COMBUSTION CHARACTERISTICS OF CANADIAN COALS VOLUME 2

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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 of CANMET's Energy Research Laboratories, and its predecessor, the Canadian Combustion Research Laboratory, have generated detailed performance data on the combustion properties of various coals and solid fuels of interest to Canadian industry. The combustion evaluations, conducted in a pilot-scale research boiler designed to duplicate or closely simulate fireside conditions in operational utility units, have contributed significantly to the increasing use of Canadian thermal coals in both domestic and foreign markets.

Individual research reports, which describe 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 standard 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 in 1981 and 1982. A companion volume (Volume 1) containing combustion data generated between 1972 and 1982 was published in May 1989. The authors wish to acknowledge the helpful suggestions and invaluable editorial efforts of J.L. Harcourt (Nita) in the original tests and the subsequent compilation of these volumes. Other volumes are planned as data are released for publication.

D.A. Reeve
Director
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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 étrangers.

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 en 1981 et 1982. Un second volume (Volume 1), contenant d'autres données émises pendant la période 1972–1982 a été publié en mai 1989. Les auteurs désirent manifester leur gratitude à Monsieur J.L. Harcourt (NITA), pour les suggestions utiles et les efforts remarquables qu'il a su déployer sur le plan de l'édition, tant au niveau des textes originaux que des compilations subséquentes de ces volumes. On prévoit publier d'autres volumes à mesure que les données deviendront disponibles.

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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, issued in May 1989, contains 21 summaries of key data from trials conducted on 15 Canadian fuels between 1972 and 1982. Volume 2 contains 15 summaries on 12 more coals evaluated in 1981 and 1982.

The derivation of the alphanumeric codes assigned to the fuels is described in Section 2 of this volume. Section 3 outlines the test procedures used in the combustion trials. 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, 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 these areas, 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 content

Two digits signify the percentage of 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 percentage of sulphur in 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 percentage of 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 MJ/kg and 20 MJ/kg
7	P: Fuel is processed

Note: When data or information for any 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;
- evaluate the combustion performance of the pulverized coal at specified levels of excess combustion air and coal fineness;
- characterize the particulate and gaseous pollutants generated during combustion;
- assess the slagging and fouling potential of the fuel ash on radiant and convective heat transfer surfaces;
- assess the corrosion potential of condensed sulphuric acid on cold-end boiler surfaces;
- determine the fly ash resistivity characteristics; and
- assess the ease of fly ash collection by electrostatic precipitation.

Objectives other than these 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 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.

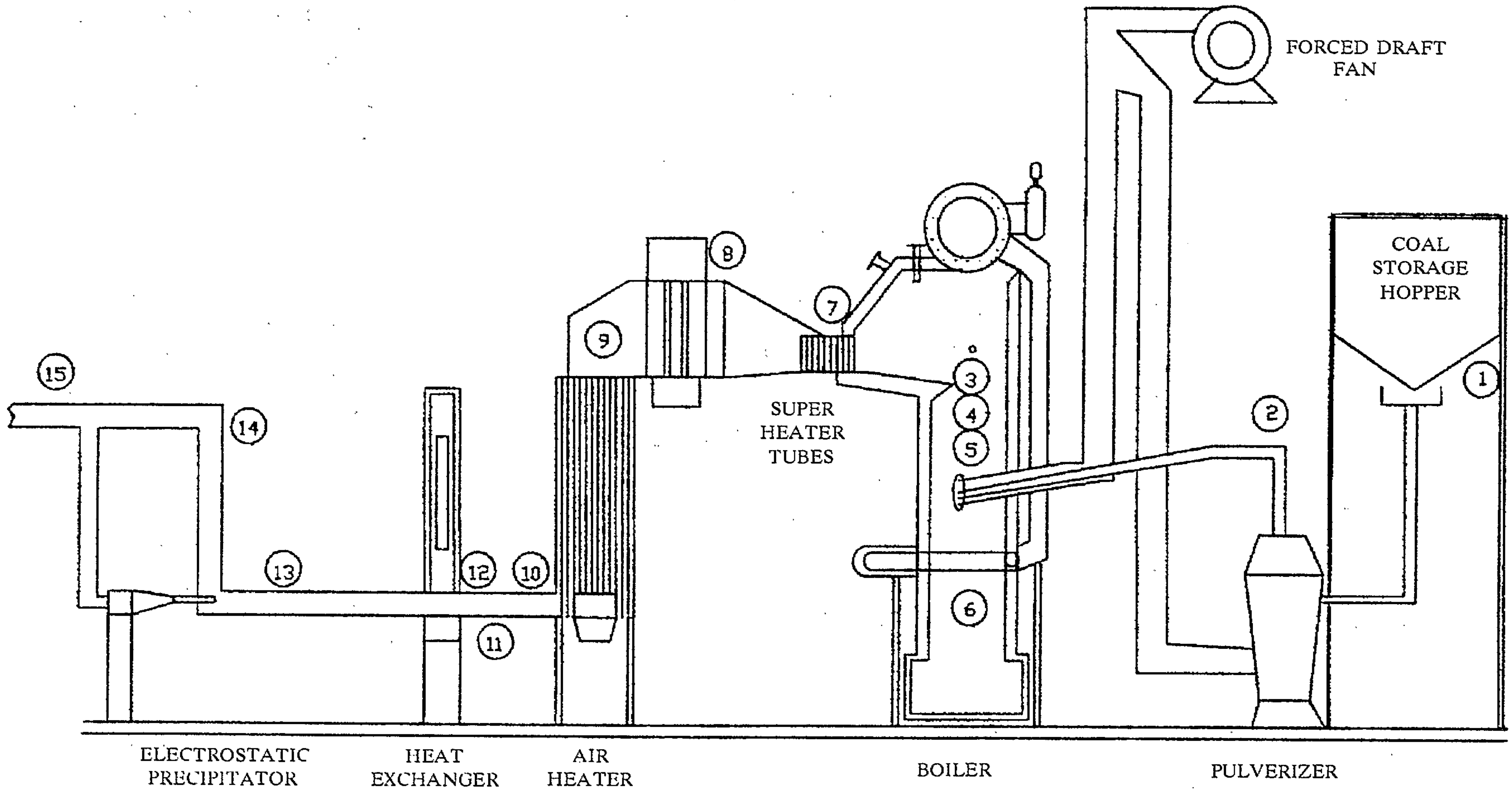

Figure 1 – Schematic Illustration of the Pilot-scale Boiler Showing the Sampling Stations

Combustion gases leave the furnace at 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 vary 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 Ringelmann. 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 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 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 to examine 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°C 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 and their significance in pulverized fuel combustion:

Maceral Reactivity – This directly influences ignition, flame stability and combustion efficiency as shown in Figure 2. Coals containing more 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 with 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 DECREASES ———→

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

Figure 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.

The slagging and fouling potential of the coals burned in these pilot–scale experiments is assessed using accepted empirical indices based on analyses of the raw coal, ash and 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 corresponds roughly 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 temperature of the ash and the hemispherical deformation temperature are those at which the ash surfaces show a much greater 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 applying only to coals having "eastern–" or "western–" type ash. Western–type ash is defined as coal with more CaO + MgO than Fe_2O_3, when each is measured as a weight per cent of the coal ash. This criterion depends 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 questions arise 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 a percentage 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 further evaluate 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

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.

Research and operating practices have generally agreed 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	0.5–1.0	2.0–6.0
High	1.0–2.5	6.0–8.0
Severe	>2.5	>8.0

Low-Temperature Corrosion Problems – These normally result from 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.
22	Combustion trials with Shaugnessy coal in a pilot-scale utility boiler	G.N. Banks R. Prokopuk H. Whaley G.K. Lee	ERP/ERL 81-37
23	Combustion evaluation of Quintette coal in a pilot-scale utility boiler	G.N. Banks R. Prokopuk H. Whaley G.K. Lee	ERP/ERL 81-47
24	Pilot-scale combustion evaluation of three Blackfoot thermal coals from the Gleichen area of Alberta	H. Whaley R. Prokopuk G.K. Lee G.N. Banks	ERP/ERL 81-48
25	Combustion evaluation of Coalspur coal in a pilot-scale utility boiler	G.N. Banks R. Prokopuk H. Whaley G.K. Lee	ERP/ERL 81-53
26	Combustion evaluation of Galt seam coal from the Kipp mine in a pilot-scale boiler	G.N. Banks R. Prokopuk H. Whaley G.K. Lee	ERP/ERL 81-57
27	Combustion evaluation of Magna coal in a pilot-scale utility boiler	H. Whaley G.N. Banks R. Prokopuk G.K. Lee	ERP/ERL 81-59
28	Combustion evaluation of Greenhills coal in a pilot-scale utility boiler	G.N. Banks R. Prokopuk H. Whaley G.K. Lee	ERP/ERL 82-05
29	Combustion evaluation of mixed Mercoal in a pilot-scale utility boiler	H. Whaley G.N. Banks R. Prokopuk G.K. Lee	ERP/ERL 82-17

Summary No.	ERL Report Title	Authors	No.
30	Combustion evaluation of McLeod River coal in a pilot-scale utility boiler	G.N. Banks H. Whaley R. Prokopuk G.K. Lee	ERP/ERL 82-21
31	Combustion evaluation of Balmer mine (Harmer seam) coal in a pilot-scale utility boiler	J. Wong G.N. Banks R. Prokopuk H. Whaley	ERP/ERL 83-02
32	Combustion evaluation of Belcourt thermal coal in a pilot-scale utility boiler	J. Wong H. Whaley G.N. Banks R. Prokopuk	ERP/ERL 83-04
33	Combustion evaluation of thermal Lodgepole coal in a pilot-scale utility boiler	J. Wong G.N. Banks R. Prokopuk H. Whaley	ERP/ERL 83-07
34	Combustion evaluation of washed Blackfoot coal in a pilot-scale utility boiler	J. Wong G.N. Banks R. Prokopuk H. Whaley	ERP/ERL 83-12
35	Combustion evaluation of thermal Coalspur coal sample no. 2 in a pilot-scale utility boiler	J. Wong G.N. Banks R. Prokopuk H. Whaley	ERP/ERL 83-20
36	Combustion evaluation of washed Quintette coal in a pilot-scale utility boiler	G.N. Banks J. Wong R. Prokopuk H. Whaley	ERP/ERL 83-29

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

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Coal	Summary No.	Report
Balmer Mine	31	ERP/ERL 83–02
Belcourt	32	ERP/ERL 83–04
Blackfoot (3 coals)	24	ERP/ERL 81–48
Blackfoot (washed)	34	ERP/ERL 83–12
Coalspur	25	ERP/ERL 81–53
Coalspur	35	ERP/ERL 83–20
Galt Seam	26	ERP/ERL 81–57
Greenhills	28	ERP/ERL 82–05
Lodgepole	33	ERP/ERL 83–07
Luscar Coal Valley	33	ERP/ERL 83–07
Magna	27	ERP/ERL 81–59
McLeod River (2 seams)	30	ERP/ERL 82–21
Mercoal	29	ERP/ERL 82–17
Quintette	23	ERP/ERL 81–47
Quintette (washed)	36	ERP/ERL 83–29
Shaughnessy (washed)	22	ERP/ERL 81–37

6. SUMMARIES OF COMBUSTION CHARACTERISTICS

6. SUMMARIES OF COMBUSTION CHARACTERISTICS

6.22 SUMMARY 22: SHAUGHNESSY COAL

1. Coal identification

Coal name and code: Shaughnessy AL B 40 10 15 30 P
Mine: near Lethbridge, Alberta
Status: Newly opened seam

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Fording Coal Limited
Reference report (date): ERP/ERL 81–37 (July 1981)
Related summary: None

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – A 10–tonne sample of freshly mined, washed Shaughnessy coal was shipped to CCRL in plastic lined 45–gal drums. The as–received coal was air and kiln dried to about 11% moisture and this produced a free–flowing material that conveyed and metered easily. No problems were experienced moving or feeding the dried coal through the pilot–scale coal handling system.
As–received moisture – 15% to 20%
As–fired screen size <200 mesh – 67% to 85%

6. Flame observations

Bright, clean and stable under steady–state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential	– Medium to high; based on base/acid ratio, potential slagging temperature and observation
Fouling potential	– Low; based on sodium content and observation
Resistivity	– 9.3 to 11.7 log ohm–cm
Particle size	– Table 6
ESP efficiency	– 84% to 88%
Combustible efficiency	– 99.6%

8. Low–temperature corrosion

Not measured.

9. Emissions

The carbon monoxide level constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions were less than theoretical, indicating about 10% neutralization by alkaline ash constituents. The average emission rate was close to the 1977 U.S. Environmental Protection Agency (EPA) guideline of 0.58 kg SO_2/GJ for new combustion sources, but it is anticipated emissions could be reduced by injecting small quantities of limestone to the fuel. The nitric oxide emissions exceeded the maximum 1977 EPA guidelines of 0.34 kg NO/GJ, but could be reduced through a staged–combustion system modification. See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Table 3
Coal ash analyses	– Table 3
Trace elements	– Not measured
Coal grind	– Table 4
Combustion performance	– Table 5
Gaseous emissions	– Table 5
Fly ash analyses	– Table 6
Characteristics	– Table 6
Size	– Table 6
Maceral analyses of coal	– Table 2

Table 1 – Analyses of coal

	Shaughnessy	Pacific Rim specifications
Moisture, wt %		
As-received	15–20	15
Equilibrium	11	–
Proximate analysis, wt %		
Ash	11.2	<17
Volatile matter	38.9	22–36
Fixed carbon	49.9	50–60
Ultimate analysis, wt %		
Carbon	67.6	–
Hydrogen	4.8	–
Sulphur	0.89	<1
Nitrogen	1.8	<2
Ash	11.2	<17
Oxygen (by diff.)	13.8	–
Calorific value, MJ/kg	27.86	>25.05
Grindability, HGI	44	>45
Chlorine in coal, wt %	<0.01	–
Ash fusibility, °C*		
Reducing atmosphere		
Initial	1171	>1250
Spherical	1260	–
Hemispherical	1388	–
Fluid	1443	–
Oxidizing atmosphere		
Initial	1238	–
Spherical	1282	–
Hemispherical	1360	–
Fluid	>1482	–

*See Section 3.6

Table 2 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		2.6
Resinite		0.4
Vitrinite		60.0
Reactive semifusinite		5.0
	Subtotal	68.0
Inerts, vol %		
Oxidized vitrinite		6.5
Fusinite		4.1
Semifusinite		11.0
Micrinite		3.4
Mineral matter		6.4
	Subtotal	32.0

Table 3 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	55.1	MgO	2.4
Al_2O_3	20.3	SO_3	3.8
Fe_2O_3	5.4	Na_2O	1.0
TiO_2	0.9	K_2O	1.0
P_2O_5	0.7	SrO	0.2
CaO	7.2	BaO	0.3

Trace elements in coal sample, ppm

by X-ray fluorescence				by neutron activation			
As	1.8	Pb	9.1	Br	2	Hf	<1
Se	0.7	Zn	11.4	Cl	10	Ho	1
Sb	0.4	Sr	179.9	I	<10	La	8
Hg	0.05	Mn	22.5	Dy	1	Lu	<0.1
Ni	14.5	Be	0.7	Eu	0.3	Mo	<5
Cr	9.1	Cu	8.1	Sm	1	Nd	<50
Co	10.8	V	30.3	U	0.7	Sc	3
Cd	0.7			Ce	10	Th	3
				Cs	<2	Rb	<100

Table 4 – Screen analyses of pulverized coal, wt %

	Trial	
	1	2
	$3\%O_2$	$5\%O_2$
Screen size, mesh		
>100	0.2	0.2
<100 >140	1.0	1.0
<140 >200	15.0	32.0
<200 >325	40.0	35.0
<325 >400	17.0	17.0
<400	27.0	15.0
<200	85.0	67.0

Table 5 – Summary of combustion performance

	Trial	
	1	2
Duration, h	7.2	7.1
Firing rate, kg/h	91.4	88.0
Pulverized coal		
Moisture, wt %	6.0	6.0
Fineness, % <200 mesh	85	67
Thermal input, MJ/h	2394	2305
Air temp., °C		
Pulverizer inlet	200	215
Pulverizer outlet	120	115
Secondary	250	240
Steam conditions		
Flow, kg/h	553	537
Rate, kg/MJ	0.23	0.25
Boiler exit temp., °C	1000	975
Flue gas conditions		
Gas volume (dry), Nm^3/h	675	736
Exit temp., °C	141	154
Flue gas analyses, volume		
O_2, %	3.0	5.1
CO_2, %	16.3	14.2
CO, ppm	<100	<100
SO_3, ppm	<1	<1
SO_2, ppm	730	620
NO, ppm	1310	1320
Emission rates, g/MJ		
SO_2	0.588	0.567
NO	0.495	0.566

Table 6 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading, g/Nm^3	3.4	7.1
Combustible content, wt %	3.5	3.5
Aerodynamic particle size, wt %		
>30 µm	26	25
>10 µm	46	50
>1 µm	91	93
ESP efficiency, %	88	84
Electrical resistivity, log ohm–cm		
at 180°C	11.0	11.7
340°C	9.4	9.3
Ash analyses, wt %		
SiO_2	51.4	53.1
Al_2O_3	20.8	20.9
Fe_2O_3	5.4	4.9
TiO_2	1.0	0.9
P_2O_5	0.7	0.7
CaO	9.1	9.0
MgO	1.8	2.0
SO_3	0.2	0.4
Na_2O	1.1	1.1
K_2O	0.9	0.9
BaO	0.6	0.7
SrO	0.2	0.2
LOF*	6.8	4.6
Combustion efficiency, %**	99.6	99.6

*LOF – Loss on fusion

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

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

6.23 SUMMARY 23: QUINTETTE COAL

1. Coal identification

Coal name and code: Quintette BC B 25 05 20 30 R
Mine: Quintette, Northeastern BC
Status: Active

2. Reference report features

Topic: Pilot-scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Denison Mines Limited
Reference report (date): ERP/ERL 81-47 (August 1981)
Related summary: 36

3. Reference coal

None

4. Pilot-scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As-received handling – A 3.5-tonne sample of Quintette coal was delivered to CCRL in sealed plastic-lined drums. The coal was free flowing and there was no difficulty moving or feeding it through the pilot-scale coal handling system.
As-received moisture – 8%
As-fired screen size <200 mesh – 95%

6. Flame observations

Bright, clean and stable under steady-state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Low to medium; based on analysis and observation
Fouling potential – Low; based on analysis and observation
Resistivity – Below optimal range, Table 6
Particle size – Table 6
ESP efficiency – 87%
Combustion efficiency – 97.4%

8. Low-temperature corrosion

Potential for low-temperature corrosion minimal.

9. Emissions

The carbon monoxide level constituted neither an emission problem nor a significant thermal penalty. Emissions of nitric oxide and sulphur dioxide were less than the current allowable North American guidelines. See Table 4.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Not measured
Coal ash analyses	– Table 2
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 1 – Analyses of coal

	Quintette	Pacific Rim specifications	
		KECO	EPDC
As–received moisture, wt %	8.0	<15	<10
Proximate analysis, wt %			
Ash	16.81	<17	<20
Volatile matter	21.95	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	61.24	50–60	
Ultimate analysis, wt %			
Carbon	73.41	–	–
Hydrogen	4.10	–	–
Sulphur	0.37	<1.0	<1.0
Nitrogen	0.86	<2.0	<1.8
Ash	16.81	<17	<20
Oxygen (by diff.)	4.45	–	–
Calorific value, MJ/kg	29.17	>25.05	>25.05
Grindability, HGI	78.0	>45	>45
Chlorine in coal, wt %	0.01	–	–
Ash fusibility, °C*			
Reducing atmosphere			
Initial	1221	>1250	–
Spherical	1438	–	–
Hemispherical	>1480	–	–
Fluid	>1480	–	–
Oxidizing atmosphere			
Initial	1343	–	–
Spherical	1454	–	>1200
Hemispherical	>1480	–	–
Fluid	>1480	–	>1300

*See Section 3.6

Table 2 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	61.80	MgO	0.95
Al_2O_3	22.35	SO_3	1.93
Fe_2O_3	4.36	Na_2O	0.43
TiO_2	0.85	K_2O	1.95
P_2O_5	0.42	BaO	0.76
CaO	3.35	SrO	0.09

Table 4 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		1
Vitrinite		24
Reactive semifusinite		14
	Subtotal	39
Inerts, vol %		
Oxidized vitrinite		24
Fusinite		6
Semifusinite		13
Micrinite		8
Mineral matter		10
	Subtotal	61

Table 5 – Summary of combustion performance

Duration, h	7.2
Firing rate, kg/h	72
Moisture, wt %	1.1
Coal fineness, mesh	
>100	0.2
<100 >140	0.5
<140 >200	4
<200 >325	46
<325 >400	25
<400	24
<200	95
Thermal input, MJ/h	2077
Boiler exit temp., °C	1030
Air temp., °C	
Pulverizer inlet	202
Pulverizer outlet	138
Secondary	236
Steam rate, kg/MJ	0.180
Flue gas rate, Nm^3/MJ	0.329
Flue gas analyses, volume	
O_2, %	4.8
CO_2, %	14.8
CO, ppm	<100
SO_3, ppm	<1
SO_2, ppm	270
NO, ppm	735
Emission rates, g/MJ	
SO_2	0.254
NO	0.324

Table 6 – Characteristics of fly ash

Precipitator inlet loading	
g/Nm^3	4.14
g/MJ	1.36
Combustible content, wt %	11
Aerodynamic particle size, wt %	
>30 μm	11
>10 μm	26
>1 μm	85
Precipitator efficiency, %	87
Electrical resistivity, log ohm–cm	
at 180°C	4.8
340°C	5.2
Combustion efficiency, %*	97.4

$$\text{*Combustion efficiency, } \% = 100 - \frac{14\,500\ CA}{(100 - C)C_V}$$

where: C = % carbon in ash
A = % ash in coal
C_V = calorific value of coal, Btu/lb

Table 7 – Analyses of fly ash

Major elemental oxides, wt %			
SiO_2	60.03	MgO	1.53
Al_2O_3	23.66	SO_3	<0.01
Fe_2O_3	4.53	Na_2O	0.54
TiO_2	1.05	K_2O	1.92
P_2O_5	0.64	BaO	0.98
CaO	4.96	SrO	0.15

6.24 SUMMARY 24: BLACKFOOT COALS

1. Coal identification

Coal name and code: All three coals are Blackfoot coals but are designated in the reference report as:

Poor Eagle	AL S 35 05 35 20 R
Eastern	AL S 40 05 30 25 R
Central	AL L 40 05 45 15 R

Mine: Gliechen area, Blackfoot deposit, Edmonton formation east of Calgary, Alberta
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Crows Nest Resources Limited
Reference report (date): ERP/ERL 81–48 (October 1981)
Related summary: 34

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – Freshly mined samples of Blackfoot coal were shipped to CCRL in plastic–lined drums. Poor Eagle, Eastern and Central weighed 9.0, 8.5 and 5.2 tonnes respectively. The as–received coals were kiln dried, after which they were free flowing and conveyed and metered readily.

	Poor Eagle	Eastern	Central
As–received moisture –	16%	16%	28%
As–fired screen size <200 mesh –	25% to 94%	57%	75% to 85%

6. Flame observations

The ignition and flame stability of the Poor Eagle and Eastern coals were excellent. The combustion performance of Central coal was poor and required about 34% oil support and fine grinding to maintain combustion.

7. Fly ash properties

Slagging potential – Low to medium; based on analysis and observation for all three coals
Fouling potential – Low for Poor Eagle coal, medium for Eastern and Central coals; based on sodium content of ash and confirmed by observation

For resistivity, particle size, combustion efficiency, ESP efficiency and other fly ash characteristics see Table 7.

8. Low–temperature corrosion

Potential for low–temperature corrosion virtually non–existent.

9. Emissions

The carbon monoxide level constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions were well below the 1977 U.S. EPA guideline for new utility sources. These emissions indicated between 5% and 25% neutralization of sulphur by cations in the ash. The nitric oxide emissions marginally exceeded the EPA guideline but could be reduced through a staged–combustion system modification. See Table 6.

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 6
Combustion performance	– Table 6
Gaseous emissions	– Table 6
Fly ash analyses	– Table 7
Characteristics	– Table 7
Size	– Table 7
Trace elements	– Table 8
Other	
Maceral analyses of coal	– Table 5
Coal ash characteristics	– Not measured

Table 2 – Analyses of coals

	Poor Eagle	Eastern	Central
Equilibrium moisture, wt %	16	18	29
Proximate analysis, wt %			
Ash	30.21	25.10	40.11
Volatile matter	33.97	39.33	37.03
Fixed carbon	35.82	35.57	22.86
Ultimate analysis, wt %			
Carbon	50.11	53.02	35.30
Hydrogen	3.61	4.36	2.81
Sulphur	0.45	0.39	0.32
Nitrogen	1.20	1.18	1.16
Ash	30.21	25.10	40.11
Oxygen	14.42	15.92	20.30
Calorific value, MJ/kg	19.9	21.5	12.7
Grindability, HGI	43	36	120
Chlorine in coal, wt %	<0.01	<0.01	<0.01
Ash fusibility, °C*			
Reducing atmosphere			
Initial	1210	1195	1216
Spherical	1300	1289	1300
Hemispherical	1372	1350	1372
Fluid	1440	1450	1480
Oxidizing atmosphere			
Initial	1283	1222	1250
Spherical	1394	1350	1389
Hemispherical	1461	1378	1428
Fluid	>1480	1467	>1480
Rank (Parr)	◄— Subbituminous B —►		Lignite B

*See Section 3.6

Table 3 – Analyses of coal ash

	Poor Eagle	Eastern	Central
Major elemental oxides, wt %			
SiO_2	62.49	61.70	58.17
Al_2O_3	20.19	19.05	23.37
Fe_2O_3	4.50	3.92	3.93
TiO	0.37	0.42	0.43
P_2O_5	0.41	0.29	0.35
CaO	4.16	4.68	4.94
MgO	1.15	0.95	2.59
SO_3	2.48	2.22	1.75
Na_2O	0.73	3.49	2.08
K_2O	1.39	0.82	1.11
SrO	0.11	0.15	0.15
BaO	0.33	0.34	0.26

Table 4 – Trace elements in coal sample, ppm

	Poor Eagle	Eastern	Central
by atomic absorption spectroscopy			
Chromium	7.7	6.0	9.2
Arsenic	4.0	4.8	2.8
Selenium	1.0	0.8	1.5
Antimony	0.6	0.4	0.6
Mercury	0.05	0.04	0.04
Cadmium	1.3	1.2	1.8
Cobalt	5.1	4.2	9.1
Manganese	330.0	303.0	249.0
Copper	5.1	5.4	8.3
Beryllium	0.6	0.6	0.9
Vanadium	19.9	18.4	30.5
Zinc	15.4	14.3	23.1
Nickel	0.01	0.01	7.4
Lead	16.7	14.9	24.0
by neutron activation			
Bromine	1.0	1.0	2.0
Dysprosium	1.6	1.3	2.1
Europium	0.2	0.2	0.4
Lanthanum	14.9	12.5	18.7
Lutecium	0.2	0.2	0.2
Samarium	2.1	1.8	2.6
Scandium	2.3	2.5	3.5
Thorium	6.1	5.5	9.2
Uranium	2.7	2.1	4.6

Table 5 – Petrographic examination of coal macerals

Maceral form		Poor Eagle	Eastern	Central
Reactives, vol %				
Exinite + resinite		1	<1	2
Vitrinite		63	44	56
Reactive semifusinite		7	16	3
	Subtotal	71	61	61
Inerts, vol %				
Fusinite		2	6	8
Semifusinite		7	17	4
Micrinite		1	1	<1
Mineral matter		19	15	27
	Subtotal	29	39	39

Table 6 – Summary of combustion performance

	Poor Eagle		Eastern	Central	
	1	2	3	4	5
Firing rate, kg/h (wet)	111	82	96	128	133
Moisture, wt %	13	11	12	22	15
Thermal input, MJ/h					
Coal	1915	1446	1812	1243	1352
Oil	nil	nil	nil	0205	0682
Total	1915	1446	1812	1448	2034
Coal fineness, mesh					
>100	23	0.2	6	13	7
<100 >140	24	1	12	8	5
<140 >200	28	5	25	4	3
<120 >325	18	55	30	47	28
<325 >400	5	18	12	12	23
<400	2	21	14	17	34
<200	25	94	57	75	85
Air temp., °C					
Primary	149	171	160	166	188
Secondary	166	166	160	188	199
Steam conditions					
Flow, kg/h	535	423	540	440	590
Pressure, kPa	386	434	372	303	421
Rate, kg/MJ	0.219	0.225	0.231	0.216	0.222
Flue gas analyses, volume					
O_2, %	3.3	3.1	3.3	5.3	2.8
CO_2, %	16.8	16.5	16.5	15.6	17.0
CO %	<0.01	<0.01	<0.01	<0.01	<0.01
SO_3, ppm	<1	<1	<1	<1	<1
SO_2, ppm	520	496	360	–	420
NO, ppm	1050	1140	1050	–	950

Table 7 – Characteristics of fly ash

	Poor Eagle		Eastern	Central	
	1	2	3	4	5
Combustible content, wt %	8–13	1–2	3–5	>20	5–8
Grain loading gr/scm*	8.5	7.7	9.6	–	14.2
Aerodynamic particle size, wt %, µm					
>30	12	23	8	–	6
<30 >9.2	22	21	27	–	21
<9.2 >5.5	14	9	19	–	20
<5.5 >3.3	16	7	16	–	16
<3.3 >2	12	12	11	–	12
<2.0 >1	11	12	9	–	11
<1.0 >0.3	8	9	6	–	8
<0.3 >0.1	4	4	3	–	4
<0.1	2	2	1	–	1
ESP efficiency, %	99.0	98.6	99.3	–	98.6
Electrical resistivity, log ohm–cm at flue gas temperature	5.0	11.4	8.9	5.0	10.2
Ash analyses, wt %					
SiO_2	50.0	56.2	56.8	–	52.4
Al_2O_3	20.9	22.4	19.6	–	23.6
Fe_2O_3	4.4	5.1	3.8	–	4.6
TiO_2	0.5	0.6	0.5	–	0.5
P_2O_5	0.6	0.8	0.5	–	0.5
CaO	3.7	6.7	6.8	–	7.0
MgO	1.4	1.8	1.0	–	2.9
SO_3	<0.01	0.3	<0.01	–	0.2
Na_2O	0.4	0.6	3.7	–	2.1
K_2O	1.2	1.1	0.7	–	0.9
Emission rates, g/MJ					
SO_2	0.43	0.40	0.30	–	0.36
NO	0.41	0.44	0.40	–	0.40
% Sulphur neutralized	5–10	10–15	15–20	–	20–25
Combustion efficiency, %**	92–96	>99	>98	>73	91–94

*Grains per standard cubic metre

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

where: A = % ash in coal
C = % carbon in ash
Q = calorific value of coal, Btu/lb

Table 8 – Trace elements in fly ash, ppm

	Poor Eagle	Eastern	Central
	2	3	5
Be	5	3	5
Co	80	81	5
Cu	28	32	65
Ni	38	12	30
V	106	137	<1
Cr	28	12	22
Zn	61	67	82
Mn	997	952	839
Pb	<1	<1	74
Cd	<1	<1	1

6.25 SUMMARY 25: COALSPUR COAL

1. Coal identification

Coal name and code: Coalspur AL B 40 05 10 30 R
Mine: Coalspur Mine, Robb Block, near Hinton in the Foothills Region of Alberta
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Denison Mines Limited
Reference report (date): ERP/ERL 81053 (September 1981)
Related summary: 35

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – A 4.5–tonne sample of Coalspur coal was delivered to CCRL in plastic–lined drums. The coal was free flowing and it was not difficult to move or feed it through the pilot–scale coal handling system.
As–received moisture – 13%
As–fired screen size <200 mesh – Trial 1, 86%; Trial 2, 70%

6. Flame observations

Bright, clean and stable under steady state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Low to medium; based on analysis and observation
Fouling potential – Low; based on analysis and observation

For resistivity, particle size, electrostatic precipitator efficiency, combustion efficiency and other characteristics of fly ash see Table 6.

8. Low–temperature corrosion

Potential for low–temperature corrosion minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions were well below the 1977 U.S. EPA guidelines for new combustion sources. Only trace quantities of sulphur trioxide were detected. Nitric oxide emissions were close to the maximum EPA guideline. This was expected because of the high flame temperatures from the high reactivity of the coal. NO emissions could be reduced by an appropriate burner design system and efficient utilization of excess combustion air. See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Table 3
Coal ash analyses	– Table 2
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
Coal ash characteristics	– Table 1

Table 1 – Analyses of coal

	Coalspur	Pacific Rim specifications	
		KECO	EPDC
Moisture, wt %			
As-received	13	<15	<10
Equilibrium	9	–	–
Proximate analysis, wt %			
Ash	9.47	<17	<20
Volatile matter	37.09	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	53.44	50–60	
Ultimate analysis, wt %			
Carbon	71.91	–	–
Hydrogen	4.66	–	–
Sulphur	0.23	<1.0	<1.0
Nitrogen	1.10	<2.0	<1.8
Ash	9.47	–	–
Oxygen (by diff.)	12.63	–	–
Calorific value, MJ/kg	28.40	>25.05	>25.05
Grindability, HGI	44	>45	>45
Chlorine in coal, wt %	0.1	–	–
Free swelling index	NA*	–	–
Ash fusibility, °C**			
Reducing atmosphere			
Initial	1327	>1250	–
Spherical	>1480	–	–
Hemispherical	>1480	–	–
Fluid	>1480	–	–
Oxidizing atmosphere			
Initial	>1480	–	–
Spherical	>1480	–	>1200
Hemispherical	>1480	–	–
Fluid	>1480	–	>1300

*Non-agglomerating
**See Section 3.6

Table 2 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	56.59	MgO	0.62
Al_2O_3	30.74	SO_3	0.65
Fe_2O_3	4.85	Na_2O	0.16
TiO_2	1.69	K_2O	1.07
P_2O_5	1.28	SrO	0.28
CaO	1.56	BaO	0.51

Table 3 – Trace elements in coal sample, ppm

by X-ray fluorescence				by neutron activation			
As	2.4	Cd	<1.0	Br	17	Hf	1
Se	0.4	Pb	5.0	Cl	40	Ho	<1
Sb	0.8	Zn	15.0	I	<10	La	9
Hg	0.03	Mn	33.0	Dy	1	Lu	<1
Ni	3.0	Be	<1.0	Eu	<1	Mo	<5
Cr	4.0	Cu	7.0	Sm	1	Nd	<50
Co	1.0	V	11.0	U	2	Sc	2
				Ce	20	Th	2
				Cs	<2	Rb	<100

Table 4 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		4
Vitrinite		69
Reactive semifusinite		3
	Subtotal	76
Inerts, vol %		
Fusinite		6
Semifusinite		7
Micrinite		6
Mineral matter		5
	Subtotal	24
Mean reflectance		0.64

Table 5 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	73.0	73.1
Moisture, wt %	4.1	4.5
Coal fineness, mesh		
>100	0.2	0.2
<100 >140	0.4	2.0
<140 >200	14	28
<200 >325	60	41
<325 >400	12	14
<400	14	15
<200	86	70
Thermal input, MJ/h	1988	1982
Air temp., °C		
Pulverizer inlet	195	191
Pulverizer outlet	128	128
Secondary	222	222
Steam rate, kg/MJ	0.199	0.201
Flue gas rate, Nm^3/MJ	0.324	0.291
Flue gas analyses, volume		
O_2, %	4.8	3.0
CO_2, %	14.8	16.2
CO, ppm	60	80
SO_3, ppm	1	1
SO_2, ppm	225	255
NO, ppm	860	840
Emission rates, g/MJ		
SO_2	0.209	0.213
NO	0.373	0.324

Table 6 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	2.05	2.91
g/MJ	0.66	0.85
Combustible content, wt %	4–6	10–14
Aerodynamic particle size, wt %		
>30 µm	20	20
>10 µm	32	28
>1 µm	86	90
Electrical resistivity, log ohm–cm		
at 143°C	8.1	4.5
310°C	7.2	4.8
Combustion efficiency, %*	99.3–99.5	98.2–98.8

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

where: A = % ash in coal
C = % carbon in ash
Q = calorific value of coal, Btu/lb

Table 7 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	60.31	60.18
Al_2O_3	22.67	22.33
Fe_2O_3	6.38	6.57
TiO_2	1.05	0.96
P_2O_5	0.67	0.76
CaO	5.80	5.75
MgO	1.29	1.54
SO_3	0.19	0.00
Na_2O	0.17	0.30
K_2O	0.86	0.84
BaO	0.51	0.57
SrO	0.10	0.20

6.26 SUMMARY 26: GALT SEAM COAL

1. Coal identification

   Coal name and code: Galt Seam AL B 40 10 15 30 P
   Mine: Kipp Mine, near Lethbridge, Alberta
   Status: Exploratory

2. Reference report features

   Topic: Pilot–scale combustion trial
   Objectives: Evaluation of combustion and ash fouling characteristics
   Client: Petro Canada Exploration Inc.
   Reference report (date): ERP/ERL 81–57 (December 1981)
   Related summary: None

3. Reference coal

   None

4. Pilot–scale boiler system

   Furnace configuration – I with deep bottom
   System modification – None

5. Coal characteristics

   As–received handling – A 10–tonne sample of beneficiated Galt Seam coal was delivered to CCRL in sealed plastic–lined drums. The coal was free flowing and it was not difficult to move or feed it through the pilot–scale coal handling system. A small sample of raw Galt Seam coal was also received for comparative analysis.
   As–received moisture – 14%
   As–fired screen size <200 mesh – Trial 1, 83%; Trial 2, 66%

6. Flame observations

   Bright, clean and stable under steady–state conditions. No support fuel required after start up.

7. Fly ash properties

   Slagging potential – Medium to high; based on analysis and observation
   Fouling potential – Low; based on analysis and observation
   Resistivity – 8.4 to 9.5 log ohm–cm
   Particle size – Table 6
   ESP efficiency – Not measured but potentially high
   Combustible efficiency – Trial 1, 99.7%; Trial 2, 99.6%

8. Low–temperature corrosion

   Potential for low–temperature corrosion minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. The sulphur dioxide emissions were well below the 1977 U.S. EPA guideline of 0.58 gSO_2/MJ for new combustion systems. The nitric oxide emissions were considerably higher than the EPA guideline of 0.34 g NO/MJ but could be reduced by modifying the combustion system arrangement. See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Table 3
Coal ash analyses	– Table 2
Trace elements	– Table 10
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
Coal ash characteristics	– Table 1

Table 1 – Analyses of coal

	Galt Seam		Pacific Rim specifications	
	Raw	Washed	KECO	EPDC
Moisture, wt%				
As-received	5–10	10–15	15	10
Equilibrium	9.7	11.5	–	–
Proximate analysis, wt %				
Ash	14.54	11.70	<17	<20
Volatile matter	39.30	39.20	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	46.16	49.10	50–60	
Ultimate analysis, wt %				
Carbon	65.99	68.88	–	–
Hydrogen	4.46	4.73	–	–
Sulphur	0.55	0.59	<1.0	<1.0
Nitrogen	1.89	2.03	<2.0	<1.8
Ash	14.54	11.70	<17	<20
Oxygen (by diff.)	12.57	12.07	–	–
Calorific value, MJ/kg	26.88	28.42	>25.12	>25.05
Grindability, HGI	42	41	>45	>45
Chlorine in coal, wt %	<0.1	<0.1	–	–
Free swelling index	NA*	NA*	–	–
Ash fusibility, °C***				
Reducing atmosphere				
Initial	1188	1171	>1250	–
Spherical	1277	1271	–	–
Hemispherical	1332	1332	–	–
Fluid	1382	1349	–	–
Oxidizing atmosphere				
Initial	1260	1260	–	–
Spherical	1288	1304	–	>1200
Hemispherical	1338	1343	–	–
Fluid	1416	1427	–	>1300
Rank (ASTM)	HVBit**B	HVBit**A	Bituminous	Bituminous

*Non-agglomerating

**High-volatile bituminous

***See Section 3.6

Table 2 – Analyses of coal ash

	Raw	Washed		Raw	Washed
Major elemental oxides					
SiO_2	49.76	49.73	SO_3	4.25	3.78
Al_2O_3	20.65	20.35	Na_2O	1.91	2.13
Fe_2O_3	5.43	7.49	K_2O	0.56	0.59
TiO_2	0.43	0.65	BaO	0.76	0.61
P_2O_5	1.00	1.99	SrO	0.35	0.32
CaO	10.65	8.32	LOF*	1.84	1.07
MgO	1.58	1.48			

*Loss on fusion

Table 3 – Trace elements in coal, ppm

	Raw	Washed		Raw	Washed
by X-ray fluorescence					
As	1.5	1.1	Cd	<0.01	<1
Se	0.6	0.8	Pb	<0.01	6.0
Sb	4.0	0.3	Zn	11.3	14.3
Hg	0.04	0.03	Mn	19.8	16.6
Ni	3.5	4.9	Be	0.7	<1
Cr	4.2	4.1	Cu	7.4	6.6
Co	13.1	<1	V	18.4	14.0
by neutron activation					
Br	11	2600*	Hf	<1	<1
Cl	12	1200*	Ho	<1	<1
I	<10	<10	La	7	8
Dy	<1	<1	Lu	<1	<1
Eu	<1	<1	Mo	<5	<5
Sm	1	<1	Nd	<50	<50
U	1	1	Sc	2	2
Ce	<50	<50	Th	2	2
Cs	<2	<2	Rb	<100	<100

*Contaminated during beneficiation

Table 4 – Petrographic examination of coal macerals

Maceral form		Raw	Washed
Reactives, vol %			
Exinite		3	3
Vitrinite		81	82
Reactive semifusinite		0.6	1
	Subtotal	85	86
Inerts, vol %			
Fusinite		3	3
Semifusinite		1	3
Micrinite		3	2
Mineral matter		8	6
	Subtotal	15	14
Mean reflectance		0.62	0.62

Table 5 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	70.4	72.9
Moisture, wt %	5.2	5.2
Coal fineness, mesh		
>100	0.2	0.2
<100 >140	0.3	0.6
<140 >200	17	33
<200 >325	52	40
<325 >400	14	10
<400	17	16
<200	83	66
Thermal input, MJ/h	1897	1964
Air temp., °C		
Pulverizer inlet	200	189
Pulverizer outlet	128	111
Secondary	225	236
Steam rate, kg/MJ	0.201	0.204
Flue gas rate, Nm^3/h	603	551
Flue gas analyses, volume		
O_2, %	5.0	2.9
CO_2, %	14.8	16.3
CO, ppm	60	65
SO_3, ppm	<1	<1
SO_2, ppm	350	395
NO, ppm	1210	1150
Emission rates, g/MJ		
SO_2	0.318	0.317
NO	0.515	0.432

Table 6 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	2.64	2.51
g/MJ	0.84	0.70
Combustible content, wt %	2	3
Aerodynamic particle size, wt %		
>30 μm	9	25
>10 μm	23	45
>1 μm	90	89
Electrical resistivity, log ohm–cm		
at 170°C	9.5	9.2
325°C	8.4	8.4
Combustion efficiency, %*	99.7	99.6

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

where: A = % ash in coal
C = % carbon in ash
Q = calorific value of coal, Btu/lb

Table 7 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	53.74	54.68
Al_2O_3	21.57	21.21
Fe_2O_3	7.68	8.35
TiO_2	0.55	0.50
P_2O_5	1.82	1.49
CaO	7.59	7.11
MgO	1.04	1.24
SO_3	0.44	0.40
Na_2O	1.61	1.88
K_2O	0.65	0.67
BaO	0.58	0.60
SrO	0.30	0.26
LOF*	Nil	Nil

*Loss on fusion

Table 10 – Trace elements in furnace ash and dust deposits, ppm

		Furnace bottom deposits		Furnace dust samples (Multiclone)	
		Trial		Trial	
		1	2	1	2
by X-ray fluorescence					
Nickel	(Ni)	27	24	39	49
Chromium	(Cr)	34	40	39	40
Cobalt	(Co)	<19	<19	<18	<18
Cadmium	(Cd)	<5	<5	<5	<5
Lead	(Pb)	22	8	29	31
Zinc	(Zn)	51	54	81	82
Manganese	(Mn)	152	143	134	125
Berylium	(Be)	5	4	6	7
Copper	(Cu)	87	92	89	73
Vanadium	(V)	53	47	163	89
by neutron activation					
Bromine	(Br)	<1	<1	32	<1
Chlorine	(C1)	<100	<100	<100	120
Iodine	(I)	<10	<10	32	83
Dysprosium	(Dy)	7	6	9	9
Europium	(Eu)	2	2	2	2
Samarium	(Sm)	9	9	10	11
Uranium	(U)	7	7	9	9
Cerium	(Ce)	77	84	80	120
Caesium	(Cs)	<2	<2	<2	<2
Hafnium	(Hf)	6	<1	<1	9
Holmium	(Ho)	3	2	3	4
Lanthanum	(La)	41	38	46	55
Lutecium	(Lu)	1	1	1	2
Molybdenum	(Mo)	<5	<5	25	24
Neodymium	(Nd)	<50	<50	60	<50
Scandium	(Sc)	11.7	11.6	17.1	19.7
Thorium	(Th)	18	18	20	22
Rubidium	(Rb)	<100	<100	<100	<100

6.27 SUMMARY 27: MAGNA COAL

1. Coal identification

Coal name and code: Magna BC S 35 05 30 25 R
Mine: Wapiti, near Dawson Creek, Northeastern BC
Status: Active

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Gulf Canada Resources Inc.
Reference report (date): ERP/ERL81–59 (November 1981)
Related summary: None

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with normal or deep bottom as indicated
System modification – None

5. Coal characteristics

As–received handling – A 7.5–tonne sample of Magna coal was delivered to CCRL in sealed plastic–lined drums. The as–received coal was kiln dried to convert it from a cohesive agglomerate to a free–flowing solid that conveyed and metered easily through the pilot–scale coal handling system.
As–fired moisture – 10% to 16%
As–fired screen size <200 mesh – 60% to 96%

6. Flame observations

Bright, clean and stable under steady–state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Low; based on analysis and observation
Fouling potential – Low; based on analysis and observation
Resistivity – Table 6
Particle size – Table 6
ESP efficiency – Table 6
Combustible efficiency – 98.0% to 98.5 %

8. Low–temperature corrosion

Potential for low–temperature corrosion minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. Emissions of sulphur dioxide were less than the current allowable U.S. 1977 EPA guideline of 0.58 g SO_2/MJ for new combustion sources. The nitric oxide emissions were slightly more than the maximum EPA guideline of 0.34 g NO/MJ, but could be reduced by an appropriate design for the burner system. See Table 5.

10. Tabulations attached from reference report

Coal analyses	– Table 1
Trace elements	– Table 3
Coal ash analyses	– Table 2
Trace elements	– Not measured
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 4
Coal ash characteristics	– Table 1

Table 1 – Analyses of coal

	Magna	Pacific Rim specifications	
		KECO	EPDC
Moisture, wt %			
As-received	10–15	<15	<10
Equilibrium	20	–	–
Proximate analysis, wt %			
Ash	29.29	<17	<20
Volatile matter	30.40	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	40.31	50–60	
Ultimate analysis, wt %			
Carbon	52.98	–	–
Hydrogen	3.55	–	–
Sulphur	0.37	<1.0	<1.0
Nitrogen	1.07	<2.0	<1.8
Ash	29.29	–	–
Oxygen	12.74	–	–
Calorific value, MJ/kg	20.10	>25.05	>25.05
Grindability, HGI	50	>45	>45
Chlorine in coal, wt %	<0.01	–	–
Ash fusibility, °C*			
Reducing atmosphere			
Initial	1360	>1250	–
Spherical	>1480	–	–
Hemispherical	>1480	–	–
Fluid	>1480	–	–
Oxidizing atmosphere			
Initial	1382	–	–
Spherical	>1480	–	>1200
Hemispherical	>1480	–	–
Fluid	>1480	–	>1300

*See Section 3.6

Table 2 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	48.99	MgO	0.65
Al_2O_3	31.24	SO_3	2.95
Fe_2O_3	3.25	Na_2O	0.15
TiO_2	1.42	K_2O	0.42
P_2O_5	2.30	SrO	0.40
CaO	7.36	BaO	0.33

Table 3 – Trace elements in coal sample, ppm

by X-ray fluorescence				by neutron activation			
As	2.60	Cd	<0.10	Br	<10	Hf	2
Se	2.60	Pb	30.50	Cl	80	Ho	<1
Sb	1.20	Zn	38.70	I	<10	La	18
Hg	0.04	Mn	52.80	Dy	2	Lu	<1
Ni	7.60	Be	1.20	Eu	<1	Mo	<5
Cr	18.20	Cu	22.30	Sm	2	Nd	50
Co	4.10	V	54.00	U	4	Sc	6
				Ce	10	Th	8
				Cs	2	Tb	<100

Table 4 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		5
Vitrinite		54
Reactive semifusinite		4
	Subtotal	63
Inerts, vol %		
Fusinite		6
Semifusinite		8
Micrinite		6
Mineral matter		18
	Subtotal	38
Mean reflectance		0.66

Table 5 – Summary of combustion performance

	Trial			
	1	2	3	4
Duration, h	4.8	4.1	4.1	6
Furnace configuration*	n	n	d	d
Firing rate, kg/h	112	115	112	113
Moisture, wt %	8.2	8.2	8.0	8.0
Coal fineness, mesh				
>100	variable	0.2	0.2	0.2
<100 >140	"	2.0	3.0	2.0
<140 >200	"	3.0	16.0	30.0
<200 >325	"	52.0	38.0	34.0
<325 >400	"	18.0	21.0	12.0
<400	"	24.0	22.0	22.0
<200	60–96	95	81	68
Thermal input, MJ/h	2071	2127	2071	2090
Air temp., °C				
Pulverizer inlet	194	194	194	194
Pulverizer outlet	100	97	100	103
Secondary	227	210	217	233
Steam rate, kg/h	545	540	545	515
m^3/h at 25°C and 101.3 kPa	627	644	627	692
Flue gas analyses, volume				
O_2, %	2.8	3.1	3.2	4.9
CO_2, %	15.1	15.4	15.2	14.8
CO, ppm	<100	<100	<100	<100
SO_3, ppm	–	–	–	–
SO_2, ppm	425	390	400	360
NO, ppm	1120	1080	1000	940
Emission rates, g/MJ				
SO_2	0.34	0.31	0.32	0.31
NO	0.39	0.37	0.35	0.36

*n = normal bottom
d = deep adiabatic bottom

Table 6 – Characteristics of fly ash

	Trial			
	1	2	3	4
Heat exchanger inlet				
Mean loading, g/Nm^3	10.5	10.2	10.8	8.4
Combustible content, wt %	2–3	3–4	2–3	3–4
Aerodynamic particle size, wt %				
>30 μm	4	5	15	19
>10 μm	17	25	40	43
>1 μm	89	90	90	87
Precipitator efficiency, %	75	64–72	70–72	63–70
Electrical resistivity, log ohm–cm				
at 180°C	–	11.3	10.9	10.9
300°C	9.2	9.6	8.5	8.6
Ash analyses, wt %				
SiO_2	–	–	42.31	64.15
Al_2O_3	–	–	30.77	20.47
Fe_2O_3	–	–	3.49	4.55
TiO_2	–	–	1.26	0.41
P_2O_5	–	–	2.39	0.36
CaO	–	–	9.34	3.75
MgO	–	–	1.04	1.04
SO_3	–	–	0.23	<0.01
Na_2O	–	–	0.20	0.68
K_2O	–	–	0.42	1.40
BaO	–	–	0.80	0.27
SrO	–	–	0.40	0.11
LOF*	–	–	7.90	2.20
Combustion efficiency, %**	98.5	98.0	98.5	98.0

*Loss on fusion

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

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

6.28 SUMMARY 28: GREENHILLS COAL

1. Coal identification

Coal name and code: Greenhills BC B 30 10 15 35 P
Mine: Greenhills Mine, Sparwood, British Columbia
Status: Active

2. Reference report features

Topic: Pilot-scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: BC Coal Ltd.
Reference report (date): ERP/ERL 82-05 (March 1982)
Related summary: None

3. Reference coal

None

4. Pilot-scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As-received handling – A 10-tonne sample of Greenhills coal was delivered to CCRL in sealed plastic-lined drums. The coal was a blend of seams 1, 16 and 20 in weight proportions of 20%, 40%, and 40% respectively. The as-received coal was free flowing and conveyed and metered easily through the pilot-scale coal handling system.
As-fired moisture – less than 5%
As-fired screen size <200 mesh – Trial 1, 94.7%; Trial 2, 92.7%

6. Flame observations

Bright and stable under steady-state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Low to medium; based on analysis but tending to be higher based on observation. Trials produced a glazed-sinter with porous structure in furnace bottom
Fouling potential – Low; based on analysis and observation
Combustion efficiency – 95.8% to 96.5%

For resistivity, particle size, electrostatic precipitator efficiency and other characteristics of fly ash, see Table 7. Trace elements in fly ash are given in Table 9.

8. Low-temperature corrosion

Potential for low-temperature corrosion minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. Emissions of sulphur dioxide were less than the current allowable 1977 U.S. EPA guideline of 0.58 g SO_2/MJ for new combustion sources. Only trace quantities of sulphur trioxide were detected. Nitric oxide emissions were close to the EPA guideline of 0.34 g NO/MJ, but these emissions could be reduced through a staged-combustion system modification. See Table 6.

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 6
Combustion performance	– Table 6
Gaseous emissions	– Table 6
Fly ash analyses	– Table 8
Characteristics	– Table 7
Size	– Table 7
Trace elements	– Table 9
Other	
Maceral analyses of coal	– Table 5
Coal ash characteristics	– Table 2

Table 2 – Analyses of coal

	Greenhills	Pacific Rim specifications KECO	Pacific Rim specifications EPDC
Moisture, wt %			
As–received	3.7	<15	<10
Equilibrium	3.0	–	–
Proximate analysis, wt % (dry)			
Ash	13.52	<17	<20
Volatile matter	25.76	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	60.72	50–60	
Ultimate analysis, wt % (dry)			
Carbon	74.63	–	–
Hydrogen	4.21	–	–
Sulphur	0.54	<1.0	<1.0
Nitrogen	1.10	<2.0	<1.8
Ash	13.52	–	–
Oxygen	6.00	–	–
Calorific value, MJ/kg	30.38	>25.05	>25.05
Grindability, HGI	78	>45	>45
Chlorine in coal, wt %	0.1	–	–
Free swelling index	5.5	–	–
Ash fusibility, °C*			
Reducing atmosphere			
Initial	1260	>1250	–
Spherical	1429	–	–
Hemispherical	>1480	–	–
Fluid	>1480	–	–
Oxidizing atmosphere			
Initial	1371	–	–
Spherical	1460	–	>1200
Hemispherical	>1480	–	–
Fluid	>1480	–	>1300

*See section 3.6

Table 3 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	57.21	SO_3	1.24
Al_2O_3	24.96	Na_2O	0.02
Fe_2O_3	5.66	K_2O	1.96
TiO_2	1.17	BaO	0.07
P_2O_5	1.82	SrO	0.17
CaO	2.49	LOF*	4.40
MgO	<0.10		

*Loss on fusion

Table 4 – Trace elements in coal sample, ppm

by X-ray fluorescence			by neutron activation		
Antimony	(Sb)	0.5	Bromine	(Br)	<1
Arsenic	(As)	0.2	Caesium	(Cs)	2
Beryllium	(Ba)	0.6	Cerium	(Ce)	30
Cadmium	(Cd)	2.3	Chlorine	(Cl)	<100
Cobalt	(Co)	0.6	Dysprosium	(Dy)	1
Copper	(Cu)	9.2	Europium	(Eu)	1
Chromium	(Cr)	12.1	Hafnium	(Hf)	<1
Lead	(Pb)	10.7	Holnium	(Ho)	<1
Manganese	(Mn)	29.7	Iodine	(I)	<10
Mercury	(Hg)	<0.1	Lanthanum	(La)	7
Nickel	(Ni)	4.9	Lutecium	(Lu)	1
Selenium	(Se)	3.0	Molybdenum	(Mo)	<5
Vanadium	(V)	36.0	Neodynium	(Na)	<50
Zinc	(Zn)	17.8	Rubidium	(Rb)	<100
			Samarium	(Sm)	1
			Scandium	(Sc)	3
			Tantalum	(Ta)	<5
			Thorium	(Th)	2
			Uranium	(U)	1

Table 5 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		<1
Vitrinite		64
	Subtotal	65
Inerts, vol %		
Fusinite		7
Semifusinite		14
Micrinite		6
Mineral matter		8
	Subtotal	35
Mean reflectance		1.00

Table 6 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	70.8	67.5
Moisture, wt %	0.1	0.1
Coal fineness, mesh		
>100	0.3	0.2
<100 >140	1.2	1.8
<140 >200	3.8	5.3
<200 >325	50.9	53.2
<325 >400	20.0	17.8
<400	23.8	21.7
<200	94.7	92.7
Thermal input, MJ/h	2149	2048
Air temp., °C		
Pulverizer inlet	175	167
Pulverizer outlet	117	106
Secondary	172	167
Steam rate, kg/MJ	0.18	0.20
Flue gas rate, Nm^3/MJ	0.315	0.287
Flue gas analyses, volume		
O_2, %	4.7	3.1
CO_2, %	14.4	15.3
CO, ppm	80	100
SO_3, ppm	1	1
SO_2, ppm	405	370
NO, ppm	860	880
Emission rates, g/MJ		
SO_2	0.365	0.304
NO	0.363	0.338

Table 7 – Characteristics of fly ash

	Trial 1	Trial 2
Precipitator inlet loading		
g/Nm^3	4.31	6.73
g/MJ	1.36	1.93
Combustible content, wt %	19	22
Aerodynamic particle size, wt %		
>30 µm	12	7
>10 µm	28	19
>1 µm	86	85
Electrical resistivity, log ohm–cm		
at 177°C	4.4	4.4
343°C	5.3	5.2
Combustion efficiency, %*	96.5	95.8

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

where: A = % ash in coal
C = % carbon in fly ash
Q = calorific value of coal, Btu/lb

Table 8 – Analyses of fly ash

	Trial 1	Trial 2
Major elemental oxides, wt %		
SiO_2	41.68	39.84
Al_2O_3	18.61	17.72
Fe_2O_3	3.23	3.17
TiO_2	0.95	1.00
P_2O_5	1.77	1.90
CaO	2.67	2.82
MgO	0.63	0.50
SO_3	nil	nil
Na_2O	0.08	0.09
K_2O	1.41	1.44
BaO	0.46	0.20
SrO	0.16	0.17
LOF*	27.71	31.20

*Loss on fusion

Table 9 – Trace elements in fly ash, ppm

		Trial	
		1	2
by X-ray fluorescence (dry fuel basis)			
Beryllium	(Be)	2.0	–
Cadmium	(Cd)	<2.0	<2.0
Cobalt	(Co)	1.4	1.8
Copper	(Cu)	6.2	7.4
Chromium	(Cr)	8.9	8.5
Lead	(Pb)	4.8	26.5
Manganese	(Mn)	27.5	11.8
Mercury	(Hg)	<0.1	0.2
Nickel	(Ni)	2.3	–
Selenium	(Se)	7.5	7.0
Vanadium	(V)	20.5	–
Zinc	(Zn)	8.6	–
by neutron activation (dry fuel basis)			
Antimony	(Sb)	3	3
Arsenic	(As)	13	8
Bromine	(Br)	14	14
Caesium	(Cs)	8	11
Cerium	(Ce)	<30	68
Chlorine	(Cl)	<100	<100
Dysprosium	(Dy)	7	7
Europium	(Eu)	2	2
Hafnium	(Hf)	<1	<1
Holmium	(Ho)	3	2
Iodine	(I)	<10	<10
Lanthanum	(La)	5	5
Lutecium	(Lu)	<1	<1
Molybdenum	(Mo)	<5	<5
Neodynium	(Nd)	50	<50
Rubidium	(Rb)	<100	<100
Samarium	(Sm)	9	9
Scandium	(Sc)	21	19
Tantalum	(Ta)	<5	<5
Thorium	(Th)	13	13
Uranium	(U)	6	8

6.29 SUMMARY 29: MERCOAL COAL

1. Coal identification

Coal name and code: Mercoal AL B 35 05 15 30 P
Mine: Mercoal deposit, Northwestern Alberta
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Techman Engineering Limited
Reference report (date): ERP/ERL 82–17 (September 1982)
Related summary: None

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – A 6–tonne sample of Mercoal coal was delivered to CCRL in sealed plastic–lined drums; 25 drums contained Val d'Or seam and 5 contained Silkstone seam. The coal from each seam was free flowing and no difficulty was experienced in mixing them or feeding the mix through the pilot–scale coal handling system. The coal mix was 88%:12% by weight Val d'Or:Silkstone. Analyses of the individual seams are given in the reference report.
As–received moisture – 11%
As–fired screen size <200 mesh – Trial 1, 85.8%; Trial 2, 71.8%

6. Flame observations

Bright, clean and stable under steady–state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Low to medium; based on analysis and observation
Fouling potential – Low; based on analysis and observation
Resistivity – Close to maximum desirable range, Table 9
Particle size – Table 9
ESP efficiency – Not measured but will probably require liberally sized specific collection areas because of high ash resistivity
Combustion efficiency – 99.9%

8. Low–temperature corrosion

Potential for low–temperature corrosion is minimal.

9. Emissions

The carbon monoxide level constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions were well below the 1977 U.S. EPA guideline of 0.58 g SO_2/MJ for new combustion systems. These emissions were less than theoretical because of internal neutralization reactions. The nitric oxide emissions were slightly lower than the EPA guideline of 0.34 g/MJ for new sources. See Table 8.

10. Tabulations attached from reference report

Coal analyses	– Table 6
Trace elements	– Not measured
Coal ash analyses	– Table 7
Trace elements	– Not measured
Coal grind	– Table 8
Combustion performance	– Table 8
Gaseous emissions	– Table 8
Fly ash analyses	– Table 10
Characteristics	– Table 9
Size	– Table 9
Other	
Maceral analyses of coal seams	– Table 5

Table 5 – Petrographic examination of coal macerals

Maceral form		Val d'Or	Silkstone
Reactives, vol %			
Exinite		2	2
Vitrinite		74	66
Reactive semifusinite		–	–
	Subtotal	76	68
Inerts, vol %			
Fusinite		10	13
Semifusinite		6	10
Micrinite		1	2
Mineral matter		8	7
	Subtotal	24	32
Mean reflectance		0.54	0.60

Table 6 – Analyses of coal*

	Mixed Coal		Pacific Rim specifications: KECO	Pacific Rim specifications: EPDC
As-received moisture, wt %	<11		<15	<10
Proximate analysis, wt %				
Ash	13.67		<17	<20
Volatile matter	34.68		22–38	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	51.65		50–60	
Ultimate analysis, wt %				
Carbon	66.65		–	–
Hydrogen	3.92		–	–
Sulphur	0.22		<1.0	<1.0
Nitrogen	0.65		<2.0	<1.8
Ash	13.67		<17	<20
Oxygen (by diff.)	14.89		–	–
Calorific value, MJ/kg	27.01		>25.05	>25.05
Grindability, HGI	43		>45	>45
Chlorine in coal, wt %	<0.1		–	–
Free swelling index	NA**		–	–
Ash fusibility, °C***	Reducing	Oxidizing	Reducing	Oxidizing
Initial	1210	1271	>1250	–
Spherical	1285	1313	–	>1200
Hemispherical	1318	1441	–	–
Fluid	1452	1471	–	>1300

*all analyses, except ash fusibility, were prorated from the component seams

**non-agglomerating

***measured values

Table 7 – Analyses of coal ash*

Major elemental oxides	wt %
SiO_2	63.47
Al_2O_3	18.36
Fe_2O_3	4.95
TiO_2	0.52
P_2O_5	0.16
CaO	6.06
MgO	1.17
SO_3	2.13
Na_2O	0.41
K_2O	1.50
BaO	0.47
SrO	0.03
LOF**	1.23

*Prorated from component seams

**Loss on fusion

Table 8 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	76.3	70.1
Moisture, wt %	3.1	3.1
Coal fineness, mesh		
>100	0.2	0.2
<100 >140	4.0	1.0
<140 >200	10.0	27.0
<200 >325	57.0	38.0
<325 >400	15.0	16.0
<400	13.8	17.8
<200	85.8	71.8
Thermal input, MJ/h	1996	1835
Boiler exit temp., °C	912	890
Air temp., °C		
Pulverizer inlet	380	370
Pulverizer outlet	240	230
Secondary	400	400
Steam rate, kg/MJ	0.183	0.201
Flue gas rate, Nm^3/MJ	0.277	0.312
Flue gas analyses, volume		
O_2, %	3.0	5.0
CO_2, %	15.8	14.1
CO, ppm	45	30
SO_3, ppm	<1	<1
SO_2, ppm	200	160
NO, ppm	870	790
Emission rates, g/MJ		
SO_2	0.158	0.142
NO	0.322	0.330

Table 9 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	3.57	2.61
g/MJ	0.99	0.81
Combustible content, wt %	1–2	1–2
Aerodynamic particle size, wt %		
>30 μm	22	28
>10 μm	25	37
>1 μm	76	90
Electrical resistivity, log ohm–cm		
at 143°C	11.4	10.3
310°C	10.6	11.5
Combustion efficiency, %*	>99.9	>99.9

*Combustion efficiency, % = $100 - \dfrac{14\,500\ CA}{(100 - C)CQ}$

where: C = % carbon in ash
A = % ash in coal
Q = calorific value of coal, Btu/lb

Table 10 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	57.59	58.45
Al_2O_3	20.51	20.32
Fe_2O_3	5.61	5.66
TiO_2	0.79	0.79
P_2O_5	0.23	0.23
CaO	9.50	8.53
MgO	1.65	1.86
SO_3	0.32	0.61
Na_2O	0.38	0.33
K_2O	1.43	1.44
BaO	0.73	0.64
SrO	0.08	0.07
LOF*	2.00	2.40

*Loss on fusion

6.30 SUMMARY 30: McLEOD RIVER COAL

1. Coal identification

Coal name and code: McLeod River AL B 40 05 15 30 P
Mine: McLeod River deposit, Northwestern Alberta
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Techman Engineering Limited
Reference report (date): ERP/ERL 82–21 (September 1982)
Related summary: None

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – A 6–tonne sample of McLeod River coal was delivered to CCRL in sealed plastic–lined drums; 4.5 tonnes was Val d'Or seam and 1.5 tonnes was McPherson seam. The coal from each seam was free flowing and there was no difficulty was experienced in mixing them or feeding the mix through the pilot–scale coal handling system. The coal mix was 77%:23% by weight Val d'Or:McPherson. Analyses of the individual seams are in the reference report.
As–received moisture – 9%
As–fired screen size <200 mesh – Trial 1, 87.4%; Trial 2, 64.8%

6. Flame observations

Bright, clean and stable under steady–state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Medium to high; based on analysis and observation
Fouling potential – Low; based on analysis and observation
Resistivity – Close to maximum desirable range, Table 9
Particle size – Table 9
ESP efficiency – Not measured
Combustion efficiency – 99.7%

8. Low–temperature corrosion

Potential for low–temperature corrosion is minimal.

9. Emissions

The carbon monoxide level constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions were well below the 1977 U.S. EPA guideline of 0.58 g SO_2/MJ for new combustion systems. These emissions were less than theoretical due to neutralization reactions. The nitric oxide emissions were slightly higher than the 1977 EPA guideline of 0.34 g/MJ for new sources but could be reduced through a staged–combustion system modification. See Table 8.

10. Tabulations attached from reference report

Coal analyses	– Table 6
Trace elements	– Not measured
Coal ash analyses	– Table 7
Trace elements	– Not measured
Coal grind	– Table 8
Combustion performance	– Table 8
Gaseous emissions	– Table 8
Fly ash analyses	– Table 10
Characteristics	– Table 9
Size	– Table 9
Other	
Maceral analyses of coal seams	– Table 5

Table 5 – Petrographic examination of coal macerals

Maceral form		Seam	
		Val d'Or	McPherson
Reactives, vol %			
Exinite		2	2
Vitrinite		72	64
Reactive semifusinite		–	–
	Subtotal	74	66
Inerts, vol %			
Fusinite		8	9
Semifusinite		10	14
Micrinite		1	2
Mineral matter		7	9
	Subtotal	26	34
Mean reflectance		0.53	0.53

Table 6 – Analyses of coal*

	McLeod River Coal		Pacific Rim specifications	
			KECO	EPDC
As–received moisture, wt %	9		<15	<10
Proximate analysis, wt %				
Ash	13.14		<17	<20
Volatile matter	35.29		22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	51.57		50–60	
Ultimate analysis, wt %				
Carbon	67.50		–	–
Hydrogen	3.77		–	–
Sulphur	0.27		<1.0	<1.0
Nitrogen	0.77		<2.0	<1.8
Ash	13.14		–	–
Oxygen (by diff.)	14.55		–	–
Calorific value, MJ/kg	26.89		>25.12	>25.12
Grindability, HGI	41		>45	>45
Chlorine in coal, wt %	<0.1		–	–
Free swelling index	NA**		–	–
Ash fusibility, °C***	Reducing	Oxidizing	Reducing	Oxidizing
Initial	1138	1251	>1250	–
Spherical	1260	1285	–	–
Hemispherical	1293	1352	–	>1200
Fluid	1329	1382	–	>1300

*all analyses, except ash fusibility, were prorated from component seams

**non–agglomerating

***see section 3.6

Table 7 – Analyses of coal ash

Major elemental oxides	wt %
SiO_2	56.31
Al_2O_3	18.77
Fe_2O_3	7.65
TiO_2	0.55
P_2O_5	0.07
CaO	8.79
MgO	1.17
SO_3	3.45
Na_2O	0.60
K_2O	0.74
SrO	0.07
BaO	0.59
LOF**	1.50

*Prorated from component seams
**Loss on fusion

Table 8 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	73.1	72.8
Moisture, wt %	5.5	5.3
Coal fineness, mesh		
>100	0.1	0.2
<100 >140	0.5	4.0
<140 >200	12.0	31.0
<200 >325	59.0	36.0
<325 >400	12.0	15.0
<400	16.4	13.8
<200	87.4	64.8
Thermal input, MJ/h	1857	1854
Boiler exit temp., °C	910	880
Air temp., °C		
Pulverizer inlet	178	192
Pulverizer outlet	108	111
Secondary	194	200
Steam rate, kg/MJ	0.193	0.187
Flue gas rate, Nm^3/MJ	0.280	0.315
Flue gas analyses, volume		
O_2, %	3.0	4.9
CO_2, %	16.0	14.6
CO, ppm	30	35
SO_3, ppm	<1	<1
SO_2, ppm	240	250
NO, ppm	900	860
Emission rates, g/MJ		
SO_2	0.192	0.225
NO	0.338	0.363

Table 9 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	2.957	2.710
g/MJ	0.828	0.854
Combustible content, wt %	2	<1
Aerodynamic particle size, wt %		
>30 μm	20	32
>10 μm	30	40
>1 μm	82	90
Electrical resistivity, log ohm–cm		
at 185°C	11.3	11.2
285°C	11.2	10.6
Combustion efficiency, %*	99.7	99.8

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

where: C = % carbon in ash
A = % ash in coal
Q = calorific value of coal, Btu/lb

Table 10 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	52.00	53.59
Al_2O_3	20.36	20.37
Fe_2O_3	7.06	7.18
TiO_2	0.99	0.88
P_2O_5	0.22	0.19
CaO	11.79	12.29
MgO	1.46	1.65
SO_3	0.25	0.32
Na_2O	0.68	0.66
K_2O	0.71	0.67
BaO	0.64	0.80
SrO	0.11	0.11
LOF*	3.60	0.50

*Loss on fusion

6.31 SUMMARY 31: BALMER COAL

1. Coal identification

Coal name and code: Balmer BC B 20 05 20 35 R
Mine: Balmer, Southeastern BC
Status: Active

2. Reference report features

Topic: Pilot-scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Denison Mines Limited
Reference report (date): ERP/ERL 83-02 (January 1983)
Related summary: None

3. Reference coal

None

4. Pilot-scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As-received handling – A 6-tonne sample of Balmer (Harmer seam) coal was delivered to CCRL in sealed plastic-lined drums. The coal was free flowing and it was not difficult to move or feed it through the pilot-scale coal handling system.
As-received moisture – 5%
As-fired screen size <200 mesh – Trial 1, 85%; Trial 2, 95%

6. Flame observations

It was difficult to establish a stable flame. Support fuel was required for an extended period at the start up of each trial.

7. Fly ash properties

Slagging potential – Low; based on analysis and observation
Fouling potential – Low; based on analysis and observation
Resistivity – Below optimal range, Table 7
Particle size – Table 7
ESP efficiency – Trial 1, 84%; Trial 2, 89%
Combustion efficiency – Trial 1, 90%; Trial 2, 93%

8. Low-temperature corrosion

Not measured.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions were well below the 1981 Canadian national emission guideline of 0.258 g SO_2/MJ of fuel input for new combustion systems. Emissions of nitric oxide were greater than the maximum Canadian guideline of 0.168 g NO/MJ of fuel input, but could be reduced through a staged-combustion system modification. See Table 6.

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 6
Combustion performance	– Table 6
Gaseous emissions	– Table 6
Fly ash analyses	– Table 8
Characteristics	– Table 7
Size	– Table 7
Other	
Maceral analyses of coal	– Table 5

Table 2 – Analyses of coal

	Balmer Coal		Pacific Rim specifications KECO	Pacific Rim specifications EPDC
As-received moisture, wt %	–		<15	<10
Proximate analysis, wt %				
Ash	15.93		<17	<20
Volatile matter	19.75		22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	64.32		50–60	
Ultimate analysis, wt %				
Carbon	72.82		–	–
Hydrogen	3.88		–	–
Sulphur	0.19		<1.0	<1.0
Nitrogen	0.86		<2.0	<1.8
Ash	15.93		–	–
Oxygen (by diff.)	6.32		–	–
Calorific value, MJ/kg	30.13		>25.01	>25.01
Grindability, HGI	84		>45	>45
Chlorine in coal, wt %	<0.1		–	–
Free swelling index	3.0		–	–
Ash fusibility, °C*	Reducing	Oxidizing	Reducing	Oxidizing
Initial	1482	>1482	>1250	–
Spherical	>1482	>1482	–	>1200
Hemispherical	>1482	>1482	–	–
Fluid	>1482	>1482	–	>1300

*See Section 3.6

Table 3 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	57.82	SO_3	1.72
Al_2O_3	31.05	Na_2O	0.05
Fe_2O_3	3.09	K_2O	0.34
TiO_2	1.41	BaO	0.24
P_2O_5	0.45	SrO	0.01
CaO	2.05	LOF*	1.54
MgO	1.01		

*Loss on fusion

Table 4 – Trace elements in coal sample, ppm

by X-ray fluorescence				by neutron activation			
As	0.2	Cd	0.6	Br	<1	Hf	1.0
Se	0.7	Pb	14.9	Cl	80	Ho	<1
Sb	0.2	Zn	13.4	I	<10	La	8.4
Hg	0.03	Mn	25.9	Dy	1.6	Lu	0.1
Ni	2.7	Be	0.3	Eu	0.4	Mo	<5
Cr	5.7	Cu	12.5	Sm	1.49	Nd	<50
Co	2.7	V	26.5	U	1	Sc	5.5
				Ce	<30	Th	3
				Cs	<2	Rb	<100

Table 5 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		0.0
Vitrinite		38.7
	Subtotal	38.7
Inerts, vol %		
Fusinite		8.4
Semifusinite		36.5
Micrinite		7.3
Mineral matter		9.1
	Subtotal	61.3
Mean reflectance		1.34

Table 6 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	69.0	71.5
Moisture, wt %	<1	<1
Coal fineness, mesh		
>100	0.5	0.4
<100 >140	4.0	1.0
<140 >200	11.0	4.0
<200 >325	50.0	48.0
<325 >400	18.0	25.0
<400	17.0	22.0
<200	85.0	95.0
Thermal input, MJ/h	2058	2133
Air temp., °C		
Pulverizer inlet	171	179
Pulverizer outlet	118	118
Secondary	169	179
Steam conditions		
Flow kg/h	495	547
Pressure kPa	296	324
Rate, kg/MJ	0.167	0.182
Flue gas rate, Nm^3/MJ	0.307	0.274
Flue gas analyses, volume		
O_2, %	4.7	2.8
CO_2, %	14.4	15.7
CO, ppm	140	120
SO_3, ppm	<1	<1
SO_2, ppm	140	150
NO, ppm	690	830
Emission rates, g/MJ		
SO_2	0.123	0.118
NO	0.283	0.305
Sulphur neutralized, %	<5	5–10

Table 7 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	5.02	5.07
g/MJ	1.54	1.39
Combustible content, wt %	36	27
Aerodynamic particle size, wt %		
>30 μm	14	16
>10 μm	26	27
>3 μm	67	58
>1 μm	88	82
ESP efficiency, %	84	89
Electrical resistivity, log ohm–cm		
at 188°C	4.5	4.7
310°C	4.9	4.9
Combustion efficiency, %*	90	93

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

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

Table 8 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	25.83	33.48
Al_2O_3	11.82	15.62
Fe_2O_3	1.27	1.00
TiO_2	0.72	0.83
P_2O_5	0.33	0.37
CaO	1.94	1.71
MgO	0.37	0.35
SO_3	<0.01	<0.01
Na_2O	0.13	0.06
K_2O	0.32	0.19
BaO	0.07	0.01
SrO	0.04	0.02
LOF*	56.8	45.4

*Loss on fusion

6.32 SUMMARY 32: BELCOURT COAL

1. Coal identification

   Coal name and code: Belcourt BC B 30 05 15 30 R
   Mine: Belcourt, Northeastern BC
   Status: Exploratory

2. Reference report features

   Topic: Pilot–scale combustion trial
   Objectives: Evaluation of combustion and ash fouling characteristics
   Client: Denison Mines Limited
   Reference report (date): ERP/ERL 83–04 (January 1983)
   Related summary: None

3. Reference coal

   None

4. Pilot–scale boiler system

   Furnace configuration – I with deep bottom
   System modification – None

5. Coal characteristics

   As–received handling – A 3.5–tonne sample of Belcourt coal was delivered to CCRL in sealed plastic–lined drums. The coal was free flowing and it was not difficult to move or feed it through the pilot–scale coal handling system.
   As–received moisture – 2.5%
   As–fired screen size <200 mesh – Trial 1, 80%; Trial 2, 90%

6. Flame observations

   Bright, clean and stable under steady–state conditions. No support fuel required after start up.

7. Fly ash properties

   Slagging potential – Low; based on analysis and observation
   Fouling potential – Low; based on analysis and observation
   Resistivity – Below optimal range, Table 7
   Particle size – Table 7
   ESP efficiency – Trial 1, 63%; Trial 2, 89%
   Combustion efficiency – Trial 1, 94.4%; Trial 2, 97.8%

8. Low–temperature corrosion

   Potential for low–temperature corrosion is minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. Emissions of sulphur dioxide were within the current Canadian national emission guidelines. Nitrogen oxide emissions exceeded these guidelines, but could be reduced through a staged–combustion system modification. See Table 6.

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 6
Combustion performance	– Table 6
Gaseous emissions	– Table 6
Fly ash analyses	– Table 8
Characteristics	– Table 7
Size	– Table 7
Other	
Maceral analyses of coal	– Table 5

Table 2 – Analyses of coal

	Belcourt		Pacific Rim specifications	
			KECO	EPDC
Moisture, wt %				
As–received	2.49		<15	<10
Equilibrium	4.0		–	–
Proximate analysis, wt %				
Ash	13.89		<17	<20
Volatile matter	25.19		22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	60.92		50–60	
Ultimate analysis, wt %				
Carbon	73.46		–	–
Hydrogen	4.15		–	–
Sulphur	0.31		<1.0	<1.0
Nitrogen	0.68		<2.0	<2.0
Ash	13.89		–	–
Oxygen (by diff.)	7.51		–	–
Calorific value, MJ/kg	29.55		>25.05	>25.05
Grindability, HGI	77		45	45
Chlorine in coal, wt %	<0.1		–	–
Free swelling index	1.5		–	–
Ash fusibility, °C*	Reducing	Oxidizing	Reducing	Oxidizing
Initial	1260	1288	>1250	–
Spherical	1391	1435	–	>1200
Hemispherical	1482	1463	–	–
Fluid	>1482	1466	–	>1300

*See Section 3.6

Table 3 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	57.66	SO_3	2.49
Al_2O_3	24.36	Na_2O	0.92
Fe_2O_3	3.01	K_2O	1.30
TiO_2	1.16	BaO	0.89
P_2O_5	0.55	SrO	0.10
CaO	4.70	LOF*	0.63
MgO	1.43		

*Loss on fusion

Table 4 – Trace elements in coal sample, ppm

by X-ray fluorescence (dry fuel basis)				by neutron activation (dry fuel basis)			
As	1.3	Cd	0.6	Br	1.0	Hf	1.0
Se	1.1	Pb	0.0	Cl	180	Ho	<1
Sb	1.1	Zn	23.4	I	<10	La	9.8
Hg	0.1	Mn	11.8	Dy	1.3	Lu	0.1
Ni	6.8	Be	0.9	Eu	0.3	Mo	<5
Cr	15.1	Cu	8.9	Sm	1.3	Nd	<50
Co	3.9	V	35.0	U	1.0	Sc	3.1
				Ce	<30	Th	3.0
				Cs	2.0	Rb	<100

Table 5 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		0.2
Vitrinite		56.2
Reactive semifusinite		10.2
	Subtotal	66.6
Inerts, vol %		
Fusinite		7.8
Semifusinite		10.2
Micrinite		7.5
Mineral matter		7.9
	Subtotal	33.4
Mean reflectance		1.15

Table 6 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	73	75
Moisture, wt %	1	1
Coal fineness, mesh		
>100	0.2	0.2
<100 >140	2.0	1.0
<140 >200	18	9
<200 >325	41	45
<325 >400	20	22
<400	18	23
<200	80	90
Thermal input, MJ/h	2136	2194
Air temp., °C		
Pulverizer inlet	171	171
Pulverizer outlet	110	107
Secondary	160	165
Steam rate, kg/MJ	0.17	0.19
Flue gas rate, Nm^3/MJ	0.32	0.28
Flue gas analyses, volume		
O_2, %	4.9	2.7
CO_2, %	14.4	15.8
CO, ppm	60	68
SO_3, ppm	<1	<1
SO_2, ppm	190	244
NO, ppm	662	767
Emission rates, g/MJ		
SO_2	0.17	0.20
NO	0.28	0.29
Sulphur neutralized, %	17	6

Table 7 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	4.64	3.73
g/MJ	1.49	1.05
Combustible content, wt %	14	12
Aerodynamic particle size, wt %		
>30 μm	12	26
>10 μm	30	41
>1 μm	88	88
Precipitator efficiency, %	63	89
Electrical resistivity, log ohm–cm		
at 188°C	4.9	6.5
293°C	5.2	5.6
Combustion efficiency, %*	97.4	97.8

*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 8 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	42.71	44.69
Al_2O_3	19.57	20.42
Fe_2O_3	2.53	3.11
TiO_2	0.94	1.23
P_2O_5	0.49	0.52
CaO	4.50	5.54
MgO	1.13	1.15
SO_3	<0.01	<0.01
Na_2O	0.67	0.77
K_2O	0.99	1.07
BaO	1.23	0.81
SrO	0.16	0.13
LOF*	26.36	19.66

*Loss on fusion

6.33 SUMMARY 33: LODGEPOLE COAL

1. Coal identification

Coal name and codes: Lodgepole; Raw–A, Washed–B, Blended–C
A AL B 20 05 35 25 R
B AL B 20 05 20 30 P
C AL B 20 05 15 35 P
Mine: Lodgepole, Drayton Valley area of Alberta
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics with different degrees of beneficiation and as a blend with reference coal
Client: Crows Nest Resources Ltd.
Reference report (date): ERP/ERL 83–07 (January 1983)
Related summary: None

3. Reference coal

Name and code: Luscar Coal Valley AL B 40 05 15 30 R
Mine: Luscar Coal Valley, Coalspur coalfield, Foothills Region of Alberta
Status: Active

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – A 9–tonne sample of beneficiated Lodgepole coal was delivered to CCRL in three groups of sealed plastic–lined drums. The coal was grouped according to ash content. About 3 tonnes of water was decanted from the 46 barrels of coal. After air–drying to less than 5% moisture, the coal was free flowing and it was not difficult to move or feed it through the pilot–scale coal handling system.
As–fired screen size <200 mesh – 84% to 95% (See Table 8)

The coal designations used for evaluating Lodgepole coal or blends were as follows (see Table 2):

A – Raw Lodgepole coal with high ash content
B – Washed Lodgepole coal with high ash content, T4
C – Washed and blended Lodgepole coal with low ash content, T1/T2 (80/20, % by weight)
D – Reference coal with low ash content
T1, T2. T4 – Washed Lodgepole coals with varying ash contents.

The Lodgepole coal was first air–dried and then the Lodgepole/reference coal blends were prepared in a 1–tonne capacity "V"–type riffle. In each case the coals were dried to less than 5% moisture before final bunkering.

6. Flame observations

Bright, clean and stable under steady–state conditions for all the beneficiated coals and blends. No support fuel required after start up.

7. Fly ash properties

Slagging potential	– Low to medium; based on analysis and observation
Fouling potential	– Low; based on analysis and observation
Resistivity	– Below optimal range, Table 9
Particle size	– Table 9
Combustion efficiency	– 92.8% to 98.7%

It is likely that liberally sized specific collection areas will be required for good precipitator performance.

8. Low–temperature corrosion

Potential for low–temperature corrosion is minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty in any of the trials. Sulphur dioxide emissions were close to current Canadian national emission guidelines of 0.258 g/MJ of fuel input for new combustion systems. Emissions of nitric oxide exceeded the current Canadian guideline of 0.168 g NO/MJ of fuel input but could be reduced through a staged–combustion system modification to lower maximum temperatures and excess air levels. See Table 8.

10. Tabulations attached from reference report

Coal analyses	– Tables 2 and 4
Trace elements	– Not measured
Coal ash analyses	– Tables 3 and 5
Trace elements	– Not measured
Coal grind	– Table 8
Combustion performance	– Table 8
Gaseous emissions	– Table 8
Fly ash analyses	– Table 10
Characteristics	– Table 9
Size	– Table 9
Other	
Maceral analyses of coal	– Table 6

Table 2 – Analyses of coals

	A	B	C	D
	Raw coal	Washed coal (T4)	Washed coal blend (T1/T2)	Reference coal
Moisture, wt %				
As-received	–	3.0	–	8.0
Equilibrium	5.0	5.0	–	8.2
Proximate analysis, wt %				
Ash	30.45	16.37	10.90	10.93
Volatile matter	16.81	18.15	18.01	37.08
Fixed carbon	52.74	65.48	71.09	51.99
Ultimate analysis, wt %				
Carbon	60.83	74.45	79.93	70.38
Hydrogen	3.11	3.79	3.99	4.15
Sulphur	0.42	0.41	0.41	0.19
Nitrogen	0.71	0.89	0.86	1.10
Ash	30.45	16.37	10.90	10.93
Oxygen (by diff.)	4.84	4.09	3.91	13.25
Calorific value, MJ/kg	24.05	29.60	31.83	27.84
Grindability, HGI	96	88	86	42
Chlorine in coal, wt %	<0.1	<0.1	<0.1	–
Free swelling index	1.5	1.0	1.5	NA*
Ash fusibility, °C**				
Reducing atmosphere				
Initial	>1480	1371	>1480	1121
Spherical	>1480	>1480	>1480	1232
Hemispherical	>1480	>1480	>1480	1260
Fluid	>1480	>1480	>1480	1421
Oxidizing atmosphere				
Initial	>1480	>1480	>1480	1204
Spherical	>1480	>1480	>1480	1316
Hemispherical	>1480	>1480	>1480	1405
Fluid	>1480	>1480	>1480	1421

*non-agglomerating

**See Section 3.6

Table 3 – Analyses of coal ash

	Coals			
	A	B	C	D
Major elemental oxides, wt %				
SiO_2	57.92	56.53	55.18	55.78
Al_2O_3	29.60	29.50	30.23	16.72
Fe_2O_3	1.54	3.00	1.93	5.12
TiO	1.51	1.91	2.10	0.63
P_2O_5	0.41	0.76	1.38	0.25
CaO	2.13	2.76	3.12	10.55
MgO	–	0.67	0.41	1.35
SO_3	1.88	2.12	2.03	6.37
Na_2O	0.08	0.13	0.16	0.92
K_2O	1.36	1.05	0.79	0.76
SrO	–	0.13	0.21	0.09
BaO	0.02	0.47	0.61	0.42
LOF*	5.45	0.75	0.91	–

*Loss on fusion

Table 4 – Analyses of blended coals

	Blended coal		Pacific Rim specifications	
	60B/40D	40B/60D	KECO	EPDC
Moisture, wt %				
As–received	–	–	<15	<10
Proximate analysis, wt %				
Ash	13.96	14.11	<17	<20
Volatile matter	25.59	27.45	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	60.45	58.44	50–60	
Ultimate analysis, wt %				
Carbon	73.12	71.26	–	–
Hydrogen	3.69	3.74	–	–
Sulphur	0.33	0.29	<1.0	<1.0
Nitrogen	0.85	0.82	<2.0	<1.8
Ash	13.97	14.11	–	–
Oxygen (by diff.)	8.04	9.78	–	–
Calorific value, MJ/kg	28.89	28.14	>25.12	>25.12
Grindability, HGI	>45	>45	>45	>45
Chlorine in coal, wt %	>0.1	<0.1	–	–
Free swelling index	NA*	NA	–	–
Ash fusibility, °C**				
Reducing atmosphere				
Initial	1277	1282	>1250	–
Spherical	1435	1371	–	–
Hemispherical	>1480	>1480	–	–
Fluid	>1480	>1480	–	–
Oxidizing atmosphere				
Initial	1318	1316	–	–
Spherical	1480	1377	–	>1200
Hemispherical	>1480	1427	–	–
Fluid	>1480	>1480	–	>1300

*non–agglomerating

**See Section 3.6

Table 5 – Analyses of coal ash in blended coals

Elemental oxides, wt %	Blended 60B/40D	Blended 40B/60D
SiO_2	57.69	56.93
Al_2O_3	26.06	25.02
Fe_2O_3	3.97	5.04
TiO_2	1.51	1.47
P_2O_5	0.61	0.55
CaO	4.93	5.69
MgO	0.83	0.76
SO_3	3.50	4.00
Na_2O	0.42	0.42
K_2O	0.94	0.92
SrO	0.11	0.09
BaO	0.48	0.33
LOF*	0.60	0.46

*Loss on fusion

Table 6 – Petrographic examination of coal macerals

Maceral form		Coal designation			
		A	B	C	D
Reactives, vol %					
Exinite		–	–	<1	7
Vitrinite		41	45	47	47
Reactive semifusinite		15	18	–	<1
	Subtotal	56	63	48	55
Inerts, vol %					
Fusinite		5	4	9	16
Semifusinite		15	17	34	15
Micrinite		5	5	3	5
Mineral matter		19	11	6	9
	Subtotal	44	37	52	45
Mean reflectance, %		1.44	1.45	1.42	–

Table 8 – Summary of combustion performance

	Coals					
	B	B	C	60B/40D	40B/60D	D
Firing rate, kg/h	74.5	71.3	71.6	76.0	72.8	76.0
Moisture, wt %	0.2	0.2	0.1	1.4	1.0	4.3
Coal fineness, mesh						
>100	0.2	0.3	0.3	0.2	0.2	0.1
<100 >140	5	0.7	0.8	2	1	3
<140 >200	8	4	12	14	13	21
<200 >325	31	44	53	55	54	45
<325 >400	23	22	16	14	18	4
<400	33	29	18	14	14	27
<200	87	95	87	84	86	76
Thermal input, MJ/h	2199	2107	2275	2163	2029	2053
Air temp., °C						
Pulverizer inlet	193	183	183	172	167	179
Pulverizer outlet	122	122	122	110	106	110
Secondary	195	195	183	167	161	196
Steam rate, kg/MJ	0.162	0.169	0.162	0.165	0.163	0.180
Flue gas rate, Nm^3/MJ	0.323	0.352	0.324	0.322	0.314	0.312
Flue gas analyses, volume						
O_2, %	4.8	6.1	4.8	4.9	4.9	4.7
CO_2, %	14.2	13.4	13.9	14.2	14.5	14.0
CO, ppm	125	180	140	90	80	<100
SO_3, ppm	<1	<1	<1	<1	<1	<1
SO_2, ppm	320	270	265	230	235	165
NO, ppm	740	620	675	750	820	760
Emission rates, g/MJ						
SO_2	0.30	0.27	0.24	0.21	0.21	0.15
NO	0.32	0.29	0.29	0.32	0.34	0.32

Table 9 – Characteristics of fly ash

	Coals					
	B	B	C	60B/40D	40B/60D	D
Precipitator inlet loading						
g/Nm^3	4.06	4.43	5.30	4.93	3.70	1.16
g/MJ	1.31	1.56	1.72	1.59	1.16	0.36
Combustible content, wt %	22	28	34	17	10	2
Aerodynamic particle size, wt %						
>30 µm	10	13	12	16	25	30
>10 µm	14	24	24	27	35	47
>1 µm	73	78	84	86	84	90
Electrical resistivity, log ohm–cm						
at 143°C	4.4	4.5	4.3	4.5	4.8	11.0
310°C	4.9	5.3	4.7	5.3	–	–
Combustion efficiency, %*	94.7	92.8	94.1	96.7	98.1	99.8

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

where: A = % ash in coal
C = % carbon in fly ash
Q = calorific value of coal, Btu/lb

6.34 SUMMARY 34: WASHED BLACKFOOT COAL

1. Coal identification

Coal name and code: Blackfoot washed AL S 35 10 20 25 P
Mine: Gliechen area, Blackfoot deposit, Edmonton formation east of Calgary, Alberta
Status: Exploratory

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Crows Nest Resources Limited
Reference report (date): ERP/ERL 83–12 (March 1983)
Related summary: 24

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – Samples of Poor Eagle and Eastern coal from the Blackfoot deposit that were sent to CCRL for trials described in reference report 24 were returned to Alberta for blending and beneficiating. The blend had equal weights of the two coals. After blending and beneficiating, a 7.5–tonne sample of washed Blackfoot coal was delivered to CCRL in sealed plastic–lined drums. The as–received coal was kiln dried to make it easy to convey and meter through the pilot–scale coal handling system.
As–received moisture – 14%
As–fired screen size <200 mesh – 74% to 80%

6. Flame observations

Bright stable flame. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Medium to high; based on base/acid ratio and potential slagging temperature and confirmed by observation
Fouling potential – Low to medium; based on analysis and observation
Resistivity – 8.26 to 9.73 log ohm–cm
Particle size – Table 7
Combustion efficiency – 99.0% to 99.3%
ESP efficiency – Not measured but should be high based on resistivity

8. Low–temperature corrosion

Potential for low–temperature corrosion virtually non–existent.

9. Emissions

The carbon monoxide level constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions exceeded the Canadian national emission guideline of 0.258 g SO_2/MJ of fuel input for new combustion systems. These emissions indicated about 15% neutralization of sulphur by cations in the ash. The nitric oxide emission rate was above the current Canadian guideline of 0.169 g NO/MJ of fuel, but could be reduced through a staged–combustion system modification. See Table 6.

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 6
Combustion performance	– Table 6
Gaseous emissions	– Table 6
Fly ash analyses	– Table 8
Characteristics	– Table 7
Size	– Table 7
Trace elements	– Table 9
Other	
Maceral analyses of coal	– Table 5

Table 2 – Analyses of coal

	Washed Blackfoot	Pacific Rim specifications	
		KECO	EPDC
Moisture, wt %	13.43	<15	<10
Proximate analysis, wt %			
Ash	17.05	<17	<20
Volatile matter	34.76	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	48.19	50–60	
Ultimate analysis, wt %			
Carbon	60.81	–	–
Hydrogen	3.57	–	–
Sulphur	0.52	<1.0	<1.0
Nitrogen	1.46	<2.0	<1.8
Ash	17.05	<17	<20
Oxygen (by diff.)	16.59	–	–
Calorific value, MJ/kg	24.04	>25.05	>25.05
Grindability, HGI	36	>45	>45
Chlorine in coal, wt %	<0.1	–	–
Free swelling index	NA*	–	–
Ash fusibility, °C**			
Reducing atmosphere			
Initial	1199	>1250	–
Spherical	1279	–	–
Hemispherical	1360	–	–
Fluid	1377	–	–
Oxidizing atmosphere			
Initial	1266	–	–
Spherical	1299	–	>1200
Hemispherical	1349	–	–
Fluid	>1480	–	>1300

*non-agglomerating
**See Section 3.6

Table 3 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	57.89	SO_3	3.95
Al_2O_3	20.11	Na_2O	2.34
Fe_2O_3	3.79	K_2O	0.95
TiO_2	0.46	BaO	0.58
P_2O_5	0.64	SrO	0.18
CaO	6.42	LOF*	0.72
MgO	1.34		

*Loss on fusion

Table 4 – Trace elements in coal sample, ppm

by neutron activation (dry fuel basis)					
Antimony	(Sb)	0.5	Lanthanum	(La)	12
Arsenic	(As)	4.0	Lutecium	(Lu)	0.2
Barium	(Ba)	840	Manganese	(Mn)	200
Bromine	(Br)	5.0	Mercury	(Hg)	0.02
Cerium	(Ce	<30	Molybdenum	(Mo)	<5
Caesium	(Cs)	<2.0	Neodymium	(Nd)	<50
Chlorine	(cl)	<100	Nickel	(Ni)	<500
Chromium	(Cr)	<5.0	Rubidium	(Rb)	<100
Cobalt	(co)	<1.0	Samrium	(Sn)	1.6
Copper	(Cu)	<100	Scandium	(Sc)	1.9
Dysprosium	(Dy)	1.3	Tantalum	(Ta)	<5
Europium	(Eu)	0.2	Thorium	(Th)	4.3
Hafnium	(Hf)	<0.5	Uranium	(U)	1.5
Holmium	(Ho)	<1.0	Vanadium	(V)	11
Iodine	(I)	<10	Zinc	(Zn)	<100

Table 5 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		2
Vitrinite		81
Reactive semifusinite		2
	Subtotal	85
Inerts, vol %		
Fusinite		2
Semifusinite		2
Micrinite		1
Mineral matter		10
	Subtotal	15
Mean reflectance		0.49

Table 6 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	95	94
Moisture, wt %	5.4	5.4
Coal fineness, mesh		
>100	<1	<1
<100 >140	2	7
<140 >200	24	13
<200 >325	39	46
<325 >400	16	17
<400	19	17
<200	74	80
Thermal input, MJ/h	2160	2138
Air temp., °C		
Pulverizer inlet	199	193
Pulverizer outlet	110	105
Secondary	216	210
Steam rate, kg/MJ	0.199	0.205
Flue gas rate, Nm^3/MJ	0.306	0.277
Flue gas analyses, volume		
O_2, %	4.9	2.9
CO_2, %	15.0	16.7
CO, ppm	55	45
SO_3, ppm	<1	<1
SO_2, ppm	420	470
NO, ppm	1060	1090
Emission rates, g/MJ		
SO_2	0.37	0.37
NO	0.44	0.40
Sulphur neutralized, %	15	15

Table 7 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	7.44	3.55
g/MJ	2.28	0.98
Combustible content, wt %	3	4
Aerodynamic particle size, wt %		
>30 μm	15	7
>10 μm	34	29
>1 μm	93	93
Electrical resistivity, log ohm–cm		
at 180°C	9.73	9.47
305°C	8.26	8.76
Combustion efficiency, %*	99.3	99.0

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

where: A = % ash in coal
C = % carbon in fly ash
Q = calorific value of coal, Btu/lb

Table 8 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	48.69	48.28
Al_2O_3	18.28	19.01
Fe_2O_3	4.41	6.27
TiO_2	0.60	0.57
P_2O_5	0.67	0.86
CaO	11.96	11.09
MgO	2.10	2.20
SO_3	0.44	0.42
Na_2O	2.02	2.29
K_2O	0.80	0.73
BaO	0.45	0.64
SrO	0.20	0.21
LOF*	8.60	7.61

*Loss on fusion

Table 9 – Trace elements in fly ash, ppm

		Trial	
		1	2
Antimony	(Sb)	2.9	4.5
Arsenic	(As)	30	43
Barium	(Ba)	3900	4300
Bromine	(Br)	16	14
Cerium	(Ce)	110	100
Caesium	(Cs)	7	6
Chlorine	(Cl)	1600	580
Chromium	(Cr)	27	<5
Cobalt	(Co)	14	9
Copper	(Cu)	<100	<100
Dysprosium	(Dy)	7.6	8.6
Europium	(Eu)	1.2	1.4
Hafnium	(Hf)	5.4	<0.3
Holmium	(Ho)	<1.0	2.0
Iodine	(I)	<10	<10
Lanthanum	(La)	63	69
Lutecium	(Lu)	0.7	0.8
Manganese	(Mn)	840	950
Molydenum	(Mo)	18	21
Neodymium	(Nd)	<50	<50
Nickel	(Ni)	<500	<500
Rubidium	(Rb)	<100	<100
Samarium	(Sn)	9.7	11
Scandium	(Sc)	13	14
Tantalum	(Ta)	<5	<5
Thorium	(Th)	23	22
Uranium	(U)	12	11
Vanadium	(V)	62	71
Zinc	(Zn)	<100	<100

6.35 SUMMARY 35: COALSPUR COAL (SAMPLE 2)

1. Coal identification

Coal name and code: Coalspur AL B 35 05 10 30 P
Mine: Coalspur Mine, Robb Block, near Hinton in the Foothills Region of Alberta
Status: Exploratory

2. Reference report features

Topic: Pilot-scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Denison Mines Limited
Reference report (date): ERP/ERL 83-20 (June 1983)
Related summary: 25

3. Reference coal

None

4. Pilot-scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As-received handling – The coal used was a blend of samples from the proposed mine. A 3-tonne sample of the blended beneficiated coal was delivered to CCRL in plastic-lined drums. The coal was free flowing and it was not difficult to move or feed through the pilot-scale coal handling system.
As-received moisture – 6.5%
As-fired screen size <200 mesh – Trial 1, 66%; Trial 2, 91%

6. Flame observations

Bright, clean and stable under steady-state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Low to medium; based on analysis and observation
Fouling potential – Low; based on analysis and observation
ESP efficiency – Potentially high; based on electrical resistivity

For resistivity, particle size, combustion efficiency and other characteristics of fly ash, see Table 7.

8. Low-temperature corrosion

Potential for low-temperature corrosion is minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. Sulphur dioxide emissions were within the current Canadian national emission guideline of 0.258 g SO_2/MJ of fuel input for new combustion systems. Only trace quantities of sulphur trioxide were detected. The nitric oxide emission rate was well above the current Canadian guideline of 0.168 g NO/MJ of fuel input. This was expected because of the high flame temperatures caused by the high reactivity of the coal. NO emissions could be reduced through a staged–combustion system modification. See Table 6.

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 6
Combustion performance	– Table 6
Gaseous emissions	– Table 6
Fly ash analyses	– Table 8
Characteristics	– Table 7
Size	– Table 7
Other	
Maceral analyses of coal	– Table 5
Coal ash characteristics	– Table 2

Table 2 – Analyses of coal

		Pacific Rim specifications	
	Coalspur	KECO	EPDC
Moisture, wt %			
As–received	6.49	<15	<10
Proximate analysis, wt %			
Ash	9.87	<17	<20
Volatile matter	34.31	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	55.82	50–60	
Ultimate analysis, wt %			
Carbon	70.61	–	–
Hydrogen	4.41	–	–
Sulphur	0.32	<1.0	<1.0
Nitrogen	1.07	<2.0	<1.8
Ash	9.87	–	–
Oxygen (by diff.)	13.92	–	–
Calorific value, MJ/kg	28.46	>25.12	>25.12
Grindability, HGI	42	>45	>45
Chlorine in coal, wt %	0.1	–	–
Free swelling index	NA*	–	–
Ash fusibility, °C**			
Reducing atmosphere			
Initial	1327	>1250	–
Spherical	>1480	–	–
Hemispherical	>1480	–	–
Fluid	>1480	–	–
Oxidizing atmosphere			
Initial	>1480	–	–
Spherical	>1480	–	>1200
Hemispherical	>1480	–	–
Fluid	>1480	–	>1300

*non–agglomerating

**See Section 3.6

Table 3 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	61.46	SO_3	3.74
Al_2O_3	19.97	Na_2O	0.34
Fe_2O_3	4.31	K_2O	0.86
TiO_2	0.91	BaO	0.25
P_2O_5	0.37	SrO	0.10
CaO	6.02	LOF*	0.72
MgO	1.20		

*Loss on fusion

Table 4 – Trace elements in coal sample, ppm

by X-ray fluorescence		by neutron activation			
As	40.5	Br	2	Hf	<0.5
Se	22.3	Cl	<100	Ho	<1
Sb	7.1	I	<10	La	7.3
Hg	0.2	Dy	1.4	Lu	0.1
Mn	415.4	Eu	0.3	Mo	<5
V	172.2	Sm	1.3	Nd	<50
Cr	70.9	U	1.6	Sc	2.2
Co	30.4	Ce	<30	Th	2.8
		Cs	<2	Rb	<100

Table 5 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		4
Vitrinite		67
Reactive semifusinite		4
	Subtotal	75
Inerts, vol %		
Fusinite		8
Semifusinite		8
Micrinite		3
Mineral matter		6
	Subtotal	25
Mean reflectance		0.54

Table 6 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	79.5	78.3
Moisture, wt %	1.6	1.3
Coal fineness, mesh		
>100	0.2	0.2
<100 >140	0.8	0.4
<140 >200	33	9
<200 >325	44	63
<325 >400	6	8
<400	16	20
<200	66	91
Thermal input, MJ/h	2226	2199
Air temp., °C		
Pulverizer inlet	208	199
Pulverizer outlet	129	123
Secondary	226	322
Steam rate, kg/MJ	0.197	0.219
Flue gas rate, Nm^3/MJ	0.301	0.285
Flue gas analyses, volume		
O_2, %	5.0	3.1
CO_2, %	14.4	16.2
CO, ppm	35	30
SO_3, ppm	<1	<1
SO_2, ppm	300	270
NO, ppm	820	840
Emission rates, g/MJ		
SO_2	0.258	0.220
NO	0.330	0.316
Sulphur neutralized, %	<5	<5

Table 7 – Characteristics of fly ash

	Trial 1	Trial 2
Precipitator inlet loading		
g/Nm^3	2.14	2.73
g/MJ	0.64	0.78
Combustible content, wt %	2–5	1.4
Aerodynamic particle size, wt %		
>30 μm	21	19
>10 μm	39	41
>1 μm	94	88
Electrical resistivity, log ohm–cm		
at 177°C	8.74	10.32
354°C	9.46	8.34
Combustion efficiency, %*	99.64	99.76

*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 8 – Analyses of fly ash

	Trial 1	Trial 2
Major elemental oxides, wt %		
SiO_2	55.45	56.04
Al_2O_3	18.58	18.90
Fe_2O_3	4.59	5.50
TiO_2	0.89	1.00
P_2O_5	0.41	0.40
CaO	7.79	8.18
MgO	1.39	1.78
SO_3	0.09	0.27
Na_2O	0.43	0.39
K_2O	0.75	0.76
BaO	0.61	0.66
SrO	0.13	0.12
LOF*	9.22	6.44

*Loss on fusion

6.36 SUMMARY 36: WASHED QUINTETTE COAL

1. Coal identification

Coal name and code: Quintette washed BC B 25 05 10 35 P
Mine: Quintette, Northeastern BC
Status: Active

2. Reference report features

Topic: Pilot–scale combustion trial
Objectives: Evaluation of combustion and ash fouling characteristics
Client: Denison Mines Limited
Reference report (date): ERP/ERL 83–29 (July 1983)
Related summary: 23

3. Reference coal

None

4. Pilot–scale boiler system

Furnace configuration – I with deep bottom
System modification – None

5. Coal characteristics

As–received handling – A 7–tonne sample of washed Quintette coal was delivered to CCRL in sealed plastic–lined drums. The coal was free flowing and it was not difficult to move or feed through the pilot–scale coal handling system.
As–received moisture – 3.2%
As–fired screen size <200 mesh – 84% to 92%

6. Flame observations

Bright, clean and stable under steady–state conditions. No support fuel required after start up.

7. Fly ash properties

Slagging potential – Low to medium; based on analysis and observation
Fouling potential – Low; based on analysis and observation
Resistivity – 4.5 to 5.6 log ohm–cm
Particle size – Table 7
ESP efficiency – Not measured
Combustion efficiency – 97.8%

8. Low–temperature corrosion

Potential for low–temperature corrosion is minimal.

9. Emissions

The carbon monoxide constituted neither an emission problem nor a significant thermal penalty. The sulphur dioxide emissions were slightly higher than the Canadian national emission guideline of 0.258 g SO_2/MJ of fuel input for new combustion systems. The nitric oxide emissions exceed the current Canadian guideline of 0.168 g NO/MJ of fuel input but could be reduced by an appropriate design of burner system. See Table 6.

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 6
Combustion performance	– Table 6
Gaseous emissions	– Table 6
Fly ash analyses	– Table 8
Characteristics	– Table 7
Size	– Table 7
Other	
Maceral analyses of coal	– Table 5

Table 2 – Analyses of coal

		Pacific Rim specifications	
	Quintette	KECO	EPDC
Moisture, wt %	3.2	<15	<10
Proximate analysis, wt %			
Ash	9.34	<17	<20
Volatile matter	23.66	22–36	$\frac{VM}{FC} \geq 0.4$
Fixed carbon	67.00	50–60	
Ultimate analysis, wt %			
Carbon	78.47	–	–
Hydrogen	3.71	–	–
Sulphur	0.34	<1.0	<1.0
Nitrogen	0.83	<2.0	<1.8
Ash	9.34	–	–
Oxygen (by diff.)	7.31	–	–
Calorific value, MJ/kg	30.04	>25.12	>25.12
Grindability, HGI	83	>45	>45
Chlorine in coal, wt %	<0.1	–	–
Free swelling index	NA*	–	–
Ash fusibility, °C**			
Reducing atmosphere			
Initial	1246	>1250	–
Spherical	1396	–	–
Hemispherical	1476	–	–
Fluid	>1480	–	–
Oxidizing atmosphere			
Initial	1313	–	–
Spherical	1427	–	>1200
Hemispherical	1462	–	–
Fluid	1474	–	>1300

*non–agglomerating
**See Section 3.6

Table 3 – Analyses of coal ash

Major elemental oxides, wt %			
SiO_2	57.89	SO_3	3.45
Al_2O_3	23.10	Na_2O	0.42
Fe_2O_3	4.35	K_2O	1.10
TiO_2	1.15	BaO	0.89
P_2O_5	0.72	SrO	0.18
CaO	4.44	LOF*	0.48
MgO	1.16		

*Loss on fusion

Table 5 – Petrographic examination of coal macerals

Maceral form		
Reactives, vol %		
Exinite		<1
Vitrinite		55
Reactive semifusinite		–
	Subtotal	55
Inerts, vol %		
Fusinite		10
Semifusinite		25
Micrinite		5
Mineral matter		5
	Subtotal	45
Mean reflectance		1.1

Table 6 – Summary of combustion performance

	Trial	
	1	2
Firing rate, kg/h	75.9	75.2
Moisture, wt %	1.1	2.1
Coal fineness, mesh		
>100	<1	<1
<100 >140	2	2
<140 >200	14	6
<200 >325	48	52
<325 >400	15	16
<400	21	24
<200	84	92
Thermal input, MJ/h	2255	2212
Boiler exit temp., °C	920	915
Air temp., °C		
Pulverizer inlet	204	199
Pulverizer outlet	131	126
Secondary	228	215
Steam rate, kg/MJ	0.19	0.20
Flue gas rate, Nm^3/MJ	0.34	0.31
Flue gas analyses, volume		
O_2, %	5.6	3.6
CO_2, %	14.1	15.8
CO, ppm	74	94
SO_3, ppm	<1	<1
SO_2, ppm	280	300
NO, ppm	737	775
Emission rates, g/MJ		
SO_2	0.28	0.27
NO	0.34	0.33

Table 7 – Characteristics of fly ash

	Trial	
	1	2
Precipitator inlet loading		
g/Nm^3	3.61	3.23
g/MJ	1.25	1.01
Combustible content, wt %	17.3	17.5
Aerodynamic particle size, wt %		
>30 μm	7	9
>10 μm	25	26
>1 μm	87	85
Electrical resistivity, log ohm–cm		
at 180°C	4.6	4.5
325°C	5.6	5.3
Combustion efficiency, %*	97.8	97.8

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

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

Table 8 – Analyses of fly ash

	Trial	
	1	2
Major elemental oxides, wt %		
SiO_2	57.13	57.13
Al_2O_3	24.18	23.94
Fe_2O_3	4.65	8.67
TiO_2	1.14	1.10
P_2O_5	0.65	0.86
CaO	7.50	7.71
MgO	1.66	1.37
SO_3	0.51	1.94
Na_2O	0.96	0.87
K_2O	0.47	0.50