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THE EFFECT OF COAL QUALITY ON THE COMBUSTION PERFORMANCE OF TWO CANADIAN THERMAL COALS

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G.K. Lee*, F.D. Friedrich** and H. Whaley**

ABSTRACT

The expanded use of Canadian thermal coals for electricity generation highly depends on both the composition and quality control of coal.

Purchase of off-specification, substitute coals or lack of consistency in supplies of a design coal often cause severe operational problems in utility boilers. To minimize the risks in utilizing coals with unpredictable burning properties, combustion experiments were conducted in a pilot-scale research boiler to evaluate the influence of changes in coal quality on the combustion, ash deposition and emission characteristics of two Canadian thermal coals which had not been used previously as a boiler fuel. One, a lignite coal with highly variable ash and moisture content, was highly reactive but required admixing of three different seams to optimize resource recovery. The other, an oxidized bituminous coal selected for its relatively low reactivity, was successfully burned by blending with a more reactive coal from a different deposit.

The pilot-scale trials, by closely simulating utility boiler conditions, provided advance information on potential combustion-related problems prior to commercial use.

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L'EFFET DE LA QUALITÉ SUR LA PERFORMANCE DE DEUX CHARBONS THERMIQUES CANADIENS SOUMIS À DES ESSAIS DE COMBUSTION

par

G.K. Lee*, F.D. Friedrich** et H. Whaley**

RÉSUMÉ

L'accroissement de l'utilisation des charbons thermiques du Canada pour la production de l'électricité dépend dans une large mesure de leur composition et du contrôle de leur qualité.

L'achat des charbons non-spécifiés et des charbons de remplacement ainsi que des lacunes quant à l'approvisionnement régulier en charbons spécifiés peuvent modifier considérablement le fonctionnement des chaudières des centrales électriques. Afin de minimiser les risques associés à l'utilisation des charbons ayant des caractéristiques de combustion imprévisibles, des essais de combustion ont été effectués dans une chaudière à l'échelle pilote, ce qui a permis d'évaluer le rapport entre la qualité du charbon et les caractéristiques de combustion, de dépôt et d'émission des deux charbons thermiques canadiens qui, jusqu'ici, n'ont jamais été utilisés comme combustible de chaudière. L'un des charbons, un lignite ayant une teneur en cendres et en humidité très variable, quoique très réactif, a exigé l'addition de charbons provenant de trois différents filons pour optimiser la récupération des ressources. L'autre, un charbon bitumineux oxydé, a été choisi en raison de sa réactivité relativement faible et a été brulé avec succès après l'addition d'un charbon plus réactif provenant d'un autre gisement.

Les essais effectués à l'échelle pilote, en simulant précisement les conditions de combustion d'une chaudière de centrale électrique, ont fourni des données préalables sur les problèmes possibles relatifs à une exploitation commerciale ultérieure.

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INTRODUCTION

The expanded use of Canadian thermal coals for electricity generation is strongly dependent on both the ability of existing utility boilers to burn a wide range of off-specification coals and the ability of individual coal suppliers to provide coals having close quality control. Small variations in the moisture, maceral and mineral content of coals from either captive or export sources can have a dramatic effect on boiler availability and efficiency.

Typical operational problems have been experienced because of inconsistent or unsuitable coal quality:

a) decreased combustion efficiency and steaming rate;
b) increased ash fouling or slagging;
c) overloading of ash handling and collection systems and
d) unacceptable stack gas emissions.

This paper describes the results of two series of pilot-scale combustion trials in which the behaviour of inert and partially inert coal constituents was studied under utility boiler conditions. In the first series, the combustion performance of a low-quality lignite from an undeveloped deposit was evaluated at different ash and moisture levels. The second series involved studies on the use of blends of a reactive and an unreactive bituminous coal as alternative fuels in boilers designed for high reactivity coal.

RESEARCH FACILITY

The pilot-scale research boiler used for these trials, is designed to burn coal at 60-100 kg/h 1 with independent control over combustion air, coal fineness and firing rate (Fig. 1). The two opposed burners are mounted in the upper ports to burn high-reactivity coals and in the lower ports to burn moderate or low-reactivity coals. Details of this research facility are described elsewhere (1).

In all trials the coal pulverizer was set to provide 70% to 80% minus 74 µm particles and the total combustion air was adjusted to provide 3% and 5% O_2 in the flue gas.

HIGH-ASH LIGNITE TRIALS

ASTM ANALYSIS

An analysis of the six lignite samples burned in the first series of trials is given in Table 1. A commercial coal was included in these trials to provide a baseline for comparing the combustion performance of the previously uncharacterized lignites. Figure 2 shows calorific values, ash contents and moisture levels of the "as fired" coals. The dry lignites had ash contents from 18% to 50% whereas the dry reference coal had an ash content of 15%.

Ash analyses and ash fusion data, indicate that ash slagging and fouling during combustion will be low (Table 2).

COAL REACTIVITY

Petrographic examinations showed that all of the lignites on a moisture, mineral matter free basis, contained over 80% vitrinite, a high reactivity maceral. Therefore, ignition, flame stability and carbon burn-out were predicted to be good to excellent, and its potential for spontaneous combustion in storage, particularly if the total moisture content falls 15% was rated as high. The petrographic data also suggest that the experimental coals need not be as finely ground as higher rank coals in conventional pulverized-fired boilers.

The lignite samples, that containing 50% ash, had volatile matter contents comparable to the reference coal which was known to have excellent ignition and burn-out. Crucible-scale burn tests on two size fractions (-44 mμ and +105 mμ) of the pulverized lignites showed that char burn-out times, particularly for large particles, will increase with increases in ash content, and that most of the ash was concentrated in the fine size fraction.

COMBUSTION PERFORMANCE

The steaming rates for the lignite trials when normalized with respect to the reference coal were found to increase linearly with decreases in ash and moisture content and with decreases in excess combustion air. This linear relationship, shown in Fig. 3, occurred because the reference coal and the six lignites had almost the same calorific value on a dry, mineral matter free basis.

Carbon burn-out, which is a measure of combustion efficiency, decreased with increases in the ash content and the mean particle size of the coal and was generally unaffected by changes in excess combustion air and fuel moisture. The carbon in fly ash corresponded to a thermal loss of 1% to about 3% for the 18% ash and the 52% ash coal, respectively.

FIRESIDE DEPOSITS

The lignites produced highly porous, sintered ash deposits on refractory surfaces around the flame zone. These deposits decreased in thickness but increased in sinter strength when the input ash content decreased below 25%; decreases in lignite moisture also resulted in an increase in sinter strength. Downstream of the flame, all of the fireside deposits were powdery and easily removed by soot blowing.

X-ray diffraction analyses showed the same components in all of the lignitic ash deposits irrespective of their furnace location. The major ash components, listed in order of relative abundance, were mullite, quartz and cristobalite. All are highly abrasive compounds which caused severe erosion of convection surfaces.

The mullite and cristobalite represent thermal transformation products of kaolinite and montmorillinite which originally existed in the parent coal ash. The quartz was also present in the parent coal ash, but appeared to have passed through the flame without change.

FLUE GAS EMISSIONS

Sulphur dioxide emissions from burning lignite, shown in Fig. 4, decreased with increases in calorific value, but exceeded the North American New Source Performance Standards of 0.58 g/MJ for all coals except that having the lowest ash content. These emissions accounted for about 90% of the input sulphur because the parent coal ash contained cations with some potential for sulphur neutralization. No acid dewpoints were detected and SO_3 levels were consistently less than 4 ppm.

Nitrogen oxide emissions increased with decreases in fuel moisture and ash content with most values close to the 0.38 g/MJ specified by the North American New Source Performance Standards.

Figure 5 shows that the fly ash loading at the precipitator inlet increased progressively with ash content of the lignite with the increase being exponential above 40% ash.

The precipitator efficiencies with fly ash from the lignites which averaged about 95% were superior to those obtained with fly ash from the reference coal. These results appear to be anomalous because the fly ash resistivity values for the reference coal, which bracketed 10^9 ohm-cm at 150°C are generally associated with optimal precipitator efficiencies, whereas those for the lignites, being all above 10^{11} ohm-cm at 150°C, suggest that precipitator efficiencies will be low. The apparent discrepancy can, however, be explained by the difference in particle size distribution of the fly ash shown in Fig. 6.

Most of the particles of the fly ash from the experimental coals were not only larger than those of the fly ash from the reference coal but a smaller fraction of the fly ash from the experimental coal was from 0.1 μm to 3 μm, the "difficult-to-collect" size range. Thus, the fly ash from the experimental coals appear to be more susceptible to precipitation than the fly ash from the reference coal.

BLENDED COAL TRIALS

COAL PROPERTIES

An analyses of the two coals used in the coal blends are given in Table 3. Petrographic examinations showed that the inert maceral content of the unreactive and reactive coals was 74% and 40% by volume, respectively. Most of the inert macerals in the unreactive coal were present as oxidized vitrinite.

Thermograms for the two parent coals showed that the high-volatile coal had a shorter burn-out time and a higher peak volatilization rate than the low-volatile coal (Fig. 7). The marked decrease in volatilization rate for the low-volatile coal, shown by the deep valley in the thermogram, appears to be characteristic of all oxidized coals.

The analytical data suggest that ignition and burn-out of the unreactive coal will be poor to marginal when burned in equipment designed for more reactive coals. Blending of unreactive with reactive coals has been successful in improving flame stability and combustion efficiency but optimal blend ratios can only be determined by pilot-scale or full-scale combustion trials that duplicate operational conditions (2).

Ash fusion data, shown in Table 4, indicate that the unreactive coal ash will reduce the fouling and slagging potential of the lower fusion temperature ash of the reactive coal and that formation of an ash eutectic by blending is improbable.

COMBUSTION PERFORMANCE

The particle size distribution of the coal blends containing the highly friable unreactive coal was much finer than for the reactive coal alone, as shown in Table 5. However, the coarser reactive coal produced slightly shorter flames and slightly higher steam rates than the blends, indicating the dominant role of the inert macerals on combustion.

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, close to the new maximum source guideline of 0.38 g/MJ, 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.

In all cases, sulphur trioxide levels were less than 1 ppm and would have little potential for corrosion of low-temperature heat exchange surfaces. Figure 8 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 essentially unaffected by blending with the coarser unoxidized coal. Nonetheless, it is evident that blends containing a reactive coal and 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.

With combustible contents in ash below 6%, the fly ash resistivity values were over 10^{11} ohm-cm indicating that both the reactive coal and the coal blends will require liberally-sized specific collection areas for good precipitator performance. When the combustible content exceeded 6%, the fly ash resistivities dropped to 10^{5} ohm-cm, well below the optimum from 10^{8} ohm-cm to 10^{10} ohm-cm. At low resistivity values, precipitated fly ash can be easily re-entrained in the gas stream, giving poor precipitator performance.

FIRESIDE DEPOSITS

The blended coals all produced loose, powdery fireside deposits in contrast to the unblended coal which produced partially sintered deposits. These observations were consistent with predictive indicators for slagging and fouling potential based on ash input properties because selective enrichment of the ash from the parent coals did not occur during combustion.

CONCLUSIONS

1. Preliminary indicators of combustion reactivity and ash melting behaviour can be obtained from ASTM and other physico-chemical analysis of coal and coal ash. These indicators, however, give qualitative trends rather than quantitative data.
2. Reliable data on the combustion performance and ash deposition tendency of coals or coal blends with unknown burning properties can be provided by pilot-scale combustion trials, in which full-scale furnace conditions are closely duplicated.
3. Pilot-scale combustion trials are a practical alternative to full-scale burns which are more expensive and more risky to conduct, more difficult to instrument and less amenable to equipment modifications.

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 4:127-132; New York; 1972.

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Table 1 - Lignite coal analysis

Coal Identification	Ref Coal	Lignite #1	#2	#3	#4	#5	#6
Analysis							
Calorific value, MJ/kg	24.1	12.1	18.8	17.2	20.6	19.6	22.7
Proximate, wt % dry							
Ash	14.9	50.2	30.2	32.4	20.9	28.1	18.9
Volatile matter	34.5	25.0	32.8	34.8	39.2	35.3	38.1
Fixed carbon	50.6	24.3	37.1	32.8	40.0	36.5	43.1
Ultimate, wt % dry	16.2	12.0	14.1	13.3	14.1	13.8	14.4
Carbon	63.0	32.4	48.0	46.4	54.8	49.5	57.7
Hydrogen	3.9	2.7	3.4	3.5	3.9	3.6	4.0
Sulphur	0.2	1.1	1.2	1.0	0.8	0.8	0.7
Nitrogen	0.8	0.7	1.0	1.0	1.0	1.0	1.2
Oxygen	17.2	13.4	14.8	15.8	17.7	17.1	17.6
Ash	14.9	49.8	30.0	32.3	22.1	28.1	18.1
Sulphur forms, wt %							
Pyrite		0.5	0.6	0.5	0.6	0.5	
Organic		0.4	0.3	0.3	0.1	0.1	
Sulphate		0.2	0.3	0.2	0.1	0.2	
Equilibrium moisture, wt %	17	22	25	22	23	24	24
Hardgrove grindability index	43	60	44	46	43	44	38

Table 2 - Lignite ash data

Coal Identification	Ref Coal	Lignite #1	#2	#3	#4	#5	#6
Ash Analysis, wt %							
SiO_2	49.0	56.5	54.6	50.0	48.7	50.8	50.7
Al_2O_3	23.8	29.8	29.5	29.8	31.4	30.1	29.5
Fe_2O_3	4.5	7.1	8.3	9.6	6.7	7.2	5.8
Mn_3O_4	1.0	0.3	0.1	0.1	0.1	0.1	0.1
TiO_2	0.5	1.1	1.7	1.3	1.5	1.1	1.3
P_2O_5	0.2	0.1	0.2	0.4	0.4	0.2	0.4
CaO	13.1	1.4	2.5	4.0	4.6	2.6	3.6
mgO	0.9	1.3	1.2	1.2	1.5	1.3	1.6
SO_3	2.5	1.0	2.0	3.3	2.9	2.8	3.2
Na_2O	2.4	0.5	0.5	0.3	0.3	0.5	0.6
K_2O	0.3	0.8	0.7	0.4	0.4	0.6	0.6
Cl	0	0.01	0.01	0.01	0	0	0.02
Ash Fusion Data							
Reducing Atm, °C							
- Initial	1274	1371	1352	1381	1378	1391	1327
- Spherical	1313	+1500	1471	1458	+1500	+1500	1487
- Hemispherical	1374	+1500	+1500	1490	+1500	+1500	+1500
- Fluid	1440	+1500	+1500	+1500	+1500	+1500	+1500
Oxidizing Atm, °C							
- Initial	1324	+1500	1449	1465	1445	1477	1445
- Spherical	1363	+1500	+1500	+1500	+1500	+1500	+1500
- Hemispherical	1398	+1500	+1500	+1500	+1500	+1500	+1500
- Fluid	1438	+1500	+1500	+1500	+1500	+1500	+1500

Table 3 - Analysis of unreacive and reactive coal

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 4 - Ash fusion temperatures

ASTM Fusion Temp, °C	Coal blends				
	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 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

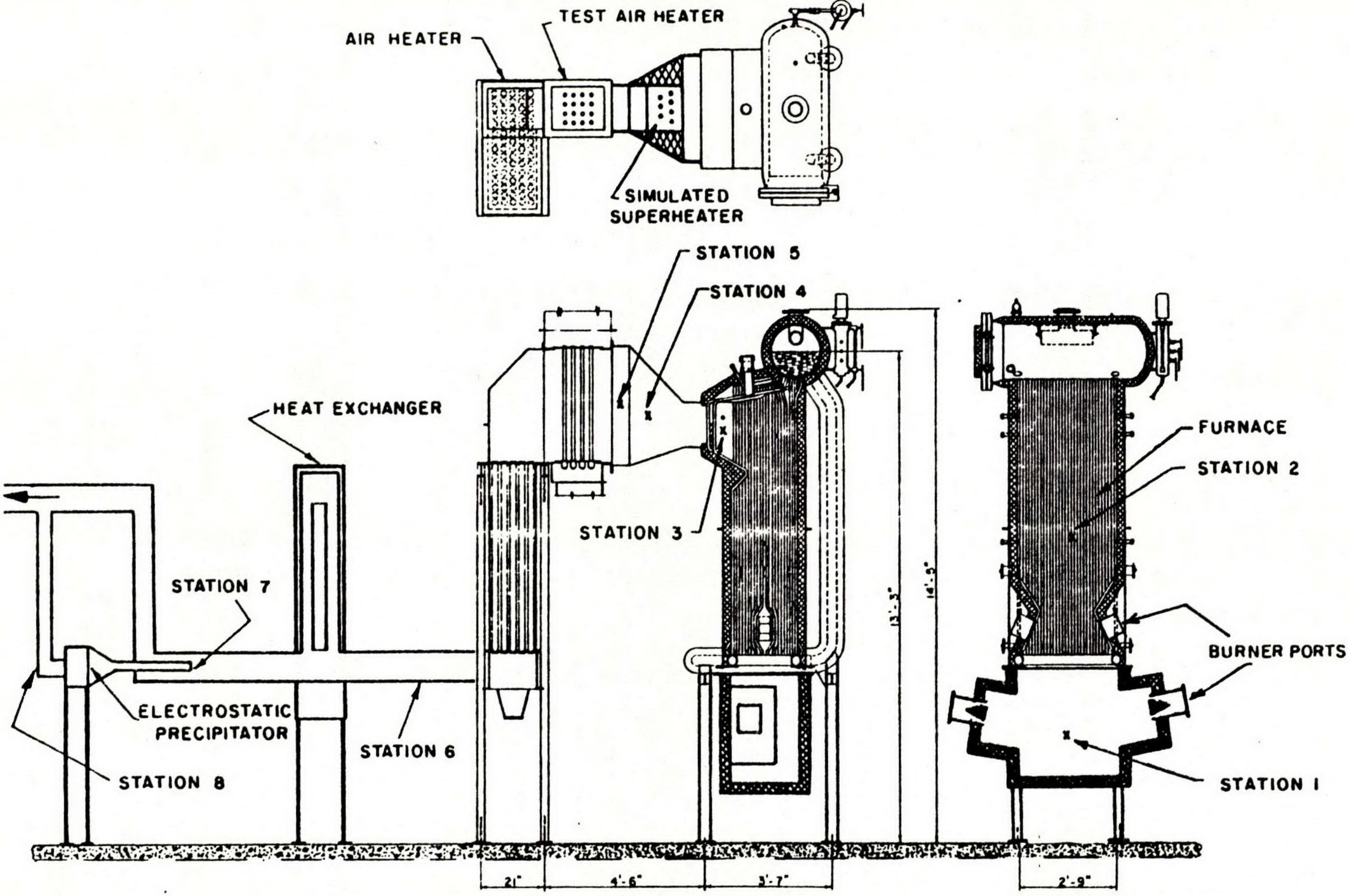

Fig. 1 - CCRL pilot-scale research boiler used for coal combustion trials

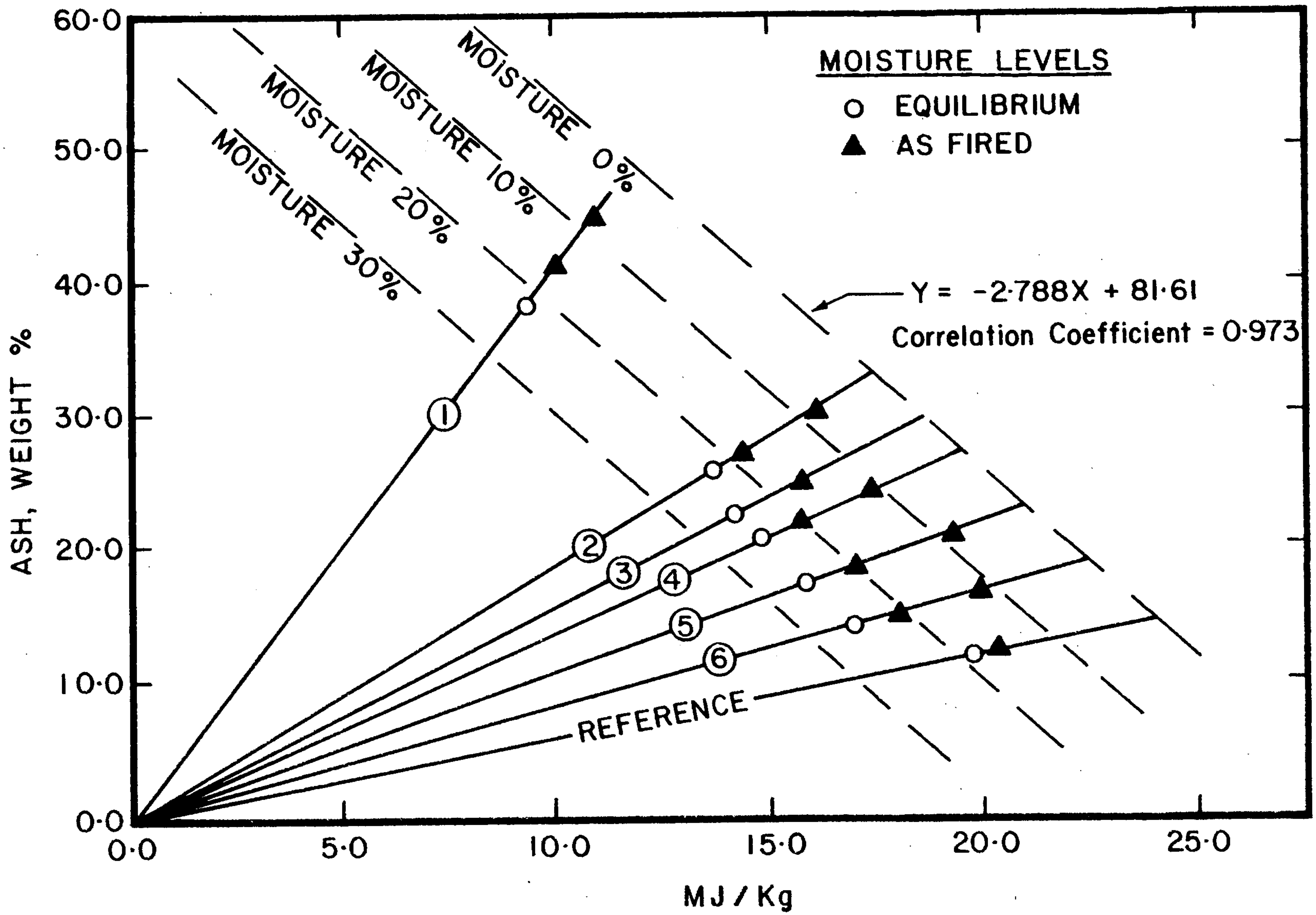

Fig. 2 – Ash-calorific value graph for lignites. The lines extending from the origin show the effect of moisture on the calorific value of each coal. Equation is the linear regression for the 18 data points.

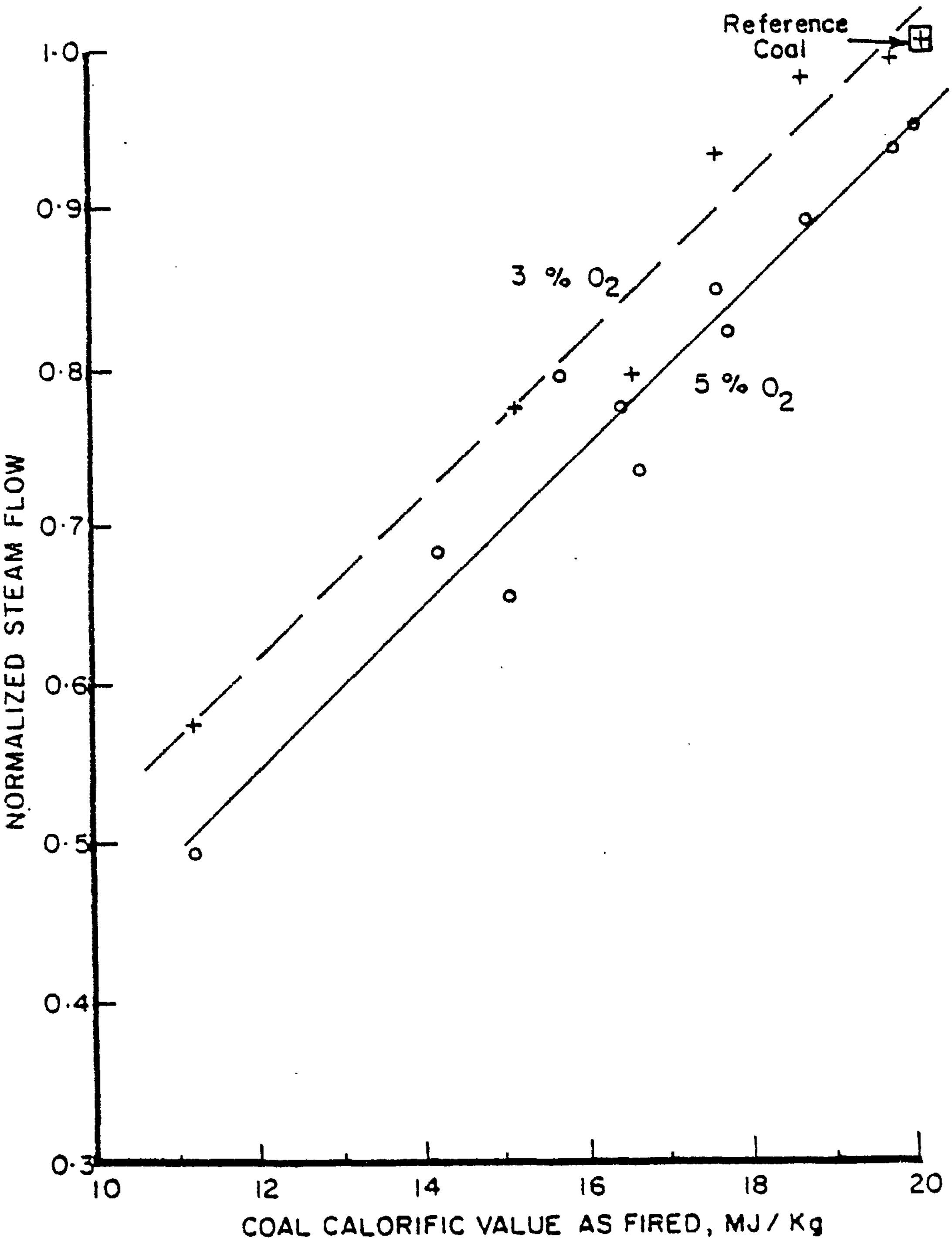

Fig.3 - Steam flow for lignites normalized to the reference coal at 3% O_2

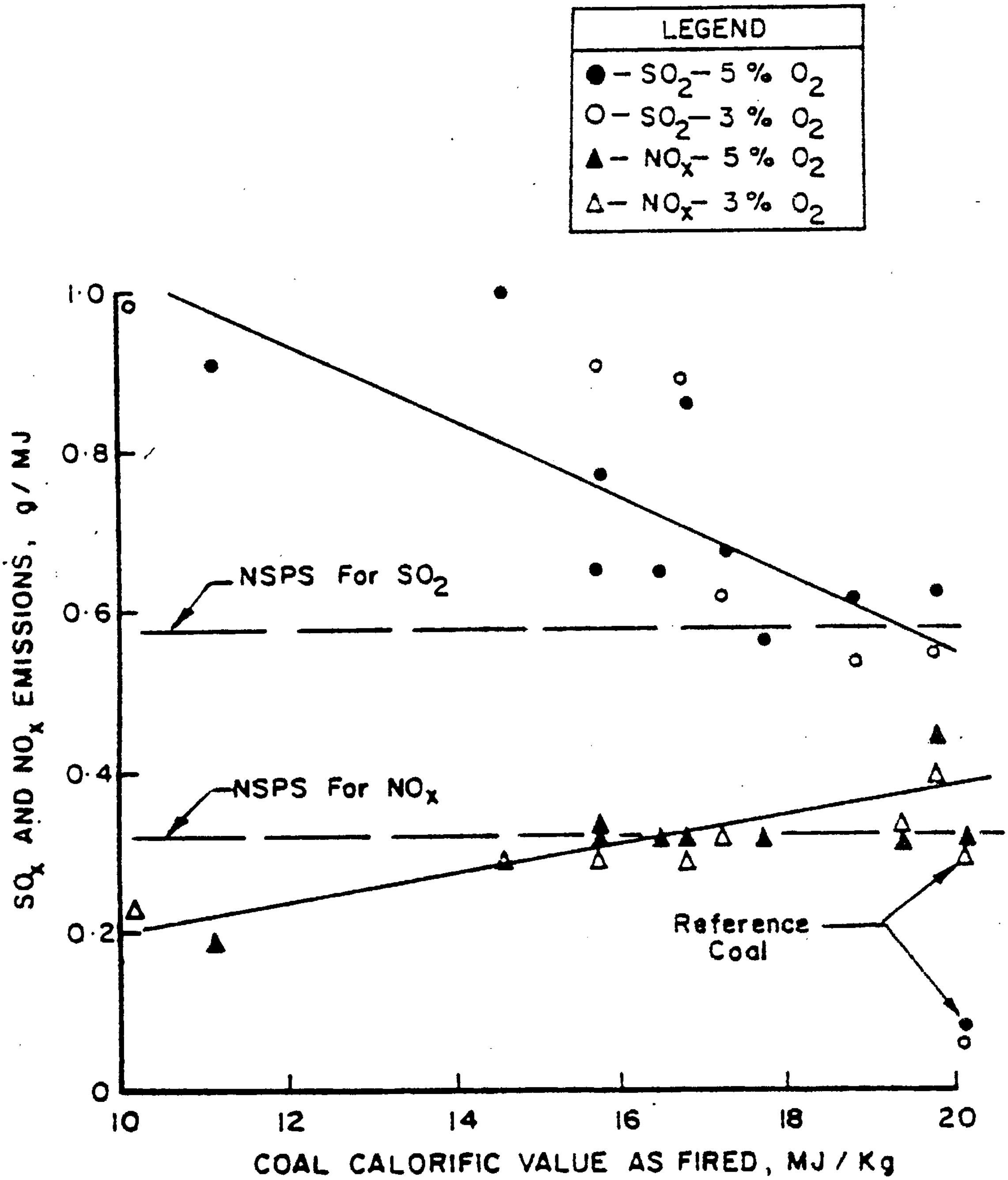

Fig. 4 - SO_x and NO_x emissions for various lignite qualities

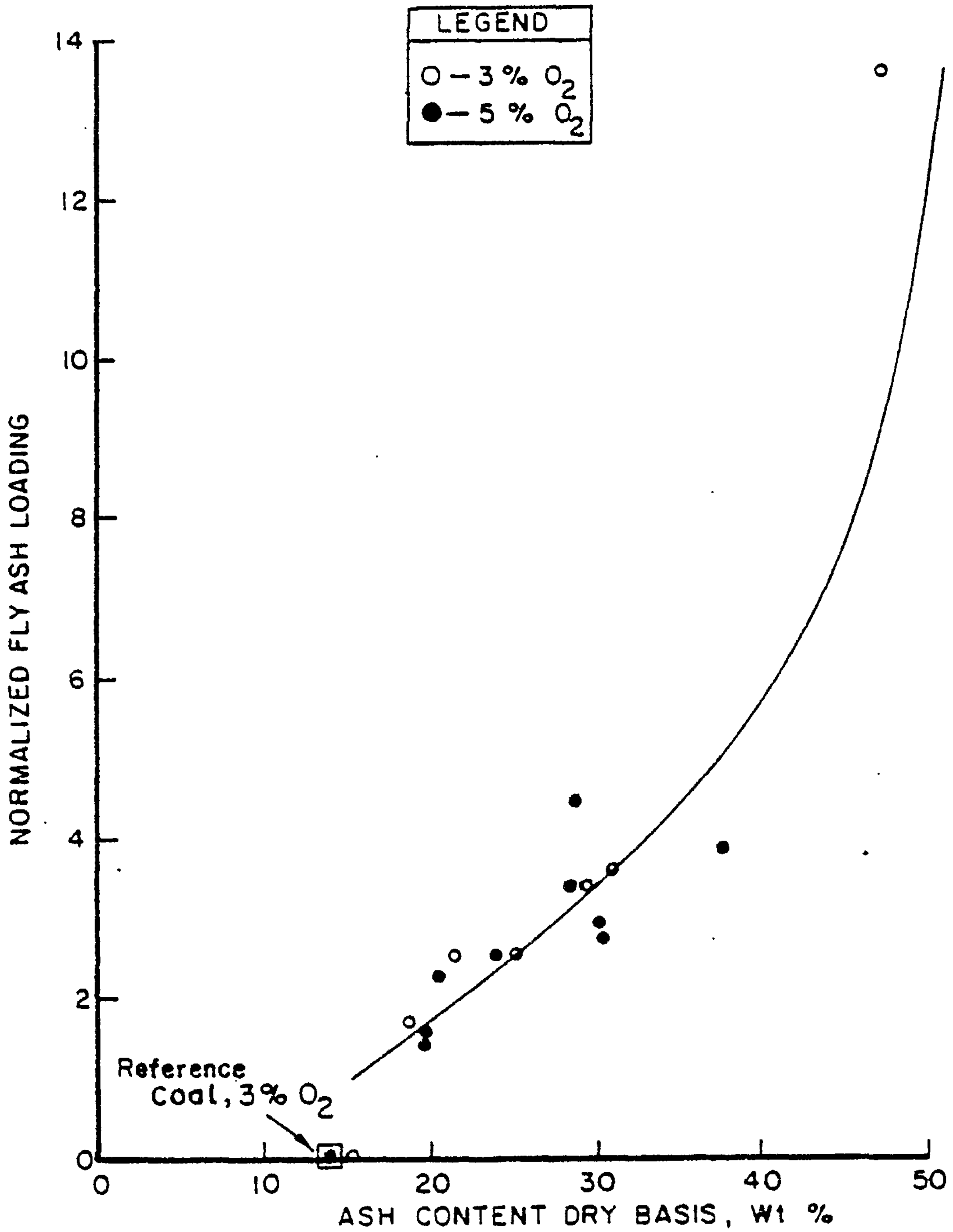

Fig. 5 - Fly ash loading for lignites at precipitator inlet normalized to the reference coal at 3% O_2

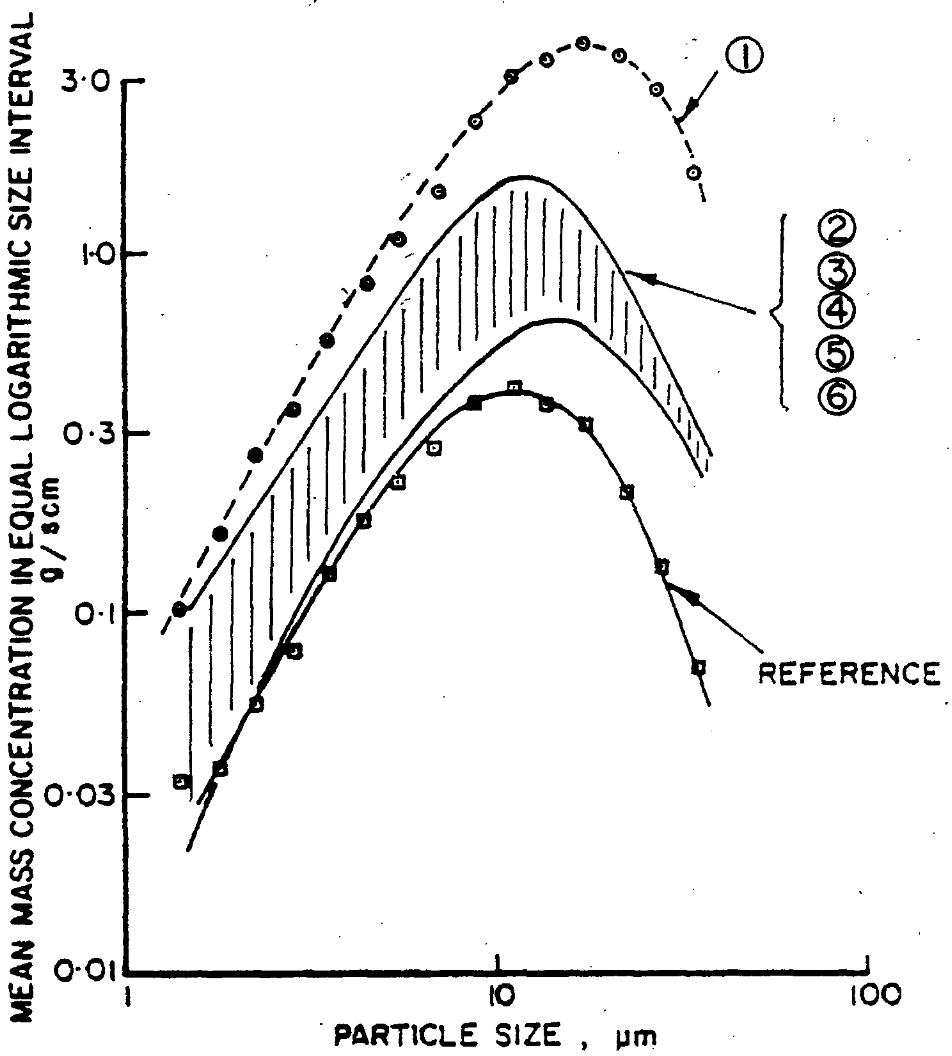

Fig. 6 - Variation in fine particle sizes of the lignitic fly ash entering the electrostatic precipitator

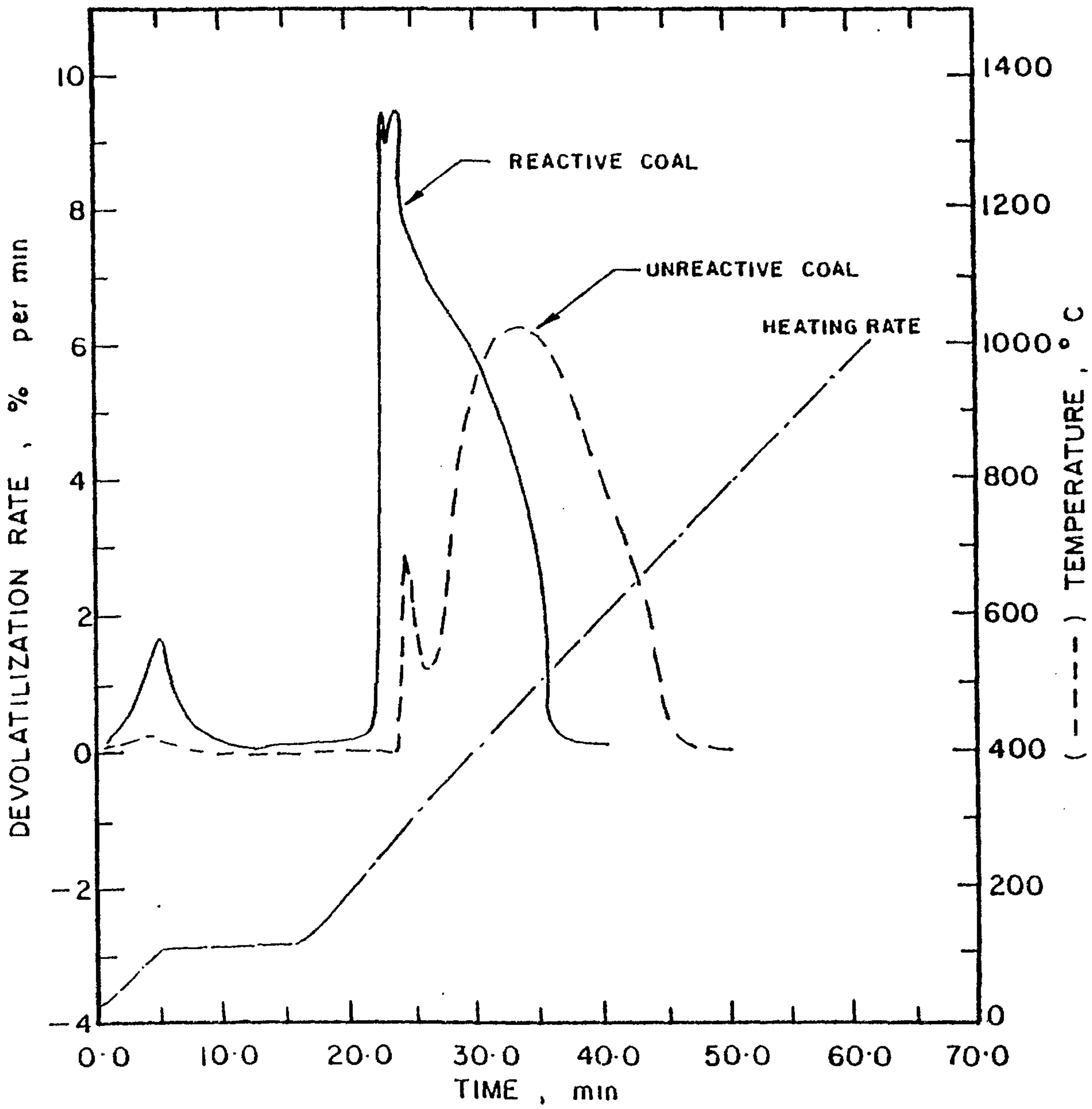

Fig. 7 - Thermogravimetric analysis of reactive and unreactive coals

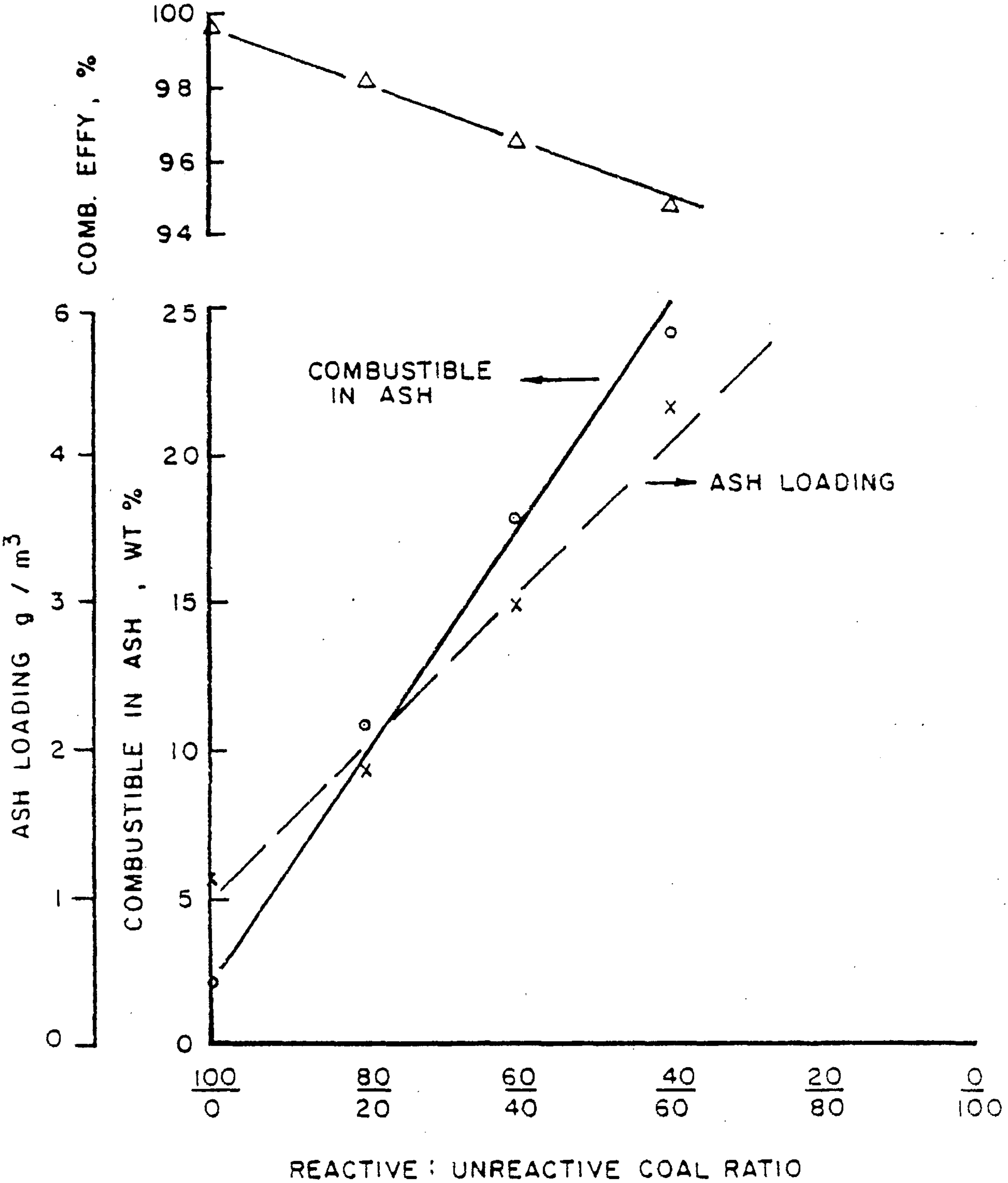

Fig. 8 - Fly ash loadings and combustion efficiencies
for reactive and unreactive coal blends