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PILOT-SCALE COMBUSTION EVALUATION OF THERMAL LINE CREEK COAL FROM FERNIE, BRITISH COLUMBIA

by

R. Prokopuk*, G.N. Banks**, H. Whaley** and G.K. Lee***

ABSTRACT

The combustion performance of Line Creek coal was assessed as a boiler fuel. Chemical and petrographic analyses confirm combustion trials which indicate that coal blends containing a maximum of 50% Line Creek coal could be burned acceptably in large boiler furnaces.

The coal blends handled and pulverized easily, ignited readily and produced stable flames. The coal ashes were friable and did not present slagging problems on high-temperature boiler surfaces. The coal's potential for low-temperature corrosion was minimal.

The coal blends produced moderate levels of nitric oxides and sulphur oxide emissions were considerably less than current allowable North American guidelines. The resistivity of the fly ash (about 10^{12} ohm-cm at 0% combustibles) indicated that electrostatic precipitation collection will be more difficult than for higher sulphur coals. The combustion, fouling and emission characteristics of the coal blends were similar in most respects to those of the bituminous reference coal.

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1.0 INTRODUCTION

Under a cost-shared agreement with Crowsnest Resources Ltd. (CANADA), the Canadian Combustion Research Laboratory (CCRL) carried out a combustion performance evaluation to determine the feasibility of using Line Creek coal from Fernie, B.C., as a boiler fuel. This coal, obtained from seam 8, test pit No. 2, Kootenay formation, was ranked as a low-volatile bituminous coal by ASTM classification procedures. A commercially available bituminous thermal coal was included to provide a reference against which the Line Creek coal and blends would be compared.

The joint project formed part of the CANMET Energy Research Program and included an analytical investigation of the coal and coal ash properties as well as combustion studies in the CCRL pilot-scale, pulverized-coal-fired boiler under conditions representing those in large steam boilers.

This report describes the objectives of the project, the analyses of the coals burned, the facilities used and the operational procedures selected. An evaluation of the experimental results is also given together with the conclusions reached.

2.0 RESEARCH OBJECTIVES

The objectives of this study included the evaluation of Line Creek coal, both separately and as a blend with the reference coal:

(a) to determine comminution and handling characteristics;

(b) to evaluate the combusiton performance of the pulverized coals at a fineness level greater than 75% less than 200-mesh and at an excess air level corresponding to 5% O_2 in the flue gases;

(c) to characterize the particulate and gaseous pollutants generated during combustion;

(d) to determine the slagging and fouling potential of the coal ash constituents on radiant heat transfer surfaces and superheater tubes;

(e) to assess the electrical resistivity characteristics of the fly ash; and

(f) to compare the above measurements with those obtained from an identical combustion trial with a reference coal.

3.0 COAL CHARACTERISTICS

3.1. Handling and Preparation

A 7.5 tonne sample of Line Creek coal was delivered to CCRL in sealed plastic-lined drums. The coal, with its "as received" moisture content of about 1%, was free of surface moisture, uniformly blended and free flowing. No problems were experienced in moving or feeding it through the pilot-scale coal handling system.

The coal blends were prepared in a 1-tonne capacity "V"-type riffle. Before final bunkering, they were dried to less than 5% moisture.

3.2. Analytical Data

Table 1 shows the proximate and ultimate analyses of the Line Creek coal, the reference coal and the coal blends as fed to the pulverizer after pre-crushing to minus 3.2 mm in a hammer mill. Although both the Line Creek and the reference coals are of the same rank, the Line Creek coal's lower volatile matter content and lower calorific value suggest that it would be less reactive than the reference coal. These coal analyses fall within typical thermal coal specifications (also shown in Table 1) for utility boilers designed to burn bituminous coal.

Table 1 - Coal Analyses

Analysis \ Coal	Line Creek	Reference	Blends			Typical Specification Limits
	100/0	0/100	60/40	40/60	20/80	
Proximate, wt% *						
Ash	18.70	10.72	13.23	12.94	11.97	<17
Volatile matter	19.84	38.57	26.59	29.75	32.96	22-36
Fixed carbon	61.46	50.71	61.18	57.31	55.07	50-60
Ultimate, wt% *						
Carbon	69.80	72.21	73.85	70.99	70.45	-
Hydrogen	3.80	4.16	4.15	4.23	4.31	-
Sulphur	0.30	0.25	0.26	0.21	0.23	<1
Nitrogen	0.89	1.04	0.92	1.02	1.01	<2
Ash	18.70	10.72	13.23	12.94	11.97	<17
Oxygen (by diff.)	6.51	11.62	7.58	10.61	12.03	-
Calorific value (MJ/kg)	27.45	28.22	27.78	28.01	27.90	>25.05
Hardgrove index	81	42	68	58	52	>45
Ash fusibility, °C						
Initial **	1480	1150	1440	1350	1285	>1250
Rank	Bituminous	Bituminous	-	-	-	Bituminous
Moisture, wt%						
As received	2.9	8.0	-	-	-	<15
As fired	1.0	4.3	1.0	1.0	1.5	-

*Dry basis

*Reducing atmosphere

3.3. Coal Reactivity

Past experience has shown that a good indicator of coal reactivity is the volatile matter combustion temperature or the adiabatic gas temperature achieved by a stoichiometric mixture of coal and air. In this calculation, the coal is considered to be dry, the combustion air is considered to carry all the moisture in the coal as fed to the pulverizer, and the combusion of volatile matter is considered to be complete prior to combustion of the fixed carbon. The volatile-matter combustion temperatures for the Line Creek coal, the reference coal, and the coal blends shown in Table 2, range from 680°C to 1040°C. Any value above 800°C suggests that the coal will ignite easily and that combustion will be stable; it should also be possible to operate at low loads (25% of full load) without oil or gas support.

Table 2 - Volatile matter combustion temperature

Coal	V.M. flame temperature (°C)
Line Creek, 1.0% moisture	680
Reference, 4.3% moisture	1040
Blend (60L.C./40 ref.), 1.0% moisture	685
Blend (40L.C./60 ref.), 1.0% moisture	850
Blend (20L.C./80 ref.), 1.5% moisture	905

According to the volatile-matter combustion temperature, the Line Creek coal is below the threshold VM combustion temperature of 800°C and much less reactive than the reference coal. This threshold value is gradually overcome upon blending the Line Creek coal with the reference coal.

The reactivity of a thermal coal can also be assessed from a petrographic examination of its maceral composition. Table 3 lists maceral analysis of the Line Creek, reference and blended coals. Maceral reactivity directly influences ignition, flame stability and combusiton efficiency as shown in Figure 1. Coals containing over 60% by volume of low reactivity macerals (fusinite, semi-fusinite, micrinite, oxidized vitrinite and mineral matter) generally require finer grinding, longer residence times and hotter flame zone temperatures, either alone or in combination, to ensure good burn-out.

The coal analyses, together with the reactivity assessment, indicate that the Line Creek coal would have to be blended with at least 50% (by weight) of a more reactive coal, before it could be burned acceptably in large boiler furnaces.

Table 3 - Petrographic examination of coal macerals

Maceral type \ Coal	Line Creek 100/0	Reference 0/100	Blend 60/40	Blend 40/60	Blend 20/80
Reactive, % volume					
Resinite	<1	<1	<1	<1	<1
Exinite	<1	7	3	4	6
Tellinite	<1	<1	<1	<1	<1
Vitrinite	5	47	22	31	39
Semi-fusinite	17	<1	10	7	3
Sub total	23	55	36	43	49
Inert, % volume					
Fusinite	5	16	9	12	14
Semi-fusinite	17	15	16	16	16
Micrinite	2	5	4	4	4
Oxidized vitrinite	43	<1	26	17	9
Mineral matter	10	9	9	8	8
Sub total	77	45	64	57	51
Total	100	100	100	100	100

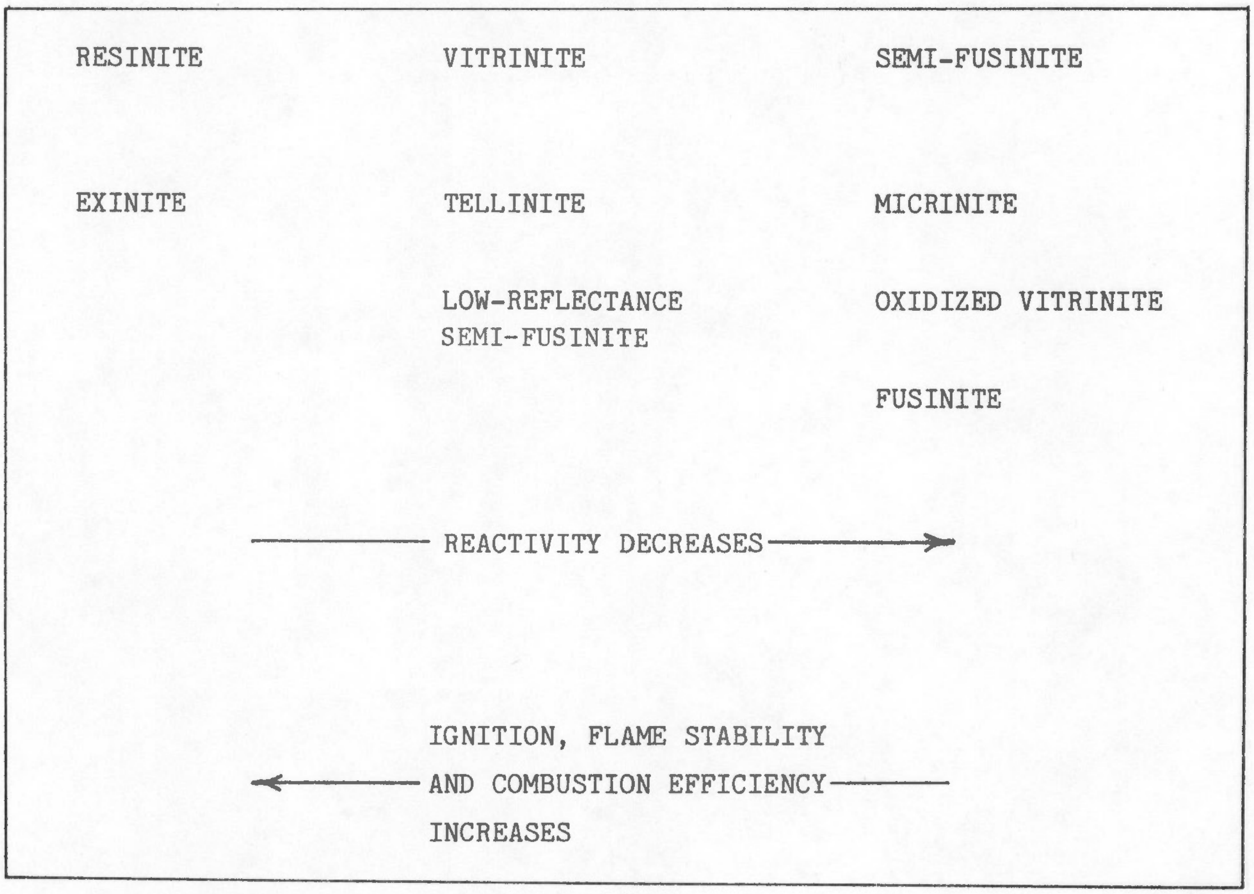


Fig. 1 - Influence of coal maceral type on combustion

4.0 PILOT-SCALE RESEARCH BOILER

The CCRL research boiler, illustrated schematically in Figure 2, is a pulverized-coal-fired boiler incorporating two tangentially opposed in-shot burners. The furnace is of membrane-wall construction and operates at pressures of up to 2.5 kPa (10 in. WC). At the full-load firing rate of 2500 MJ/h (0.7 MW) the boiler generates 730 kg/h of steam at 690 kPa (6.8 atm.). The heat is dissipated in an air cooled condenser.

Crushed coal is supplied from a 4500 kg hopper, mounted on an electronic weigh scale, through a variable-speed worm feeder to a ring-and-roller type of pulverizer, which is normally swept and pressurized by air at any temperature up to 230°C. If necessary, the pulverizer can be swept and pressurized with a mixture of air and flue gas at any temperature up to 490°C. The pulverizer contains a motor-driven classifier for controlling coal fineness, and a riffle at the pulverizer outlet proportions the coal to each burner. Secondary air can be supplied to the burner at any temperature up to 260°C.

Combustion gases leave the furnace between 760°C and 860°C and then pass through a transition section, a test-air heater and a conventional three-pass air heater before entering a long horizontal sampling duct. A by-pass from the air heater to the stack breeching and additional heat exchanger surface in the sampling duct permit the gas temperature in the sampling duct to be varied between 150°C and 300°C.

A forced-draft fan supplies air to the air heater at 7 kPa (28 in. WC). The air, on leaving the heater, is divided into three streams: primary air to the pulverizer, secondary air to the burners and cooling air to the test-air heater. The last stream, after leaving the test-air heater, can either be exhausted to the atomosphere or blended with the primary-air supply to the pulverizer.

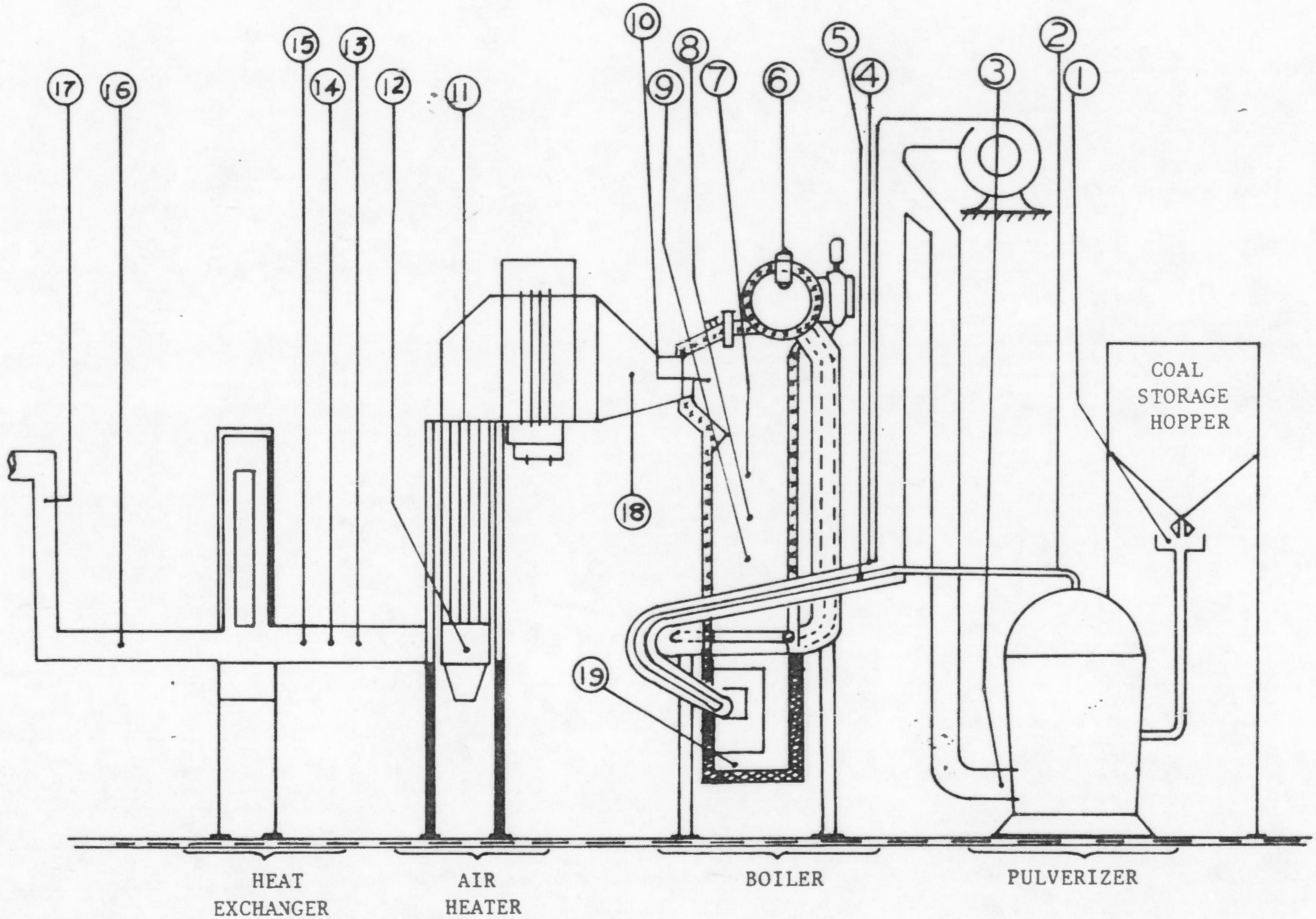


Fig. 2 - Illustration of pilot-scale boiler showing location of sampling station 5

The research boiler is manually controlled, except for electrical interlocks to ensure that safe start-up and shutdown procedures are followed. When burning high-grade coals, it has been possible to operate with as little as 1.0% O_2 and no more than 0.1% CO in the flue gases, with a smoke density of less than No. 1 Ringelmann. When severe fouling of the convective heat-transfer surfaces occurs, firing-rate or excess-air level must be reduced to control furnace pressure.

5.0 EXPERIMENTAL PROCEDURES

5.1. Operating Procedure

The operating procedure given below was used for all trials with some minor variations in timing, as necessary.

1. Before starting each test, all boiler and air heater fireside surfaces were thoroughly cleaned by air lancing and the feed rate was adjusted to provide six hours of operation.
2. At 0700 h, the cold boiler was fired up on No. 2 fuel oil at 16 gph. Excess air was adjusted to provide 5% O_2 in the flue gas and the boiler was allowed to stabilize at full steaming rate and pressure. All continuous monitoring instruments were put into service.
3. At 0830 h, pulverized coal feed to the boiler was started with the specified classifier speed, mill temperature and excess oxygen in the flue gas. One oil torch was left in operation.
4. At 0845 h, the oil torch was removed, leaving the boiler operating on pulverized coal only.
5. At 0900 h, scheduled testing was begun. Boiler panel readings were recorded hourly. The specified coal feed rate and excess oxygen level were maintained as closely as possible.
6. By 1600 h all measurements were completed. When the coal bunker was empty, the boiler was shut down.
7. The furnace was allowed to cool overnight. Then the furnace bottom was removed and the ash remaining in the furnace bottom and boiler hoppers was collected and weighed.

5.2. Parameters of Combustion Performance

The following parameters of combustion performance were measured in each test at appropriate measuring stations.

1. Proximate, ultimate and ash analyses and ash fusion determinations of samples taken from a bulk sample of crushed coal obtained by hourly grab samples at the pulverizer inlet. Station 1.
2. Moisture and sieve analyses of samples of pulverized coal taken every two hours at the pulverizer outlet. Station 2.
3. CO_2 and CO content of the flue gas, measured continuously by infrared monitors. Station 10.
4. O_2 content of the flue gas, measured continuously by a paramagnetic monitor. Station 10.
5. NO content of the flue gas, measured continuously by a chemiluminescent monitor. Station 13.
6. SO_2 content of the flue gas, measured continuously by an infrared monitor. Station 14.
7. SO_3 content of the flue gas, measured by the modified Shell-Thornton methods. Station 15.
8. Fly-ash loading, measured by an isokinetic sampling system, two to four samples per test. These samples were analyzed for carbon content, chemical composition and size distribution. Station 16.
9. Ash fouling of heat-transfer surfaces evaluated by visual examination of deposits on a simulated superheater, installed immediately downstream of the screen tubes to accommodate studies of fly ash build-up on high-temperature boiler surfaces. A supplemental method of evaluating ash fouling was by examining the thickness, physical structure, chemical composition and melting characteristics of ash deposits selected from various parts of the furnace and air heater after shutdown. Stations 7,8,9,11,18 and 19.
10. Fly-ash resistivities were measured by an in situ, point-plane resistivity apparatus at flue gas temperatures of 200°C at Station 17. A series of static isothermal measurements on blended samples of fly ash extracted from the gas stream, after the secondary air heater were also made.

11. After each trial, areas of ash build-up on the superheater and furnace walls of the cold boiler were photographed.

6.0 COMBUSTION PERFORMANCE

6.1. Coal Comminution

The coals were crushed, metered and pulverized to the selected degree of fineness without difficulty. They were then transported directly to the burner without moisture separation from the carrying air; no blockage or segregation occurred in either of the coal pipes to the boiler. The size distribution of the pulverized coals used in each combustion test is shown in Table 4.

Table 4 - Particle size distribution of pulverized coals

% in range \ Coal	Reference	Blends		
	0/100	60/40	40/60	20/80
$\%O_2$	4.7	4.8	4.6	4.5
Tyler mesh				
>100	0.1	0.3	0.2	0.3
100 x 140	3	2	0.7	1
140 x 200	21	12	6	13
200 x 325	45	52	57	36
325 x 400	4	9	5	4
-400	27	26	30	46
-200	76	86	93	86

6.2. Flame Characteristics

The boiler operating conditions, shown in Table 5, 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 adiabatic flame temperature, produced slightly longer flames and yielded slightly higher gas temperatures at the furnace exit than did the reference coal.

Table 5 - Boiler operating conditions

Coal / Conditions	Reference	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 conditions				
Flow (kg/h)	370	410	385	400
Rate (kg steam/MJ input)	0.180	0.175	0.171	0.180
Furnace exit temp (°C)	690	730	760	705
Flue gas conditions				
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

6.3. Flue Gas Analyses

The average flue gas analyses for each combusion trial are also summarized in Table 5. The carbon monoxide level was generally less than 0.01% and did not constitute either an emission problem or a significant thermal penalty.

The sulphur dioxide emissions from all trials were less than theoretical, indicating neutralization of about 15% of the sulphur by ash constituents. In addition, it should also be noted that sulphur oxide concentrations were well below current emission standards for coal-fired boilers in North America as shown in Table 6.

Sulphur trioxide, a precursor to acid soot formation and low-temperature heat exchanger fouling and corrosion, was present in amounts of less than 1 ppm. At this level, sulphur trioxide would have little detrimental effect on either air pollution control equipment or low-temperature heat exhanger performance.

Nitric oxide concentrations rose as coal blend reactivity increased, although fuel nitrogen contents were essentially the same for all coals. The higher flame temperatures obtained with the more reactive reference coal resulted in enhanced oxidation of atmospheric nitrogen to nitric oxide levels. It is important to note that although the trend of the nitric oxide levels is valid, the absolute level of nitric oxide emissions is also strongly dependent on burner geometry, burner arrangements, boiler configurations and boiler heat release rates.

Table 6 - Comparison of SO_x and NO_x emissions from burn trials with current North American quidelines (APCD, U.S.A.)

Emission / Coal	SO_x (kg/GJ)		NO_x (kg/GJ)	
	Trial burn	Guideline	Trial burn	Guideline
Reference	0.15	0.52	0.33	0.30
Blend (60/40)	0.15	0.52	0.29	0.30
Blend (40/60)	0.15	0.52	0.32	0.30
Blend (20/80)	0.15	0.52	0.31	0.30

6.4. Ash Properties

6.4.1. Fly-ash loadings and combustion efficiency

The fly ash loadings and the combustible losses in the fly ash for each burn trial are summarized in Table 7.

Table 7 - Flyash loadings and combustion efficiency

Coal / Fly ash Properties	Reference	Blends		
	0/100	60/40	40/60	20/80
O_2 (% in flue gas)	4.7	4.8	4.6	4.5
Loading (g/m^3)	1.16	2.92	3.52	1.83
Combustible in ash (wt%)	2	24	18	11
Combustion efficiency* (%)	99.8	97.7	98.4	99.1

$$\text{* \% Combustion efficiency (dry basis)} = 100 - \frac{(\text{\%Ash in coal})(\text{\%Combustibles in fly ash})}{(\text{\% VM + FC in coal})}$$

The fly ash loadings after the secondary airheater were consistent with the input ash and the excess combustion air levels.

Combustion efficiencies were reflective of the coal reactivity. These efficiencies will, however, be much better in full-scale utility boilers where relative to the pilot-scale boiler, residence times are much longer and flame quenching is less severe.

6.4.2. Electrical resistivity

The in situ and bulk fly-ash resistivities for the reference coal and coal blends are illustrated in Figure 3. The particle size distribution of each fly ash is shown in Figure 4.

In general, high electrical resistivity ($>10^{10}$ ohm-cm) indicates that precipitated fly ash will retain a strong electrical charge and repel any similarly charged particle or generate a back corona within the deposit; precipitation, conversely, is therefore difficult. A low resistivity ($<10^{7}$ ohm-cm) fly ash will readily precipitate but will not adhere strongly to the collecting plates and will easily be re-entrained in the flue gas. Intermediate resistivity values of approximately 10^{8} ohm-cm to 10^{9} ohm-cm are considered to yield the best precipitator efficiencies.

The in situ resistivity values for the reference coal were about 10^{11} ohm-cm indicating that precipitability may be poor. On the other hand, the in situ resistivity values of the fly ash from the blended coals fell below the optimum range of 10^{8} ohm-cm to 10^{10} ohm-cm, because of the presence of high levels of combustible matter. Accordingly, a series of bulk resistivity measurements were made in an electric furnace to determine the critical combustion content at which the fly ash from each coal would produce a maximum resistivity value at 180°C. These data, plotted in Figure 3, show maximum resistivity values of about 10^{12} ohm-cm. Although bulk resistivity values are typically an order of magnitude higher than in situ measurements because of procedural differences, the two curves are usually parallel. It follows that both the reference coal and the coal blends will require liberally-sized specific collection areas for good precipitator performance.

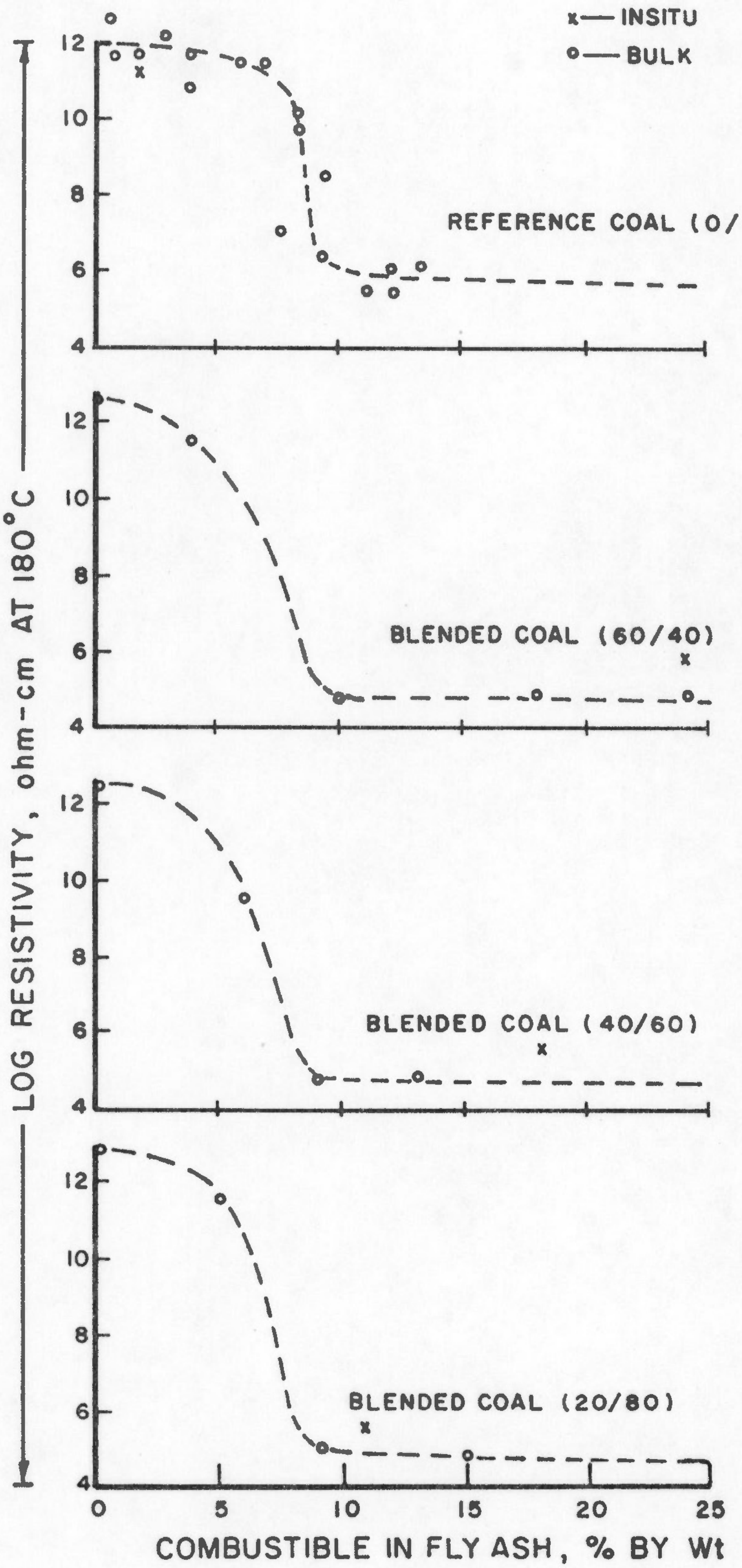


Fig. 3 - In situ and bulk electrical resistivities of fly ash

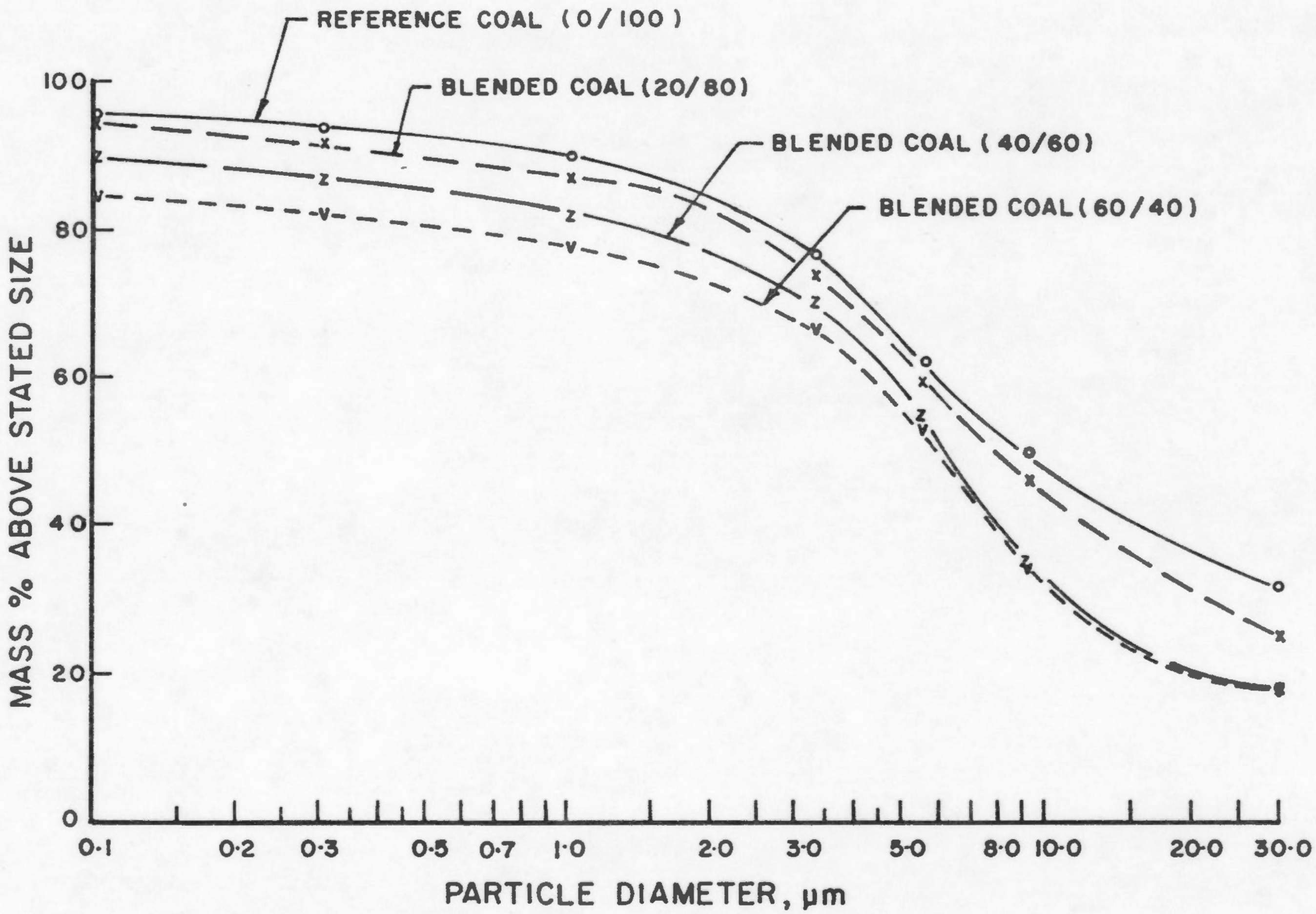


Fig. 4 - Particle-size distribution of fly ash

7.0 HIGH TEMPERATURE ASH DEPOSITS

Two types of high-temperature ash deposits can occur on the surfaces of coal-fired boilers exposed to combustion gases:

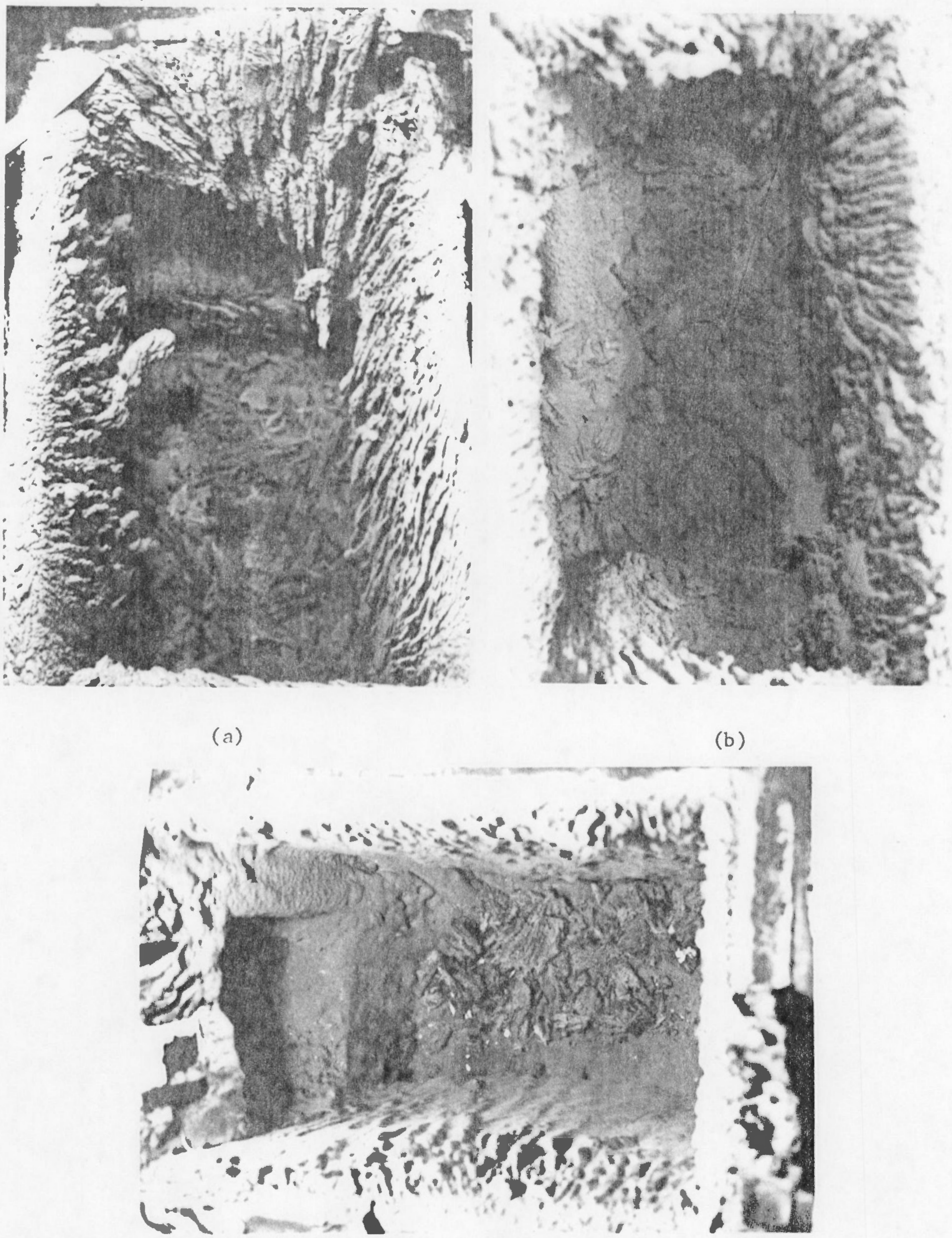
1. Slagging - fused deposits that form on surfaces exposed predominantly to radiant heat transfer;
2. Fouling - high temperature bonded deposits that form on surfaces exposed predominantly to convective heat transfer. Particularly troublesome areas are superheaters and reheaters.

An assessment of the slagging and fouling potential of the coals used in these pilot-scale experiments was done using accepted empirical indices based on the ash analysis of the raw coal, the analysis of the fireside deposits and the visual assessment of the deposits produced within the boiler (1).

7.1. Ash Fusion Characteristics

The deposits produced in the furnace bottom and on the refractory quarls surrounding the burners were bulky and granular, Figure 5. The fusion temperatures of the deposits and the ash from the reference coal and the blends are given in Table 8.

Ash fusion characteristics, determinerd according to procedures described in ASTM D1857, define four temperatures at which physical changes in a standard specimen become apparent. The test can be carried out in either a reducing or an oxidizing atmosphere, but normal reference is to the reducing atmosphere which usually generates lower temperatures and is therefore a more restrictive condition.



(a) (b)

(c)

Fig. 5 - Furnace bottom, showing sintered ash deposits from burning blended Line Creek coal. (a) 60/40, (b) 40/60, (c) 20/80.

Table 8 - Characteristics of coal ash, boiler deposits and superheater deposits

Coal	Line Creek	Reference			Blends (Line Creek/Reference) 60/40			40/60			20/80		
Characteristics of ash / Source of ash	Coal	Coal	Boiler deposit	Super heater deposit	Coal	Boiler deposit	Super heater deposit	Coal	Boiler deposit	Super heater deposit	Coal	Boiler deposit	Super heater deposit
Ash analysis (wt %)													
SiO_2	58.81	57.01	56.32	59.59	57.72	59.97	58.15	57.31	60.62	57.34	58.27	61.46	56.69
Al_2O_3	33.55	16.08	22.25	19.17	27.40	29.29	27.70	24.95	26.36	24.67	21.94	24.03	21.48
Fe_2O_3	2.53	5.14	5.61	5.66	4.31	3.94	4.58	5.07	4.75	5.02	5.20	5.46	6.40
TiO_2	1.41	0.46	0.88	0.65	1.23	1.04	1.23	1.05	0.93	1.05	0.89	0.75	0.90
P_2O_5	0.60	0.22	0.32	0.13	0.46	0.20	0.44	0.39	0.23	0.34	0.27	0.19	0.27
CaO	0.99	11.96	8.29	10.05	3.63	2.42	3.49	5.19	3.81	5.87	6.60	5.08	8.44
MgO	0.41	1.15	1.10	1.31	0.63	0.31	0.56	0.79	0.57	0.94	0.88	0.54	0.95
SO_3	0.32	3.57	1.60	0.95	2.74	0.13	0.70	2.61	0.07	1.12	3.22	0.20	1.26
Na_2O	0.08	0.38	0.25	0.33	0.12	0.09	0.14	0.20	0.15	0.25	0.25	0.19	0.47
K_2O	0.72	0.73	0.64	0.73	0.57	0.63	0.57	0.63	0.64	0.61	0.70	0.67	0.64
BaO	0.08	0.62	0.45	0.56	0.30	0.18	0.12	0.44	0.22	0.27	0.46	0.26	0.36
Ash fusion temp (°C)													
Reducing atmosphere													
Initial	>1480	1150	1305		1440	>1480		1350	>1480		1285	1400	
Spherical	>1480	1295	1380		>1480	>1480		1450	>1480		1415	>1480	
Hemispherical	>1480	1400	>1480		>1480	>1480		>1480	>1480		>1480	>1480	
Fluid	>1480	>1480	>1480		>1480	>1480		>1480	>1480		>1480	>1480	
Oxidizing atmosphere													
Initial	>1480	1205	1320		>1480	>1480		1360	1395		1345	1400	
Spherical	>1480	1340	1430		>1480	>1480		>1480	>1480		1430	>1480	
Hemispherical	>1480	1430	>1480		>1480	>1480		>1480	>1480		>1480	>1480	
Fluid	>1480	>1480	>1480		>1480	>1480		>1480	>1480		>1480	>1480	

The fusion temperatures of the furnace bottom and wall deposits were higher than those recorded for the parent coal ash, irrespective of the nature of the atmosphere, indicating that preferential volatilization of fluxing components (e.g. Na_2O, K_2O) during combustion was minimal. The fusion temperatures recorded are normally associated with a low slagging potential. The moderately low slagging tendency experienced with the reference coal, which has an initial deformation temperature of 1150°C and a fluid temperature of 1480°C, indicates that furnace slagging with either the Line Creek coal or the coal blends should not be a problem since the ash from these coals are considerably more refractory than the reference coal.

7.2. Slagging Indicators

The assessment of slagging potential in pulverized coal-fired boilers has been attempted by several workers who have produced indices or composite parameters to describe the nature and severity of the slag deposits (1). These indices are frequently described as "specific" in the sense that they reflect the type of combustion equipment used in a particular unit.

Many ash slagging indices are described as being applicable only to coals with "eastern type" ash or to coals with "western type" ash. "Western type" ash is defined as having more $CaO + MgO$ than Fe_2O_3 when all are measured as a weight per cent of the coal ash.

The results presented in Table 9 indicate that the coals evaluated are of the "western type". This criterion is dependent on ash analysis and does not have any rank or geographic connotation. The importance of this will become apparent in the following discussion of three common indices for determining slagging potential.

Table 9 - Ash slagging indices

Coal \ Index	$\frac{CaO+MgO^{*}}{Fe_2O_3}$	Base/Acid**	T_{250}(°C)	T_{cv}(°C)
Line Creek				
Coal ash	0.99	0.05	1570	1465
Reference				
Coal ash	2.55	0.26	1460	2075
Boiler deposit	1.67	0.20	1475	1398
60/40 Blend				
Coal ash	0.99	0.11	1540	1370
Boiler deposit	0.69	0.08	1565	1395
40/60 Blend				
Coal ash	1.18	0.14	1520	1360
Boiler deposit	0.92	0.11	1550	1385
20/80 Blend				
Coal ash	1.44	0.17	1515	1455
Boiler deposit	1.03	0.14	1530	1435

*$\frac{CaO + MgO}{Fe_2O_3} < 1 < \frac{CaO + MgO}{Fe_2O_3}$, Eastern type ash <1< Western type ash

**$\frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$ = Base/Acid , B/A <0.5-Dry bottom firing

7.2.1. <u>The base: acid ratio</u>

The base: acid ratio is defined as

$$\frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$$

where each oxide is expressed as a percentage of the total ash. A maximum value of 0.5 for the base: acid ratio has been suggested for dry bottom-pulverized-fired units although this is not a necessary restriction. Values below 0.27 indicate that the coal ash has a very low slagging potential. The low base to acid ratios, shown in Table 9 for both the coal ash and the furnace bottom deposits, ranged between 0.05 to 0.26. Thus, slagging should not be a problem with the Line Creek coal either alone or as a component in a coal blend.

7.2.2. <u>Ash viscosity and slagging</u>

Further evaluation of the slag-forming potential of the bottom ash can be made by calculating the viscosity/temperature relationship for both the coal and the bottom ash deposits using the method outlined below:

$$T_{250}\ (^\circ C) = \left(\frac{10^7 M}{2.3979 - C}\right)^{\frac{1}{2}} + 150,$$

where T_{250} is the temperature in °C at which the viscosity of a potential bottom ash slag is 250 poise with 20% of the iron in ferrous form,

$$M = 0.00835(SiO_2) + 0.00601(Al_2O_3) - 0.109,$$

and

$$C = 0.0415(SiO_2) + 0.0192\ (Al_2O_3) + 0.0276\ (Fe_2O_3) + 0.016\ (CaO) - 3.92,$$

where

$$SiO_2 + Al_2O_3 + Fe_2O_3 + MgO + CaO = 100$$

For wet-bottom furnaces the preferred slag viscosity for easy tapping is below 100 poise and the T_{250} temperature should not normally exceed 1425°C.

For dry-bottom furnaces the T_{250} temperature, which can be one factor used to rate the coal ash in relation to furnace slagging, should preferably exceed 1450°C.

As shown in Table 9 the indicated T_{250} values agree with the low ash slagging potential indicated by the other slagging indices. These predictive calculations were confirmed by the appearance of the furnace deposits, shown in Figure 5 which were generally lightly sintered and friable.

The critical viscosity temperature (T_{cv}), Table 9, is the temperature at which molten slag will run freely from the furnace walls. It can be calculated from the ash analysis by the following relationship:

$$T(C_V)°C = 2990 - 1470\left(\frac{SiO_2}{Al_2O_3}\right) + 360\left(\frac{SiO_2}{Al_2O_3}\right)^2 - 14.7\,(Fe_2O_3 + CaO + MgO) + 0.15\,(Fe_2O_3 + CaO + MgO)^2$$

where $SiO_2 + Al_2O_3 + Fe_2O_3 + MgO + CaO = 100$.

T_{cv} is also the temperature limit above which the viscosity/temperature relationship can be confidently calculated from the ash analysis. It should be noted that in the case of the reference coal ash this critical viscosity temperature is quite high, ($T_{cv} > T_{250}$) indicating that the viscosity/temperature relationship cannot be confidently calculated from the coal ash analysis.

7.3. Fouling Indicators

A most convincing indicator of the low fouling tendency of the coals was the visible inspection of the deposits on the simulated superheater which was controlled at a surface temperature of 550°C. The deposits from all trials were light and powdery with no evidence of sintering. Photographs of the in situ deposits are shown in Figure 6. All coals were therefore tentatively classified as having low fouling tendencies. The following calculation of fouling indicators was made to confirm this conclusion.

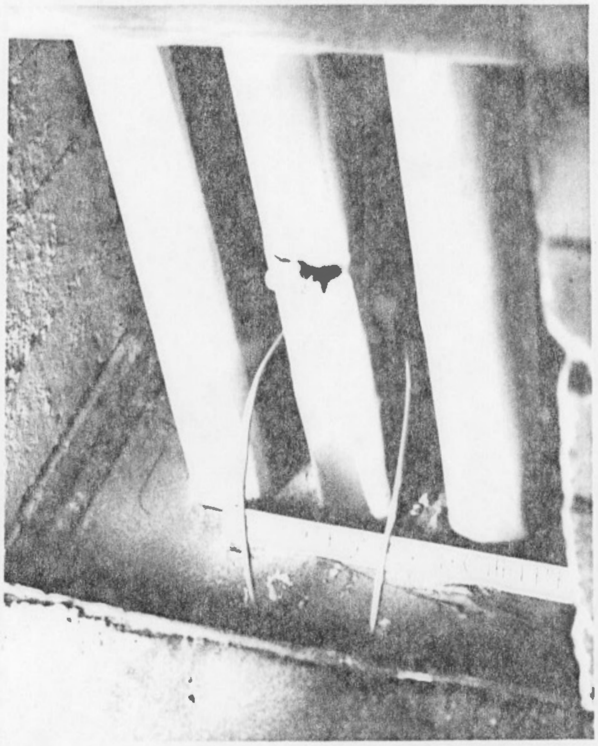
7.3.1. Sodium content of the coal ash

There has been general agreement between research and operating practice that the dominant factor correlating with superheater fouling is the sodium content of the coal ash.

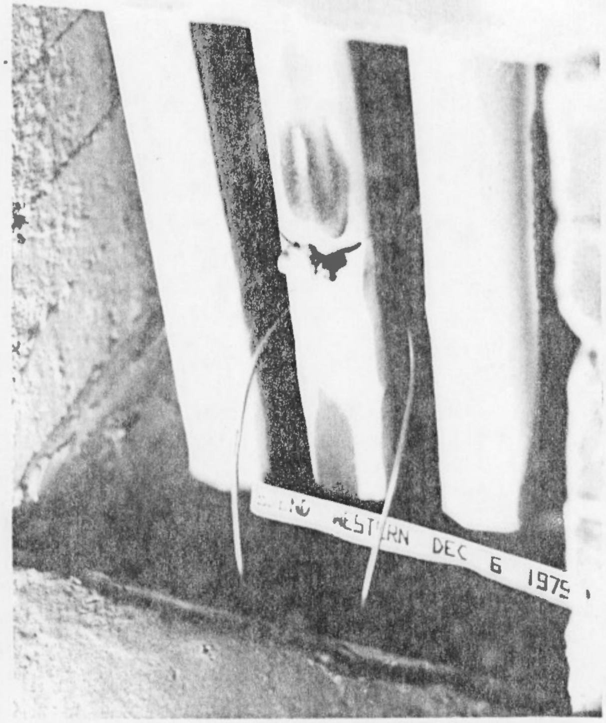
The following classification has been proposed:

Fouling Category	% Na_2O in Ash	
	"Eastern" Coals	"Western" Coals
Low	<0.5	<2.0
Medium	0.5 - 1	2.0 - 6.0
High	1.0 - 2.5	6.0 - 8.0
Severe	>2.5	>8.0

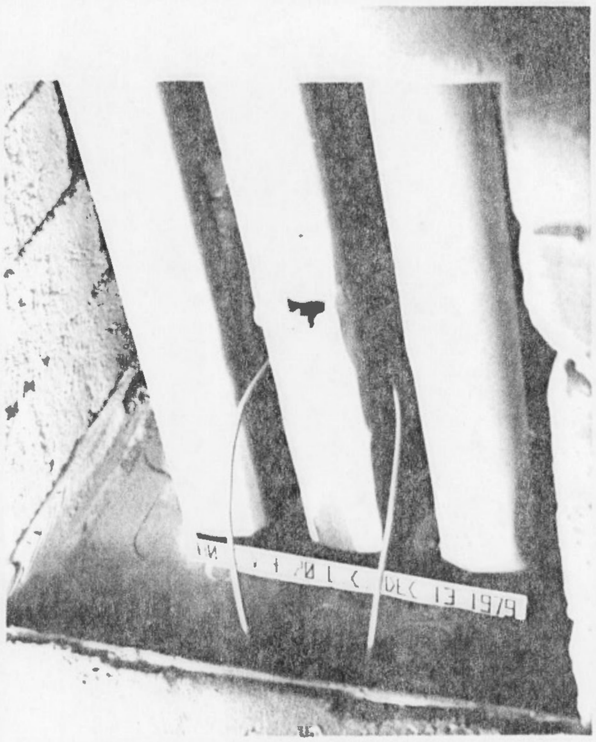
As shown previously in Table 1 the parent coal ash from each coal has less than 0.5% Na_2O, thus classifying the coals as having a low fouling potential. Moreover, the superheater deposits for all coals contained less than 0.5% Na_2O, indicating little volatilization of Na_2O during the combustion process.



(a)



(b)



(c)

Fig. 6 - Superheater, showing loose friable deposits from burning blended Line Creek coal (a) 60/40, (b) 40/60, (c) 20/80

8.0 CONCLUSIONS

8.1. The blended coals handled and flowed readily and produced easily ignitable and stable flames.

8.2. The calculated sulphur emissions from the blended coals were less than one half of current North American guidelines.

8.3. Nitrogen oxide emissions were moderate and reflective of reactivity and fuel nitrogen content.

8.4. The burn-out of the coal blends corresponded to a thermal loss ranging from 2.3 to 0.9% of the heat input. In full-scale boilers, these thermal losses will be less than 1% because of longer furnace residence times.

8.5. The high electrical resistivity of the fly ash from the blended coals, indicates that precipitability will be poorer than for the higher sulphur coals. Conditioning or hot precipitators may be required.

8.6. The tendency for the ash to slag boiler surfaces or to cause fouling of superheater surfaces is very low. The coal blends should perform well in a dry-bottom furnace using normal soot blowing procedures to remove high-temperature fireside deposits.

8.7. The coal has virtually no low-temperature corrosion potential.

8.8. The Line Creek coal, blended with more reactive coals, should burn readily and efficiently in pulverized-coal-fired boilers of conventional design. Fly ash loadings will be considerably higher with the Line Creek coal blends than for typical thermal coals, but dust emissions can probably be held within acceptable limits with available precipitator designs.

8.9. When blended with a thermal coal meeting the specifications given in Table 1, the performance of the Line Creek coal in a utility boiler can be predicted with reasonable accuracy.

9.0. The coal analyses, together with the reactivity assessment, indicate that the Line Creek coal would have to be blended with a minimum of 50% of a more reactive coal before it can be burned acceptably in full-scale utility boilers.

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REFERENCES

1. Winegartner, E.C. "Procedures and definitions of fouling and slagging parameters for coal-fired boilers"; ASME Research Committee on Corrosion and Deposits from Combustion Gases and published in the American Society of Mechanical Engineers (ASME); New York; November 1972.