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COMBUSTION PERFORMANCE OF BLENDS OF A REACTIVE AND AN UNREACTIVE CANADIAN COAL

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COMBUSTION PERFORMANCE OF BLENDS OF A REACTIVE AND AN UNREACTIVE CANADIAN COAL

by

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ABSTRACT

Pilot-scale boiler trials were conducted to study the combustion, deposition and ash emission characteristics of blends of two western Canadian bituminous coals. Both coals contained less than 0.5% sulphur, but one was unoxidized, high volatile and highly reactive, whereas the other was oxidized, low-volatile and relatively unreactive.

The blending trials, which were designed to establish whether the combustion efficiency of the low-reactivity coal could be enhanced by blending with a more reactive coal, showed that the carbon carry-over and fly ash loadings were directly dependent on the proportion of unreactive coal in each blend. As predicted the slagging and fouling propensity of all coal blends was low as was the potential for low temperature corrosion.

Emission levels of SO_x and NO_x using opposed tangential burners were within current North American guidelines for new plants.

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INTRODUCTION

Many utilities and industries that burn thermal coal from multiple sources have experienced a number of boiler operational problems due to wide fluctuations in the combustion reactivity of the coals being supplied. These difficulties have been controlled to a certain extent by judiciously blending reactive and unreactive coals, either on-site or prior to delivery, to ensure that the quality of the coal feed to the furnace does not exceed prescribed limits.

Based on past experience with thermal coals, volatile contents of less than 20% coupled with inert maceral contents greater than 65% are often indicative of poor combuston reactivity.

In the combustion trials described, blends of two commercially available coals from western Canada were burned in a pilot-scale research boiler under conditions representative of those existing in large utility boilers. The two coals, which had significantly different grindabilities and combustion reactivities, were bituminous in rank and had similar calorific values.

COAL PROPERTIES

The analyses of the two parent coals and their ASTM ash is given in Table 1 and the petrographic data for each coal is given in Table 2. Relative to the high-volatile coal, the low-volatile coal was characterized by higher ash content, slightly higher sulphur, higher grindability and higher amounts of inert macerals.

Figure 1 shows the thermograms for the parent coals. In general, the shorter the time for complete burn-out and the higher the peak devolatization rate, the more reactive the coal. The high-volatile coal was therefore, much more reactive than the low-volatile coal which not only had a lower peak devolatization rate but had a much longer burn-out time. The marked decrease in devolatization rate for the low reactivity or non-reactive coal, shown by the deep valley in its thermogram, appears to be characteristic of all oxidized coals. Research is now in progress to determine the significance of this anomaly with oxidized coal and if possible to clarify its role in combustion reactivity.

The coal analyses, together with the petrographic and the thermogravimetric data, strongly indicate that ignition, flame stability and carbon burn-out of the unreactive coal alone would be poor to marginal when burned in equipment designed for more reactive coals of the same rank. Although not reported, the coal analyses for each blend closely approximated the values obtained by pro-rating the proportion of the parent coals in the mix.

The ash melting characteristics of the parent coals, however, cannot be pro-rated for coal blends, because combinations of high ash fusion mineral constituents from different sources may produce unpredictable low-melting eutectics during combustion. The ash fusion data for both the parent coals and the blends shown in Table 3, strongly suggest that such eutectics will not form with blends of the two parent coals.

RESEARCH FACILITY AND PROCEDURES

The combustion trials were carried out in the CCRL pulverized-fired research boiler using opposed, tangentially-mounted burners, as illustrated in Figure 2. The boiler which is direct fired, is designed for a coal input of 2.5 GJ/h (0.7 MWt) and a steam output of 730 kg/h at 690 kPa at full load. It is described in detail elsewhere (1).

Each trial lasted 6 h to 8 h, with the following parameters being held constant:

(a) coal fineness - 75% <74 mμ minimum
(b) heat input - 2.3 GJ/h
(c) O_2 in flue gas - 4.5%

Moisture levels of the ash-fired coal were consistently less than 1% after pulverizing.

On the day following each trial, all fireside surfaces were examined for slagging and ash samples from selected locations throughout the boiler were sampled and analyzed. In addition, the ash from the furnace, boiler and dust collector hoppers was collected and weighed.

Parameters of combustion performance that were measured during each trial included:

1. Proximate and ultimate analysis of the crushed minus 3.2 mm coal feed.
2. Fineness and moisture content of the pulverized coal.
3. Flue gas analysis.
4. Fly ash loading, combustible content and electrical resistivity.
5. Ash fouling and slagging tendency.

EXPERIMENTAL RESULTS

The boiler operating conditions, shown in Table 4, remained essentially constant throughout each combustion trial and confirmed that the handling characteristics of all coals were excellent. The flames during each trial were bright, clean and extremely stable under the experimental conditions selected and an oil support flame was required for only about five minutes after the start of each trial.

The blended coals, as would be expected from their lower volatile matter and lower reactive maceral contents, produced slightly longer flames and slightly higher gas temperatures at the furnace exit than did the reactive coal. As shown in Table 5, the pulverized reactive coal was much coarser than the pulverized coal blends containing the highly friable unreactive coal.

Flue Gas Emissions

Sulphur oxide emissions, which were well below North American guidelines for new sources, were close to theoretical indicating little or no fixation of sulphur by alkaline cations in the coal ash. Nitrogen oxide emissions, although close to the North American guidelines, tended to increase slightly and progressively as the proportion of reactive coal increased. These nitrogen oxide levels are to some extent dependent on fuel nitrogen but the absolute levels emitted are also influenced by burner aerodynamics, furnace heat release rates and the volatile fuel nitrogen.

Sulphur trioxide levels were in all cases less than 1 ppm and would have little potential for corrosion of low-temperature heat exchange surfaces.

Fly Ash

Figure 3 shows that the fly ash loadings and the combustible in fly ash of the coal blends increased almost linearly with additions of unreactive coal, and that the combustion efficiencies were reflective of the relative proportions of the parent coals present. These efficiencies will, however, be higher in full-scale utility boilers, where relative to the pilot-scale boiler, residence times are much longer and flame quenching is less severe.

The graphical data also revealed that the combustion performance or degree of burn-out of the finely-ground oxidized coal component was essentially unaffected by blending with the coarser unoxidized coal. This suggests that oxygen preferentially reacted with the volatiles evolved from the coarser, reactive coal leaving the finer, unreactive coal to burn in an oxygen depleted atmosphere. Nonetheless, it is evident that blends containing up to 40% of the highly oxidized coal can be burned successfully in pulverized-fired boilers designed for reactive coals. Higher amounts of oxidized coal in a blend, could be tolerated in furnaces with refractory-lined flame zones.

Figure 4 shows that the mass median diameter of the fly ash decreased progressively from 10 μm for the unoxidized coal alone to 5 μm for the 60/40 blend, the highest ratio of oxidized to unoxidized coal. Since, the decreases in mass median diameter for the blends were accompanied by increases in combustible content, it would appear that the particle size distribution of these fly ashes can be directly related to the high grindability index of the oxidized coal.

In-situ and bulk resistivities for fly ash from the unoxidized and the blended coals are plotted against combustible content in Figure 7. With combustible contents below 6%, the ash resistivity values were all about 10^{12} ohm-cm indicating that collection in an electrostatic precipitator designed for higher sulphur coals may be difficult due to back corona effects. Conversely, with more than 6% combustible, the ash resistivities fell suddenly to 10^5 ohm-cm, well below the optimum range of 10^8 - 10^{10} ohm-cm. At low resistivity values, precipitated fly ash could easily be re-entrained in the gas stream, giving poor precipitator performance.

It is clear from the resistivity measurements that both the reactive coal and the coal blends will require liberally-sized specific collection areas for good precipitator performance.

Ash Deposits

An inspection of the boiler fireside surfaces after the blended coal trials showed a moderate build-up of loose, sintered ash in the furnace bottom. The unoxidized coal, however, produced adherent deposits on the refractory surfaces which had been partially melted. These observations were consistent with the empirical indicators for slagging potential, based on the ash composition and the ash fusion temperatures, shown in Table 6.

All of the coals produced a light, powdery build-up of ash on the 550°C surfaces of the simulated superheater tubes. The low fouling tendency of the unblended and blended coals all of which contained 0.5% sodium oxide confirmed the rating predicted by the empirical classification given in Table 7.

Chemical analyses and ash fusion temperatures of the ash deposits collected from the furnace and superheater surfaces at the end of each trial were not significantly different from the input coals, indicating that the formation of low-melting eutectics due to selective enrichment of ash components during combustion was minimal. Empirical relationships, based on input properties of the parent coals and their proportions in a blend will therefore provide a good indication of fouling and slagging tendencies for blend ratios other than those evaluated.

CONCLUSIONS

1. Petrographic, thermogravimetric and ASTM analysis of each of the parent coals provided a reliable pre-combustion assessment of possible operational problems with flame stability, carbon burn-out, ash deposition and stack gas emissions.

2. The pilot-scale combustion trials showed that the unreactive coal, when blended with more than 40% of the reactive coal, should burn readily and efficiently in pulverized-fired boilers of conventional design.

3. The burn-out of the coal blends corresponded to thermal losses ranging from 5.1% to 1.8% of the heat input. In full-scale boilers, these losses would probably be less than 2% because of longer furnace residence times.

4. The burn-out of unreactive, low-volatile coals, even if more finely ground, may not improve by blending with reactive, highly volatile coals because of preferential reaction between available oxygen and easily evolved volatile matter.

5. Both the ash slagging and fouling tendency of the coal blends was low. Empirical indicators of ash behaviour, based on the analysis of the parent coal ash, showed good agreement with the experimental observations because selective deposition of ash constituents through the boiler during combustion was minimal.

6. The high electrical resistivity of the fly ash from the coal blends indicated that flue gas conditioning agents or liberally-sized collection areas may be required for efficient precipitator operation.

7. Sulphur and nitrogen oxides emissions were within North American guidelines for new sources and low-temperature corrosion potential due to SO_3 is very low.

ACKNOWLEDGEMENTS

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REFERENCES

1. Friedrich, F. D., Lee, G. K. and Mitchell, E. R. "Combustion and fouling characteristics of two Canadian lignites"; Trans ASME J Eng Power, New York, Vol 4; 127-132; 1972.

Table 1 - Coal analysis

Analysis	Coal	
	Unreactive	Reactive
Proximate, wt % (dry basis)		
Ash	18.70	10.72
Volatile Matter	19.84	38.57
Fixed Carbon	61.46	50.71
Ultimate, wt % (dry basis)		
Carbon	69.80	72.21
Hydrogen	3.80	4.16
Sulphur	0.30	0.25
Nitrogen	0.89	1.04
Ash	18.70	10.72
Oxygen (by diff)	6.51	11.63
Calorific Value (MJ/kg)	27.45	28.22
Hardgrove Index	81	42
Rank	LV bituminous	HV bituminous
Moisture, wt %		
As Received	2.9	8.0
As Fired	1.0	4.3
Ash Analysis, wt %		
SiO_2	58.81	57.01
Al_2O_3	33.55	16.08
Fe_2O_3	2.53	5.14
TiO_2	1.41	0.46
P_2O_5	0.60	0.22
CaO	0.99	11.96
MgO	0.41	1.15
SO_3	0.32	3.57
Ng_2O	0.08	0.38
K_2O	0.72	0.73
BaO	0.08	0.62

Table 2 - Petrographic data

Maceral Type	Coal	
	Unreactive	Reactive
Reactive, % volume		
Resinite	<1	<1
Exinite	<1	7
Tellinite	<1	<1
Vitrinite	5	47
Semi-fusinite (low refl)	17	<1
Sub-total	23	55
Inert, % volume		
Fusinite	5	16
Semi-fusinite	17	15
Micrinite (massive)	2	5
Oxidized vitrinite	43	<1
Mineral Matter	10	9
Sub-total	77	45
Total	100	100

Table 3 - Ash fusion temperatures

	Coal Blends				
ASTM Fusion Temp, °C	100/0	60/40	40/60	20/80	0/100
Reducing Atmosphere					
Initial	>1480	1440	1350	1295	1150
Spherical	>1480	>1480	1450	1415	1295
Hemispherical	>1480	>1480	>1480	>1480	1400
Fluid	>1480	>1480	>1480	>1480	>1480
Oxidizing Atmosphere					
Initial	>1480	>1480	1360	1345	1205
Spherical	>1480	>1480	>1480	1430	1340
Hemispherical	>1480	>1480	>1480	>1480	1430
Fluid	>1480	>1480	>1480	>1480	>1480

Table 4 - Boiler operating conditions

Operating Conditions	Coal Blends 0/100	60/40	40/60	20/80
Coal Firing Rate, kg/h	76	85	81	81
Thermal Input, MJ/h	2053	2337	2253	2226
Steam				
Flow, kg/h	370	410	385	400
Rate, kg steam/MJ Input	0.180	0.175	0.171	0.180
Flue Gas				
Flue Gas Exit Temp, °C	175	165	165	170
CO_2 %	14.0	14.4	14.4	14.4
O_2 %	4.7	4.8	4.6	4.5
CO %	0.01	0.01	0.01	0.01
NO ppm	760	690	770	740
SO_2 ppm	165	165	165	170
SO_3 ppm	1	1	1	1

Table 5 - Particle size distribution of pulverized coals

Mesh Size	Diam μm	Mass % Above Size 0/100	60/40	40/60	20/80
100	149	0	0.3	0	0
140	105	3	2.3	1	1
200	74	24	14	7	14
325	44	69	66	64	50
400	37	73	75	69	54

Table 6 - Slagging propensity of coal ashes

Slagging Propensity	Reference Limits	Coal Blends 100/0	60/40	40/60	20/80	0/100
<u>Base/Acid (BA) Ratio</u>						
Low	0.15	0.05	0.11	0.14	-	-
Medium	0.15-0.30	-	-	-	0.17	0.26
High	0.27-0.50	-	-	-	-	-
Severe	0.50	-	-	-	-	-
<u>Potential Slagging</u> (Tps), °C						
Low	1340	1480	1448	1376	-	-
Medium	1340-1230	-	-	-	1324	-
High	1230-1150	-	-	-	-	1178
Severe	1150	-	-	-	-	-

Table 7 - Fouling potential of coal ash

Fouling Category	% Na_2O in Ash*
Low	<2
Medium	2.0 - 6.0
High	6.0 - 8.0
Severe	>8.0

*For $\frac{CaO + MgO}{Fe_2O_3} > 1$ {all unblended and blended coal ash and their superheater deposits}

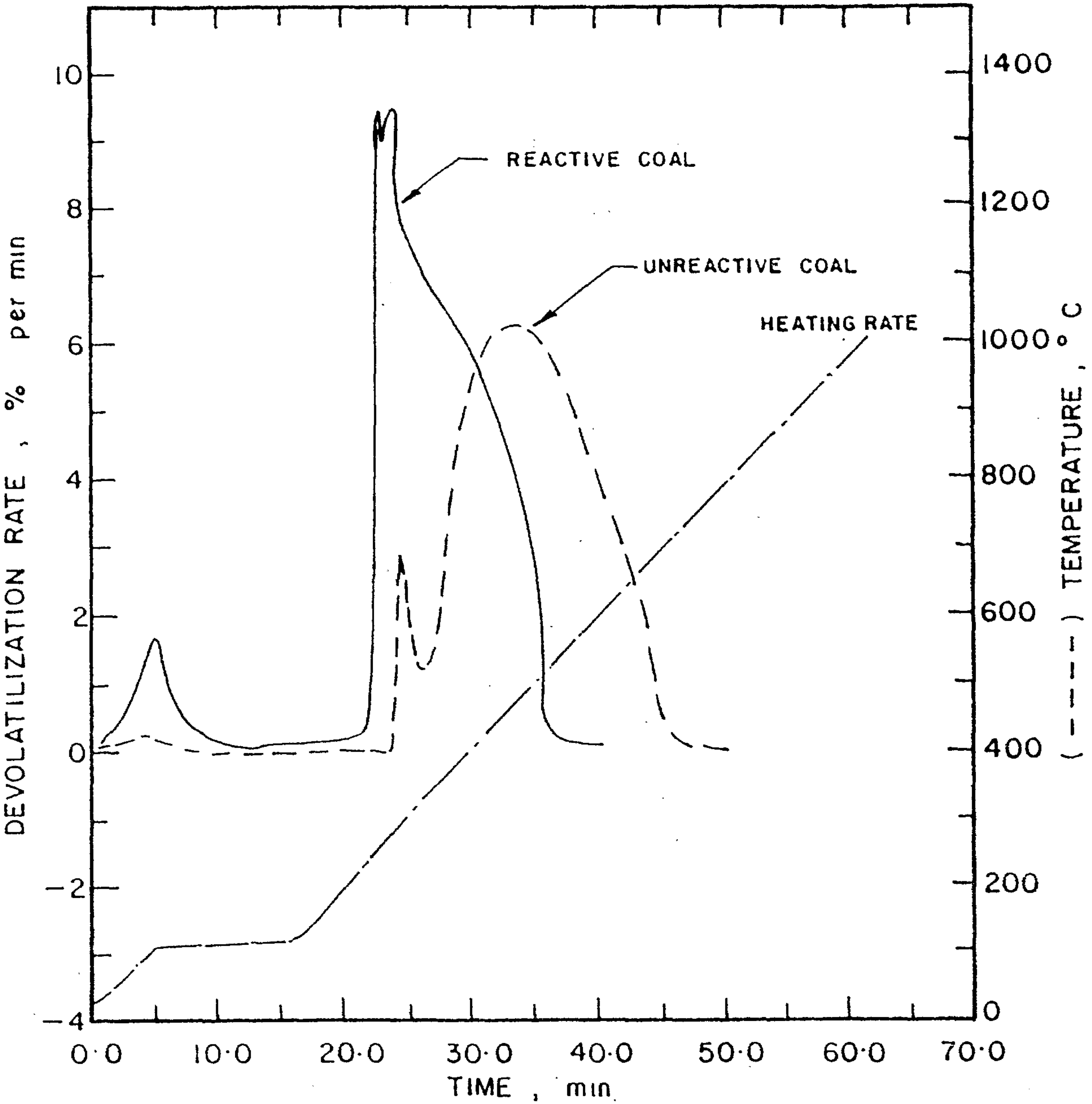

Fig. 1 - Thermogravimetric analysis of reactive and unreactive coals

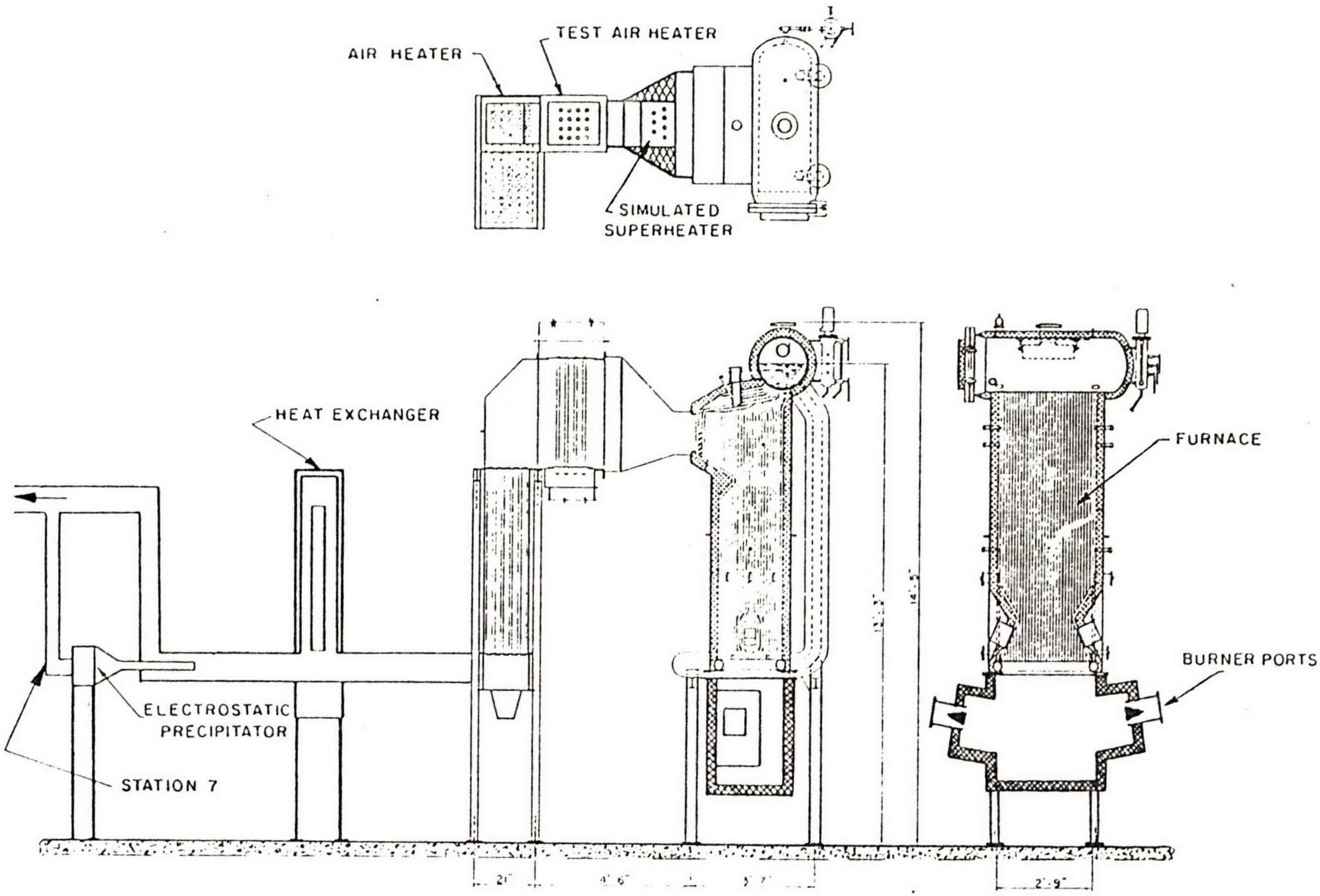

Fig. 2 - CCRL pilot-scale research boiler used for coal blending trials

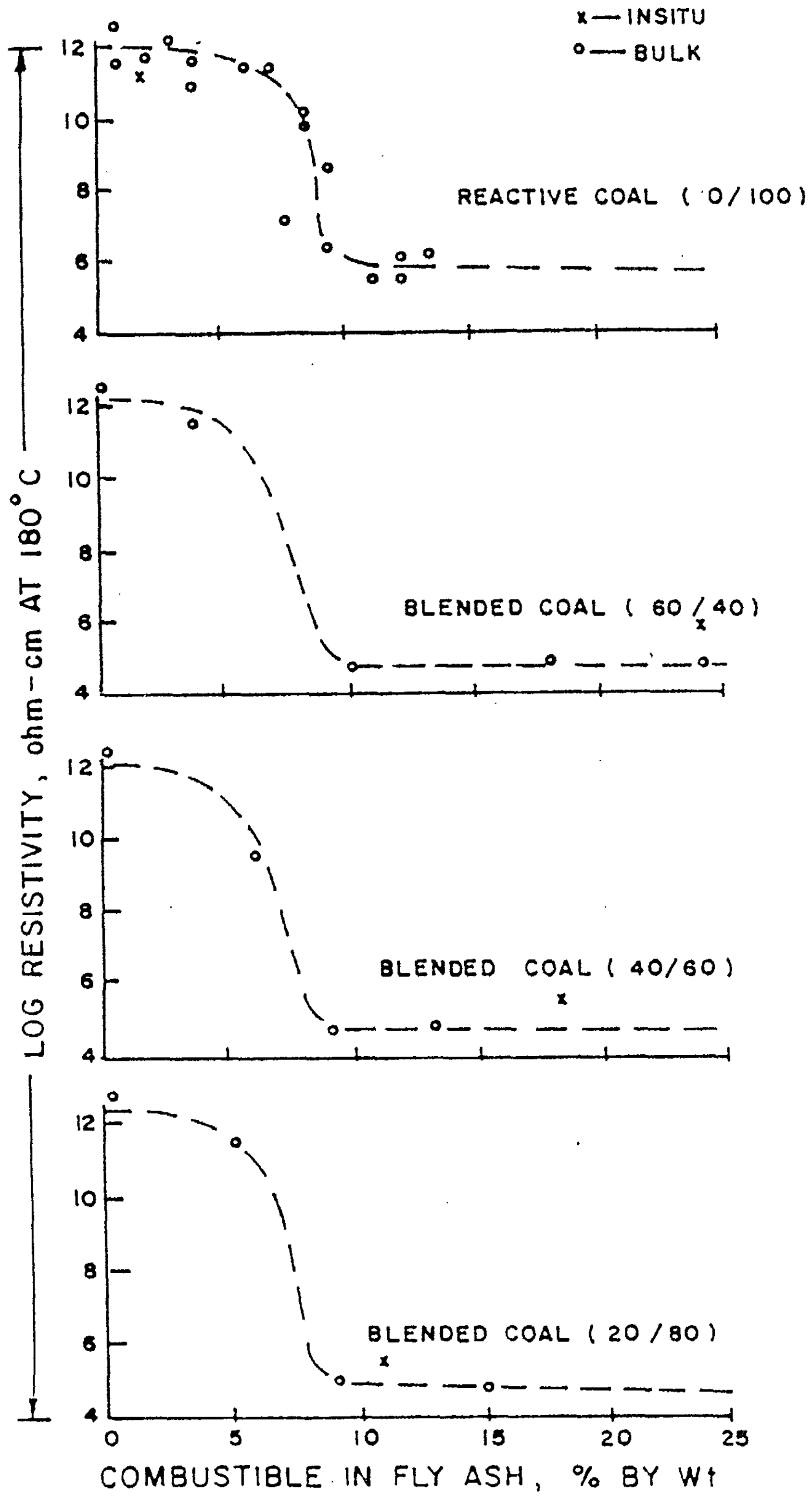

Fig. 3 - In-situ and bulk electrical resistivities of fly ash

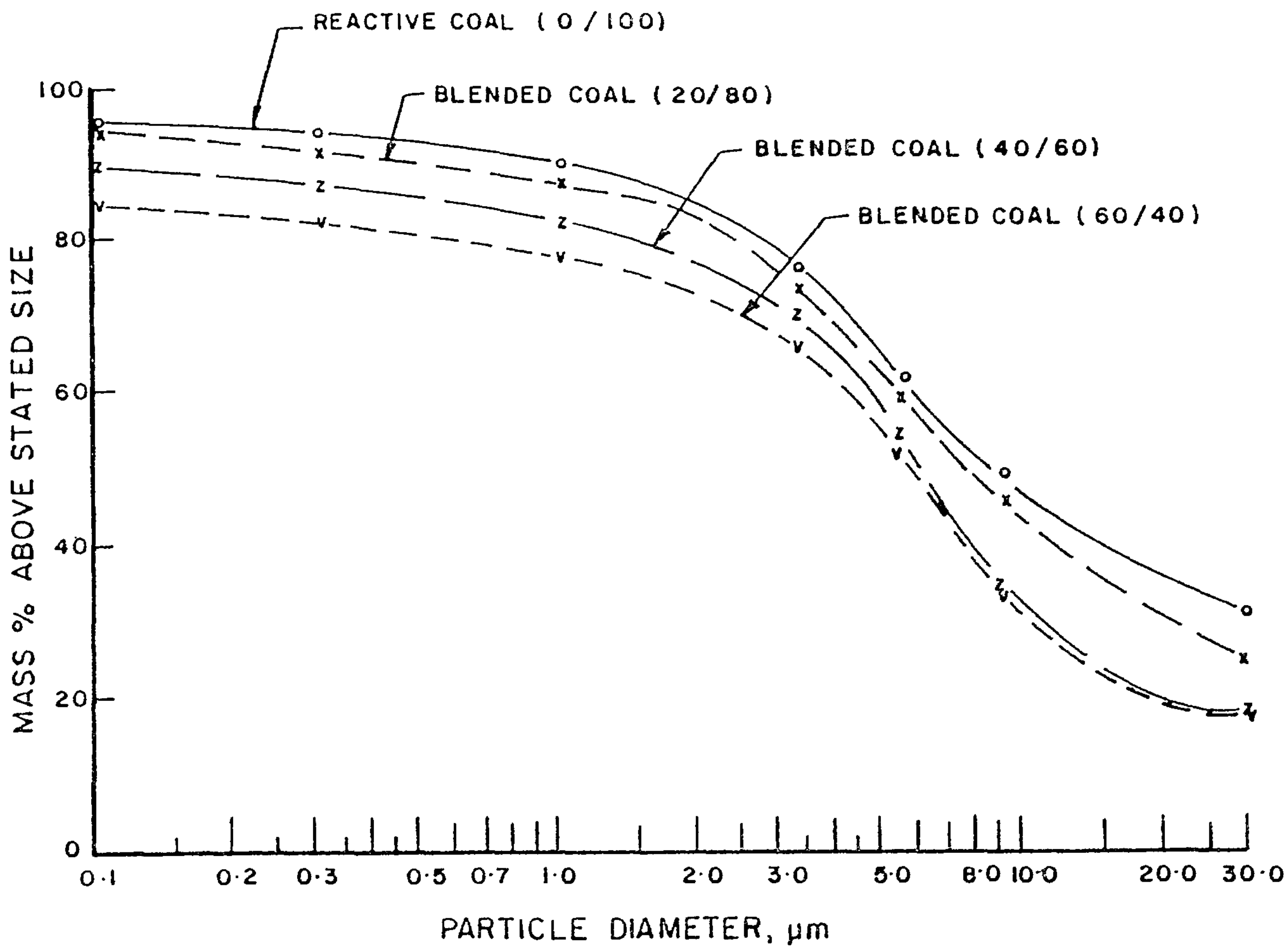

Fig. 4 - Particle-size distribution of fly ash

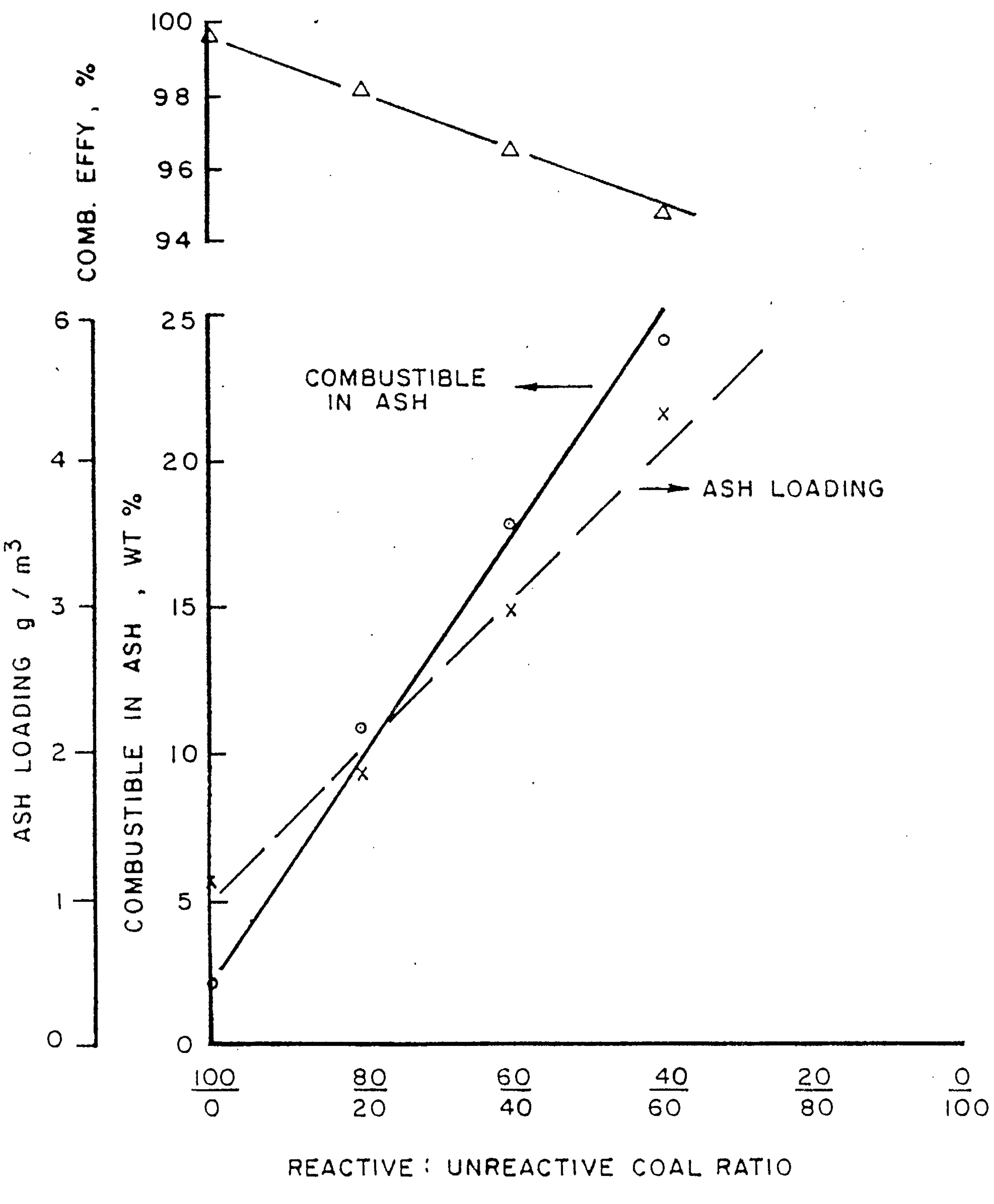

Fig. 5 - Fly ash loadings and combustion efficiency