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FEASIBILITY STUDIES OF IN-SITU COAL GASIFICATION
IN THE WARRIOR COAL FIELD

by

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Prepared for

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and
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I. SHRINKING CORE MODEL

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In order to study the application of the shrinking core model, experimental runs were carried out at different conditions. The coke samples used for this study were made by pyrolyzing the bituminous coal. The details of this pyrolyzing procedure along with the apparatus used are presented in the previous quarterly report.

An overall summary of run conditions and the variables studied are presented in Table 1. The combustion experiments were carried out using two different sizes of particles (1-inch and 0.5-inch diameter), three different gas flow rates (0.27 SCFM, 0.216 SCFM, 0.1485 SCFM), three oxygen concentrations (21%, 9.5%, 5.0%), and several temperatures.

The results obtained from these variables by the application of the shrinking core model are presently under investigation and will be presented in the next quarterly report.

Table 1
Overall Summary of Run Conditions

Run No.	Particle Size ¹ (IN)	Temperature (°F)	O ₂ Conc. (%)		Flow Rate (SCFM)
			In	Out ²	
1	1.0	1267	21	13.5	0.27
2	1.0	1028	21	14.0	0.27
3	1.0	896	21	13.1	0.27
4	0.5	1030	21	18.9	0.27
5	0.5	1267	21	18.9	0.27
6	1.0	1311	21	10.8	0.1485
7	0.5	1230	21	17.5	0.1485
8	0.5	890	21	19.8	0.27
9	0.5	1285	21	16.4	0.216
10	0.5	1211	9.5	8.8	0.27
11	0.5	1246	5.0	5.0	0.27

¹Particle size refers to the diameter of particle.

²Concentration of O₂ coming out when 50% conversion is achieved.

II. LABORATORY COMBUSTOR STUDIES

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Previous quarterly reports have discussed studies in various types of laboratory combustors with the purpose of describing the in-situ gasification process. The last report described studies being planned for off-gas quality for forward combustion in a coal/char mixture. Before starting these tests, plans were made to attempt to experimentally determine the gas composition as a function of distance from the reaction zone in a horizontal cylindrical combustor. It was felt that such tests would aid in determining the length of the oxidation and reduction zones and would thus provide information relevant to the design of a combustor for the purpose of studying off-gas quality both with and without water injection. To this end, a 10-ft. long combustor was fabricated from an eight inch ID steel pipe as shown in Fig. 1. Thermocouple and gas sample ports were provided at one foot intervals down the combustor. The combustor was wrapped in two layers of Kaowool ceramic insulation, each layer being two inches thick, in order to reduce heat loss.

Fig. 1. 10-Ft. Combustor

The combustor was packed with 100 pounds of coke. Diameters of the coke pieces ranged from 0.5 inches to 1.5 inches. A small layer of charcoal was packed at the end of the combustor to aid in ignition which was achieved by means of an oxygen/natural gas torch. During the ignition phase air was fed to the combustor (in the forward mode) at a rate of 0.5 SCFM. After ignition was achieved and the torch was turned off the air rate was set at 2.0 scfm and then, after three hours, at 1.25 SCFM. The total length of this run was 48 hours and gas samples were taken periodically as shown in Figs. 3 through 9 .

Upon unpacking the combustor it was found that the bouyant effects of the heated gases had caused the burn to proceed along the upper portion of the combustor as depicted in Fig. 2. This effect made interpretation of the sampling data as regards reaction and reduction zone lengths difficult if not impossible. Only about one-third of the coke charge was consumed.

Since the combustion zone overrode the coke charge, the sampling results are really inconclusive. It is felt that this effect will probably occur in other horizontal combustor tests so future gas quality tests are planned for vertical combustors. The results shown in Figs. 3 through 9 are presented for the record.

Fig. 2. Combustion Override of Char

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

III. THERMAL CONDUCTIVITY OF COKE

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Knowledge of properties of coke is of importance in the in-situ coal gasification during reverse combustion. Calculations of the temperature profile within a piece of coke during heating require the numerical values of the thermal conductivity and thermal diffusivity of coke and the variation of these quantities with temperature. At temperatures above 200°C there is very little information except for packed beds of coal and briquettes. Thermal conductivities of solids have to be established experimentally because they depend on many factors and are difficult to predict. For porous solids like coke the thermal conductivity is strongly dependent on void fraction, the pore size and mineral contents.

Different methods of determining the thermal conductivity of coke were mentioned in ASTM Standard Handbooks and other published papers. Examples are the use of envelope-type cold plates in thermal conductivity apparatus and various methods using steady state heat transfer for the determination of thermal conductivities. Fitch⁽¹⁾ used a heat source of constant temperature and a heat sink of variable temperature. A flat sample of constant cross-sectional area was put in between the heat source and heat sink. Another method which is chosen is called the hot wire method developed by E. F. Van Der Held, et al.,⁽²⁾ for the determination of the thermal conductivity of poor conductors and has been applied in the present case to determine also the thermal diffusivity.

A. METHODS OF MAKING COKE

One of the important criteria of coke used for this experiment is that the coke had to be made under constraint so as to simulate the condition underground. A rectangular steel container (Fig.10A) was first used as shown in Fig.10B. A perforated plate was welded to the lid to allow the volatile matter to pass through and still keep the contents under constraint. Pieces of coal were cut to fill the container completely. The furnace used to prepare coke was turned upwards. The container was slowly lowered and rested on the refractory of the furnace. The sample was filled with N_2 to prevent it from burning while

Fig. 10. Rectangular Coke Container

being heated. This was done with a vacuum pump to evacuate the air in the sample; N_2 was then admitted to the sample. The furnace was turned on and the coal was heated in a slow stream of nitrogen to about 1200°F . After the coke was made, however, there was great difficulty in removing the coke from the container without breaking up the coke.

A new cylindrical container (Fig.11) of a smaller size was designed having a lid both on top and bottom of the container. Coal was cut and placed in the container, the remaining space being filled with "steel-kon". The coal was pre-treated as before and heated in a slow stream of nitrogen. After the coke was made the top and the bottom lid were removed and the coke, still inside the cylinder, would be used for the hot-wire method. The latter procedure of coke making was found to be

Fig. 11. Cylindrical Coke Container

more convenient and it has the definite advantage of eliminating the need of getting the coke out of the container. Hence, the coke can be kept intact for use in the hot wire method.

B. HOT WIRE METHOD

The accuracy of the temperature-time readings largely depend on how well the thermocouple is in contact with the coke. Any air space between the coke and the thermocouple will cause erroneous readings. Hence, three different methods of embedding thermocouples are evaluated and compared.

A 2 mm hole was drilled centrally in a lump of coke perpendicular to the bedding plane, and a 26 gauge nichrome heater wire was placed in it. Two more holes were drilled parallel to the first, one as close as possible to it and the other 15 mm from it. (See Fig.12.) Twenty gauge butt-welded chromel-alumel thermocouples were passed right through the

Fig.12. Set-up for Hot Wire Method

coke, one wire from the top and the other from the bottom, with their junction in the middle. All wires were insulated from the coke by ceramic insulation. However, an air space exists between the weld and the coke, which can cause a large temperature gradient. (See Fig.13.) This can be remedied by applying epoxy or a second medium of known thermal conductivity around the weld. (See Fig.14.) However, this method increases the complexity of obtaining the true thermal conductivity of coke. A suitable second medium is hard to find since it has to be able to stand temperatures up to 1000°C and must have a constant thermal conductivity. Another alternative is to pack the air space with fine coke powder; this method proved to be more effective. However, it is noted that minute air spaces are present between the coke particles.

Fig.13. Thermocouple Placement in Coke Sample

Fig.14. Thermocouple Placement with Epoxy

The best alternative is to embed the thermocouples inside the coal before pyrolysis. As the coal is heated to 300-400°C, it begins to soften, swell and agglomerate. Hence, when coke is formed, the thermocouple welds will be in direct contact with the coke to provide accurate readings. Yet, one of the disadvantages of this method is that the thermocouples will be under chemical attack during coke formation and the high temperature will render the thermocouples brittle. Hence, they should be handled with care. Work on this technique is continuing.

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IV. REACTIVITY OF COKE

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M. D. McKinley

The reactivity of coke made from Alabama coal is being studied by a method developed by P. L. Walker, Jr. and his co-workers^{1,2} using a Fisher thermogravimetric analyzer (TGA). In order to compare our results with Walker's on other coal and in order to check out our apparatus and procedure a sample of PSOC 189 was obtained from Pennsylvania State University. This coal was used in some of Walker's tests, and several preliminary runs were made using it in our apparatus using the same procedure as Walker. After the apparatus was thoroughly checked out and calibrated, experiments were begun. Coke from PSOC 189 was made in the TGA by placing 40 mg of crushed coal (-40 + 100 mesh) in the sample pan and heating to 1000°C at a rate of 10°C/min under a N₂ atmosphere. The sample was maintained at 1000°C for 2 hours and then cooled to ambient temperature under N₂.

The reactivity of the coke made from PSOC 189 coal was measured by placing 5-10 mg (-40 + 100 mesh) crushed coke in the sample pan and heating to 500°C at 10°C/min under N₂. Fifteen minutes after the sample reached 500°C, air at 500 cm³/min was fed to the sample chamber and the weight of the sample vs. time was recorded. The reactivity is defined by

$$R_T = \frac{1}{W_o} \frac{dW}{dt}$$

when

R_T = reactivity at T °C,

W_o = initial mass of coke, MAFB, and

$\frac{dW}{dt}$ = rate of oxidation of sample during "linear period" of oxidation.

The oxidation rate during the linear period is determined as shown in Fig. 15.

Fig. 15. A Typical Oxidation Curve of Coke

The reactivity of PSOC 189 determined here was 1.51 compared to 1.2 as determined by Walker. The value of 1.51 was in line with other values we obtained during preliminary runs, and the difference is felt to be due either to slight differences in the coal samples or to a small difference in temperature calibration of the instruments. The temperature was found to have a strong effect upon reactivity.

Preparing coke samples in the TGA was found to be too slow because of the small sample size, so an alternate procedure was developed. Small pieces of coal were placed in a ceramic boat inside a quartz tube heated by a tube furnace. The temperature of the samples was raised by stages by 1000°C , which was held for about 3 hours. The pyrolysis took place under N_2 . The samples were then cooled under N_2 for storage. Eighteen samples of Alabama coke were prepared in this manner.

Reactivities for the Utley 1-A and Utley 1-B cokes with air at 500°C have been measured and were found to be 0.282 and 0.133, respectively.

Measurements of reactivities of selected Alabama cokes with air at 500°C are continuing, and reactivities to CO₂ at 900°C are planned.

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U.S. Bureau of Mines Publications 1910 - 1976

A total of 1328 references was compiled, and by use of key words was sorted into 33 different subtopics. The results of this work follow.

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