COMBUSTION CHARACTERISTICS OF CANADIAN COALS VOLUME 1

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COMBUSTION AND CARBONIZATION RESEARCH LABORATORY
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FOREWORD

Over the past 15 years, the Combustion and Carbonization Research Laboratory (CCRL) of CANMET's Energy Research Laboratories (ERL) and its predecessor, the Canadian Combustion Research Laboratory, generated detailed performance data on the combustion properties of various coals and solid fuels of interest to Canadian industry. The combustion evaluations, which were conducted in a pilot-scale research boiler designed to duplicate or closely simulate fireside conditions in operational utility units, have contributed significantly to the increasingly successful utilization of Canadian thermal coals in both domestic and export markets.

Individual research reports describing various studies on the grinding, combustion, ash deposition and emissions characteristics of specific solid fuels have been reviewed, and the salient results have been compiled into a standardized format for easy reference by consultants, fuel producers, equipment manufacturers, industrial users, utilities, research organizations and government agencies.

The experimental combustion data contained in this volume were generated prior to 1983. A companion volume with further data generated during the same time period is in preparation. Subsequent volumes are planned for publication as data become available.

D.A. Reeve
Director
Energy Research Laboratories
CANMET

AVANT-PROPOS

Au cours des 15 dernières années, le Laboratoire de recherche sur la combustion et la carbonisation (LRCC) des Laboratoires de recherche sur l'énergie (LRE) de CANMET et son prédécesseur, le Laboratoire canadien de recherche sur la combustion, ont produit des données de performance détaillées sur les propriétés de combustion de divers charbons et combustibles solides présentant un intérêt pour l'industrie canadienne. Les évaluations de la combustion, menées dans une chaudière de recherche à l'échelle pilote conçue pour reproduire ou simuler de très près les conditions régnant à l'intérieur des chaudières de centrales en exploitation, ont grandement contribué au succès croissant de l'utilisation de charbons thermiques canadiens, à la fois sur les marchés nationaux et sur les marchés d'exportation.

Des rapports de recherche individuels décrivant diverses études sur le broyage, la combustion, les dépôts de cendres et les caractéristiques d'émission de combustibles solides particuliers ont été examinés et les résultats saillants ont été rassemblés en un document de format classique afin de les rendre plus facilement accessibles aux experts-conseils, aux producteurs de combustibles, aux fabricants d'équipement, aux utilisateurs industriels, aux entreprises de services publics, aux organismes de recherche et aux organismes gouvernementaux.

Les données de combustion expérimentales contenues dans le présent volume ont été obtenues avant 1983. Un second volume contenant d'autres données produites pendant la même période est en préparation. On prévoit publier d'autres volumes à mesure que les données deviendront disponibles.

D.A. Reeve
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1. INTRODUCTION

Summaries of the results of coal and solid fuel combustion evaluations in a pulverized–coal–fired research boiler at CANMET's Combustion and Carbonization Research Laboratory (CCRL) have been compiled for easy reference by utilities, engineers, consultants, industrial users, coal producers and fuel buyers.

Volume 1 contains 21 summaries of key data from trials conducted on 15 Canadian fuels between 1972 and 1982. Volume 2, now in preparation, will include 12 additional coals evaluated in 1981 and 1982.

The derivation of the alphanumeric codes assigned to the fuels is described in Section 2 of this volume. In Section 3, the test procedures used in the combustion trials are outlined. The elements specific to a particular test are included in the corresponding summary. Section 4 cross references the summary to the original divisional report title, author and number. Section 5 lists the fuels alphabetically and cross references them to their related summary and report numbers.

The final section of this volume, Section 6, contains the summaries of combustion characteristics from the trials. The summaries consist of selected results and tabulations from the original evaluation reports. Each summary relates to only one report but may include more than one coal. Results reported relate only to specific samples received and to the combustion conditions under which they were evaluated.

2. NOMENCLATURE

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FUEL CODE

An alphanumeric code has been assigned to each coal or solid fuel to signify pertinent information. The code has seven zones:

Zone 1: region

Two letters signify the geographical area of the fuel source:

Letters	Region
NS	Nova Scotia
NB	New Brunswick
ON	Ontario
SA	Saskatchewan
AL	Alberta
BC	British Columbia
YU	Yukon
NT	Northwest Territories
US	United States
OT	Other

When fuels are blended from two or more of the areas designated above, the letters of zone 1 designating the region are replaced by two digits, which represent the number of regional sources:

Digits	Fuel blend
02	Blend of fuels from two areas
03	Blend of fuels from three areas, etc.

Zone 2: rank

One letter signifies the rank or form of the fuel:

Letter	Fuel
W	Wood
P	Peat
L	Lignite
S	Subbituminous
B	Bituminous
A	Anthracite
C	Coke
G	Solid waste

Mixtures or blends of two or more fuels having different ranks are designated in zone 2 by the letter M:

Letter	Fuel
M	Mixture or blend

Zone 3: volatile matter

Two digits signify the per cent volatile matter (%VM) in the fuel on a dry basis:

Digits	% VM	Digits	% VM
05	0–5	30	25–30
10	5–10	35	30–35
15	10–15	40	35–40
20	15–20	45	40–45
25	20–25	50	45–50

Zone 4: sulphur content

Two digits signify the per cent sulphur of the fuel on a dry basis:

Digits	% Sulphur	Digits	% Sulphur
05	0.0–0.5	55	5.0–5.5
10	0.5–1.0	60	5.5–6.0
15	1.0–1.5	65	6.0–6.5
20	1.5–2.0	70	6.5–7.0
25	2.0–2.5	75	7.0–7.5
30	2.5–3.0	80	7.5–8.0
35	3.0–3.5	85	8.0–8.5
40	3.5–4.0	90	8.5–9.0
45	4.0–4.5	95	9.0–9.5
50	4.5–5.0	99	>9.5

Zone 5: ash content

Two digits signify the per cent ash in the fuel on a dry basis:

Digits	% Ash	Digits	% Ash
01	0–1	30	25–30
05	1–5	35	30–35
10	5–10	40	35–40
15	10–15	45	40–45
20	15–20	50	45–50
25	20–25	55	50–55

Zone 6: higher heating value (HHV)

Two digits signify the HHV of the fuel on an as received basis:

Digits	HHV (MJ/kg)	Digits	HHV (MJ/kg)
10	<10	30	25–30
15	10–15	35	30–35
20	15–20	40	35–40
25	20–25	45	40–45

Zone 7: type of coal

One letter signifies whether the fuel is raw or processed:

Letter	Type
R	Raw
P	Processed or beneficiated

EXAMPLE: Hat Creek coal

Coal code: BC S 50 10 25 20 P

Zone	
1	BC: Fuel is from British Columbia
2	S: Fuel is subbituminous
3	50: Volatile matter is between 45 and 50%
4	10: Sulphur content is between 0.5 and 1.0%
5	25: Ash content is between 20 and 25%
6	20: Higher heating value is between 15 and 20 MJ/kg
7	P: Fuel is beneficiated (processed)

Note: When data or information for any of the zones are not available, that zone will be designated * or ** as appropriate.

3. COMMON TEST ELEMENTS

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3.1 RESEARCH OBJECTIVES

The general objectives of each combustion trial and the related analytical studies were:

- to determine the comminution and handling characteristics of the coal
- to evaluate the combustion performance of the pulverized coal at specified levels of excess combustion air and coal fineness
- to characterize the particulate and gaseous pollutants generated during combustion
- to assess the slagging and fouling potential of the fuel ash on radiant and convective heat transfer surfaces
- to assess the corrosion potential of condensed sulphuric acid on cold–end boiler surfaces
- to determine the fly ash resistivity characteristics
- to assess the ease of fly ash collection by electrostatic precipitation.

Objectives other than the above are given in the summaries.

3.2 FUEL HANDLING CHARACTERISTICS

The test coals were delivered to CCRL in sealed drums. The as–received coal was crushed, metered and pulverized to the desired fineness, after which it was transported either to an indirect feed bin with moisture separation or directly to the burner without moisture separation from the carrying air. The size distribution of the pulverized coals was determined, and any problems in moving or feeding the fuel through the pilot–scale coal handling system were noted.

The fuel analyses were reported on an as–received, dried, as–pulverized, or as–fired basis. As–pulverized refers to coal samples taken from the coal handling system as the coal entered the pulverizer. As–fired refers to coal taken from the transport pipe to the burners.

A preliminary reactivity assessment was conducted on most of the fuels using either petrographic or thermogravimetric analysis.

3.3 PILOT–SCALE RESEARCH BOILER

The CCRL boiler, illustrated schematically in Figure 1, is a pulverized–coal–fired research boiler incorporating two opposed in–shot burners that tilt downward over a refractory–lined chamber. The furnace is of membrane–wall construction and operates at pressures up to 25 cm water column (2.5 kPa or 10 in water column). At its full load firing rate of 2500 MJ/h (0.7 MWt) the boiler generates 730 kg/h steam at 690 kPa (6.8 atm). The heat is dissipated in an air cooled condenser. The firing rate is maintained at the required load during each test.

Crushed fuel 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 temperatures up to 230°C or, if necessary, with a mixture of air and flue gas 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 equally to the two burners. Secondary air can be supplied to the burners at temperatures up to 260°C.

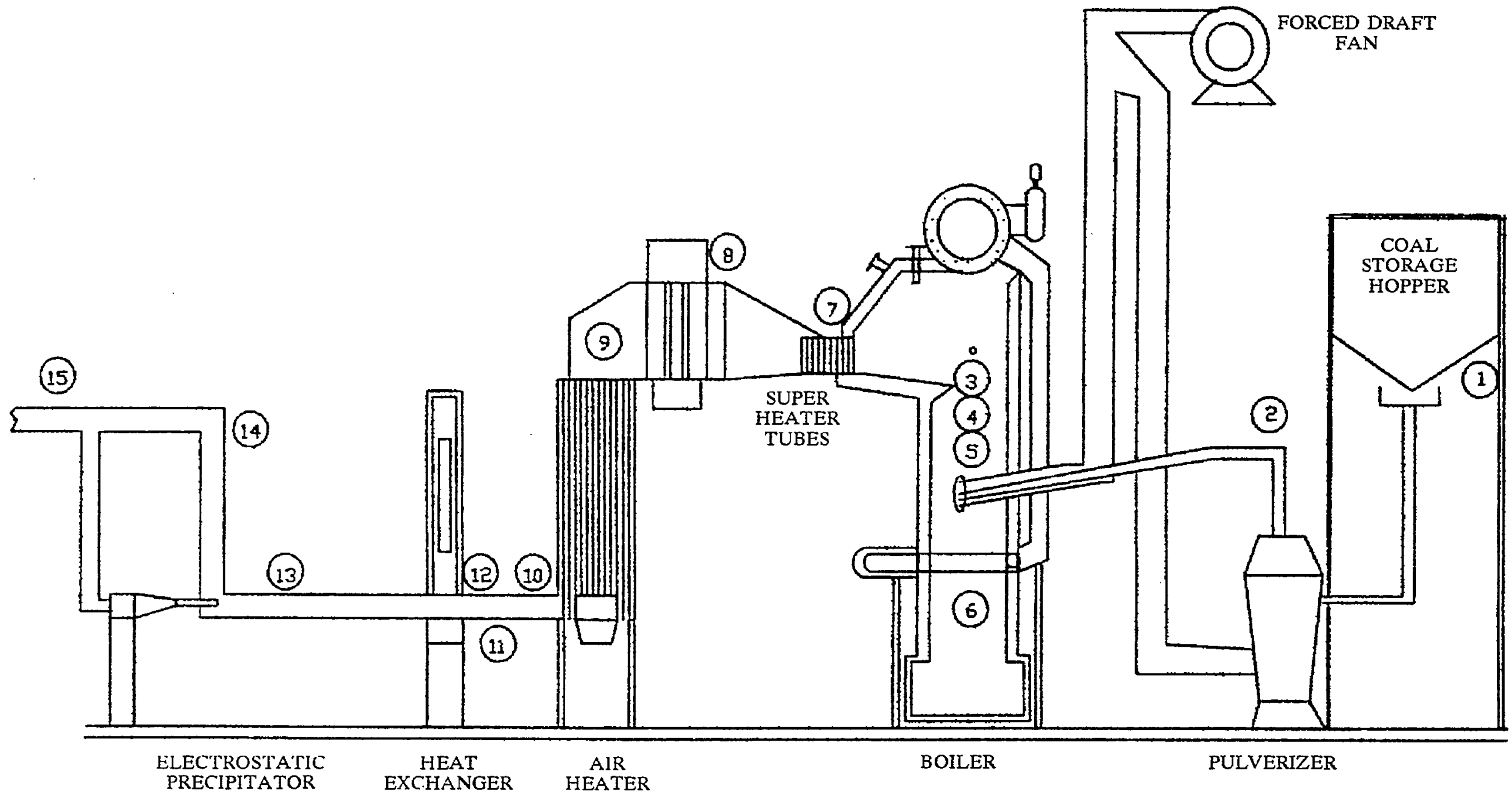

Fig. 1 – Schematic illustration of the pilot-scale boiler showing the sampling stations

Combustion gases leave the furnace between 760°C and 860°C, then pass through a transition section, a test–air heater and a conventional three–pass heater before entering a long horizontal sampling duct. At the end of the sampling duct, the gas flow can either be passed entirely into the stack or, if necessary, a portion of the gas flow to the stack can be diverted isokinetically into a small two–stage electrostatic precipitator. A bypass from the air heater to the stack breeching and an additional heat exchanger surface in the sampling duct permits 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 (0.70 atm, 28 in. water column). On leaving the heater, the air 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 be either exhausted to the atmosphere or blended with the primary air supply to the pulverizer.

The research boiler is manually controlled, except for electrical interlocks to ensure that safe startup 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 Ringelman. When severe fouling of the convective heat transfer surfaces occurs, feed rate or excess air level must be reduced to control furnace pressure.

3.4 OPERATING PROCEDURE

The operating procedure given below was used for all the combustion trials with minor variations as necessary.

1. Before each test, all boiler and air heater fireside surfaces were cleaned by air lancing. Ash deposits adhering to refractory surfaces were removed manually. Sufficient coal was bunkered to provide about 10 h of operation at the desired feed rate.

2. At 0600 h, the cold boiler was fired up on No. 2 fuel oil at 73 L/h (16 gph). Excess air was adjusted to provide the required O_2 content 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 0730 h, the pulverized coal feed was started to the boiler at the specified classifier speed, mill temperature and oxygen level in the flue gas. One oil torch was left in operation.

4. At 0745 h, the oil torch was removed, leaving the boiler to operate on pulverized coal alone.

5. At 0900 h, scheduled testing was begun and boiler panel readings were recorded hourly. The specified coal feed rate and oxygen level were maintained as closely as possible.

6. By 1500 h, scheduled tests were generally completed. Repeat measurements were begun, if required.

7. When all measurements were completed, an oil torch was inserted and the coal feed to the pulverizer was shut off. When the pulverizer was empty, the boiler was shut down.

8. The furnace was then allowed to cool overnight. The furnace bottom was removed and the ash remaining in the furnace bottom and the boiler hoppers was collected and weighed the following day.

3.5 PARAMETERS OF COMBUSTION PERFORMANCE

The following parameters of combustion performance were measured in most of the tests at the appropriate measuring stations:

1. Proximate and ultimate coal analyses, 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) and in some cases at the pulverizer outlet (Station 2).

2. Moisture and sieve analyses of pulverized coal samples taken every 2 h or as necessary at the pulverizer outlet (Station 2).

3. CO_2 and CO content of the flue gas, measured continuously by infrared monitors, (Station 8).

4. O_2 content of the flue gas, measured continuously by a paramagnetic monitor (Station 8).

5. NO content of the flue gas, measured continuously by a chemiluminescent monitor (Station 10).

6. SO_2 content of the flue gas, measured continuously by a chemifluorescent monitor or by infrared monitor (Station 11).

7. SO_2 and SO_3 content of the flue gas, measured by the American Petroleum Institute (API) and the modified Shell–Thornton methods, respectively, two or three times per test (Station 12).

8. In some tests, low temperature corrosion potential, measured by three mild steel probes inserted simultaneously into the flue gas stream and maintained at three different temperatures below the acid dewpoint for the duration of the combustion test (Station 10).

9. 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. The normal CCRL solid sampling system classified the sample into three size fractions: fine, medium and coarse. In this sampling system, the coarse fraction (>20 µm) was collected in the main barrel of a cyclone, the medium fraction (2 to 20 µm) on retaining grids in the central exhaust tube of the cyclone and the fine fraction (<20 µm) on a glass fibre filter downstream of the cyclone (Station 13).

10. Ash fouling of high temperature heat transfer surfaces evaluated by examining fly ash deposits on a simulated superheater, installed immediately downstream of the screen tubes. A second 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 3, 4, 5, 6, 7 and 9).

11. Electrostatic precipitator efficiency, measured by passing part of the flue gas through a small electrostatic precipitator for 45 min. three samples per test. The efficiency was calculated from the measured inlet and outlet dust loadings (Stations 14 and 15).

12. Fly ash resistivity, measured by in situ, point–plane resistivity apparatus at flue gas temperatures of 200 and 400°C. Two measurements on selected samples of fly ash extracted from the gas stream at the precipitator inlet as well as before and after heat exchanger were also obtained for some trials (Stations 12 and 13).

In addition, qualitative observations on flame appearance and length were recorded and areas of ash buildup on the superheater and furnace walls of the cold boiler were photographed.

3.6 SIGNIFICANCE OF PARAMETERS

Although the significance of many of the parameters measured is evident, the following is a review of the parameters given and their significance in pulverized fuel combustion:

Maceral Reactivity – Directly influences ignition, flame stability and combustion efficiency as shown in Figure 2. Coals containing greater than 60% by volume of low reactivity macerals (fusinite, semifusinite, micrinite and oxidized vitrinite) generally require fine grinding, long residence times and hot flame zone temperatures, either alone or in combination, to ensure good burn-out.

Fly Ash Resistivity and Electrostatic Precipitator Performance – A high fly ash resistivity (10 log ohm–cm) indicates that the dust can retain a strong electrical charge or generate a back corona within a deposit when subjected to an electric field. Under these circumstances, precipitator efficiency is reduced by the electrical neutralization of charged particles in the electrostatic field. Fly ash will low electrical resistivity (<7 log ohm–cm) will precipitate readily but will not adhere strongly to the collecting plates. A decreased precipitator efficiency will result because of particle re–entrainment in the flue gas. Intermediate resistivity values of 8 to 9 log ohm–cm are generally considered to yield the best precipitator performance.

RESINITE	VITRINITE	SEMIFUSINITE
EXINITE	TELLINITE	MICRINITE
FINELY–DIVIDED MICRINITE	LOW–REFLECTANCE SEMIFUSINITE	OXIDIZED VITRINITE
		FUSINITE

——— REACTIVITY DECREASE ———→

←——— IGNITION, FLAME STABILITY AND COMBUSTION EFFICIENCY INCREASES ———

Fig. 2 – Influence of coal maceral type on combustion

High Temperature Ash Deposition – By definition, two types of high temperature ash deposition can occur on gas–side surfaces of coal–fired boilers:

- slagging – fused deposits that form on surfaces exposed predominantly to radiant heat transfer;
- 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 burned in these pilot–scale experiments is done using accepted empirical indices based on the analysis of the raw coal, ash, the analysis of the fireside deposits and a visual assessment of the deposits produced within the boiler.

Ash Fusion Temperatures – These are determined according to procedures described in ASTM D.1857, which defines four temperatures at which specified physical changes in a standard specimen become apparent:

- initial deformation,
- spherical softening,
- hemispherical deformation, and
- fluid.

This test can be carried out in a reducing or oxidizing atmosphere, but usually reference is to the reducing condition which may generate lower fusion temperatures and is therefore more restrictive.

The initial deformation temperature roughly corresponds to the temperature in an operating furnace at which the molten particles of coal ash, in transit through the furnace, have been cooled only to the extent that they retain a slight tendency to stick together or to build up slowly on heat absorption surfaces. When the temperatures in an operating furnace are such that the outside surfaces of the ash particles have cooled to a temperature lower than their initial deformation temperature, they tend to accumulate as a "dry" product.

The spherical softening temperatures of the ash and the hemispherical deformation temperature are related to those at which the ash surfaces show a greatly accelerated tendency to stick together and then build up as massive deposits on heat absorption surfaces.

The fluid temperature of the ash is the temperature above which deposited ash is completely melted and tends to flow in streams or to drip from heat absorption surfaces.

Slagging Indicators – The assessment of slagging potential in coal–fired boilers has been attempted by several workers who have produced indicators or empirical parameters to describe the nature and severity of the slag deposits. 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 applicable only to coals having "eastern type" or "western type" ash. The term "western type" ash is defined as that having more CaO + MgO than Fe_2O_3, when each is measured as a weight per cent of the coal ash. It should be noted that this criterion is dependent on ash analysis and does not have any rank or geographical connotation.

In a boiler, ash low in iron and high in calcium behaves differently than the normal high–iron, low–calcium eastern coals. Most parameters used for judging the slagging and fouling characteristics of eastern coals do not apply when the coal has a western type ash. Generally there is little question as to whether the ash is of western or eastern type. In a few cases, particularly with Texas lignite, both iron and dolomite constituents may be relatively high and some question arises as to which parameters to use.

The base:acid ratio is defined as:

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

where each oxide is expressed as per cent of total ash.

A maximum value of 0.5 for the base:acid ratio has been suggested for dry–bottom pulverized coal–fired units, although this is not a necessary restriction. Values below 0.27 indicate that slagging will be an unlikely problem at normal furnace operating temperatures.

To evaluate further the potential of the bottom ash to slag, the analytical data have been used to calculate the viscosity/temperature relationship for both the coal and the bottom ash deposits using:

$$T(°C) = \frac{10^7 M}{\log V - C} + 150$$

where T = ash temperature, °C
V = ash viscosity, poise (1 Pa.s = 10 poise)
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 $SiO_2 + Al_2O_3 + Fe_2O_3 + MgO + CaO = 100$

T_{250}, °C = temperature at which the viscosity of a potential bottom slag is 250 poise with 20% of the iron in the ferrous form. For wet–bottom furnaces, the preferred slag viscosity for easy tapping is below 100 poise and T_{250} should not normally exceed 1425°C.

For dry–bottom furnaces, the T_{250} can be one factor used to rate the coal ash in relation to furnace slagging. One suggested rating system is:

Slagging category	T_{250}, °C
Low	>1275
Medium	1400–1150
High	1250–1120
Severe	<1205

It should be noted that there is considerable overlap between the categories.

Another index commonly used for determining the slagging potential of a fuel is based on ash fusibility temperatures. This potential slagging temperature (Tps) is defined as:

$$Tps\ (°C) = \frac{HT + 4IT}{5}$$

where IT is the minimum temperature (°C) at which initial ash deformation occurs (normally in a reducing atmosphere) and HT is the maximum temperature (°C) at which hemispherical deformation occurs (normally in an oxidizing atmosphere). Values greater than 1340°C indicate a low slagging potential, whereas values less than 1150°C indicate a severe slagging potential.

Fouling Indicators – A most convincing indicator of the fouling tendency of the coal is the inspection of the deposits on a simulated superheater that can be controlled at a set temperature.

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-type ash	Western-type ash
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

Low Temperature Corrosion Problems – These are normally due to the condensation of gas–phase sulphur trioxide on metal surfaces at temperatures below the acid dewpoint. The condensed acid (H_2SO_4) then reacts with air heater or economizer tubes to produce $FeSO_4$ as a corrosion product. With high sulphur fuels and high acid condensation rates, the initial corrosion product, $FeSO_4$, is converted to $Fe_2(SO_4)_3$ and catastrophic metal wastage occurs.

4. CROSS-REFERENCE OF SUMMARY NUMBER WITH ERL REPORT TITLE

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Summary No.	ERL Report Title	Authors	No.
1	Pilot-scale combustion trials with high ash Saskatchewan lignites	T.D. Brown G.K. Lee	ERP/ERL 75-50 (IR)(J)
2	Pilot-scale combustion trials with Poplar River lignite Part I: combustion performance and fouling characterization	G.K. Lee T.D. Brown	ERP/ERL 76-41 (IR)
3	Improved electrostatic precipitator performance by use of flue gas conditioning agents. Phase I: exploratory combustion trials	G.K. Lee T.D. Brown B.N. Nandi	ERP/ERL 76-59 (IR)
4	Pilot-scale combustion of high ash Saskatchewan lignites. Part II: the effect of beneficiation on Estevan lignite	G.K. Lee T.D. Brown	ERP/ERL 76-98 (IR)
5	Pilot-scale combustion trials of high ash Saskatchewan lignites. Part III: Cyprus and Wood Mountain raw lignites	G.K. Lee T.D. Brown	ERP/ERL 76-191 (IR)
6	Improved electrostatic precipitator performance by use of flue gas conditioning agents Phase II: the effect of selected conditioning agents on fly ash electrical resistivity and ESP efficiency using Luscar coal	T.D. Brown G.K. Lee	ERP/ERL 77-08 (IR)
7	Pilot-scale combustion studies with Hat Creek coal: volumes 1 and 2	F.D. Friedrich T.J. Cyr G.K. Lee T.D. Brown	ERL Reports 77-96 (TR) 77-97 (TR)
8	A pilot-scale combustion evaluation of Obed-Marsh coal	T.D. Brown G.K. Lee	ERP/ERL 78-14

Summary No.	ERL Report Title	Authors	No.
9	Improved electrostatic precipitator performance by use of flue gas conditioning agents Phase III: the effect of three conditioning agents and coal blending on the electrical resistivity and electrostatic precipitation of fly ash from Luscar coal	T.D. Brown G.K. Lee	ERP/ERL 78–17 (IR)
10	Sulphur neutralization by lignite ash: pilot–scale combustion experiments	T.D. Brown G.K. Lee H.A. Bamborough	ERP/ERL 78–55 (J)
11	Pilot–scale combustion evaluation of Manalta briquettes	T.D. Brown G.K. Lee	ERP/ERL 78–78 (TR)
12	A pilot–scale combustion evaluation of Tulameen coal	T.D. Brown G.K. Lee	ERP/ERL 79–7
13	Pilot–scale combustion evaluation of Judy Creek North coal	T.D. Brown H. Whaley G.K. Lee	ERP/ERL 79–22
14	Pilot–scale combustion evaluation of beneficiated Tent Mountain – Vicary Creek coal rejects	R. Prokopuk H. Whaley G.K. Lee	ERP/ERL 80–10
15	Pilot–scale combustion and evaluation of thermal Line Creek coal from Fernie, British Columbia	R. Prokopuk G.N. Banks H. Whaley G.K. Lee	ERP/ERL 80–36
16	Pilot–scale combustion trials with Onakawana lignite Phase I: pulverized–fired research boiler	R. Prokopuk G.N. Banks G.K. Lee H. Whaley	ERP/ERL 80–61
17	Sulphur oxide neutralization with limestone during combustion of Suncor coke	R. Prokopuk G.K. Lee G.N. Banks H. Whaley	ERP/ERL 81–04
18	Combustion trials with Sage Creek coal Phase I: Preliminary assess–ment of a 65:35 blend of No. 4 upper and No. 4 lower seams in a pilot–scale utility boiler	G.K. Lee R. Prokopuk H. Whaley G.N. Banks	ERP/ERL 81–17

Summary No.	Title	ERL Report Authors	No.
19	Pilot-scale combustion trials of two washed blends of Sage Creek coal	H. Whaley G.K. Lee R. Prokopuk G.N. Banks	ERP/ERL 81-38
20	Pilot-scale combustion evaluation of Poplar River lignite, Phase II: control of sulphur dioxide emission using dry lime	T.D. Brown G.K. Lee H. Whaley	ERP/ERL 82-36 (TR)
21	Combustion evaluation of thermal Line Creek coal sample No. 2 in a pilot-scale utility boiler	G.N. Banks J. Wong R. Prokopuk H. Whaley	ERP/ERL 83-19 (CF)

5. CROSS-REFERENCE OF TEST FUELS WITH SUMMARY AND ERL REPORT

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Coal	Summary No.	Report	
Byron Creek	3	ERP/ERL	76-59 (IR)
Cypress	5	ERP/ERL	76-191 (IR)
Estevan	1	ERP/ERL	75-50 (IR)(J)
	4	ERP/ERL	76-98
Gascoyne	10	ERP/ERL	78-55 (J)
Hat Creek	7	ERL Report	77-96&97 (TR)
Judy Creek	13	ERP/ERL	79-22
Klimax	16	ERP/ERL	80-61
Line Creek	15	ERP/ERL	80-36
	21	ERP/ERL	83-19
Line Creek/Luscar blend	15	ERP/ERL	80-36
	21	ERP/ERL	83-19
Luscar/Pennsylvania blend	9	ERP/ERL	78-17 (IR)
Luscar	3	ERP/ERL	76-59 (IR)
	6	ERP/ERL	77-08 (IR)
	9	ERP/ERL	78-17 (IR)
	14	ERP/ERL	80-10
	15	ERP/ERL	80-36
	21	ERP/ERL	83-19
Manalta briquettes	11	ERP/ERL	78-78 (TR)
Obed-Marsh	8	ERP/ERL	78-14
Onakawana	11	ERP/ERL	78-78 (TR)
	16	ERP/ERL	80-61
Pennsylvania/Byron Creek blend	3	ERP/ERL	76-59 (IR)
Pennsylvania	3	ERP/ERL	76-59 (IR)
Poplar River	2	ERP/ERL	76-41 (IR)
	10	ERP/ERL	78-55 (J)
	20	ERP/ERL	82-36 (TR)
Sage Creek	18	ERP/ERL	81-17
	19	ERP/ERL	81-38
Suncor Coke	17	ERP/ERL	81-04

Coal	Summary No.	Report
Sundance	7	ERL Report 77–96&97 (TR)
	12	ERP/ERL 79–7
	13	ERP/ERL 79–22
Tent Mountain	14	ERP/ERL 80–10
Tulameen	12	ERP/ERL 79–7
US Bituminous	9	ERP/ERL 78–17 (IR)
Utility	1	ERP/ERL 75–50 (IR)(J)
	2	ERP/ERL 76–41 (IR)
	4	ERP/ERL 76–98
	5	ERP/ERL 76–191 (IR)
	10	ERP/ERL 78–55 (J)
Vicary Creek	14	ERP/ERL 80–10
Willow Bunch	1	ERP/ERL 75–50 (IR)(J)
Wood Mountain	5	ERP/ERL 76–191 (IR)

6. SUMMARIES OF COMBUSTION CHARACTERISTICS

6. SUMMARIES OF COMBUSTION CHARACTERISTICS

6.1 SUMMARY 1: HIGH-ASH SASKATCHEWAN LIGNITES

1. Coal identification

Coal name and code: Willow Bunch SA L 40 15 25 15 R
Estevan SA L 30 10 45 15 R
Mine: Willow Bunch - Ravenscrag formation, Saskatchewan
Klimax (Estevan seam) - Ravenscrag formation, Saskatchewan
Status: Exploratory

2. Reference report features

Topic: Pilot-scale combustion trials of high ash Saskatchewan lignites
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Saskatchewan Department of Mineral Resources
Reference report (date): ERP/ERL 75-50 (IR)(J) (May 1975)
Related summaries: 4 and 6

3. Reference coal

Name and code: Utility lignite SA L 40 10 15 20 R
Mine: Boundary Dam, Saskatchewan
Status: Active, commercial

4. Pilot-scale boiler system

Furnace configuration - I
System modification - Two opposed burners supplied by indirect coal feed system, with individually metered amounts of pulverized coal
- Simulated superheater immediately downstream of screen tubes

5. Coal characteristics

Willow Bunch:
As-received handling - Wide variations in extraneous ash and free water in the as-received samples from drum to drum. Hence, total sample was air dried and mechanically blended. Considerable trouble was experienced at the feed bin where the fuel tended to compact into a cohesive solid, probably due to medium ash and medium moisture content. Continuous, gentle agitation by a spoked shaft was necessary to prevent "rat-holing" over the feeders and maintain pulverized coal flow to both burners. This feeding problem will not occur with conventional, large-scale, moisture-separating burner systems.
As-pulverized moisture - 34.89%
As-fired screen size <200 mesh - 68.7%

Estevan:

As–received handling – Wide variations in extraneous ash and free water in the as–received samples from drum to drum. Hence, the total sample was air dried and mechanically blended. This was difficult because the sample contained a number of large lumps of wet clay. Considerable trouble was experienced at the feed bin where the fuel tended to compact into a cohesive solid, probably due to the high ash, low moisture content. Continuous, gentle agitation by a spoked shaft was necessary to prevent "rat–holing" over the feeders and maintain coal flow to both burners. The coal feeding problem will not occur with conventional, large–scale, moisture–separating systems.

As–pulverized moisture – 17.71%

As–fired screen size <200 mesh – 71.0%

Utility lignite:

As–received handling – Relatively low in both free moisture and occluded clay and fairly uniformly mixed, thus neither drying nor blending was required.

As–pulverized moisture – 17.06%

As–fired screen size <200 mesh – 68.6%

6. Flame observations

Willow Bunch: Short stable flame, no support fuel required.

Estevan: Unstable, required oil support and >30% excess air. An unsupported flame was maintained with 6.5% O_2 in flue gas.

Utility: Short stable flame, no support fuel required.

7. Fly ash properties

Willow Bunch:

Slagging potential	– Low, based on observation
Fouling potential	– Low, based on observation
Resistivity	– Not measured
Particle size	– Table 6
Combustible in ash	– 2 to 4%

Estevan:

Slagging potential	– Low, based on observation
Fouling potential	– Low, based on observation
Resistivity	– Not measured
Particle size	– Table 6
Combustible in ash	– 5%

Utility:

Slagging potential	– Medium, based on observation
Fouling potential	– Low, based on observation
Resistivity	– Not measured
Particle size	– Table 6
Combustible in ash	– 2 to 4%

Note: Any buildup in fireside deposits from Willow Bunch or Estevan lignite could be controlled by properly located soot blowers. Utility lignite produced relatively thick, sintered deposits on screen tubes and simulated superheater tubes.

8. Low–temperature corrosion

Corrosion rate – Low for all three lignites. Any acid would be rapidly neutralized by superfine, alkaline fly ash particles.

9. Emissions

See Table 4.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Coal ash analyses	– Table 1
Coal grind	– Table 2
Combustion performance	– Table 3
Gaseous emissions	– Table 4
Fly ash analyses	– Table 7
Size	– Table 6

Table 1 – Analyses of lignites

Sample condition	Utility As pulverized	Utility As fired	Willow Bunch As pulverized	Willow Bunch As fired	Estevan As pulverized	Estevan As fired
Proximate analysis, wt %						
Moisture	17.06	5.36	34.89	19.18	17.71	6.80
Ash	11.11	14.89	16.04	22.57	34.61	51.10
Volatile matter	32.51	36.08	25.55	30.98	22.64	21.40
Fixed carbon	39.32	43.67	23.52	27.27	25.04	20.50
Ultimate analysis, wt %						
Carbon	50.60	56.90	34.59	39.75	33.62	29.40
Hydrogen	3.31	3.68	2.30	2.82	2.52	2.20
Sulphur	0.48	0.62	0.88	1.42	0.57	0.50
Nitrogen	0.87	0.98	0.49	0.59	0.57	0.50
Ash	11.11	14.89	16.04	22.57	34.61	51.10
Oxygen	16.57	17.57	10.81	13.67	10.40	9.10
Gross calorific value, Btu/lb	8230	9290	5600	6380	5600	4760
Fusibility of ash, °C*						
Initial	1182	1093	1288	1304	1188	1171
Spherical	1193	1149	1327	1360	1371	1371
Hemispherical	1227	1171	1349	1404	1427	>1480
Fluid	1427	1316	1415	1432	1477	>1480
Grindability, HGI	56 (5.2% moist.)		74 (6.4% moist.)		85 (3.7% moist.)	
Ash analysis, wt %						
Water soluble	–	4.89	–	26.54	–	3.50
S	–	1.22	–	6.64	–	0.90
Mg	–	0.02	–	0.13	–	0.00
Na	–	2.09	–	0.59	–	1.00
K	–	0.05	–	0.10	–	0.00
Ca	–	2.65	–	3.12	–	2.30
Acid soluble	–	16.00	–	14.90	–	8.90
Fe	–	0.98	–	0.97	–	0.60
Mg	–	0.46	–	0.44	–	0.10
Na	–	0.28	–	0.04	–	0.10
K	–	0.01	–	0.03	–	0.10
Ca	–	7.40	–	4.10	–	2.80
Al	–	1.55	–	1.72	–	1.50
Acid insoluble						
$SiO_2 + Al_2O_3$	–	79.11	–	58.56	–	87.50

*See Section 3.6

Table 2 – Screen analyses of crushed and pulverized lignites

Screen size	Utility Crushed	Utility Pulverized	Willow Bunch Crushed	Willow Bunch Pulverized	Estevan Crushed	Estevan Pulverized
>1/8 in.	2.18	–	0.33	–	0.94	–
<1/8 in. >10 mesh	39.75	–	16.68	–	24.29	–
<10 >20	32.86	–	21.08	–	33.75	–
<20 >28	8.08	–	7.79	–	7.66	–
<28 >48	8.98	–	14.41	–	12.31	–
<48	8.15	–	39.71	–	21.05	–
>140 mesh	–	17.3	–	19.2	–	18.0
<140 >200	–	14.1	–	12.1	–	11.1
<200 >325	–	17.1	–	18.7	–	14.4
<325	–	51.5	–	50.0	–	56.6

Table 3 – Summary of combustion performance

	Firing rate lb/h	Oil support US gph	O_2 in flue gas vol %	Steam flow lb/h	Temperature, °C Comb air	Flue gas	SHT*	Pulverizer air in	Pulverizer air out
Utility	343	–	5.9	1150	204	271	85	571	271
		–	3.2	1180	203	279	84	551	320
		–	1.1	1220	199	263	82	532	366
Willow Bunch	340	–	4.8	950	177	207	51	502	270
		–	2.8	1100	191	213	51	502	274
		–	1.0	1050	171	191	50	460	248
Estevan	347	5	2.7	1450	202	263	77	543	321
		3	2.7	1350	204	321	77	527	346
		1¼	2.8	1200	204	311	73	518	344
		–	6.5	900	160	304	74	443	327

*SHT – superheater tubes

Table 4 – Flue gas analyses

	Firing rate lb/h	Oil support US gph	O_2 vol %	CO_2 vol %	CO vol %	SO_2 ppm	SO_3 ppm	NO ppm	Ringleman smoke no.
Utility	343	–	5.9	15.8	0.01	211	10.5	330	<1
		–	3.2	17.2	0.01	235	4.9	330	<1
		–	1.1	19.2	0.02	267	–	200	<1
Willow Bunch	340	–	4.8	16.6	0.02	619	5.9	213	<1
		–	2.8	17.0	0.02	704	3.4	243	<1
		–	1.8	18.2	0.02	789	1.6	228	<1
Estevan	347	5	2.7	16.8	0.03	317	3.9	175	<1
		3	2.7	17.0	0.03	309	9.4	140	<1
		1¼	2.8	17.2	0.04	320	6.3	150	<1
		–	6.5	13.0	0.05	200	–	138	<1

Table 6 – Size distribution of fly ash

	O_2 in flue gas %	Oil support %	Size distribution wt % in fraction		
			Coarse >20 μm	Medium 20 to 2 μm	Fine <2 μm
Utility	5.9	–	43.2	35.4	21.4
	3.2	–	44.5	43.3	12.2
	1.1	–	53.4	30.8	15.8
Willow Bunch	4.8	–	46.1	38.0	15.9
	2.8	–	62.2	13.8	24.0
Estevan	2.7	25	68.0	16.1	15.9
	2.7	16	77.0	15.1	7.9
	2.8	8	73.1	16.8	10.1
	6.5	–	69.2	20.2	10.6

Table 7 – Analyses of fly ash

	Utility			Willow Bunch		Estevan			
O_2 in flue gas, vol %	5.9	3.2	1.1	4.8	2.8	2.7	2.7	2.8	6.5
Oil support, vol %	0	0	0	0	0	25	16	8	0
Components, wt %									
Water soluble									
Total	10.25	7.18	6.10	7.60	6.78	1.89	2.27	2.04	1.54
S (as SO_4)	4.91	3.13	2.54	3.30	2.53	0.91	1.18	1.18	1.16
Fe	–	–	–	0.08	0.07	0.04	0.03	0.04	0.13
Mg	0.01	0.03	0.02	0.01	0.01	0.03	0.03	0.02	0.02
Na	1.39	0.92	1.23	0.02	0.02	0.44	0.18	0.30	0.76
K	0.38	0.46	0.41	0.03	0.06	0.04	0.02	0.05	0.07
Acid–soluble									
Fe	2.23	2.71	3.11	1.35	2.61	1.15	1.48	1.25	1.17
Mg	1.54	1.75	1.75	1.17	2.20	0.38	0.44	0.32	0.31
Na	5.91	7.21	7.41	0.08	0.10	0.66	0.71	0.63	0.62
K	0.51	0.54	0.48	0.19	0.21	0.78	0.69	0.61	0.70
Ca	9.62	11.16	7.05	3.68	6.12	0.54	0.69	0.35	0.51
Al	9.74	11.07	10.68	13.90	13.60	6.79	6.28	6.98	9.16
Acid–insoluble									
Al + Si	41.60	37.29	33.86	49.05	46.97	83.84	82.52	83.06	83.72
Total alkali									
Na + K	8.19	9.13	9.53	0.32	0.39	1.92	1.60	1.59	2.16

6.2 SUMMARY 2: POPLAR RIVER LIGNITE

1. Coal identification

Coal name and code: Poplar River SA L 40 10 25 20 R
Mine: Poplar River, Coronach, Southwestern Saskatchewan
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trials
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Saskatchewan Power Corporation
Reference report (Date): ERP/ERL 76–41 (IR) (May 1976)
Related summary: 20

3. Reference coal

Name and code: Utility lignite SA L 40 10 15 20 R
Mine: Boundary Dam, Saskatchewan
Status: Active, commercial

4. Pilot–scale boiler system

Furnace configuration – I
System modification – Simulated superheater installed immediately downstream of the screen tubes and a rotary drier installed to dry the as received coal before crushing and pulverizing.

5. Coal characteristics

As–received handling – the 5–ton bulk sample was delivered in sealed drums. Before drying, the entire sample was mixed in a mechanical riffle and a number of large, shale–like lumps (about 50 kg) were removed manually. Thereafter the Poplar River lignite handled, dried and crushed without difficulty although the pulverizer capacity was less than that recorded with Utility lignite at identical classifier settings.
As–pulverized moisture – 12.91%
As–fired screen size <200 mesh – 62.8%

6. Flame observations

Short stable flame, no support fuel required

7. Fly ash properties

Slagging potential	- Low based on observation
Fouling potential	- Low based on observation
Resistivity	- 2.2 to 4.5 x 10^{10} ohm–cm
Sulphur neutralization	- 33%
Electrostatic precipitator efficiency	- 91%
Particle size	- Reference report Table 6
Combustible in ash	- 6.4 to 3%, for 3 to 5% O_2 in flue gas
Loading	- 6 gr/scf (grains per standard cubi,c foot)

Deposits from Poplar River lignite were easily removed by sootblowing whereas those from Utility lignite were sintered and difficult to dislodge.

8. Low–temperature corrosion

SO_3	- Not available
Corrosion rate	- No significant free acid in low temperature deposits

9. Emissions

NOx and SO_2	- See Table 4

10. Tabulations attached from reference report

Coal analyses	- Table 1
Coal ash analyses	- Table 1
Coal grind	- Table 2
Combustion performance	- Table 3
Gaseous emissions	- Table 4
Fly ash analyses	- Table 9
Size	- Table 6

Table 1 – Analyses of lignites

	Utility		Poplar River		
	As pulverized	As fired	As received	As pulverized	As fired
Proximate analysis, wt %					
Moisture	17.06	5.36	21.68	12.91	11.60
Ash	11.11	14.89	18.19	17.30	19.96
Volatile matter	32.51	36.08	29.27	33.23	37.53
Fixed carbon	39.32	43.67	30.86	36.56	30.89
Ultimate analysis, wt %					
Carbon	50.60	56.90	42.21	49.11	48.78
Hydrogen	3.31	3.68	2.81	3.21	3.17
Sulphur	0.48	0.62	0.65	0.60	0.75
Nitrogen	0.87	0.98	0.60	0.66	0.66
Ash	11.11	14.89	18.19	17.30	20.11
Oxygen	16.57	17.57	13.86	16.21	14.93
Gross calorific value, Btu/lb	8230	9290	6826	7942	–
Fusibility of ash, °C*					
Initial	1182	1093	1271	1266	1250
Spherical	1193	1149	1288	1288	1280
Hemispherical	1227	1171	1320	1338	1325
Fluid	1427	1316	1410	1416	1400
Grindability, HGI	56 (5.2% moist.)		65	62 (13% moist.)	
Ash analysis, wt %					
Water soluble	–	4.89	–	–	10.75
S	–	1.22	–	–	1.63
Mg	–	0.02	–	–	0.10
Na	–	2.09	–	–	0.10
K	–	0.05	–	–	0.00
Ca	–	2.65	–	–	ND**
Acid soluble	–	16.00	–	–	ND
Fe	–	0.98	–	–	1.60
Mg	–	0.46	–	–	1.10
Na	–	0.28	–	–	0.10
K	–	0.01	–	–	0.20
Ca	–	7.40	–	–	9.00
Al	–	1.55	–	–	ND
Acid insoluble					
$SiO_2 + Al_2O_3$	–	79.11	–	–	64.80

*See Section 3.6

**ND: not determined

Table 2 – Screen analyses of crushed and pulverized lignites

Screen size		Utility		Poplar River	
		Crushed	Pulverized	Crushed	Pulverized
>1/8 in.		2.2	–	3.5	–
<1/8 in.	>10 mesh	39.7	–	37.2	–
<10	>20	32.9	–	31.4	–
<20	>28	8.1	–	9.4	–
<28	>48	9.0	–	8.7	–
<48		8.1	–	9.8	–
>140 mesh		–	17.3	–	25.3
<140	>200	–	14.1	–	11.9
<200	>325	–	17.1	–	17.3
<325		–	51.5	–	45.5

Table 3 – Summary of combustion performance

	Firing rate lb/h	O_2 in flue gas vol %	Steam flow lb/h	Temperature, °C				
				Comb air	Flue gas out	SHT* metal	Pulverizer air in	Pulverizer air out
Utility	343	5.9	1150	204	271	85	571	271
		3.2	1180	203	279	84	551	320
		1.1	1220	199	263	82	532	366
Poplar River	394	5.1	1210	236	249**	68	566	232
		3.3	1270	225	261**	72	570	222

* SHT – superheater tubes

**In the case of the Poplar River lignite the feed to the pulverizer was a 23:77 mixture of preheated air and combustion products.

Table 4 – Flue gas analyses

	Firing rate lb/h	O_2 %	CO_2 %	CO %	NO ppm	SO_2 ppm	Calculated sulphur neutralization wt %
Utility	343	5.9	15.8	0.01	330	211	60
		3.2	17.2	0.01	330	235	62
		1.1	19.2	0.02	200	267	62
Poplar River	394	5.1	15.4	0.011	310	555	30
		3.3	15.6	0.013	242	602	33

Table 6 – Size distribution of fly ash

	O_2 In flue gas %	Size distribution wt % in fraction		
		Coarse >20 μm	Medium 20 to 2 μm	Fine <2 μm
Utility	5.9	43.2	35.4	21.4
	3.2	44.5	43.3	12.2
	1.1	53.4	30.8	15.8
Poplar River	5.1	47.2	35.1	17.8
	3.3	50.4	29.7	19.9

Table 9 – Analyses of fly ash

	Utility			Poplar River	
O_2 in flue gas, vol %	5.9	3.2	1.1	5.1	3.3
Components, wt %					
Water soluble					
Total	10.25	7.18	6.10	7.90	6.60
S (as SO_4)	4.91	3.13	2.54	2.75	3.2
Fe	–	–	–	0.03	0.07
Mg	0.01	0.03	0.02	–	–
Na	1.39	0.92	1.23	trace	trace
K	0.38	0.46	0.41	–	–
Ca	0.05	0.05	0.05	0.10	0.10
Acid soluble					
Fe	2.20	2.71	3.11	2.5	3.0
Mg	1.54	1.75	1.75	2.4	2.6
Na	5.91	7.21	7.41	0.3	0.3
K	0.51	0.54	0.48	0.5	0.5
Ca	9.62	11.16	7.05	23.0	21.2
Al	9.74	11.07	10.68	–	–
Acid insoluble					
Al + Si	41.6	37.29	33.86	51.4	54.1
Total alkali					
Na + K	8.19	9.13	9.53	0.8	0.8

6.3 SUMMARY 3: BYRON CREEK, LUSCAR AND PENNSYLVANIA COALS

1. Coal identification

Coal name and code:	Pennsylvania	US	B	40	35	10	35	R
	Byron Creek	BC	S	25	05	20	30	R
	Byron Creek/Pennsylvania Blend	02	B	30	15	15	30	R
	Luscar Coal Valley	AL	B	35	05	15	30	P

Mine: Pennsylvania, United States
Byron Creek Corbin Mine, Byron Creek Collieries, British Columbia
Luscar Coal Valley, Coalspur coalfield, Foothills region of Alberta
Status: Active

2. Reference report features

Topic: Improved electrostatic precipitator performance using flue gas conditioning agents
Objectives: Determination of major parameters associated with the electrical resistivity of fly ash found in full-scale boilers, hence selection of a low-sulphur Western Canadian coal as a reference source for fly ash having high electrical resistivity
Client: Ontario Hydro
Reference report (Date): ERP/ERL 76-59(IR) (July 1976)
Related summaries: 6 and 9

3. Reference coal

None

4 Pilot-scale boiler system

Furnace configuration - I
System modification - A rotary coal drier was incorporated into the coal feed system before the coal crushing and pulverizing stages
- An additional two-pass low-temperature heat exchanger was added to the flue system downstream of high-temperature air heater

5. Coal characteristics

Pennsylvania:
As-received handling - No problems
As-fired moisture - 3.93%
As-fired screen size <200 mesh - 85%

Byron Creek:
As-received handling - No problems
As-fired moisture - 5.58%
As-fired screen size <200 mesh - 78%

Pennsylvania/Byron Creek Blend:
As-received handling - No problems
As-fired moisture - 0.64%
As-fired screen size <200 mesh - 72%

Luscar:

As-received handling	- No problems
As-fired moisture	- 5.54%
As-fired screen size <200 mesh	- 65.2 through 90.1%

The maceral analyses are given in Table 13.

6. Flame observations

Pennsylvania: Stable, no support fuel required.

Byron Creek: Generally stable, but combustion efficiency low. Flame 150°C cooler than that for Pennsylvania coal. Serious problems with flame stability at full scale (Ontario Hydro experience).

Pennsylvania/Byron Creek Blend: Stable, no support fuel required.

Luscar Coal Valley: No problems. Serious problems with flame stability at full scale (Ontario Hydro experience).

7. Fly ash properties

Pennsylvania:

Slagging potential	- Not measured
Fouling potential	- Not measured
Resistivity	- 1.0 x 10^5 to 4 x 10^9 ohm-cm (from run 1)
Particle Size	- Not measured
Combustible in ash	- 16.8% (from run 1)
ESP efficiency	- 97.8% (from run 1)

Bryon Creek:

Slagging potential	- Not measured
Fouling potential	- Not measured
Resistivity	- 1.4 x 10^3 to 1.4 x 10^4 ohm-cm (from run 5)
Particle size	- Not measured
Combustible in ash	- 58.5% (from runs 5 and 10a)
ESP efficiency	- 82% (from run 10a)

Pennsylvania/Byron Creek Blend:

Slagging potential	- Not measured
Fouling potential	- Not measured
Resistivity	- 6.7 x 10^9 to 7.5 x 10^{10} ohm-cm (from runs 3 and 4)
Particle Size	- Not measured
Combustible in ash	- 22.8 to 40.2% (from runs 3 and 4)
ESP efficiency	- 99.3% (from run 3)

Luscar Coal Valley:

Slagging potential	- Not measured
Fouling potential	- Not measured
Resistivity	- 6.2 x 10^6 to 1.0 x 10^{12} ohm-cm (from run 15)
Particle size	- See reference report Table 12
Combustible in ash	- 7.4% (from run 15)
ESP efficiency	- 80.7% (from run 15)

8. Low-temperature corrosion

Not measured.

9. Emissions

See tables listed below.

10. Tabulations attached from reference report:

Coal analyses	– Table 1
Coal ash analyses	– Not measured
Coal analyses	– Table 1
Coal grind	– Not detailed
Combustion performance	– Tables 2, 4, 6, 7 and 9
Gaseous emissions	– Tables 2, 4, 6 and 9
Fly ash analyses	– Not done
Characteristics	– Tables 3, 5, 8, 10 and 11
Size	– Table 12
Other	
Maceral analyses of coals	– Table 13

Table 1 – Analyses of coals (as fired)

	Pennsylvania	Byron Creek	Pennsylvania/ Byron Creek blend	Luscar
Proximate analysis, wt %				
Moisture	3.93	5.58	0.64	5.54
Ash	9.03	17.19	13.44	13.36
Volatile matter	34.87	23.41	28.26	31.96
Fixed carbon	52.17	53.82	57.66	49.14
Ultimate analysis, wt %				
Carbon	72.54	66.45	77.69	63.73
Hydrogen	5.31	3.83	3.86	4.18
Sulphur	3.04	0.32	1.44	0.36
Nitrogen	1.44	0.99	1.32	1.06
Ash	9.03	17.19	13.44	13.36
Oxygen	4.71	5.64	6.61	12.27
Gross calorific value Btu/lb	13 167	11 464	12 300	11 030

Table 2 – Pennsylvania coal – summary of combustion performance

Trial	Firing rate lb/h	Coal feed size distribution <200 mesh wt %	Flue gas analyses					Combustible content in fly ash wt %
			O_2 %	CO_2 %	CO ppm	NO ppm	SO_2 ppm	
1	154	85	4.3	13.9	50	820	921	16.8
2	150	85	4.3	13.1	122	–	–	–

Table 3 – Pennsylvania coal – characteristics of fly ash

Trial	Coal feed size distribution <200 mesh wt %	O_2 in flue gas vol %	Combustible in fly ash wt %	Electrostatic precipitator efficiency %	Combustible in precipitator samples wt %	Electrical resistivity of fly ash ohm–cm	Combustible in resistivity sample wt %
1	85	4.5	19.6	97.9	21.9	1.0×10^5	41.6
			14.5	97.3	24.5	8.3×10^5	43.5
			15.9	97.3	34.4	1.7×10^9	27.7
			17.1	98.7	40.9	4×10^9	–
						1.4×10^6	34.6
						2.6×10^9	22.1
						2×10^8	27.4
2	85	4.3	32.4	83.4	51.0	–	–
			34.9	85.4	–	–	–
			34.1	83.8	51.3	–	–
			36.7	82.1	–	–	–

Table 4 – Byron Creek/Pennsylvania coal blend – summary of combustion performance

Trial	Firing rate lb/h	Coal feed size distribution <200 mesh wt %	Flue gas analyses					Combustible content in fly ash wt %
			O_2 vol %	CO_2 vol %	CO ppm	NO ppm	SO_2 ppm	
3	162	72	4.0	15.0	65	798	595	27.7
4	158	72	3.8	15.5	–	–	–	37.5

Table 5 – Byron Creek/Pennsylvania coal blend – Characteristics of fly ash

Trial	Coal feed size distribution <200 mesh wt %	O_2 in flue gas vol %	Combustible in fly ash wt %	Electrostatic precipitator efficiency %	Combustible in precipitator samples wt %	Electrical resistivity of fly ash ohm–cm	Combustible in resistivity sample wt %
1	85	4.5	19.6	97.9	21.9	1.0×10^5	41.6
3	72	4.0	34.0	–	–	–	–
			26.4	98.2	45.0	1.1×10^{10}	36.7
			–	99.7	52.0	7.5×10^{10}	37.9
			22.8	99.4	51.0	1.4×10^{10}	41.1
			–	99.8	52.4	6.7×10^9	41.2
4	72	3.8	40.2	91.8	53.0	8.7×10^9	–
			32.9	83.9	50.8	1.4×10^{10}	–
			37.7	83.7	50.0	–	–
			39.2	88.6	48.3	–	–

Table 6 – Byron Creek coal – Summary of combustion performance

Trial	Firing rate lb/h	Air supply primary: secondary ratio	Flue gas analyses					Combustible content in fly ash wt %
			O_2 vol %	CO_2 vol %	CO ppm	NO ppm	SO_2 ppm	
5	225	820 : 1090	4.0	14.9	280	–	–	59.8
6a	203	375 : 1350	4.2	15.3	145	630	139	41.9
6b		525 : 1350	–	–	–	–	–	45.2
7a	215	477 : 1350	3.8	15.4	135	628	121	47.9
7b	172	212 : 1250	3.9	14.6	132	–	–	47.5
8a	191	625 : 1000	3.6	15.5	105	630	120	47.1
8b	191	626 : 900	4.1	15.4	100	510	140	48.4
8c	191	625 : 600	3.9	15.5	110	425	115	47.6
8d	191	625 : 550	4.0	15.0	110	400	–	49.5
9a	192	197 : 1435	4.0	14.3	108	–	142	53.4
9b**	192	190 : 1400	4.0	14.8	–	490	110	52.8
9c**		189 : 1750	5.0	15.3	80	–	–	43.8
10a	200	601 : 1100	4.0	15.1	280	577	130	57.1
10b	200	650 : 1050	4.5	–	–	–	–	–

*Gas support
**Oil support

Table 7 – Byron Creek combustion performance – the effect of primary air proportion

Trial	Nominal O_2, vol %	Primary air as % of total air supplied	Combustible in fly ash, wt %
5	4.0	43	59.8
10b	4.5	35	57.3
10a	4.0	35	57.1
6b	4.2	30	45.2
7a	3.8	26	47.9
6a	4.2	22	41.9
7b	3.9	15	47.5
9a	4.0	12	53.5

Table 8 – Byron Creek coal – characteristics of fly ash

Trial	Coal feed size distribution <200 mesh wt %	O_2 in flue gas vol %	Combustible in fly ash wt %	Electrostatic precipitator efficiency %	Electrical resistivity of fly ash ohm–cm	Combustible in resistivity sample wt %
1	78	4.5	19.6	97.9	1.0×10^5	41.6
5		4.0	59.8	–	1.4×10^4	–
				–	1.4×10^3	–
6a	78	4.2	41.9	–	6.0×10^3	–
6b	78	4.2	45.2	–	4.4×10^6	–
				–	5.3×10^3	–
7a	78	3.8	47.9	–	2.0×10^{10}	–
7b	78	3.9	47.5	–	4.0×10^4	–
8a	78	3.6	47.1	–	0.7×10^3	–
8b	78	4.1	48.4	–	1.5×10^4	50.5
8c	78	3.9	47.6	–	1.7×10^4	48.2
8d	78	4.0	49.5	–	1.6×10^4	47.3
				–	1.5×10^4	49.8
				–	4.4×10^5	37.4
9a	78	4.0	53.4	–	–	–
9b	78	4.1	52.8	–	–	–
9c	78	5.0	43.8	–	–	–
10a	78	4.0	57.1	82.0	–	–
10b	78	4.5	57.3	81.6	–	–

Table 9 – Luscar coal – summary of combustion performance

Trial	Firing rate lb/h	Coal feed size distribution <200 mesh wt %	Flue gas analyses O_2 vol %	CO_2 vol %	CO ppm	NO ppm	SO_2 ppm	Combustible content in fly ash wt %
11	158	65.2	4.1	14.8	138	630	320	22.1
12a*	147	71.3	3.9	15.1	–	780	160	12.2
12b*	147	76.9	4.1	15.1	–	–	–	10.5
13*	176	77.0	4.1	14.9	–	820	188	11.5
14a*	176	81.8	3.8	15.0	65	780	154	10.7
14b*	176	83.0	4.3	15.2	75	793	157	9.1
15	182	85.0	4.0	14.8	27	820	165	7.4
	–	–	3.9	14.1	49	785	172	8.8
16**	175/165	85.2	4.0	14.6	37	–	–	7.9
	–	–	3.9	14.7	39	–	–	8.1
17a**	165	89.0	3.9	14.8	–	–	–	9.4
17b**	165	90.1	4.3	14.4	–	–	–	8.7

*Gas support
**Oil support

Table 10 – Luscar coal – characteristics of fly ash I

Trial	Coal feed size distribution <200 mesh wt %	O_2 in flue gas vol %	Combustible in fly ash wt %	Electrostatic precipitator efficiency %	Combustible in resistivity samples wt %
12a*	71.3	3.9	12.2	64.5	12.3
13*	77.0	4.0	11.5	45.2	9.2
			–	51.1	7.6
			–	42.8	9.2
			–	73.2	10.9
			–	45.6	9.0
14a*	81.8	3.8	10.7	50.8	12.4
15	85.0	4.0	7.4	89.8	7.7
			–	77.3	10.1
			–	75.0	10.2
17a**	89.0	3.9	9.4	88.9	7.4
			–	90.5	7.0
			–	92.6	7.4
			–	93.1	–

*Gas support
**Oil support

Table 11 – Luscar coal – characteristics of fly ash II

Trial	Coal feed size distribution <200 mesh wt %	O_2 in flue gas vol %	Electrical resistivity of fly ash ohm–cm	Combustible in resistivity sample wt %
12a*	71.3	3.9	1.5×10^{6}	11.8
12b*	76.9	4.1	3.3×10^{7}	9.9
			3.0×10^{6}	9.6
			2.0×10^{6}	11.3
13*	77.0	4.1	1.8×10^{6}	10.8
			2.6×10^{5}	11.4
			5.1×10^{5}	11.5
14a*	81.8	3.8	5.0×10^{5}	14.4
			1.7×10^{6}	10.8
14b*	83.0	4.3	1.5×10^{7}	10.2
			4.5×10^{8}	7.7
15	85.0	4.0	6.2×10^{6}	8.0
			1.1×10^{7}	7.2
			1.0×10^{12}	7.6
			1.5×10^{11}	10.0
			4.4×10^{10}	–
16a**	85.2	4.0	1.0×10^{9}	9.5
			9.3×10^{9}	8.9
			2.3×10^{10}	8.1
16b**	85	3.9	2.7×10^{7}	8.3
			5.0×10^{7}	7.6
			2.3×10^{7}	7.7
			6.0×10^{10}	7.8

*Gas support
**Oil support

Table 12 – Luscar coal – characteristics of fly ash III

	Coal feed size distribution <200 mesh wt %	Size distribution, wt % in fraction		
		Coarse >20 μm	Medium 20 to 2 μm	Fine <2 μm
12a	71.3	63.8	16.3	19.8
12b	76.9	57.1	20.8	22.1
13	77.0	60.5	14.2	25.2
14a	81.8	55.3	21.8	22.9
15	85.0	53.0	22.3	24.5
16	85.2	53.4	23.4	23.2
17b	90.1	53.9	24.3	21.8

*Gas support
**Oil support

Table 13 – Petrographic examination of coal macerals, volume %

	Vitrinite	Micrinite	Fusinite	Semi-fusinite	Exinite
Pennsylvania	73.2	5.8	3.4	6.0	11.6
Byron Creek	40.0	6.4	35.2	17.8	0.6
Luscar	52.2	5.8	17.4	16.8	7.8

6.4 SUMMARY 4: HIGH ASH ESTEVAN LIGNITE

1. Coal identification

Coal name and code: Estevan SA L 40 15 25 20 P
Mine: Klimax (Estevan seam) – Ravenscrag formation, Saskatchewan
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trials of high ash Saskatchewan lignites
Objectives: Effect of beneficiation on combustion performance of Estevan lignite, evaluation of combustion and ash fouling characteristics (report also includes data from earlier tests on raw Estevan and Utility lignites)
Client: Saskatchewan Department of Mineral Resources
Reference report (Date): ERP/ERL 76–98 (September 1976)
Related summaries: 1 and 5

3. Reference coal

Name and code: Utility SA L 40 10 15 25 R
Mine: Boundary Dam, Saskatchewan
Status: Active, commercial

4. Pilot–scale boiler system

Furnace configuration – I
System modification – Two opposed burners supplied by indirect coal feed system with individually metered amounts of pulverized coal
– Simulated superheater immediately downstream of screen tubes

5. Coal characteristics

As–received handling – The beneficiated Estevan lignite was handled and pulverized without difficulty. The direct feed of the pulverized coal to the burners did not cause settling–out or agglomeration.
As–pulverized moisture – 17.52%
As–fired screen size <200 mesh – 69.3%

6. Flame observations

Stable flame, no support fuel required at equilibrium furnace temperature.

7. Fly ash properties

Slagging potential – Low, based on observation
Fouling potential – Low, based on observation
Resistivity – Not measured
Particle size – Table 6
Combustible in ash – 2 to 3% at 25 to 15% excess air

Note: The beneficiated Estevan lignite produced a scale–like deposit on the leading surface of the superheater tubes which was not apparent in the deposits from untreated Estevan lignite. Deposits were similar to those from Utility lignite.

8. Low–temperature corrosion

Corrosion rate – Low, should not be a problem, although calcium content is lower in the washed Estevan lignite, than for the raw lignite which implies a marginally greater susceptibility to low temperature corrosion.

9. Emissions

See Table 4.

10. Tabulations attached from reference report:

Coal analyses	– Table 1
Coal ash analyses	– Table 1
Coal grind	– Table 2
Combustion performance	– Table 3
Gaseous emissions	– Table 4
Fly ash analyses	– Table 7
Size	– Table 6

Table 1 – Analyses of lignites

Sample condition	Utility As pulverized	Utility As fired	Estevan As pulverized	Estevan As fired	Washed Estevan As pulverized	Washed Estevan As fired
Proximate analysis, wt %						
Moisture	17.06	5.36	17.71	6.89	17.52	–
Ash	11.11	14.89	34.61	51.16	16.81	–
Volatile matter	32.51	36.08	22.64	21.45	31.77	–
Fixed carbon (by diff)	39.32	43.67	25.04	20.50	33.90	–
Ultimate analysis, wt %						
Carbon	50.60	56.90	33.62	29.42	45.96	–
Hydrogen	3.31	3.68	2.52	2.23	3.12	–
Sulphur	0.48	0.62	0.57	0.58	0.88	–
Nitrogen	0.87	0.98	0.57	0.53	0.04	–
Ash	11.11	14.89	34.61	51.16	16.81	–
Oxygen (by diff)	16.57	17.57	10.40	9.19	15.67	–
Gross calorific value, Btu/lb	8230	9290	5600	4760	7613	–
Fusibility of ash, °C*						
Initial	1182	1093	1188	1171	1188	–
Spherical	1193	1149	1371	1371	1243	–
Hemispherical	1227	1171	1427	>1480	1327	–
Fluid	1427	1316	1477	>1480	1482	–
Grindability, HGI	56 (5.2% moist.)		85 (2.7% moist.)			
Ash analyses, wt %						
Water soluble		4.89		3.58		–
S		1.22		0.90		0.1
Mg		0.02		0.01		1.0
Na		2.09		1.00		0.0
K		0.05		0.06		12.3
Ca		2.65		2.35		–
Acid soluble		16.0		8.91		–
FeO		0.98		0.60		0.9
MgO		0.46		0.14		2.6
NO		0.28		0.10		0.1
K		0.01		0.12		0.1
Ca		7.40		2.84		1.4
Al		1.55		1.59		–
Acid insoluble						
$SiO_2 + Al_2O_3$		79.11		87.51		77.0

*See Section 3.6

Table 2 – Screen analyses of crushed and pulverized lignites

Screen size	Utility Crushed	Utility Pulverized	Estevan Crushed	Estevan Pulverized	Washed Estevan Crushed	Washed Estevan Pulverized
>1/8 in.	2.18	–	0.94	–	–	–
<1/8 in. >10 mesh	39.75	–	24.29	–	–	–
<10 >20	32.86	–	33.75	–	–	–
<20 >28	8.08	–	7.66	–	–	–
<28 >48	8.98	–	12.31	–	–	–
<48	8.15	–	21.05	–	–	–
>140 mesh	–	17.3	–	18.0	–	16.4
<140 >200	–	14.1	–	11.1	–	14.3
<200 >325	–	17.1	–	14.4	–	17.6
<325	–	51.5	–	56.6	–	51.7

Table 3 – Summary of combustion performance

	Coal firing rate lb/h	Oil support US gph	O_2 in flue gas vol %	Steam flow lb/h	Temperature, °C				
					Comb air	Flue gas	SHT* metal	Pulverizer air in	Pulverizer air out
Utility	343	–	5.9	1150	204	271	571	271	85
		–	3.2	1180	203	320	551	279	84
		–	1.1	1220	199	366	532	263	82
Estevan	347	5	2.7	1450	202	321	543	263	77
		3	2.7	1350	204	346	527	321	77
		1¼	2.8	1200	204	344	518	311	73
		–	6.5	900	160	327	443	304	74
Washed Estevan	320	–	3.1	1300	225	175	546	201	74
		–	5.0	1350	228	210	550	195	65

*SHT – superheater tubes

Table 4 – Flue gas analyses

	Coal firing rate lb/h	Oil support US gph	O_2 vol %	CO_2 vol %	CO vol %	SO_2 ppm	SO_3 ppm	NO ppm
Utility	343	–	5.9	15.8	0.01	211	10.5	330
		–	3.2	17.2	0.01	235	4.9	330
		–	1.1	19.2	0.02	267	–	200
Estevan	347	5	2.7	16.6	0.02	317	3.9	175
		3	2.7	17.0	0.03	309	9.4	140
		1¼	2.8	17.2	0.04	320	6.3	150
		–	6.5	13.0	0.05	200	–	138
Washed	320	–	3.1	17.4	0.01	796	–	760
Estevan		–	5.0	16.0	0.01	715	–	500

Table 6 – Size distribution of fly ash

	O_2 in flue gas %	Oil support %	Size distribution, wt % in fraction		
			Coarse >20 µm	Medium 20 to 2 µm	Fine <2 µm
Utility	5.9	–	43.2	35.4	21.4
	3.2	–	44.5	43.3	12.2
	1.1	–	53.4	30.8	15.8
Estevan	2.7	25	68.0	16.1	15.9
	2.7	16	77.0	15.1	7.9
	2.8	8	73.1	16.8	10.1
	6.5	–	9.2	20.2	10.6
Washed	5.0	–	46.9	27.9	25.2
Estevan	3.1	–	48.1	27.3	24.6

Table 7 - Analyses of fly ash

	Utility			Estevan			Washed Estevan	
O_2 in flue gas, vol %	5.9	3.2	1.1	2.7	2.8	6.5	5.0	3.1
Oil support, wt %	nil	nil	nil	16.0	8.0	nil	nil	nil
Ash components, wt %								
Water soluble								
Total	10.25	7.18	6.10	2.27	2.04	1.54	5.1	6.6
S (as SO_4)	4.91	3.13	2.54	1.18	1.18	1.16	2.2	2.7
Fe	-	-	-	0.03	0.04	0.13	0.06	0.10
Mg	0.01	0.03	0.02	0.03	0.02	0.02	-	-
Na	1.39	0.92	1.23	0.18	0.30	0.76	-	-
K	0.38	0.46	0.41	0.02	0.05	0.07	0.41	0.43
Ca	0.05	0.05	0.05	1.09	2.63	2.27	6.48	4.23
Acid soluble								
Fe	2.23	2.71	3.11	1.48	1.25	1.17	2.26	2.53
Mg	1.54	1.75	1.75	0.44	0.32	0.31	1.33	1.18
Na	5.91	7.21	7.41	0.71	0.63	0.62	2.75	3.06
K	0.51	0.54	0.48	0.69	0.61	0.71	1.09	1.08
Ca	9.62	11.16	7.05	0.69	0.35	0.51	4.13	4.66
Acid insoluble	41.60	37.30	33.70	82.50	83.10	83.70	59.40	59.40
Total alkali								
Na + K	8.19	9.13	9.53	1.60	1.59	2.16	4.25	4.57

6.5 SUMMARY 5: HIGH ASH CYPRESS AND WOOD MOUNTAIN LIGNITES

1. Coal identification

Coal name and code: Cypress SA L 40 15 30 20 R
Wood Mountain SA L 45 10 30 20 R
Mine: Cypress – Ravenscrag formation, Saskatchewan
Wood Mountain – Ravenscrag formation, Saskatchewan
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trials of high ash Saskatchewan lignites
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Saskatchewan Department of Mineral Resources
Reference report (Date): ERP/ERL 76–191 (IR) (September 1976)
Related summaries: 1 and 4

3. Reference coal

Name and code: Utility SA L 40 10 20 25 R
Mine: Boundary Dam, Saskatchewan
Status: Active, commercial

4. Pilot–scale boiler system

Furnace configuration – I
System modification – Two opposed burners supplied by indirect coal feed system, with individually metered amounts of pulverized coal
– Simulated superheater immediately downstream of screen tubes

5. Coal characteristics

As–received handling – Both lignites had wide variations in extraneous ash and free water among the drums of the as–received samples, depending on drill core location. Hence it was decided to riffle the entire contents of each bulk sample prior to drying, crushing, grinding and burning. Each lignite contained about 30% by weight of moisture after riffling, so it was passed through a rotary coal dryer prior to crushing to less than 1/8 inch. A second drying of the minus 1/8–inch coal was necessary to reduce the moisture content and eliminate handling and feeding problems.

Cypress:
As–pulverized moisture – 15.51%
As–fired screen size <200 mesh – 79.4%

Wood Mountain:
As–pulverized moisture – 14.51%
As–fired size <200 mesh – 78.9%

6. Flame observations

Cypress:	Stable, did not require support fuel when coal feed was dried to below 15% moisture content.
Wood Mountain:	Stable, did not require support fuel when coal feed was dried to below 15% moisture content.

7. Fly ash properties

Cypress:

Slagging potential	– Low, based on coal ash fluid temperature of 1435°C
Fouling potential	– Low, based on observation
Resistivity	– Not measured
Particle size	– Reference report Table 6
Combustible in ash	– Reference report Figure 3 gives heat loss due to combustible content of fly ash
ESP efficiency	– 75.6% at 5.2% O_2 in flue gas
	– 83.5% at 2.7% O_2 in flue gas

Wood Mountain:

Slagging potential	– Low, based on coal ash fluid temperature of 1480°C
Fouling potential	– Low, based on observation
Resistivity	– Not measured
Particle size	– Reference report Table 6
Combustible in ash	– Reference report Fig. 3 gives heat loss due to combustible content of fly ash
ESP efficiency	– 77.2% at 4.3% O_2 in flue gas
	– 80.5% at 3.1% O_2 in flue gas

Deposits from both Cypress and Wood Mountain were unsintered and easily removed by soot–blowers. Fly ash loading with both lignites was high.

8. Low–temperature corrosion

Data available in reference report, Table 5.

9. Emissions

See Table 4.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Coal ash analyses	– Table 1
Coal grind	– Table 2
Combustion performance	– Table 3
Gaseous emissions	– Table 4
Fly ash analyses	– Table 7
Size	– Table 6
Other	
Low–temperature corrosion probe data	– Table 5

Table 1 – Analyses of lignites

	Utility		Cypress		Wood Mountain	
	As crushed	As fired	As crushed	As fired	As crushed	As fired
Proximate analysis, wt %						
Moisture	17.06	5.36	15.51	6.53	14.51	8.31
Ash	11.11	14.89	21.07	23.49	21.49	23.04
Volatile matter	32.51	36.08	31.34	34.94	34.33	36.82
Fixed carbon	39.32	43.67	31.43	35.04	29.71	31.83
Ultimate analysis (m.f.), wt %						
Carbon		60.12		53.07		50.47
Hydrogen		3.89		3.49		3.62
Sulphur		0.65		1.27		0.83
Nitrogen		1.03		0.75		0.61
Ash		15.73		25.13		25.12
Oxygen		18.57		16.29		19.35
Gross calorific value, Btu/lb		9290		8539		8365
Grindability, HGI	56		–		73	
Fusibility of ash, °C*						
Initial		1093		1240		1340
Spherical		1149		1270		1380
Hemispherical		1171		1300		1420
Fluid		1316		1435		1480
Ash analysis, wt %						
Water soluble		4.9		7.7		6.8
SO_4		1.2		1.5		1.2
Mg		<0.05		0.1		0.4
Na		2.1		0.6		<0.05
K		0.1		0.0		0.0
Ca		2.7		9.2		1.6
Acid soluble						
Fe		1.0		0.9		1.1
Mg		0.5		0.3		0.4
Na		0.3		0.1		<0.05
K		<0.05		0.3		<0.05
Ca		7.4		5.3		1.8
Acid insoluble						
$SiO_2 + Al_2O_3$		79.1		72.7		81.3

*See Section 3.6

Table 2 – Screen analyses of pulverized lignites

Screen size mesh		Utility	Cypress	Wood Mountain
>140		17.3	9.5	9.1
<140	>200	14.1	11.1	12.0
<200	>325	17.1	17.8	18.3
<325		51.5	61.6	60.6

Table 3 – Summary of combustion performance

	Firing rate lb/h	O_2 in flue gas vol %	Steam flow lb/h	Temperature, °C			
				Pulverizer air		SHT*	Flue
				in	out	metal	gas
Utility	343	5.9	1150	571	271	85	271
		3.2	1180	551	320	84	279
		1.1	1220	532	366	82	263
Cypress	310	5.2	1340	544	359	81	204
		2.7	1390	569	335	66	188
Wood Mountain	304	4.3	1360	552	330	81	193
		3.1	1375	544	364	90	212

* SHT – superheater tubes

Table 4 – Flue gas analyses

	Coal firing rate lb/h	O_2 vol %	CO_2 vol %	CO vol %	SO_2 ppm	SO_3 ppm	NO ppm	Theoretical SO_2 ppm	Sulphur neutralization wt %
Utility	343	5.9	15.8	0.01	211	10.5	330	577	63
		3.2	17.2	0.01	235	4.9	330	601	61
		1.1	19.2	0.02	267	–	200	665	60
Cypress	310	5.2	14.7	0.01	676	–	620	1209	44
		2.7	16.6	0.02	904	2.8	550	1403	36
Wood	304	4.3	16.3	0.01	660	–	715	963	31
Mountain		3.1	16.8	0.01	594	–	695	1033	42

Table 5 – Low-temperature corrosion probe data

	Probe temp °C	Water-soluble components in deposits – with 3% O_2 in flue gases				
		Fe	Ca	Mg	Na	SO_4
Utility	104	1.9	1.7	0.1	2.1	5.0
	121	2.2	1.1	0.1	0.7	1.9
	138	0.8	1.5	1.7	2.2	5.2
Cypress	104	1.1	1.1	0.02	0.04	1.3
	121	1.1	1.7	0.1	0.05	1.8
	138	1.2	2.4	0.03	0.06	1.5
Wood	104	2.9	–	0.01	–	1.8
Mountain	121	1.5	–	0.05	–	1.9
	138	0.5	–	0.01	–	1.6

Table 6 – Size distribution of fly ash

	O_2 In flue gas %	Size distribution, wt % in fraction		
		Coarse >20 µm	Medium 20 to 2 µm	Fine <2 µm
Utility	5.9	43.2	35.4	21.4
	3.2	44.5	43.3	12.2
Cypress	5.2	59.7	30.7	9.6
	2.7	49.5	37.2	13.3
Wood	4.3	62.8	29.4	7.8
Mountain	3.1	67.6	26.2	6.2

Table 7 –Analyses of fly ash

	Utility		Cypress		Wood Mountain	
O_2 in flue gas, vol %	5.9	3.2	5.2	2.7	4.3	3.1
Ash analysis, wt %						
Water soluble						
Total	10.25	7.18	4.81	6.29	2.57	2.21
S (as SO_4)	4.91	3.13	2.92	3.23	1.15	1.24
Fe	–	–	0.10	0.21	0.29	0.07
Mg	0.01	0.03	0.10	0.10	0.06	0.01
Na	1.39	0.92	0.33	0.29	0.03	0.03
K	0.38	0.46	0	0	0	0
Ca	0.05	0.05	0.78	0.63	0.80	1.00
Acid soluble						
Fe	2.23	2.71	1.53	1.97	2.04	1.82
Mg	1.54	1.75	1.30	1.41	1.41	1.38
Na	5.91	7.21	1.65	2.21	0.11	0.11
K	0.51	0.54	0.58	0.68	0.30	0.24
Ca	9.62	11.16	9.52	10.05	3.52	3.58
Acid insoluble						
Al + Si	41.60	37.29	43.63	38.12	68.70	70.25
Total alkali						
Na + K	8.19	9.13	2.56	3.18	0.44	0.38

6.6 SUMMARY 6: LUSCAR COAL AND SELECTED CONDITIONING AGENTS

1. Coal identification

Coal name and code: Luscar Coal Valley AL B 35 05 15 30 P
Mine: Luscar Coal Valley, Coalspur coalfield, Foothills region of Alberta
Status: Active

2. Reference report features

Topic: Improved electrostatic precipitator performance using flue gas conditioning agents
Objectives: Examination of the effects of the following chemical and physical conditioning agents on fly ash resistivity and on the efficiency of a small electrostatic precipitator: temperature, moisture, sulphuric acid, sulphur trioxide (sulfan), sulphamic acid, ammonia and sodium carbonate
Client: Ontario Hydro
Reference report (Date): ERP/ERL 77–08 (IR) (January 1977)
Related summaries: 3 and 9

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuratio	– I
System modification	– Twin–opposed burners, originally located in the water–walled combustion chamber, were replaced by twin tangentially inclined burners firing into a refractory–lined combustion chamber below the bottom headers of the steam and water–walled combustion chamber; in this modified combustion system, the incoming pulverized coal was ignited and largely burned out prior to the flame being subjected to any significant thermal load.

5. Coal characteristics

As–received handling	– No problems
As–fired moisture	– 5.54%
As–fired screen size	
<200 mesh	– 65.2 to 90.1%

The maceral analysis is given in Table 1.

6. Flame observations

Luscar Coal Valley: No problems.

7. Fly ash properties

Slagging potential	– Not measured
Fouling potential	– Not measured
Resistivity	– 4.2×10^{11} ohm–cm for 4% combustible in the fly ash at 120°C

Particle size	– Not measured
Combustible in ash	– 3.2% (mean)
ESP efficiency	– 85% (at 4% combustible) up to 99% efficiency using SO_3 conditioning agent.

The reference report contains many figures illustrating the effects investigated.

8. Low–temperature corrosion

Not measured.

9. Emissions

See Table 2.
SO_2 and NOx not measured.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Coal ash analyses	– Not measured
Coal grind	– Not detailed
Combustion performance	– Table 2
Gaseous emissions	– Table 2
Fly ash analyses	
No conditioning agents	– Table 3
With conditioning agents	– Table 4
Other	
Maceral analyses of coal	– Table 1

Table 1 – Analyses of coal

	Luscar coal As fired
Proximate analysis, wt %	
Moisture	5.54
Ash	13.36
Volatile	31.96
Fixed carbon	49.14
Ultimate analysis, wt %	
Carbon	63.73
Hydrogen	4.18
Sulphur	0.36
Nitrogen	1.06
Ash	13.36
Oxygen	12.27
Gross calorific value, Btu/lb	11 030
Maceral component, vol %	
Vitrinite	52.2
Micrinite	5.8
Fusinite	17.4
Semifusinite	16.8
Exinite	7.8

Table 2 – Summary of combustion performance

	Mean value	RMS deviation
Firing rate, kg/h	73.5	±3.5
Steaming rate, kg/h	548	±23.6
CO_2, vol %	16.0	±0.5
O_2, vol %	3.2	±0.5
Fly ash loading, g/m^3	2.751	±0.565
Combustible in fly ash, wt %	3.22	±2.4

Table 3 – Analyses of fly ash emissions without use of conditioning agents

Electrostatic precipitator, °C	Water extract pH	Water–soluble component of fly ash, wt %			
		SO_4	Ca	Mg	Na
140 to 150	9.3	0.2	6.3	T*	T
	8.8	0.7	6.5	0.1	T
	9.9	0.6	5.7	T	0.1
	9.8	0.6	10.6	T	T
	9.2	0.7	5.4	T	T
	9.9	0.5	2.6	T	T

Table 4 – Analyses of fly ash emissions with use of conditioning agents

Conditioning agent	Agent concentration	Electrostatic precipitator °C	Water extract pH	Water–soluble component of fly ash, wt %			
				SO_4	Ca	Mg	Na
None	–	300	9.2	1.0	4.8	T*	T
			10.1	0.5	5.8	T	T
Moisture	RH** = 10%	140/150	9.5	0.7	9.5	0.1	T
			9.4	0.7	10.0	T	T
			9.4	0.7	9.8	T	T
H_2SO_4	9.5 ppm equivalent SO_3	140/150	5.0	4.1	43.4	0.2	0.2
			4.5	5.7	82.4	0.3	0.2
			5.1	8.3	61.2	0.3	0.1
			5.1	4.3	43.3	0.1	0.1
	62 ppm equivalent SO_3	140/150	3.3	19.6	8.3	0.1	0.1
			3.3	14.3	13.6	0.1	0.1
NH_2SO_2OH	10.2 ppm equivalent SO_3	140/150	5.3	2.4	5.6	T	T
			8.9	0.8	2.4	T	T
NH_3	76 ppm equivalent SO_3	140/150	9.1	0.7	3.0	T	T
			9.1	0.7	3.1	T	T
Na_2CO_3	0.5 g/1000 g fuel	140/150	9.6	2.7	1.0	T	1.1
			9.4	2.2	1.3	T	0.7
	1.33 g/1000 g fuel	140/150	9.4	4.1	2.1	T	1.4
			9.8	3.4	2.4	T	1.6

* T: trace, less than 0.1%

**RH: relative humidity

6.7 SUMMARY 7: HAT CREEK COAL

1. Coal identification

Coal name and code:	Hat Creek A raw	BC S 30 10 55 10 R
	Hat Creek B raw	BC S 40 15 35 15 R
	Hat Creek C raw	BC S 40 10 30 15 R
	Hat Creek A ben	BC S 35 15 30 15 P
	Hat Creek B ben	BC S 50 10 25 20 P
	Hat Creek C ben	BC S 40 10 20 20 P

Mine: Hat Creek, British Columbia
Status: Exploratory

2. Reference report features

Topic: Pilot-scale combustion trials on Hat Creek coal
Objectives: Evaluation of effect of beneficiation on combustion performance; establishment of design parameters for utility-scale steam generator to burn Hat Creek coal
Client: British Columbia Hydro
Reference report (Date): ERL 77-96 (TR) and ERL 77-97 (TR) (October 1977)
General: This report summarizes 75 research and progress reports.

3. Reference coal

Name and code: Sundance AL S 35 05 15 20 R
Mine: Highvale, Alberta
Status: Active, commercial

4. Pilot-scale boiler system

Furnace configuration – I
System modification – Refractory-lined furnace bottom for on-line ash dumping to quench tank

5. Coal characteristics

As-received handling – The coals were delivered to CCRL in plastic bags sealed in 45 gallon drums.

Hat Creek raw:
The raw coals were wet with surface moisture, very cohesive and could not be readily handled. The poor handling qualities of the raw coal can be attributed to the high clay content of the ash. In general the first two raw coals (coals A and B in reference report) came out of the barrels as a single cylindrical lump with a very steep angle of repose. Very little free water drained from these coals.

Hat Creek beneficiated:
These were beneficiated by heavy-media separation in water. The beneficiated coals had much better handling properties than those of the raw Hat Creek coals.
Both raw and beneficiated Hat Creek coals had to be dried before they would pass through the chutes and hoppers with acceptable reliability.

Sundance coal:

No problems in handling or firing. Coal handling properties and moisture content of the sample coals are given in reference report Table 3.1. The size of the as-fired coals is included in reference report Table 3.8. The maceral analyses are given in Table 3.3.

6. Flame observations

Hat Creek raw: Stable, no support fuel required.
Hat Creek beneficiated: Flame more stable and hotter than flame for raw coal, no support fuel required.
Sundance: Stable, no support fuel required.

7. Fly ash properties

Slagging potential – Low, based on observation
Fouling potential – Based on sodium content
  Hat Creek A–raw, B–raw and B–beneficiated coals: Low
  Hat Creek C–raw and A– and C–beneficiated coals: Medium
  Sundance: Medium
Fouling Potential – Based on base:acid ratio
  Hat Creek (all samples): Low
  Sundance: High
Resistivity – In situ at 150°C
  Hat Creek (all samples): 10^{11} to 10^{12} ohm–cm
  Sundance: 10^{9} to 10^{11} ohm–cm
Particle size – Reference report Table 6.18
Combustible in ash
  Hat Creek: 2.0 to 8.6%
  Sundance: 1.3 to 2.4%

8. Low–temperature corrosion

Minimal. Reference report Table 6.13 gives free acid in low–temperature corrosion probe deposits. This corrosion will be minimized by operating at excess oxygen level of 3% and maintaining all heat transfer surfaces above 130°C, or 5% and 135°C.

9. Emissions

SO_2 – See Table 6.14
NO – See Table 6.16

10. Tabulations attached from reference report

Coal analyses	– Table 3.2
Coal ash analyses	– Not measured
Coal grind	– Table 3.8
Combustion performance	– Table 5.1
SO_2 emissions	– Table 6.14
NO, NO_2 emissions	– Table 6.16
Fly ash analyses	– Table 6.20
Size	– Table 6.18

Other

Coal handling and moisture	– Table 3.1
Maceral analyses of coals	– Table 3.3
Analytical data for coals	– Table 3.6
Heat content of coals	– Table 6.2
Steaming rates	– Table 6.3
Thermal loss and carbon carry over	– Table 6.4
Low–temperature corrosion	– Table 6.13

Table 3.1 – Coal handling properties and moisture content of sample coals crushed to minus 1/8 inch

	Moisture, wt %	Condition	Remarks
Sundance	16	As received	Adequate
Hat Creek			
A–raw	27	As received	Not adequate, formed cakes and balls in hoppers
A–raw	16	Kiln dried	Not adequate, hung in hopper and feed chute to pulverizer, pulverized easily
A–raw	7	Kiln dried twice	Adequate
A–washed	25	As received	Not adequate, hung in hoppers
A–washed	16	Air and kiln dried	Adequate
B–raw	22	As received	Not adequate, hung in hoppers
B–raw	17	Kiln dried	Adequate, but required constant attention to feed chute to pulverizer, pulverized easily
B–raw	9	Kiln dried twice	Adequate
B–washed	23	As received	Not adequate, appeared to cake, pulverized easily
B–washed	20	Air dried	Adequate
B–washed	9	Air and kiln dried	Adequate
C–raw	24	As received	Not adequate, appeared to cake
C–raw	20	Air dried	Adequate
C–raw	9	Air and kiln dried	Adequate
C–washed	24	As received	Not adequate, appeared to cake
C–washed	22	Air dried	Adequate
C–washed	13	Air and kiln dried	Adequate

Table 3.2 – Analyses of Hat Creek raw coal

	A–raw	B–raw	C–raw
Proximate analysis, wt %			
Air–dried moisture	15.64	13.53	18.99
Ash	44.51	29.94	20.57
Volatile matter	22.16	30.55	31.34
Fixed carbon	16.69	25.98	29.10
Ultimate analysis, wt %			
Carbon	35.88	39.02	42.35
Hydrogen	2.23	3.07	3.20
Sulphur	0.80	1.04	0.58
Nitrogen	0.54	0.82	0.93
Ash	44.51	29.94	20.57
Oxygen	10.51	12.58	13.38
Gross calorific value			
Cal/g	2355	3601	4006
Btu/lb	4239	6482	7211
Btu/lb dry, mineral–matter–free basis	8318	9665	9319
ASTM classification	←	Subbituminous C	→

Table 3.3 – Petrographic examination of coal macerals

		Volume, % A*	Volume, % B**	
A–raw	Vitrinite	36.0	38	55
	Structured vitrinite	–	17	
	Exinite	0.8	3	
	Resinite and telinite	–	3	
	Micrinite	1.2	–	
	Semifusinite	0.4	–	
	Pyrite	0.4	–	
	Fusinite	–	–	
	Mineral matter	61.2	39	
	Mean max reflectance, Ro	0.38	0.46	
B–raw	Vitrinite	27.6	27	50
	Structured vitrinite	–	23	
	Exinite	–	2	
	Resinite and telinite	–	3	
	Micrinite	–	3	
	Semifusinite	0.4	2	
	Pyrite	–	–	
	Fusinite	–	–	
	Mineral matter	72.0	43	
	Mean max reflectance, Ro	0.34	0.41	
C–raw	Vitrinite	55.6	40	73
	Structured vitrinite	–	33	
	Exinite	1.2	2	
	Resinite and telinite	–	1	
	Micrinite	1.8	–	
	Semifusinite	5.6	1	
	Pyrite	0.2	–	
	Fusinite	2.2	–	
	Mineral matter	33.4	23	
	Mean max reflectance, Ro	0.34	0.43	

*A: Energy Research Laboratories
**B: Bergbau–Forschung Laboratories

Table 3.6 – Analyses of coals

	Trial	Equil. moist. wt %	Proximate, wt % dry Ash	VM	FC	Ultimate, wt % dry C	H	S	N	Ash	O	Cal value dry basis MJ/kg	Sulphur forms in coal, wt % SO_3	FeS	Org	Total
Sundance	1.1	16	14.61	34.71	50.68	63.29	3.90	0.21	0.82	14.61	17.17	24.20	–	–	–	–
	1.2	18	15.16	34.38	50.46	62.75	3.88	0.18	0.86	15.16	17.17	23.96	–	–	–	–
Hat Creek																
A–raw	2.1	22	52.98	25.04	22.88	30.60	2.58	1.12	0.62	52.08	13.00	11.32	0.12	0.47	0.45	1.04
A–raw	2.2		47.39	26.88	25.73	34.17	2.82	1.08	0.73	47.39	13.81	12.89	0.13	0.38	0.50	1.01
A–washed	3.1	25	30.27	33.15	36.58	47.92	3.41	1.20	0.96	30.27	13.24	18.65	0.12	0.29	0.61	1.02
A–washed	3.2		29.75	32.61	37.64	48.19	3.37	1.20	0.96	29.75	16.53	18.85	0.12	0.31	0.60	1.03
B–raw	4.1	22	37.43	33.13	29.44	42.10	3.28	1.10	0.93	37.43	15.16	16.44	0.11	0.51	0.40	1.02
B–raw	4.2		30.84	35.35	33.81	47.80	3.62	0.91	1.00	30.84	15.84	15.83	0.06	0.32	0.46	0.84
B–raw	4.3		28.80	35.95	35.25	49.21	3.67	0.92	1.03	28.80	16.37	19.27	0.08	0.24	0.44	0.76
B–washed	5.1	23	23.81	53.69	22.50	53.23	3.77	0.78	0.10	23.81	18.31	18.72	0.05	0.17	0.50	0.72
B–washed	5.2		21.91	47.70	30.39	54.91	3.93	0.90	1.08	21.91	17.27	21.58	0.04	0.14	0.64	0.82
B–washed	5.3		20.68	45.99	33.33	56.13	3.88	0.77	1.10	20.68	17.44	21.48	0.04	0.10	0.49	0.63
C–raw	6.1	24	28.32	35.42	36.26	48.62	3.62	0.70	0.12	28.32	18.61	19.39	0.05	0.12	0.46	0.63
C–raw	6.2		25.84	36.03	38.13	51.39	3.73	1.17	1.11	25.84	16.76	20.28	–	–	–	–
C–raw	6.3		30.26	34.68	35.06	48.62	3.47	0.62	1.08	30.26	15.95	19.05	–	–	–	–
C–washed	7.1	24	19.09	37.61	43.30	57.33	4.07	0.71	1.21	19.09	17.59	22.73	–	–	–	–
C–washed	7.2		18.16	38.36	43.48	57.71	3.98	0.75	1.24	18.16	18.16	22.65	–	–	–	–
C–washed	7.3		19.00	38.36	42.64	57.89	3.96	0.74	1.20	19.00	17.21	22.60	–	–	–	–

Table 3.8 – Grindability and screen analyses of crushed and pulverized coals

	Trial	HGI[a]	Coal feed[b] to pulverizer, wt % size fractions in inches >1/4	<1/4 >1/8	<1/8 >1/16	<1/16 >1/32	<1/32	Pulverized coal[b], % size fractions in mesh size >100	<100 >140	<140 >200	<200 >325	<325	Residual[c] moisture, %
Sundance	1.1	43	0	3.2	36.3	32.8	27.7	0.7	4.4	7.9	16.8	70.1	17.1
	1.2	43	0	4.5	46.8	31.1	17.6	0.7	5.8	12.9	14.0	66.5	16.0
Hat Creek													
A–raw	2.1	61	0	0.3	16.5	28.1	55.1	1.5	6.8	9.2	18.8	63.6	7.1
A–raw	2.2	58	0	0.8	25.9	28.7	44.6	3.0	10.2	13.0	19.9	53.8	7.4
A–washed	3.1	44	0	2.9	34.0	32.1	31.0	1.9	7.2	8.5	33.4	49.0	16.3
A–washed	3.2	44	0	2.8	35.2	33.4	28.6	7.4	21.0	9.4	17.5	44.7	16.5
B–raw	4.1	48	0	0.4	12.0	39.3	48.3	3.9	15.1	9.9	24.2	46.9	8.6
B–raw	4.2	47	0	0.9	32.3	38.5	28.3	3.8	16.8	8.6	23.3	47.4	9.3
B–raw	4.3	42	0	4.8	49.2	24.3	21.7	16.9	12.8	6.4	16.2	47.7	16.6
B–washed	5.1	45	0	3.9	30.2	33.2	32.7	12.4	17.1	8.2	14.0	48.0	8.6
B–washed	5.2	44	0	6.1	40.1	31.1	22.7	11.2	17.5	8.2	14.9	48.2	8.6
B–washed	5.3	39	0	15.4	51.7	19.0	13.9	3.1	17.1	9.7	23.7	46.4	20.3
C–raw	6.1	45	0	2.6	20.4	28.1	48.9	9.2	15.0	7.0	16.0	52.8	11.0
C–raw	6.2	43	0	4.5	41.2	29.5	27.8	8.5	15.2	6.7	17.2	52.5	13.0
C–raw	6.3	43	0	1.6	15.9	24.8	57.7	2.3	12.2	10.9	17.1	57.5	19.6
C–washed	7.1	40	0	3.0	32.1	34.7	30.2	2.5	13.3	10.7	18.6	55.0	12.8
C–washed	7.2	38	0	6.8	55.3	25.1	12.8	1.6	11.6	11.3	22.5	53.0	13.8
C–washed	7.3	36	0	5.8	33.1	25.1	36.0	2.1	9.5	16.1	12.1	60.4	21.8

[a] Method ASTM D 409–71. The coal feed to the pulverizer and the pulverized coal were sampled at regular intervals. The accumulated samples were quartered and riffled to ASTM standards before testing Hardgrove Grindability Test (HGI).

[b] ASTM E11–70 specifies the wire cloth sieves that were used for testing. Crushed coal was tested according to ASTM D 311–30 (1969) and pulverized coal was tested using a "sonic sifter."

[c] Residual moisture is moisture in coal fed to pulverizer.

Table 5.1 – Test conditions

Coal	Trial	Degree of drying	Feed rate kg/h	Excess O_2 level, %
Sundance	1.1	None	100	5
	1.2	None	100	3
Hat Creek				
A – raw	2.1	KD* twice	196	5
A – raw	2.2	KD twice	196	3
A – washed	3.1	AD** + KD	134	5
A – washed	3.2	AD + KD	134	3
B – raw	4.1	KD twice	131	5
B – raw	4.2	KD twice	131	3
B – raw	4.3	KD	142	5
B – washed	5.1	AD + KD	120	5
B – washed	5.2	AD + KD	120	3
B – washed	5.3	AD	120	5
C – raw	6.1	KD twice	110	5
C – raw	6.2	KD twice	110	3
C – raw	6.3	KD	120	5
C – washed	7.1	AD + KD	110	5
C – washed	7.2	AD + KD	110	3
C – washed	7.3	AD	110	5

*KD = kiln dried
**AD = air dried

Table 6.2 – Heat content of coal

Coal	Trial	Heat content, MJ/kg: As fired	Heat content, MJ/kg: Dry, mineral–matter free
Sundance	1.1	20.1	28.3
	1.2	20.1	28.2
Hat Creek			
A–raw	2.1	10.5	23.6
A–raw	2.2	11.9	24.5
A–washed	3.1	15.6	26.8
A–washed	3.2	15.7	26.8
B–raw	4.1	15.0	26.3
B–raw	4.2	16.9	27.0
B–raw	4.3	16.1	27.1
B–washed	5.1	17.1	24.6
B–washed	5.2	19.7	27.6
B–washed	5.3	17.1	27.1
C–raw	6.1	17.3	27.1
C–raw	6.2	17.6	27.4
C–raw	6.3	15.3	27.3
C–washed	7.1	19.8	28.1
C–washed	7.2	19.5	27.7
C–washed	7.3	17.7	27.9

Table 6.3 – Comparison of steaming rates

Coal	Trial	O_2 in flue gas vol %	RM[a] wt %	Combustible As fired wt %	Steaming rate kg steam/kg coal	Relative steaming rate[b] %	Relative firing rate[c] %
Sundance	1.1	5	17.1	70.8	5.84	94.8	1.05
	1.2	3	16.0	71.3	6.16	100.0	1.0
Hat Creek							
A–raw	2.1	5	7.1	44.5	3.01	48.9	2.04[d]
	2.2	3	7.4	48.7	3.54	57.5	1.74[d]
A–washed	3.1	5	16.3	58.4	4.02	65.2	1.53
	3.2	3	16.5	58.6	4.75	77.1	1.30
B–raw	4.1	5	8.6	57.2	4.50	73.0	1.34
	4.2	3	9.3	62.7	4.90	79.5	1.26
	4.3	5	16.6	59.4	4.22	68.5	1.46
B–washed	5.1	5	8.6	69.6	5.48	89.0	1.23
	5.2	3	8.6	74.4	5.92	96.1	1.04
	5.3	5	20.3	63.2	4.77	77.4	1.29
C–raw	6.1	5	11.0	63.8	5.17	83.9	1.19
	6.2	3	13.0	64.5	5.74	93.2	1.07
	6.3	5	19.6	56.1	4.86	78.9	1.27
C–washed	7.1	5	12.8	70.6	5.73	93.0	1.08
	7.2	3	13.8	70.6	6.02	97.7	1.02
	7.3	5	21.8	63.3	5.03	81.7	1.22

[a] Residual moisture in coal as fed to the pulverizer

[b] To designed firing capacity as per cent of the Sundance 3% steaming rate

[c] To designed steaming capacity as per cent of Sundance 3% firing rate

[d] These firing rates are judged not acceptable for designed firing capacity of coal B–raw.

Table 6.4 – Thermal loss by carbon carryover as per cent of heat input

				Coal fineness			Combustion conditions		
Coal	Trial	LOI[a] wt %	Thermal loss, % of heat input	<200 mesh wt %	D[b] μm	Deff[c] μm	O_2 vol %	Ash wt %	Moisture wt %
Sundance:	1.1	1.3	0.2	82	60	71	5.1	14.6	17.1
	1.2	2.4	0.4	93	64	75	3.1	15.2	16.0
Hat Creek									
A–raw	2.1	2.0	2.7	76	65	132	5.3	52.0	7.1
A–raw	2.2	3.5	2.9	76	75	142	2.9	47.4	7.4
A–washed	3.1	4.0	1.4	64	71	105	5.1	30.3	16.3
A–washed	3.2	5.6	2.2	74	92	127	3.2	29.8	16.5
B–raw	4.1	3.8	2.3	75	81	126	5.1	37.4	8.6
B–raw	4.2	4.5	1.5	84	82	117	3.1	30.8	9.3
B–raw	4.3	3.3	1.2	82	101	150	5.0	28.8	16.6
B–washed	5.1	6.3	2.0	73	97	127	5.0	23.8	8.6
B–washed	5.2	8.6	2.1	74	95	122	3.0	21.9	8.6
B–washed	5.3	4.0	1.0	83	81	104	5.0	20.7	20.3
C–raw	6.1	4.6	2.1	74	88	122	5.1	28.3	11.0
C–raw	6.2	4.3	1.3	67	86	114	3.0	25.8	13.0
C–raw	6.3	4.5	1.9	72	73	99	4.9	30.3	19.6
C–washed	7.1	4.1	0.8	70	75	92	5.0	19.1	12.8
C–washed	7.2	4.5	0.7	75	73	89	3.0	18.2	13.8
C–washed	7.3	2.2	0.4	72	72	89	5.0	19.0	21.8

[a] LOI: Loss on ignition

[b] D is obtained graphically from the cumulative particle size distribution of the pulverized coal for each test.

[c] $$\text{Deff} = \left(\sum \frac{mC}{D^1} \right)^{-1}$$

where m is fraction of size consist, D^1 is size of opening in sieve and C is combustible content of coal particles.

Table 6.13 – Free acid in low temperature corrosion probe deposits

Trial	Sulphur content of coal, wt %	Deposition rate of fee acid (H_2SO_4), mg/m^2h		
		138°C	121°C	104°C
1.1	0.21	Nil	Nil	Nil
1.2	0.18	Nil	Nil	Nil
2.1	1.12	13.7	26.5	17.3
2.2	1.08	Nil	43.5	Nil
3.1	1.2	148	125	104
3.2	1.2	Nil	Nil	Nil
4.1	1.1	129	83	73.4
4.2	0.91	34.3	Nil	27.8
4.3	0.92	6.1	29.7	4.3
5.1	0.78	176	38.4	16.6
5.2	0.90	Nil	Nil	Nil
5.3	0.77	Nil	Nil	Nil
6.1	0.70	Nil	Nil	Nil
6.2	1.17	Nil	5.8	5.0
6.3	0.62	Nil	Nil	7.2
7.1	0.71	Nil	Nil	Nil
7.2	0.75	9.1	Nil	Nil
7.3	0.74	2.2	Nil	Nil

Table 6.14 – Theoretical and measured sulphur dioxide emissions

Trial	O_2 in flue gas vol %	Fuel sulphur wt %	Theoretical maximum			Measured concentrations		
			ppm	lb SO_2/ton coal, dry	lb $SO_2/10^6$ Btu	ppm	lb SO_2/ton coal, dry	lb $SO_2/10^6$ Btu
1.1	5.1	0.21	185	8.4	0.40	80	3.7	0.18
1.2	3.1	0.18	179	7.2	0.35	88	3.5	0.17
2.1	5.3	1.12	1964	44.8	4.60	909	20.7	2.13
2.2	2.9	1.08	1957	43.2	3.90	1158	25.6	2.31
3.1	5.1	1.20	1374	48.0	2.99	968	33.8	2.11
3.2	3.2	1.20	1537	48.0	2.96	1000	31.3	1.93
4.1	5.1	1.10	1420	44.0	3.11	937	29.1	2.06
4.2	3.1	0.91	1164	36.4	2.27	1016	31.8	1.98
4.3	5.0	0.92	1025	36.8	2.22	1076	38.6	2.33
5.1	5.0	0.78	815	31.2	1.72	731	28.0	1.54
5.2	3.0	0.90	1014	36.0	1.94	707	25.1	1.35
5.3	5.0	0.77	758	30.8	1.67	691	28.1	1.52
6.1	5.1	0.70	798	28.0	1.68	745	26.1	1.57
6.2	3.0	1.17	1407	46.8	2.68	768	25.6	1.47
6.3	4.9	0.62	709	24.8	1.51	706	24.7	1.50
7.1	5.0	0.71	681	28.4	1.45	685	28.6	1.46
7.2	3.0	0.75	810	30.0	1.54	677	25.1	1.29
7.3	5.0	0.74	705	29.6	1.52	612	25.7	1.32

Table 6.16 – Nitrogen oxide emissions

Trial	Excess oxygen vol %	Measured nitric oxide (NO) ppm	Calculated nitrogen dioxide (NO_2)	
			lb/ton coal (dry)	lb/10^6 Btu
1.1	5	600	19.3	0.77
1.2	3	567	16.9	0.69
2.1	5	276	4.7	0.45
2.2	3	450	6.6	0.55
3.1	5	595	14.8	0.77
3.2	3	608	14.2	0.73
4.1	5	519	11.7	0.76
4.2	3	580	12.1	0.68
4.3	5	587	13.5	0.68
5.1	5	563	15.4	0.78
5.2	3	667	17.2	0.85
5.3	5	644	17.6	0.76
6.1	5	581	14.5	0.77
6.2	3	693	16.0	0.80
6.3	5	690	17.2	0.84
7.1	5	958	29.1	1.29
7.2	3	741	20.5	0.90
7.3	5	653	19.8	0.80

Table 6.18 – Mean size characteristics of fly ash collected in air heater and electrostatic precipitator

		Air heater		Electrostatic precipitator	
Coal	Trial	Dg*, μm	σg**	Dg, μm	σg
Sundance:	1.1	27.8	1.0	10.1	1.9
	1.2	31.2	1.0	10.6	2.2
Hat Creek:					
A–raw	2.1	33.5	1.7	19.0	2.4
A–raw	2.2	20.0	1.7	17.9	2.6
A–washed	3.1	21.6	1.7	12.7	2.1
A–washed	3.2	25.4	1.8	13.0	2.2
B–raw	4.1	24.4	1.8	11.5	2.2
B–raw	4.2	21.6	1.7	15.0	2.1
B–raw	4.3	32.0	1.8	13.7	2.1
B–washed	5.1	25.4	1.8	1 5.3	2.1
B–washed	5.2	20.0	1.6	14.6	2.3
B–washed	5.3	23.2	1.6	13.3	2.1
C–raw	6.1	22.7	1.7	14.3	2.1
C–raw	6.2	23.2	1.6	15.6	2.0
C–raw	6.3	24.3	1.7	13.9	2.2
C–washed	7.1	33.1	1.8	13.3	2.1
C–washed	7.2	21.7	1.6	14.6	2.1
C–washed	7.3	21.1	1.6	13.3	2.2
Average value for all Hat Creek coals except A–raw		24.3	1.7	13.9	2.1

*Dg: volume geometric mean diameter
**σg: standard deviation

Table 6.20 – Ash analyses of deposits from electrostatic precipitator

Coal	Trial	Chemical composition, wt %									
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	SO_3	Na_2O	K_2O
Sundance	1.1	40.8	21.4	5.0	1.0	0.4	21.8	2.4	1.1	3.5	0.4
	1.2*	49.6	23.5	4.7	0.8	0.3	15.5	1.5	0.5	1.6	0.3
Hat Creek											
A–raw	2.1	58.8	28.2	6.5	1.2	0.1	1.8	1.3	0.9	0.7	1.0
A–raw	2.2*	57.5	27.6	7.2	1.1	0.1	1.5	1.1	0.6	0.5	1.0
A–washed	3.1	55.6	25.7	7.3	1.6	0.2	3.0	1.4	1.0	0.6	0.9
A–washed	3.2	55.5	25.5	6.7	1.8	0.2	3.5	1.8	1.0	0.8	1.1
B–raw	4.1	50.3	27.0	9.4	1.2	0.4	5.0	1.9	1.3	0.4	0.5
B–raw	4.2	53.3	29.2	7.4	1.3	0.3	5.0	1.5	0.8	0.4	0.5
B–raw	4.3	52.5	28.9	7.9	1.3	0.3	4.7	1.5	1.1	0.4	0.6
B–washed	5.1	50.8	29.4	6.5	1.6	0.4	5.6	1.8	0.6	0.5	0.7
B–washed	5.2	51.4	29.9	5.6	1.6	0.5	5.8	1.9	0.8	0.4	0.5
B–washed	5.3	51.8	30.3	6.0	1.6	0.5	5.6	1.8	0.1	0.4	0.5
C–raw	6.1	53.3	30.9	6.5	1.4	0.4	3.8	1.7	0.7	0.7	0.6
C–raw	6.2	52.3	30.8	5.9	1.5	0.4	4.0	1.9	0.6	0.7	0.6
C–raw	6.3	51.4	29.8	6.2	1.4	0.3	3.6	1.7	0.7	0.7	0.6
C–washed	7.1	50.9	30.1	6.2	1.7	0.5	5.1	2.0	0.7	0.9	0.6
C–washed	7.2	56.1	32.8	5.6	1.2	0.3	3.4	1.3	0.6	0.9	0.6
C–washed	7.3	52.2	31.0	6.3	1.6	0.4	4.9	1.7	0.6	0.8	0.7

*Analyses of deposits collected from the tube sheet between the second and third passes of the air heater.

6.8 SUMMARY 8: OBED–MARSH COAL

1. Coal identification

Coal name and code: Obed–Marsh AL B 40 10 15 30 P
Mine: Obed–Marsh, Hinton, Alberta
Status: New

2. Reference report features

Topic: Pilot–scale combustion trials
Objectives: Evaluation of combustion and ash fouling characterisics
Client: Union Oil Company of Canada Limited
Reference report (Date): ERP/ERL 78–14 (February 1978)
Related summaries: None

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with adiabatic bottom
System modification – None

5. Coal characteristics

As–received handling – A 4–ton sample of dried, beneficiated Obed–Marsh coal was delivered to CCRL in sealed, plastic–lined drums. The coal was free of surface moisture, uniformly blended and free flowing. No problems occurred in moving or feeding this coal through the CCRL pilot–scale coal handling system.
As–received moisture – 11%
As–fired screen size <200 mesh – 67 to 92% – see paragraph 5. on page 62
The maceral analysis is given in Table 3.

6. Flame Observations

Ignited readily and produced bright stable flame. No support fuel required.

7. Fly ash properties

Slagging potential – Low based on observation
Fouling potential – Low based on observation
Resistivity – Generally greater than 10^{10} ohm–cm
Particle size – Table 7
Combustible in ash – 3 to 11%

8. Low–temperature corrosion

Corrosion barely detected on probe surfaces at 104°C. 121°C and 138°C.

9. Emissions

Nitric oxide levels high (due to high-temperature flame), sulphur oxide emissions generally less than theoretical because of retention by boiler ash and fly ash.

10. Tabulations attached from reference report:

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 1
Trace elements	– Not measured
Coal grind	– Table 4
Combustion performance	– Table 7
Gaseous emissions	– Table 5
Fly ash analyses	– Not measured
Size	– Table 7
Other	
Maceral analyses of coal	– Table 3
Ash fusion temperatures	– Table 13

Table 1 – Analyses of coal

Trial	1	2	3	4
Proximate analysis, wt %				
Moisture	10.95	10.65	11.49	10.71
Ash	12.40	12.57	13.25	12.70
Volatile matter	33.36	32.98	34.33	33.48
Fixed carbon	43.29	43.80	40.95	43.11
Ultimate analysis, wt %				
Carbon	65.18	65.11	64.17	66.30
Hydrogen	4.45	4.35	3.47	5.03
Sulphur	0.53	0.59	0.60	0.56
Nitrogen	1.61	1.57	1.47	1.58
Ash	13.92	14.07	14.95	14.22
Oxygen	14.31	14.31	15.34	12.31
Calorific value				
Cal/g	6267	6208	6188	6304
Btu/lb	11281	11175	11139	11347
Ash analysis, wt %				
SiO_2	60.92	61.35	60.31	61.33
Al_2O_3	20.85	20.26	20.17	20.45
Fe_2O_3	4.23	4.14	4.38	4.45
TiO_2	0.85	0.86	0.83	0.82
P_2O_5	0.39	0.34	0.32	0.31
CaO	8.11	8.17	8.48	7.88
MgO	2.00	1.70	2.13	1.61
SO_3	3.45	3.71	3.53	2.76
Na_2O	0.20	0.23	0.22	0.22
K_2O	0.60	0.60	0.55	0.61

Table 3 – Petrographic examination of coal macerals

Maceral type	Vol %
Vitrinite	66.5
Exinite + Resinite	4.3
Micrinite	3.1
Semifusinite	14.8
Fusinite	3.1
Mineral matter (calculated by Parr's formula)	8.2

Table 4 – Screen analyses of pulverized coal

Screen size mesh		Trial 1	2	3	4
>100		0.5	0.4	0.0	0.0
<100	>140	14.1	11.6	0.4	0.8
<140	>200	18.5	20.1	7.5	10.3
<200	>325	47.3	44.6	68.4	69.4
<325	>400	1.6	2.1	1.3	–
<400		17.7	21.2	22.4	–
<200		66.6	67.9	92.1	88.8

Table 5 – Flue gas analyses

			Flue gas composition				
Trial	Coal grind	Firing rate kg/h	O_2 vol %	CO_2 vol %	CO vol %	SO_2 ppm	NO ppm
1	Coarse	87.7	4.7	14.6	0.1	345	913
2	Coarse	85.9	3.0	15.9	0.12	476	873
3	Fine	85.3	4.8	14.9	0.09	424	1089
4	Fine	84.6	2.9	16.2	0.09	419	1080

Table 7 – Fly ash retention in the boiler system

				Size fractions of emitted fly ash wt %			Fly ash retention	
Trial	Coal size wt % <200 mesh	Firing rate kg/h	Ash input kg/h	Coarse	Medium	Fine	Rate kg/h	wt % of input
1	66.6	87.7	11.02	76.4	9.5	14.1	7.02	63.7
2	67.9	87.7	11.02	78.5	9.9	11.6	6.96	63.2
3	92.1	85.3	11.29	73.5	10.8	15.7	5.51	48.8
4	88.8	84.6	10.74	73.5	10.7	15.8	5.51	51.3

Table 13 – Coal ash fusion temperatures

Trial	Excess oxygen vol %	Fusion characteristics*	Temperature °C Oxidizing atms.	Temperature °C Reducing atms.
1	4.7	Initial	1330	1371
		Spherical	1390	1454
		Hemispherical	1460	>1480
		Fluid	>1480	>1480
2	3.0	Initial	1330	1360
		Spherical	1390	1460
		Hemispherical	>1480	>1480
		Fluid	>1480	>1480
3	4.8	Initial	1300	1290
		Spherical	1390	1380
		Hemispherical	1450	1430
		Fluid	>1480	>1480
4	2.9	Initial	1315	1280
		Spherical	1390	1380
		Hemispherical	1470	1440
		Fluid	>1480	>1480

*See Section 3.6

6.9 SUMMARY 9: LUSCAR COAL WITH ADDITIONAL CONDITIONING AGENTS AND BLENDED COALS

1. Coal identification

Coal name and code: Luscar Coal Valley AL B 35 05 15 30 P
US Bituminous US B 35 25 15 ** R
Mine: Luscar Coal Valley, Coalspur coalfield, Foothills region of Alberta
US Bituminous, Pennsylvania
Status: Active

2. Reference report features

Topic: Improved electrostatic precipitator performance using flue gas conditioning agents
Objectives: Examination of the effects of ammonia sulphate, sodium sulphate, triethylamine and coal blending on fly ash resistivity and electrostatic precipitator performance
Client: Ontario Hydro
Reference report (Date): ERP/ERL 78–17 (IR) (January 1978)
Related summaries: 3 and 6

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I
System modification – Twin–opposed burners, originally located in the water–walled combustion chamber, were replaced by twin tangentially inclined burners firing into a refractory–lined combustion chamber below the bottom headers of the steam and water–walled combustion chamber. In this modified combustion system, the incoming pulverized coal was ignited and largely burned out prior to the flame being subjected to any significant thermal load.

5. Coal characteristics

Luscar Coal Valley:
As–received handling – No problems
As–fired moisture – 6.3%
As–fired screen size <200 mesh – Not identified

6. Flame observations

Luscar Coal Valley: No problems.

**Information not available.

7. Fly ash properties

Luscar Coal Valley:

Slagging potential	– Not measured
Fouling potential	– Not measured
Resistivity	– 4.2 x 10^{11} ohm–cm (mean, untreated fly ash) Table 3
Particle size	– (in critical carbon range) Table 3
Combustible in ash	– 2.1% (mean)
ESP efficiency	– 76.6% (when collecting fly ash with an electrical resistivity of 4.85 x 10^{11} ohm–cm)

Reference report contains many figures and tables illustrating the effects investigated.

8. Low–temperature corrosion

Not measured.

9. Emissions

See Table 2.
SO_2 and NOx not measured.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Coal ash analyses	– Not measured
Coal grind	– Not detailed
Combustion performance	– Table 2
Gaseous emissions	– Table 2 (O_2 only)
Fly ash analyses	– Table 11
Size	– Table 3

Table 1 – Analyses of coals

	Coal		Blends*		
	Luscar As fired	US Bituminous As fired	75% Luscar 25% US	50% Luscar 50% US	25% Luscar 75% US
Proximate analysis, wt %					
Moisture	6.30	4.31	–	–	–
Ash	12.91	9.71	–	–	–
Volatile matter	31.70	32.70	–	–	–
Fixed carbon	49.09	53.28	–	–	–
Ultimate analysis, wt %					
Carbon	63.41	71.42	–	–	–
Hydrogen	4.32	5.14	–	–	–
Sulphur	0.31	2.18	1.04	1.63	2.08
Nitrogen	0.95	1.28	–	–	–
Ash	12.91	9.71	–	–	–
Oxygen	11.80	5.33	–	–	–

*Sulphur is the only value determined on the blended samples

Table 2 – Summary of combustion performance

	Coal		Blends		
	Luscar	US	75% Luscar 25% US	50% Luscar 50% US	25% Luscar 75% US
Feed rate, kg/h	69.5	60.3	69.6	65.9	62.6
O_2 in flue gas, vol %	4.9	4.9	5.0	5.0	5.0
Fly ash loading, g/m^3	1.62	1.37	1.58	1.64	1.57
Fly ash combustible, wt %	2.16	4.17	2.98	3.68	5.06

Table 3 – Fly ash resistivity and size distribution in the critical carbon range

	Sample	Carbon in fly ash wt %	Fly ash resistivity ohm–cm	Size distribution wt %		
				Fine	Medium	Coarse
Phase II trials	1	7.4	1.1×10^7	24.5	22.3	53.0
	2	7.4	6.2×10^6	–	–	–
	3	7.7	2.3×10^7	23.2	23.4	53.4
	4	8.3	2.7×10^7	27.1	22.0	50.9
Phase III trials	5	3.3	4.7×10^8	52.2	28.6	19.2
	6	3.5	3.0×10^8	74.1	12.2	13.8
	7	4.0	4.5×10^8	59.6	25.1	15.3

Table 11 – Analyses of fly ash in precipitator outlet

Blend ratio Luscar:US	Water extract pH	Water soluble content wt %	Water–soluble ions, wt % of total fly ash					
			SO_4	CA	Fe	Mg	K	Na
100:0	6.36	15.5	0	3.0	0.1	0.18	0.13	0.19
75:25	6.98	71.6	0	1.7	0.05	0.10	0.03	0.08
50:50	4.22	76.7	3.6	1.04	0.05	0.08	0.05	0.08
25:75	5.12	81.0	0	1.87	0.09	0.18	0.10	0.30
0:100	5.11	96.2	0	.57	0.03	0.05	0.03	0.07

6.10 SUMMARY 10: SULPHUR NEUTRALIZATION OF GASCOYNE, UTILITY AND POPLAR RIVER LIGNITE

1. Coal identification

Coal name and code: Gascoyne US L 45 15 15 15 R
Utility SA L 40 10 15 20 R
Poplar River SA L 40 10 20 20 R

Mine: Gascoyne, North Dakota, USA
Utility, southeastern Saskatchewan
Poplar River, Coronach, Southwestern Saskatchewan

Status: Gascoyne and Utility: Active, commercial
Poplar River: Under development

2. Reference report features

Topic: Sulphur neutralization

Objectives: Confirmation of degree of sulphur neutralization by indigenous ash cations in lignite; evaluation of effect of flue gas recirculation on SOx emissions when Utility lignite is burned; study of enhancement of sulphur retention when Poplar River lignite was blended with lime upstream of pulverizer

Client: Environment Canada, but Saskatchewan Power Corporation for combustion trials with Utility and Poplar River lignite

Reference report (Date): ERP/ERL 78-55 (J) (June 1978)

Related summaries: None directly related (2 and 20 for combustion trials with Utility and Poplar River lignite)

3. Reference coal

None

4. Pilot-scale boiler system

Furnace configuration - I
System modification - Provision of system to permit external flue gas recirculation at 200°C to the secondary-air annuli of the burners and to both above and below the flames

5. Coal characteristics

As-received handling - No information in reference report
As-pulverized moisture - Table 1
As-fired screen size - Not given in reference report

6. Flame observations

None given in reference report.

7. Fly ash properties

Slagging potential	– Not given in reference report
Fouling potential	– Not given in reference report
Sulphur neutralization	– Table 3
Particle size	– Not given in reference report
Combustible in ash	– Given as graphs in reference report
Loading	– Not given in reference report

8. Low–temperature corrosion

SO_3	– Table 2
Corrosion rate	– No information in reference report

9. Emissions

SO_2 – Table 2
NO_x – Not given in reference report

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 1
Trace elements	– Not measured
Coal grind	– Not given in reference report
Combustion performance	– Not given in reference report
Gaseous emissions	
SO_2 and SO_3 only	– Table 2
Fly ash analysis	– Not given in reference report
Size	– Not given in reference report
Other	
Sulphur neutralization	– Table 3

Table 1 – Analyses of lignites (as pulverized)

	Gascoyne	Utility	Poplar River
Proximate analysis, wt %			
Moisture	38.72	17.06	12.91
Ash	7.65	11.11	17.30
Volatile matter	27.11	32.51	33.23
Fixed carbon	27.52	39.32	36.56
Ultimate analysis, wt %			
Carbon	38.08	50.60	49.11
Hydrogen	2.59	3.31	3.21
Sulphur	0.74	0.48	0.60
Nitrogen	0.64	0.87	0.66
Ash	7.65	11.11	17.30
Oxygen	11.58	16.57	16.21
Gross calorific value, Cal/g	3530	4570	4410
Grindability, HGI	–	56	65
Ash analysis, wt %			
SiO_2	33.23	26.57	44.14
Al_2O_3	10.03	15.77	22.10
Fe_2O_3	5.10	6.43	5.63
TiO_2	0.51	0.58	1.02
P_2O_5	0.25	0.74	0.27
CaO	20.09	22.54	12.67
MgO	7.56	4.13	4.18
SO_3	18.77	14.13	7.97
Na_2O	3.55	6.78	0.70
K_2O	0.60	0.37	1.60

Table 2 – Sulphur balances for Gascoyne lignite

Trial	1	2	3	4
Sulphur input, kg/h	0.912	0.999	0.956	0.956
Sulphur outputs, kg/h				
as SO_2	0.530	0.740	0.780	0.776
as SO_3	–	0.018	0.016	0.018
as particulates	0.073	0.089	0.081	0.085
Sulphur retained in boiler, kg/h	0.150	0.143	0.116	0.116
Total accountable sulphur, kg/h	0.753	0.990	0.993	0.995
Accountable sulphur as % of sulphur input	82.6	99.1	103.9	104.2

Table 3 – Effect of recirculation ratio on sulphur neutralization during combustion of Utility lignite

O_2 in flue gas vol %	Recirculation ratio of flue gas	% SO_2 neutralized*
5	0.00	54
	0.20	47
	0.23	49
	0.26	54
3	0.00	48
	0.23	51
	0.27	50
	0.28	50
1	0.00	43
	0.26	43
	0.27	58
	0.30	46

$$^{*}\%\ SO_2\ \text{neutralized} = \frac{SO_2\ \text{theoretical} - SO_2\ \text{measured}}{SO_2\ \text{theoretical}} \times 100$$

6.11 SUMMARY 11: ONAKAWANA - MANALTA BRIQUETTES

1. Coal identification

Coal name and code: Manalta Briquettes ON L 45 10 20 20 P
Mine: Onakawana, south of James Bay, Northeastern Ontario
Status: Active

2. Reference report features

Topic: Pilot-scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Manalta Coal Company
Reference report (Date): ERP/ERL 78-78 (TR) (October 1978)
Related summary: 16

3. Reference coal

None burned in these trials but reference is made to Sundance coal and Utility lignite for comparison of performance

4. Pilot-scale boiler system

Furnace configuration - I with adiabatic bottom
System modification - None

5. Coal characteristics

As-received handling - A 1-ton sample of the lignite briquettes was delivered to CCRL in sealed drums. The briquettes handled and pulverized easily and no problems occurred in moving or feeding this fuel through the pilot-scale coal handling system.
As received moisture - 11%
As fired screen size
<200 mesh - 77.5 to 81.0%

6. Flame observations

Bright clean flame, extremely stable. No support fuel required.

7. Fly ash properties

Slagging potential - Medium to high, based on T250 classification
Fouling potential - Low, based on observation; medium, based on sodium and iron content of coal ash
Resistivity - 7.5×10^9 to 7.5×10^8 ohm-cm
Particle size - Not measured
Combustible in ash - 2% approximately
ESP efficiency - 86 to 92%

8. Low-temperature corrosion

Free acid accumulation above 104°C was negligible. The probe exposed at 104°C showed a maximum acid accumulation rate of 2 $g/cm^2.h$, which is regarded as being exceptionally low.

9. Emissions

Sulphur accountability close to 100% by theory and measurement. Nitric oxide concentrations higher than those normally encountered when burning lignites in pilot-scale boiler due to low moisture and hence higher than normal flame temperature. Significant reductions in NO emissions achieved by reducing excess oxygen level from 5% to 3%. See Table 4.

10. Tabulations attached from reference report:

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 1
Trace elements	– Not measured
Coal grind	– Table 3
Combustion performance	– Table 4
Gaseous emissions	– Table 4
Fly ash analyses	– Not measured
Size	– Not measured

Table 1 – Analyses of briquettes

Proximate analysis, wt %	
Moisture	10.8
Ash	16.1
Volatile matter	38.5
Fixed carbon	34.6
Ultimate analysis, wt%	
Carbon	51.21
Hydrogen	2.44
Sulphur	0.55
Nitrogen	0.51
Ash	16.13
Oxygen	18.40
Calorific value, Cal/g	4495
As-received basis, Btu/lb	8091
Ash analysis, wt %	
SiO_2	37.77
Al_2O_3	12.89
Fe_2O_3	10.19
TiO_2	0.70
P_2O_5	0.40
CaO	15.86
MgO	4.41
SO_3	16.21
Na_2O	0.91
K_2O	0.66

Table 3 – Screen analyses of briquettes

Screen size mesh		Trial 1	Trial 2	Trial 3
>100		0.8	0.8	0.7
<100	>140	8.4	6.9	6.4
<140	>200	13.3	14.1	11.9
<200	>325	27.5	22.0	24.1
<325	>400	4.0	5.5	5.5
<400		46.0	50.7	51.4
<200		77.5	78.2	81.0

Table 4 – Summary of combustion performance

Trial	Fuel firing rate kg/h	Nominal excess oxygen concentration vol %	Steaming rate kg/h	Flue gas composition				
				O_2 vol %	CO_2 vol %	CO vol %	NO ppm	SO_2 ppm
1	76.0	5	446	4.6	16.2	0.05	548	632
2	74.2	3	445	2.9	17.0	0.05	435	768
3	77.8	1	464	1.0	17.7	0.05	421	810

6.12 SUMMARY 12: TULAMEEN COAL

1. Coal identification

Coal name and code: Tulameen BC B 35 10 20 25 P
Mine: Tulameen, British Columbia
Status: Newly developed

2. Reference report features

Topic: Pilot-scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics at two levels of fineness and with two burner configurations
Client: Cyprus-Anvil Mining Corporation
Reference report (Date): ERP/ERL 79-7 (November 1978)
Related summaries: None

3. Reference coal

Name and code: Sundance AL S 35 05 20 25 R
Mine: Highvale, Alberta
Status: Active, commercial

4. Pilot-scale boiler system

Furnace configuration – I
System modification – I with adiabatic furnace bottom to demonstrate furnace temperature and residence time effects

5. Coal characteristics

As-received handling – The coal was crushed, metered, pulverized and transported without difficulty
As-pulverized moisture – 11.76%
As fired screen size <200 mesh – 56.1 to 92.8%

6. Flame observations

Bright, clean and extremely stable flame. No support fuel required after startup.

7. Fly ash properties

Slagging potential	– Low, based on T250
Fouling potential	– Low, based on sodium content and confirmed by observation
Resistivity	– About 10^{11} (see below)
Particle size	– Not measured
Combustible in ash	– 2.1 to 8.0%
Loading	– 1245 to 2220 mg/m^3
ESP efficiency	– 59 to 77%

Fly ash resistivity and electrostatic precipitator performance are given in Table 7. Any results measured with a carbon content more than the critical value of about 4% are suspect.

Extrapolation of data indicates that a high temperature precipitator would be required to operate well above 400°C to accommodate an "in-situ" ash resistivity of 5 x 10^9 ohm-cm. An alternative to hot precipitators would be injection of conditioning agents into the combustion products to reduce resistivity.

8. Low-temperature corrosion

No significant low-temperature corrosion expected on surfaces maintained above 120°C with up to 5% excess oxygen in the flue gas. (Calcium in the coal ash was capable of neutralizing any free acid either after deposition or in the gas stream.)

9. Emissions

See Table 5.

10. Tabulations attached from reference report:

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analysis	– Table 8
Trace elements	– Not measured
Coal grind	– Table 4
Combustion performance	– Table 5
Gaseous emissions	– Table 5
Fly ash analyses	– Not measured
Characteristics	– Table 7
Size	– Not measured
Other	
Burner configuration	– Table 3

Table 1 – Analyses of coals (as fed to the pulverizer)

	Tulameen	Sundance
Proximate analysis, wt %		
Moisture	11.76	13.61
Ash	15.08	13.84
Volatile matter	29.17	29.12
Fixed carbon	43.99	43.43
Ultimate analysis, wt %		
Carbon	57.54	54.89
Hydrogen	2.99	2.19
Sulphur	0.57	0.21
Nitrogen	0.99	0.67
Oxygen	11.07	14.60
Ash	15.08	13.84
Calorific value		
Cal/g	5427	5020
Btu/lb	9768	9036
Equilibrium moisture	10.82	–
ASTM classification	High–volatile bituminous C	Subbituminous B

Table 3 – Burner configuration and pulverized coal size

Trial	Conditions
1	Exploratory
2	Sidewall burners Coal: 70% <200 mesh
3	Sidewall burners Coal: 90% <200 mesh
4	Adiabatic furnace bottom Coal: 90% <200 mesh
5	Adiabatic furnace bottom Coal: 60% <200 mesh
6	Adiabatic furnace bottom Coal: 70% <200 mesh

Table 4 – Screen analyses of coal

Screen size mesh		Trial 2	3	4	5	6
>100		0.5	0.4	0.6	2.9	0.7
<100	>140	5.1	0.9	1.2	25.2	13.4
<140	>200	16.4	5.9	6.9	15.8	18.0
<200	>325	46.0	58.5	36.9	28.1	36.8
<325	>400	4.7	3.9	6.5	4.7	5.8
<400		27.3	30.4	47.9	23.3	25.3
<200		78.0	92.8	91.3	56.1	67.9

Table 5 – Summary of combustion performance

Trial	Fuel wt % <200 mesh	Feed rate kg/h	Steaming rate kg/h	Flue gas analyses O_2 vol %	CO_2 vol %	CO vol %	NO ppm	SO_2 ppm
1*	–	72.8	495	4.3	16.4	NIL	680	401
2	78.1	71.3	483	4.9	16.5	NIL	654	390
3	92.8	70.9	478	4.9	–	NIL	753	393
4	91.8	70.6	467	5.0	–	–	798	–
5	56.1	70.3	468	5.0	–	TRACE	693	–
6	67.9	69.1	479	5.0	–	TRACE	767	399

*Trial 1 was used to establish experimental conditions for subsequent experiments.

Table 7 – Characteristics of fly ash

Trial	Flue gas temperature °C	Carbon content wt %	Electrical resistivity ohm–cm	Mean trial ESP* efficiency %
2	205	7.8	1.2×10^{4}	
	270	7.8	2.4×10^{4}	59
3	195	8.0	–	
	260	8.0	–	58
4	199	2.1	7.9×10^{11}	
	220	2.1	4.8×10^{11}	
	220	2.1	4.16×10^{11}	66
	280	2.1	1.3×10^{10}	
	280	2.1	1.07×10^{10}	
5	200	7.3	1.9×10^{6}	
	210	7.3	2.5×10^{7}	73
	250	7.3	9.6×10^{4}	
	260	7.3	6.8×10^{4}	
6	210	4.0	9.5×10^{10}	
	270	4.0	6.3×10^{5}	77

*ESP: Electrostatic Precipitator

Table 8 – Analyses of coal ash from trial 3

Ash component	wt %
SiO_2	71.7
Al_2O_3	14.3
Fe_2O_3	9.07
TiO_2	0.84
P_2O_5	0.15
CaO	1.03
MgO	0.46
Na_2O	0.11
K_2O	2.80
SO_3	0.32

6.13 SUMMARY 13: JUDY CREEK NORTH COAL

1. Coal identification

Coal name and code: Judy Creek North AL S 40 05 30 20 R
Mine: Whitecourt, Alberta
Status: New, undeveloped

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics.
Client: Imperial Oil Limited, Production Research Division.
Reference report (Date): ERP/ERL 79–22 (TR) (February 1979)
Related summaries: None

3. Reference coal

Name and code: Sundance AL S 35 05 20 25 R
Mine: Highvale, Alberta, Edmonton formation
Status: Active, commercial

4. Pilot–scale boiler system

Furnace configuration – I
System modification – None

5. Coal characteristics

As–received handling – The coal was crushed, metered, pulverized and transported without difficulty.
As–fired moisture – 16.24%
As–fired screen size <200 mesh – 75.3 to 77.7%

6. Flame observations

Bright, clean and extremely stable flame. No support fuel required after startup.

7. Fly ash properties

Slagging potential	– Low, based on ash fusion temperature
Fouling potential	– Low, based on sodium content and confirmed by observation
Resistivity	– 2.4×10^9 to 1.4×10^{10}
Particle size	– Figure 3 in reference report
Combustible in ash	– 0.6%
Loading before ESP	– 7887 mg/Nm^3 mean value
ESP efficiency	– 97%

8. Low–temperature corrosion

No free acid accumulation on low–temperature probes, hence potential for low–temperature corrosion would appear to be very low or nonexistent.

9. Emissions

See Table 4.

10. Tabulations attached from reference report:

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 1
Trace elements	– Not measured
Coal grind	– Table 3
Combustion performance	– Table 4
Gaseous emissions	– Table 4
Fly ash analyses	– Not measured
Size	– Not measured

Table 1 – Analyses of coals

	Judy Creek North	Sundance
Proximate analysis, wt %		
Moisture	16.24	13.61
Ash	24.98	13.84
Volatile matter	32.88	29.12
Fixed carbon	25.90	43.43
Ultimate analysis, wt %		
Carbon	49.06	63.67
Hydrogen	1.71	2.54
Sulphur	0.35	0.24
Nitrogen	0.54	0.78
Ash	29.73	16.04
Oxygen	18.29	16.94
Calorific value		
Cal/g	3778	5020
Btu/lb	6800	9036
Ash analysis, wt %		
SiO_2	60.15	54.97
Al_2O_3	21.57	20.08
Fe_2O_3	2.54	4.77
TiO_2	0.77	0.68
P_2O_5	0.18	0.43
CaO	7.04	11.93
MgO	0.56	1.31
SO_3	2.96	3.08
Na_2O	0.98	2.66
K_2O	0.31	0.35
ASTM classification	Subbituminous C	Subbituminous B

Table 3 – Screen analyses of pulverized coals

Screen size mesh		Judy Creek North Sample 1	2	3	Sundance Sample 4	5
>100		0.4	0.5	0.4	0.5	0.6
<100	>140	4.9	6.2	12.1	5.2	8.8
<140	>200	17.1	15.7	12.1	15.4	11.6
<200	>325	26.6	28.8	34.5	27.1	27.4
<325	>400	7.1	7.7	2.8	3.0	3.4
<400		44.0	41.1	38.0	48.8	48.1
<200		77.7	77.6	75.3	78.9	79.0

Table 4 – Summary of combustion performance

	Coal firing rate kg/h	Thermal input to boiler MJ/h	Steam flow kg/h	Flue gas analyses O_2 vol %	CO_2 vol %	CO vol %	NO ppm	SO_2 ppm	Theoretical SO_2 ppm
Judy Creek North	94.1	1486	460	5.1	15.0	0.01	483	275	443
Sundance	87.3	1832	498	5.1	14.7	0.01	643	113	223

6.14 SUMMARY 14: TENT MOUNTAIN–VICARY CREEK COAL REJECTS

1. Coal identification

   Coal name and code: Tent Mountain–Vicary Creek AL B 25 05 25 30 P
   Mine: Tent Mountain strip mine and Vicary Creek underground mine, Coleman region of Alberta.
   Status: Active

2. Reference report features

   Topic: Pilot–scale combustion trials
   Objectives: Evaluation of combustion performance using beneficiated rejects alone and a blend of rejects with a commercially available bituminous thermal fuel
   Client: Coleman Collieries Limited
   Reference report (Date): ERP/ERL 80–10 (February 1980)
   Related summaries: None

3. Reference coal

   Name and code: Luscar Coal Valley AL B 40 05 15 30 P
   (Referred to as "Reference" in report)
   Mine: Luscar Coal Valley, Coalspur coalfield, Foothills region of Alberta
   Status: Active

4. Pilot–scale boiler system

   Furnace configuration – I with adiabatic furnace bottom
   System modification – None

5. Coal characteristics

   Beneficiated Tent Mountain–Vicary Creek rejects:
   As–received handling – The beneficiated coal was crushed, metered pulverized and transported without difficulty
   As–fired moisture – <1.0%
   As–fired screen size <200 mesh – 85 to 87%
   The maceral analyses on the coals are given in Table 3.

6. Flame observations

   Flames were bright, clean and extremely stable. No support fuel required after start up. The beneficiated coal produced slightly longer flames and yielded slightly higher temperatures at the furnace exit than the reference coal or the coal blend.

7. Fly ash properties

   Slagging potential – Low
   Fouling potential – Low
   Resistivity – 10^{11} to 10^{12} ohm–cm
   Particle size – Not measured

Combustible in ash	– 13% at 4.5% O_2 in flue gas
Loading	– 6.81 g/Nm^3 at 4.5% O_2 in flue gas
ESP efficiency	– Not measured but good precipitator performance will be more difficult to achieve than for higher sulphur coals

8. Low–temperature corrosion.

   Virtually none.

9. Emissions

   See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 8
Trace elements	– Not measured
Coal grind	– Table 4
Combustion performance	– Table 5
Gaseous emissions	– Table 5
Fly ash analyses	– Not measured
Other	
Maceral analyses of coal	– Table 3
Coal ash characteristics	– Table 8

Table 1 – Analyses of coals

	Beneficiated	Reference	Blend	Typical specification limits
Proximate analysis, wt %*				
Ash	20.76	10.72	15.37	<17
Volatile matter	23.94	38.57	31.51	22 – 36
Fixed carbon	55.30	50.71	53.12	50 – 60
Ultimate analysis, wt %*				
Carbon	69.01	72.21	70.68	–
Hydrogen	3.99	4.16	4.10	–
Sulphur	0.41	0.25	0.28	<1
Nitrogen	1.06	1.04	0.77	<2
Ash	20.76	10.72	15.37	<17
Oxygen (by diff)	4.77	11.62	8.80	–
Calorific value, MJ/kg	26.84	28.22	27.74	>25.05
Grindability, HGI	71	42	55	>45
Ash fusibility, °C				
Initial **	1350	1150	1285	>1250
ASTM classification	Bituminous	Bituminous	–	Bituminous
Moisture, wt %				
As–received	1.0	8.0	–	<15
As–fired	0.6	4.3	2.8	–

*Dry basis

**Reducing atmosphere (See Section 3.6)

Table 3 – Petrographic examination of coal macerals

Maceral type, vol %	Beneficiated	Reference	Blend
Reactive			
Resinite	3	1	1
Exinite	2	7	5
Tellinite	<1	<1	<1
Vitrinite	36	47	43
Inert			
Fusinite	8	16	13
Semifusinite	37	15	24
Micrinite	2	5	4
Mineral matter	11	9	10
Total	100	100	100

Table 4 – Screen analyses of pulverized coals

Screen size mesh	Beneficiated		Reference	Blend
>100	2	0.5	0.1	1
<100 >140	2	3	3	3
<140 >200	11	10	21	12
<200 >325	58	46	45	57
<325 >400	5	6	4	6
<400	22	36	27	22
<200	85	87	76	84

Table 5 – Summary of combustion performance

	Coal firing rate kg/h	Thermal input to boiler MJ/h	Steam flow kg/h	Steam rate kg Steam/ MJ input	Flue gas analyses						Theoretical SO_2 ppm
					O_2 vol %	CO_2 vol %	CO vol %	NO ppm	SO_2 ppm	SO_3 ppm	
Beneficiated	78	2081	385	0.185	6.0	12.8	0.01	680	230	<1	298
	77	2054	375	0.183	4.5	14.2	0.01	735	260	<1	329
Reference	76	2053	370	0.180	4.8	14.5	0.01	760	165	<1	194
Blend*	80	2157	390	0.181	4.7	14.0	0.01	770	175	<1	221

*40 wt % beneficiated + 60 wt % reference coal

Table 8 – Characteristics of coal ash

	Beneficiated	Reference	Blend
Ash analysis, wt %			
SiO_2	51.54	57.01	52.57
Al_2O_3	28.11	16.08	23.17
Fe_2O_3	4.26	5.14	6.17
TiO_2	1.62	0.46	1.29
P_2O_5	0.77	0.22	0.55
CaO	5.49	11.96	7.21
MgO	1.58	1.15	1.72
SO_3	4.15	3.57	3.70
Na_2O	0.16	0.38	0.27
K_2O	0.73	0.73	0.73
BaO	0.57	0.62	0.46
Ash fusion temperature, °C*			
Reducing atmosphere			
Initial	1350	1150	1285
Spherical	1460	1295	1345
Hemispherical	>1480	1400	1405
Fluid	>1480	>1480	>1480
Oxidizing atmosphere			
Initial	1405	1205	1305
Spherical	>1480	1340	1380
Hemispherical	>1480	1430	1430
Fluid	>1480	>1480	>1480

*See Section 3.6

6.15 SUMMARY 15: LINE CREEK THERMAL COAL

1. Coal identification

Coal name and code: Line Creek 0BC B 20 05 20 30 R
Line Creek/Luscar Blend (40/60) 02 B 30 05 15 30 P
Mine: Line Creek, Fernie, BC
Seam 8, test pit No. 2, Kootenay formation
Status: Active

2. Reference report features

Topic: Pilot–scale combustion trials
Objectives: Evaluation of combustion performance of Line Creek coal as a boiler fuel when burned alone and when blended with Luscar Coal Valley coal.
Client: Crows Nest Resources Ltd.
Reference report (Date): ERP/ERL 80–36 (March 1980)
Related summary: 21

3 Reference coal

Name and code: Luscar Coal Valley AL B 40 05 15 30 P
(Referred to as "Reference" in report)
Mine: Luscar Coal Valley, Coalspur coalfield, Foothills region of Alberta
Status: Active

4. Pilot–scale boiler system

Furnace configuration – I with adiabatic furnace bottom
System modification – Both coals and the blends were precrushed to minus 3.2 mm in a hammer mill prior to feeding to the pulverizer

5. Coal characteristics

Line Creek:
As–received handling – A 7.5–tonne sample of Line Creek coal was delivered to CCRL in sealed, plastic–lined drums. The coal was crushed, metered, pulverized and transported without difficulty.
As–received moisture – <1.0%
As–fired screen size <200 mesh – 76%

Blends:
The coal blends were prepared in a 1–tonne "V"–type riffle. Before final bunkering, they were dried to less than 5% moisture. No problems were encountered in handling.
The maceral analyses on the coals are given in Table 3.

6. Flame observations

The coal analyses, together with the reactivity assessment, indicated that the Line Creek coal would have to be blended with at least 50% (by weight) of a more reactive coal, before it would burn acceptably in commercial–size boilers. Therefore, combustion trials were conducted at operating conditions given in Table 5. Flames were bright, clean and extremely stable. No support fuel was required after start up. The blended coals produced slightly longer flames and yielded slightly higher temperatures at the furnace exit than the reference coal.

7. Fly ash properties

Slagging potential	– Low, based on base: acid ratio
Fouling potential	– Low, based on sodium content and confirmed by observation
Resistivity	– Figure 3 in reference report
Particle size	– Figure 4 in reference report
Combustible in ash	– 2% at 4.7% O_2 for 2 flue gas for Luscar Coal – 11 to 24% for blends
Loading	– 1.16 g/Nm^3 at 4.7% O_2 in flue gas for Luscar Coal – 1.83 to 3.52 g/Nm^3 in blends

8. Low–temperature corrosion.

Virtually none.

9. Emissions

See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 8
Trace elements	– Not measured
Coal grind	– Table 4
Combustion performance	– Table 5
Gaseous emissions	– Table 5
Fly ash analyses	– Not measured
Other	
Maceral analyses of coal	– Table 3
Coal ash characteristics	– Table 8

Table 1 – Analyses of coal

	Coal		Blends			
	Line Creek 100/0	Reference 0/100	60/40	40/60	20/80	Typical specification limits
Proximate analysis, 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 analysis, 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
Grindability, HGI	81	42	68	58	52	>45
Ash fusibility, °C**						
Initial	1480	1150	1440	1350	1285	1250
ASTM classification	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 (See Section 3.6)

Table 3 – Petrographic examination of coal macerals

Maceral type vol %	Coal		Blends		
	Line Creek, 100/0	Reference 0/100	60/40	40/60	20/80
Reactive					
Resinite	<1	<1	<1	<1	<1
Exinite	<1	7	3	4	6
Tellinite	<1	<1	<1	<1	<1
Vitrinite	5	47	22	31	39
Semifusinite	17	<1	10	7	3
Subtotal	23	55	36	43	49
Inert					
Fusinite	5	16	9	12	14
Semifusinite	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
Subtotal	77	45	64	57	51
Total	100	100	100	100	100

Table 4 – Screen analyses of pulverized coals

	Reference	Blends		
	0/100	60/40	40/60	20/80
O_2 in flue gas, vol %	4.7	4.8	4.6	4.5
Screen size, mesh				
>100	0.1	0.3	0.2	0.3
<100 >140	3	2	0.7	1
<140 >200	21	12	6	13
<200 >325	45	52	57	36
<325 >400	4	9	5	4
<400	27	26	30	46
<200	76	86	93	86

Table 5 – Summary of combustion performance

	Reference	Blends		
	0/100	60/40	40/60	20/80
Coal firing rate, kg/h	76	85	81	81
Thermal input, MJ/h	2053	2336	2253	2226
Steam conditions:				
Flow, kg/h	370	410	385	400
Rate, kg/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, vol %	14.0	14.4	14.4	14.4
O_2, vol %	4.7	4.8	4.6	4.5
CO, vol %	<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 8 – Characteristics of coal ash

	Line Creek	Reference	Blends		
	100/0	0/100	60/40	40/60	20/80
Ash analysis, wt %					
SiO_2	58.81	57.01	57.72	57.31	58.27
Al_2O_3	33.55	16.08	27.40	24.95	21.94
Fe_2O_3	2.53	5.14	4.31	5.07	5.20
TiO_2	1.41	0.46	1.23	1.05	0.89
P_2O_5	0.60	0.22	0.46	0.39	0.27
CaO	0.99	11.96	3.63	5.19	6.60
MgO	0.41	1.15	0.63	0.79	0.88
SO_3	0.32	3.57	2.74	2.61	3.22
Na_2O	0.08	0.38	0.12	0.20	0.25
K_2O	0.72	0.73	0.57	0.63	0.70
BaO	0.08	0.62	0.30	0.44	0.46
Ash fusion temperature, °C*					
Reducing atmosphere					
Initial	>1480	1150	1440	1350	1285
Spherical	>1480	1295	>1480	1450	1415
Hemispherical	>1480	1400	>1480	>1480	>1480
Fluid	>1480	>1480	>1480	>1480	>1480
Oxidizing atmosphere					
Initial	>1480	1205	>1480	1360	1345
Spherical	>1480	1340	>1480	>1480	1430
Hemispherical	>1480	1430	>1480	>1480	>1480
Fluid	>1480	>1480	>1480	>1480	>1480

*See Section 3.6

6.16 SUMMARY 16: ONAKAWANA

1. Coal identification

Coal name and code: Onakawana ON L 40 15 25 25 R
Mine: Onakawana, south of James Bay, Northeastern Ontario
Status: Active

2. Reference report features

Topic: Pilot-scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Onakawana Development Limited
Reference report (Date): ERP/ERL 80-61 (October 1980)
Related summary: 11

3. Reference coal

Coal name and code: Klimax SA L 50 15 20 25 R
Mine: Klimax, Saskatchewan
Status: Active

4. Pilot-scale boiler system

Furnace configuration – I with adiabatic bottom
System modification – None

5. Coal characteristics

As-received handling – A 15-tonne sample of lignite was delivered to CCRL in sealed, plastic-lined drums. The as-received lignite was not homogeneous and severe problems occurred in conveying it through the pilot-scale coal handling system. The lignite was subsequently air dried for three days, followed by kiln drying, to reduce its moisture from about 50% to 20%. This resulted in problem-free handling.
As-received moisture (before drying) – 45 to 55%
As-pulverized moisture (after drying) – 20%
As-fired moisture – 9%
As-fired screen size <200 mesh – 65 to 80%

6. Flame observations

Bright, clean flame, extremely stable. No support fuel required.

7. Fly ash properties

Onakawana:
Slagging potential – Medium, based on theory and observation
Fouling potential – Low, based on sodium content of coal ash, confirmed by observation
Resistivity – 10^{10} ohm-cm

Particle size	– Table 6
Combustible in ash	– 0.1 to 0.8%
ESP efficiency	– 99%

Reference coal (Klimax):

Slagging potential	– Low to medium, based on theory and observation
Fouling potential	– Medium, based on sodium content of coal ash, confirmed by observation
Resistivity	– 10^9 ohm–cm
Particle size	– Table 6
Combustible in ash	– 0.1 to 0.8%
ESP efficiency	– 97%

8. Low temperature corrosion

Trace indication of iron corrosion by condensed sulphuric acid on low–temperature probes.

9. Emissions

Sulphur neutralization was about 30% for Onakawana and 20% for Klimax by measurement. SO_2 concentration for Onakawana coal exceeded current emission standards for new boilers, however, these levels can be reduced by dry SO_2 removal technology. Nitric oxide concentrations were lower than current guidelines. See Table 4.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 1
Trace elements	– Not measured
Coal grind	– Table 2
Combustion performance	– Table 3
Gaseous emissions	– Table 3
Fly ash analyses	– Not measured
Characteristics	– Table 6
Size	– Table 6

Table 1 – Analyses of lignites

	Onakawana		Reference	
Proximate analysis, wt %				
Ash	24.47		15.46	
Volatile matter	38.59		49.90	
Fixed carbon	36.94		34.64	
Ultimate analysis, wt %				
Carbon	52.62		60.74	
Hydrogen	3.78		4.47	
Sulphur	1.30		1.04	
Nitrogen	0.78		1.22	
Ash24.47	15.46			
Oxygen	17.05		17.07	
Calorific value, MJ/kg	20.18		23.87	
Grindability, HGI	46		46	
Moisture, wt %				
As–received	45 – 55		35	
As–fired	20		25	
Ash fusibility, °C*	Oxidizing	Reducing	Oxidizing	Reducing
Initial	1182	1149	1177	1110
Spherical	1249	1232	1249	1166
Hemispherical	1282	1249	1327	1182
Fluid	1449	1393	1360	1227
Ash analysis, wt %				
SiO_2	44.95		34.88	
Al_2O_3	11.47		17.03	
Fe_2O_3	7.93		6.16	
TiO_2	0.86		0.63	
P_2O_5	0.28		0.23	
CaO	12.85		15.70	
MgO	3.49		3.50	
$SO_3$13.33	14.88			
Na_2O	1.01		3.42	
K_2O	1.07		0.31	
SrO	0.12		0.38	
BaO	0.23		1.63	
LOF	1.99		1.80	
ASTM classification	Lignite A		Lignite A	

*See Section 3.6

Table 2 – Screen analyses of pulverized lignites

	Onakawana		Reference
O_2 in flue gas, vol %	3.2	5.0	5.2
Screen size, mesh			
>100	2	0.7	0.6
<100 >140	15	5	2
<140 >200	18	14	17
<200 >325	36	53	63
<325 >400	6	8	4
<400	23	19	13
<200	65	80	80
Coal moisture, wt %	9	9	8

Table 3 – Summary of combustion performance

	Onakawana		Reference
Coal firing rate, kg/h	130	133	109
Coal moisture, as-fired, wt %	20	20	25
Thermal input, MJ/h	2.10	2.15	1.96
Steam conditions			
Flow, kg/h	550	545	505
Rate, kg/MJ fuel input	0.20	0.19	0.19
Combustion air, °C			
Pulverizer inlet	210	225	205
Pulverizer outlet	65	75	65
Secondary air, °C	225	230	215
Flue gas conditions			
Flue gas exit temp., °C	200	210	185
Flue gas analysis, volume			
CO_2, %	16.6	15.4	15.1
O_2, %	3.2	5.0	5.2
CO, %	<0.01	<0.01	<0.01
NO, ppm	640	640	870
SO_2, ppm	1050	995	725
SO_3, ppm	<1	<1	<1

Table 6 – Characteristics of fly ash

	Onakawana		Reference
O_2 in flue gas, vol %	3.2	5.0	5.2
Particle size at precipitator inlet			
>30 μm	39	26	27
>1 μm	81	79	67
<1 μm	19	21	33
Flue gas temp., °C	200	210	185
In situ ash resistivity, ohm–cm	10^{10}	10^{10}	10^{9}
ESP* efficiency, %	99.2	99.0	97.0

*ESP: electrostatic precipitator

6.17 SUMMARY 17: SUNCOR COKE

1. Coal identification

Coal name and code: Suncor coke AL C 15 65 05 35 P
(Mine) Source: By-product of delayed coking operation, from Suncor Inc., Fort McMurray, Alberta
Status: On line

2. Reference report features

Topic: Sulphur oxide neutralization using limestone
Objectives: Determination of effect of limestone addition on operating performance, fireside deposits, fly ash characteristics and acid rain precursors
Client: Suncor Inc.
Reference report (Date): ERP/ERL 81-04 (February 1981)
Related summaries: None

3. Reference coal

None

4. Pilot-scale boiler system

Furnace configuration - I with adiabatic bottom
System modification - None

5. Coal characteristics

As-received handling	- Coke, precrushed to minus 50 mm was shipped to Ottawa in sealed drums. No handling problems were identified
As-pulverized moisture	- Zero
As-fired screen size <200 mesh	- 83 to 96%

6. Flame observations

Not described.

7. Fly ash properties

Slagging potential	- Thin slag layer with untreated coke; thick dense slag at lowest and highest limestone dosage rates. At the two intermediate limestone dosage rates the slag appeared viscous and porous.
Fouling potential	- Deposits were loose and powdery and could be removed easily by sootblowing. Degree of buildup increased with limestone dosage.
Resistivity	- 10^5 ohm-cm for untreated coke (10^8 to 10^{10} ohm-cm range at 350°C with limestone treated coke)
Particle size	- Table 6
Combustible in ash	- 50% for untreated coke
ESP efficiency	- Table 6
Loading	- Fly ash loading was five times higher for coke treated with Ca:S mol ratio of 3.2:1 than for untreated coke

8. Low-temperature corrosion

Corrosion rate – 4.1 to 0.3 μg $Fe/cm^2/h$ at 104°C to 135°C for untreated coke. These rates were reduced by limestone addition to 0.4 and 0.2 μg $Fe/cm^2/h$ at a Ca:S ratio of 2.5. (Figure 11, reference report)

9. Emissions

SO_2 – 14% reduction with untreated coke
– 58% reduction with coke treated at a Ca:S ratio of 3.2:1
NO – 585 to 640 ppm (unaffected by limestone addition)

10. Tabulations attached from reference report

Coal (coke) analyses	– Table 1
Trace elements	– See ash trace elements
Coal (coke) ash analyses	– Table 2
Trace elements	– Table 2
Coal (coke) grind	– Table 3
Combustion performance	– Table 3
Gaseous emissions	– Table 3
Fly ash analysis	– Table 6
Characteristics	– Table 6
Size	– Table 6

Table 1 – Analyses of coke, coke blends and limestone

	Ca:S mol ratio					
	0.1	1.2	2.0	2.5	3.2	Limestone
Proximate analysis, wt %						
Ash	2.6	19.2	23.3	25.6	29.1	–
Volatile matter	13.8	17.5	21.3	22.5	23.7	–
Fixed carbon	83.5	63.3	55.4	51.9	47.2	–
Ultimate analysis, wt %						
Carbon	85.8	71.5	64.9	62.2	59.1	12.7
Hydrogen	3.9	3.5	2.9	2.6	2.4	0.01
Sulphur	6.0	4.8	4.3	4.1	3.9	0.04
Nitrogen	1.7	1.0	1.1	1.2	0.9	0.01
Ash	2.6	19.2	23.3	25.6	29.1	37.6
Oxygen (by diff)	–	–	3.5	4.3	4.6	49.7
Grindability, HGI	51	–	–	–	–	–
Ash fusibility, °C*						
Reducing atmosphere						
Initial	1410	>1480	>1480	>1480	>1480	–
Spherical	>1480	>1480	>1480	>1480	>1480	–
Hemispherical	>1480	>1480	>1480	>1480	>1480	–
Fluid	>1480	>1480	>1480	>1480	>1480	–
Oxidizing atomosphere						
Initial	1140	1300	1270	>1480	>1480	–
Spherical	>1480	1350	1295	>1480	>1480	–
Hemispherical	>1480	1355	1300	>1480	>1480	–
Fluid	>1480	1415	1340	>1480	>1480	–
Calorific value						
Kcal/kg	8164	6893	5793	5551	5088	–
MJ/kg	34.11	28.80	24.20	23.19	21.26	–

*See Section 3.6

Table 2 – Analyses of ash from coke, coke blends and limestone

	Ca:S mol ratio					
	0.1	1.2	2.0	2.5	3.2	Limestone
Major elements, wt %*						
SiO_2	45.0	5.9	3.8	3.6	3.3	0.4
Al_2O_3	28.9	3.5	1.9	1.7	1.5	–
Fe_2O_3	7.6	1.1	1.1	0.9	0.8	0.5
TiO_2	3.2	0.5	0.4	0.4	0.3	0.2
P_2O_5	0.3	0.2	0.2	0.2	0.1	–
CaO	1.3	40.2	51.7	55.6	59.5	54.3
MgO	1.0	0.5	0.8	0.4	–	–
SO_3	–	42.5	38.4	34.4	30.1	1.0
Na_2O	0.5	0.1	0.2	0.2	0.2	0.1
K_2O	1.3	0.2	0.1	0.1	0.1	0.3
Trace elements, wt ppm*						
Ni	440	370	315	300	280	–
V	1050	880	755	715	670	38
As	2	2	2	2	2	1
Sb	0.1	0.1	0.1	0.1	0.1	–
Se	1	1	1	1	1	0.3
Hg	0.05	0.05	0.05	0.05	0.05	–
Pb	8	13	17	19	20	42
Ba	<2	<15	<20	<20	<25	–
Sr	<2	<15	<20	<20	<25	–
Cr	5	7	9	10	10	21
Cd	0.1	0.8	1.3	1.4	1.6	4
Mo	43	36	31	29	28	–
Mn	21	23	25	26	27	38
Cu	3	3	4	4	5	9
Co	6	6	6	6	7	9
Be	0.1	0.1	0.1	0.1	0.1	–
Zn	4	8	10	11	12	25

*Dry basis

Table 3 – Summary of combustion performance

	Ca:S mol ratio					
	0.1	0.1	1.2	2.0	2.5	3.2
Firing rate, kg/h	62.4	66.4	80.7	90.2	93.0	106.0
Heat input, GJ/h	2.13	2.27	2.32	2.15	2.16	2.25
Steam rate, kg/GJ	0.18	0.18	0.17	0.16	0.15	0.14
Coke fineness, mesh						
>100	0.5	1	3	0.5	0.5	1.5
<100 >140	0.5	2	1	0.5	0.5	2.5
<140 >200	10	14	2	3	4	2
<200 >325	80	69	78	77	73	72
<325	9	14	16	19	22	22
<200	89	83	94	96	95	94
Flue gas analyses						
CO_2 %	14.3	14.7	14.9	15.5	15.2	15.9
CO %	0.01	0.01	0.01	0.01	0.01	0.01
O_2 %	4.9	4.6	4.5	4.4	4.8	4.0
NO ppm	630	610	585	640	630	620
SO_2 ppm	3290	3330	2950	2225	1870	1590
Sulphur neutralized, %	14	13	31	38	49	58
Furnace exit temp., °C						
Before ash deposition	885	900	895	865	895	920
After deposit equilibration	960	1000	1015	1155*	1045*	1185*
dT/dt**, °C/h	12.5	13.3	20	48	50	53

*Soot blowing of screen tubes required
**From clean tubes to deposit equilibration

Table 6 – Characteristics of fly ash

Ca:S mol ratio in fuel	0.1	1.2	2.0	2.5	3.2
Ca:S mol ratio in fly ash	36.3	9.0	11.1	10.3	12.7
Combustible in fly ash, wt %	50	11	2	3	3
ESP efficiency, %	98.9	97.6	96.7	96.5	96.3
Major elements, wt %					
SiO_2	14.3	7.6	4.3	3.5	3.5
Al_2O_3	8.4	4.6	2.5	2.0	1.9
Fe_2O_3	2.7	2.2	1.2	1.1	0.9
TiO_2	0.8	0.7	0.1	0.2	0.2
P_2O_5	0.1	0.2	0.1	0.2	0.2
CaO	2.6	65.9	74.9	72.2	76.1
MgO	0.7	1.0	0.8	0.8	1.0
SO_3	0.1	13.1	12.0	12.5	10.7
Na_2O	0.5	0.2	0.2	0.1	0.2
K_2O	0.5	0.3	0.3	0.2	0.2
NiO	0.4	0.2	0.1	0.1	0.1
V_2O_5	1.1	0.6	0.5	0.4	0.4
Aerodynamic particle size, wt %					
>30 μm	18	22	21	26	22
>3.3 μm	75	56	35	53	42
>1 μm	93	85	74	84	78
>0.1 μm	99	98	96	98	97
Solids loading in flue gas, wt %	1.6	4.7	5.0	6.6	7.8

6.18 SUMMARY 18: SAGE CREEK COAL – No. 4 SEAMS BLEND

1. Coal identification

Coal name and code: Sage Creek Blend BC B 25 05 15 35 P
Mine: Sage Creek, British Columbia
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trials
Objectives: Preliminary assessment of combustion and ash fouling characteristics of 65:35 blend of No. 4 upper and No. 4 lower seams coal
Client: Techman Ltd.
Reference report (Date): ERP/ERL 81–17 (March 1981)
Related summary: 19

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I
System modification – None

5. Coal characteristics

As–received handling – Washed Sage Creek coal was shipped in plastic–lined 45–gallon drums. As–received coal was very fine and contained more than 15% total moisture. Air and kiln drying of this wet material to less than 5% moisture produced a free–flowing solid that conveyed and metered easily.
As–pulverized moisture – 2 to 3.4%
As–fired screen size <200 mesh – 54, 86 and 80% tests 1, 2 and 3
The maceral analyses are given in Table 3.

6. Flame observations

Stable for both fine and coarse grinds.

7. Fly ash properties

Slagging potential – Severe based on observation (neither base:acid ratio nor ash fusion temperature indicated potential for slagging problems)
Fouling potential – Low based on sodium and ash content and confirmed by observation
Resistivity – 4.6 to 5.0 log ohm–cm at 180°C
Particle size – Table 6
Combustible in ash – Above 15% by weight
ESP efficiency – Table 6

8. Low–temperature corrosion

Not measured.

9. Emissions

See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 2
Trace elements	– Not measured
Coal ash analyses	– Table 4
Trace elements	– Table 4
Coal grind	– Table 5
Combustion performance	– Table 5
Gaseous emissions	– Table 5
Fly ash analyses	– Table 6
Characteristics	– Table 6
Size	– Table 6
Other	
Maceral analyses of coal	– Table 3

Table 2 – Analyses of coal

	Washed Sage Creek 4U:4L*		Typical Pacific rim specifications	
			KECO	EPDC
As-received moisture, wt %	13–15		15	10
Proximate analysis, wt %				
Ash	14.4		17	20
Volatile matter	22.2		22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	63.4		50–60	
Ultimate analysis, wt %				
Carbon	75.6		–	–
Hydrogen	4.2		–	–
Sulphur	0.4		1.0	1.0
Nitrogen	1.2		2.0	1.8
Ash	14.4		–	–
Oxygen	4.2		–	–
Calorific value, Kcal/kg	7183		6000	6000
Free swelling index	2.5		–	–
Grindability, HGI	85		45	45
Ash fusibility, °C**	Reducing	Oxidizing	Reducing	Oxidizing
Initial	1354	1471	>1250	–
Spherical	>1482	>1482	–	>1200
Hemispherical	>1482	>1482	–	–
Fluid	>1482	>1482	–	>1300

*Blend of No. 4 upper and No. 4 lower seam's coal, at 65:35

**See Section 3.6

Table 3 – Petrographic examination of coal macerals

Maceral form		vol %
Reactives		
Exinite		<1
Vitrinite		26
Reactive semifusinite		9
	Subtotal	35
Inerts		
Oxidized vitrinite		26
Fusinite		18
Semifusinite		9
Micrinite		6
Mineral matter		6
	Subtotal	65

Table 4 – Analyses of coal ash

Elemental oxides	wt %
SiO_2	51.1
Al_2O_3	30.5
Fe_2O_3	5.7
TiO_2	2.0
P_2O_5	0.4
CaO	3.4
MgO	2.1
SO_3	3.6
Na_2O	0.3
K_2O	0.5

Trace elements	ppm
As	1
Se	0.7
Sb	0.8
Hg	0.07
Ni	14
Cr	10
Co	18
Cd	0.9
Pb	16
Zn	7
Sr	132
Mn	19
Be	0.9
Cu	19
V	47
Ba	556

Table 5 – Summary of combustion performance

Trial	1	2	3
Duration, h	6.6	7.1	7.4
Fuel rate, kg/h	79.6	76.8	72.3
Fuel moisture, wt %	2.0	3.4	3.4
Coal fineness, mesh			
>100	7	2	1
<100 >140	6	2	2
<140 >200	33	10	17
<200 >325	33	29	42
<325 >400	10	21	19
<400	10	36	19
<200	54	86	80
Heat input, GJ/h	2.3	2.2	2.1
Boiler exit temp., °C	1020	1135	1160
Air temp., °C			
Pulverizer in	170	190	215
Pulverizer out	115	125	135
Secondary	185	215	235
Steam rate, kg/MJ	0.18	0.17	0.16
Flue gas analyses, volume			
CO_2, %	16.0	15.8	14.6
O_2, %	2.9	2.7	5.2
CO, ppm	<100	110	160
NO, ppm	710	815	815
SO_2, ppm	305	285	240
SO_3, ppm	<1	<1	<1
Emission rates, kg/GJ			
NO	0.31	0.36	0.39
SO_2	0.28	0.27	0.25

Table 6 – Characteristics of fly ash

Trial	1	2	3
Precipitator inlet loading, g/Nm^3	7.7	5.6	3.7
Combustible in ash, wt %	21	17	15
Aerodynamic particle size			
>30 μm	16	21	14
>2 μm	80	72	71
ESP efficiency, %	93–94	89	84–86
Resistivity, log ohm–cm at 180°C	4.6	4.9	5.0
Ash analyses, wt %			
SiO_2	47.0	50.1	50.6
Al_2O_3	29.2	31.3	31.2
Fe_2O_3	5.4	5.7	4.4
TiO_2	1.9	2.1	2.0
P_2O_5	0.6	0.5	0.5
CaO	8.1	5.6	5.7
MgO	2.2	1.8	2.2
SO_3	2.2	1.3	1.1
Na_2O	1.9	0.6	0.6
K_2O	0.5	0.5	0.5
BaO	0.7	0.4	0.6
SrO	0.2	0.1	0.1
Combustion efficiency, %	95.0	96.8	96.9

6.19 SUMMARY 19: SAGE CREEK COAL - NO. 2 AND NO. 4 SEAMS BLENDS

1. Coal identification

Coal name and code: Sage Creek Blend 1 BC B 25 05 20 30 P
Sage Creek Blend 2 BC B 25 05 15 35 P
Mine: Sage Creek, British Columbia
Status: Exploratory

2. Reference report features

Topic: Pilot-scale combustion trials
Objectives: Determination of effect of individual seams on combustion and ash fouling characteristics of two blends of Sage Creek coal; 25:25:50 No. 2, No. 4 lower and No. 4 upper with different ash contents, blend 1 had 16% ash and blend 2 had 12% ash
Client: Techman Ltd.
Reference report (Date): ERP/ERL 81-38 (June 1981)
Related summary: 18

3. Reference coal

None

4. Pilot-scale boiler system

Furnace configuration - I
System modification - None

5. Coal characteristics

As-received handling - Washed Sage Creek coal was shipped in plastic lined 45-gallon drums. As-received coal was very fine and contained about 10% total moisture. Kiln drying of this wet material to less than 5% moisture produced a free-flowing solid that conveyed and metered easily.
As-pulverized moisture - <1.0%
As-fired screen size <200 mesh - 85% for blend 1 and 75% for blend 2
The maceral analyses are given in Table 5.

6. Flame observations

Stable for both blends.

7. Fly ash properties
Slagging potential - Low based on ash analysis and ash fusion data, and confirmed by observation
Fouling potential - Low based on sodium and ash content, and confirmed by observation
Resistivity - 4.6 to 5.5 log ohm-cm at 180°C
Particle size - Table 8
Combustible in ash - Below 15% by weight
ESP efficiency - Table 8

8. Low-temperature corrosion

Virtually none.

9. Emissions

See Table 7.

10. Tabulations attached from reference report

Coal analyses	– Table 2
Trace Elements	– Table 4
Coal ash analyses	– Table 3
Trace elements	– Not measured
Coal grind	– Table 7
Combustion performance	– Table 7
Gaseous emissions	– Table 7
Fly ash analyses	– Table 8
Characteristics	– Table 8
Size	– Table 8
Other	
Maceral analyses of coal	– Table 5

Table 2 – Analyses of coal

Coal blend	1		2	
As-received moisture, wt %	10–15		10–15	
Proximate analysis, wt %				
Ash	16.3		12.6	
Volatile matter	22.8		23.1	
Fixed carbon	60.9		64.3	
Ultimate analysis, wt %				
Carbon	73.7		77.2	
Hydrogen	4.1		4.4	
Sulphur	0.5		0.4	
Nitrogen	1.0		1.1	
Ash	16.3		12.6	
Oxygen	4.4		4.4	
Calorific value, MJ/kg	29.3		30.9	
Free swelling index	NA*		NA	
Grindability, HGI	82		86	
Ash fusibility, °C**	Oxidizing	Reducing	Oxidizing	Reducing
Initial	>1480	1366	>1480	>1480
Spherical	>1480	>1480	>1480	>1480
Hemispherical	>1480	>1480	>1480	>1480
Fluid	>1480	>1480	>1480	>1480
Rank (ASTM)	MV Bituminous		MV Bituminous	

*Non-agglomerating
**See Section 3.6

Table 3 – Analyses of coal ash

Major oxides by XRF*	Coal blend, wt %	
	1	2
SiO_2	52.66	52.34
Al_2O_3	30.87	30.46
Fe_2O_3	4.39	4.47
TiO_2	1.86	2.12
P_2O_5	0.48	0.67
CaO	3.54	3.91
MgO	1.35	1.28
SO_3	2.21	2.60
Na_2O	0.22	0.29
K_2O	0.88	0.56
SrO	0.08	0.11
BaO	0.26	0.39

*X-ray fluorescence analysis

Table 4 – Trace elements in coal, ppm

Element by XRF*	Blend 1	Blend 2	Element by NAA**	Blend 1
As	2.1	1.8	Cl	15
Se	0.7	0.8	Br	18
Sb	1.1	0.5	I	12
Hg	<0.1	<0.1	Dy	2
Ni	4.9	4.6	Eu	1
Cr	3.8	9.4	Sm	2
Co	2.7	2.1	U	2
Cd	<0.01	<0.01	Ce	20
Pb	15.5	15.8	Cs	<2
Zn	27.5	20.3	Hf	<1
Mn	20.8	15.8	Ho	1
Be	0.9	0.9	La	12
Cu	19.5	17.6	Lu	<1
V	54.0	43.7	Mo	<5
			Nd	30
			Sc	6
			Th	4
			Rb	<100

*X-ray fluorescence analysis
**Neutron activation analysis

Table 5 – Petrographic examination of coal macerals*

Maceral form		Coal blend 1	Coal blend 2
Reactives, vol %			
Exinite		1	1
Vitrinite		30	33
Reactive semifusinite		17	17
	Subtotal	48	51
Inerts, vol %			
Oxidized vitrinite		12*	12*
Fusinite		10	10
Semifusinite		17	17
Micrinite		4	3
Mineral matter		9	7
	Subtotal	52	49

*Calculated from examination of blends of No. 4 upper and lower seams with No. 2 seam

Table 7 – Summary of combustion performance

	Coal blend	
	1	2
Fuel rate, kg/h moist	76.1	73.9
Fuel moisture, wt % as fired	1.0	1.0
Coal fineness, mesh		
>100	0.2	0.2
<100 >140	3.0	4.0
<140 >200	12.0	21.0
<200 >325	41.0	40.0
<325 >400	22.0	17.0
<400	22.0	18.0
<200	85	75
Heat input, GJ/h	2.21	2.26
Boiler exit temp., °C	1078	1090
Air temp., °C		
Pulverizer in	94	91
Pulverizer out	59	57
Secondary	228	217
Steam rate, kg/MJ	0.16	0.17
Flue gas analyses		
CO_2, %	14.5	14.3
O_2, %	4.8	5.0
CO, ppm	100	100
NO, ppm	760	790
SO_2, ppm	380	365
SO_3, ppm	nd*	nd*
Emission rates, g/MJ		
NO	0.34	0.35
SO_2	0.36	0.34
Combustion efficiency, %	97.8	97.6

*Not detectable

Table 8 – Characteristics of fly ash

	Coal blend	
	1	2
Precipitator inlet loading, g/Nm^3	3.87	3.14
Combustible in ash, wt %	12	15
Aerodynamic particle size		
>30 µm	14	11
>10 µm	28	20
>1 µm	86	85
ESP efficiency, %	89	86
Resistivity, log ohm–cm		
at 180°C	5.5	4.6
340°C	5.3	5.5
Ash analyses, wt %		
SiO_2	53.71	53.36
Al_2O_3	31.45	31.49
Fe_2O_3	4.07	3.68
TiO_2	2.00	2.31
P_2O_5	0.64	0.74
CaO	4.94	5.07
MgO	1.27	1.74
SO_3	0.01	0.01
Na_2O	0.30	0.35
K_2O	0.77	0.62
BaO	0.70	0.46
SrO	0.14	0.17
Total	100.00	100.00

6.20 SUMMARY 20: POPLAR RIVER LIGNITE - LIME ADDITIONS

1. Coal identification

Coal name and code: Poplar River Lignite SA L 40 10 20 20 R
Mine: Poplar River, Coronach, Southwestern Saskatchewan
Status: Exploratory (in 1976)

2. Reference report features

Topic: Pilot-scale combustion trials
Objectives: Evaluation of combustion and ash fouling characteristics; determination of the effect of dry lime additions on sulphur emissions
Client: Saskatchewan Power Corporation
Reference report (Date): ERP/ERL 82-36 (TR) (Revised June 1982) [(Re-write of Report ERP/ERL 76-189 (IR) (December 1976)]
Related summary: 2

3. Reference coal

Name and code: Utility lignite SA L 40 10 15 20 R
Mine: Boundary Dam, Saskatchewan
Status: Active, commercial

4. Pilot-scale boiler system

Furnace configuration - I
System modification - Simulated superheater installed immediately downstream of the screen tubes and a rotary drier installed to dry the as-received coal before crushing and pulverizing

5. Coal characteristics

As-received handling - Handled, dried and crushed without difficulty.
As-pulverized moisture - 12.91%
(For lime addition experiments, 1-ton batches of lignite were blended with pebble lime (<1/8 in.) in a rotary riffle to ensure a uniform distribution of lime thoughout the fuel.)

6. Flame observations

Short stable flame. No support fuel required.

7. Fly ash properties

Slagging potential - Low based on observation
Fouling potential - Low based on observation
Sulphur neutralization - Table 4
ESP efficiency - Table 5
Particle size - Not measured
Combustible in ash - Not measured
Loading - Table 5
Deposits were lightly sintered, friable and easily removed with no evidence of slagging.

8. Low temperature corrosion

SO_3	– Not available
Corrosion rate	– No significant free acid in low–temperature deposits

9. Emissions

SO_2 – Table 3
NOx – Not measured

10. Tabulations from reference report attached

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Not included in reference report
Trace elements	– Not measured
Coal grind	– Not included in reference report
Combustion performance	– Table 2
Gaseous emissions (some)	– Tables 2 and 3
Fly ash analyses	– Not included in reference report
Characteristics	– Table 5
Size	– Not included in reference report
Other	
Sulphur neutralization	– Table 4

Table 1 – Analyses of lignite

Proximate analysis, wt %	
Moisture	12.91
Ash	17.30
Volatile matter	33.23
Fixed carbon	36.56
Ultimate analysis, wt %	
Carbon	56.39
Hydrogen	3.69
Sulphur	0.69
Nitrogen	0.76
Ash	19.86
Oxygen (by diff)	18.61
Gross calorific value, Btu/lb	7942
Ash fusibility, °C*	
Initial	1266
Spherical	1288
Hemispherical	1338
Fluid	1416

*See Section 3.6

Table 2 – Summary of combustion performance

	Feed rate kg/h	Steam flow kg/h	Flue gas analysis O_2 %	CO_2 %	CO ppm
Poplar River	157	695	1.0	18.9	100
		660	3.1	16.6	90
		661	4.7	16.5	55
Poplar River with 0.5% CaO	151	693	1.1	18.6	160
		659	3.1	16.8	160
		643	4.9	15.5	110
Poplar River with 1% CaO	162	704	1.0	17.9	140
		702	3.0	16.6	165
		682	4.9	14.9	105

Table 3 – Effect of lime on SO_2 concentrations

Excess O_2 in flue gas vol %	Sulphur dioxide concentration, PPM			
	Maximum theoretical conversion	Lime addition, wt %		
		0	1/2	1
1	1068	715	712	609
3	960	664	672	561
5	850	577	563	436

Table 4 – Lime utilization during SO_2 neutralization

Excess O_2 in flue gas vol %	Experimental conditions wt %	Gas phase SO_2 concentration ppm	Neutralization g/kg fuel	Lime utilization* %
1	Theoretical	1068	–	–
	0% lime	715	–	–
	1/2% lime	712	0	0
	1% lime	609	0.08	14.74
3	Theoretical	960	–	–
	0% lime	664	–	–
	1/2% lime	672	0	0
	1% lime	561	0.09	15.92
5	Theoretical	850	–	–
	0% lime	577	–	–
	0.5% lime	563	0.1	4.90
	1% lime	436	0.14	24.62

* Defined as $\frac{\text{Sulphur neutralization due to lime g/kg fuel}}{\text{Theoretical maximum neutralization capacity of lime}} \times 100$

Table 5 – Characteristics of fly ash

Lime addition rate wt %	O_2 in flue gas vol %	Fly ash loadings, g/scf		ESP efficiency %
		Before precipitator	After precipitator	
0	1	6.51	0.480	89.6
	3	5.98	0.596	92.6
	5	9.84	0.550	94.3
0.5	1	6.45	0.735	88.5
	3	5.91	0.671	88.5
	5	10.11	0.731	92.6
1	1	7.28	0.710	89.8
	3	7.38	0.726	89.9
	5	10.87	0.800	92.2

6.21 SUMMARY 21: THERMAL LINE CREEK COAL SAMPLE 2

1. Coal identification

Coal name and code: Line Creek BC B 25 05 20 30 R
Mine: Line Creek, Fernie, British Columbia
Current mine production (1982)
Status: Active

2. Reference report features

Topic: Pilot-scale combustion trials
Objectives: Evaluation of combustion performance of sample 2 of Line Creek coal as a boiler fuel when burned as a blend with Luscar Coal Valley coal
Client: Crows Nest Resourses Ltd.
Reference report (Date): ERP/ERL 83-19 (March 1983)
Related summary: 15

3. Reference coal

Name and code: Luscar Coal Valley AL B 35 05 15 30 R
(Referred to as "Reference" in report)
Mine: Luscar Coal Valley, Coalspur coalfield, Foothills region of Alberta
Status: Active

Note: Although this is the same reference coal as used in earlier trials (Reference report 15), the stockpile of the coal at CCRL had undergone spontaneous combustion a few months prior to the series of tests decribed in the present Reference report (21), reducing the volatile content of the coal.

4. Pilot-scale boiler system

Furnace configuration – I with adiabatic furnace bottom
System modification – Both coals and the blends were precrushed to minus 3.2 mm in a hammer mill prior to feeding to the pulverizers

5. Coal characteristics

Line Creek:
As-received handling – A 3-tonne sample of Line Creek coal was delivered to CCRL in sealed, plastic-lined drums. The coal was crushed, dried and blended without difficulty.
As-received moisture – 6.0%

Blends:
The coal blends were prepared in a 1-tonne "V"-type riffle. Before final bunkering, they were dried to less than 5% moisture. No problems were encountered in handling.
The maceral analyses are given in Table 4.
Results of thermogravimetric analyses of the Line Creek coals from these trials and those reported in Reference report 15 and of the Luscar (reference) coal are given in Figure 3 of the Reference report.

6. Flame observations

The coal analyses and the reactivity assessment indicated that the Line Creek coal would have to be blended with a more reactive coal before it would burn acceptably in large boiler furnaces. Therefore, combustion trials were conducted with operating conditions given in Table 5. Flames were bright, clean and extremely stable. No support fuel was required after startup.

7. Fly ash properties

Slagging potential	– Low, based on base:acid ratio
Fouling potential	– Low, based on sodium content and confirmed by observation
Resistivity	– Table 6
Particle size	– Table 6
Combustible in ash	– 8% and 13% for blends 60/40 and 80/20 respectively

8. Low–temperature corrosion

Not investigated.

9. Emissions

See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 2
Trace elements	– Not measured
Coal ash analyses	– Table 3
Trace elements	– Not measured
Coal grind	– Table 5
Combustion performance	– Table 5
Gaseous emissions	– Table 5
Fly ash analyses	– Table 7
Characteristics	– Table 6
Size	– Table 6
Other	
Maceral analyses of coal	– Table 4

Table 2 – Analyses of coal

	Line Creek 2	Reference	Pacific Rim specifications KECO	EPDC
As–received moisture, wt %	6.07	–	<15	<10
Proximate analysis, wt %				
Ash	18.97	10.86	<17	<20
Volatile matter	20.21	34.76	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	60.82	54.32	50–50	
Ultimate analysis, wt %				
Carbon	69.14	68.28	–	–
Hydrogen	3.35	4.38	–	–
Sulphur	0.22	0.23	<1.0	<1.0
Nitrogen	0.73	0.74	<2.0	<1.8
Ash	18.97	10.86	–	–
Oxygen (by diff)	7.59	15.51	–	–
Calorific value, MJ/kg	27.09	26.97	>25.12	>25.12
Grindability, HGI	82	42	>45	>45
Chlorine in coal, wt %	<0.1	<0.1	–	–
Free swelling index	NA*	NA*	–	–
Ash fusibility, °C**				
Reducing atmosphere				
Initial	>1480	1191	>1250	–
Spherical	>1480	1254	–	–
Hemispherical	>1480	1302	–	–
Fluid	>1480	1418	–	–
Oxidizing atmosphere				
Initial	>1480	1260	–	–
Spherical	>1480	1296	–	>1200
Hemispherical	>1480	1416	–	–
Fluid	>1480	1438	–	>1300

*Non–agglomerating

**See Section 3.6

Table 3 – Analyses of coal ash

Elemental oxides wt %	Line Creek 2	Reference
SiO_2	61.14	55.55
Al_2O_3	29.59	17.70
Fe_2O_3	2.79	6.41
TiO_2	1.46	0.66
P_2O_5	0.42	0.21
CaO	1.29	8.86
MgO	0.69	1.30
SO_3	0.37	3.55
Na_2O	0.23	0.38
K_2O	1.39	0.75
BaO	0.17	0.36
SrO	0.03	0.07
LOF*	1.45	2.16

*Loss on fusion

Table 4 – Petrographic examination of coal macerals

Maceral form	Line Creek 2	Reference
Reactives, vol %		
Exinite	<1	6
Vitrinite	42	61
Reactive semifusinite	–	–
Subtotal	42	67
Inerts, vol %		
Fusinite	12	7
Semifusinite	33	15
Micrinite	2	5
Mineral matter	11	6
Subtotal	58	33
Mean reflectance	1.21	–

Table 5 – Summary of combustion performance

Trial	1 Reference 0/100	2 Blend 60/40	3 Blend 80/20
Fuel rate, kg/h	74.9	79.1	77.1
Fuel moisture, wt %	2.5	2.1	2.0
Coal fineness, mesh			
>100	<1	<1	<1
<100 >140	2	6	5
<140 >200	8	4	5
<200 >325	58	55	51
<325 >400	13	10	21
<400	18	25	17
<200	89	90	89
Heat input, MJ/h	1969	2093*	2045*
Air temp., °C			
Pulverizer in	193	193	204
Pulverizer out	116	116	127
Secondary	204	204	215
Steam rate, kg/MJ	0.183	0.179*	0.176*
Flue gas rate, Nm^3/MJ	0.321	0.323*	0.322*
Flue gas analyses, volume			
CO_2, %	14.8	14.6	14.5
O_2, %	4.9	5.1	4.9
CO, ppm	90	40	100
NO, ppm	870	880	760
SO_2, ppm	170	143	182
SO_3, ppm	<1	<1	<1
Emission rates, g/MJ			
NO	0.374	0.380	0.328
SO_2	0.156	0.126	0.168

*Prorated on basis of blend

Table 6 – Characteristics of fly ash

Trial	1 Reference 0/100	2 Blend 60/40	3 Blend 80/20
Precipitator inlet loading			
g/Nm^3	1.67	4.30	5.51
g/MJ	0.54	1.39	1.77
Combustible content, wt %	1	8	13
Aerodynamic particle size, wt %			
>30 µm	29.2	8.6	4.7
>10 µm	42.0	27.0	18.0
>1 µm	91.8	86.5	87.4
Electrical resistivity, log ohm–cm			
at 143°C	10.3	4.7	4.7
at 310°C	10.1	5.3	5.3
Combustion effiency, %*	99.8	98.3	96.8

*Combustion efficiency, % = $100 - \frac{14\,500\ AC}{(100 - C)Q}$

where:

A = % ash in coal (dry basis)
C = % carbon in fly ash
Q = calorific value of coal, Btu/lb (dry basis)

Table 7 – Analyses of fly ash

Trial	1 Reference 0/100	2 Blend* 60/40	3 Blend* 80/20
Major elemental oxides, wt %			
SiO_2	50.80	50.00	47.25
Al_2O_3	19.82	22.55	20.94
Fe_2O_3	6.48	3.11	3.32
TiO_2	1.15	1.32	1.09
P_2O_5	0.28	0.40	0.38
CaO	11.59	3.15	3.04
MgO	1.58	0.87	0.68
SO_3	0.88	0.70	0.75
Na_2O	1.12	0.64	0.68
K_2O	0.53	0.56	0.57
BaO + SrO + LOF**	5.77	16.70	21.30

*Line Creek 2/Reference

**Loss on fusion