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COMBUSTION CHARACTERISTICS OF FINE-GROUND COAL

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Project 61052 Quarterly Technical Report
For the Period June 1 Through August 31, 1981

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Prepared by
Institute of Gas Technology
IIT Center, 3424 S. State Street
Chicago, Illinois 60616

Date Published — March 1982

Prepared for the
UNITED STATES DEPARTMENT OF ENERGY,
PITTSBURGH ENERGY TECHNOLOGY CENTER

Under Contract No. DE-AC22-81PC40269

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DOE/PC40269-6
Subj. Category UC-90e

DOE/PC/40269--6

DE82 009958

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EXECUTIVE SUMMARY

This program consists of a research study to investigate the effect of coal particle size on the flame characteristics of pulverized coal. The purpose is to determine if fine grinding will allow replacement of oil by coal in some industrial applications. The Plant Engineering Development Department of General Motors Corporation (GM) and the Research and Development Staff of York-Shipley, Inc. (Y-S), a major boiler manufacturer, are assisting IGT in this effort. These companies have offered to donate time to the program as industrial consultants.

Pulverized coal will be fired at about 2 million Btu/hr (approximately 160 lb/hr) in a special experimental furnace designed to collect data on the combustion and heat-transfer characteristics of flames. Combustion trials with No. 6 oil are also planned to allow for direct correlation with the coal combustion data.

Some of the information to be obtained from this study will be a determination of how the flame heat release density, mass burning rate, flame temperatures, and heat-transfer characteristics change with fuel particle size (fineness of coal grinding). It will also be possible to directly compare these parameters from the various coal flames with comparable oil flames to determine the feasibility of substituting fine-ground pulverized coal flames for heavy-oil flames.

Data will also be collected to allow for the correlation of the flue-gas pollutant emissions with the fuel characteristics.

Progress in this quarter included purchasing the major equipment for the coal milling system, coal selection, and preparation of the combustion facility.

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1. SCOPE

Many industrial furnaces and boilers are designed for oil firing, and many of these might be converted to pulverized fuel firing if heat release densities of pulverized fuel flames could be increased. Even more might be converted if the operators were also willing to downrate the production capacity and thus combine reduced thermal input to the existing combustion chamber with the increased heat release density. Some industrial concerns might find this possible, especially those using boilers that are sized for peak, rather than average, demand.

Generally, the combustion chambers of industrial furnaces and boilers designed for coal combustion are 3 to 4 times larger than those of the same capacity designed for oil firing. The primary reasons that coal is burned with lower heat release densities are the slower burnout times of typical-size coal particles compared with oil droplets and the requirement that the furnace or boiler exit gas temperature be below the ash fusion temperature to prevent slagging of the convective surfaces or flue passages. The burnout times of coal particles, however, depend on the particle size, and evidence suggests that very fine grinding of coal would allow for much higher heat release rates than are currently employed in pulverized fuel firing. Figure 1¹ shows that above about 10 microns, the burning times of single particles are proportional to the squares of their diameter, while below 10 microns the burning times are proportional to the diameter to the 1.4 power.

A 1957 article by A. L. Bayles² discusses how the properties of a pulverized fuel change with the fineness of grind. Table 1 is adapted from Bayles' paper and shows how the mass and free-fall time of a coal particle change with particle size. This table shows that as coal particles are ground to finer sizes, the mass of the particles rapidly diminishes and the falling time rapidly increases. The falling time is a good measure of the tendency of a particle to follow a moving gas stream. Thus, smaller particles would stay in suspension better and the resultant ash would have less tendency to slag or foul surfaces.

Although particles in pulverized fuel flames would not burn in exactly the same manner as individual particles, the smaller the particle is the better "fuel-air mixing" and the faster and more complete the combustion should be.

Typical grinder specifications are that 70% of the coal is ground to less than 200 mesh. Table 1 shows that the larger particles (greater than 200 mesh or 74 microns) would require more time to burn and have a greater tendency for deposition. A survey of

Figure 1. VARIATION OF COMBUSTION TIME WITH PARTICLE DIAMETER FROM VARIOUS EXPERIMENTAL AND THEORETICAL SOURCES (Reference 1.)

Table 1. COAL PARTICLE CHARACTERISTICS²

<u>Diameter, Microns</u>	<u>Relative Mass*</u>	<u>Falling Time,** Seconds</u>
1651	4,510,000,000	>1
833	578,000,000	>1
417	72,400,000	>1
246	14,900,000	1.09
175	5,360,000	2.19
147	3,175,000	3.12
104	1,125,000	6.25
74	405,000	12.50
61	227,000	17.50
43	79,500	35.00
30	27,000	75.00
20	8,000	175.00
15	3,375	312.00
10	1,000	675
5	125	2,750
4	64	4,375
1	1	67,500

* Relative mass is equal to the cube of the particle diameter.

** Falling time from a distance of 10 ft.

the literature has not revealed any comprehensive investigation of the effect of coal grinds less than 200 mesh on the flame characteristics of a typical pulverized fuel. A 1969 article by Beer³ discussed the effect of fineness of grind on anthracite flames with from 20% to 100% less than 200 mesh. The experiments showed that the flames shortened and moved closer to the burner as the coal was ground finer. Experiments with bituminous and subbituminous coal are lacking as well as data with grinds much finer than 200 mesh.

Although very fine grinding of coal can reduce flame lengths, increase heat release rates in the flame, and reduce the combustion volume necessary for a given thermal input, additional research is needed to determine how the flame characteristics (flame temperatures, flame radiation, heat release density) change as a function of coal grind before attempts can be made to convert existing boilers and furnaces. Because these fundamental data are lacking, it is not possible to determine whether the potential benefits of fine-ground coal outweigh the added cost of grinding.

This program is designed to provide the experimental data to verify the technical capability and economic feasibility of converting industrial oil-fired boilers and furnaces to direct pulverized coal combustion.

2. PROGRAM OBJECTIVE

The objective of this study is to determine how the flame heat release density, mass burning rate, flame temperatures, and heat-transfer characteristics change with coal particle size. It will also be possible from the experimental test results to directly compare these parameters with comparable oil flames. Data will also be collected on pollutant emissions from the pulverized coal combustion.

These experimental data will be provided to verify the technical capability and economic feasibility of converting industrial oil-fired boilers and furnaces to direct pulverized coal combustion.

3. TECHNICAL APPROACH

IGT, with the assistance of GM and Y-S, is conducting a series of experiments to investigate the effect of particle size on the characteristics of coal flames. The experiments will be conducted at the IGT Applied Combustion Research Laboratory using a test furnace that can simulate a wide variety of industrial furnaces. This type of furnace is necessary because the flame should be studied under conditions similar to commercial-scale furnace conditions. In addition to the coal combustion trials, baseline data will also be collected with an oil flame to allow direct comparison, again, under the same conditions. GM and Y-S are providing technical consultation to aid in maintaining the proper furnace conditions and assist in data analysis and correlation.

The program is divided into three major tasks. These include Facility Preparation, Combustion Trials, and Data Analysis.

3.1. Task 1. Facility Preparation

IGT already has coal handling, drying, and crushing facilities, many of which are owned by DOE. This equipment is available to the project as needed and in cooperation with the requirements of other DOE projects. Additional equipment, however, is to be installed to provide for the very fine grinding. This grinding equipment will be procured, installed, and put into operation. The analytic instrumentation also will be repaired and calibrated and minor furnace repairs will be made.

3.2. Task 2. Combustion Trials

This task includes the actual experimental trials and data collection. The experiments include variations in the particle size (fineness of grind), type of coal, air preheat, amount of excess air, and combustion chamber heat release density. Table 2 is a list of the trials and shows the variation in input conditions. Twelve combustion trials are included in the program, eight trials with coal to be chosen in consultation among IGT, GM, Y-S, and DOE personnel. Two trials will be conducted with a second type of coal or a beneficiated coal (with sulfur and ash substantially removed), and two trials will be conducted with No. 6 oil for comparison with the coal data.

A small boiler-type burner will be used in the trials. The furnace will be operated with a furnace load adjusted to provide combustion chamber conditions similar to those found in an industrial boiler or furnace. The test conditions are determined in consultations among IGT, Y-S, and DOE personnel. These conditions will be obtained by

Table 2. VARIATIONS IN EXPERIMENTAL PARAMETERS

<u>Trial</u>	<u>Fuel Type</u>	<u>Size Range (Mesh)</u>	<u>Air Preheat</u>	<u>% Heat to Load</u>	<u>Firing Rate, 10⁶ Btu/hr</u>
1	Bituminous	80% <200	Low	30	2
2	Bituminous	100% <200	Low	30	2
3	Bituminous	100% <270	Low	30	2
4	Bituminous	100% <400	Low	30	2
5	Bituminous	100% <400	Low	30	1
6	Bituminous	100% <400	High	30	2
7	Bituminous	100% <200	High	30	2
8	Bituminous	100% <400	High	15	2
9	Beneficiated	100% <400	High	30	2
10	Beneficiated	100% <400	High	30	1
11	No. 6 Oil	--	Low	30	2
12	No. 6 Oil	--	Low	30	1

adjusting the fuel/air ratio and by inserting cooling tubes as heat-absorption surfaces to provide a furnace load. After adjustment of the furnace conditions during the baseline trials, the same furnace load configuration will be used for all subsequent trials.

The following data will be collected for each combustion trial:

- Fuel analysis including proximate analysis, ultimate analysis, and particle size distribution (for coal)
- Flame size and shape by visible examination and by analysis of gaseous and particulate samples (primarily unburned carbon and carbon monoxide)
- Solids sampling for unburned carbon (proximate analysis) along the flame axis
- Gas species sampling along the flame axis (O_2 , CO, CO_2 , NO, NO_x , combustibles, SO_2)
- Flame temperature across the flame at selected positions along the flame axis using a suction pyrometer
- Total heat transfer and heat-transfer distribution to the furnace load
- Radiant heat transfer from the flame and total radiant heat transfer at the wall at various points along the flame axis
- Furnace exit gas temperature and composition (O_2 , CO, CO_2 , NO, NO_x , combustibles, SO_2)
- Mass and composition of ash and slag material on special probes at the furnace exit
- Flue gas smoke number by Bacharach Smoke Meter.

3.3. Task 3. Data Analysis and Final Report Preparation

During this task, the data collected during the experimental trials will be analyzed and correlations will be developed. The data will be compared with the limited data that is currently available. The data collected in this program will also be made available to groups developing mathematical models of coal-fired furnaces. The data collected, analyses, and correlations will be compiled, and a final report will then be prepared.

4. PROGRESS TO DATE

4.1 Task 1. Facility Preparation.

During this quarter, most of the major equipment components to mill and transport the fine-ground coal were purchased. Figure 2 is a block diagram of the fine-ground coal supply system from coal mine to the IGT pilot-scale research furnace.

The coal for this program will be a bituminous coal that is normally fired in boilers. The coal must have a Hardgrove grindability of below 50 or the capacity of the fluid energy mill that we plan to use may be limited and may not be able to reduce the coal to the proper size needed.

A list of candidate coals was obtained from the Lawrence Livermore Laboratory, and they helped us to locate a mine that can supply a suitable low-sulfur bituminous coal with the appropriate grindability and high ash fusion temperature. The suppliers at the coal mine will reduce the coal to 3 inches or below and load the coal into a railroad hopper car. Hopper cars hold about 100 tons of coal, which is sufficient for our use.

The coal must be crushed to 1/8 inch and below to meet the input requirements of the fluid energy mill. There are several options available to us for coal crushing. There are facilities to crush the coal at the IGT Energy Development Center (EDC), but these facilities are scheduled to be used during the period in which this project testing is to begin. Also, this crushing system is on-line and would need additional equipment and manpower to modify it for our use. Therefore, two commercial firms (Particle Reduction, Chicago, and Solomon Grind-Chem Service, Springfield, IL) have been contacted and identified as capable of crushing the coal. Also, Iowa State University at Ames, Iowa, has coal preparation facilities to crush and beneficiate materials. We have contacted Iowa State, and they are willing to crush our coal. The major advantage of having Iowa State crush the coal is that we had already considered sending some of the coal to Ames for beneficiation.

The crushed coal (1/8 inch and below) will be shipped by railroad and/or truck to the IGT Energy Development Center. During the experiments, the crushed coal will be loaded into a 3-ton hopper equipped with a variable screwfeeder. The drawings for the hopper and screwfeeder have been prepared and are currently being studied by two local fabricators.

Figure 2. BLOCK DIAGRAM OF FINE-GROUND COAL TRANSPORT AND MILLING SYSTEM

Figure 3 shows the hopper, the screwfeeder, and the fluid energy mill. The hopper will have a lid and grate to keep foreign materials from the coal. The variable-speed screwfeeder will convey the crushed coal at a constant rate to the fluid energy mill. The rate at which the coal will be fed will depend on the heating value and grindability of the coal, but will be about 200 pounds an hour.

The mill used to reduce the coal to 99.9% below 400 mesh ($37\ \mu$) will be a Model 0405-C Jet-O-Mizer Mill (left side of Figure 3) from Fluid Energy Processing and Equipment Company, Hatfield, Pennsylvania. This mill was chosen over other fluid energy mills mainly because of its low cost. The other type of mill considered capable of producing fine-ground coal, the vibration mill, required dried coal, which would add capital and personnel costs to the program.

The fluid energy mill uses compressed air or steam to energize the coal particles and cause the particles to flow in a cyclonic motion. This results in the particles colliding with each other and against the wall of the grinding chamber, thus fracturing the particles. This fracturing continues until the particle size is reduced so that the particle goes near the center of the cyclonic flow and exits the mill, as in a cyclonic separator.

The Jet-O-Mizer is capable of milling coal at a rate of up to 400 lbs/hr. With a feed stock particle of 1/8 inch, the top end particle size will be in the range of $30\ \mu$ and the average end particle size will be $2\ \mu$. The Model 0405-C Jet-O-Mizer uses approximately 400 to 600 SCF/min of compressed air at an inlet temperature of 70°F and an inlet pressure of 90 to 100 psig.

The compressed air requirement for the Jet-O-Mizer was not immediately available at our combustion facilities. The on-site air compressors either did not have sufficient rate or were not piped to our building. Piping compressed air from another facility at the EDC involved underground piping and could supply compressed air at an irregular pressure due to the demands of other equipment. A used air compressor that can meet the air requirement and is less costly than piping compressed air in from another facility was found at Air Service Co. The compressor is a Worthington Model Rollair 100-110, air-cooled, rotary screw air compressor that can supply 480 SCF/min at 100 psig.

Figure 3. HOPPER, SCREWFEEDER, AND JET-O-MIZER FLUID ENERGY MILL

The air compressor will be installed on an already existing concrete equipment pad. The Jet-O-Mizer, hopper, and screwfeeder will be installed on a new (to be constructed) concrete pad just outside of the Applied Combustion Research Laboratory.

The output from the Jet-O-Mizer will contain fine-ground coal (approximately 200 lb/hr) and 480 SCF/min air at several ounces of pressure. The ratio of air-to-coal is much too high for supplying a burner, and the pressure is insufficient to transport the coal to the burner. To separate the air from the fine-ground coal, a dust collector that uses a 30-bag filter has been purchased from Com-Weigh Equipment. The air passing through the bag filter is vented, and the fine-ground coal falls into a hopper. On the exit of the dust collector's hopper is a 4 inch x 4 inch rotary air lock with a 1/3-horsepower explosion-proof motor.

The fine-ground coal will flow through the rotary air lock then through a short diagonal duct into a surge hopper. This hopper and a screwfeeder were used in previous experiments to meter and convey coal into the pneumatic conveying air stream to the burner. The fine-ground coal will be conveyed pneumatically to the burner nozzle by a metered flow of primary air.

Figure 4 shows a tentative floor plan of the fine-ground coal milling system. Other equipment that will be used in these experiments and are already on-site at the IGT Applied Combustion Research Laboratory are the IGT furnace No. 1, the combustion air system, and the movable-vane boiler burner.

The overall IGT Furnace No. 1 system is shown in Figure 5. The furnace has a square cross-sectional area of 13.5 ft² with a length of 14 feet. The furnace is constructed of 23 cm (9 in.) hard refractory walls with exterior steel cladding. One side has 31 independently removable panels or sampling doors to insert probes to any radial or axial position in the combustion chamber. Combustion air preheat temperatures of up to 1200°F can be achieved with a separately fired air preheater.

The furnace is equipped with up to 58 cooling tubes, each of which has a 2.4-inch OD. Each tube can be independently inserted through the roof to any desired depth in the furnace to simulate a furnace load. The heat absorbed by each tube is calculated by measuring the water flow rate to each tube and the temperature difference between the water inlet and water outlet temperatures.

Figure 4. FLOOR PLAN FOR FINE-GROUND COAL MILLING SYSTEM

Figure 5. OVERALL FURNACE SYSTEM

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A movable-vane boiler burner (Figure 6) will be used for all the combustion trials. The burner has air swirl vanes that can be rotated to change the degree of combustion air swirl. For all tests, the vane angle will be set to 60 degrees. The burner is mounted on a block that has a 110-degree total exit cone. Different fuel nozzles can be inserted down the axis of the burner to vary the fuel velocity rates, injection angle, and location of nozzle tip on the burner axis.

4.2. Task 2. Combustion Trials

No work has been done task.

4.3. Task 3. Data Analysis and Final Report Preparation

No work has been done on this task.

a. Diagram of Movable-Vane Boiler Burner

b. Method of Measuring Movable-Vane Angle for Boiler Burner

Figure 6. SCHEMATIC CROSS SECTIONS OF THE MOVABLE-VANE BOILER BURNER

5. OPEN ITEMS

Because of difficulties in specifying, finding, and obtaining the appropriate equipment for the grinding system at a reasonable cost, we have spent more time than anticipated negotiating with equipment suppliers, obtaining cost estimates, and securing the equipment to prepare and transport the fine-ground coal. Our initial estimate of equipment cost could not predict the sudden increase in prices that has occurred over the past year. This increase has forced us to evaluate and compare each system component more stringently than planned in order to stay within or close to our program budget. In addition, equipment delivery schedules are significantly longer than originally anticipated.

6. WORK FORECAST

During the next quarter, we plan to complete the grinding system installation and begin shakedown on the equipment. Fabrication of the slag deposition probes will begin and modification of existing probes will start.