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FLUIDIZED-BED COMBUSTORS FOR COAL DRYING

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FLUIDIZED-BED COMBUSTORS FOR COAL DRYING

by

F. D. Friedrich*, I. G. Lutes** and C. M. Wheeler***

ABSTRACT

The paper explains that large-scale coal drying is generally accomplished with heat from oil- or gas-fired furnaces. The utilization of coal as a dryer fuel is handicapped by the fact that conventional technology, i.e., pulverized firing, frequently requires washed coal, whereas, from the viewpoints of economy and energy conservation, the use of unwashed coal would be preferable. Even greater benefits could be obtained if the large quantities of energy in coal washery rejects could be used for drying.

To demonstrate that these benefits are within reach, pilot-scale tests were conducted in a 2 ft diam fluidized-bed combustor using both a high-ash Alberta coal and simulated washery rejects of the same coal containing up to 70% ash. The paper explains that both coals were burned successfully at temperature conditions suitable for a commercial coal-drying system. It is concluded that existing fluidized-bed combustion technology, having no in-bed heat transfer surfaces and as presently used commercially for disposal of wood waste and sewage sludge, could be used to fire a coal dryer, using coal-washery rejects as fuel.

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INTRODUCTION

Fluidized-bed combustion has received a great deal of attention in the past few years as a potential technology for burning coals of low quality, for burning high-sulphur solid fuels with acceptable sulphur oxide emissions, for utilizing coal in plants too small to economically justify pulverized firing, and for a variety of high-efficiency combined cycles. Advantages expected include highly efficient heat transfer to steam-generating tubes immersed in the bed, elimination of the need to pulverize the coal, and the ability to control combustion temperatures below the melting temperature of the ash. Undoubtedly fluidized-bed combustion will play a very important role in the North American energy picture over the next few decades but it is presently viewed as an embryo technology. At the time of writing there is on this continent only one prototype fluidized-bed-fired boiler incorporating most of the aforementioned advantages[1/].

It appears to be sometimes overlooked that a simple form of fluidized-bed combustor, available from a number of manufacturers, has been successfully employed on an industrial scale for the past ten years. These units are primarily waste destructors; they are commonly refractory-lined and have no heat transfer surfaces in the bed; heat recovery, if employed at all, being by means of downstream waste heat boilers. They typically burn fuels such as wet wood waste, sewage sludge, cereal husks and various industrial wastes and, while they accomplish this successfully, their application to steam generation with high quality fuels is limited by problems of bed temperature control. With no in-bed extraction, it is necessary to resort to high excess air or water injection to keep bed temperatures below the ash fusion point and, in the context of efficient steam generation, both these expedients are unacceptable.

There are, however, some industrial combustion processes in which high excess air is not a handicap. One such application is the supply of heat for coal drying, where the heating medium is a mixture of air and flue gas.

1/ Gamble, Robert L., "Design of the Rivesville Multicell Fluidized-bed Steam Generator" pp 133-151 Proceedings of the Fourth International Conference on Fluidized Bed Combustion Dec 9-11, 1975. Published by the Mitre Corporation Westgate Research Park, McLean, Virgina, U.S.A. 22101

It appeared that existing designs of industrial-scale fluidized-bed combustors might be suitable for burning coal in this application and incentive to do so was substantially increased by recent legislation in Alberta prohibiting new coal-drying installations from using oil or natural gas as fuel. Coal can, of course, be burned using the long established technology of pulverized firing, but this technique, being sensitive to ash quantity and properties, in many cases would require the use of washed rather than raw coal. Also, with pulverized firing, there is no possibility of using coal wastes, for example, washery rejects, as fuel. The time therefore seemed ripe to investigate the capabilities of a fluidized-bed combustor.

THE SCOPE OF THE INVESTIGATION

In the Spring of 1976, the federal Department of Energy, Mines and Resources initiated a contract involving the Department, Copeland Systems Ltd., and Luscar Ltd. Under its terms, Copeland Systems Ltd., with departmental sponsorship, carried out combustion tests with unwashed Luscar coal in a pilot-scale (2 ft diam) fluidized-bed combustor. Also on the basis of the information thus obtained, they subsequently prepared preliminary designs and cost estimates for three sizes of fluidized-bed combustion systems, capable of producing hot gases for coal drying at the rate of 220 million, 110 million and 55 million Btu/hr. Luscar Ltd. contributed to the program by supplying and shipping the coal for the pilot-scale combustion tests.

The present paper describes the performance and results of the pilot-scale combustion tests. These were conducted under the direction of the authors during the period from June 28th to July 1st, 1976, in a facility designed by Copeland Systems Ltd. and located at Hazen Research Inc., Golden, Colorado.

THE TEST FUELS

The terms of the agreement under which the research program was carried out required combustion tests with unwashed Luscar coal from Coal Valley, Alberta. Luscar Ltd. accordingly shipped drums containing 7000 lb of coal, crushed to $-\frac{1}{4}$ in., to the pilot plant in Golden, Colorado. Analytical data on the coal are given in Table 1 and Figure 1.

During the course of the combustion tests with coal it became clear that no major difficulties need be expected, and it was decided to expand the scope of the tests to evaluate the feasibility of burning coal washery rejects. It was felt that this could be done by burning a suitable mixture of coal and fly ash, using fly ash from the coal already burned. Simon-Carves of Canada Ltd. in Toronto kindly provided information on the probable composition and quantity of the various reject streams to be expected from a washery working with Luscar coal, from which the following composite analysis was computed:

Moisture	%	8.7
Ash	%	51.2
Btu/lb		3557

Calculation showed that the computed ash and heating values could not be met simultaneously by mixing fly ash with the sample coal. Therefore, two samples of simulated washery rejects were prepared; one to match the ash content, the other to match the calorific value of the computed analysis for washery rejects. The measured analyses of these mixtures are given in Table 1.

To facilitate mixing the -¼ in. coal with the much finer fly ash, both materials were passed through a crusher which reduced the coal to -10 mesh. The coal feeders on the pilot-scale combustor are not capable of handling wet fuel, therefore water to match the 8.7% moisture content of the computed analysis could not be added directly to the simulated washery rejects. Instead it was decided to spray an equivalent amount of water onto the bed during combustion. The amount of spray water was calculated to be 10% by weight of the feed rate, less the moisture in the coal, which was assumed to be 5%.

THE PILOT-SCALE FLUIDIZED-BED COMBUSTOR

The fluidized-bed combustion system used for the tests is shown schematically in Figure 2. The reactor column has an inside diameter of 2 ft and a height of 7 ft measured upward from the distributor plate. The disengagement section, located immediately above it, has an inside diameter of 3 ft and a height of 6 ft. A windbox, connecting at right angles to the reactor

TABLE 1

Analyses of the Luscar Test Fuels

		Unwashed Coal	Simulated Washery Rejects (44% Ash)	(72% Ash)
Proximate Analysis				
Moisture	%	4.3	1.7	1.5
Ash	%	18.3	43.8	72.5
Volatile Matter	%	30.5	21.7	10.3
Fixed Carbon	%	46.9	33.8	15.7
Ultimate Analysis				
Carbon	%	60.5		
Hydrogen	%	4.0		
Sulphur	%	0.3		
Nitrogen	%	1.0		
Oxygen	%	11.6		
Ash	%	18.3		
Higher Heating Value:	Btu/lb	10,400	6,650	3,650

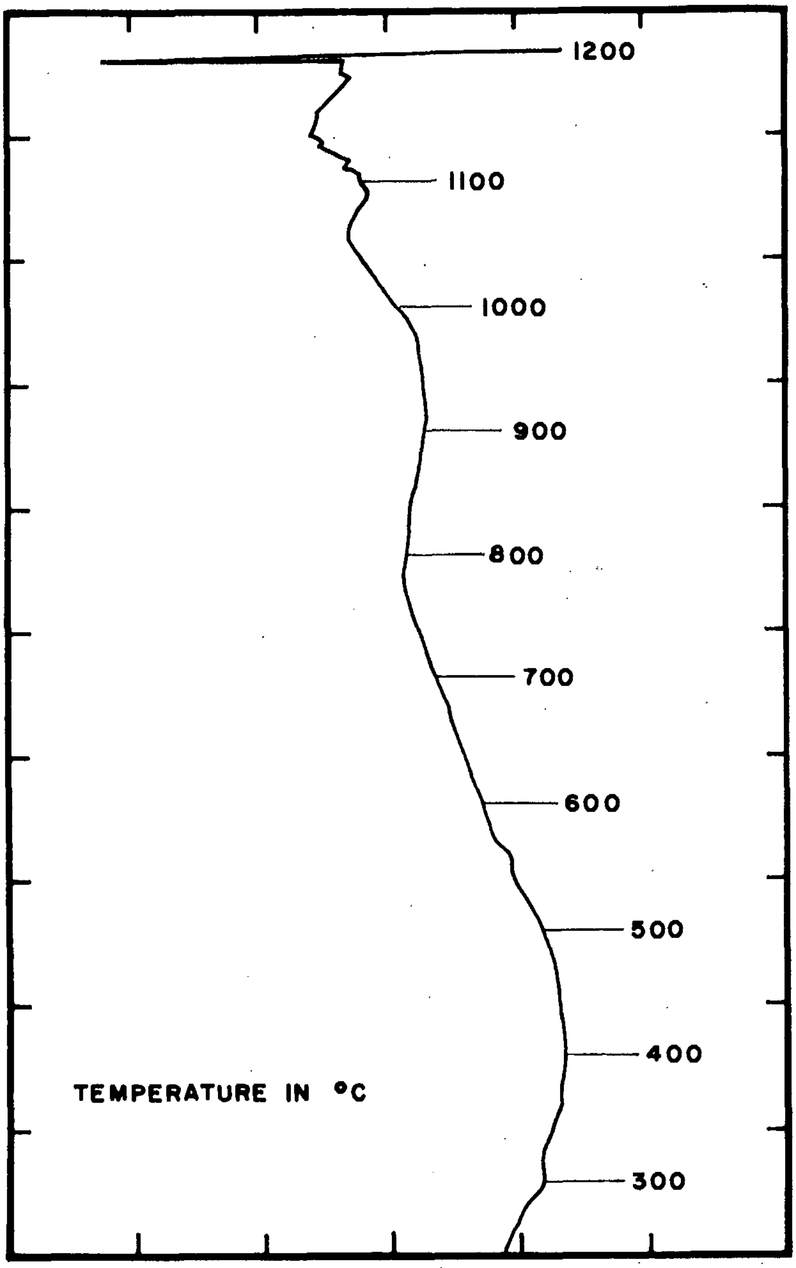

FIGURE 1. Differential thermal analysis for a sample of the Luscar test coal

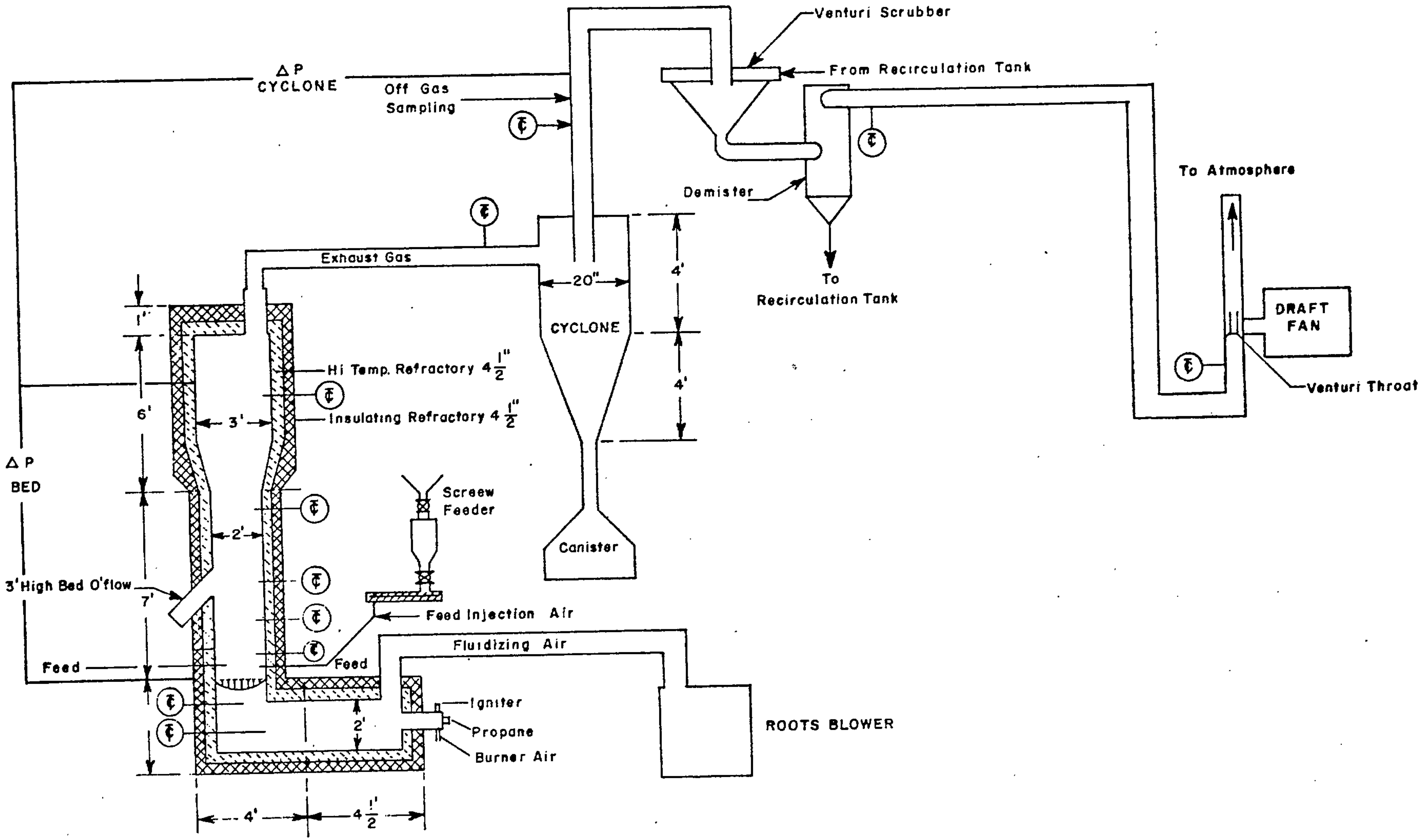

FIGURE 2. Schematic layout of pilot-scale fluidized-bed combustor system

column below the distributor plate, serves as combustion chamber for a propane burner which pre-heats the bed to ignition temperature. The reactor column, disengagement section and windbox are all lined with refractory. Air for combustion and fluidizing is supplied to the windbox by a Roots blower.

Silica sand, double-screened to 20 x 30 mesh, is normally used as starter bed material. The reactor is equipped with two coal feeders, each consisting of a metering screw and a pneumatic injector which blows the coal into the bed slightly above the distributor plate. Bed material can be removed by means of a valved overflow line connected to the reactor column 3 ft above the distributor plate.

Combustion gases leave the top of the disengagement section and enter a small, single-cyclone dust collector. They then pass through a venturi scrubber, a de-mister, and an induced draft fan before being exhausted to the stack. The cyclone hopper terminates in an interchangeable cannister arrangement which makes it possible to determine quantity and quality of particulate carry-over. Material escaping the cyclone but trapped by the scrubber can be assessed by sampling the water which is recirculated through the scrubber.

Flue gas samples are normally drawn from the cyclone discharge. The pilot plant is equipped with a continuous oxygen analyzer; other gas components are analyzed periodically by means of a gas chromatograph. Mass flow meters, manometers and thermocouples, located as shown in Figure 2, complete the instrumentation.

The combustor is normally uncooled but a U-shaped cooling loop made up of 1-in. pipe can be inserted into the bed if desired. Its primary function is to provide a measure of heat transfer rates. Bed cooling can also be accomplished by means of an overbed water spray system. Flow to both the cooling loop and the spray system is measured by rotameters.

TEST PROCEDURE

A total of ten tests were carried out. These were performed in a continuous series, with no shutdown between the, and were of varying length to suit the diverse objectives of each test. Seven tests were carried out using coal as supplied at $-\frac{1}{4}$ in. as fuel; three were carried out with mixtures of coal and fly ash which were prepared to simulate coal washery rejects. Initially the reactor was charged with 800 lb of silica sand, which gave a settled bed depth of 34 in.

Test 1 was begun by fluidizing the sand bed, preheating it to 600°C by means of the propane burner in the windbox, then initiating coal feed and gradually shutting off the preheater. The purpose of the test was to establish the feed rate required to maintain a bed temperature of 850°C. These conditions were maintained for approximately 24 hr, which gave the entire system ample time to reach thermal equilibrium.

In Test 2, bed temperature was brought to 950°C. This was accomplished by maintaining the same air flow as before, and increasing the feed rate only slightly. The test lasted 10 hr.

In Test 3, both feed rate and air flow were increased to maintain a bed temperature of 1060°C. Superficial fluidizing velocity at this temperature was 3.5 fps. These conditions were maintained for 17 hr.

In Test 4, which lasted $5\frac{1}{2}$ hr, air flow was increased to approximately double the superficial fluidizing velocity, while maintaining the same bed temperature (1060°C).

In Test 5, an attempt was made to establish the maximum superficial fluidizing velocity compatible with a bed temperature of 1050°C. The maximum output of the fluidizing air blower was reached at a velocity only slightly higher than that achieved in Test 4. The test lasted 3 hr.

Test 6 was intended to establish the maximum possible feed rate, using water sprays to control bed temperature at 1060°C. Feed rate was increased by about 7% over Test 5, and still left an ample margin of excess air in the flue gas. These conditions were maintained for approximately 13 hr.

Test 7 was a brief ($1\frac{1}{2}$ hr) test with simulated washery rejects having 44% ash. Water was sprayed onto the bed at a rate equivalent to 10% moisture in the feed material, assuming that the raw coal contained 5% moisture. Bed temperature was maintained at 1065°C and superficial fluidizing velocity was 3.2 fps.

Test 8 was carried out with the same fuel and the same bed temperature as Test 7 but the feed rate was increased and the superficial fluidizing velocity was doubled. The test continued for 1 hr.

Test 9 was carried out with a second mixture of simulated washery rejects, this time having an ash content of about 72%. Again water was injected at a rate equivalent to 10% of the feed material. The feed rate was adjusted to maintain a bed temperature of 1050°C, with a superficial fluidizing velocity of 5.2 fps. The test lasted $1\frac{1}{2}$ hr.

Test 10 was carried out with coal, and was intended to establish the bed temperature at which ash agglomeration would commence. Over a period of about 7 hr, coal feed was increased from 55 to 85 lb/hr, while air flow was adjusted as necessary to maintain 2.4% O_2 in the flue gas. Bed temperatures rose gradually from 1050°C to 1200°C, whereupon it became evident that agglomeration was occuring in the bed, and the reactor was shut down.

Throughout the tests, bed temperatures and pressures were monitored continuously, while the cyclone exhaust gases were analyzed continuously for O_2 and periodically for O_2, SO_2, CO, CO_2, N_2, NO_x and total hydrocarbons. The cyclone canister was emptied hourly or oftener if necessary; the collected fly ash was weighed to provide a material balance and sampled to establish carbon content. The scrubber water was also sampled during each test to provide a material balance and to determine the particulate loading.

The most significant test conditions and results are summarized in Table 2.

TABLE 2

Summary of Test Conditions and Results

Test No.	1	2	3	4	5	6	7[1]	8[1]	9[2]	10
Firing Rate 1000 Btu/ft^2hr	125	132	196	285	313	322	222	318	290	233
Superficial Fluidizing Velocity, ft/sec[3]	2.7	2.9	3.5	7.2	7.6	6.9	3.2	6.7	5.2	3.2-5.2
Bed Temp, °C	865	950	1060	1060	1050	1060	1065	1065	1050	1130-1200
Bed Pressure Drop, in. Water Column	34	34	31	33	33	33	35	36	38	37
Spray Cooling Water US gpm	0	0	0	0	0	0.156	0.016	0.024	0.018	0
Material Elutriated, % of Feed	12.2	19.4	15.8	24.9	22.2	20.3	56.1	27.2	38.2	17.0
Carbon in Cyclone Product, % of Feed	0.157	0.276	0.236	0.045	0.067	0.068	0.73	0.0545	0.191	0.12
O_2 in Flue Gas %	10.4	5.6	1.6	8.0	8.4	4.4	2.6	5.0	2.4	2.4
Hydrocarbons in Flue Gas, %	0.17	0.41	0.31	0.05	0.51	0.005	-	-	-	-
NO_x in Flue Gas ppm	280	360	240	300	310	610				
SO_2 in Flue Gas	less than 20 ppm for all tests									
CO in Flue Gas	less than 10 ppm for all tests									

1/ Simulated washery rejects, containing about 44% ash, 10% moisture, 6100 Btu/lb.

2/ Simulated washery rejects, containing about 72% ash, 10% moisture, 3340 Btu/lb.

3/ Calculated at bed temperature.

DISCUSSION OF RESULTS

Combustion Tests with Coal (Tests 1 through 6)

It is noteworthy that the pilot-scale fluidized-bed combustor successfully burned fairly high quality coal with good control of bed temperature and without significant heat extraction in the bed. Firing rate ranged from 125,000 Btu/ft^2hr to 313,000 Btu/ft^2hr without water cooling. When cooling by means of a water spray was employed, firing rate was increased to 322,000 Btu/ft^2hr and could have gone higher. This suggests that a fluidized-bed combustor with no in-bed heat extraction can be operated with a turn-down range of about 2.5 to 1. However, whether this would be true for large-scale systems is questionable, because of differences in surface-to-volume ratio.

Only a rough correlation exists between superficial fluidizing velocity and the weight of material elutriated from the bed. As would be expected, the weight of material collected tended to increase with increasing velocity. At velocities in excess of 7 ft/sec, elutriation amounted to nearly 25% of feed.

One would expect elutriated carbon, measured as percentage of feed, to be inversely proportional to both bed temperature and excess air level. While this is generally verified by the data in Table 2, several inconsistencies exist, and no clear-cut correlation was found.

Hydrocarbons in the flue gas ranged from 1/20 to 1/2 of 1%, and NO_x ranged from 240 to 360 ppm in Tests 1 through 5. In Test 6, the injection of water for cooling coincided with an order-of-magnitude reduction in hydrocarbons and a doubling in NO_x.

Combustion Tests with Simulated Washery Rejects (Tests 7, 8 and 9)

Although these tests were all of short duration because of the work involved in preparing the mixtures of coal and fly ash, they were adequate to demonstrate that high-ash material could be successfully burned at firing rates comparable to good-quality coal. For example, the material containing 44% ash (6650 Btu/lb) was burned at a rate of 318,000 Btu/ft^2hr and the and the material containing 72% ash was burned at a rate of 290,000 Btu/ft^{2}hr. In all three tests bed temperature was maintained at or above 1050°C.

Percentage of material elutriated was very high, 56% in the case of Test 7, because the fly ash added to the coal to simulate washery rejects was, of course, fine material that had already been elutriated. Furthermore, the coal was crushed to -10 mesh, to facilitate mixing the fly ash. Presumably elutriation on this scale would not necessarily occur with real washery rejects.

Test 7, in which the bed temperature was maintained at 1065°C and superficial fluidizing velocity was 3.2 ft/sec, was the only test of the entire series in which carbon carry-over approached 1% of feed. This may have been partly caused by the relatively low excess oxygen level of 2.6%. In Test 8, with the same feed material and the same bed temperature but approximately double the velocity and double the excess oxygen, carbon carry-over was about 1/20 of 1%. In Test 9, with a fuel containing 72% ash, excess oxygen level was 2.4% but carbon carry-over was less than 1/5 of 1%.

Ash Agglomeration Test with Coal (Test 10)

Starting from a bed temperature of 1050°C, coal feed and air were gradually increased, while oxygen in the flue gas was maintained at 2.4%.

When the bed temperature reached 1135°C, the quantity of material collected in the cyclone began to decrease, indicating that some ash was agglomerating in the bed. When the bed temperature was increased to 1180°C, the material collected in the cyclone dropped sharply, indicating that a substantial quantity of ash was fusing in the bed. There was, however, no change in pressure drop through the bed as operation at this temperature continued. When bed temperature was subsequently increased to 1200°C, bed pressure drop began to decrease, indicating that the bed was no longer completely fluidized.

Fuel feed was then shut off but the flow of fluidizing air was maintained while the bed cooled. Subsequent examination of the bed material revealed numerous particles approximately 1 in. in diameter. These were glassy on the outside but porous on the inside, and of low density. Their appearance and structure were consistent with the wide range between initial softening temperature and fluid temperature that is typical of Luscar coal ash.

CONCLUSIONS

The most important conclusion from this brief investigation is that, by means of presently available fluidized-bed combustors, either unwashed coal or coal washery rejects can be used as a source of heat for coal drying. Compared to a pulverized-fired combustor burning washed coal, the economic advantages are impressive, as shown by the following data calculated for a system requiring an input of 200 million Btu/hr, and having an annual load factor of 0.7.

1. Washed coal, assuming 12,000 Btu/lb and $40/ton.

   Annual Consumption: 51,000 tons — Annual Cost: $2.04 million

2. Unwashed coal, assuming 10,000 Btu/lb and $25/ton.

   Annual Consumption: 61,400 tons — Annual Cost: $1.53 million
   Annual Savings Over Washed Coal: $0.51 million

3. Washery rejects, assuming 3560 Btu/lb, no cost.

   Annual Consumption: 160,000 tons — Annual Cost: nil
   Annual Savings Over Unwashed Coal: $1.53 million
   Annual Savings Over washed Coal: $2.04 million

The foregoing figures are admittedly rough estimates; a system burning washery rejects would require additional capital equipment to handle and prepare them, but this would be partially offset by a reduction in disposal costs of the rejects, by environmental benefits, and by energy conservation considerations.

From the data obtained during the tests, it appears that a fluidized-bed combustor with no heat extraction in the bed can burn 10,000 Btu/lb coal with a turndown ratio of about 2.5 to 1. For a bed temperature of 1050°C and cooling only by combustion air, maximum firing rates appear to be about 200,000 Btu/ft^{2}hr with 1.6% oxygen in the flue gas, and about 315,000 Btu/ft^{2}hr with 8.4% oxygen in the flue gas. Similar firing rates appear to be achievable with washery rejects having a much lower calorific value.