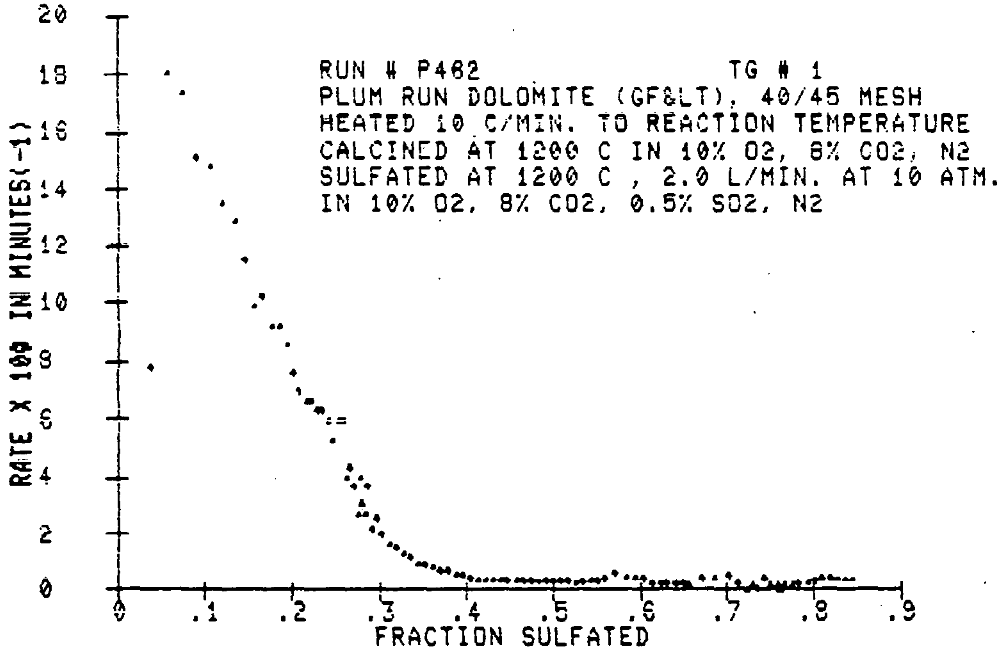
RUN # P461 TEMPERATURE = (1189.08 +/- 0.89) C

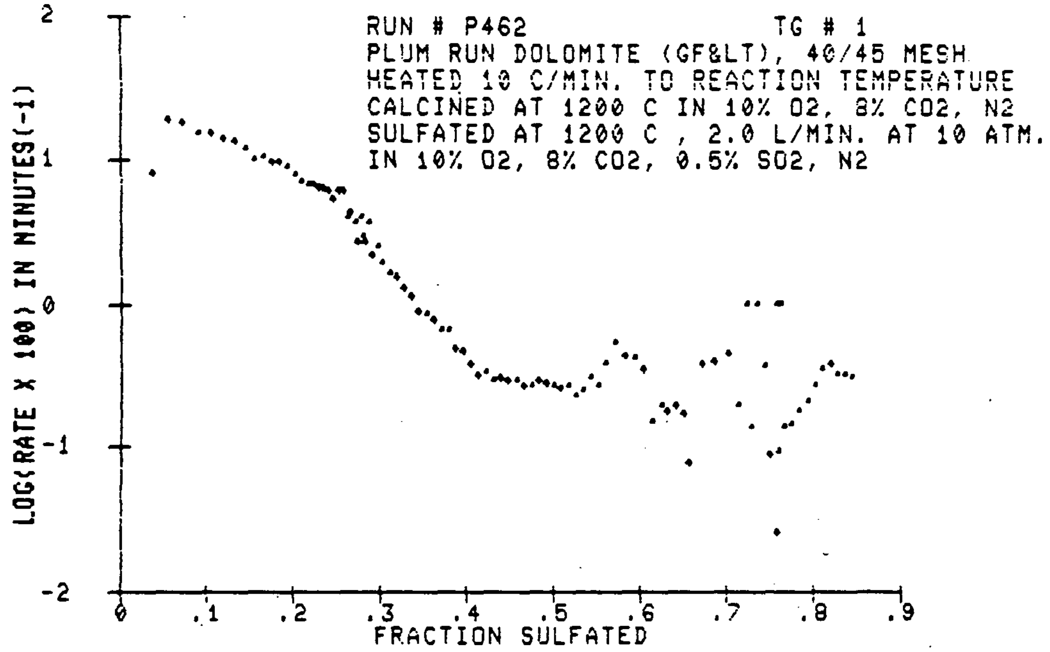
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.2633	5.10
0.0056	0.10	0.2661	5.20
0.0154	0.20	0.2689	5.30
0.0378	0.30	0.2675	5.40
0.0546	0.40	0.2689	5.50
0.0700	0.50	0.2689	5.60
0.0868	0.60	0.2745	5.70
0.0980	0.70	0.2787	6.20
0.1092	0.80	0.2843	6.50
0.1204	0.90	0.2885	7.00
0.1302	1.00	0.2927	7.70
0.1358	1.10	0.2983	9.40
0.1456	1.20	0.3025	11.30
0.1569	1.30	0.3165	11.50
0.1597	1.40	0.3133	14.80
0.1667	1.50	0.3179	16.40
0.1723	1.60	0.3235	18.60
0.1765	1.70	0.3263	20.50
0.1835	1.80	0.3333	21.90
0.1835	1.90	0.3361	22.90
0.1919	2.00	0.3641	24.90
0.1975	2.10	0.3473	29.60
0.2003	2.20	0.3501	31.50
0.2017	2.30	0.3557	34.40
0.2073	2.40	0.3613	37.60
0.2101	2.50	0.3641	38.70
0.2143	2.60	0.3697	43.50
0.2157	2.70	0.3753	45.00
0.2213	2.80	0.3823	50.30
0.2199	2.90	0.3837	52.30
0.2227	3.00	0.3893	57.70
0.2269	3.10	0.3949	60.90
0.2311	3.20	0.3977	65.00
0.2325	3.30	0.4047	68.50
0.2353	3.40	0.4075	74.60
0.2381	3.50	0.4145	79.60
0.2367	3.60	0.4173	85.10
0.2409	3.70	0.4243	90.00
0.2423	3.80	0.4271	90.70
0.2465	3.90	0.4313	98.40
0.2493	4.00	0.4369	101.40
0.2521	4.10	0.4411	102.80
0.2493	4.20	0.4468	104.70
0.2507	4.30	0.4510	106.30
0.2549	4.40	0.4566	107.70
0.2549	4.50	0.4608	110.30
0.2563	4.60	0.4650	111.70
0.2605	4.70	0.4706	113.80
0.2605	4.80	0.4748	115.00
0.2619	4.90	0.4790	116.10
0.2633	5.00		

RUN # P461

RATE	FRACTION	RATE	FRACTION
0.13654	0.0227	0.01751	0.2647
0.16107	0.0367	0.01050	0.2658
0.17855	0.0529	0.01401	0.2669
0.15054	0.0695	0.00700	0.2681
0.13656	0.0837	0.01400	0.2697
0.12603	0.0969	0.01400	0.2717
0.10855	0.1090	0.01541	0.2751
0.09453	0.1188	0.01401	0.2790
0.09103	0.1283	0.00910	0.2837
0.09104	0.1378	0.00613	0.2885
0.07352	0.1456	0.00379	0.2933
0.07703	0.1529	0.00622	0.2997
0.06652	0.1602	0.00276	0.3045
0.04901	0.1664	0.00280	0.3095
0.05953	0.1717	0.00288	0.3145
0.04201	0.1765	0.00109	0.3193
0.04902	0.1815	0.00296	0.3227
0.05251	0.1865	0.00280	0.3274
0.04201	0.1913	0.00645	0.3367
0.04552	0.1949	0.00231	0.3414
0.03851	0.1997	0.00175	0.3462
0.03151	0.2033	0.00170	0.3507
0.03501	0.2067	0.00185	0.3557
0.03501	0.2098	0.00185	0.3557
0.03501	0.2137	0.00163	0.3602
0.02451	0.2162	0.00185	0.3652
0.02101	0.2188	0.00165	0.3706
0.02801	0.2213	0.00144	0.3750
0.02451	0.2244	0.00138	0.3801
0.03151	0.2266	0.00123	0.3851
0.03151	0.2297	0.00105	0.3896
0.02801	0.2328	0.00130	0.3941
0.01400	0.2347	0.00108	0.3989
0.02101	0.2367	0.00105	0.4039
0.01751	0.2386	0.00098	0.4084
0.02101	0.2409	0.00091	0.4137
0.03151	0.2431	0.00122	0.4182
0.02801	0.2462	0.00089	0.4229
0.01750	0.2479	0.00120	0.4274
0.01050	0.2496	0.00131	0.4322
0.01400	0.2512	0.00140	0.4367
0.00700	0.2524	0.00248	0.4414
0.01750	0.2532	0.00311	0.4465
0.02451	0.2554	0.00261	0.4512
0.01401	0.2574	0.00260	0.4560
0.01750	0.2588	0.00261	0.4608
0.01751	0.2605	0.00249	0.4655
0.00700	0.2619	0.00314	0.4700
0.01400	0.2630		


FRACTION SULFATED
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
26
52
78
104
130
156
182
208
234
260
TIME IN MINUTES
RUN # P462 TG # 1
PLUM RUN DOLOMITE (GF&LT), 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
20
18
16
14
12
10
8
6
4
2
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
FRACTION SULFATED
RUN # P462 TG # 1
PLUM RUN DOLOMITE (GF&LT), 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

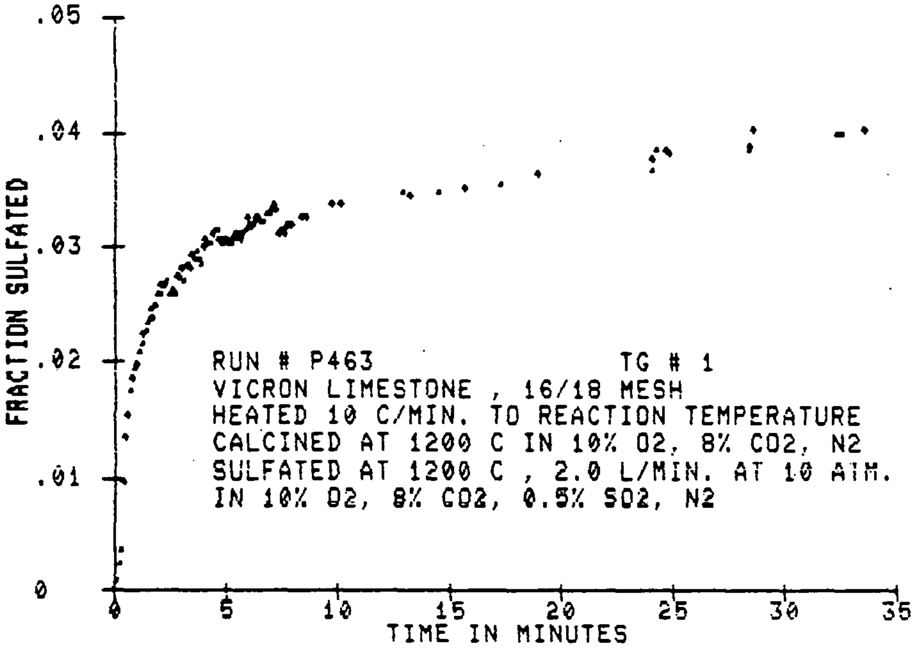

RUN # P462 TG # 1
PLUM RUN DOLOMITE (GF&LT), 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
FRACTION SULFATED

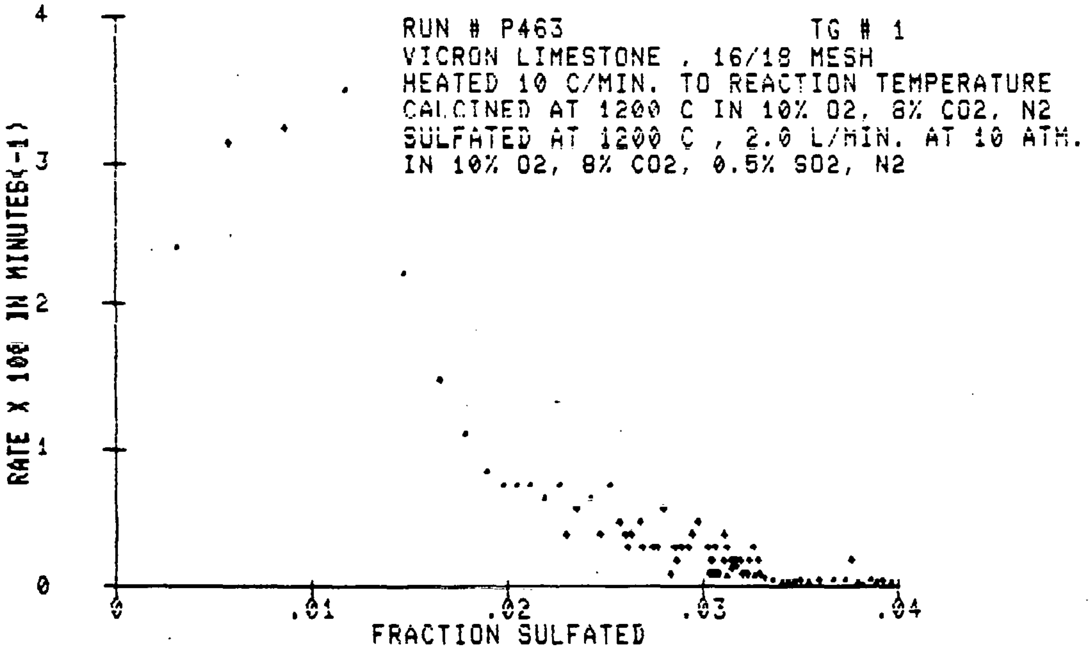
RUN # P462 TEMPERATURE = (1175.84 +/- 1.75) C

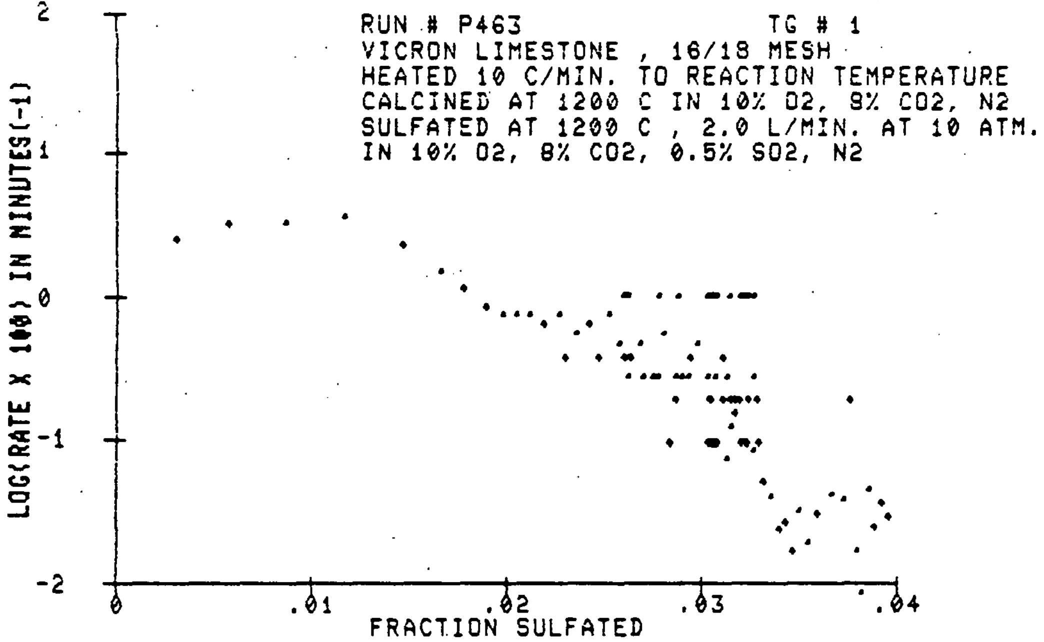
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.4391	28.60
0.0197	0.70	0.4483	32.00
0.0367	0.80	0.4561	34.80
0.0616	0.90	0.4666	39.30
0.0773	1.00	0.4758	41.40
0.0918	1.10	0.4824	45.10
0.1062	1.20	0.4902	47.70
0.1219	1.30	0.4994	51.00
0.1363	1.40	0.5099	54.10
0.1455	1.50	0.5164	58.00
0.1573	1.60	0.5256	62.10
0.1678	1.70	0.5348	64.30
0.1756	1.80	0.5426	68.80
0.1861	1.90	0.5505	72.00
0.1940	2.00	0.5623	74.40
0.2045	2.10	0.5675	76.60
0.2097	2.20	0.5767	78.00
0.2163	2.30	0.5990	81.30
0.2215	2.40	0.6121	86.50
0.2307	2.50	0.6147	88.10
0.2359	2.60	0.6160	89.70
0.2412	2.70	0.6292	102.00
0.2464	2.80	0.6501	106.60
0.2543	2.90	0.6475	107.40
0.2569	3.00	0.6645	116.00
0.2648	3.10	0.6619	122.40
0.2700	3.20	0.6645	125.90
0.2700	3.30	0.7235	128.20
0.2739	3.40	0.7157	129.30
0.2792	3.50	0.7537	143.35
0.2805	3.60	0.7117	150.85
0.2857	3.70	0.7130	151.75
0.2857	3.80	0.7524	156.70
0.2897	3.90	0.7471	169.30
0.2949	4.00	0.7917	173.35
0.3028	4.50	0.7471	192.25
0.3106	4.80	0.7511	205.30
0.3185	5.40	0.7576	210.70
0.3290	6.10	0.7655	215.20
0.3355	6.70	0.7746	222.40
0.3447	7.50	0.7825	229.00
0.3539	8.60	0.7917	235.00
0.3618	9.90	0.8048	238.00
0.3709	10.90	0.8100	239.80
0.3788	12.00	0.8179	242.50
0.3880	13.80	0.8284	245.80
0.3958	15.10	0.8402	247.60
0.4050	18.10	0.8428	250.30
0.4129	19.60	0.8520	253.30
0.4221	23.20	0.8599	256.30
0.4299	26.20		

RUN # P462

RATE	FRACTION	RATE	FRACTION
0.07733	0.0391	0.00294	0.4391
0.18022	0.0574	0.00280	0.4480
0.17369	0.0747	0.00287	0.4572
0.15073	0.0918	0.00260	0.4658
0.14747	0.1067	0.00264	0.4742
0.13434	0.1203	0.00280	0.4829
0.12779	0.1334	0.00268	0.4915
0.11470	0.1458	0.00264	0.4997
0.09830	0.1565	0.00246	0.5083
0.10159	0.1665	0.00266	0.5172
0.09175	0.1762	0.00223	0.5259
0.09175	0.1856	0.00243	0.5340
0.08521	0.1940	0.00298	0.5432
0.07536	0.2021	0.00266	0.5516
0.06882	0.2092	0.00370	0.5599
0.06553	0.2165	0.00521	0.5712
0.06553	0.2228	0.00412	0.5835
0.06227	0.2291	0.00410	0.5940
0.06226	0.2351	0.00336	0.6037
0.05899	0.2417	0.00146	0.6142
0.05243	0.2469	0.00189	0.6244
0.05898	0.2527	0.00170	0.6315
0.05899	0.2585	0.00184	0.6415
0.03932	0.2632	0.00161	0.6506
0.04260	0.2671	0.00075	0.6577
0.03604	0.2716	0.00365	0.6724
0.02621	0.2747	0.00384	0.6860
0.03933	0.2779	0.00438	0.7039
0.02949	0.2810	0.00189	0.7138
0.02622	0.2842	-.00045	0.7235
0.03604	0.2873	0.00134	0.7293
0.02130	0.2918	-.00025	0.7356
0.02490	0.2968	0.00355	0.7432
0.01922	0.3033	0.00084	0.7503
0.01623	0.3112	-.00003	0.7579
0.01490	0.3193	0.00025	0.7589
0.01262	0.3277	-.00063	0.7626
0.01106	0.3363	0.00091	0.7592
0.00862	0.3450	0.00133	0.7663
0.00843	0.3534	0.00140	0.7744
0.00757	0.3620	0.00172	0.7838
0.00655	0.3707	0.00203	0.7927
0.00655	0.3791	0.00262	0.8014
0.00473	0.3877	0.00340	0.8106
0.00448	0.3961	0.00369	0.8203
0.00363	0.4048	0.00312	0.8279
0.00307	0.4131	0.00316	0.8362
0.00325	0.4218	0.00300	0.8446
0.00285	0.4304		


.05
.04
.03
.02
.01
0
FRACTION SULFATED
0
5
10
15
20
25
30
35
TIME IN MINUTES
RUN # P463 TG # 1
VICRON LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


4
3
2
1
0
RATE X 100 IN MINUTES(-1)
0
.01
.02
.03
.04
FRACTION SULFATED
RUN # P463 TG # 1
VICRON LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

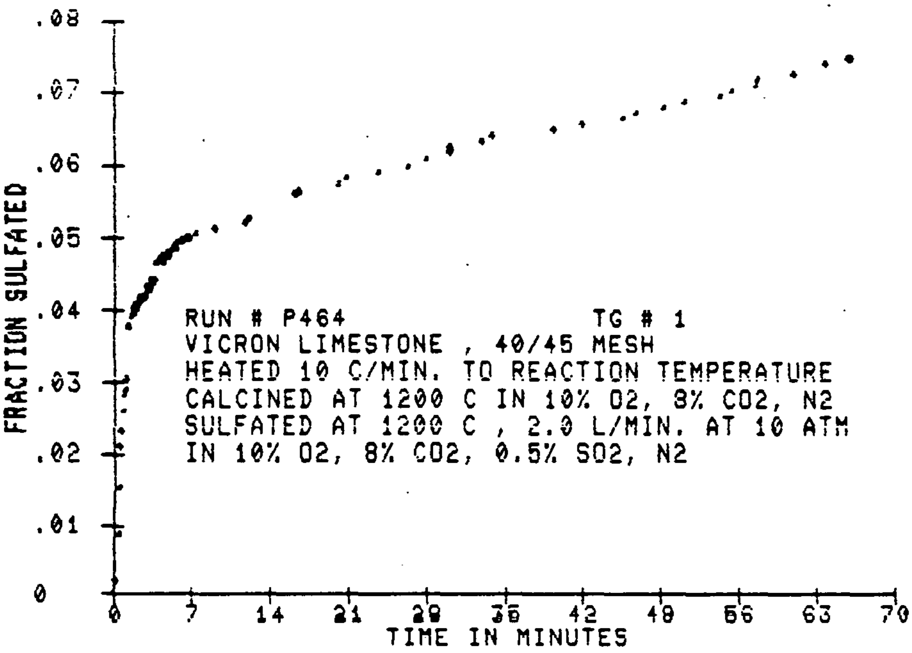

RUN # P463 TG # 1
VICRON LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.01
.02
.03
.04
FRACTION SULFATED

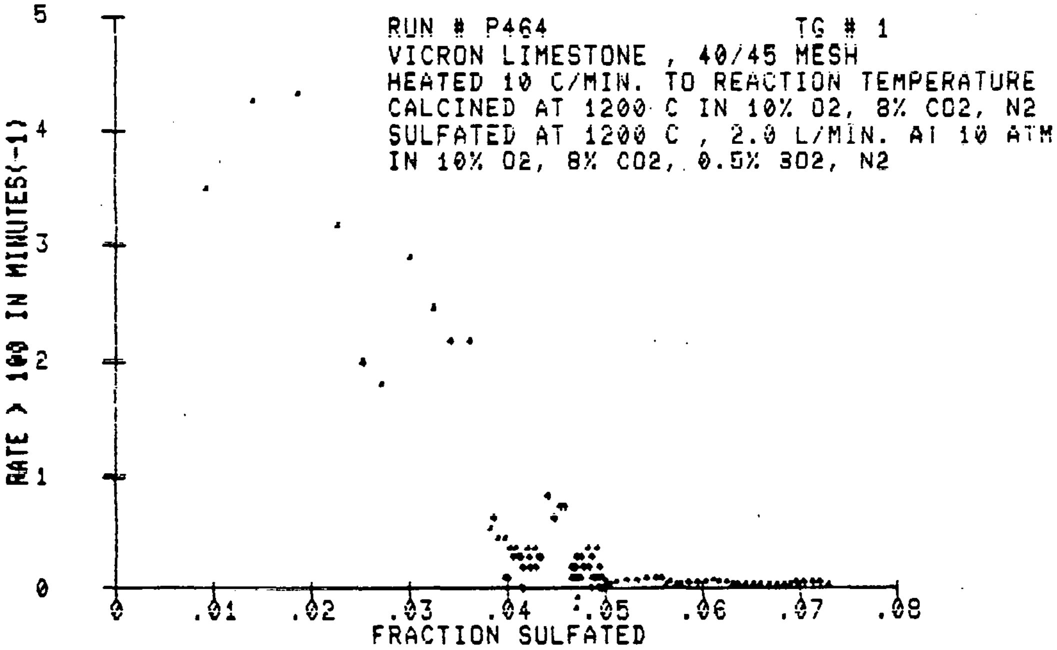
```
RUN # P463       TEMPERATURE = (1189.94 +/-  1.73 ) C

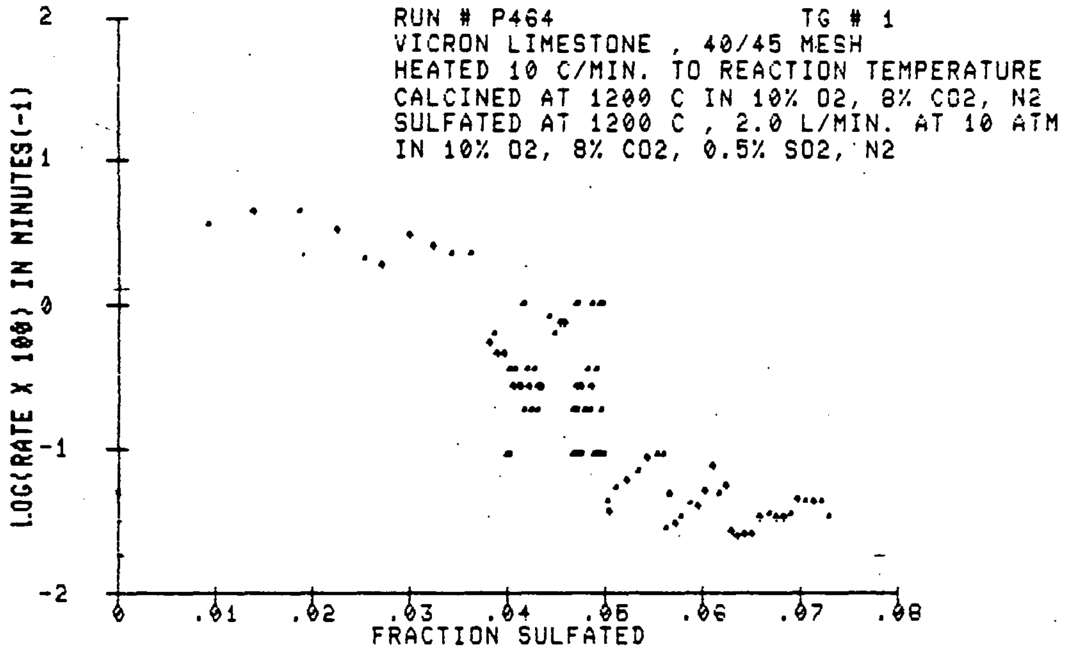

FRACTION           TIME              FRACTION           TIME
0.0000             0.00              0.0305             5.00
0.0007             0.10              0.0302             5.10
0.0022             0.20              0.0302             5.20
0.0033             0.30              0.0305             5.30
0.0096             0.40              0.0309             5.40
0.0132             0.50              0.0309             5.50
0.0151             0.60              0.0305             5.60
0.0173             0.70              0.0309             5.70
0.0184             0.80              0.0313             5.80
0.0191             0.90              0.0324             5.90
0.0195             1.00              0.0316             6.00
0.0206             1.10              0.0316             6.10
0.0213             1.20              0.0320             6.20
0.0221             1.30              0.0324             6.30
0.0224             1.40              0.0324             6.40
0.0232             1.50              0.0320             6.50
0.0243             1.60              0.0320             6.60
0.0235             1.70              0.0327             6.70
0.0246             1.80              0.0327             6.80
0.0257             1.90              0.0327             6.90
0.0357             2.00              0.0331             7.00
0.0265             2.10              0.0335             7.10
0.0265             2.20              0.0331             7.20
0.0268             2.30              0.0309             7.30
0.0257             2.40              0.0313             7.40
0.0257             2.50              0.0313             7.50
0.0261             2.60              0.0309             7.60
0.0257             2.70              0.0316             7.70
0.0272             2.80              0.0316             7.90
0.0272             2.90              0.0324             8.40
0.0280             3.00              0.0324             8.60
0.0268             3.10              0.0335             9.70
0.0283             3.20              0.0335            10.10
0.0283             3.30              0.0346            12.80
0.0280             3.40              0.0342            13.20
0.0291             3.50              0.0346            14.40
0.0287             3.60              0.0349            15.60
0.0294             3.70              0.0353            17.20
0.0287             3.80              0.0360            18.90
0.0283             3.90              0.0364            24.00
0.0298             4.00              0.0375            24.10
0.0305             4.10              0.0383            24.20
0.0302             4.20              0.0383            24.60
0.0302             4.30              0.0379            24.80
0.0309             4.40              0.0383            28.40
0.0313             4.50              0.0386            28.50
0.0313             4.60              0.0401            28.60
0.0305             4.70              0.0397            32.30
0.0302             4.80              0.0397            32.50
0.0305             4.90              0.0401            33.60
```

RUN # P463

RATE	FRACTION	RATE	FRACTION
0.02391	0.0032	0.00000	0.0303
0.03127	0.0058	0.00000	0.0304
0.03218	0.0087	0.00092	0.0305
0.03494	0.0117	0.00184	0.0305
0.02207	0.0147	0.00092	0.0306
0.01471	0.0166	0.00092	0.0307
0.01103	0.0179	0.00092	0.0309
0.00827	0.0190	0.00368	0.0312
0.00736	0.0198	0.00276	0.0313
0.00736	0.0205	0.00184	0.0316
0.00736	0.0212	0.00184	0.0318
0.00644	0.0219	0.00000	0.0320
0.00736	0.0227	0.00184	0.0320
0.00368	0.0231	0.00092	0.0321
0.00552	0.0236	0.00000	0.0321
0.00644	0.0243	0.00092	0.0323
0.00368	0.0248	0.00092	0.0324
0.00736	0.0252	0.00184	0.0324
0.00460	0.0258	0.00276	0.0327
0.00276	0.0263	0.00184	0.0330
0.00000	0.0263	0.00092	0.0330
-.00184	0.0263	-.00460	0.0327
-.00092	0.0262	-.00460	0.0324
-.00276	0.0260	-.00552	0.0320
0.00368	0.0261	-.00552	0.0315
0.00368	0.0264	0.00184	0.0312
0.00460	0.0268	0.00074	0.0313
0.00276	0.0270	0.00123	0.0316
0.00276	0.0275	0.00147	0.0318
0.00276	0.0277	0.00092	0.0323
0.00000	0.0279	0.00084	0.0327
0.00552	0.0281	0.00050	0.0332
0.00092	0.0285	0.00040	0.0336
0.00276	0.0287	0.00023	0.0341
0.00184	0.0288	0.00027	0.0344
-.00184	0.0288	0.00017	0.0347
0.00276	0.0290	0.00032	0.0350
0.00276	0.0293	0.00019	0.0355
0.00368	0.0295	0.00030	0.0360
0.00460	0.0298	0.00042	0.0367
0.00276	0.0303	0.00039	0.0373
0.00184	0.0306	0.00184	0.0377
0.00276	0.0307	0.00017	0.0380
0.00092	0.0308	0.00009	0.0383
-.00184	0.0308	0.00046	0.0386
-.00184	0.0307	0.00035	0.0389
-.00184	0.0306	0.00036	0.0393
-.00092	0.0304	0.00029	0.0396


RUN # P464 TG # 1
VICRON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.08
.07
.06
.05
.04
.03
.02
.01
0
0
7
14
21
28
35
42
49
56
63
70
TIME IN MINUTES


RUN # P464 TG # 1
VICRON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
5
4
3
2
1
0
0
.01
.02
.03
.04
.05
.06
.07
.08
FRACTION SULFATED

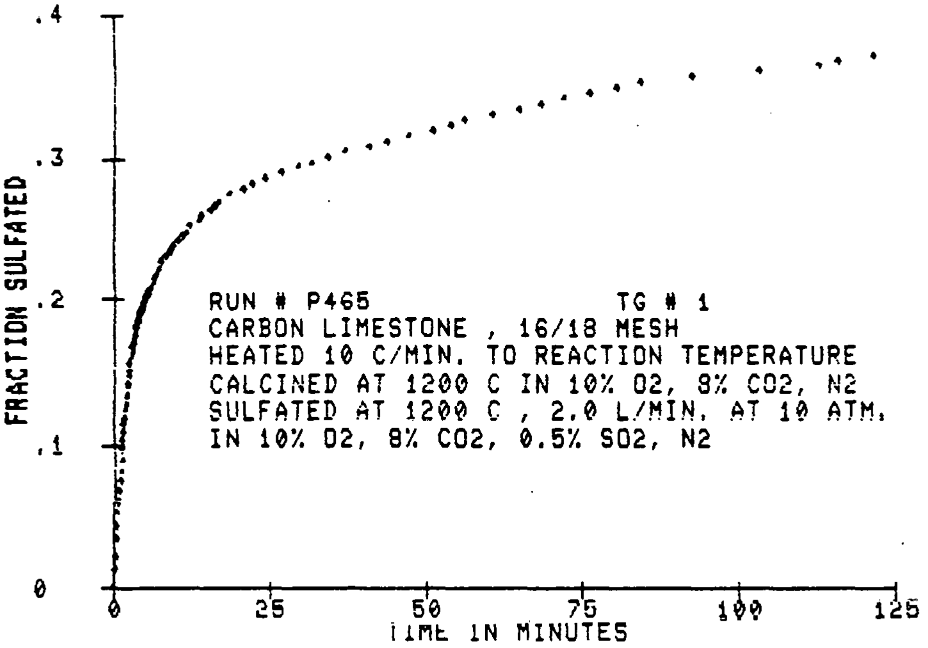

RUN # P464 TG # 1
VICRON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.01
.02
.03
.04
.05
.06
.07
.08
FRACTION SULFATED

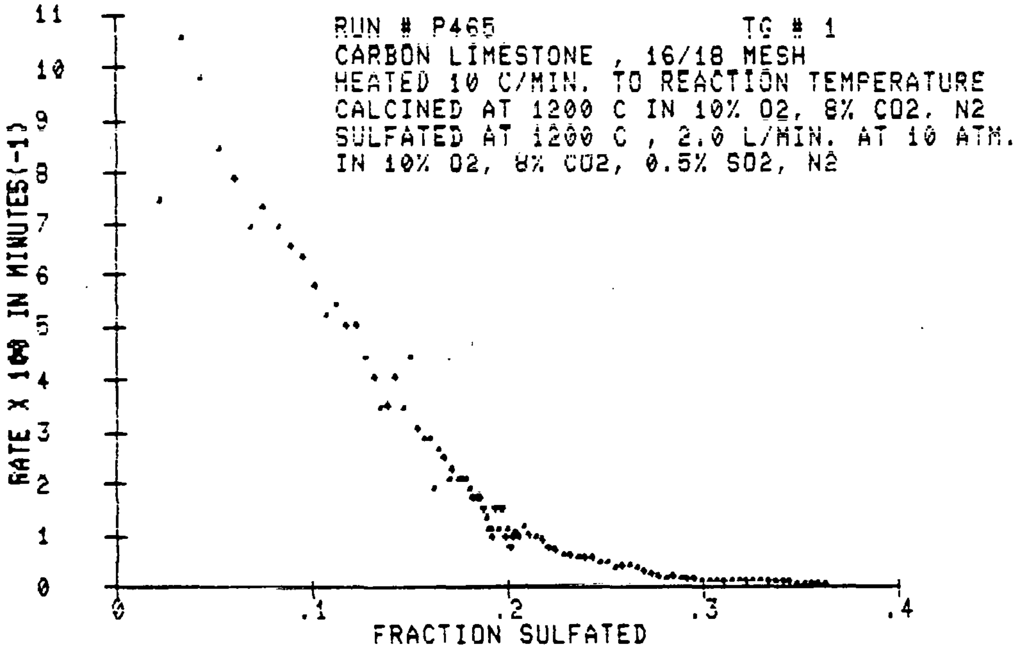
RUN # P464 TEMPERATURE = (1201.33 +/- 0.05) C

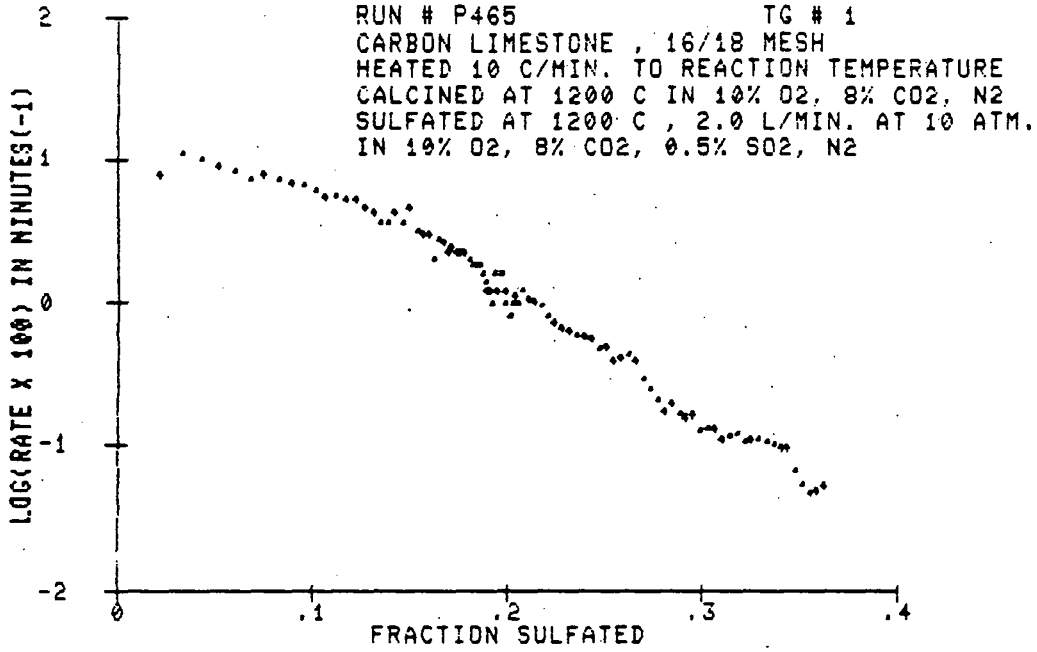
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.0482	5.20
0.0018	0.20	0.0482	5.30
0.0086	0.40	0.0489	5.40
0.0155	0.50	0.0489	5.50
0.0209	0.60	0.0493	5.60
0.0230	0.70	0.0482	5.70
0.0259	0.80	0.0493	5.80
0.0281	0.90	0.0493	5.90
0.0288	1.00	0.0497	6.00
0.0302	1.10	0.0497	6.10
0.0374	1.20	0.0493	6.20
0.0378	1.30	0.0497	6.30
0.0374	1.40	0.0497	6.40
0.0389	1.50	0.0497	6.50
0.0396	1.60	0.0500	6.60
0.0403	1.70	0.0500	6.70
0.0392	1.80	0.0497	6.80
0.0407	1.90	0.0504	7.30
0.0399	2.00	0.0511	9.10
0.0407	2.10	0.0518	11.70
0.0407	2.20	0.0525	12.10
0.0417	2.30	0.0558	16.20
0.0414	2.40	0.0561	16.30
0.0417	2.50	0.0558	16.40
0.0417	2.60	0.0565	16.50
0.0417	2.70	0.0561	16.60
0.0421	2.80	0.0572	20.10
0.0417	2.90	0.0579	20.80
0.0432	3.00	0.0586	23.70
0.0428	3.10	0.0594	26.30
0.0428	3.20	0.0604	27.90
0.0432	3.30	0.0615	30.00
0.0439	3.40	0.0619	30.10
0.0439	3.50	0.0622	30.20
0.0439	3.60	0.0630	33.00
0.0464	3.70	0.0637	33.90
0.0464	3.80	0.0644	39.50
0.0468	3.90	0.0651	41.90
0.0468	4.00	0.0662	45.60
0.0471	4.10	0.0669	46.70
0.0468	4.20	0.0676	49.30
0.0475	4.30	0.0684	51.10
0.0475	4.40	0.0691	54.30
0.0464	4.50	0.0698	55.40
0.0471	4.60	0.0705	57.50
0.0479	4.70	0.0712	57.60
0.0471	4.80	0.0720	60.90
0.0475	4.90	0.0734	63.80
0.0475	5.00	0.0741	65.80
0.0482	5.10	0.0741	66.10

RUN # P464

```
RATE            FRACTION        RATE            FRACTION
0.03478         0.0094          0.00360         0.0482
0.04246         0.0140          0.00180         0.0485
0.04317         0.0188          0.00270         0.0487
0.03149         0.0227          0.00000         0.0487
0.01979         0.0253          0.00090         0.0489
0.01799         0.0272          0.00090         0.0490
0.02878         0.0301          0.00090         0.0491
0.02428         0.0325          0.00360         0.0492
0.02159         0.0343          0.00000         0.0494
0.02159         0.0363          0.00090         0.0495
0.00540         0.0382          0.00000         0.0496
0.00630         0.0388          0.00000         0.0496
0.00450         0.0391          0.00180         0.0497
0.00450         0.0397          0.00090         0.0498
0.00090         0.0399          0.00000         0.0498
0.00090         0.0402          0.00090         0.0499
0.00360         0.0402          0.00043         0.0502
0.00270         0.0407          0.00036         0.0506
0.00360         0.0409          0.00054         0.0511
0.00270         0.0412          0.00061         0.0523
0.00270         0.0414          0.00070         0.0535
0.00000         0.0417          0.00084         0.0544
0.00180         0.0417          0.00090         0.0553
0.00000         0.0418          0.00090         0.0561
0.00360         0.0421          0.00028         0.0563
0.00270         0.0423          0.00049         0.0567
0.00180         0.0425          0.00030         0.0573
0.00360         0.0427          0.00033         0.0579
0.00180         0.0432          0.00042         0.0587
0.00270         0.0433          0.00039         0.0596
0.00270         0.0435          0.00051         0.0604
0.00809         0.0443          0.00074         0.0611
0.00630         0.0449          0.00049         0.0618
0.00720         0.0455          0.00055         0.0625
0.00720         0.0461          0.00027         0.0630
0.00180         0.0467          0.00025         0.0637
0.00090         0.0468          0.00026         0.0645
0.00180         0.0470          0.00025         0.0653
0.00180         0.0471          0.00033         0.0661
-.00180         0.0471          0.00035         0.0669
0.00090         0.0471          0.00033         0.0676
0.00090         0.0473          0.00033         0.0684
-.00090         0.0472          0.00035         0.0691
0.00270         0.0472          0.00044         0.0698
0.00090         0.0474          0.00044         0.0705
0.00090         0.0476          0.00043         0.0714
0.00270         0.0477          0.00043         0.0722
0.00180         0.0479          0.00034         0.0730
```


.4
.3
.2
.1
0
FRACTION SULFATED
0
25
50
75
100
125
TIME IN MINUTES
RUN # P465 TG # 1
CARBON LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


11
10
9
8
7
6
5
4
3
2
1
0
RATE X 100 IN MINUTES(-1)
0
.1
.2
.3
.4
FRACTION SULFATED
RUN # P465 TG # 1
CARBON LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

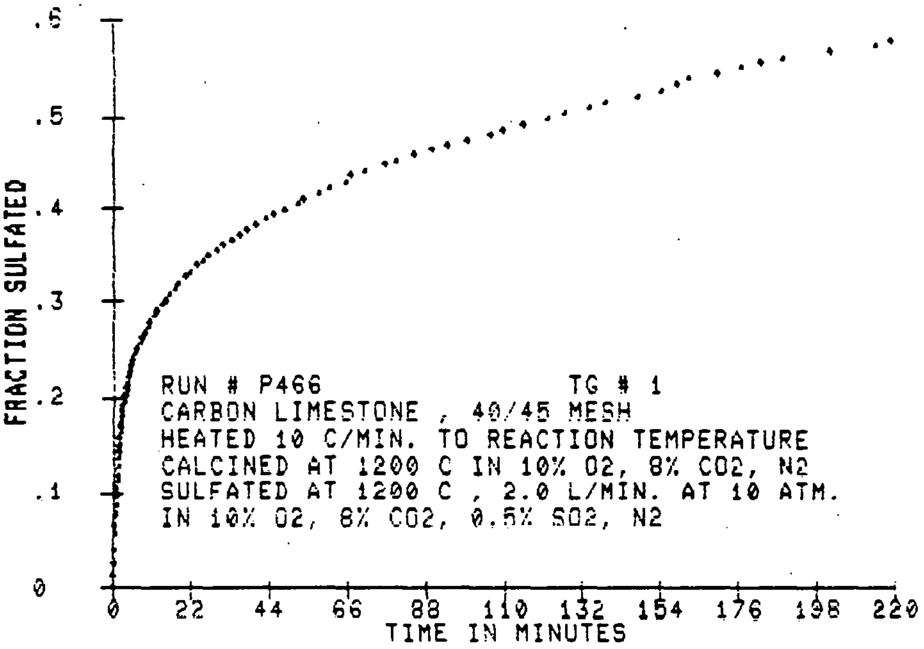
RUN # P465 TG # 1
CARBON LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
FRACTION SULFATED

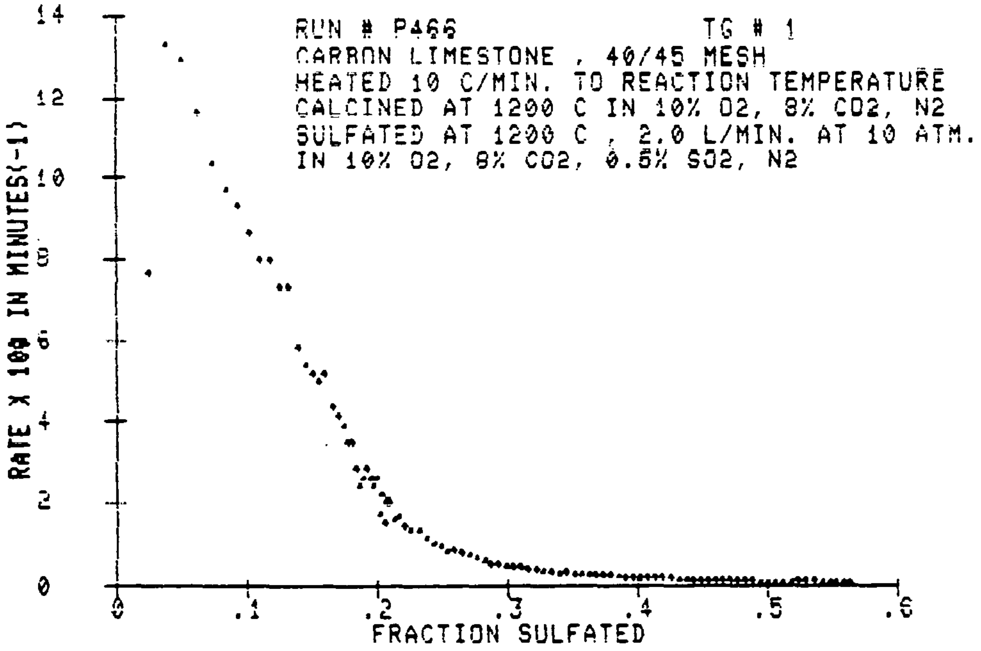
```
RUN # P465        TEMPERATURE = (1193.53 +/-  1.96 ) C

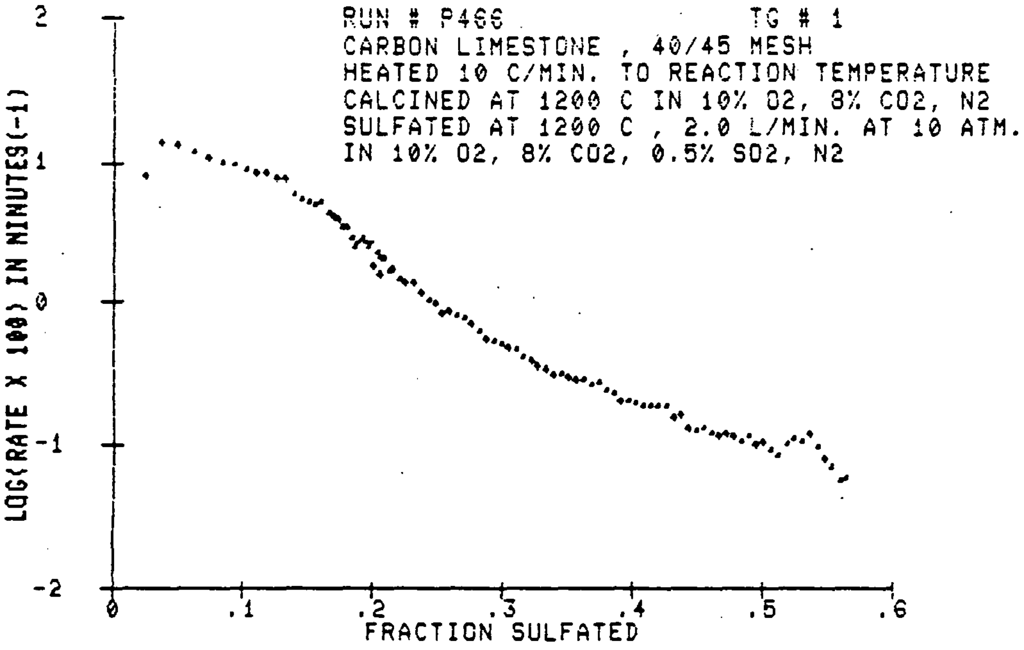

FRACTION          TIME              FRACTION          TIME
0.0000              0.00             0.2009              5.20
0.0123              0.30             0.2017              5.30
0.0216              0.40             0.2032              5.40
0.0346              0.50             0.2032              5.50
0.0446              0.60             0.2048              5.60
0.0547              0.70             0.2071              5.80
0.0608              0.80             0.2109              6.20
0.0685              0.90             0.2140              6.40
0.0762              1.00             0.2171              6.80
0.0824              1.10             0.2209              7.20
0.0901              1.20             0.2248              7.70
0.0962              1.30             0.2286              8.30
0.1024              1.40             0.2325              9.00
0.1078              1.50             0.2363              9.60
0.1132              1.60             0.2403             10.20
0.1170              1.70             0.2440             11.00
0.1239              1.80             0.2471             11.60
0.1278              1.90             0.2509             12.30
0.1332              2.00             0.2556             13.50
0.1347              2.10             0.2586             14.10
0.1401              2.20             0.2625             15.60
0.1416              2.30             0.2663             16.20
0.1470              2.40             0.2694             16.80
0.1509              2.50             0.2748             18.30
0.1539              2.60             0.2771             20.70
0.1593              2.70             0.2810             22.20
0.1593              2.80             0.2848             24.30
0.1624              2.90             0.2887             26.90
0.1655              3.00             0.2933             29.50
0.1670              3.10             0.2956             31.50
0.1701              3.20             0.2994             34.10
0.1724              3.30             0.3040             36.90
0.1740              3.40             0.3071             40.80
0.1763              3.50             0.3110             43.60
0.1786              3.60             0.3156             47.10
0.1809              3.70             0.3187             50.90
0.1824              3.80             0.3218             53.90
0.1840              3.90             0.3256             56.00
0.1855              4.00             0.3294             60.60
0.1878              4.10             0.3333             64.70
0.1894              4.20             0.3371             68.30
0.1901              4.30             0.3418             71.80
0.1909              4.40             0.3448             76.10
0.1924              4.50             0.3479             80.40
0.1940              4.60             0.3518             84.10
0.1940              4.70             0.3556             92.50
0.1971              4.80             0.3595            103.00
0.1971              4.90             0.3633            112.80
0.2001              5.00             0.3672            116.00
0.2001              5.10             0.3710            121.60
```

RUN # P465

RATE	FRACTION	RATE	FRACTION
0.07441	0.0226	0.00770	0.2012
0.10585	0.0336	0.00770	0.2018
0.09814	0.0433	0.00962	0.2027
0.08468	0.0527	0.01078	0.2040
0.07889	0.0610	0.00962	0.2058
0.06927	0.0685	0.01197	0.2080
0.07313	0.0756	0.01026	0.2108
0.06927	0.0827	0.00990	0.2140
0.06543	0.0894	0.00924	0.2175
0.06350	0.0958	0.00770	0.2211
0.05773	0.1019	0.00700	0.2248
0.05196	0.1073	0.00641	0.2286
0.05388	0.1128	0.00616	0.2325
0.05004	0.1179	0.00570	0.2363
0.05003	0.1230	0.00563	0.2400
0.04426	0.1273	0.00542	0.2437
0.04041	0.1319	0.00467	0.2475
0.03464	0.1355	0.00472	0.2512
0.03464	0.1393	0.00385	0.2549
0.04041	0.1429	0.00395	0.2588
0.03464	0.1467	0.00420	0.2625
0.04426	0.1506	0.00385	0.2663
0.03079	0.1541	0.00287	0.2700
0.02887	0.1572	0.00244	0.2737
0.02886	0.1601	0.00205	0.2774
0.01924	0.1627	0.00161	0.2813
0.02694	0.1649	0.00184	0.2850
0.02502	0.1675	0.00157	0.2887
0.02117	0.1698	0.00149	0.2923
0.02309	0.1720	0.00154	0.2962
0.02117	0.1743	0.00123	0.2999
0.02117	0.1764	0.00127	0.3034
0.02117	0.1784	0.00124	0.3074
0.01925	0.1804	0.00104	0.3113
0.01732	0.1823	0.00112	0.3148
0.01732	0.1841	0.00118	0.3185
0.01732	0.1858	0.00103	0.3222
0.01539	0.1874	0.00106	0.3258
0.01347	0.1887	0.00107	0.3294
0.01155	0.1901	0.00102	0.3335
0.01155	0.1914	0.00099	0.3373
0.00962	0.1923	0.00093	0.3410
0.01539	0.1937	0.00093	0.3447
0.01155	0.1949	0.00067	0.3484
0.01539	0.1964	0.00054	0.3519
0.01539	0.1977	0.00048	0.3556
0.00962	0.1991	0.00048	0.3595
0.01155	0.2000	0.00053	0.3633


RUN # P466 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.6
.5
.4
.3
.2
.1
0
0
22
44
66
88
110
132
154
176
198
220
TIME IN MINUTES


RUN # P466 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
14
12
10
8
6
4
2
0
0
.1
.2
.3
.4
.5
.6
FRACTION SULFATED


RUN # P466 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
FRACTION SULFATED

RUN # P466 TEMPERATURE = (1190.09 +/- 1.90) C

FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.2949	13.60
0.0112	0.40	0.2992	14.70
0.0241	0.50	0.3052	15.70
0.0378	0.60	0.3112	17.10
0.0533	0.70	0.3164	18.30
0.0645	0.80	0.3232	20.10
0.0757	0.90	0.3284	21.60
0.0843	1.00	0.3344	23.40
0.0946	1.10	0.3396	25.20
0.1032	1.20	0.3456	27.00
0.1126	1.30	0.3516	29.50
0.1186	1.40	0.3568	30.90
0.1264	1.50	0.3628	33.50
0.1350	1.60	0.3688	35.60
0.1419	1.70	0.3740	37.60
0.1479	1.80	0.3800	40.00
0.1496	1.90	0.3869	42.60
0.1565	2.00	0.3912	45.20
0.1625	2.10	0.3972	48.00
0.1676	2.20	0.4032	52.00
0.1702	2.30	0.4084	53.60
0.1737	2.40	0.4144	57.50
0.1788	2.50	0.4204	60.80
0.1831	2.60	0.4264	65.00
0.1840	2.70	0.4324	67.00
0.1874	2.80	0.4376	70.50
0.1900	2.90	0.4436	76.50
0.1926	3.00	0.4488	79.40
0.1943	3.10	0.4548	84.80
0.1986	3.20	0.4608	89.60
0.2003	3.30	0.4660	94.10
0.2020	3.40	0.4720	99.30
0.2046	3.50	0.4780	105.90
0.2055	3.60	0.4831	109.20
0.2089	3.70	0.4893	115.05
0.2080	3.80	0.4952	121.95
0.2123	3.90	0.5012	126.60
0.2132	4.00	0.5064	133.50
0.2201	4.40	0.5124	138.30
0.2261	4.90	0.5184	147.45
0.2321	5.30	0.5236	153.75
0.2373	5.80	0.5313	158.55
0.2442	6.20	0.5373	161.55
0.2485	6.90	0.5416	169.95
0.2553	7.60	0.5493	176.25
0.2596	8.20	0.5536	182.25
0.2648	8.80	0.5579	188.25
0.2717	9.70	0.5640	203.05
0.2768	10.40	0.5708	214.50
0.2828	11.30	0.5751	219.00
0.2880	12.30		

```
RUN # P466


RATE              FRACTION          RATE              FRACTION
0.07614           0.0253            0.00508           0.2940
0.13325           0.0382            0.00484           0.2997
0.12895           0.0511            0.00457           0.3054
0.11607           0.0631            0.00446           0.3110
0.10316           0.0744            0.00393           0.3169
0.09672           0.0844            0.00368           0.3227
0.09241           0.0941            0.00336           0.3284
0.08596           0.1026            0.00324           0.3343
0.07953           0.1111            0.00294           0.3399
0.07952           0.1192            0.00298           0.3456
0.07308           0.1269            0.00280           0.3513
0.07307           0.1339            0.00270           0.3571
0.05803           0.1401            0.00276           0.3628
0.05374           0.1461            0.00255           0.3685
0.05158           0.1517            0.00265           0.3745
0.04944           0.1568            0.00233           0.3802
0.05158           0.1613            0.00223           0.3858
0.04298           0.1661            0.00193           0.3917
0.04084           0.1706            0.00195           0.3974
0.03868           0.1747            0.00189           0.4029
0.03439           0.1780            0.00181           0.4087
0.03439           0.1814            0.00179           0.4145
0.02794           0.1847            0.00180           0.4204
0.02364           0.1874            0.00179           0.4262
0.02579           0.1896            0.00148           0.4321
0.02794           0.1926            0.00155           0.4378
0.02579           0.1952            0.00126           0.4434
0.02364           0.1976            0.00122           0.4491
0.02579           0.2000            0.00127           0.4548
0.01719           0.2022            0.00117           0.4605
0.02149           0.2043            0.00110           0.4663
0.01504           0.2058            0.00114           0.4720
0.01934           0.2079            0.00111           0.4776
0.01934           0.2096            0.00102           0.4835
0.01597           0.2125            0.00112           0.4893
0.01641           0.2160            0.00096           0.4950
0.01412           0.2208            0.00100           0.5009
0.01337           0.2258            0.00091           0.5067
0.01337           0.2319            0.00082           0.5124
0.01118           0.2376            0.00100           0.5184
0.01009           0.2435            0.00107           0.5246
0.00931           0.2490            0.00103           0.5304
0.00794           0.2545            0.00115           0.5366
0.00829           0.2600            0.00094           0.5426
0.00768           0.2656            0.00077           0.5480
0.00749           0.2711            0.00070           0.5533
0.00663           0.2768            0.00056           0.5591
0.00595           0.2828            0.00058           0.5643
0.00520           0.2883
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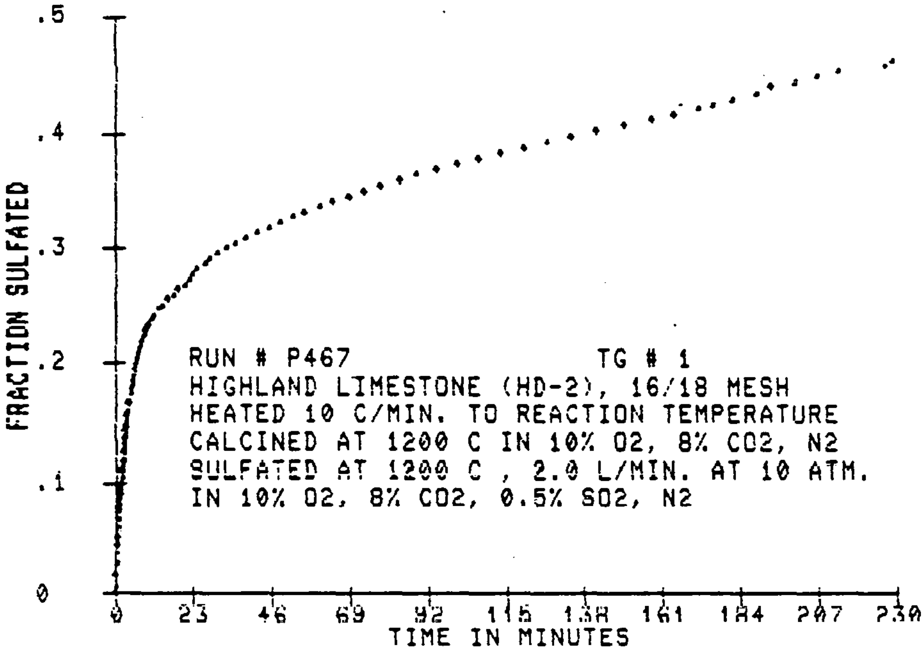
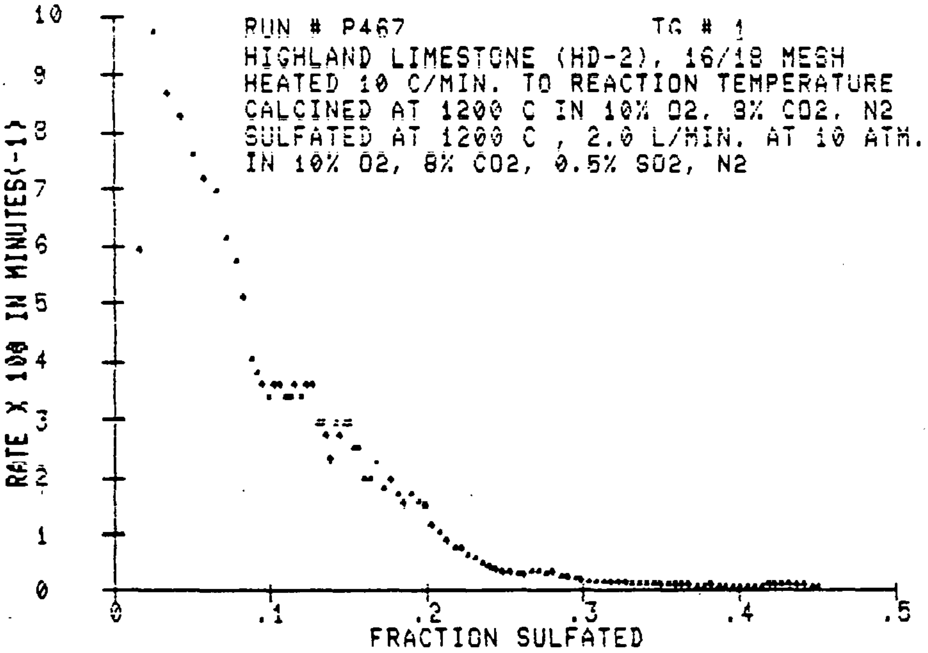
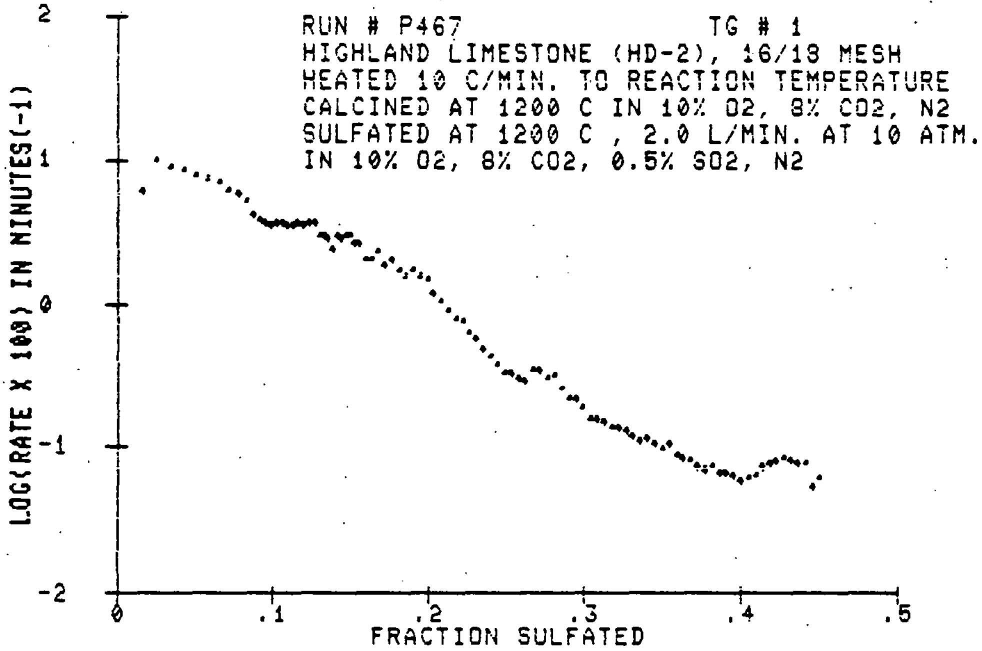

FRACTION SULFATED
.5
.4
.3
.2
.1
0
RUN # P467 TG # 1
HIGHLAND LIMESTONE (HD-2), 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
23
46
69
92
115
138
161
184
207
230
TIME IN MINUTES


RATE X 100 IN MINUTES(-1)
10
9
8
7
6
5
4
3
2
1
0
RUN # P467 TG # 1
HIGHLAND LIMESTONE (HD-2), 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
0
.1
.2
.3
.4
.5
FRACTION SULFATED

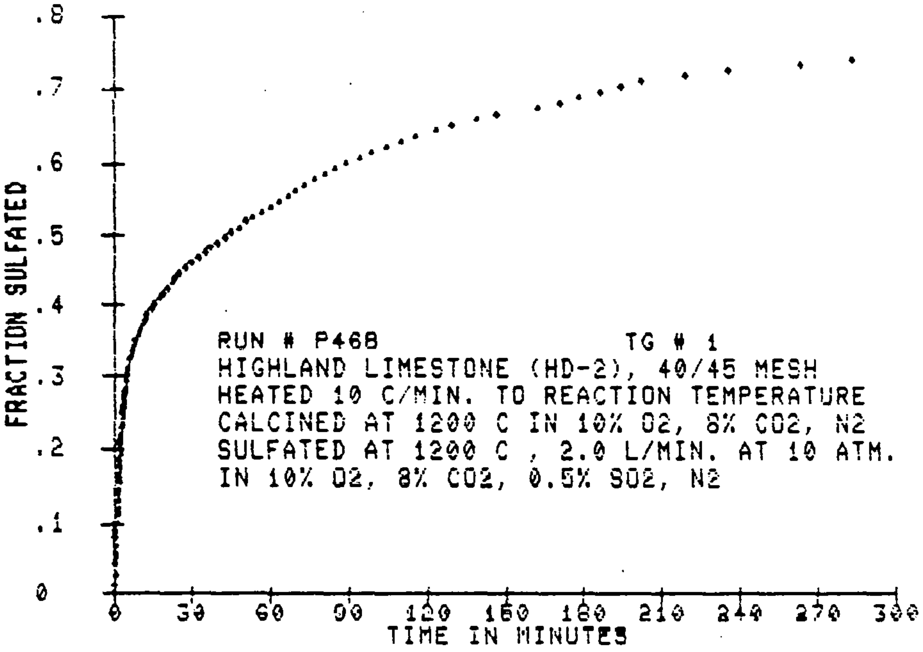

RUN # P467
TG # 1
HIGHLAND LIMESTONE (HD-2), 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
FRACTION SULFATED

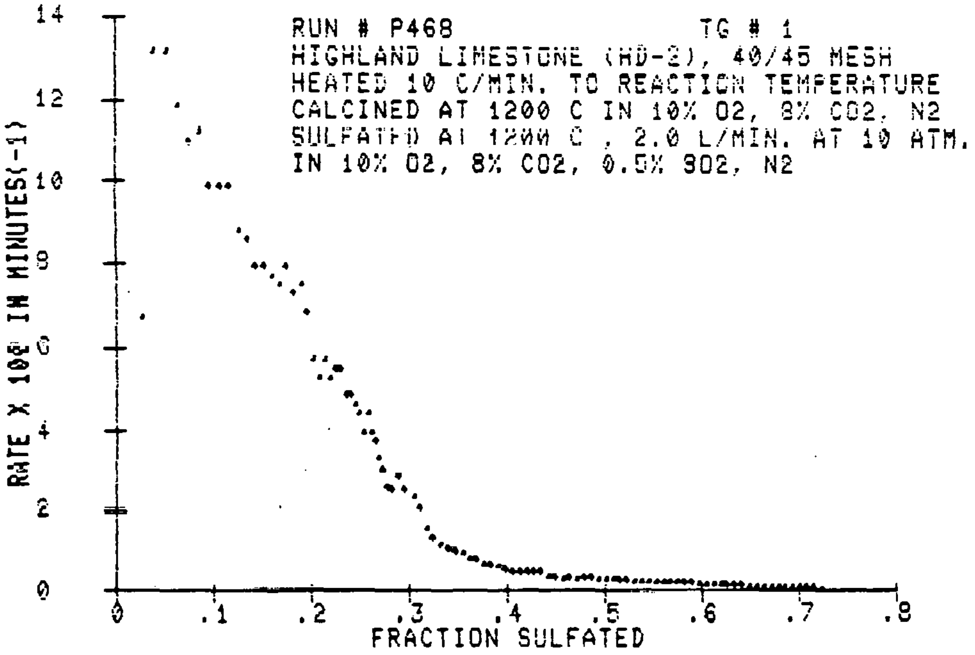
RUN # P467 TEMPERATURE = (1190.13 +/- 0.90) C

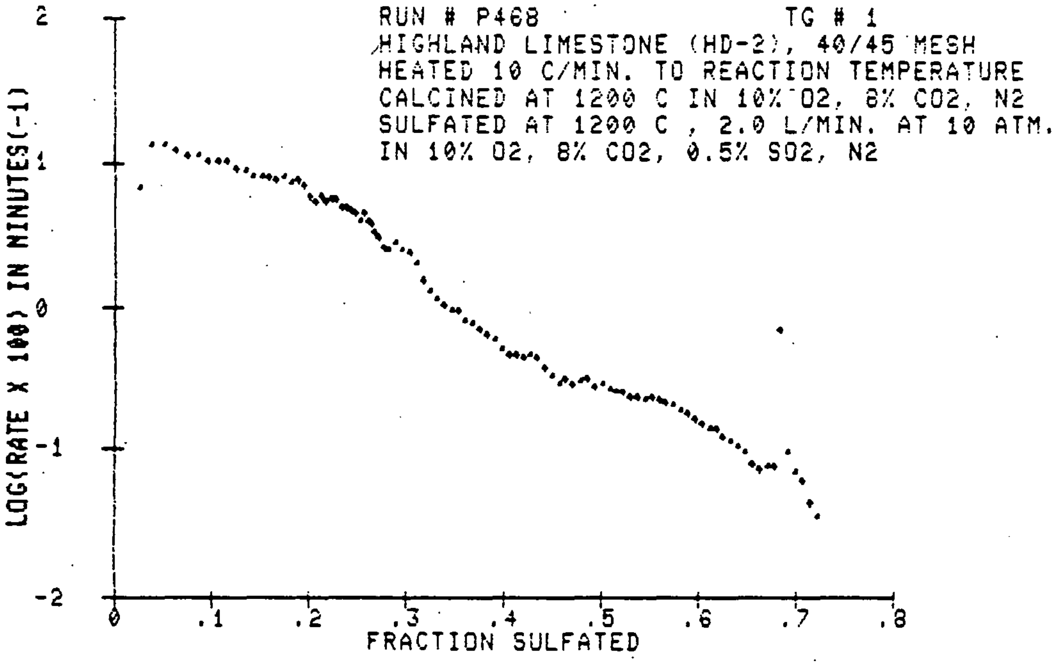
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.2356	10.60
0.0051	0.30	0.2390	11.30
0.0160	0.40	0.2449	13.00
0.0262	0.50	0.2483	13.80
0.0355	0.60	0.2533	15.40
0.0439	0.70	0.2576	17.00
0.0507	0.80	0.2626	18.50
0.0591	0.90	0.2669	20.10
0.0659	1.00	0.2711	21.70
0.0726	1.10	0.2761	22.40
0.0785	1.20	0.2804	23.80
0.0836	1.30	0.2854	26.30
0.0887	1.40	0.2897	27.60
0.0929	1.50	0.2947	29.70
0.0946	1.60	0.2989	32.50
0.0988	1.70	0.3040	35.20
0.1030	1.80	0.3082	38.00
0.1064	1.90	0.3125	41.50
0.1089	2.00	0.3175	45.00
0.1132	2.10	0.3226	48.20
0.1165	2.20	0.3268	52.10
0.1199	2.30	0.3310	55.70
0.1233	2.40	0.3361	59.80
0.1267	2.50	0.3403	63.80
0.1309	2.60	0.3445	68.80
0.1343	2.70	0.3496	72.80
0.1351	2.80	0.3538	77.55
0.1385	2.90	0.3589	83.40
0.1419	3.00	0.3640	88.05
0.1436	3.10	0.3682	94.35
0.1469	3.20	0.3724	100.20
0.1495	3.30	0.3775	106.65
0.1537	3.40	0.3817	113.10
0.1554	3.50	0.3859	120.15
0.1571	3.60	0.3918	126.75
0.1647	3.90	0.3952	133.80
0.1655	4.00	0.4003	141.30
0.1731	4.40	0.4045	149.70
0.1773	4.50	0.4096	157.80
0.1807	4.00	0.4138	164.25
0.1849	5.00	0.4197	171.45
0.1900	5.40	0.4231	175.95
0.1942	5.60	0.4273	181.35
0.1993	5.90	0.4324	188.25
0.2035	6.20	0.4374	192.75
0.3077	6.00	0.4417	199.65
0.2128	7.20	0.4459	206.10
0.2170	7.60	0.4510	213.55
0.2221	8.30	0.4552	226.20
0.2255	8.90	0.4594	228.30
0.2305	9.60		

RUN # P467

RATE	FRACTION	RATE	FRACTION
0.05911	0.0166	0.00474	0.2351
0.09712	0.0253	0.00422	0.2397
0.08655	0.0345	0.00369	0.2442
0.08233	0.0431	0.00326	0.2486
0.07601	0.0510	0.00322	0.2533
0.07178	0.0584	0.00295	0.2577
0.06968	0.0654	0.00281	0.2623
0.06122	0.0719	0.00344	0.2669
0.05700	0.0779	0.00335	0.2714
0.05067	0.0833	0.00300	0.2760
0.04011	0.0877	0.00315	0.2805
0.03801	0.0917	0.00255	0.2853
0.03589	0.0956	0.00214	0.2898
0.03378	0.0991	0.00209	0.2946
0.03589	0.1024	0.00179	0.2991
0.03589	0.1061	0.00150	0.3037
0.03378	0.1096	0.00149	0.3082
0.03378	0.1130	0.00143	0.3130
0.03589	0.1164	0.00132	0.3175
0.03378	0.1199	0.00131	0.3221
0.03589	0.1235	0.00126	0.3268
0.03589	0.1270	0.00114	0.3314
0.02956	0.1301	0.00106	0.3358
0.02956	0.1331	0.00109	0.3403
0.02745	0.1361	0.00100	0.3449
0.02322	0.1387	0.00095	0.3494
0.02956	0.1412	0.00101	0.3542
0.02744	0.1441	0.00086	0.3589
0.02956	0.1471	0.00082	0.3635
0.02956	0.1498	0.00080	0.3682
0.02533	0.1525	0.00071	0.3728
0.02534	0.1561	0.00069	0.3771
0.01971	0.1593	0.00073	0.3819
0.01970	0.1632	0.00065	0.3864
0.02252	0.1675	0.00066	0.3910
0.01783	0.1723	0.00063	0.3956
0.01942	0.1763	0.00057	0.4003
0.01689	0.1812	0.00061	0.4047
0.01535	0.1854	0.00064	0.4096
0.01689	0.1898	0.00071	0.4141
0.01548	0.1944	0.00075	0.4187
0.01478	0.1990	0.00077	0.4233
0.01161	0.2035	0.00083	0.4280
0.01043	0.2081	0.00078	0.4324
0.00885	0.2126	0.00075	0.4369
0.00771	0.2170	0.00076	0.4417
0.00739	0.2216	0.00053	0.4462
0.00619	0.2262	0.00062	0.4506
0.00563	0.2305		


RUN # P468 TG # 1
HIGHLAND LIMESTONE (HD-2), 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

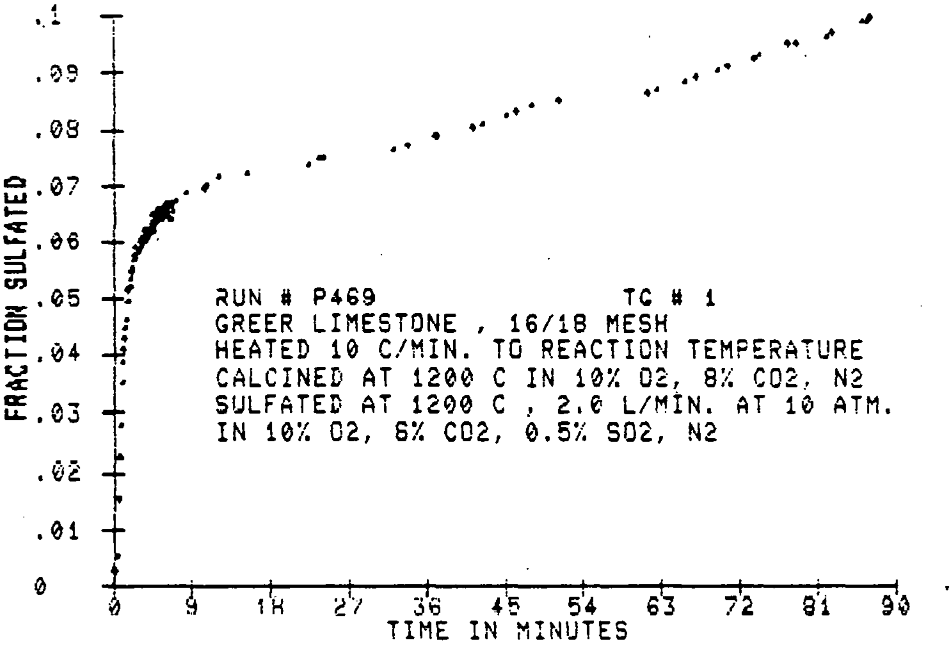

RUN # P468 TG # 1
HIGHLAND LIMESTONE (HD-2), 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

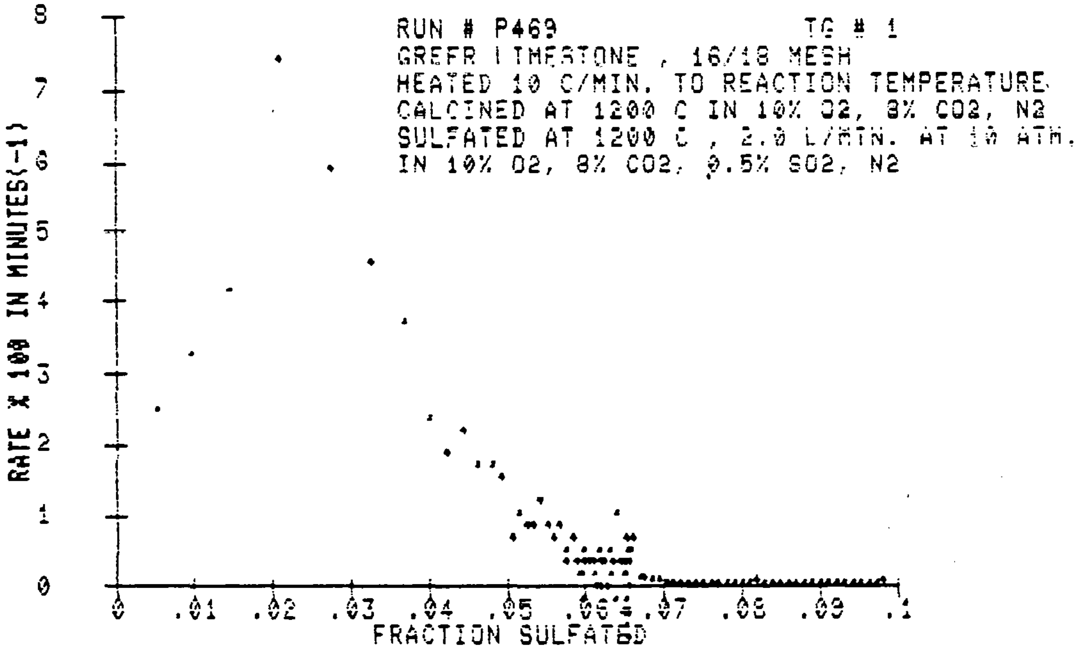

RUN # P468
TG # 1
HIGHLAND LIMESTONE (HD-2), 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
FRACTION SULFATED

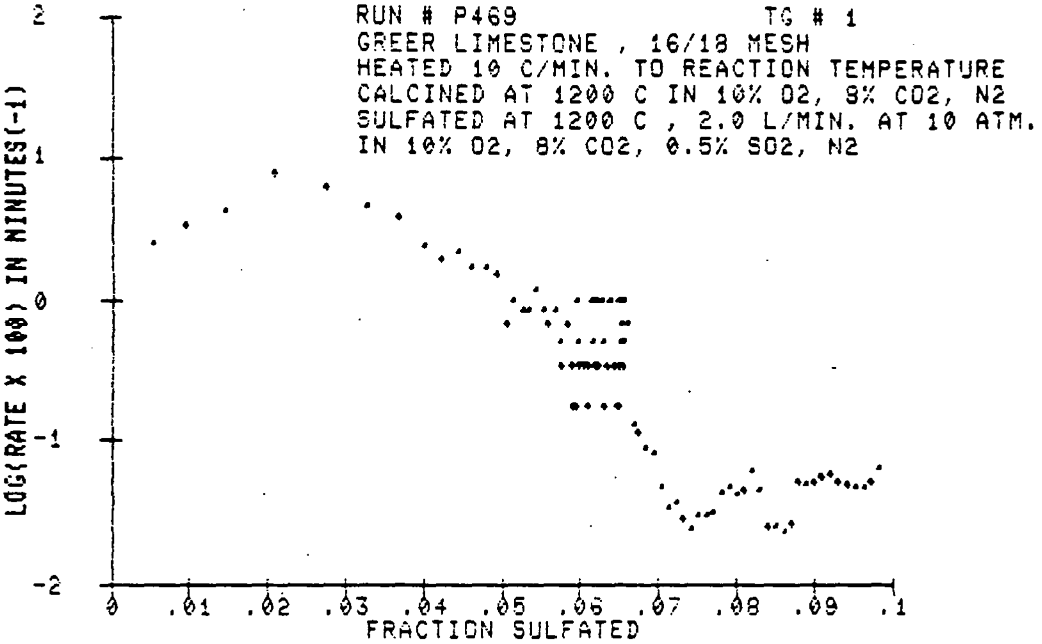
```
RUN # P468       TEMPERATURE = (1192.33 +/-  1.26 ) C

FRACTION         TIME             FRACTION         TIME
0.0000             0.00            0.3765            12.10
0.0114             0.50            0.3836            13.00
0.0254             0.60            0.3914            14.30
0.0412             0.70            0.3984            15.40
0.0534             0.80            0.4081            17.40
0.0639             0.90            0.4133            18.90
0.0779             1.00            0.4203            20.70
0.0884             1.10            0.4308            22.60
0.0972             1.20            0.4352            23.70
0.1086             1.30            0.4431            25.40
0.1173             1.40            0.4501            27.50
0.1279             1.50            0.4580            30.10
0.1366             1.60            0.4650            32.80
0.1436             1.70            0.4720            35.40
0.1515             1.80            0.4799            37.20
0.1594             1.90            0.4869            40.30
0.1681             2.00            0.4956            42.90
0.1743             2.10            0.5010            45.00
0.1813             2.20            0.5088            48.00
0.1909             2.30            0.5175            51.00
0.1970             2.40            0.5237            53.40
0.2040             2.50            0.5315            56.70
0.2084             2.60            0.5385            59.90
0.2137             2.70            0.5464            63.60
0.2180             2.80            0.5534            66.50
0.2268             2.90            0.5604            69.80
0.2294             3.00            0.5683            73.00
0.2356             3.10            0.5753            76.90
0.2399             3.20            0.5832            80.70
0.2461             3.30            0.5911            84.70
0.2487             3.40            0.5981            88.90
0.2539             3.50            0.6051            93.80
0.2575             3.60            0.6121            98.70
0.2618             3.70            0.6200           104.10
0.2662             3.80            0.6270           109.80
0.2697             3.90            0.6349           115.90
0.2723             4.00            0.6419           123.40
0.2750             4.10            0.6409           129.80
0.2811             4.30            0.6568           138.70
0.2899             4.70            0.6638           146.60
0.2969             5.00            0.6717           162.00
0.3056             5.20            0.6787           171.20
0.3109             5.50            0.6865           178.00
0.3196             6.00            0.6935           186.40
0.3249             6.40            0.7005           194.80
0.3328             7.00            0.7084           202.40
0.3406             7.80            0.7154           219.60
0.3468             8.40            0.7233           236.00
0.3547             9.30            0.7303           264.00
0.3625            10.10            0.7373           284.00
0.3695            10.90
```

RUN # P468

RATE	FRACTION	RATE	FRACTION
0.06677	0.0263	0.00688	0.3767
0.13135	0.0391	0.00642	0.3839
0.13135	0.0524	0.00595	0.3916
0.11823	0.0650	0.00505	0.3990
0.10945	0.0762	0.00452	0.4063
0.11166	0.0872	0.00450	0.4142
0.09851	0.0979	0.00431	0.4216
0.09851	0.1079	0.00458	0.4286
0.09852	0.1175	0.00438	0.4359
0.08756	0.1268	0.00362	0.4434
0.08539	0.1354	0.00327	0.4503
0.07881	0.1438	0.00289	0.4576
0.07881	0.1518	0.00307	0.4650
0.07663	0.1594	0.00283	0.4723
0.07443	0.1669	0.00303	0.4799
0.07882	0.1748	0.00310	0.4872
0.07224	0.1823	0.00268	0.4946
0.07443	0.1895	0.00286	0.5021
0.06787	0.1963	0.00267	0.5095
0.05692	0.2028	0.00254	0.5167
0.05255	0.2082	0.00250	0.5240
0.05692	0.2142	0.00229	0.5315
0.05254	0.2193	0.00227	0.5387
0.05474	0.2247	0.00221	0.5461
0.05473	0.2300	0.00227	0.5534
0.04817	0.2356	0.00217	0.5608
0.04816	0.2399	0.00210	0.5681
0.04597	0.2448	0.00206	0.5757
0.04379	0.2492	0.00187	0.5832
0.03940	0.2536	0.00176	0.5906
0.04379	0.2576	0.00161	0.5979
0.03940	0.2618	0.00149	0.6053
0.03721	0.2655	0.00138	0.6125
0.03284	0.2690	0.00135	0.6198
0.02977	0.2729	0.00121	0.6272
0.02518	0.2776	0.00112	0.6345
0.02452	0.2830	0.00103	0.6419
0.02786	0.2897	0.00094	0.6492
0.02481	0.2969	0.00077	0.6566
0.02290	0.3046	0.00072	0.6639
0.02002	0.3116	0.00076	0.6715
0.01508	0.3188	0.00075	0.6788
0.01295	0.3258	0.00088	0.6862
0.01131	0.3329	0.00095	0.6935
0.01027	0.3399	0.00069	0.7009
0.00960	0.3475	0.00060	0.7083
0.00932	0.3548	0.00043	0.7156
0.00805	0.3620	0.00035	0.7230
0.00781	0.3694		


RUN # P469 TC # 1
GREER LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
0
9
18
27
36
45
54
63
72
81
90
TIME IN MINUTES

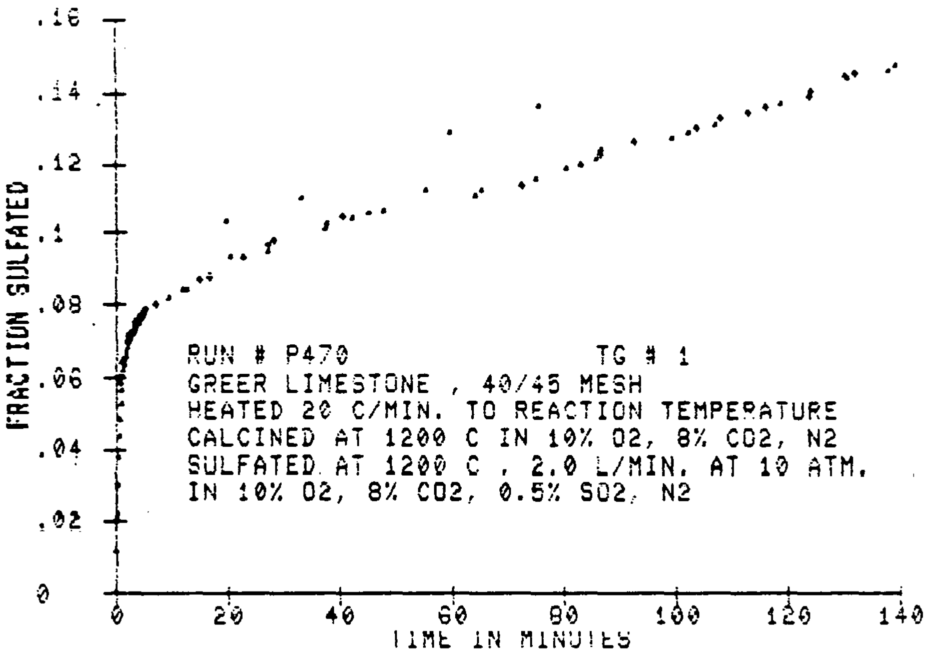

RUN # P469 TC # 1
GREER LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
8
7
6
5
4
3
2
1
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED


RUN # P469
TG # 1
GREER LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED

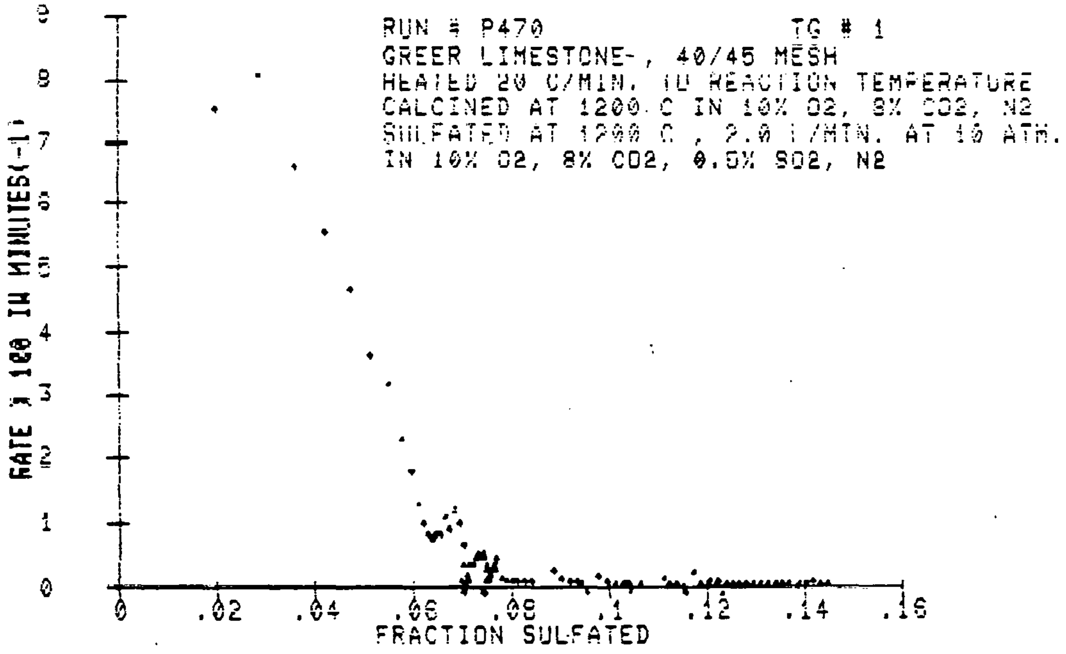
```
RUN # P469        TEMPERATURE = (1160.80 +/-  1.61 ) C


FRACTION          TIME              FRACTION          TIME
0.0000             0.00              0.0660            5.30
0.0027             0.10              0.0646            5.40
0.0027             0.20              0.0640            5.50
0.0054             0.50              0.0653            5.60
0.0148             0.60              0.0653            5.70
0.0222             0.70              0.0660            5.80
0.0276             0.80              0.0646            5.90
0.0350             0.90              0.0666            6.00
0.0384             1.00              0.0653            6.10
0.0404             1.10              0.0646            6.20
0.0424             1.20              0.0666            6.30
0.0444             1.30              0.0640            6.40
0.0458             1.40              0.0640            6.50
0.0491             1.50              0.0666            6.60
0.0491             1.60              0.0653            6.70
0.0512             1.70              0.0666            6.80
0.0518             1.80              0.0673            7.00
0.0518             1.90              0.0687            8.20
0.0532             2.00              0.0693           10.40
0.0545             2.10              0.0700           10.70
0.0558             2.20              0.0714           12.10
0.0565             2.30              0.0720           15.30
0.0565             2.40              0.0734           22.40
0.0572             2.50              0.0747           23.60
0.0586             2.60              0.0747           24.20
0.0586             2.70              0.0761           32.20
0.0579             2.80              0.0767           33.80
0.0599             2.90              0.0788           37.10
0.0599             3.00              0.0788           37.20
0.0592             3.10              0.0801           41.40
0.0586             3.20              0.0808           42.30
0.0606             3.30              0.0821           45.10
0.0592             3.40              0.0828           46.30
0.0613             3.50              0.0841           48.00
0.0599             3.60              0.0848           51.20
0.0619             3.70              0.0862           61.50
0.0606             3.80              0.0868           62.50
0.0619             3.90              0.0882           65.70
0.0613             4.00              0.0889           67.00
0.0619             4.10              0.0902           69.40
0.0626             4.20              0.0909           70.70
0.0619             4.30              0.0922           73.70
0.0626             4.40              0.0929           74.30
0.0633             4.50              0.0949           77.60
0.0646             4.60              0.0949           78.60
0.0619             4.70              0.0963           82.00
0.0633             4.80              0.0969           82.80
0.0646             4.90              0.0990           86.10
0.0640             5.00              0.0990           86.60
0.0660             5.10              0.0996           87.20
0.0646             5.20
```

RUN # P469

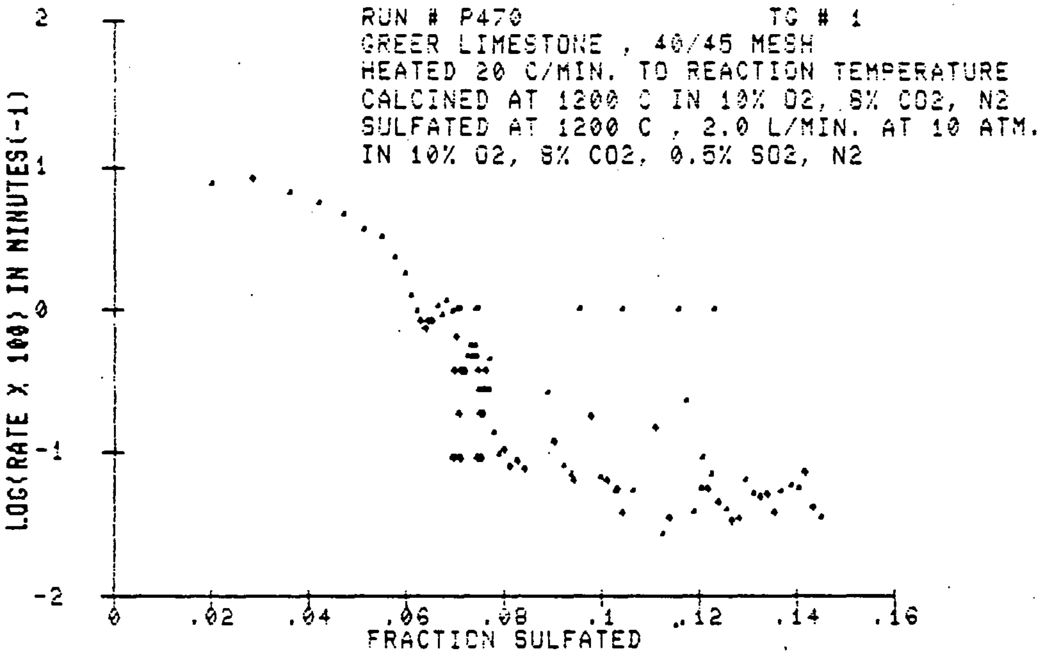
RATE	FRACTION
0.02468	0.0051
0.03253	0.0096
0.04151	0.0145
0.07404	0.0210
0.05890	0.0276
0.04544	0.0327
0.03702	0.0368
0.02356	0.0401
0.01851	0.0423
0.02188	0.0444
0.01683	0.0462
0.01683	0.0479
0.01515	0.0494
0.00673	0.0506
0.01010	0.0514
0.00842	0.0525
0.00841	0.0533
0.01178	0.0543
0.00841	0.0552
0.00673	0.0560
0.00842	0.0568
0.00505	0.0575
0.00337	0.0578
0.00673	0.0584
0.00337	0.0590
0.00168	0.0591
0.00168	0.0591
0.00168	0.0596
-.00168	0.0595
0.00505	0.0598
0.00337	0.0599
0.00337	0.0606
0.00337	0.0606
0.00168	0.0611
0.00337	0.0611
0.00000	0.0615
0.00505	0.0617
0.00000	0.0619
0.00337	0.0621
0.00337	0.0625
0.00505	0.0630
0.00000	0.0629
0.00168	0.0631
0.00337	0.0635
-.00168	0.0637
0.01010	0.0640
0.00337	0.0645
0.00337	0.0650
0.00168	0.0650
-.00505	0.0650
0.00168	0.0649
-.00168	0.0650
0.00337	0.0650
0.00168	0.0650
0.00337	0.0656
0.00000	0.0656
-.00337	0.0654
0.00505	0.0656
-.00673	0.0654
-.00337	0.0649
0.00505	0.0652
-.00337	0.0653
0.00673	0.0653
0.00673	0.0660
0.00126	0.0669
0.00109	0.0675
0.00086	0.0684
0.00079	0.0693
0.00047	0.0703
0.00034	0.0712
0.00037	0.0723
0.00028	0.0732
0.00024	0.0742
0.00030	0.0751
0.00030	0.0762
0.00031	0.0770
0.00044	0.0781
0.00048	0.0790
0.00042	0.0801
0.00044	0.0809
0.00061	0.0820
0.00045	0.0829
0.00025	0.0840
0.00025	0.0850
0.00023	0.0860
0.00026	0.0870
0.00051	0.0881
0.00049	0.0890
0.00050	0.0901
0.00055	0.0910
0.00057	0.0922
0.00051	0.0932
0.00049	0.0942
0.00048	0.0952
0.00048	0.0964
0.00050	0.0972
0.00065	0.0981



RUN # P470 TG # 1
GREER LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2



RUN # P470 TG # 1
GREER LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

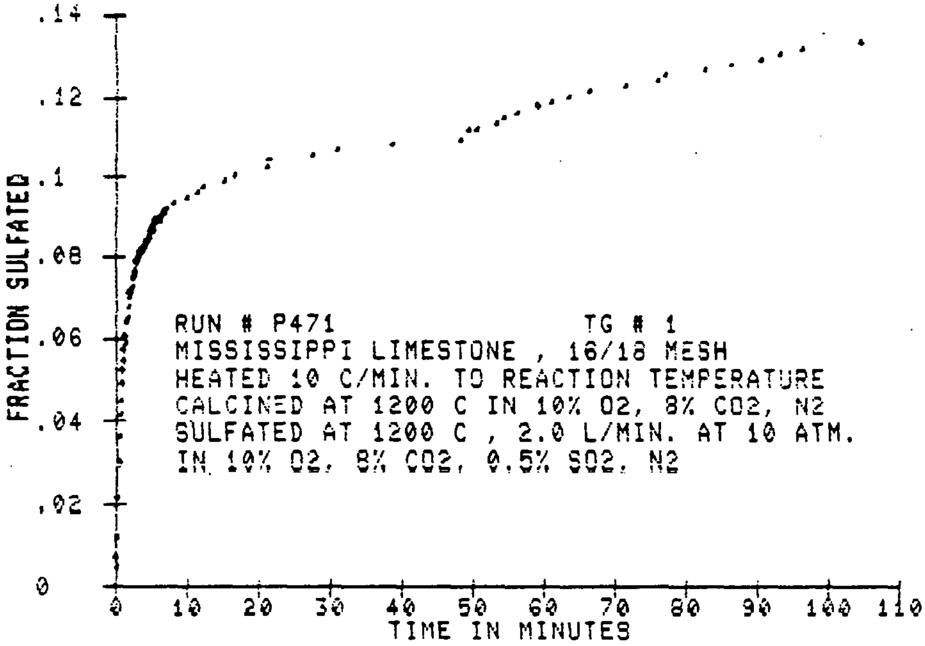

RUN # P470 TG # 1
GREER LIMESTONE , 40/45 MESH
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.02
.04
.06
.08
.1
.12
.14
.16
FRACTION SULFATED

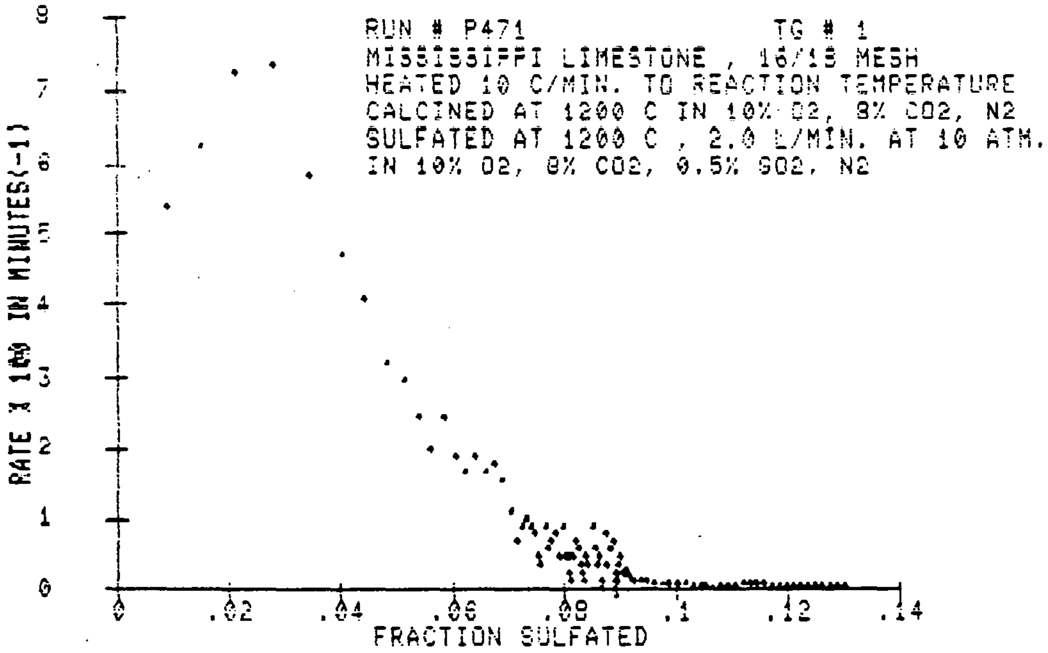
RUN # P470 TEMPERATURE = (1192.05 +/- 1.92) C

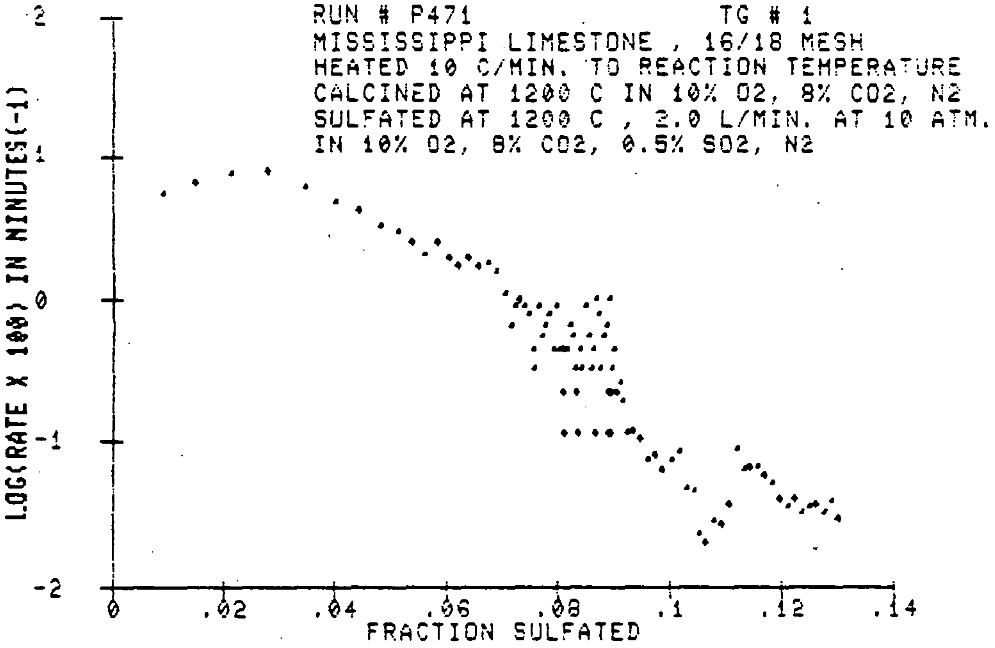
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.0775	5.20
0.0112	0.20	0.0772	5.30
0.0214	0.30	0.0782	5.50
0.0302	0.40	0.0796	7.20
0.0375	0.50	0.0814	9.30
0.0435	0.60	0.0838	11.90
0.0477	0.70	0.0838	12.70
0.0523	0.80	0.0863	15.10
0.0561	0.90	0.0870	16.80
0.0579	1.00	0.1031	19.50
0.0602	1.10	0.0926	20.40
0.0614	1.20	0.0923	22.60
0.0632	1.30	0.0940	26.80
0.0628	1.40	0.0961	27.30
0.0642	1.50	0.0975	28.20
0.0646	1.60	0.1098	33.10
0.0660	1.70	0.1010	37.30
0.0660	1.80	0.1024	37.40
0.0674	1.90	0.1042	40.40
0.0688	2.00	0.1038	42.00
0.0695	2.10	0.1053	44.90
0.0705	2.20	0.1063	47.60
0.0712	2.30	0.1123	55.20
0.0691	2.40	0.1284	59.40
0.0709	2.50	0.1105	64.10
0.0705	2.60	0.1123	65.10
0.0709	2.70	0.1133	72.50
0.0716	2.80	0.1151	75.00
0.0709	2.90	0.1356	75.40
0.0712	3.00	0.1182	80.50
0.0712	3.10	0.1193	83.10
0.0719	3.20	0.1210	85.90
0.0723	3.30	0.1221	86.60
0.0726	3.40	0.1238	86.70
0.0726	3.50	0.1260	92.70
0.0737	3.60	0.1270	99.30
0.0744	3.70	0.1284	102.30
0.0744	3.80	0.1295	103.80
0.0747	3.90	0.1309	106.90
0.0754	4.00	0.1326	108.00
0.0740	4.10	0.1340	113.20
0.0740	4.20	0.1354	116.20
0.0751	4.30	0.1366	118.60
0.0758	4.40	0.1386	124.00
0.0751	4.50	0.1400	124.30
0.0754	4.60	0.1438	130.40
0.0758	4.70	0.1435	130.50
0.0761	4.80	0.1445	132.30
0.0761	4.90	0.1456	137.90
0.0761	5.00	0.1470	139.30
0.0768	5.10		

RUN # P470

RATE	FRACTION	RATE	FRACTION
0.07508	0.0201	0.00421	0.0772
0.08069	0.0288	0.00134	0.0779
0.06578	0.0361	0.00094	0.0788
0.05526	0.0422	0.00101	0.0801
0.04648	0.0474	0.00078	0.0814
0.03596	0.0515	0.00084	0.0830
0.03157	0.0549	0.00075	0.0845
0.02280	0.0576	0.00254	0.0888
0.01754	0.0598	0.00114	0.0906
0.01228	0.0611	0.00080	0.0923
0.00965	0.0624	0.00070	0.0938
0.00789	0.0632	-.00090	0.0956
0.00702	0.0641	0.00063	0.0945
0.00789	0.0647	0.00167	0.0980
0.00789	0.0656	0.00067	0.0997
0.01053	0.0665	0.00063	0.1014
0.00877	0.0675	0.00055	0.1030
0.01140	0.0684	-.00067	0.1043
0.00965	0.0695	0.00055	0.1034
0.00088	0.0698	0.00038	0.1044
0.00351	0.0702	0.00055	0.1064
0.00000	0.0704	0.00141	0.1112
-.00088	0.0705	0.00027	0.1125
0.00614	0.0706	0.00034	0.1140
0.00000	0.0709	0.00006	0.1154
0.00175	0.0710	-.00085	0.1159
0.00088	0.0711	0.00224	0.1174
0.00088	0.0714	0.00039	0.1189
0.00351	0.0715	0.00056	0.1203
0.00351	0.0719	0.00055	0.1219
0.00351	0.0721	-.00122	0.1233
0.00439	0.0726	0.00091	0.1209
0.00526	0.0731	0.00069	0.1224
0.00439	0.0735	0.00045	0.1240
0.00526	0.0740	0.00040	0.1255
0.00439	0.0745	0.00033	0.1269
-.00088	0.0746	0.00035	0.1283
-.00088	0.0745	0.00065	0.1297
0.00088	0.0747	0.00051	0.1311
0.00088	0.0749	0.00046	0.1325
0.00263	0.0748	0.00051	0.1339
0.00351	0.0751	0.00037	0.1355
0.00175	0.0754	0.00054	0.1370
0.00088	0.0756	0.00059	0.1389
0.00263	0.0757	0.00056	0.1405
0.00175	0.0759	0.00072	0.1421
0.00263	0.0762	0.00041	0.1435
0.00351	0.0766	0.00035	0.1449
0.00263	0.0768		

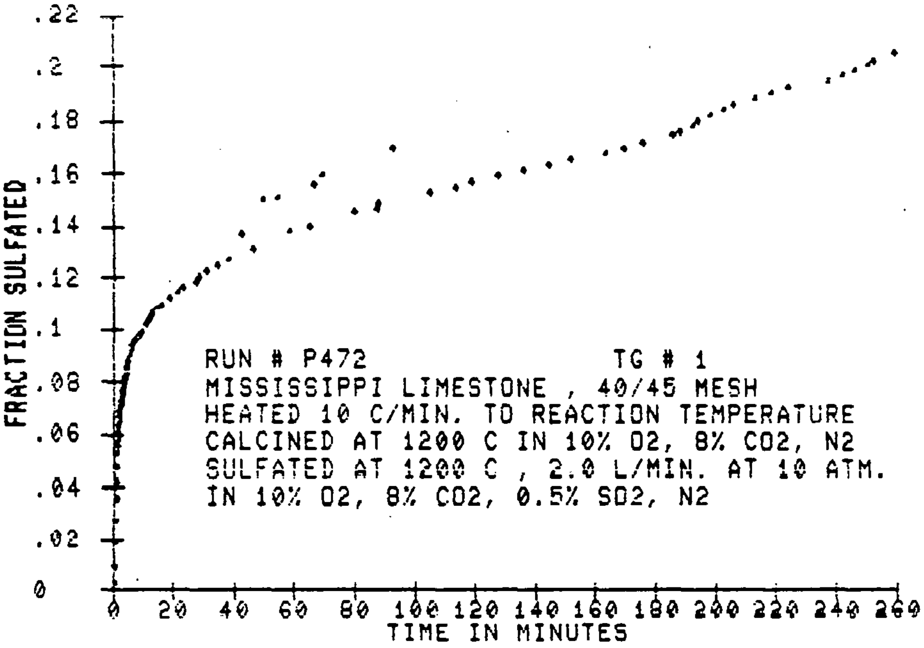

RUN # P471 TG # 1
MISSISSIPPI LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

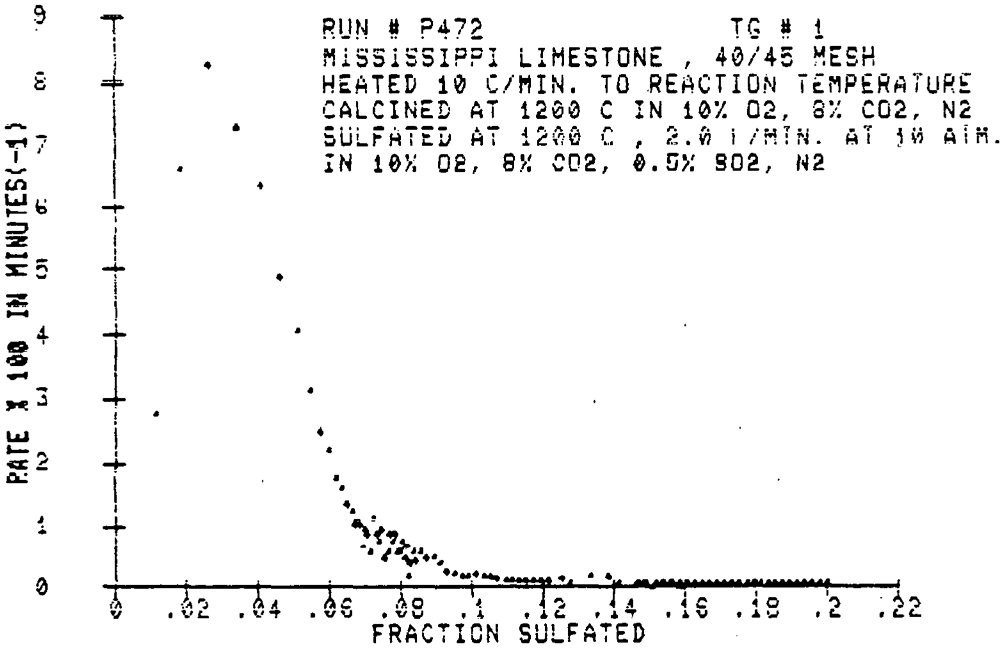

RUN # P471 TG # 1
MISSISSIPPI LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

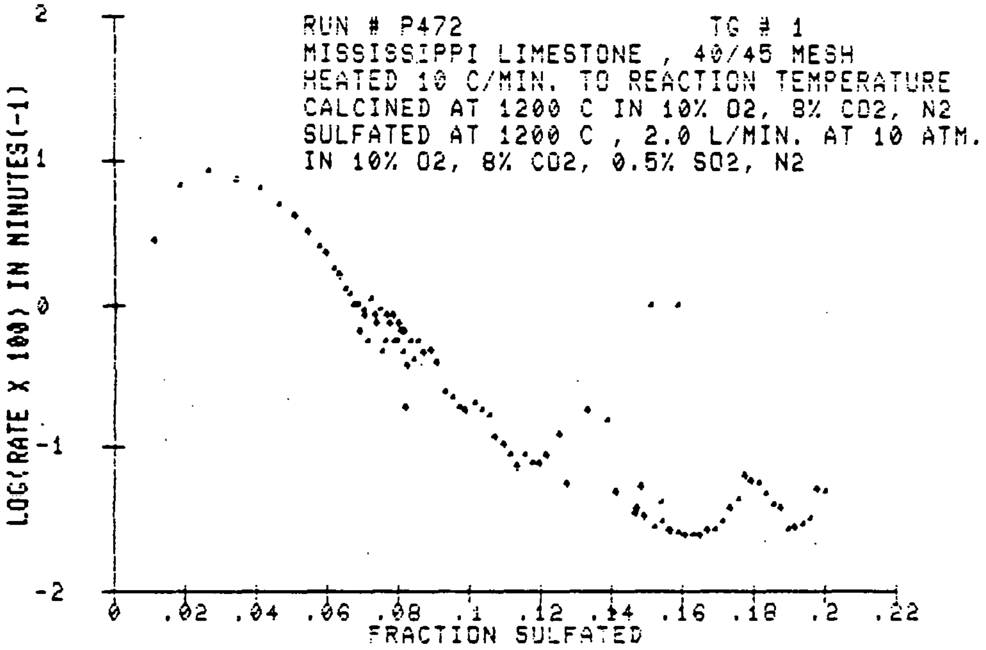

RUN # P471 TG # 1
MISSISSIPPI LIMESTONE , 16/18 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.02
.04
.06
.08
.1
.12
.14
FRACTION SULFATED

```
RUN # P471        TEMPERATURE = (1160.48 +/-  1.60 ) C


FRACTION          TIME              FRACTION          TIME
0.0000            0.00              0.0864             5.10
0.0048            0.10              0.0872             5.20
0.0070            0.20              0.0868             5.30
0.0118            0.30              0.0868             5.40
0.0215            0.40              0.0894             5.50
0.0298            0.50              0.0886             5.60
0.0359            0.60              0.0890             5.70
0.0412            0.70              0.0894             5.80
0.0447            0.80              0.0894             5.90
0.0487            0.90              0.0894             6.00
0.0522            1.00              0.0894             6.10
0.0539            1.10              0.0890             6.20
0.0566            1.20              0.0903             6.30
0.0583            1.30              0.0899             6.40
0.0601            1.40              0.0907             6.50
0.0636            1.50              0.0907             6.60
0.0640            1.60              0.0912             6.70
0.0649            1.70              0.0907             6.80
0.0675            1.80              0.0921             7.00
0.0701            1.90              0.0934             8.00
0.0710            2.00              0.0947             9.80
0.0710            2.10              0.0960            11.40
0.0719            2.20              0.0973            12.20
0.0728            2.30              0.0986            15.20
0.0745            2.40              0.1000            16.60
0.0750            2.50              0.1021            21.20
0.0754            2.60              0.1039            21.30
0.0758            2.70              0.1039            21.50
0.0763            2.80              0.1052            27.60
0.0763            2.90              0.1065            30.90
0.0789            3.00              0.1078            38.70
0.0780            3.10              0.1092            42.20
0.0789            3.20              0.1114            49.40
0.0793            3.30              0.1118            50.50
0.0807            3.40              0.1131            53.20
0.0815            3.50              0.1144            54.80
0.0807            3.60              0.1157            56.20
0.0811            3.70              0.1175            59.10
0.0815            3.80              0.1184            61.00
0.0820            3.90              0.1197            62.50
0.0824            4.00              0.1210            65.50
0.0837            4.10              0.1223            71.30
0.0837            4.20              0.1236            75.90
0.0833            4.30              0.1249            77.00
0.0833            4.40              0.1263            82.60
0.0842            4.50              0.1276            86.40
0.0855            4.60              0.1289            90.60
0.0846            4.70              0.1302            93.30
0.0860            4.80              0.1315            96.30
0.0864            4.90              0.1328           104.70
0.0868            5.00
```

```
RUN # P471

RATE        FRACTION      RATE        FRACTION
0.05370     0.0090        0.00110     0.0867
0.06247     0.0150        0.00000     0.0868
0.07234     0.0212        0.00767     0.0873
0.07342     0.0281        0.00329     0.0878
0.05809     0.0346        0.00548     0.0881
0.04712     0.0401        0.00658     0.0886
0.04055     0.0445        0.00000     0.0892
0.03179     0.0481        0.00219     0.0892
0.02959     0.0512        0.00110     0.0893
0.02411     0.0539        -.00110     0.0893
0.01973     0.0562        0.00219     0.0895
0.02411     0.0585        0.00110     0.0896
0.01863     0.0605        0.00329     0.0899
0.01644     0.0622        0.00438     0.0901
0.01863     0.0640        0.00219     0.0906
0.01644     0.0660        0.00219     0.0907
0.01753     0.0675        0.00263     0.0911
0.01534     0.0689        0.00188     0.0916
0.01096     0.0703        0.00113     0.0924
0.00658     0.0714        0.00114     0.0934
0.00877     0.0722        0.00101     0.0947
0.00986     0.0730        0.00073     0.0960
0.00877     0.0739        0.00077     0.0973
0.00767     0.0747        0.00063     0.0988
0.00438     0.0754        0.00072     0.1004
0.00329     0.0758        0.00084     0.1017
0.00877     0.0765        0.00048     0.1030
0.00548     0.0771        0.00045     0.1043
0.00658     0.0777        0.00023     0.1055
0.00767     0.0783        0.00020     0.1065
0.00438     0.0792        0.00028     0.1080
0.00877     0.0797        0.00027     0.1093
0.00438     0.0802        0.00036     0.1106
0.00438     0.0807        0.00086     0.1120
0.00219     0.0811        0.00064     0.1133
0.00110     0.0814        0.00066     0.1145
0.00438     0.0815        0.00067     0.1159
0.00658     0.0822        0.00057     0.1171
0.00548     0.0827        0.00052     0.1185
0.00329     0.0830        0.00040     0.1198
0.00219     0.0833        0.00035     0.1210
0.00110     0.0836        0.00039     0.1223
0.00438     0.0840        0.00032     0.1236
0.00329     0.0842        0.00035     0.1249
0.00877     0.0849        0.00036     0.1263
0.00548     0.0855        0.00032     0.1276
0.00329     0.0860        0.00038     0.1289
0.00438     0.0862        0.00029     0.1302
0.00110     0.0867
```


.22
.2
.18
.16
.14
.12
.1
.08
.06
.04
.02
0
FRACTION SULFATED
0
20
40
60
80
100
120
140
160
180
200
220
240
260
TIME IN MINUTES
RUN # P472 TG # 1
MISSISSIPPI LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


9
8
7
6
5
4
3
2
1
0
RATE X 100 IN MINUTES(-1)
0
.02
.04
.06
.08
.1
.12
.14
.16
.18
.2
.22
FRACTION SULFATED
RUN # P472 TG # 1
MISSISSIPPI LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RUN # P472
TG # 1
MISSISSIPPI LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1200 C IN 10% O2, 8% CO2, N2
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.02
.04
.06
.08
.1
.12
.14
.16
.18
.2
.22
FRACTION SULFATED

RUN # P472 TEMPERATURE = (1178.04 +/- 1.79) C

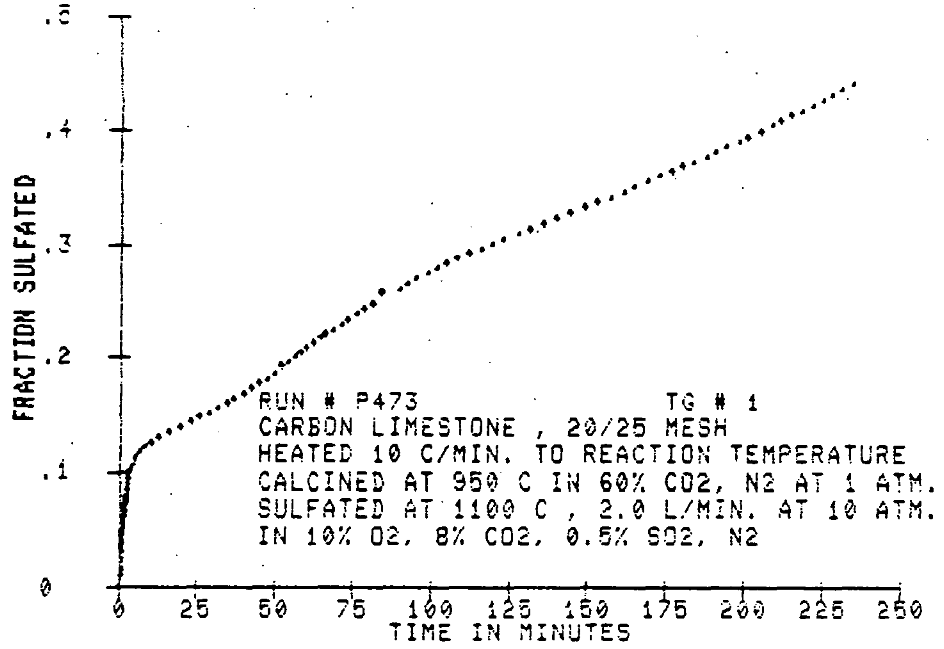
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.1034	12.20
0.0026	0.60	0.1056	13.00
0.0088	0.80	0.1078	14.50
0.0187	0.90	0.1093	15.80
0.0275	1.00	0.1115	19.20
0.0356	1.10	0.1140	21.30
0.0418	1.20	0.1155	23.30
0.0477	1.30	0.1177	27.70
0.0528	1.40	0.1199	29.00
0.0550	1.50	0.1217	31.40
0.0579	1.60	0.1239	34.60
0.0601	1.70	0.1265	38.10
0.0627	1.80	0.1364	42.70
0.0638	1.90	0.1302	46.60
0.0649	2.00	0.1500	49.40
0.0664	2.10	0.1511	54.20
0.0678	2.20	0.1375	58.50
0.0686	2.30	0.1393	65.40
0.0689	2.40	0.1558	66.60
0.0704	2.50	0.1591	69.30
0.0704	2.60	0.1456	80.15
0.0722	2.70	0.1467	87.65
0.0722	2.80	0.1485	87.80
0.0726	2.90	0.1690	92.75
0.0748	3.00	0.1525	104.90
0.0755	3.10	0.1547	113.45
0.0752	3.20	0.1569	119.15
0.0763	3.30	0.1588	128.00
0.0766	3.40	0.1610	136.40
0.0777	3.50	0.1628	144.35
0.0785	3.60	0.1650	152.00
0.0792	3.70	0.1676	163.25
0.0799	3.80	0.1690	169.55
0.0799	3.90	0.1712	176.00
0.0807	4.00	0.1742	186.05
0.0821	4.10	0.1753	188.30
0.0825	4.20	0.1774	192.05
0.0818	4.30	0.1793	194.45
0.0832	4.40	0.1818	196.35
0.0829	4.50	0.1837	202.85
0.0840	4.60	0.1855	206.30
0.0851	4.90	0.1881	212.90
0.0869	5.30	0.1899	218.60
0.0895	5.70	0.1917	224.15
0.0917	6.30	0.1939	237.05
0.0931	6.60	0.1961	242.15
0.0950	7.40	0.1980	245.90
0.0972	8.90	0.2002	250.35
0.0990	9.60	0.2020	252.80
0.1012	10.90	0.2049	259.70

RUN # P472

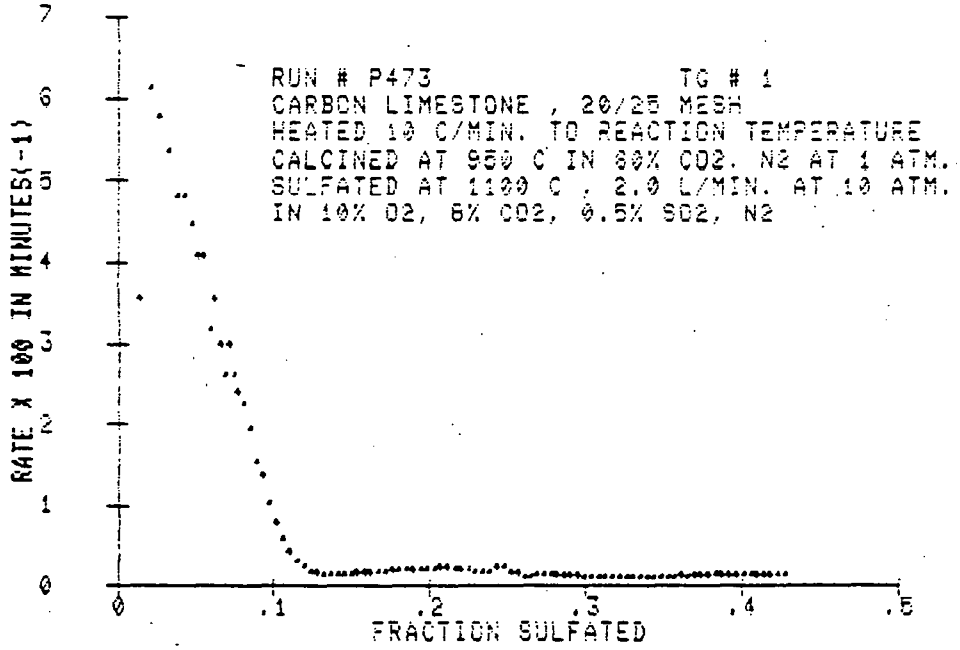
RATE	FRACTION	RATE	FRACTION
0.02750	0.0115	0.00180	0.1034
0.05599	0.0186	0.00165	0.1054
0.08249	0.0265	0.00115	0.1075
0.07241	0.0342	0.00102	0.1096
0.06325	0.0411	0.00087	0.1116
0.04858	0.0466	0.00071	0.1136
0.04033	0.0510	0.00086	0.1157
0.03116	0.0547	0.00076	0.1178
0.02475	0.0577	0.00075	0.1197
0.02200	0.0599	0.00085	0.1219
0.01741	0.0619	0.00120	0.1257
0.01558	0.0636	0.00055	0.1277
0.01283	0.0651	0.00176	0.1334
0.01191	0.0663	0.00153	0.1388
0.01008	0.0673	0.00007	0.1410
0.01008	0.0684	0.00049	0.1416
0.00642	0.0692	0.00034	0.1467
0.00917	0.0701	0.00053	0.1486
0.00825	0.0708	0.00037	0.1475
0.00550	0.0716	0.00033	0.1493
0.01100	0.0724	-.00035	0.1511
0.00825	0.0735	0.00042	0.1538
0.00733	0.0741	0.00028	0.1524
0.00917	0.0749	0.00031	0.1543
0.00458	0.0757	0.00027	0.1563
0.00550	0.0763	-.00029	0.1554
0.00825	0.0768	0.00027	0.1568
0.00733	0.0777	0.00026	0.1588
0.00825	0.0784	0.00025	0.1609
0.00550	0.0790	0.00025	0.1630
0.00550	0.0796	0.00024	0.1651
0.00733	0.0804	0.00027	0.1671
0.00642	0.0810	0.00027	0.1694
0.00458	0.0814	0.00031	0.1714
0.00642	0.0821	0.00037	0.1734
0.00183	0.0825	0.00044	0.1755
0.00367	0.0829	0.00063	0.1776
0.00550	0.0834	0.00058	0.1795
0.00407	0.0844	0.00057	0.1816
0.00550	0.0856	0.00048	0.1837
0.00453	0.0874	0.00040	0.1858
0.00474	0.0892	0.00036	0.1878
0.00394	0.0912	0.00027	0.1898
0.00241	0.0933	0.00028	0.1920
0.00222	0.0952	0.00030	0.1939
0.00188	0.0971	0.00032	0.1960
0.00176	0.0991	0.00051	0.1981
0.00206	0.1013	0.00050	0.2003

APPENDIX B3

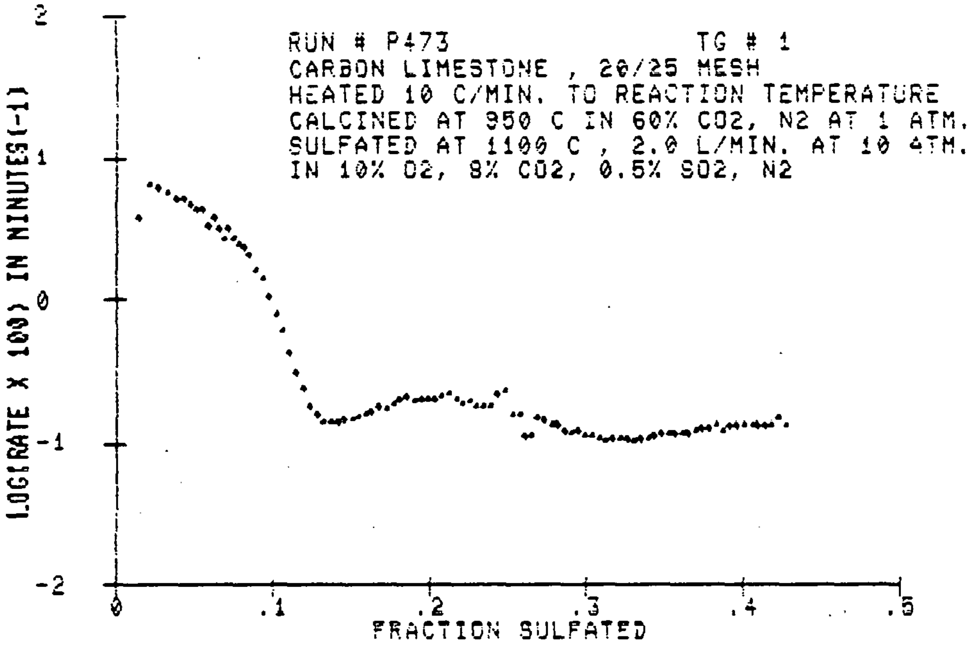
PRETREATED SORBENTS IN SO_2



RUN # P473 TG # 1
CARBON LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2



RUN # P473 TG # 1
CARBON LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RUN # P473 TG # 1
CARBON LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
FRACTION SULFATED

RUN # P473 TEMPERATURE = (1101.25 +/- 0.01) C

FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.2206	66.20
0.0089	0.50	0.2243	68.50
0.0148	0.60	0.2287	71.20
0.0222	0.70	0.2332	73.10
0.0281	0.80	0.2383	76.00
0.0333	0.90	0.2420	78.30
0.0377	1.00	0.2465	81.10
0.0437	1.10	0.2561	83.60
0.0474	1.20	0.2568	84.00
0.0526	1.30	0.2598	89.50
0.0555	1.40	0.2642	92.30
0.0600	1.50	0.2687	95.10
0.0637	1.60	0.2731	98.60
0.0651	1.70	0.2776	101.50
0.0696	1.80	0.2820	104.80
0.0718	1.90	0.2865	108.40
0.0740	2.00	0.2909	112.10
0.0770	2.10	0.2946	115.70
0.0799	2.20	0.2990	119.20
0.0836	2.40	0.3035	122.60
0.0896	2.70	0.3079	127.40
0.0925	2.90	0.3124	131.40
0.0970	3.30	0.3168	135.60
0.1014	3.70	0.3212	139.75
0.1058	4.30	0.3257	144.40
0.1103	5.20	0.3309	148.35
0.1150	6.40	0.3346	152.65
0.1192	8.00	0.3390	157.15
0.1236	10.10	0.3435	161.35
0.1281	12.70	0.3479	164.65
0.1325	16.00	0.3523	169.00
0.1369	19.50	0.3568	172.75
0.1414	22.90	0.3612	176.65
0.1458	25.60	0.3657	180.25
0.1495	28.60	0.3694	183.40
0.1540	31.50	0.3738	187.65
0.1584	34.60	0.3782	190.65
0.1628	36.90	0.3827	193.95
0.1673	39.90	0.3879	198.15
0.1717	42.40	0.3916	200.85
0.1762	44.80	0.3960	205.05
0.1806	47.20	0.4019	208.65
0.1850	49.30	0.4049	211.35
0.1902	51.70	0.4101	214.65
0.1947	53.70	0.4138	218.25
0.1984	56.20	0.4182	221.25
0.2028	58.20	0.4227	224.85
0.2073	60.10	0.4271	227.05
0.2117	62.20	0.4323	230.85
0.2161	64.50	0.4360	234.45

```
RUN # P473


RATE                FRACTION            RATE                FRACTION
0.03516             0.0148              0.00189             0.2203
0.06107             0.0215              0.00198             0.2246
0.05736             0.0272              0.00181             0.2290
0.05367             0.0330              0.00181             0.2333
0.04811             0.0380              0.00179             0.2378
0.04811             0.0429              0.00219             0.2432
0.04442             0.0474              0.00231             0.2480
0.04071             0.0516              0.00159             0.2523
0.04071             0.0558              0.00159             0.2567
0.03146             0.0594              0.00109             0.2611
0.03516             0.0628              0.00112             0.2645
0.02961             0.0660              0.00148             0.2687
0.02591             0.0688              0.00142             0.2731
0.02961             0.0715              0.00134             0.2776
0.02591             0.0745              0.00132             0.2820
0.02369             0.0773              0.00120             0.2863
0.02221             0.0808              0.00118             0.2906
0.01943             0.0845              0.00120             0.2949
0.01548             0.0885              0.00111             0.2992
0.01366             0.0928              0.00113             0.3035
0.01018             0.0973              0.00108             0.3079
0.00772             0.1014              0.00104             0.3124
0.00597             0.1060              0.00104             0.3168
0.00413             0.1104              0.00107             0.3214
0.00306             0.1149              0.00104             0.3258
0.00237             0.1193              0.00102             0.3303
0.00177             0.1238              0.00105             0.3347
0.00154             0.1281              0.00107             0.3392
0.00139             0.1325              0.00109             0.3435
0.00138             0.1369              0.00114             0.3479
0.00135             0.1412              0.00116             0.3523
0.00142             0.1455              0.00114             0.3568
0.00146             0.1498              0.00118             0.3611
0.00151             0.1541              0.00114             0.3654
0.00157             0.1584              0.00122             0.3697
0.00163             0.1628              0.00124             0.3739
0.00174             0.1673              0.00125             0.3784
0.00172             0.1717              0.00135             0.3828
0.00189             0.1762              0.00123             0.3873
0.00199             0.1808              0.00131             0.3920
0.00208             0.1853              0.00129             0.3964
0.00197             0.1898              0.00134             0.4009
0.00200             0.1942              0.00135             0.4053
0.00203             0.1987              0.00129             0.4098
0.00200             0.2030              0.00132             0.4139
0.00214             0.2073              0.00132             0.4184
0.00222             0.2117              0.00147             0.4228
0.00203             0.2160              0.00135             0.4272
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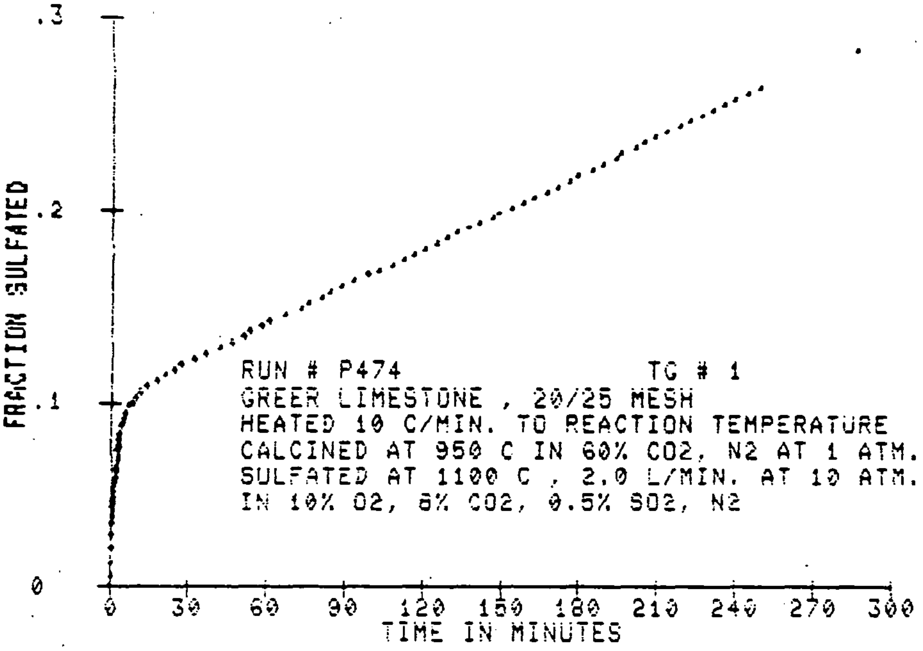
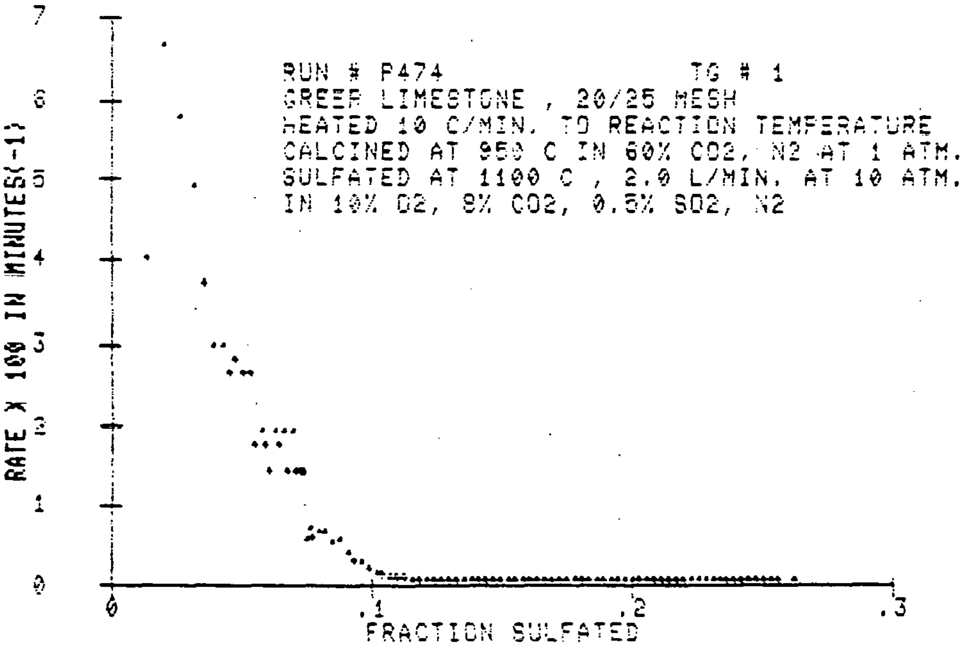
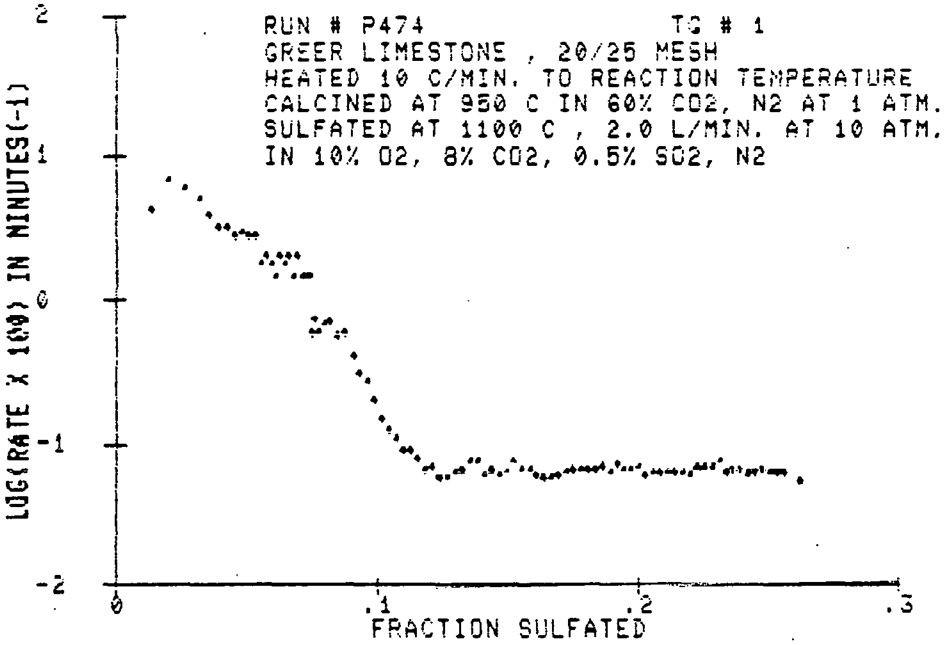

.3
.2
.1
0
FRACTION SULFATED
0
30
60
90
120
150
180
210
240
270
300
TIME IN MINUTES
RUN # P474 TG # 1
GREER LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


7
6
5
4
3
2
1
0
RATE X 100 IN MINUTES(-1)
0
.1
.2
.3
FRACTION SULFATED
RUN # P474 TG # 1
GREER LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RUN # P474
TG # 1
GREER LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
FRACTION SULFATED

RUN # P474 TEMPERATURE = (1100.90 +/- 0.01) C

FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.1353	53.90
0.0063	0.40	0.1381	58.00
0.0133	0.50	0.1409	61.20
0.0210	0.60	0.1444	66.70
0.0280	0.70	0.1472	73.20
0.0329	0.80	0.1500	76.00
0.0364	0.90	0.1528	80.70
0.0407	1.00	0.1556	84.00
0.0428	1.10	0.1584	88.30
0.0449	1.20	0.1612	92.90
0.0484	1.30	0.1647	98.45
0.0512	1.40	0.1668	102.80
0.0540	1.50	0.1696	107.90
0.0554	1.60	0.1724	111.95
0.0589	1.70	0.1752	116.00
0.0582	1.80	0.1780	120.20
0.0617	1.90	0.1808	124.85
0.0624	2.00	0.1836	128.60
0.0645	2.10	0.1864	132.95
0.0659	2.20	0.1893	137.15
0.0687	2.30	0.1921	141.35
0.0701	2.40	0.1949	146.15
0.0701	2.50	0.1977	148.55
0.0736	2.60	0.2005	153.80
0.0743	2.70	0.2033	158.00
0.0757	2.80	0.2061	162.05
0.0757	2.90	0.2089	167.15
0.0764	3.10	0.2117	171.35
0.0792	3.40	0.2145	175.70
0.0820	3.90	0.2173	179.45
0.0862	4.50	0.2201	185.15
0.0876	4.80	0.2229	188.90
0.0904	5.50	0.2257	194.00
0.0932	5.90	0.2285	195.80
0.0974	7.30	0.2313	201.50
0.0988	8.60	0.2341	205.10
0.1016	9.70	0.2369	208.70
0.1044	11.70	0.2397	212.50
0.1072	14.20	0.2425	216.60
0.1100	17.80	0.2453	222.35
0.1136	20.80	0.2481	226.85
0.1157	24.50	0.2509	231.50
0.1185	27.00	0.2537	235.70
0.1213	32.30	0.2565	239.75
0.1241	36.50	0.2593	244.70
0.1276	41.80	0.2621	249.20
0.1297	45.60	0.2818	266.70
0.1325	51.20		

```
RUN # P474

RATE          FRACTION      RATE          FRACTION
0.04006       0.0137        0.00077       0.1353
0.06658       0.0203        0.00077       0.1382
0.05783       0.0264        0.00062       0.1412
0.04906       0.0318        0.00066       0.1441
0.03680       0.0362        0.00061       0.1471
0.02979       0.0395        0.00065       0.1500
0.02979       0.0426        0.00074       0.1528
0.02629       0.0456        0.00066       0.1555
0.02804       0.0482        0.00067       0.1586
0.02628       0.0507        0.00060       0.1614
0.02629       0.0536        0.00057       0.1642
0.01752       0.0555        0.00059       0.1670
0.01928       0.0576        0.00060       0.1698
0.01752       0.0593        0.00064       0.1724
0.01402       0.0611        0.00066       0.1752
0.01928       0.0625        0.00067       0.1780
0.01752       0.0646        0.00066       0.1808
0.01928       0.0663        0.00066       0.1836
0.01402       0.0678        0.00068       0.1864
0.01927       0.0697        0.00064       0.1893
0.01402       0.0714        0.00072       0.1921
0.01402       0.0728        0.00067       0.1949
0.01402       0.0739        0.00067       0.1977
0.00561       0.0751        0.00071       0.2005
0.00701       0.0763        0.00060       0.2033
0.00574       0.0778        0.00064       0.2061
0.00657       0.0799        0.00063       0.2089
0.00660       0.0823        0.00064       0.2117
0.00534       0.0851        0.00062       0.2145
0.00561       0.0879        0.00064       0.2173
0.00401       0.0910        0.00061       0.2201
0.00295       0.0925        0.00069       0.2229
0.00267       0.0963        0.00069       0.2257
0.00193       0.0991        0.00069       0.2285
0.00142       0.1019        0.00076       0.2313
0.00122       0.1044        0.00063       0.2341
0.00107       0.1074        0.00066       0.2369
0.00088       0.1102        0.00065       0.2397
0.00088       0.1130        0.00062       0.2425
0.00077       0.1158        0.00062       0.2453
0.00067       0.1186        0.00066       0.2481
0.00069       0.1214        0.00064       0.2509
0.00057       0.1242        0.00063       0.2537
0.00059       0.1270        0.00063       0.2565
0.00064       0.1298        0.00055       0.2627
0.00065       0.1326
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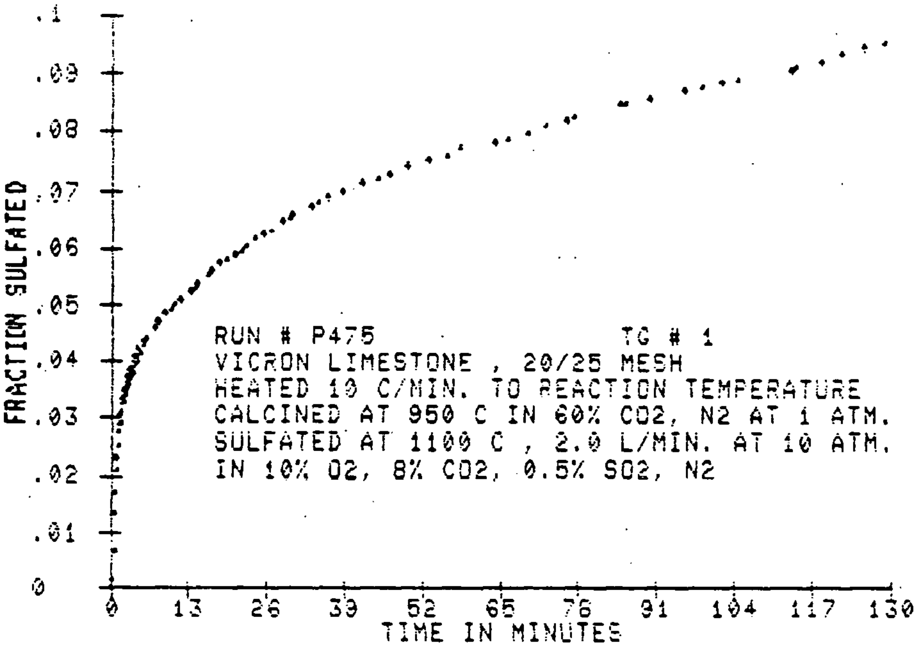
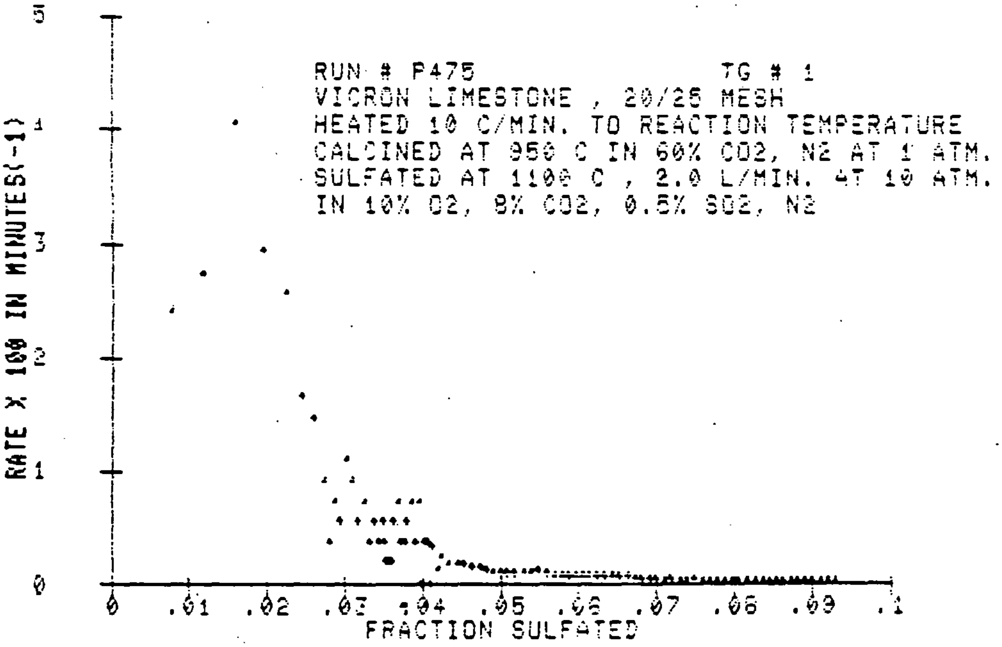
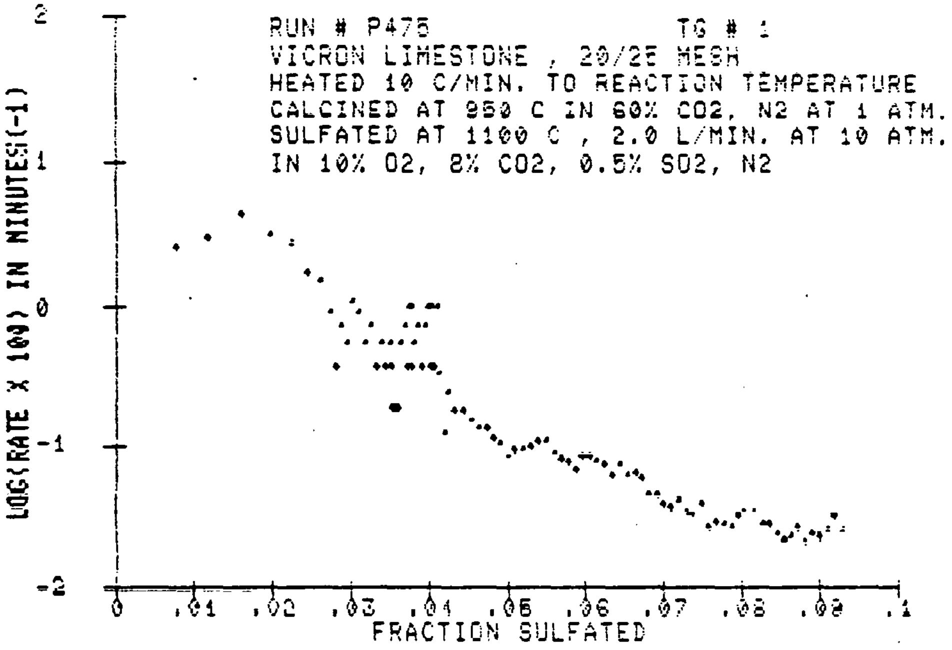

FRACTION SULFATED
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
0
13
26
39
52
65
78
91
104
117
130
TIME IN MINUTES
RUN # P475 TG # 1
VICRON LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2


RATE X 100 IN MINUTES(-1)
5
4
3
2
1
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED
RUN # P475 TG # 1
VICRON LIMESTONE , 20/25 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

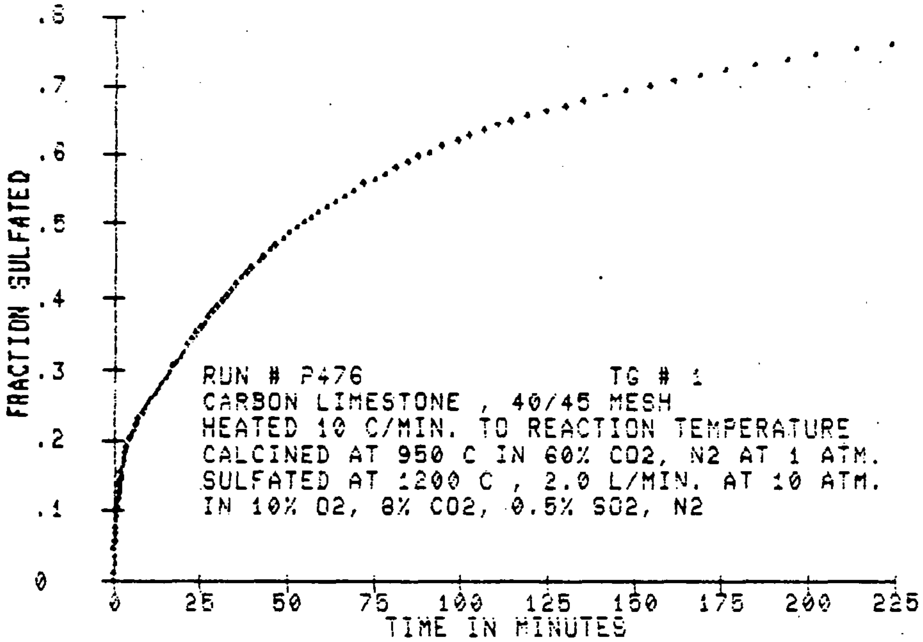
RUN # P475 TG # 1
VICRON LIMESTONE , 20/28 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1100 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED

RUN # P475 TEMPERATURE = (1103.29 +/- 0.10) C

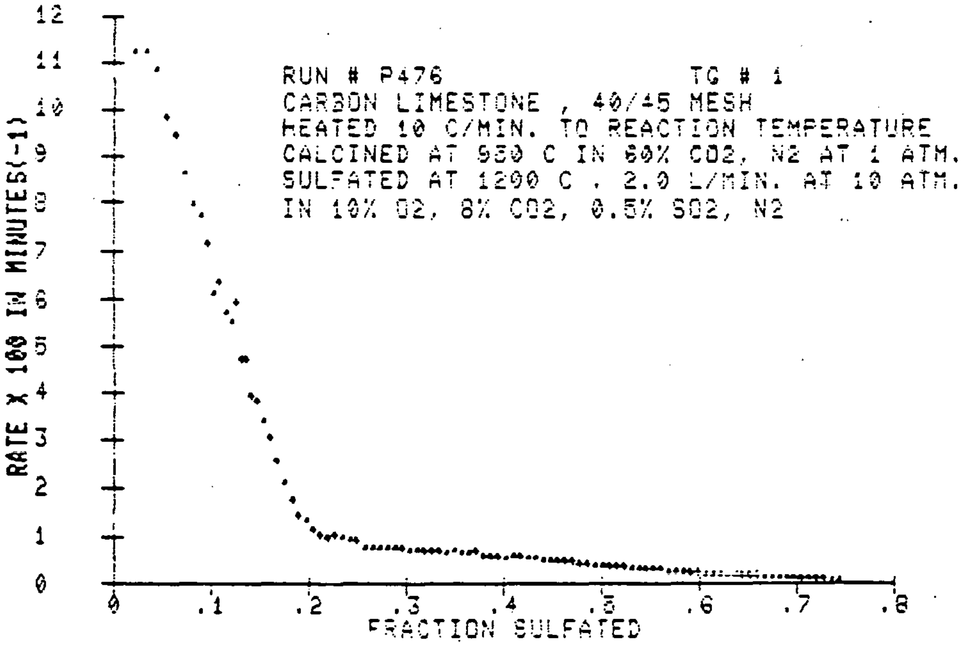
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.0484	9.00
0.0015	0.10	0.0492	10.00
0.0066	0.50	0.0499	10.40
0.0132	0.60	0.0506	11.60
0.0169	0.70	0.0521	13.40
0.0206	0.80	0.0528	14.00
0.0228	0.90	0.0536	14.30
0.0250	1.00	0.0550	16.20
0.0272	1.10	0.0558	16.90
0.0272	1.20	0.0572	18.10
0.0286	1.30	0.0580	19.40
0.0286	1.40	0.0587	20.90
0.0286	1.50	0.0595	21.80
0.0301	1.60	0.0602	22.60
0.0308	1.70	0.0617	23.90
0.0330	1.80	0.0624	25.40
0.0323	1.90	0.0631	26.60
0.0323	2.00	0.0646	28.80
0.0338	2.10	0.0653	30.00
0.0345	2.20	0.0661	30.40
0.0338	2.30	0.0675	33.70
0.0345	2.40	0.0683	34.60
0.0352	2.50	0.0690	36.30
0.0367	2.60	0.0697	38.70
0.0352	2.70	0.0712	41.90
0.0352	2.80	0.0719	44.40
0.0360	2.90	0.0727	46.60
0.0374	3.00	0.0741	49.70
0.0374	3.10	0.0749	53.00
0.0382	3.20	0.0756	56.00
0.0374	3.30	0.0771	58.30
0.0367	3.40	0.0778	64.10
0.0389	3.50	0.0785	66.10
0.0374	3.60	0.0793	69.50
0.0396	3.70	0.0807	72.40
0.0396	3.80	0.0815	76.30
0.0404	3.90	0.0822	77.30
0.0404	4.00	0.0844	84.80
0.0396	4.10	0.0844	85.90
0.0411	4.20	0.0851	90.00
0.0396	4.30	0.0866	95.80
0.0418	4.40	0.0873	98.60
0.0411	4.50	0.0881	102.00
0.0411	4.70	0.0888	104.50
0.0426	5.20	0.0903	113.70
0.0433	5.60	0.0910	114.20
0.0440	5.70	0.0917	118.50
0.0455	7.20	0.0932	122.00
0.0470	7.70	0.0939	125.80
0.0470	8.00	0.0947	128.80

RUN # P475

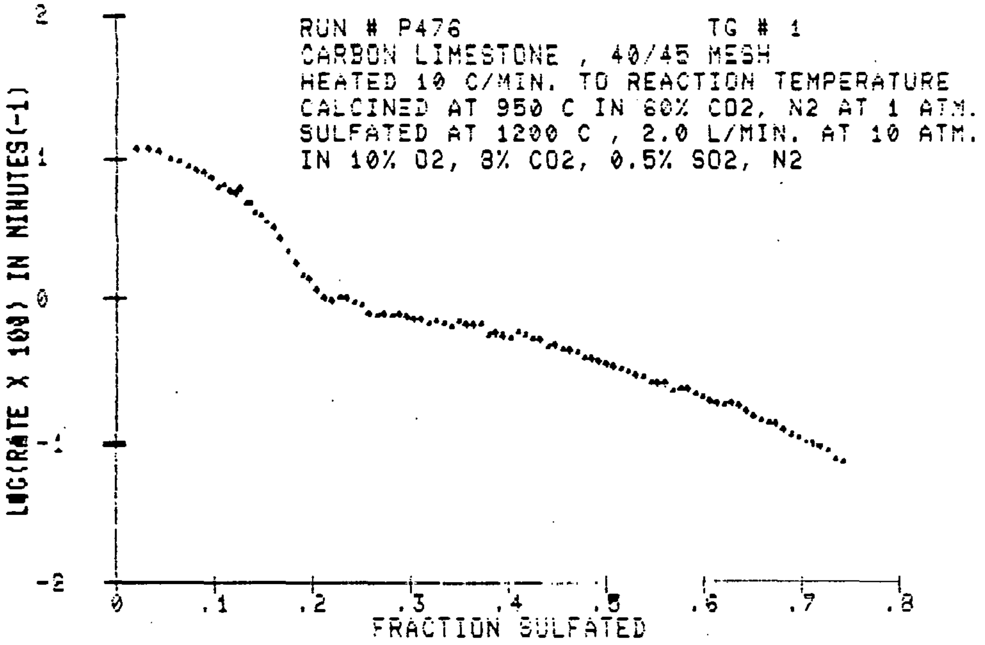
RATE	FRACTION	RATE	FRACTION
0.02412	0.0076	0.00109	0.0483
0.02726	0.0117	0.00102	0.0490
0.04037	0.0160	0.00083	0.0501
0.02936	0.0197	0.00092	0.0509
0.02569	0.0225	0.00094	0.0518
0.01651	0.0245	0.00096	0.0528
0.01468	0.0261	0.00105	0.0539
0.00917	0.0273	0.00107	0.0549
0.00367	0.0280	0.00086	0.0559
0.00734	0.0286	0.00078	0.0570
0.00550	0.0294	0.00075	0.0578
0.01101	0.0302	0.00065	0.0587
0.00917	0.0310	0.00082	0.0596
0.00551	0.0317	0.00082	0.0605
0.00734	0.0324	0.00076	0.0614
0.00367	0.0332	0.00071	0.0624
0.00367	0.0333	0.00060	0.0634
0.00550	0.0338	0.00072	0.0643
0.00367	0.0343	0.00062	0.0653
0.00550	0.0349	0.00063	0.0663
0.00367	0.0351	0.00058	0.0672
0.00184	0.0354	0.00044	0.0681
0.00183	0.0357	0.00045	0.0691
0.00184	0.0361	0.00037	0.0700
0.00550	0.0363	0.00036	0.0709
0.00734	0.0366	0.00040	0.0719
0.00367	0.0373	0.00033	0.0730
-.00183	0.0374	0.00032	0.0738
0.00367	0.0377	0.00038	0.0749
-.00183	0.0377	0.00025	0.0759
0.00550	0.0380	0.00028	0.0768
0.00734	0.0385	0.00027	0.0777
0.00367	0.0392	0.00026	0.0787
0.00734	0.0395	0.00030	0.0796
0.00000	0.0399	0.00033	0.0804
0.00367	0.0402	0.00034	0.0816
-.00184	0.0402	0.00037	0.0826
0.00367	0.0405	0.00027	0.0835
0.00367	0.0407	0.00024	0.0846
0.00000	0.0410	0.00021	0.0856
0.00326	0.0412	0.00023	0.0863
0.00122	0.0420	0.00025	0.0872
0.00245	0.0424	0.00021	0.0882
0.00176	0.0433	0.00024	0.0891
0.00176	0.0445	0.00022	0.0900
0.00153	0.0454	0.00025	0.0910
0.00133	0.0464	0.00030	0.0920
0.00131	0.0474	0.00025	0.0929



FRACTION SULFATED
.8
.7
.6
.5
.4
.3
.2
.1
0
0
25
50
75
100
125
150
175
200
225
TIME IN MINUTES
RUN # P476 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2



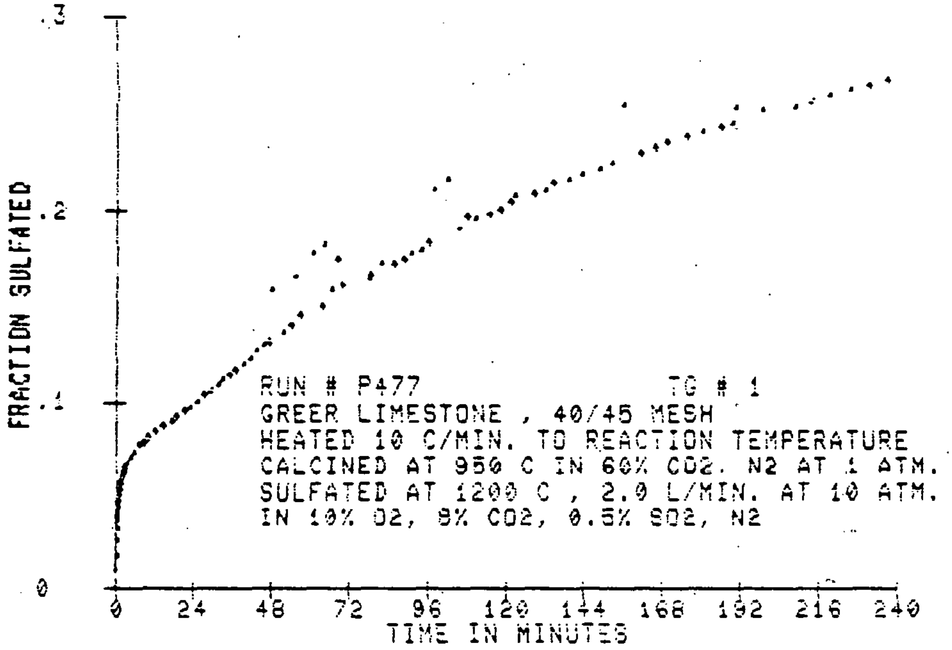
RATE X 100 IN MINUTES(-1)
12
11
10
9
8
7
6
5
4
3
2
1
0
0
.1
.2
.3
.4
.5
.6
.7
.8
FRACTION SULFATED
RUN # P476 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2

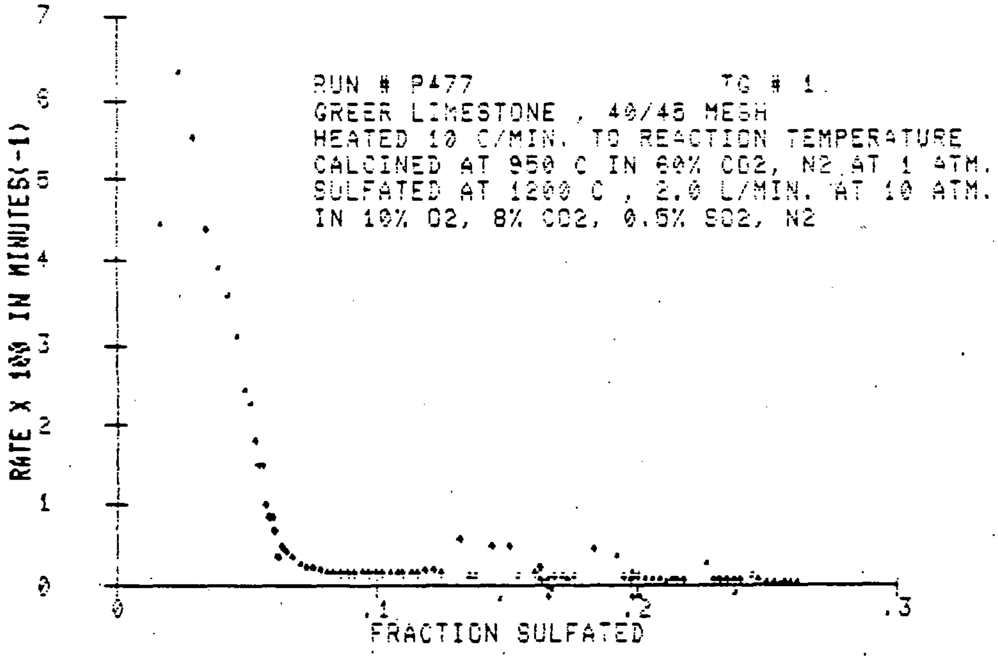

RUN # P476 TG # 1
CARBON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
FRACTION SULFATED

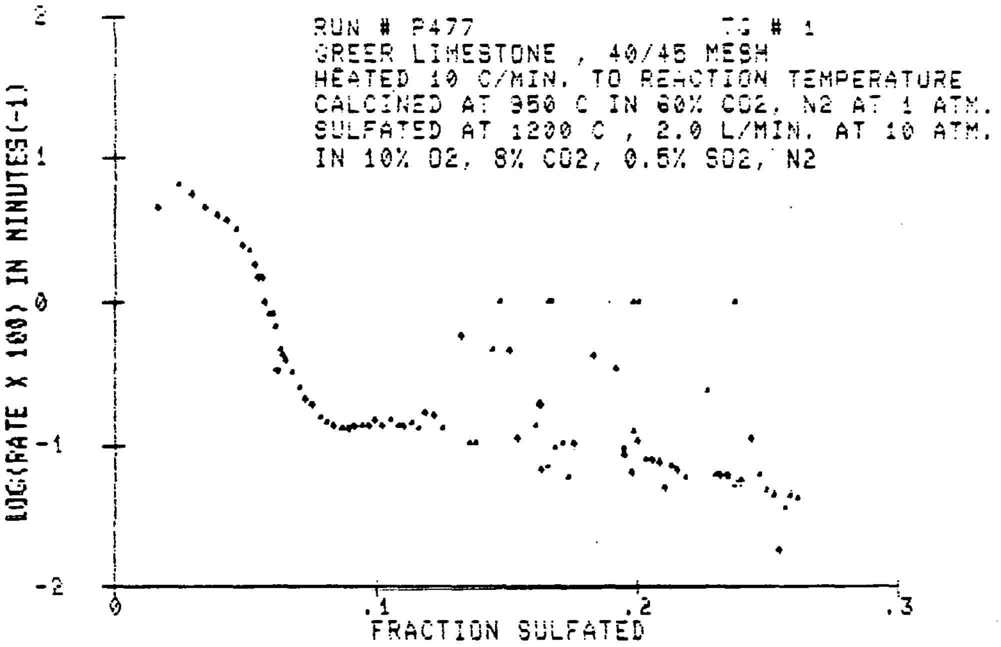
```
RUN # P476        TEMPERATURE = (1199.90 +/-  0.02 ) C

FRACTION          TIME           FRACTION          TIME
0.0000            0.00            0.3865           29.50
0.0106            0.10            0.3947           31.20
0.0228            0.20            0.4020           32.50
0.0343            0.30            0.4094           33.80
0.0449            0.40            0.4167           35.20
0.0555            0.50            0.4257           36.60
0.0661            0.60            0.4322           38.00
0.0734            0.70            0.4395           39.50
0.0824            0.80            0.4485           41.40
0.0897            0.90            0.4550           43.00
0.0979            1.00            0.4640           44.70
0.1044            1.10            0.4697           46.30
0.1109            1.20            0.4787           48.40
0.1142            1.30            0.4852           50.10
0.1231            1.40            0.4926           52.10
0.1272            1.50            0.5007           54.40
0.1329            1.60            0.5080           56.50
0.1378            1.70            0.5154           58.70
0.1419            1.80            0.5235           61.30
0.1460            1.90            0.5309           63.60
0.1525            2.10            0.5382           66.10
0.1607            2.30            0.5456           68.90
0.1688            2.60            0.5545           72.00
0.1761            2.90            0.5611           74.90
0.1827            3.30            0.5684           77.80
0.1900            3.70            0.5774           81.30
0.1998            4.40            0.5839           84.70
0.2055            5.00            0.5912           87.40
0.2128            5.60            0.5986           90.60
0.2202            6.40            0.6067           94.50
0.2275            7.20            0.6141           98.90
0.2340            8.10            0.6214          102.60
0.2430            8.60            0.6296          106.70
0.2504            9.50            0.6369          110.50
0.2577           10.50            0.6442          114.60
0.2667           11.70            0.6516          118.90
0.2732           12.60            0.6597          124.60
0.2805           13.60            0.6671          130.00
0.2897           14.60            0.6744          135.20
0.2960           15.70            0.6826          141.40
0.3043           16.70            0.6907          147.40
0.3107           17.80            0.6972          154.35
0.3189           18.90            0.7046          161.25
0.3262           20.00            0.7127          168.45
0.3343           21.30            0.7201          175.95
0.3417           22.40            0.7274          184.20
0.3490           23.50            0.7356          193.65
0.3572           25.00            0.7429          201.90
0.3637           25.60            0.7502          213.75
0.3719           27.10            0.7576          224.10
0.3792           28.20
```

RUN # P476

RATE	FRACTION	RATE	FRACTION
0.11212	0.0225	0.00559	0.3869
0.11214	0.0336	0.00539	0.3944
0.10805	0.0447	0.00529	0.4019
0.09785	0.0548	0.00574	0.4097
0.09379	0.0644	0.00549	0.4172
0.08562	0.0734	0.00529	0.4247
0.07952	0.0819	0.00513	0.4325
0.07747	0.0895	0.00459	0.4402
0.07135	0.0970	0.00475	0.4479
0.06117	0.1034	0.00444	0.4554
0.06320	0.1101	0.00431	0.4632
0.05709	0.1160	0.00425	0.4705
0.05504	0.1217	0.00386	0.4780
0.05912	0.1271	0.00383	0.4854
0.04689	0.1326	0.00362	0.4930
0.04689	0.1372	0.00351	0.5004
0.03914	0.1422	0.00337	0.5080
0.03806	0.1478	0.00328	0.5157
0.03364	0.1540	0.00314	0.5232
0.03017	0.1608	0.00296	0.5307
0.02515	0.1682	0.00290	0.5385
0.02097	0.1757	0.00267	0.5460
0.01722	0.1835	0.00258	0.5535
0.01398	0.1908	0.00256	0.5614
0.01312	0.1982	0.00231	0.5690
0.01118	0.2057	0.00241	0.5764
0.00990	0.2132	0.00236	0.5839
0.00947	0.2202	0.00222	0.5916
0.01006	0.2277	0.00212	0.5989
0.00973	0.2352	0.00199	0.6064
0.00914	0.2427	0.00192	0.6141
0.00883	0.2505	0.00189	0.6217
0.00754	0.2582	0.00192	0.6292
0.00736	0.2557	0.00185	0.6367
0.00756	0.2734	0.00169	0.6444
0.00734	0.2810	0.00155	0.6519
0.00756	0.2885	0.00146	0.6594
0.00718	0.2960	0.00138	0.6671
0.00702	0.3037	0.00136	0.6749
0.00702	0.3112	0.00124	0.6824
0.00656	0.3189	0.00116	0.6899
0.00674	0.3264	0.00112	0.6976
0.00656	0.3340	0.00103	0.7051
0.00620	0.3417	0.00101	0.7124
0.00683	0.3492	0.00096	0.7201
0.00642	0.3567	0.00090	0.7277
0.00642	0.3642	0.00080	0.7352
0.00653	0.3717	0.00076	0.7427
0.00553	0.3792		


RUN # P477 TG # 1
GREER LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2. N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.3
.2
.1
0
0
24
48
72
96
120
144
168
192
216
240
TIME IN MINUTES

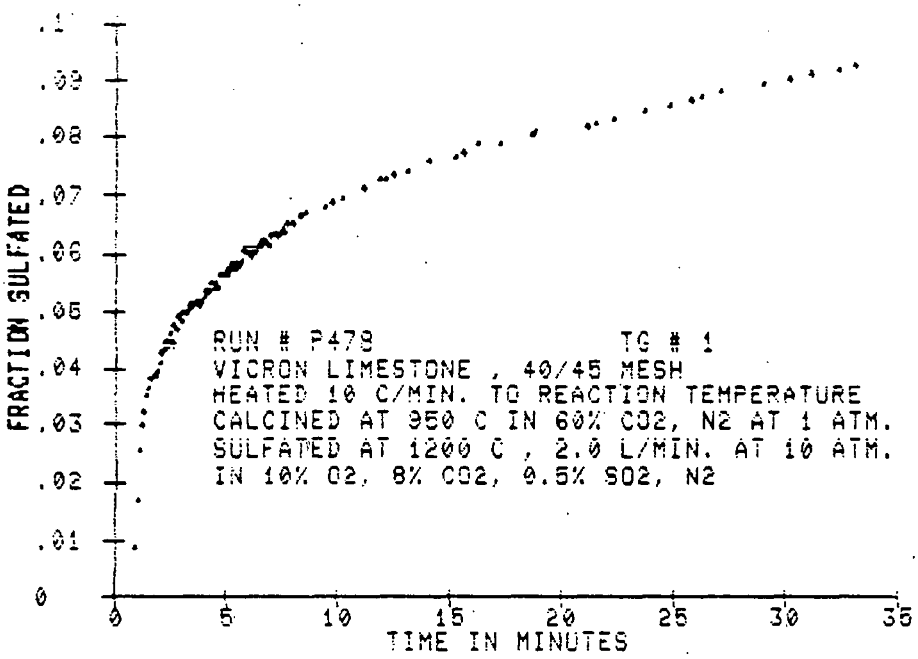

RUN # P477 TG # 1
GREER LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
7
6
5
4
3
2
1
0
0
.1
.2
.3
FRACTION SULFATED

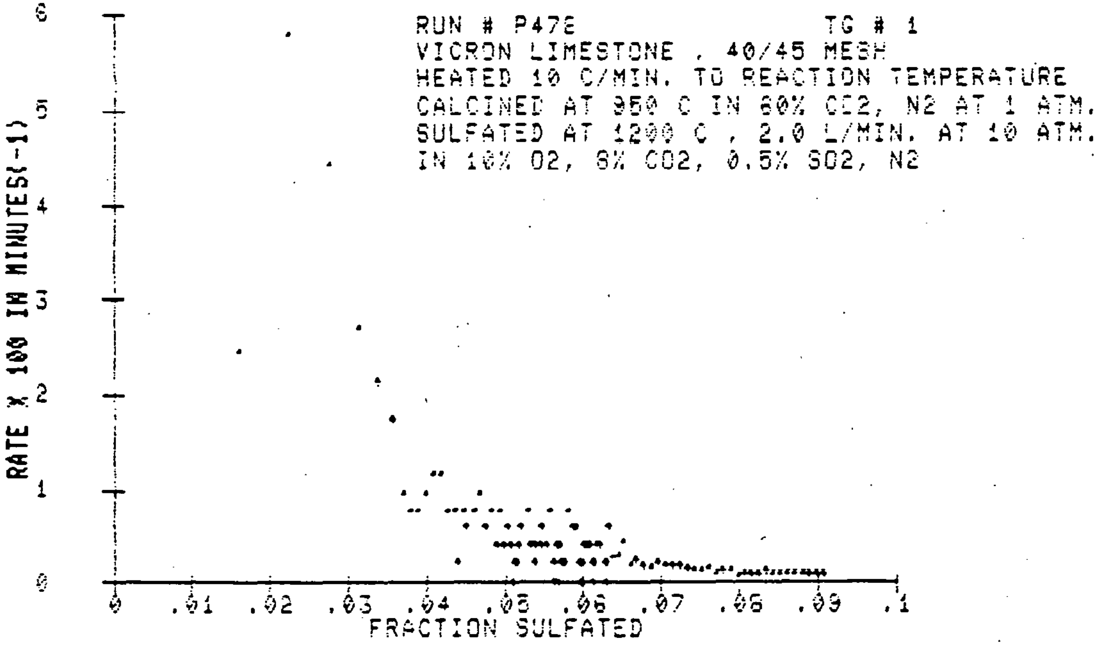

RUN # P477
TG # 1
GREER LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
FRACTION SULFATED

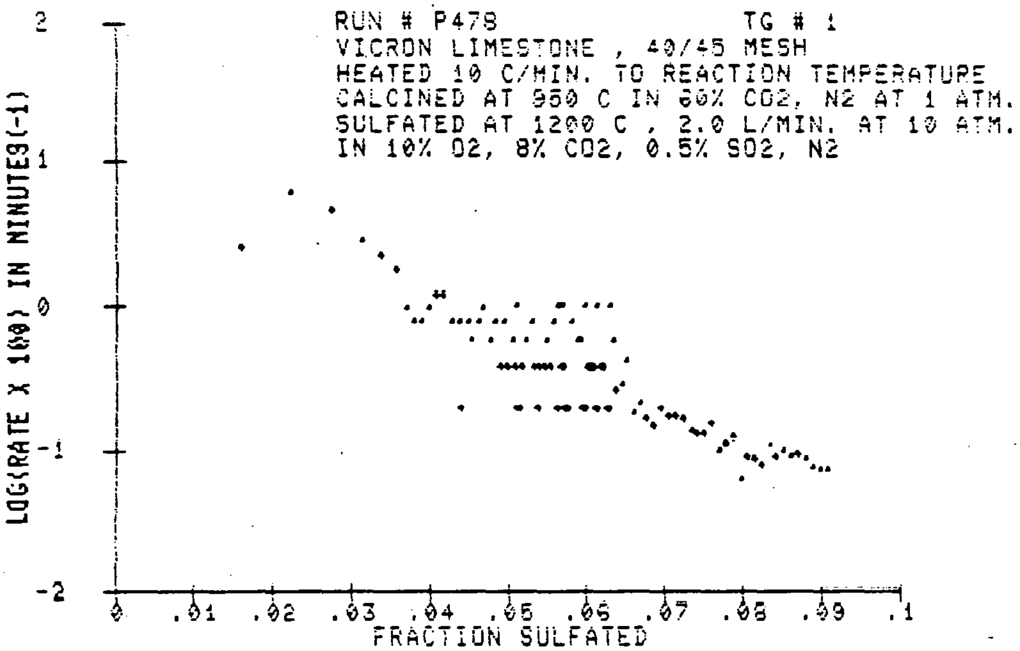
```
RUN # P477       TEMPERATURE = (1199.95 +/-  0.00 ) C

FRACTION        TIME          FRACTION        TIME
0.0000          0.00           0.1347         51.40
0.0104          0.40           0.1379         54.40
0.0175          0.50           0.1638         55.00
0.0259          0.60           0.1438         56.90
0.0311          0.70           0.1768         60.80
0.0356          0.80           0.1483         63.80
0.0395          0.90           0.1807         64.10
0.0434          1.00           0.1567         66.70
0.0466          1.10           0.1729         68.40
0.0499          1.20           0.1593         69.80
0.0518          1.30           0.1625         77.80
0.0531          1.40           0.1645         78.60
0.0557          1.50           0.1710         81.80
0.0570          1.60           0.1703         85.60
0.0576          1.70           0.1729         88.80
0.0589          1.80           0.1768         90.60
0.0596          1.90           0.1781         94.00
0.0602          2.00           0.1813         96.60
0.0609          2.10           0.2105         97.80
0.0622          2.20           0.2156        102.10
0.0622          2.30           0.1891        105.90
0.0628          2.40           0.1956        108.20
0.0632          2.50           0.1949        110.90
0.0635          2.60           0.1969        115.10
0.0654          3.00           0.1994        118.20
0.0673          3.50           0.2040        121.70
0.0706          4.70           0.2072        122.60
0.0732          5.70           0.2079        128.90
0.0764          7.50           0.2105        132.20
0.0784          9.00           0.2137        134.70
0.0809         10.40           0.2156        139.30
0.0835         12.60           0.2182        143.50
0.0868         14.90           0.2215        148.90
0.0894         17.50           0.2240        152.30
0.0920         19.00           0.2551        156.30
0.0945         21.40           0.2292        161.50
0.0971         22.90           0.2318        166.10
0.0997         25.30           0.2344        169.90
0.1030         27.50           0.2376        175.10
0.1055         29.20           0.2409        180.90
0.1081         31.40           0.2423        186.50
0.1107         32.90           0.2454        189.70
0.1133         35.20           0.2538        190.70
0.1159         37.20           0.2519        198.90
0.1191         39.30           0.2538        208.70
0.1217         41.60           0.2564        213.70
0.1263         43.20           0.2590        219.30
0.1289         45.50           0.2616        225.50
0.1295         47.50           0.2642        231.70
0.1574         48.00           0.2668        237.30
```

RUN # P477

RATE	FRACTION	RATE	FRACTION
0.04440	0.0170	0.00458	0.1447
0.06314	0.0241	-.00153	0.1475
0.05504	0.0299	0.00448	0.1514
0.04271	0.0351	0.00110	0.1541
0.03885	0.0392	0.00185	0.1627
0.03561	0.0430	0.00132	0.1612
0.03076	0.0462	-.00051	0.1671
0.02428	0.0490	0.00183	0.1636
0.02267	0.0514	-.00132	0.1664
0.01781	0.0535	0.00065	0.1632
0.01457	0.0550	-.00014	0.1660
0.01457	0.0565	0.00070	0.1655
0.00971	0.0570	0.00094	0.1682
0.00809	0.0587	0.00103	0.1711
0.00809	0.0594	0.00058	0.1738
0.00809	0.0604	0.00100	0.1759
0.00645	0.0610	0.00417	0.1839
0.00647	0.0616	0.00338	0.1924
0.00324	0.0620	0.00093	0.1949
0.00324	0.0626	0.00123	0.1964
0.00463	0.0632	-.00119	0.2011
0.00412	0.0642	-.00144	0.1984
0.00383	0.0658	0.00084	0.1952
0.00313	0.0680	0.00062	0.1961
0.00245	0.0706	0.00105	0.2005
0.00200	0.0732	0.00080	0.2031
0.00182	0.0759	0.00079	0.2058
0.00150	0.0785	0.00075	0.2086
0.00140	0.0812	0.00050	0.2110
0.00130	0.0838	0.00071	0.2132
0.00128	0.0865	0.00066	0.2159
0.00125	0.0892	0.00059	0.2186
0.00120	0.0920	0.00232	0.2269
0.00133	0.0945	0.00061	0.2296
0.00130	0.0973	0.00060	0.2323
0.00141	0.1000	0.00059	0.2349
0.00130	0.1027	-.00088	0.2376
0.00145	0.1054	0.00060	0.2348
0.00135	0.1081	0.00054	0.2375
0.00130	0.1107	0.00056	0.2402
0.00139	0.1134	0.00111	0.2441
0.00127	0.1162	0.00061	0.2470
0.00162	0.1193	0.00050	0.2496
0.00151	0.1224	0.00040	0.2520
0.00126	0.1251	0.00018	0.2550
0.00156	0.1327	0.00037	0.2566
0.00103	0.1353	0.00045	0.2590
0.00102	0.1377	0.00044	0.2616


RUN # P478 TG # 1
VICRON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
FRACTION SULFATED
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
TIME IN MINUTES
0
5
10
15
20
25
30
35


RUN # P478 TG # 1
VICRON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
RATE X 100 IN MINUTES(-1)
6
5
4
3
2
1
0
FRACTION SULFATED
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1


RUN # P478
TG # 1
VICRON LIMESTONE , 40/45 MESH
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 950 C IN 60% CO2, N2 AT 1 ATM.
SULFATED AT 1200 C , 2.0 L/MIN. AT 10 ATM.
IN 10% O2, 8% CO2, 0.5% SO2, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
FRACTION SULFATED

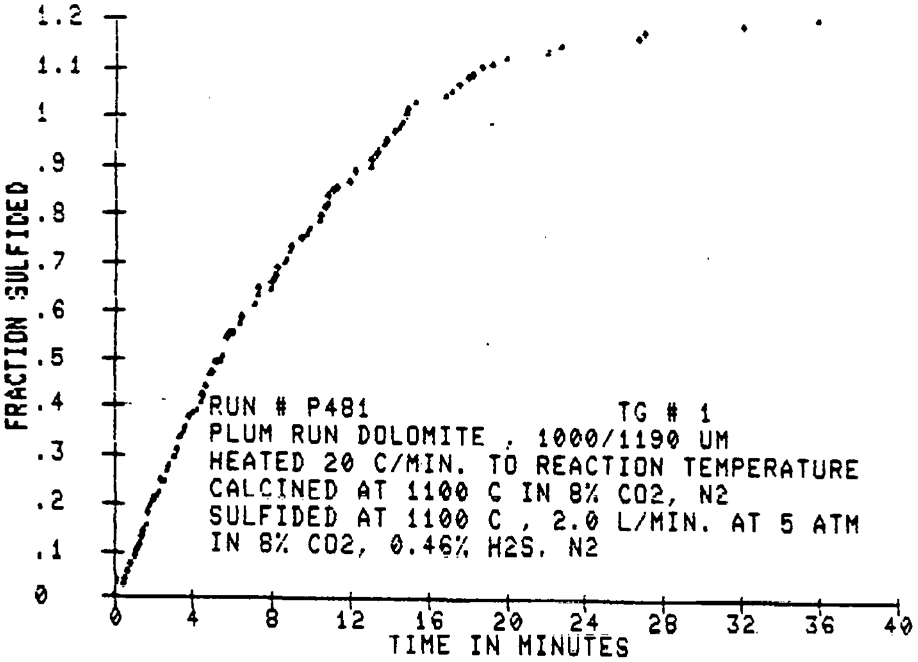
```
RUN # P478        TEMPERATURE = (1198.97 +/-  0.09 ) C

FRACTION          TIME               FRACTION          TIME
0.0000             0.00               0.0600            5.90
0.0085             0.90               0.0600            6.00
0.0169             1.00               0.0592            6.10
0.0254             1.10               0.0600            6.20
0.0292             1.20               0.0600            6.30
0.0315             1.30               0.0607            6.40
0.0346             1.40               0.0607            6.50
0.0361             1.50               0.0615            6.60
0.0377             1.60               0.0615            6.70
0.0384             1.70               0.0615            6.80
0.0384             1.80               0.0607            6.90
0.0392             1.90               0.0623            7.00
0.0408             2.00               0.0631            7.10
0.0423             2.10               0.0631            7.20
0.0431             2.20               0.0623            7.30
0.0438             2.30               0.0631            7.40
0.0438             2.40               0.0638            7.50
0.0454             2.50               0.0631            7.60
0.0438             2.60               0.0646            7.70
0.0469             2.70               0.0646            8.00
0.0461             2.80               0.0661            8.30
0.0484             2.90               0.0669            8.50
0.0477             3.00               0.0677            9.40
0.0492             3.10               0.0684            9.60
0.0492             3.20               0.0692           10.20
0.0500             3.30               0.0707           11.20
0.0507             3.40               0.0723           11.80
0.0507             3.50               0.0723           12.10
0.0515             3.60               0.0730           12.50
0.0515             3.70               0.0738           13.10
0.0507             3.80               0.0754           14.10
0.0515             3.90               0.0761           15.20
0.0523             4.00               0.0769           15.60
0.0531             4.10               0.0784           16.20
0.0531             4.20               0.0784           17.20
0.0546             4.30               0.0800           18.70
0.0538             4.40               0.0807           18.80
0.0546             4.50               0.0815           21.20
0.0538             4.60               0.0823           21.50
0.0561             4.70               0.0830           22.30
0.0561             4.80               0.0846           23.70
0.0561             4.90               0.0853           24.80
0.0569             5.00               0.0861           25.80
0.0561             5.10               0.0869           26.20
0.0569             5.20               0.0877           27.10
0.0577             5.30               0.0892           29.00
0.0569             5.40               0.0900           30.20
0.0577             5.50               0.0907           31.20
0.0577             5.60               0.0915           31.40
0.0584             5.70               0.0923           33.20
0.0600             5.80
```

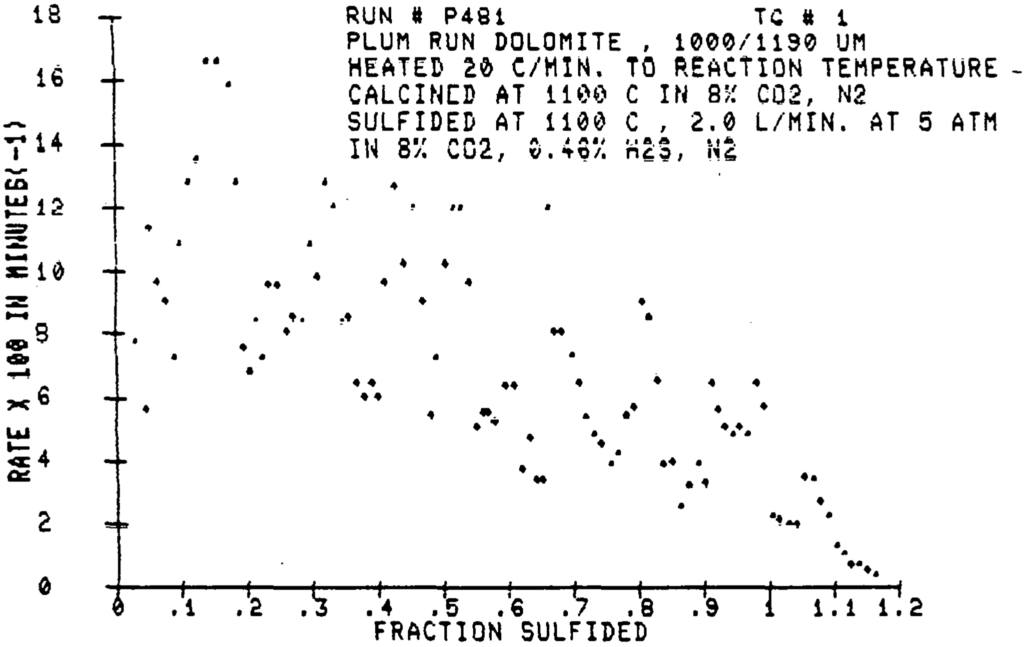
RUN # P478

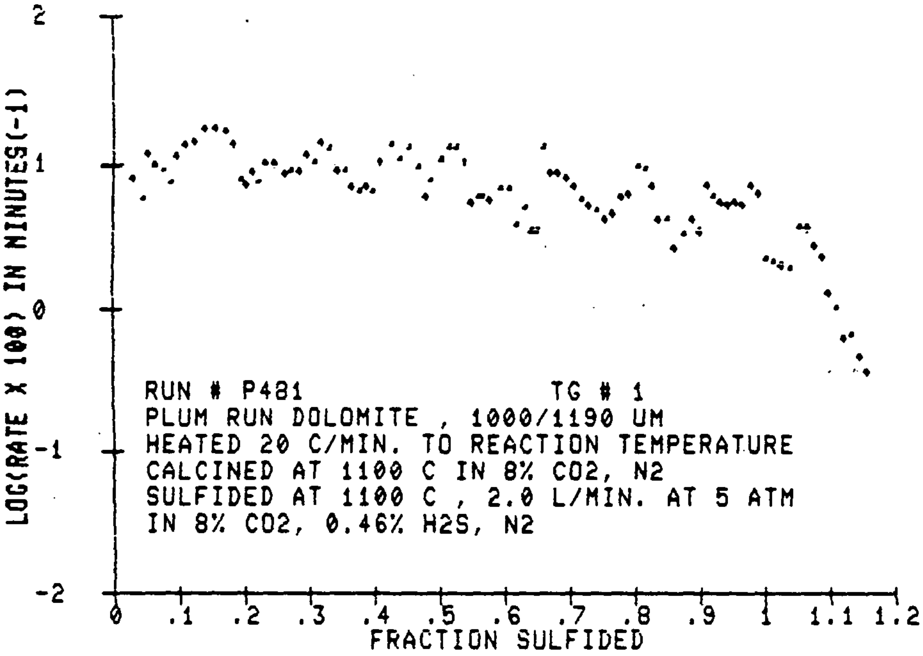
RATE	FRACTION	RATE	FRACTION
0.02435	0.0160	0.00192	0.0595
0.05766	0.0223	0.00000	0.0598
0.04422	0.0275	0.00000	0.0598
0.02691	0.0314	0.00192	0.0600
0.02115	0.0338	0.00384	0.0601
0.01730	0.0357	0.00384	0.0606
0.00961	0.0371	0.00384	0.0609
0.00769	0.0380	0.00192	0.0612
0.00769	0.0389	0.00000	0.0612
0.00961	0.0398	0.00192	0.0615
0.01153	0.0408	0.00384	0.0618
0.01153	0.0418	0.00384	0.0621
0.00769	0.0428	0.00384	0.0623
0.00769	0.0437	0.00192	0.0627
0.00192	0.0440	0.00192	0.0631
0.00769	0.0448	0.00000	0.0631
0.00577	0.0452	0.00577	0.0634
0.00769	0.0461	0.00256	0.0638
0.00961	0.0466	0.00200	0.064[illegible]
0.00577	0.0477	0.00427	0.0650
0.00769	0.0481	0.00181	0.0660
0.00384	0.0489	0.00214	0.0667
0.00769	0.0494	0.00162	0.0677
0.00384	0.0500	0.00142	0.0686
0.00577	0.0504	0.00192	0.0697
0.00384	0.0509	0.00167	0.0706
0.00000	0.0511	0.00167	0.0715
0.00192	0.0512	0.00162	0.0724
0.00192	0.0515	0.00124	0.0734
0.00384	0.0518	0.00124	0.0741
0.00577	0.0521	0.00124	0.0750
0.00769	0.0529	0.00149	0.0761
0.00384	0.0534	0.00099	0.0770
0.00384	0.0538	0.00110	0.0780
0.00192	0.0540	0.00120	0.0789
0.00384	0.0546	0.00062	0.0798
0.00577	0.0549	0.00089	0.0806
0.00384	0.0554	0.00085	0.0815
0.00769	0.0558	0.00078	0.0824
0.00000	0.0563	0.00107	0.0833
0.00192	0.0564	0.00089	0.0843
0.00384	0.0567	0.00099	0.0852
0.00000	0.0569	0.00090	0.0861
0.00384	0.0571	0.00092	0.0870
0.00192	0.0574	0.00087	0.0880
0.00192	0.0577	0.00077	0.0889
0.00769	0.0581	0.00073	0.0898
0.00577	0.0587	0.00073	0.0907
0.00577	0.0592		

APPENDIX B4

UNTREATED SORBENTS IN H_2S


RUN # P481 TG # 1
PLUM RUN DOLOMITE , 1000/1190 UM
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFIDED AT 1100 C , 2.0 L/MIN. AT 5 ATM
IN 8% CO2, 0.46% H2S, N2
FRACTION SULFIDED
1.2
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
4
8
12
16
20
24
28
32
36
40
TIME IN MINUTES


RUN # P481 TG # 1
PLUM RUN DOLOMITE , 1000/1190 UM
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFIDED AT 1100 C , 2.0 L/MIN. AT 5 ATM
IN 8% CO2, 0.46% H2S, N2
RATE X 100 IN MINUTES(-1)
18
16
14
12
10
8
6
4
2
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
1.2
FRACTION SULFIDED

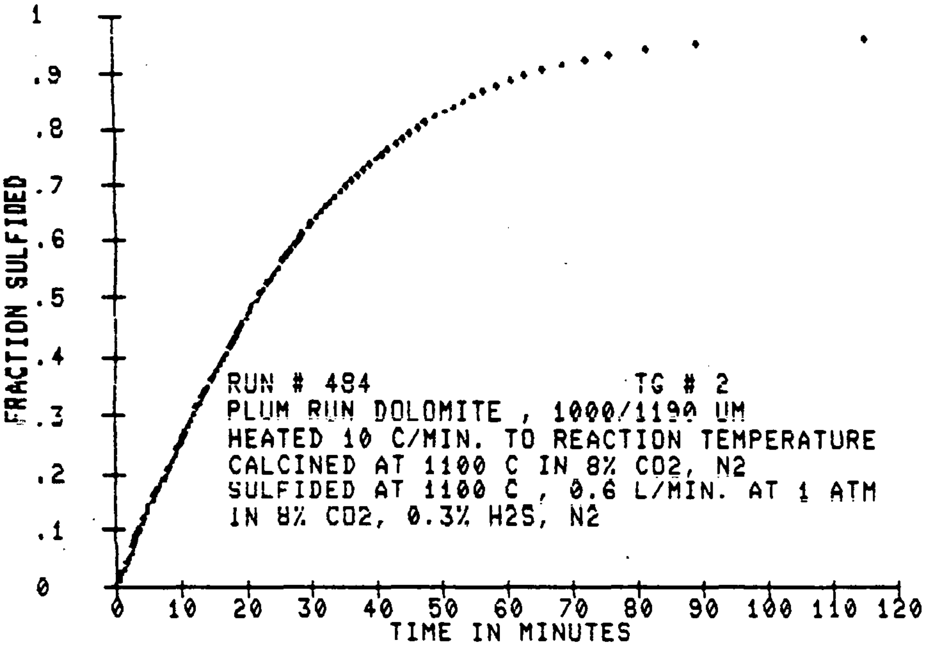

2
1
0
-1
-2
LOG(RATE X 100) IN MINUTES(-1)
RUN # P481
TG # 1
PLUM RUN DOLOMITE , 1000/1190 UM
HEATED 20 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFIDED AT 1100 C , 2.0 L/MIN. AT 5 ATM
IN 8% CO2, 0.46% H2S, N2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1.1
1.2
FRACTION SULFIDED

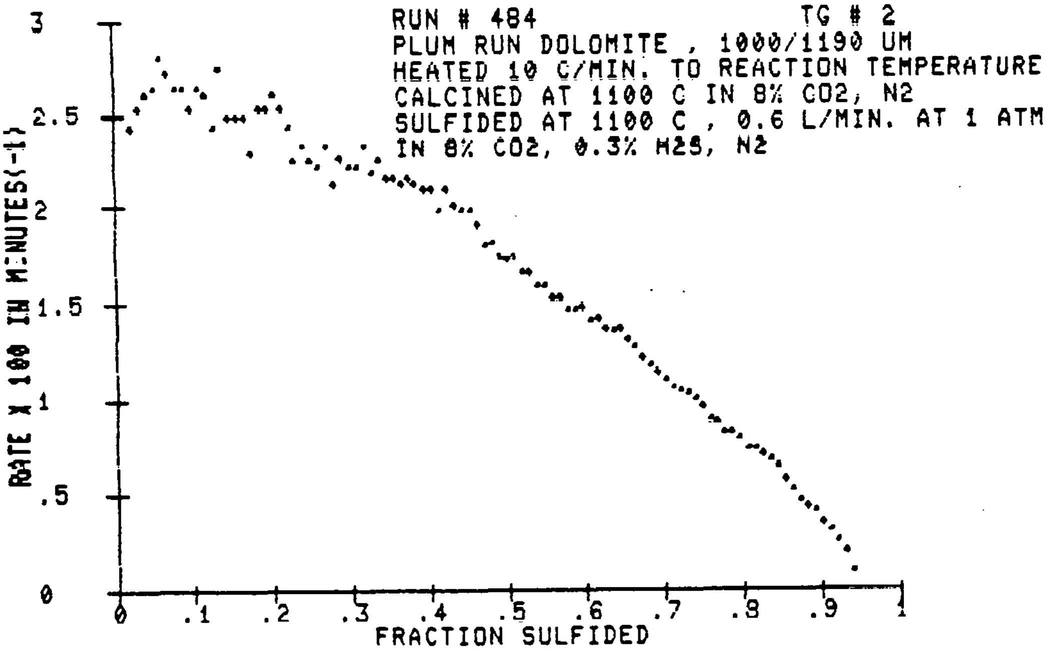
RUN # P481 TEMPERATURE = (1101.73 +/- 0.02) C

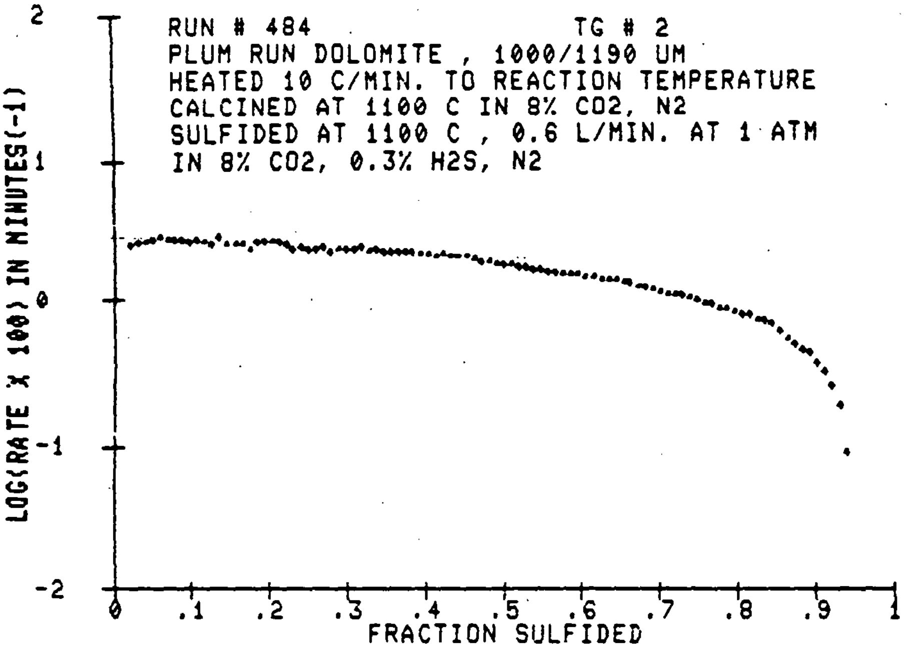
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.6111	7.10
0.0361	0.10	0.6292	7.20
0.0271	0.50	0.6412	7.30
0.0391	0.60	0.6382	7.90
0.0542	0.70	0.6533	8.00
0.0753	0.80	0.6593	8.10
0.0723	0.90	0.6713	8.20
0.0873	1.10	0.6864	8.30
0.0993	1.20	0.7014	8.60
0.1114	1.30	0.7075	8.70
0.1264	1.40	0.7225	8.90
0.1385	1.50	0.7316	9.00
0.1535	1.60	0.7496	9.50
0.1776	1.70	0.7556	9.70
0.1927	1.80	0.7677	9.90
0.2017	1.90	0.7857	10.40
0.2047	2.00	0.7918	10.50
0.2077	2.10	0.8098	10.70
0.2198	2.20	0.8189	10.80
0.2439	2.40	0.8309	10.90
0.2408	2.50	0.8429	11.10
0.2649	2.70	0.8490	11.30
0.2770	2.80	0.8610	11.90
0.2920	3.00	0.8821	12.20
0.2920	3.10	0.8911	13.00
0.3071	3.20	0.9062	13.10
0.3312	3.30	0.9152	13.30
0.3312	3.40	0.9212	13.40
0.3432	3.50	0.9363	13.70
0.3552	3.60	0.9453	13.80
0.3733	3.80	0.9603	14.20
0.3823	4.00	0.9694	14.40
0.3884	4.20	0.9814	14.60
0.4034	4.40	0.9935	14.80
0.4185	4.50	1.0055	14.90
0.4185	4.60	1.0206	15.30
0.4365	4.70	1.0296	16.80
0.4666	4.90	1.0416	17.10
0.4696	5.00	1.0567	17.50
0.4907	5.20	1.0717	18.00
0.4907	5.30	1.0778	18.20
0.4937	5.40	1.0958	18.70
0.5058	5.50	1.1018	19.20
0.5419	5.70	1.1139	19.90
0.5509	5.80	1.1259	22.00
0.5539	5.90	1.1380	22.70
0.5539	6.00	1.1500	26.70
0.5720	6.30	1.1621	27.00
0.5840	6.40	1.1741	32.10
0.5870	6.50	1.1861	35.80

RUN # P481

RATE	FRACTION	RATE	FRACTION
0.07741	0.0313	0.06356	0.6105
0.05591	0.0464	0.03656	0.6214
0.11289	0.0536	0.04683	0.6346
0.09634	0.0656	0.03345	0.6442
0.09031	0.0777	0.03345	0.6527
0.07225	0.0891	0.12043	0.6617
0.10838	0.0993	0.08028	0.6744
0.12796	0.1126	0.08028	0.6852
0.13546	0.1258	0.07311	0.6978
0.16557	0.1415	0.06451	0.7099
0.16559	0.1578	0.05352	0.7225
0.15804	0.1728	0.04817	0.7334
0.12796	0.1860	0.04516	0.7454
0.07526	0.1969	0.03871	0.7580
0.06773	0.2053	0.04215	0.7701
0.08429	0.2156	0.05419	0.7821
0.07225	0.2234	0.05687	0.7948
0.09534	0.2354	0.09031	0.8074
0.09534	0.2493	0.08529	0.8189
0.08028	0.2637	0.06523	0.8303
0.08529	0.2734	0.03831	0.8405
0.08429	0.2866	0.03937	0.8532
0.10838	0.2998	0.02535	0.8652
0.09784	0.3107	0.03178	0.8779
0.12796	0.3209	0.03871	0.8911
0.12041	0.3336	0.03261	0.9031
0.08429	0.3468	0.06451	0.9140
0.08530	0.3570	0.05591	0.9248
0.06451	0.3685	0.05017	0.9357
0.06021	0.3805	0.04817	0.9465
0.06451	0.3932	0.05017	0.9585
0.06021	0.4022	0.04817	0.9700
0.09634	0.4130	0.06451	0.9820
0.12644	0.4287	0.05687	0.9941
0.10236	0.4419	0.02190	1.0061
0.12043	0.4564	0.02094	1.0182
0.09032	0.4708	0.01968	1.0308
0.05419	0.4823	0.01895	1.0440
0.07225	0.4901	0.03441	1.0555
0.10236	0.5046	0.03387	1.0687
0.12042	0.5166	0.02656	1.0808
0.12042	0.5292	0.02218	1.0922
0.09634	0.5413	0.01268	1.1031
0.05018	0.5545	0.01054	1.1151
0.05519	0.5630	0.00642	1.1259
0.05519	0.5702	0.00678	1.1380
0.05200	0.5816	0.00477	1.1500
0.06355	0.5967	0.00368	1.1621


1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
FRACTION SULFIDED
0
10
20
30
40
50
60
70
80
90
100
110
120
TIME IN MINUTES
RUN # 484 TG # 2
PLUM RUN DOLOMITE , 1000/1190 UM
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFIDED AT 1100 C , 0.6 L/MIN. AT 1 ATM
IN 8% CO2, 0.3% H2S, N2


3
2.5
2
1.5
1
.5
0
RATE X 100 IN MINUTES(-1)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
FRACTION SULFIDED
RUN # 484 TG # 2
PLUM RUN DOLOMITE , 1000/1190 UM
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFIDED AT 1100 C , 0.6 L/MIN. AT 1 ATM
IN 8% CO2, 0.3% H2S, N2

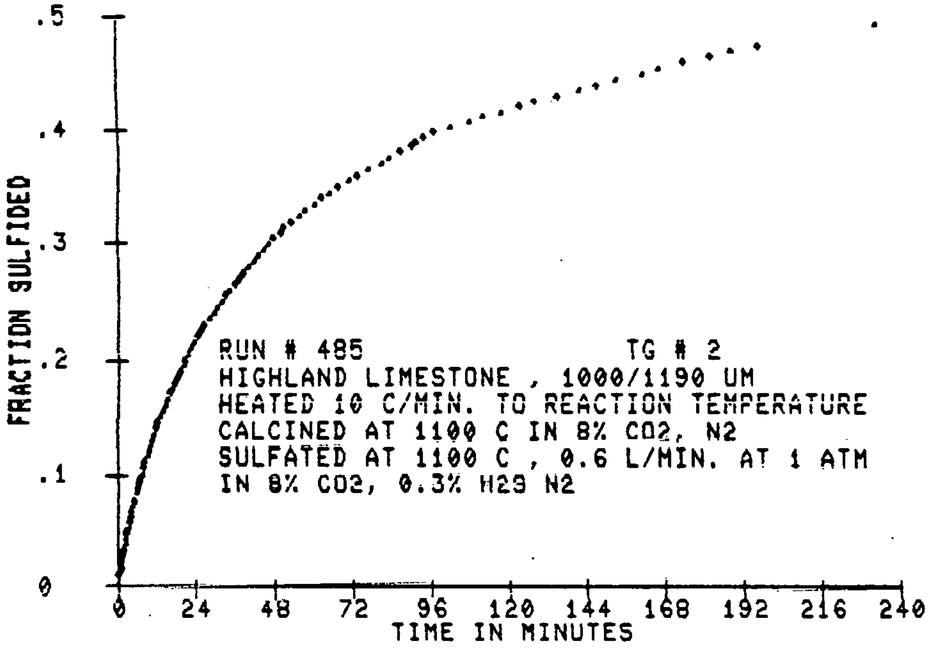

RUN # 484
TG # 2
PLUM RUN DOLOMITE , 1000/1190 UM
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFIDED AT 1100 C , 0.6 L/MIN. AT 1 ATM
IN 8% CO2, 0.3% H2S, N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
FRACTION SULFIDED

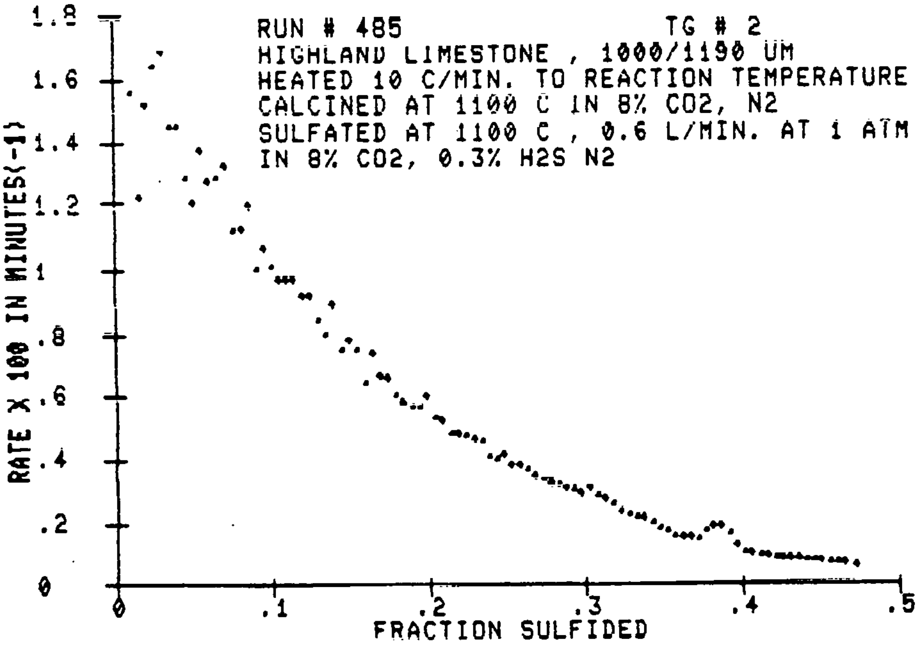
RUN # 484 TEMPERATURE = (1104.04 +/- 0.08) C

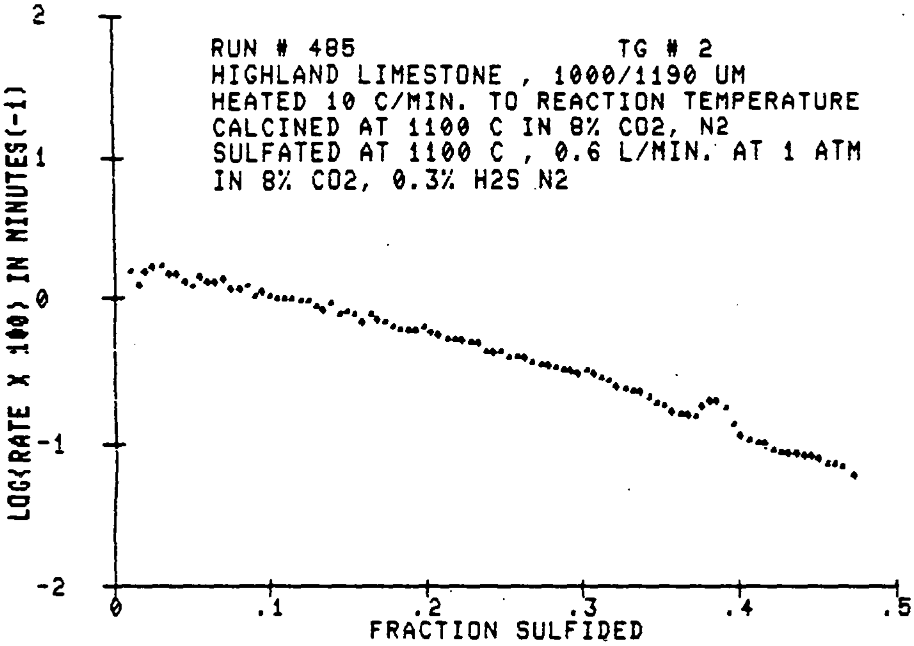
FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.4918	21.60
0.0111	0.50	0.5013	22.10
0.0221	0.90	0.5092	22.60
0.0300	1.20	0.5203	23.20
0.0411	1.70	0.5282	23.70
0.0490	2.00	0.5377	24.30
0.0585	2.30	0.5472	24.90
0.0696	2.70	0.5583	25.60
0.0775	3.00	0.5678	26.20
0.0870	3.40	0.5772	26.90
0.0981	3.80	0.5867	27.50
0.1091	4.20	0.5962	28.20
0.1155	4.50	0.6057	28.80
0.1265	4.90	0.6168	29.60
0.1344	5.20	0.6247	30.20
0.1455	5.70	0.6358	31.00
0.1566	6.00	0.6437	31.60
0.1661	6.50	0.6532	32.30
0.1740	6.80	0.6626	33.00
0.1850	7.30	0.6721	33.80
0.1929	7.60	0.6816	34.60
0.2040	8.00	0.6927	35.60
0.2119	8.30	0.7022	36.40
0.2214	8.70	0.7117	37.30
0.2309	9.10	0.7212	38.20
0.2404	9.50	0.7307	39.20
0.2499	10.00	0.7417	40.20
0.2609	10.40	0.7496	41.00
0.2689	10.80	0.7591	42.00
0.2799	11.30	0.7686	43.20
0.2894	11.70	0.7781	44.30
0.2989	12.20	0.7876	45.40
0.3116	12.70	0.7971	46.70
0.3195	13.10	0.8066	47.90
0.3390	13.50	0.8161	49.20
0.3384	13.90	0.8271	50.90
0.3463	14.30	0.8366	52.20
0.3574	14.80	0.8461	53.70
0.3653	15.20	0.8572	55.40
0.3748	15.60	0.8651	56.90
0.3843	16.10	0.8746	59.00
0.3938	16.50	0.8841	61.20
0.4033	17.00	0.8935	63.40
0.4144	17.50	0.9030	66.00
0.4238	18.00	0.9141	69.00
0.4333	18.50	0.9220	72.60
0.4428	18.90	0.9315	76.20
0.4523	19.40	0.9410	81.90
0.4634	20.00	0.9505	89.70
0.4729	20.50	0.9600	115.60
0.4808	20.90		

RUN # 484

RATE	FRACTION	RATE	FRACTION
0.02419	0.0209	0.01732	0.4912
0.02530	0.0307	0.01719	0.5007
0.02598	0.0402	0.01732	0.5102
0.02636	0.0497	0.01653	0.5194
0.02798	0.0591	0.01650	0.5285
0.02711	0.0683	0.01581	0.5383
0.02636	0.0781	0.01582	0.5478
0.02636	0.0882	0.01521	0.5576
0.02530	0.0974	0.01521	0.5674
0.02636	0.1072	0.01460	0.5772
0.02598	0.1167	0.01460	0.5867
0.02425	0.1262	0.01464	0.5965
0.02741	0.1357	0.01406	0.6060
0.02471	0.1458	0.01412	0.6158
0.02471	0.1553	0.01356	0.6253
0.02471	0.1654	0.01347	0.6348
0.02273	0.1749	0.01356	0.6440
0.02530	0.1844	0.01299	0.6535
0.02530	0.1936	0.01265	0.6626
0.02598	0.2031	0.01198	0.6725
0.02530	0.2122	0.01163	0.6823
0.02425	0.2217	0.01130	0.6921
0.02233	0.2309	0.01098	0.7019
0.02326	0.2407	0.01054	0.7117
0.02233	0.2502	0.01040	0.7215
0.02197	0.2600	0.01026	0.7310
0.02326	0.2698	0.00999	0.7405
0.02109	0.2796	0.00949	0.7499
0.02247	0.2897	0.00887	0.7594
0.02196	0.2999	0.00863	0.7686
0.02197	0.3097	0.00808	0.7781
0.02326	0.3195	0.00808	0.7876
0.02175	0.3290	0.00775	0.7971
0.02233	0.3381	0.00719	0.8069
0.02140	0.3473	0.00719	0.8167
0.02140	0.3565	0.00682	0.8265
0.02109	0.3656	0.00663	0.8366
0.02140	0.3751	0.00633	0.8464
0.02109	0.3843	0.00558	0.8559
0.02081	0.3941	0.00506	0.8654
0.02081	0.4039	0.00455	0.8749
0.01977	0.4137	0.00417	0.8841
0.02081	0.4235	0.00395	0.8939
0.01998	0.4333	0.00333	0.9034
0.01977	0.4431	0.00297	0.9128
0.01977	0.4529	0.00239	0.9223
0.01898	0.4624	0.00176	0.9318
0.01797	0.4722	0.00088	0.9410
0.01807	0.4820		


RUN # 485 TG # 2
HIGHLAND LIMESTONE , 1000/1190 UM
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFATED AT 1100 C , 0.6 L/MIN. AT 1 ATM
IN 8% CO2, 0.3% H2S N2
FRACTION SULFIDED
.5
.4
.3
.2
.1
0
TIME IN MINUTES
0
24
48
72
96
120
144
168
192
216
240


RUN # 485 TG # 2
HIGHLAND LIMESTONE , 1000/1190 UM
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFATED AT 1100 C , 0.6 L/MIN. AT 1 ATM
IN 8% CO2, 0.3% H2S N2
RATE X 100 IN MINUTES(-1)
1.8
1.6
1.4
1.2
1
.8
.6
.4
.2
0
FRACTION SULFIDED
0
.1
.2
.3
.4
.5


RUN # 485 TG # 2
HIGHLAND LIMESTONE , 1000/1190 UM
HEATED 10 C/MIN. TO REACTION TEMPERATURE
CALCINED AT 1100 C IN 8% CO2, N2
SULFATED AT 1100 C , 0.6 L/MIN. AT 1 ATM
IN 8% CO2, 0.3% H2S N2
LOG(RATE X 100) IN MINUTES(-1)
2
1
0
-1
-2
0
.1
.2
.3
.4
.5
FRACTION SULFIDED

RUN # 485 TEMPERATURE = (1098.73 +/- 0.00) C

FRACTION	TIME	FRACTION	TIME
0.0000	0.00	0.2425	30.10
0.0085	0.20	0.2478	31.70
0.0117	0.70	0.2532	32.90
0.0149	1.00	0.2574	33.90
0.0202	1.30	0.2627	35.50
0.0255	1.60	0.2681	37.10
0.0298	1.90	0.2723	38.20
0.0362	2.30	0.2776	39.80
0.0404	2.50	0.2830	41.60
0.0457	3.00	0.2872	43.10
0.0500	3.30	0.2925	44.70
0.0553	3.80	0.2968	46.20
0.0596	4.10	0.3021	48.10
0.0649	4.40	0.3074	50.20
0.0702	4.90	0.3117	51.10
0.0745	5.30	0.3170	53.40
0.0819	5.80	0.3223	55.70
0.0862	6.30	0.3266	57.70
0.0904	6.70	0.3319	60.00
0.0947	7.00	0.3372	62.50
0.0989	7.50	0.3415	64.70
0.1042	8.00	0.3468	67.40
0.1096	8.60	0.3532	70.90
0.1149	9.10	0.3564	73.20
0.1191	9.60	0.3617	76.50
0.1245	10.10	0.3670	80.50
0.1287	10.70	0.3712	82.90
0.1340	11.20	0.3766	86.80
0.1393	12.00	0.3819	90.40
0.1436	12.50	0.3861	91.80
0.1500	13.10	0.3915	94.00
0.1542	13.90	0.3957	97.20
0.1596	14.60	0.4010	102.10
0.1638	15.20	0.4063	107.80
0.1691	16.10	0.4106	112.20
0.1734	16.50	0.4159	117.80
0.1787	17.50	0.4212	123.70
0.1840	18.30	0.4255	128.60
0.1883	19.30	0.4308	135.70
0.1936	20.00	0.4361	142.10
0.1979	20.90	0.4404	147.30
0.2032	21.70	0.4457	153.60
0.2085	22.70	0.4510	161.40
0.2127	23.60	0.4553	166.60
0.2181	24.80	0.4606	174.30
0.2234	25.90	0.4659	182.40
0.2276	26.70	0.4702	188.80
0.2340	28.10	0.4755	197.00
0.2383	29.20	0.4946	232.90

```
RUN # 485

RATE                FRACTION            RATE                FRACTION
0.01555             0.0111              0.00399             0.2432
0.01216             0.0162              0.00407             0.2478
0.01507             0.0204              0.00374             0.2527
0.01637             0.0253              0.00374             0.2578
0.01684             0.0304              0.00361             0.2627
0.01444             0.0355              0.00343             0.2676
0.01444             0.0404              0.00331             0.2727
0.01276             0.0455              0.00319             0.2776
0.01197             0.0502              0.00311             0.2825
0.01368             0.0551              0.00299             0.2874
0.01263             0.0600              0.00295             0.2923
0.01276             0.0649              0.00285             0.2972
0.01314             0.0702              0.00299             0.3021
0.01120             0.0755              0.00281             0.3070
0.01123             0.0806              0.00266             0.3121
0.01189             0.0855              0.00255             0.3170
0.01001             0.0904              0.00227             0.3219
0.01064             0.0949              0.00222             0.3270
0.01008             0.0996              0.00213             0.3319
0.00962             0.1045              0.00208             0.3368
0.00962             0.1094              0.00195             0.3421
0.00962             0.1145              0.00179             0.3470
0.00912             0.1194              0.00171             0.3519
0.00912             0.1242              0.00154             0.3570
0.00842             0.1291              0.00151             0.3619
0.00798             0.1340              0.00149             0.3666
0.00886             0.1391              0.00145             0.3717
0.00749             0.1442              0.00169             0.3766
0.00777             0.1493              0.00182             0.3815
0.00749             0.1542              0.00184             0.3863
0.00638             0.1593              0.00164             0.3912
0.00736             0.1640              0.00126             0.3961
0.00660             0.1689              0.00105             0.4010
0.00652             0.1738              0.00098             0.4059
0.00598             0.1787              0.00094             0.4110
0.00577             0.1836              0.00092             0.4159
0.00563             0.1885              0.00086             0.4208
0.00563             0.1934              0.00083             0.4259
0.00594             0.1983              0.00081             0.4308
0.00532             0.2032              0.00081             0.4357
0.00518             0.2081              0.00079             0.4408
0.00481             0.2132              0.00078             0.4457
0.00479             0.2181              0.00075             0.4506
0.00473             0.2232              0.00070             0.4557
0.00459             0.2283              0.00070             0.4606
0.00456             0.2332              0.00066             0.4655
0.00404             0.2381              0.00058             0.4734
```

APPENDIX C

SULFATION REACTION DIMENSIONAL ANALYSIS

CALCIUM-BASED SO_2 SORBENT PARTICLE REACTION MODELS
DIMENSIONAL ANALYSIS

SORBENT PARTICLE DESCRIPTION

The sorbent particle is pictured as an irregularly shaped particle made up of a continuous gas phase, or pores, and a dispersed solid phase. The solid phase may be described as consisting of sorbent material grains and inert material grains that are bound together with some binding material. The gas phase can be described by either a pore structure or as intersticies between packed grains.

The raw sorbent $CaCO_3$ or $CaCO_3 \cdot MgCO_3$ structure is transformed into a much more porous CaO, $CaCO_3 \cdot MgO$, or $CaO \cdot MgO$ stucture by calcination, if conditions, temperature, and CO_2 partial pressure, allow calcination. The pore size distribution and internal surface area of the calcine is controlled by the calcination conditions.

SO_2 and SO_3 diffuse into the sorbent particle through the continuous pore phase, is adsorbed on the sorbent material grain surfaces, and some active sulfur component diffuses (by solid diffusion) into the grains, reacting with the sorbent CaO by the overall reaction

$$CaO + SO_3 \rightarrow CaSO_4$$

$$\text{or} \quad CaO \cdot MgO + SO_3 \rightarrow CaSO_4 \cdot MgO$$

$$\text{or} \quad CaCO_3 \cdot MgO + SO_3 = CaSO_4 \cdot MgO + CO_2$$

CONTINUITY EQUATIONS AND ASSUMPTIONS

Gas Phase Continuity

Gas phase continuity is expressed by

$$\partial c/\partial t = \nabla \cdot \{D \nabla (c)\} - \nabla \cdot \{c \underline{v}\} \qquad (1)$$

where $\partial/\partial t$ is the partial dirivative with respect to time, ∇ is the delta operator, and c is the gas phase SO_2 concentration. The diffusion coefficient D, for diffusion of SO_2 in the pores, may be a function of the pore diameter when the pore size is reduced into the Knudsen diffusion region. The gas phase molar average velocity vector is $\underline{v}$, where

$$\nabla \cdot \underline{v} = 0 \qquad (2)$$

It is assumed that

1) There is no convective bulk flow in the pores (equimolar counterdiffusion), but because of the moving boundaries in the particle (due to chemical reaction changes in volume of the solid phases) there is an imposed velocity.

2) The SO_2 is very dilute so that multicomponent diffusion may be neglected.

3) No homogeneous reactions occur in the gas phase.

Solid Product Phase Continuity

Similarly, the conservation of the diffusing species in the solid phase is given by

$$\partial s/\partial t = D_s \nabla^2 s - \nabla \cdot \{s \underline{v}_s\} - k_r s C_r \qquad (3)$$

where s is the sulfur component concentration in the solid phase, D_s is the solid phase diffusion coefficient, and $\underline{v}_s$ is the molar average velocity of the solid product phase. C_r is the concentration of solid reactant (CaO) in the solid phase, where a homogeneous reaction is assumed to occur. Other assumptions applied are

1) SO_2 is adsorbed on the solid product surface, reacts to become the diffusing species, and diffuses through the product phase as it reacts, converting CaO to $CaSO_4$.

2) The reaction rate is assumed to be first-order in the concentration of each of the reactant concentrations, s and C_r, with rate constant k_r.

3) The adsorption reaction is at equilibrium with the continuous gas phase concentration; $s = k_a\ c$ at the gas-solid interface.

CaO and $CaSO_4$ Continuity

The solid reactant and product species are assumed to have no diffusive flux, but are convected by the solid phase chemical reaction density changes. The continuity equations are

$$\partial C_r/\partial t = - \bar{\nabla} \cdot \{C_r \underline{v}_s\} - k_r\ s\ C_r \qquad (4)$$

$$\partial C_p/\partial t = - \nabla \cdot \{C_p \underline{v}_s\} + k_r\ s\ C_r \qquad (5)$$

where C_r is the molar concentration of CaO and C_p is the $CaSO_4$ concentration.

The product concentration at any point in the solid is related to the reactant concentration by

$$C_p = (1 - C_r/m_r)\ m_p \qquad (6)$$

m_r is the pure reactant molar density and m_p is the pure product molar density:

CaO m_r = 1/16.76 moles/cm^3
$CaCO_3$ m_r = 1/36.93
CaO·MgO m_r = 1/28.01
$CaCO_3$·MgO m_r = 1/48.18
$CaCO_3 \cdot MgCO_3$ m_r = 1/64.34
$CaSO_4$ m_p = 1/45.94
$CaSO_4$·MgO m_p = 1/57.19

If a calcined limestone is sulfated then $m_r/m_p = 2.74$. If a half-calcined dolomite is sulfate then $m_r/m_p = 1.19$. Finally, if a fully-calcined dolomite is sulfated $m_r/m_p = 2.04$. The differences in expansion in limestones and dolomites are significant, and if the sulfate volume is compared to the raw carbonate volume it is seen that limestone molecular volumes increase about 24% on sulfation while dolomite decreases about 11%.

The sum of equations 4 and 5 results in the following when applying equation 6:

$$\nabla \cdot \underline{v}_s = [1 - m_p/m_r]\ k_r\ s\ C_r/m_p \tag{7}$$

Particle Pore and Grain Structure

The key particle structural factors, ε, ε_i, A_g, R_p, R_g, and R, the particle voidage, the inert material volume fraction, the grain surface area, the pore characteristic radius, the grain characteristic dimension, and the particle characteristic dimension, respectively, are all functions of time and position in the particle. We define the particle characteristic dimension to be the equivalent radius of the particle.

$$R = [V/(4/3\ \pi)]^{1/3} \tag{8}$$

and the external particle surface area to be

$$A = 1/\Phi\ 4\ \pi\ R^2 \tag{9}$$

where Φ is the particle sphericity. Similar definitions are made for the grain characteristic dimension, R_g, the grain surface area, A_g, and the grain sphericity, Φ_g:

$$R_g = [V_g/(4/3\ \pi)]^{1/3} \tag{10}$$

$$A_g = 1/\Phi_g \; 4 \pi R_g^{\,2} \qquad (11)$$

The local particle content is made up of voids, inert grains, sorbent solid reactant and solid product, such that

$$\varepsilon + \varepsilon_i + \varepsilon_r + \varepsilon_p = 1 \qquad (12)$$

Continuity equations can be written for each of these volume fractions:

$$\partial \varepsilon_r/\partial t = - \nabla \cdot (\varepsilon_r \underline{v}_s) - k_r \; s \; C_r/m_r \qquad (13)$$

$$\partial \varepsilon_p/\partial t = - \nabla \cdot (\varepsilon_p \underline{v}_s) + k_r \; s \; C_r/m_p \qquad (14)$$

$$\partial \varepsilon_i/\partial t = - \nabla \cdot (\varepsilon_i \underline{v}_s) \qquad (15)$$

$$\partial \varepsilon/\partial t = \nabla \cdot [(1-\varepsilon) \underline{v}_s] - k_r \; s \; C_r \; (1/m_p - 1/m_r) \qquad (16)$$

We define grain and particle fractional reaction extents as

$$\alpha_g = 1 - V_g \; \varepsilon_r/V_{go} \qquad (17)$$

and

$$\alpha = 1 - \int_V \varepsilon_r \; dV/V_o \qquad (18)$$

respectively. It can be shown that the overall particle voidage is given by

$$d/dt \left(\int_V \varepsilon \; dV\right) = \int_S v_s \cdot \underline{\underline{n}} \; dS + (1/m_r - 1/m_p) \; d\alpha/dt \; [V_o(1-\varepsilon_o-\varepsilon_{io})m_r] \qquad (19)$$

while the local voidage is

$$\varepsilon = 1 - \varepsilon_{io} - (1 - \varepsilon_o - \varepsilon_{io}) \; / \; \{1 - \alpha_g \; (1 - m_r/m_p)\} \qquad (20)$$

Also, the grain volume is given by

$$V_g = V_{go} \, [1 + (1/m_p - 1/m_r) \, \alpha_g \, m_r] \tag{21}$$

The grain surface per unit total volume is roughly

$$\begin{aligned} S_p &= A_g/[V_g/(1-\varepsilon)] \; (\varepsilon/\varepsilon_o) \\ &= 1/\Phi_g \; (12 \, \pi/V_{go})^{1/3} \; (\varepsilon/\varepsilon_o) \; (1-\varepsilon) \; [1 + (1/m_r - 1/m_p) \, \alpha_g \, m_r]^{-1/3} \end{aligned} \tag{22}$$

Finally the mean pore radius is approximated as

$$\begin{aligned} R_p &= \Phi_g \; 2/(12\pi)^{1/3} \; [\varepsilon_o/(1-\varepsilon)] \; V_{go}{}^{1/3} \\ &\quad [1 + (1/m_r - 1/m_p) \, \alpha_g \, V_{go} \, m_r]^{1/3} \end{aligned} \tag{23}$$

Note that sintering phenomena may also interact to reduce the grain surface area, and if sintering is at a significant rate Equation 22 for S_p should be multiplied by the factor

$$\exp \; (- k_s \, t)$$

while Equation 23 for R_p should be divided by this factor. k_s is the sintering rate constant, a strong function of temperature. Thus, sintering reduces the internal surface area and increases the average pore radius.

Boundary and Initial Condition

The particle position vector is represented by r, from some arbitrary point of origin. A position on the pore surface is represented by r_p, the position vector for the pore surface. The outer particle surface is represented by the position vector R.

The flux of sulfur species across the gas-solid interface ($r = r_p$) is continuous with

$$-\underline{n}\cdot D\,\nabla c + \underline{n}\cdot c\,\underline{v} = -\underline{n}\cdot D_s\,\nabla s + \underline{n}\cdot s\,\underline{v}_s \tag{24}$$

where $\underline{n}$ is the unit normal vector at the surface at $r = r_p$. Also, with adsorption equilibrium, $s = k_a\,c$.

At the interface the velocity is continuous,

$$\underline{n}\cdot\underline{v} = \underline{n}\cdot\underline{v}_s. \tag{25}$$

At an inert grain surface the flux is given by

$$-D\,\underline{n}\cdot\nabla c + \underline{n}\cdot c\,\underline{v} = 0 \tag{26}$$

At time zero

$$\begin{aligned} c &= 0 \\ s &= 0 \\ C_r &= m_r \\ C_p &= 0 \end{aligned} \tag{27}$$

Finally, at the outer surface of the particle ($r = R$)

$$c = c_o \tag{28}$$

DIMENSIONAL ANALYSIS

The dimensional analysis of the above equations can provide significant insight into the nature of the sorbent sulfur removal performance without making the sorbent model any more specific or limiting the generality further.

Dimensionless Quantities

The following dimensionless groups are defined

$C^* = c/c_o$, the dimensionless concentration in the pores
$S^* = s/(k_a\ c_o)$, the dimensionless concentration in the solid phase
$C_r^* = C_r/m_r$, the dimensionless solid reactant concentration
$C_p^* = C_p/m_p$, the dimensionless solid product concentration
$t^* = t\ D_a/R_o^2$, the dimensionless time
$\underline{v}^* = \underline{v}\ R_o/D_a$, the dimensionless gas phase velocity
$\underline{v}_s^* = \underline{v}_s\ R_o/D_a$, the dimensionless solid phase velocity

where D_a is the initial average gas phase diffusion coefficient in the pores and R_o is the initial characteristic particle dimension.

Dimensionless Equations

The continuity Equations 1 through 7 become

$$\partial C^*/\partial t^* = \nabla^* \cdot (D/D_a)\ \nabla^* C^* - \nabla^* \cdot \{C^*\ \underline{v}^*\} \tag{29}$$

$$\nabla^* \cdot \underline{v}^* = 0 \tag{30}$$

$$\begin{aligned} \partial S^*/\partial t^* &= (D_s/D_a)\ (R_o/R_{go})^2\ \nabla^{*2}\ S^* \\ &- (R_o/R_{go})\ \nabla^* \cdot \{S^*\ \underline{v}_s^*\} - \{k_r\ m_r\ R_o^2/D_a\}\ S^*\ C_r^* \end{aligned} \tag{31}$$

$$\partial C_r^*/\partial t^* = -\ \nabla^* \cdot \{C_r^*\ \underline{v}_s^*\} - \{k_r\ R_o^2\ k_a\ c_o/D_a\}\ S^*\ C_r^* \tag{32}$$

$$\partial C_p^*/\partial t^* = -\ \nabla^* \cdot \{C_p^*\ \underline{v}_s^*\} + \{k_r\ R_o^2\ k_a\ c_o/D_a\}\ S^*\ C_r^* \tag{33}$$

$$C_r^* = 1 - C_p^* \tag{34}$$

$$\nabla^* \cdot \underline{v}_s^* = \{k_r\ R_o^2\ k_a\ c_o/D_a\}\ \{m_r/m_p - 1\}\ S^*\ C_r^* \tag{35}$$

The particle structure factors can be written

$$\varepsilon = 1-\varepsilon_{io} - (1-\varepsilon_o-\varepsilon_{io}) \,/\, \{1 - \alpha_g \,(1 - m_r/m_p)\} \qquad (36)$$

$$V_g^* = V_g/V_{go} = 1 - (m_r/m_p - 1)\,\alpha_g, \text{ the grain volume} \qquad (37)$$

$$S_p^* = S_p/S_{po} = \varepsilon/\varepsilon_o \,(1-\varepsilon)/(1-\varepsilon_o)\,[1 + (1-m_r/m_p)\alpha_g]^{-1/3} \exp(-k_s\, t), \qquad (38)$$

the dimensionless internal surface area per unit volume,

$$R_p^* = R_p/R_{po} = (1-\varepsilon_o)/(1-\varepsilon)\,[1 + 1\, m_r/m_p)\,\alpha_g]^{1/3} \exp(k_s\, t), \qquad (39)$$

and the dimensionless pore radius, where the sintering effect has been included.

The boundary and initial conditions, Equations 24-28, become

$$(D/D_a)\, \underline{n} \cdot \nabla^* C^* - \underline{n} \cdot C^* \underline{v}^* = (D_s/D_a)\, k_a\, \underline{n} \cdot \nabla^* S^* \qquad (40)$$

$$- \underline{n} \cdot S^* k_a\, \underline{v}_s^* \quad \text{at } r^* = r_p/R_o$$

$$S^* = C^* \quad \text{at } r^* = r_p/R_o \qquad (41)$$

$$\underline{n} \cdot \underline{v}^* = \underline{n} \cdot \underline{v}_s^* \quad \text{at } r^* = r_p/R_o \qquad (42)$$

$$(D/D_a)\, \underline{n} \cdot \nabla C^* - \underline{n} \cdot C^* \underline{v}^* = 0 \quad \text{on inert surfaces} \qquad (43)$$

$$\begin{aligned} C^* &= 0 \quad \text{at } t^* = 0 \\ S^* &= 0 \quad \text{at } t^* = 0 \\ C_r^* &= 1 \quad \text{at } t^* = 0 \\ C_p^* &= 0 \quad \text{at } t^* = 0 \end{aligned} \qquad (44)$$

$$C^* = 1 \quad \text{at } r^* = R/R_o \qquad (45)$$

Interpretation

The dimensionless equations indicate that the dimensionless concentration fields, velocity fields and structural factors

C^*
S^*
C_r^*
C_p^*

$\underline{v}^*$
$\underline{v}_s^*$
ε, S_g^*, A_g^*, R_p^*, R_g^*, R^*, V_g^*, etc

are functions of the following variables:

t^*, dimensionless time

r/R_o, dimensionless position

D/D_a, dimensionless gas phase diffusion coefficient, potentially a function of time and position if in the Knudsen difusion regime

$D_s/D_a\ (R_o/R_{go})^2\ k_a$, ratio of solid phase diffusion rate to gas phase diffusion rate

$k_r\ m_r\ R_o^2/D_a$, chemical reaction rate over gas phase diffusion rate

$k_a\ c_o/m_r$, ratio of diffusing sulfur species concentration in the solid to molar density of pure solid phase reactant CaO

m_r/m_p, ratio of pure CaO molar density to pure $CaSO_4$ molar density

k_a, adsorption coefficient

and the dimensionless geometry of the particle, r_p/R_o.

The geometric factors relate to the following dimensionless groups:

ε_o	initial particle voidage
ε_{io}	initial volume fraction of inert grains
R_{go}/R_o	initial average grain diameter over initial particle characteristic dimension

A_{go}/A_o	initial internal surface area over external initial surface area
R_p/R_o	average initial pore diameter over the initial particle characteristic dimension
$S_{go}\ R_o$	initial surface area per unit volume times the initial particle characteristic dimension

The total fraction of the particle solid phase reacted, α_t, is given by

$$\alpha_t = 1 - \int_{V^*} C_r^* / \{(1-\varepsilon_o-\varepsilon_{io})\}\ dV^* \qquad (46)$$

where V^* is the dimensionless particle volume, V/V_o. V_o is the initial particle volume.

The general equation for the overall particle reaction rate is

$$d\ \alpha_t/dt^* = k_r\ k_a\ c_o^2\ R_o/D_a \int_{V^*} S^*\ C_r^* /\ \{1-\varepsilon_o-\varepsilon_{io}\}\ dV^* \qquad (47)$$

This equation indicates that in general

$$d\ \alpha_t/dt^* = \text{function}\ \{t^*,\ D(t^*)/D_a,\ D_s/D_a\ (R_o/R_{go})^2\ k_a, \qquad (48)$$
$$k_r\ m_r\ R_o^2/D_a,\ k_a\ c_o/m_r,\ m_r/m_p,\ \text{and}$$
$$\text{structural factors}\ (\varepsilon_o,\ \varepsilon_{io},\ R_{go}/R_o,\ R_{po}/R_o,\ A_{go}/R_o)$$

and its complex form, while informative, is not directly useful.

In order to look at more limiting cases than that above, the overall particle reaction rate, $d\ \alpha_t/dt$, is given by the following three equations for pore diffusion control, chemical reaction control, and solid diffusion control, respectively:

If the rate is diffusion controlled

$$d\,\alpha_t/dt = D_a \; c_o/m_r \; A_o/\{(R_o\,V_o)(1-\varepsilon_o-\varepsilon_{io})\} \tag{49}$$

$$\times \int_{A^*} -(D/D_a)\,\underline{n}\cdot\nabla^*\,C^*\,d\,A^*$$

$$= D_a\,c_o/m_r\,A_o/\{(R_o\,V_o)(1-\varepsilon_o-\varepsilon_{io})\}$$

$$\times \;\text{function}\;\{t^*,\,D/D_a\}$$

where

$$D/D_a = \text{function}\;\{R_{po}/R_o,\;m_r/m_p,\;k_s\} \tag{50}$$

A^* is the surface area of the shrinking reaction surface, and D is the diffusion coefficient in the solid product layer, a potential function of time due to sintering.

If the rate is chemical reaction controlled

$$d\,\alpha_t/dt = k_r\;k_a\;c_o\;\int_{V^*} S^*\;C_r^*/\{(1-\varepsilon_o-\varepsilon_{io})\}\;dV^* \tag{51}$$

$$= k_r\;k_a\;c_o/\{1-\varepsilon_o-\varepsilon_{io}\}$$

$$\times\;\text{function}\;\{t\;k_r\;m_r\}$$

The definition of reaction rate control implies that S^* and C_r^* have values everwhere in the solid phase of 1 and $1-\alpha$, respectively. Thus,

$$d\,\alpha_t/dt = k_r\;k_a\;c_o\;(1-\alpha_t)\;V/V_g \tag{52}$$

for the chemical reaction controlled case.

If the rate is solid diffusion controlled

$$d\,\alpha_t/dt = D_s\;\;k_a\;c_o/m_r\;\;A_{go}/(R_{go}\;V_{go}) \tag{53}$$

$$\times \int_{A_p^*} - \underline{n} \cdot \nabla^* S^* \, d A_p^*$$

$$= D_s \, k_a \, c_o/m_r \, A_{go}/(R_{go} \, V_{go})$$

$$\times \text{ function } \{t \, D_s \, R_{go}^{-2}, \, m_r/m_p, \, k_s\}$$

where A_p^* is the pore reaction surface over A_{go}.

These dimensionless equations tell us several things about the influence of time, particle diameter, external reactant gas concentration, pressure, temperature, pore surface area, etc on the overall reaction rate.

1) time

For particles having identical values of all of the dimensionless groups, the dimensionless reaction rate is the same function of dimensionless time:

$$d \, \alpha_t/d \, t^* = \text{function } \{t^*\} \qquad (54)$$

2) particle size

For particles of similar sorbent materials at the same temperature and pressure, having the same values of dimensional quantities except for the particle size, R_o, A_o, V_o

$$d \, \alpha_t/dt^* = \text{function } \{t^*, \, k_r \, m_r \, R_o^2/D_a, \; A_{go}/A_o, \, R_{po}/R_o\} \qquad (55)$$

With limestone or dolomite particles it is not possible to change the particle size and maintain the last three of the quantities within the brackets fixed, but the limiting cases can be assessed.

a) if the pore diffusion rate is very much smaller than the chemical reaction rate or the solid diffusion rate, i.e.,

$$k_r\ m_r\ R_o^2/D_a \qquad \text{very large} \tag{56}$$

$$D_s/D_a\ (R_o/R_{go}^2)\ k_a \qquad \text{very large} \tag{57}$$

then Equation 49 becomes

$$d\ \alpha_t/dt = D_a\ c_o/m_r\ \ A_o/\{(R_o\ V_o)(1-\varepsilon_o-\varepsilon_{io})\} \\ \times \text{ function } \{t^*,\ R_p/R_o\} \tag{58}$$

or, with respect to the particle size, using $A_o/(R_o\ V_o)$

$= 3/(\Phi\ R_o^2)$,

$$(d\ \alpha_t/dt)\ \Phi\ R_o^2 = \text{function } (t/R_o^2,\ R_p/R_o) \tag{59}$$

where the term R_p/R_o, the characteristic pore radius in the product layer, can be neglected unless in the Knudsen diffusion regime.

b) if the chemical reaction rate is very much smaller than the pore diffusion or solid diffusion rates, i.e.,

$$k_r\ m_r\ R_o^2/D_a \rightarrow 0 \tag{60}$$

$$k_r\ m_r\ R_o^2/D_s \rightarrow 0 \tag{61}$$

then, from Equation 51,

$$(d\ \alpha_t/dt) = \text{function } (t) \tag{62}$$

and the rate is independent of particle size.

c) if the solid diffusion rate is much smaller than the chemical reaction or pore diffusion rates, i.e.,

$$D_s/D_a\ (R_o/R_{go})\ k_a \rightarrow 0 \tag{63}$$

$$k_r\ m_r\ R_o^{\ 2}/D_s \quad \text{very large} \tag{64}$$

then, from Equation 53,

$$d\ \alpha_t/dt = D_s\ k_a\ c_o/m_r\ A_{go}/(R_{go}\ V_{go}) \times \text{function}\ (t/R_{go}^{\ 2}) \tag{65}$$

and

$$(d\ \alpha_t/dt) = \text{function}\ (t) \tag{66}$$

The three special cases, pore diffusion control, reaction control, and solid diffusion control, are characterized by a dependency on R_o^n where n is 2, 0, and 0 respectively. Also, very large particles should approach pore diffusion control behavior, while very small particles should approach chemical reaction rate control.

3) external reaction gas concentration

For particles that are identical except for the SO_2 concentration they react in, Equation 17, 18 and 19 indicate that

$$d\ \alpha_t/dt = c_o\ \text{function}\ \{t\} \tag{67}$$

and the overall reaction rate is first order with respect to c_o for all cases.

4) pressure

For particles that are identical except for the pressure of the reaction gas and the resulting gas concentration c_o, the following cases can be determined:

a) for pore diffusion control

$$d\,\alpha_t/dt = D_a\,c_o \text{ function } \{t\,D_a,\ D/D_a\} \tag{68}$$

With the diffusion coefficient being some function of pressure given approximately by a series model of molecular and Knudsen diffusion

$$D_a = 1\ /\ [1/D_k + 1/D_m] \tag{69}$$

where the Knudsen diffusion coefficient, D_k, is

$$D_k = D_{kr}\ \ T^{1/2}\ /\ (A_g/V) \tag{70}$$

and the molecular diffusion coefficient, D_m, is

$$D_m = D_{mr}\ \ T^{1.8}\ /\ P \tag{71}$$

T is the absolute temperature, P is the absolute pressure, and D_{kr} and D_{mr} are constants.

We see that if Knudsen diffusion controls then D_a is independent of P and the overall reaction rate is directly proportional to the pressure.

$$d\,\alpha_t/dt = P \text{ function } \{t\} \tag{72}$$

The Knudsen diffusion control is promoted by larger values of the internal surface area, A_g/V, lower ε, and lower gas pressures.

If molecular diffusion controls then D_a is inversely proportional to the pressure. This makes the overall reaction rate relate to pressure as

$$d\, \alpha_t/dt = \text{function } \{t/P\} \qquad (73)$$

Molecular diffusion is promoted by small values of the internal surface area (large pores), higher ε, and higher pressures.

b) for chemical reaction rate control

$$d\, \alpha_t/dt = c_o \text{ function } \{t\ k_r\ m_r\} \qquad (74)$$

or, with respect to pressure

$$d\, \alpha_t/dt = P \text{ function } \{t\} \qquad (75)$$

c) for solid diffusion control

$$d\, \alpha_t/dt = c_o \text{ function } \{t\ D_s/R_{go}^2\} \qquad (76)$$

or, with respect to pressure

$$d\, \alpha_t/dt = P \text{ function } \{t\} \qquad (77)$$

While these equations indicate a rather simple pressure dependence, the pressure also has a great impact on the initial calcine pore and grain structure which is not considered in these equations. Higher pressures promote larger pores while smaller pressures promote smaller pores.

5) temperature

Following a similar procedure to find the impact of temperature yields these results:

a) pore diffusion control

$$d\ \alpha_t/dt = D_a\ c_o \text{ function } \{t\ D_a/R_o^2,\ D/D_a\} \tag{78}$$

The temperature dependence of D_a is given above. If the diffusion is in the Knudsen regime then the temperature dependence of D_a is T to the 1/2-power and

$$d\ \alpha_t/dt = T^{-1/2} \text{ function } \{t\ T^{1/2},\ k_s(T)\} \tag{79}$$

The sintering rate constant is assumed to be given by

$$k_s = k_{so} \exp\ (-\ E_s/T) \tag{80}$$

If the diffusion is in the molecular diffusion regime then the temperature dependence of D_a is $T^{1.8}$ and

$$d\ \alpha_t/dt = T^{0.8} \text{ function } \{t\ T^{1.8}\} \tag{81}$$

The Knudsen regime is promoted by higher temperatures, and the molecular regime by lower temperatures.

b) chemical reaction rate control

$$d\ \alpha_t/dt = k_r\ k_a\ c_o \text{ function } \{t\ k_r\ m_r\} \tag{82}$$

With the reaction rate and adsorption terms having exponetial temperature dependence

$$\begin{aligned} d\ \alpha_t/dt &= \exp\ \{-\ (E_r + E_a)/T\}\ /\ T \\ &\quad \times \text{ function } \{\ t \exp\ (-\ Er/T)\ \} \end{aligned} \tag{83}$$

c) solid diffusion rate control

$$d\ \alpha_t/dt = D_s\ k_a\ c_o \text{ function } \{t\ D_s/\ R_{go}^2\ ,\ k_s\} \qquad (84)$$

The solid diffusion coefficient has a limited understanding with respect to temperature, although it is expected to increase with temperature as $D_s = D_{so} \exp\{-Es/T\}$. Thus,

$$d\ \alpha_t/dt = \exp\{-(Ea+Es)/T\}\ /\ T$$

$$\times \text{ function } [t \exp\{-Es/T\},\ k_s(T)] \qquad (85)$$

It should be pointed out that the temperature dependence is more complex than that indicated by these equations because the temperature effects the initial calcine pore and grain structure, as well as having a transient impact on the structure if significant sintering is occuring.

6) pore and grain structure

For particles identical except for their internal pore and grain structure the following is indicated:

a) pore diffusion control

$$d\ \alpha_t/dt = 1/\ (1-\ \varepsilon_o-\varepsilon_{io})/m_r \text{ function } \{t,\ R_{po}/R_o,\ m_r/m_p\} \qquad (86)$$

where the quantity R_{po}/R_o is only important if in the Knudsen diffusion regime.

b) chemical reaction control

$$d\ \alpha_t/dt = 1\ /\ (1-\varepsilon_o-\varepsilon_{io}) \text{ function } \{t\ m_r\} \qquad (87)$$

c) solid diffusion control

$$d\ \alpha_t/dt = 1/(\Phi_g\ R_{go}{}^2)/m_r \quad \text{function}\ \{t/R_{go}{}^2,\ m_r/m_p\} \qquad (88)$$

and the rate is directly proportional to the initial internal surface area per unit volume squared because

$$1/(\Phi_g\ R_{go}{}^2) = S_{po}{}^2\ \Phi_g/\{9(1-\varepsilon_o)\} \qquad (89)$$

7) ultimate sorbent utilization

Little can be deduced about the ultimate extent of reaction, α^*, from the dimensional analysis except

1) All sorbent particles having the same dimensionless groups will have the same α^*.
2) In the pore diffusion controlled regime the sorbent utilization is limited by the reduction in the ratio D/D_a as the pore volume is reduced due to solid product expansion.
3) In the chemical reaction controlled regime there is no limitation to the utilization and $\alpha^* = 1$.
4) In the solid diffusion controlled regime the sorbent utilization is limited by the loss in internal surface area due to solid product expansion and sintering.

APPENDIX D

MODEL DEVELOPMENT FOR CALCIUM-BASED SORBENT SULFUR REMOVAL IN EXTERNAL DESULFURIZERS

1.1 INTRODUCTION

Kinetic data collected on laboratory devices require the use of a commercial process model in order to apply the data for process evaluation. Such models are used as engineering tools to select design and engineering conditions for commercial design studies. They are not substitutes for full-scale data, but should be used with full-scale data as it becomes available to evolve improved process performance correlations.

Simple models are developed here for fluidized and entrained bed external desulfurizers, using several simplifying assumptions. External desulfurizers are defined to be desulfurization stages of a gasification process or a combustion process that follow either the complete gasification or combustion process or follow an intermediate step, but are not insitu with the gasification or combustion process. Thus, they do not interact with the carbon conversion process directly. The models are suitable for use in sorbent evaluations and to predict performance for conceptual designs.

1.2 CALCIUM-BASED SORBENT SULFATION KINETICS

While sulfation kinetics for individual limestones, dolomites and other calcium-based sorbents must be determined experimentally, it is convenient to use an empirical form to fit the kinetics. The sulfation reaction kinetics are a function of the temperature, pressure, the gas composition (O_2, CO_2, H_2O and SO_2 or H_2S), particle size, fraction of the sorbent calcium content sulfated, and the particular sorbent type. A form that fits the experimental kinetics well is

$$d\,\alpha/dt = k\ (1 - \alpha)^{m} C \tag{1}$$

where α is the fraction of the calcium reacted, t is the time, k is the rate constant, m and empirical constant, and C is the SO_2 or H_2S concentration. The rate is found to be zero order in the O_2 concentration while the rate constant k is dependent on temperature, pressure, CO_2 concentration, particle size and sorbent type in a very complex way.

With the form of equation (1) the fraction sulfated for a constant SO_2 or H_2S concentration becomes

$$\alpha = 1 - \{\ 1 + (m-1)\ k\ C\ t\ \}^{1/(1-m)} \tag{2}$$

or if the sulfur gas concentration is a function of time

$$\alpha = 1 - \{1 + (m-1)\ k \int_{o}^{t} C(t)^{1/(1-m)}\ dt\} \tag{3}$$

In some cases this form will have to be fit to the kinetic data in two or three sections, so that multiple values of m and k will be needed.

1.3 GENERAL DIFFERENTIAL MATERIAL BALANCES

A general, steady-state material balance on SO_2 or H_2S in either a fluidized bed or an entrained desulfurizer is shown below:

$$U\, dC/dx = -R + G \qquad (4)$$

where U is the superficial gas velocity, x is the axial distance from the base of the bed, R is the desulfurization reaction rate and G is the SO_2 generation rate per unit bed volume.

In Equation (4)

$$R = p\, N\, k\, (1 - \alpha)^m\, C \qquad (2)$$

where p is the number of particles per unit volume, and N is average number of moles of calcium per particle. The generation term G is a function of axial position that depends on the nature of the coal, the coal size, the coal feed location, the bed temperature, the pressure and the excess air level. For the case of external desulfurization the generation term is assumed to be zero.

1.4 SPECIFIC SOLUTIONS

Bubbling Fluidized Bed Desulfurizer

The following assumptions are applied to the development of a fluidized bed desulfurizer process model, and are based on, in part, modeling conclusions developed for fluidized bed combustion:

- The prior combustion, pyrolysis or gasification reactions have been essentially completed and the composition does not change significantly due to carbon conversion within the desulfurizer. Gas compositions will change within the desulfurizer due to calcination of the sorbent (release of CO_2) and due to sorbent sulfur species reactions. If secondary reactions of gases do occur in the bed this will have only a small influence on the sulfur removal performance.

- The gas temperature is at the temperature of the prior gas temperature entering the desulfurizer and will change due to heat releases from the calcination and sulfur reaction only to a small extent . The gas and particle temperature is essentially uniform within the desulfurizer because of good particle mixing.

- The gas flows through the desulfurizer both in the bubble phase and in the emulsion phase of the fluid bed. Because the particles are relatively coarse, the gas mixing rate between the bubble and emulsion phases is high and simple plug flow of the gas may be assumed with little error. That is, the gas composition is approximately uniform across any horizontal cross-section of the bed. Design correlations are available to estimate the emulsion voidage and bubble volume fraction in the bed.

- Particles in the sorbent feed of a size having terminal velocity less than the bed superficial velocity (in their calcined state) will be elutriated from the bed. These particles will be partially sulfated or sulfided. It is assumed that this represents a small portion of the total sorbent.

- Significant sorbent particle attrition may occur in the bed. It is assumed that the fine sorbent particles attrited will not be recycled to the desulfurizer. The attrition occurs mainly during the initial period of the particles residence in the bed and generally sulfated or sulfided sorbent is not highly attrited. The attrited and elutriated particles are assumed to be reacted to an extent very similar to the coarse particles remaining in the bed.

- The sorbent particles reside in the bed with a perfectly-mixed age distribution. Because of the high rate of mixing versus the slow rate of sulfur reaction, the sorbent particles see only the average sulfur-gas species (SO_2 or H_2S) concentration in the bed.

- Significant sorbent reaction may occur in the bed "splash zone" directly above the bed surface. Design correlations are available to estimate the height and particle concentration in the splash zone. The splash-zone sorbent particle inventory is assumed to be included in the bed inventory in this model.

- Negligible sulfur release or sulfur removal occurs in the freeboard region of the desulfurizer.

- Coal ash passes through the desulfurizer with little accumulation in the bed.

- The sulfur reaction rate of the sorbent particles is very slow compared to the calcination rate of the particles. That is, the rate of calcination has little influence on the rate of sulfur reaction of the sorbent. The correlation forms developed in this test program will be utilized to represent the sulfur reaction rate as a function of the operating parameters:

$$r = N\,k\,(1 - \alpha)^m\,C \qquad (6)$$

where r is the reaction rate per sorbent particle of diameter d_p. N is the number of moles of calcium in a particle (based on the average particle diameter in the bed), C is the sulfur species concentration in the gas, and k is the sulfur rate constant. The model is based mainly on a differential material balance on sulfur in the bed. The material balance is

$$U\,d\,C/dx = G - R \qquad (7)$$

where U is the gas superficial velocity, C is the sulfur gas-phase concentration, x is the axial distance above the distribution plate, G is the rate of sulfur release per unit volume of the bed, and R is the rate of sulfur capture per unit bed volume. The sulfur generation term, G, is zero based on the assumptions stated above, and the sulfur reaction term is given by

$$R = p\,\bar{R}\,C/\bar{C} \qquad (8)$$

where p is the total number of sorbent particles per unit volume of the bed, R is the average particle reaction rate in the bed, and C is the average sulfur gas concentration in the bed. The term p is given by

$$p = 6\ (1 - \epsilon)(1 - \delta)/[\pi\ d_p^{\ 3}] \tag{9}$$

where n is the voidage in the bed emulsion phase and k is the bubble volume fraction in the bed.

Equations 7 and 8 may be combined and integrated to yield the simple concentration profile

$$C = C_o \exp \{ - p\ x\ \bar{R}/(U\bar{C}) \} \tag{10}$$

with the inlet sulfur gas concentration being C_o.

The bed sulfur removal efficiency is defined as

$$E = 1 - C(x{=}H)/C_o = 1 - \exp \{ - p\ H/U\bar{R}/\bar{C} \} \tag{11}$$

The average sulfur gas concentration is defined as

$$\bar{C} = 1/H \int_o^H C\ dx \tag{12}$$

and becomes

$$\begin{aligned} \bar{C} &= C_o/H\ U/p\ \bar{C}/\bar{R}\ [1 - \exp \{ - p\ H/U\ \bar{R}/\bar{C} \}] \\ &= - C_o\ E/\mathrm{Ln}\ \{1 - E\} \end{aligned} \tag{13}$$

The average reaction rate in the bed may be estimated for a perfectly mixed fluid bed using the residence time frequency distributions F:

$$F = 1/\tau \exp \{- t/\tau\} \tag{14}$$

where τ is the average particle residence time, and t is the time.

By definition the average sorbent utilization in the bed is

$$\alpha = \int_0^\infty \alpha \, 1/\tau \exp \{ - t/\tau\} \, dt \tag{15}$$

Since each particle in the bed effectively sees only the average sulfur gas concentration in the bed, then

$$\alpha = 1 - 1/\{1 + (m-1) \, k \, C \, t\}^{1/(m-1)} \tag{16}$$

The procedure applied to predict sulfur removal performance is:

1) Identify the bed operating conditions (T, P), the average diameter of particles in the bed (d_p) and ρ_{ca}.

2) Determine m and k for the given sorbent at its appropriate conditions of CO_2 concentration, average particle diameter, pressure and temperature from laboratory data.

3) Specify the bed sulfur removal efficiency, E, calculate C_o (from the coal properties and the conversion characteristics on the prior processing stage) and C from Equation (13).

4) Define the parameter $\sigma = C\ \tau$ and assume any positive value for it. This parameter is

$$\sigma = \bar{C}\ \tau = -\ C_o\ \tau\ E/\mathrm{Ln}\ [1 - E] \text{ from Equation 13} \tag{17}$$

5) Calculate the term α from Equations (15) and (16) for the assumed value of σ. In general a numerical integration is required.

6) Calculate $C_o\ \tau$ from Equation (17).

7) Calculate the key bed design term $H/U\,(1-\epsilon)\ (1-\delta)$ from

$$H/U\ (1 - \epsilon)(1 - \delta) = C_o\ \tau\ E/\bar{\alpha}/\rho_{ca} \tag{18}$$

This is the average gas residence time in the bed (H/U) times the volume fraction of particles in the bed, and must be determined to completely specify the desulfurizer design. The voidage terms ϵ and δ must be estimated from available fluidized bed correlations.

8) Calculate the calcium-to-sulfur ratio from

$$Ca/S = E/\bar{\alpha}$$

This of course represented the sorbent feed rate required to achieve the specified sulfur removal efficiency for the calculated value of H/U.

9) Repeat this set of calculations for a series of assumed σ values to generate a set of corresponding calcium-to-sulfur ratios versus H/U $(1-\epsilon)$ $(1-\delta)$ values. The best design point can then be selected from this family of curves.

Entrained Desulfurizer

The following assumptions are applied for the development of a sulfur removal model of an entrained desulfurizer:

- No significant combustion, pyrolysis or gasification occurs within the desulfurizer and only minor gas composition changes occur due to calcination and sulfation or sulfidation. Thus, this model does not strictly apply within a combustion or gasification stage.

- The gas temperature is constant except for minor changes due to the calcination and desulfurization reactions.

- The sorbent is either precalcined or calcination is extremely fast and can be neglected.

- There is plug flow of both the particles and gases, with the relative velocity between the two being U_s. The model neglects the possibility of gas or particle backflow due to internals in the gas stream that may be inserted to increase the slip velocity.

- There is no size segregation in the system and particle attrition is negligible.

- The gas composition is uniform across any horizontal plane of the desulfurizer. Thus, perfect gas-solid contacting is assumed in the model.

The model of the entrained desulfurizer is considerably simpler than that for the fluidized desulfurizer because of the simple plug flow assumption and the resulting uniform residence time for all sorbent particles.

The model of the entrained desulfurizer with the above assumptions starts with material balances on both the gas and sorbent phases:

$$U \, dC/dx = -R \tag{19}$$

$$(U - U_s) \, d(p N \alpha)/dx = R \tag{20}$$

where U_s is the particle slip velocity at the reactor conditions and R is the rate of the desulfurization reaction as is given by

$$R = p N k C (1 - \alpha)^m \tag{21}$$

for fine sorbent particles. Note that the assumption that "m" is zero in Equation (21) holds only up to some level of sorbent conversion beyond which the rate drops significantly.

Adding Equations (19) and (20) and integrating yields

$$C - C_o = (1 - U_s/U) \, p N \alpha \tag{22}$$

The gas phase concentration profile may also be solved for directly from Equation (19) to give

$$C = C_o \exp \{- p\ N\ k\ x/U\} \tag{23}$$

The sulfur removal efficiency is by definition

$$E = 1 - C_e/C_o \tag{24}$$

where C_e is the exit gas sulfur concentration, and from Equation (23), noting that $p\ N = \rho_{ca}\ (1-\epsilon)$, an expression for the gas passage length is obtained:

$$H/U\ (1 - \epsilon) = - \mathrm{Ln}\ (1 - E)/(\rho_{ca}\ k) \tag{25}$$

The exit utilization of the sorbent particles becomes

$$\begin{aligned} \alpha_e &= (C_e - C_o)/[p\ N\ (1 - U_s/U)] \\ &= C_o\ E/[\rho_{ca}\ (1 - \epsilon)(1 - U_s/U)] \end{aligned} \tag{26}$$

The calcium-to-sulfur ratio is

$$\begin{aligned} Ca/S = E/\alpha_e &= (1 - U_s/U)\ p\ N/C_o \\ &= [-\mathrm{Ln}\ (1 - E)][(U - U_s)/H][1/(k\ C_o)] \end{aligned} \tag{27}$$

Equation (27) is the main design equation, giving the calcium-to-sulfur ratio as a function of the sulfur removal efficiency specified (E), the particle residence time in the gas stream $[H/(U-U_s)]$, the sorbent reaction rate constant (k), and the gas initial sulfur content (C_o). In using this design equation, the resulting level of conversion, α_e, should be checked to see that the conversion has not exceeded the value at which the reaction rate begins to fall, thus violating the basic assumption of the model.

1.5 NOMENCLATURE

C: Concentration of SO_2 or H_2S in the gas.
C_e: Concentration at the exit of the desulfurizer.
C_o: Concentration at the entrance of the desulfurizer.
$\bar{C}$: Average concentration in the fluid bed.
d_p: Average particle diameter.
E: Fraction of sulfur removed in the desulfurizer.
F: Particle residence time frequency distribution in the fluid bed.
G: Rate of SO_2 generation per unit volume.
H: Fluid bed height or length of entrained desulfurizer.
k: Reaction rate constant.
m: Reaction order with respect to function of calcium reacted.
N: Average number of moles of calcium per particle.
p: Number of particles per unit volume.
r: Reaction rate per sorbent particle.
R: Reaction rate per unit volume.
t: Time
$\bar{R}$: Average reaction rate per unit volume.
U: Superficial gas velocity.
U_s: Particle velocity.
X: Distance coordinate.
Ca/S: Calcium-to-sulfur molar feed ratio.

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α: Fraction of calcium reacted.

$\bar{\alpha}$: Average fraction of calcium reacted in the fluid bed.

α_e: Fraction of calcium reacted at the desulfurizer exit.

δ: Volume fraction of bubbles in the fluid bed.

ϵ: Voidage in the fluid bed emulsion phase or total voidage in the entrained desulfurizer.

τ: Average particle residence time in the fluid bed.

σ: Defined by Equation 17.

ρ_{ca}: Moles of calcium per unit particle volume.

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LABORATORY EVALUATION OF HIGH-TEMPERATURE SULFUR REMOVAL SORBENTS FOR DIRECT COAL-FIRED TURBINES

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