Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION STUDIES WITH HAT CREEK COAL

B.C. HYDRO - CANMET JOINT RESEARCH PROJECT

F. D. Friedrich , T. J. Cyr , G. K. Lee and T. D. Brown
Canadian Combustion Research Laboratory

OCTOBER 1977

VOLUME 2 : APPENDIX - TEST DATA

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
ERL REPORT 77—97 (TR)

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION STUDIES WITH HAT CREEK COAL

B.C. HYDRO - CANMET JOINT RESEARCH PROJECT

F.D. Friedrich, T.J. Cyr, G.K. Lee and T.D. Brown
Canadian Combustion Research Laboratory

OCTOBER 1977

VOLUME 2: APPENDIX - TEST DATA

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
ERL REPORT 77 — 97 (TR)

SUMMARY

This two-volume report describes a series of pilot-scale combustion tests carried out with Hat Creek coal under a research project sponsored jointly by B.C. Hydro and CANMET. Volume 1 discusses the tests and the results in terms of the project objectives which were:

a) to evaluate the feasibility of burning various qualities of Hat Creek coal by means of conventional pulverized-fired technology,

b) to determine the effects on combustion performance of reducing the coals' ash content by washing, and

c) to establish, insofar as possible, design parameters for a utility-scale steam generator to burn Hat Creek coal.

Volume 2 is an appendix containing all of the progress reports issued during the project.

It is concluded that Hat Creek coals having a higher heating value of 6000 Btu/lb or more on an equilibrium moisture basis can be successfully burned using conventional pulverized-fired technology. However, in the design of steam generators for this coal, it is imperative that reliable facilities be provide for removing the vast quantities of ash that will be produced.

All three samples of raw Hat Creek coal burned in the project produced stable flames without support fuel. However, an obstacle to their successful utilization is a combination of high clay content and high moisture content which makes handling difficult. This problem can be minimized by drying the coal to less than equilibrium moisture. The lower the heating value of the coal, the more it must be dried. Coal having a higher heating value of 6000 Btu/lb on an equilibrium moisture basis can be adequately handled if the moisture content is about 20%, but coal having a higher heating value of 4000 Btu/lb, again on an equilibrium moisture basis, will likely have to be dried to approximately 10% residual moisture before it can be reliably handled.

The three samples of washed Hat Creek coals burned in the project generally produced hotter, more stable flames than the raw coals. The removal of much of the extraneous clay by washing facilitated handling and drying noticeably. Reactivity was also improved. In a full-scale coal handling

system washed coals subjected to normal drainage of surface moisture would likely flow freely without further drying.

The fly ash produced by Hat Creek coal, either raw or washed, has a high electrical resistivity. However, it can be collected efficiently in either a hot or a cold precipitator designed to accommodate the physico-chemical properties of the fly ash. Washing the coal produced no major differences in either the mineral composition or the physical structure of the ash residues.

Neither high- nor low-temperature corrosion of heat transfer surfaces should be a problem when burning Hat Creek coal.

Resource conservation makes it desirable to utilize as much of the Hat Creek coal deposit as possible. By beneficiating all coal with a heating value between 3500 and 6000 Btu/lb on an equilibrium moisture basis, up to 80% of the currently recoverable deposit could be burned. This upgraded coal could be fired separately, or it could be dried and blended with dried raw coal of higher quality; that is, raw coal having a higher heating value greater than 6000 Btu/lb on an equilibrium moisture basis. The blending of high-grade and low-grade raw coals to obtain an average higher heating value of 6000 Btu/lb should not be undertaken without further study. Bands or lenses of extraneous clay in the low-grade coal may create handling problems after blending. Alternatively, it may prove more economical to wash all of the raw coal, blend it to produce a fuel containing approximately 6000 Btu/lb on an equilibrium moisture basis, and burn it without thermal drying.

Compared to raw coal, washed coal would appear to provide a number of benefits. These include a smaller materials handling system at the power plant, smaller steam generators with smaller auxiliaries and smaller dust collectors, and lower pollutant emissions. In addition, there would be substantial reductions in the erosion of heat transfer surfaces and in the volume of ash deposits to be removed from the furnace bottom. The overall result would be reduced cost and increased availability of steam generator plant.

Although Hat Creek coal of reasonable quality can probably be burned in steam generators as large as 750 MWe, the absence of direct experience with high-clay coals in equipment of this size makes it prudent to limit the first unit at Hat Creek to a size somewhere between 300 and 500 MWe. Should scheduling permit, such a first unit could be built and proven before further expansion is undertaken; units installed subsequently, could be scaled up with a high degree of confidence.

CONTENTS

Contents (Continued)

FOREWORD

The test data from the Canadian Combustion Research Laboratory (CCRL) tests were made available to B.C. Hydro in the form of progress reports which are included in this Appendix. These progress reports were classified into four series A, B, C and D as described below and were numbered in accordance with the test schedule nomenclature given in Table 1 (page 2).

"A" Series Progress Reports

The "A" series reports included;

1) a schematic diagram of the experimental system showing all sampling locations (Figure 1, page 19),

2) the relevant boiler operating parameters measured during the test with the sampling station identified,

3) a record of the visual characteristics of the flame, and

4) a record of the deposition probe temperatures and the visual characteristics of the deposits.

The above information was provided to B.C. Hydro and Power Authority within two days after a test had been completed.

"B" Series Progress Reports

The "B" series reports included;

1) proximate and ultimate analysis of the coal feed to the pulverizer and

2) size distribution of the pulverized coal feed to the boiler.

"C" Series Progress Reports

The "C" series reports included;

1) photographic records of the internal surfaces of the boiler,

2) chemical analysis and ash fusion characteristics of the boiler and probe deposits,

3) chemical analysis of the fly ash collected in the

TABLE 1

CONTROL CONDITIONS FOR THE TEST PROGRAM

Test No.	Coal	Degree of Drying	Excess O_2 Level, %	Feed Rate Kg/hr
1.1	Sundance	None	5	100
1.2	"	"	3	100
2.1	Hat Creek "A" raw	KD* twice	5	196
2.2	" "	"	3	196
3.1	Hat Creek "A" washed	AD** + KD	5	134
3.2	" "	"	3	134
4.1	Hat Creek "B" raw	KD twice	5	131
4.2	" "	"	3	131
4.3	" "	KD	5	142
5.1	Hat Creek "B" washed	AD + KD	5	120
5.2	" "	"	3	120
5.3	" "	AD	5	120
6.1	Hat Creek "C" raw	KD twice	5	110
6.2	" "	"	3	110
6.3	" "	KD	5	120
7.1	Hat Creek "C" washed	AD + KD	5	110
7.2	" "	"	3	110
7.3	" "	AD	5	110

*KD = kiln-dried

**AD = air-dried

electrostatic precipitator and

4) chemical analysis of the gas borne fly ash.

"D" Series Progress Reports

The "D" series reports included;

1) differential thermal analysis of deposits,

2) petrographic examination of deposits,

3) X-ray diffraction analysis of deposits,

4) particle size distribution of fly ash and

5) electron microprobe analysis of deposits, if necessary.

The four progress reports represent a complete data report for a combustion test. For example, progress reports 1.1A, 1.1B, 1.1C and 1.1D form a complete data report for Sundance 5% O_2 combustion test. Analyses have been modified or corrected when necessary.

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY

E.R. Mitchell	Head
G.K. Lee	Research Supervisor
R.W. Braaten	Engineer
Dr. T.D. Brown	Research Scientist
R.F. Campbell	Technologist - Mechanical
Dr. T.J. Cyr	Chemist
T.J. Dunfield	Engineer
R.G. Fouhse	Engineer
F.D. Friedrich	Research Scientist
L.E. Galbraith	Technologist - Mechanical
Mrs. J. Haw	Secretary
A.C.S. Hayden	Research Scientist
R.K. Jeffrey	Technologist - Chemical
D.H.J. McLaughlin	Assistant Technologist
B.C. Post	Technologist - Combustion
H.P. Raghunandan	Technologist - Combustion
D.G. Savignac	Technologist - Combustion
Mrs. A. Splett	Secretary
S.I. Steindl	Engineer
Dr. H. Whaley	Research Scientist
F.L. Wigglesworth	Technologist - Electronic

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS WITH COALS FROM THE HAT CREEK AREA OF BRITISH COLUMBIA

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

OBJECTIVES AND PROCEDURE

CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/99

PILOT-SCALE COMBUSTION TESTS WITH COALS FROM THE HAT CREEK AREA OF BRITISH COLUMBIA

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

OBJECTIVES AND PROCEDURE

by

The Staff of the Canadian Combustion Research Laboratory*

ABSTRACT

The Hat Creek area of British Columbia contains a substantial deposit of coal, which is ranked as sub-bituminous C, and which has a high and variable ash content. The British Columbia Hydro and Power Authority, referred to as B.C. Hydro in this report, is considering using this deposit as boiler fuel for an on-site thermal power station using pulverized-firing technology. However, the combustion characteristics of the coal are largely unknown. In a program sponsored jointly by B.C. Hydro and CANMET, the Canadian Combustion Research Laboratory will carry out a series of combustion trials to provide information about fuel characteristics, combustion performance, corrosion potential, pollutant formation, and electrostatic precipitation characteristics of the fly ash. This information is necessary to provide a rational basis for boiler design.

Described in this report are the CCRL pilot-scale pulverized-fired research boiler, objectives of the program comprising eighteen tests of ten hours duration each, details of the test procedure and measurements taken, some of which are unique.

---

*Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (CANMET), Department of Energy, Mines and Resources, Ottawa, Canada.

INTRODUCTION

By an agreement dated August 3, 1976, with the British Columbia Hydro and Power Authority referred to as B.C. Hydro in this report, the Canadian Combustion Research Laboratory (CCRL) will do a series of combustion trials to assist in determining the technical feasibility of using coal from the Hat Creek area of British Columbia for thermal power generation. Hat Creek coal is ranked as sub-bituminous C by ASTM classification procedures. In addition to the high moisture content, typical of low-rank coals, this coal has a high and variable ash content. It was mined at the rate of 2,000 to 3,000 tons per year before 1947, but was never burned in industrial-size equipment. Hence there are no combustion performance data on which the design of a modern utility boiler can be used.

The agreement specifies a research program of pilot-scale combustion trials on five-to ten-ton samples of seven different coals, six of which are from the Hat Creek deposit. The seventh coal is an Alberta sub-bituminous coal from the Edmonton formation, known as Sundance, with which the performance of the Hat Creek coals will be compared. All of the coal samples have been provided by B.C. Hydro, and are described more completely in a later section.

This report (a) outlines the objectives of the research program, (b) describes the pilot-scale facilities used for the combustion tests, (c) details the experimental procedures to be followed both in the combustion tests and in the subsequent analytical studies of coal samples, ash samples, and corrosion test specimens, and (d) includes the format of progress reports which will be submitted twice monthly to B.C. Hydro.

OBJECTIVES OF THE RESEARCH PROGRAM

The objectives of the combustion tests and related analytical studies are:

1. To establish whether the various qualities of raw Hat Creek coal can be successfully burned using conventional pulverized-firing technology without supplementary fuel.

2. To establish whether combustion performance is likely to be improved by upgrading the coal by water washing;

3. To determine, within the limitations of the CCRL pilot-scale research boiler, major design features required in a utility combustion system for generating high-pressure superheated steam with Hat Creek coal.

The following performance parameters were selected for evaluation:

1. Coal comminution and handling characteristics at various levels of moisture content;

2. Combustion performance of each coal sample at excess air levels corresponding to concentrations of 3% and 5% oxygen in the flue gas, and at various levels of moisture content;

3. Generation of particulate and gaseous pollutants during combustion;

4. Corrosion potential of condensed sulphuric acid on "cold end" boiler surfaces;

5. Fouling potential of ash constituents, both in liquid and solid state, on refractory and heat-transfer surfaces at various temperatures;

6. Collection efficiency of the fly ash by electrostatic precipitation;

7. In-situ electrical resistivity of the fly ash;

8. Flame temperature profiles in the furnace.

The techniques employed to measure the foregoing parameters are described in a subsequent section entitled Experimental Procedures.

PILOT-SCALE RESEARCH BOILER

The research boiler, schematically shown in Figure 1, has been adequately described elsewhere [1/] except for an on-line ash removal system designed to accommodate the high-ash coals. This modification consists of a sheet-metal skirt enclosing a 50 cm square opening in the refractory furnace bottom and extending downward into a quench tank filled with water. The water serves to seal the slight pressure in the furnace, and eliminates the hazards of handling hot ash. Since the opening in the furnace bottom occupies approximately half the bottom area, it would normally impose a substantial and undesired thermal sink on the flame. This has been reduced by a pair of dump plates installed on hinges at the upper end of the skirt. During normal operation, the plates are fixed in the horizontal position, screening the flame from the quench tank. Periodically the plates are swung to the vertical position, allowing accumulated ash to fall through the skirt into the quench tank. The ash is then raked from the quench tank onto the floor.

Another minor modification consists of covering all the water-cooled surfaces below the furnace throat with 2.5 cm of castable refractory.

FUEL CHARACTERISTICS

Blended bulk samples of both raw and washed Hat Creek coal were shipped to CCRL in plastic-lined 45 gal drums from Birtley Engineering Ltd., Calgary, Alberta. The nominal properties and quantities of the coals received were as follows:

"A" Coal, raw; 50 drums

Residual Moisture	9.9%
Ash	45.5%
Gross Calorific Value	11.94 MJ/Kg (5136 Btu/lb)

[1/] F.D. Friedrich, G.K. Lee and E.R. Mitchell. "Combustion and Fouling Characteristics of Two Canadian Lignites", Journal of Engineering for Power, April 1972, pp 127-132.

"B" Coal, raw;			50 drums
	Residual Moisture	12.5%	
	Ash	30.3%	
	Gross Calorific Value	15.52 MJ/Kg (6676 Btu/lb)	
"C" Coal, raw;			
	Residual Moisture	20.8%	
	Ash	21.9%	
	Gross Calorific Value	16.16 MJ/Kg (6952 Btu/lb)	

"A" Coal, Washed at 1.65 SG	24 drums
"A" Coal, Washed at 1.4 SG	3 drums
"B" Coal, Washed at 1.65 SG	24 drums
"C" Coal, Washed at 1.55 SG	28 drums

These coals were reported by Birtley Engineering Ltd. to contain about 15% ash, and to have a gross calorific value of about 16.97 MJ/Kg (7300 Btu/lb). They were not dried after washing, and some drums were found to contain large amounts of free water.

In addition to the samples received for combustion evaluation experiments, a separate drum containing drill core samples of coal in sealed tins was received for petrographic evaluation by Dr. B.N. Nandi.

Before the combustion trials, proximate and ultimate analyses were carried out on samples selected from each bulk sample. These analyses, which ranked all the Hat Creek coals as sub-bituminous C , are reported in Table 1, and were used to determine the firing rates for the combustion trials. These samples were not necessarily representive of all of the coals used in the combustion tests. Therefore, cumulative samples of the crushed coal fed to the pulverizer and the pulverized coal fed to the burners will be collected for an assessment of coal quality for each test period. The preliminary coal analyses indicated that washing markedly upgraded the "A" raw coal by reducing its ash content by 40% and by increasing its moisture-free, gross calorific value to nearly 18.60 MJ/Kg (8,000 Btu/lb). There was a concomitant reduction in the initial ash-deformation temperature to 1400°C. The raw "B" and "C" coals yielded smaller reductions in ash content and correspondingly smaller increases in gross calorific value when washed. Apparently, washing had no effect on the initial ash-deformation temperature of the "C" coal, whereas, the initial deformation temperature of the "B" coal showed an increase from 1400 to 1460°C.

The Hardgrove Grindability indices for the raw and washed Hat Creek coals were low and, with the sole exception of raw coal "A", were generally similar to that of the Sundance coal.

EXPERIMENTAL PROCEDURES

Coals and Control Parameters

The 180 Kg/hr coal-handling system for the CCRL research boiler is not capable of maintaining a reliable, uniform feed to the pulverizer if the coal is wet. Furthermore, previous experience with other low-quality Canadian coals has shown that acceptable combustion conditions cannot be expected when the gross calorific value is low and the moisture content is high. Thus, it was recognized that the coal would have to be dried partially before burning.

Drying is accomplished in two ways; air-drying, by spreading a thin layer of coal on an asphalt driveway in suitable weather and by thermal drying, using a small oil-fired rotary kiln. To avoid the danger of fire while using this kiln, the feed rates and temperature are held at levels which limit moisture extraction to 6% per pass. Therefore, some coals will be passed through the dryer twice; i.e., double-dried.

However, since the effect of moisture content on combustion performance is a parameter of interest, some of the tests are scheduled with coal that has either been (a) passed through the dryer only once, (b) air dried only or (c) air-dried and then passed through the dryer once. After drying, coal samples are stored in sealed drums.

The level of excess air during combustion is another important control parameter. Consequently, tests will be done with excess oxygen in the flue gas held at two levels; 5% and 3%, corresponding to approximately 25% and 15% excess air, respectively.

Furthermore, the heat input to the furnace is a control parameter which will be held at approximately two Giga Joules/hr (two million Btu/hr) and the feed rate for each coal will be adjusted accordingly.

After consideration of the above control parameters and of the constraint imposed by the small quantities of available coal, B.C. Hydro and CCRL agreed to a basic program of 18 tests. The desired control conditions for these tests are summarized in Table 2. On completion of the basic program, other tests may be done if more information is required, and sufficient coal is available.

Operation of the Research Boiler

The general operating instructions for each test are given below.

1. Before the test: Clean all boiler and air heater fireside surfaces by air lancing and bunker sufficient coal for approximately 10 h operation at the desired feed rate.

2. At 0400 hr: Light up the boiler on No. 2 oil at 16 gph, and 3% oxygen in the flue gas; start all continuous monitoring instruments and allow the boiler to stabilize at full steaming rate and pressure.

3. At 0630 hr: Start feeding pulverized coal at the specified classifier speed, mill temperature, and excess oxygen in the flue gas, leaving one oil torch in operation.

4. At 0730 hr: Remove the oil torch.

5. At 0800 hr: Dump bottom ash and begin scheduled tests, record boiler panel readings hourly and note frequency of bottom ash removal, maintain the specified coal-feed rate and excess oxygen level as closely as possible, take whatever steps are necessary to prevent ash deposits in the furnace from interfering with combustion conditions.

6. At 1500 hr: Scheduled tests should be completed. Proceed with any repeat measurements required.

7. At 1600 hr: Insert an oil torch and shut off the coal feed to the pulverizer mill. When the mill is empty, extinguish the oil torch. The last load of bottom ash will not be dumped.

8. After the furnace has cooled overnight: Remove the quench tank and dump the remaining bottom ash on the dry floor. Collect ash samples and photograph the system as specified in the next section.

It should be pointed out that the foregoing procedures will be modified when necessary to overcome difficulties due to ash bridging in the furnace, hang-up of coal in the feed chutes, or limitations in equipment capacity. The major objective in operating the boiler is to maintain stable, efficient combustion conditions so that the measured performance parameters will be as consistent and representative as possible.

Measured Parameters of Combustion Performance

B.C. Hydro and CCRL agreed that the following parameters of combustion performance would be ascertained in each test at the sampling or measuring stations shown in Figure 1:

1. The results of proximate, ultimate and ash analyses of samples taken from a bulk sample of crushed coal obtained by hourly grab samples at the pulverizer inlet, Station 1.

2. The results of moisture and sieve analyses of samples of pulverized coal taken every two hours at the pulverizer outlet, Station 2.

3. CO_2 and CO content of the flue gas, measured by continuous infra-red monitors, Station 20.

4. O_2 content of the flue gas, measured by a continuous paramagnetic monitor, Station 20.

5. NO content of the flue gas, measured by a continuous chemiluminescent monitor, Station 14.

6. SO_2 content of the flue gas, measured by a continuous chemifluorescent monitor, Station 15.

7. SO_2 and SO_3 content of the flue gas, measured by the API and the Shell-Thornton methods, respectively, two or three times per test, Station 15.

8. Low-temperature corrosion potential, measured by three mild-steel probes inserted simultaneously into the flue-gas stream and maintained at three different temperatures for about four hours, one set per test, Station 13.

9. Fly-ash loading, measured isokinetically by a combined cyclone and filter system, two to four samples per test, Station 16. These samples are to be analyzed for carbon content, chemical composition and size distribution.

10. Ash fouling of heat-transfer surfaces, evaluated by two methods. The first method is by examination of thickness, structure and chemical composition of deposits on three pairs of temperature-monitored probes located in the furnace bottom (Station 19), above the furnace throat (Station 9) and in the transition section (Station 20), each pair to consist of an air-cooled stainless steel probe and an uncooled refractory probe. These probes are to be in place for the duration of each test. The second method of evaluating ash fouling is by examination of 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 19, 8, 20, 11).

11. Electrostatic precipitator efficiency, measured by passing part of the flue gas through a small electrostatic precipitator for a period of 45 min., three samples per test, Station 18. The efficiency is to be calculated from the measured inlet and outlet dust loadings at Stations 16 and 21, respectively. The fly ash collected is to be analyzed for carbon content, chemical composition and particle size distribution.

12. Fly ash resistivity, measured by an in-situ resistivity apparatus at flue-gas temperatures, of 150°C and 315°C at Stations 17 and 13 respectively, two measurements at each location per test. In addition, one measurement is to be taken with the flue-gas temperature at 120°C.

13. Acid or water dewpoint of the flue gas, by BCURA dewpoint meter, one or two determinations per test, Station 15 or 21.

14. Furnace temperature, traversed along the vertical furnace centreline by suction pyrometer, twice per test, Stations 7, 8 and 9.

In addition, qualitative observations on flame appearance and length, deposit build-up and appearance of ash are to be logged. When the furnace has sufficiently cooled after a test, the deposition probes, furnace walls, and second pass tube sheet of the air heater are to be photographed. The deposition probes are then to be removed and photographed. The low-temperature corrosion probes are also to be photographed.

METHOD OF REPORTING RESULTS

The requirement for twice monthly circulation of both the operating data and the physical and chemical analyses described previously in this report dictated the format adopted for reporting interim data and observations.

This first report on the Hat Creek Project defines the objectives and scope of the program, the generalized fuel characteristics, the experimental procedures, the experimental variables and the trial schedule.

Data from the tests will, subsequently, be made available in the form of progress reports, classified into four series identified A, B, C and D. Each series, will be numbered in accordance with the test schedule nomenclature given in Table 2 and described below.

"A" Series Progress Reports

"A" series reports will include;

1) a schematic diagram of the experimental system showing all sampling locations,

2) the relevant boiler operating parameters measured during the test with the sampling station identified,

3) a record of the visual characteristics of the flame, and

4) a record of the deposition probe temperatures and the visual characteristics of the deposits.

The above information is expected to be available within 48 hours after a test has been completed.

"B" Series Progress Reports

"B" series reports will include;

1) proximate and ultimate analysis of the coal feed to the pulverizer and

2) size distribution of the pulverized coal feed to the boiler.

"C" Series Progress Reports

"C" series reports will include;

1) photographic records of the internal surfaces of the boiler,

2) chemical analysis and ash fusion characteristics of the boiler and probe deposits,

3) chemical analysis of the fly ash collected in the electrostatic precipitator and

4) chemical analysis of the gas borne fly ash.

"D" Series Progress Reports

"D" series reports will include;

1) differential thermal analysis of deposits,

2) petrographic examination of deposits,

3) X-Ray diffraction analysis of fly-ash and deposits,

4) particle size distribution of fly-ash and

5) electron microprobe analysis of deposits, if necessary.

The four progress reports, when assembled, represent a complete data report for a combustion test. As an example, progress reports 1.1A, 1.1B, 1.1C and 1.1D will be a complete data report for Sundance 5% O_2 combustion test.

A final report correlating and evaluating the raw data given in the progress reports together with discussion of results and conclusions will be assembled when all tests have been completed.

TABLE 1: PRELIMINARY ANALYSES OF THE TEST COALS

		SUNDANCE	HAT CREEK COALS					
			Raw A	Raw B	Raw C	Washed A	Washed B	Washed C
Equilibrium Moisture	%	16.8	27.3	21.7	24.0	24.7	23.1	23.5
Hardgrove Grindability Index		43	62	49	39	47	43	41
Proximate Analysis (moisture free)								
Ash	%	14.1	52.8	34.6	25.4	31.9	24.1	19.5
Volatile Matter	%	35.8	26.3	35.3	38.7	46.0	38.5	39.5
Fixed Carbon	%	50.1	21.9	30.1	35.9	22.1	37.4	41.0
Ultimate Analysis								
Carbon	%	63.3	30.7	45.1	52.3	47.0	54.3	56.6
Hydrogen	%	3.9	2.6	3.6	4.0	3.6	4.1	4.2
Sulphur	%	0.2	1.0	1.2	0.7	1.3	0.8	0.8
Nitrogen	%	0.9	0.6	1.0	1.2	0.9	1.1	1.2
Ash	%	14.1	52.8	34.6	25.4	31.9	24.1	19.5
Oxygen	%	17.6	12.3	14.5	16.4	15.3	15.6	17.7
Gross Calorific Value, moisture free basis								
Btu/lb		10512	5025	7496	8901	7928	9018	9714
Cal/gm		5840	2792	4164	4945	4404	5010	5397
Ash Fusibility (Oxidizing)								
Initial	°C	1300	>1480	1398	>1480	1404	1460	>1480
Spherical	°C	1340		>1480		>1480	>1480	
Hemispherical	°C	1370						
Fluid	°C	1480						

TABLE 2

CONTROL CONDITIONS FOR THE TEST PROGRAM

Test No.	Coal	Degree of Drying	Excess O_2 Level, %	Feed Rate Kg/hr
1.1	Sundance	None	5	100
1.2	"	"	3	100
2.1	Hat Creek "A" raw	KD* twice	5	196
2.2	" "	"	3	196
3.1	Hat Creek "A" washed	AD** + KD	5	134
3.2	" "	"	3	134
4.1	Hat Creek "B" raw	KD twice	5	131
4.2	" "	"	3	131
4.3	" "	KD	5	142
5.1	Hat Creek "B" washed	AD + KD	5	120
5.2	" "	"	3	120
5.3	" "	AD	5	120
6.1	Hat Creek "C" raw	KD twice	5	110
6.2	" "	"	3	110
6.3	" "	KD	5	120
7.1	Hat Creek "C" washed	AD + KD	5	110
7.2	" "	"	3	110
7.3	" "	AD	5	110

*KD = kiln-dried

**AD = air-dried

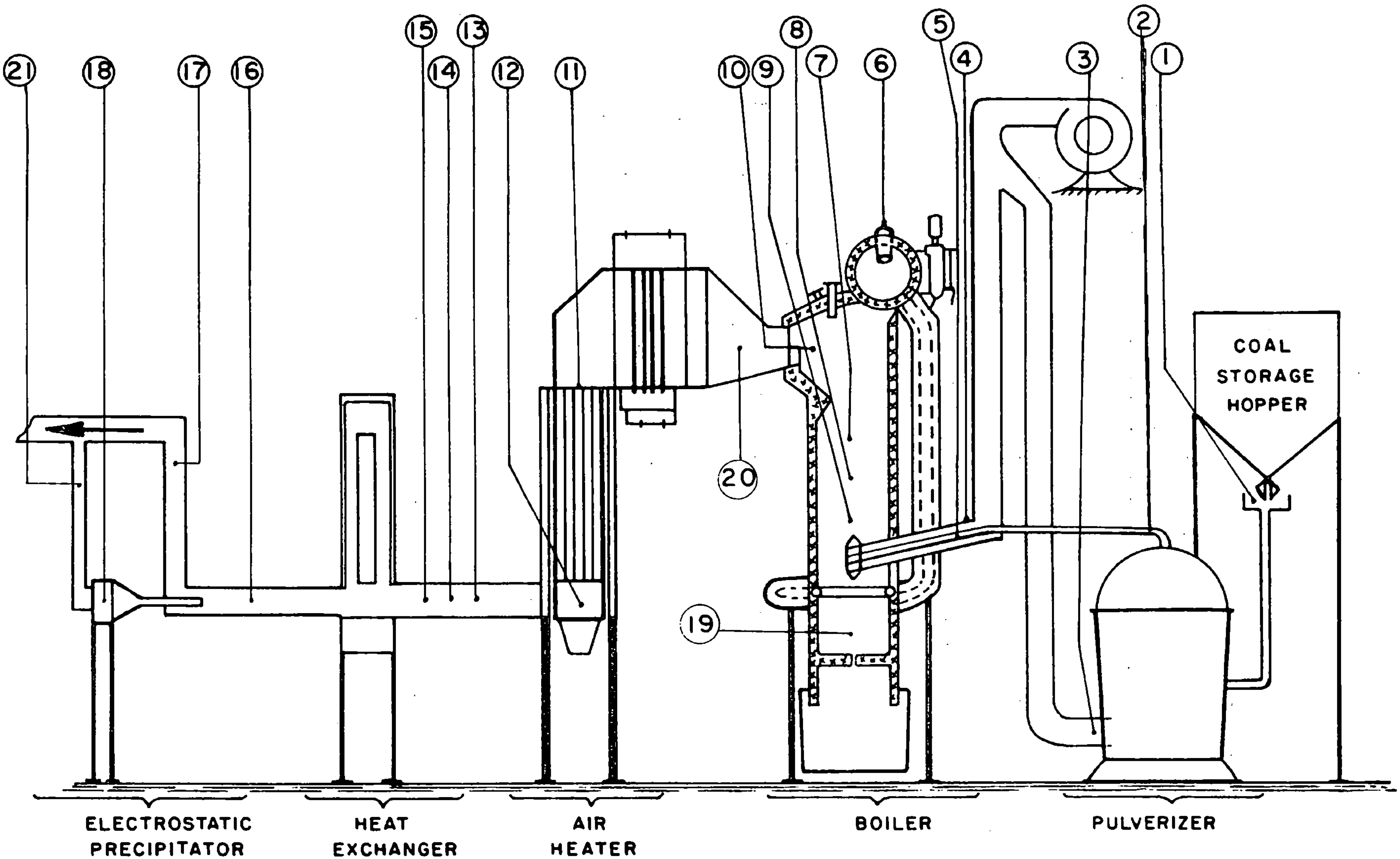


FIGURE 1 Schematic illustration of the pilot-scale boiler showing the sampling stations.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

SUNDANCE COAL

FIRED AS RECEIVED, 5% EXCESS OXYGEN

TEST NO. 1.1

CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/100-103

PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET
JOINT PROGRAM
SUNDANCE COAL
FIRED AS RECEIVED, 5% EXCESS OXYGEN

PROGRESS REPORT 1.1A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

INTRODUCTION

By an agreement between the B.C. Hydro and Power Authority (B.C. Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report [2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 1.1, which was done on October 5, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 1.1

In this test, Sundance coal, which is an Alberta sub-bituminous coal from the Edmonton formation, was burned to provide baseline data with which the performance of the Hat Creek coals could be compared. The coal was fired with an as-received moisture of 17%. The target level of excess oxygen in the flue gas was 5% (approx. 25% excess air), and the target coal-feed rate was 100 Kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

Once unsupported, stable coal combustion had been achieved, the flame was observed to be bright yellow and combustion appeared to be completed below the furnace throat, with the flame tailing out above the throat. From the top of the furnace, the throat and furnace probes could be seen plainly. The furnace bottom was transparent, and light sinter was forming on the refractory walls.

After 1.5 hr, the flame was observed to have lengthened but it remained clean. From the top of the furnace, substantial deposits could be seen building up on the furnace probes and below the furnace throat. The furnace bottom remained transparent.

Later, the deposits below the throat were observed to be 15 cm or more thick and small deposits appeared on the walls above the throat. The flame remained bright and clean, and the furnace bottom remained transparent until the test was terminated. Furnace-bottom ash was not dumped throughout the test.

Deposition Probes During Test

The deposition probes in the furnace and the furnace bottom were visible during the test, and deposits developed on them as follows:

The air-cooled probe in the furnace remained free of sinter.

The refractory probe in the furnace developed a heavy deposit of sinter.

The air-cooled probe in the furnace bottom developed a light deposit on the trailing side and this deposit appeared to have a sintered surface.

The refractory probe in the furnace bottom developed a 5 to 8 mm deposit of sinter all around.

Furnace After Test

The refractory around the furnace throat was coated with a cohesive deposit of sinter, but portions of it had fallen off, leaving the refractory clean. The furnace-bottom ash contained large lumps of friable sinter and surfaces which were exposed to the flame showed some evidence of fusion. The furnace water walls were covered by a thin layer of dust. There were 5 to 8 mm of dust on the bottom of the transition section (between the furnace and air heater), and a light dust deposit on the test air heater tubes.

Deposit Probes After Test

The refractory probe in the furnace bottom was covered lightly by a tan coloured powder which could be brushed off easily.

The air-cooled probe in the furnace bottom was covered on the trailing edge by 2 mm of orange coloured powder.

The refractory probe in the furnace was covered lightly by a tan coloured powder which adhered weakly.

The air-cooled probe in the furnace was covered lightly by an orange coloured powder.

The refractory probe in the transition section was covered lightly by a tan coloured powder which adhered weakly.

The air-cooled probe in the transition section was covered lightly by an orange coloured powder.

Test No. 1.1

Progress Report 1.1A

Revised 18/11/76

TABLE 1

OPERATING DATA

COAL SUNDANCE AS RECEIVED EXCESS O_2 5 %

5/10/76

Parameters	Station	Obs. (R.M.S. Dev.)	Comments
Test Duration		7 hours	
Firing Rate		99.0(2.0) kg/hr	
Moisture Content of Coal	1	17.1(1.8) %	feed to pulverizer
" " " "	2	2.6(0.2) %	feed to furnace
Combustible " " "	2	83.9(0.2) %	dry weight
Ash Dumping Frequency		once every —— hour	20 kg dumped at end of run, only, equivalent to 865 Kg coal.
PULVERIZER OPERATING CONDITIONS			
a) Inlet Air Pressure	3	205 (7) mmH_2O	
b) Outlet Air Pressure	2	176 (7) mmH_2O	
c) Inlet Air Temperature	3	208 (4) °C	
d) Outlet Air Temperature	2	88 (5) °C	
e) Coal Fineness	2	82% below 200 mesh	oversize, 10.5% 140 mesh; 17.6% 200 mesh; 49.1% 325 mesh
BOILER OPERATING CONDITIONS			
a) Steam Flow	6	578 (13) kg/hr	
b) Steam Pressure	6	2.97(0.05) atmospheres	
c) Combustion Air Temp.	4	198 (7) °C	
d) Furnace Pressures			
Furnace	10	29 (1) mmH_2O	
Inlet	11	29 (1) mmH_2O	
Boiler Exit	12	11 (1) mmH_2O	
Primary (Coal) Air L	5	111 (2) mmH_2O	
" R	5	120 (3) mmH_2O	
Secondary (Windbox) Air L	4	53 (2) mmH_2O	
" R	4	53 (3) mmH_2O	
FLUE GAS ANALYSIS			
a) CO_2	11	15.5 (0.4) %	
b) O_2	11	5.1 (0.1) %	
c) CO	11	46 (5) ppm	
d) NO	13	600 (45) ppm	
e) SO_2	14	80 (2) ppm	
f) SO_3	14	< 1 ppm	
g) Acid dewpoint	14	—— °C	not detectable
FLUE GAS TEMPERATURE			
a) Furnace Exit	11	670 (14) °C	
b) Boiler Exit	12	307 (7) °C	
c) Precipitator Entry	16	164 (6) °C	
SUCTION PYROMETER TEMPERATURES			
a)	7	1178, 1130 °C	readings taken in second and third two hour period
b)	8	995, 1090 °C	
c)	9	965, 1030 °C	
FLY ASH			
a) Loading	16	- $mgms/m^3$	measured at 20°C
b) Resistivity	15	$3.8(2.6)\times10^8$ Ω cm at 271°C	
"	17	4.9×10^8 Ω cm at 148°C	
c) Precipitator efficiency	18	______ %	error
d) Combustible content of ash collected from precipitator	18	1.3 (0.1) %	

TABLE 2

DEPOSITION PROBES

Deposition Probe		Station	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom	ceramic	19	1173	76	1076	1270	1098	1263	Tan powder, 1 mm thick, even, easily brushed off
	stainless	19	525	67	437	671	559	568	Orange powder on trailing edge, 2 mm thick
Furnace	ceramic	9	590	67	540	687	610	558	Tan powder, 1 mm thick, adheres weakly
	stainless	9	451	72	372	626	518	433	Orange powder, 1 mm thick,
Transition Section	ceramic	20	685	14	662	711	662	707	Tan powder, 1 mm thick, adheres weakly
	stainless	20	523	40	482	586	586	513	Orange powder, 1 mm thick, even

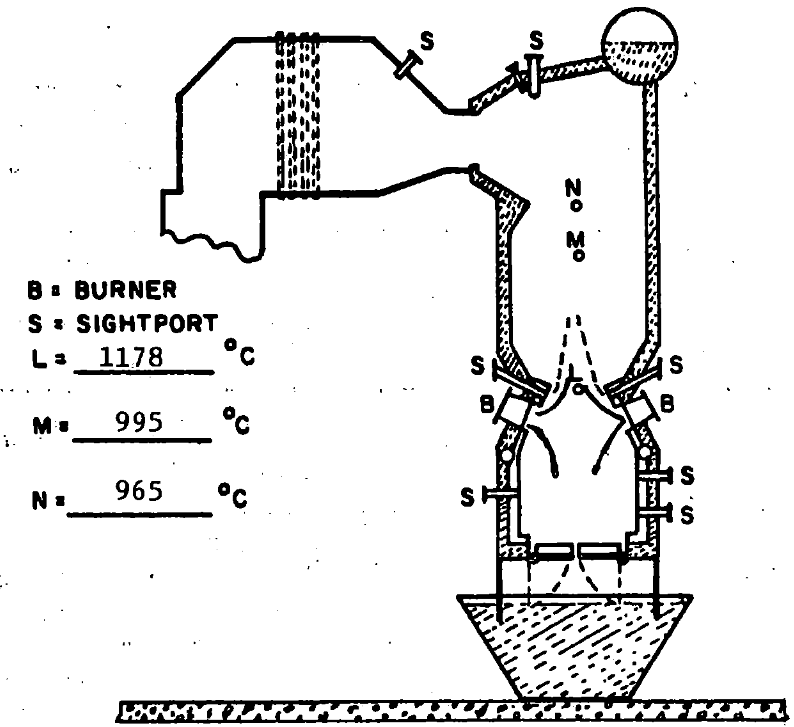


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET
JOINT PROGRAM

Sundance Coal
Fired as Received, 5% Excess Oxygen

PROGRESS REPORT 1.1B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (1.1B) presents coal analyses and size distribution of the pulverized coal burned in test 1.1 done on October 5, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

CCRL

Sundance (1.1) 5% oxygen

3046-76

A-1010

21-12-76

SAMPLE CONDITION		AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis			
Moisture		13.80	0.00
Ash		12.59	14.61
Volatile Matter		29.92	34.71
Fixed Carbon (by Diff.)		43.69	50.68
Ultimate Analysis			
Carbon	%	54.56	63.29
Hydrogen	%	3.36	3.90
Sulphur	%	0.18	0.21
Nitrogen	%	0.71	0.82
Ash	%	12.59	14.61
Oxygen (by Diff.)	%	14.80	17.17
Calorific Value			
Calories per gram		4983	5781
B.T.U. per Lb. gross		8969	10405
Caking Properties			
By Vol. Button @			
Swelling Properties			
Free Swelling Index (ASTM)			
Ash Fusibility, °F		OXID.	RED
Initial Deformation	°F	2440	2320
Softening-Spherical	°F	2490	2390
Softening-Hemispherical	°F	2560	2480
Fluid	°F	2620	2620

SCREEN ANALYSIS

Mesh Inches	%
1/4 x 3/8	0.00
3/8 x 1/8	3.16
1/8 x 1/16	36.35
1/16 x 1/32	32.80
1/32 x 0	27.69

Grindability Index (Hardgrove): 43

Equilibrium Moist (97% Hum),%: 16.59

Sulphur Forms:

Sulphate

Pyritic

Organic (by Diff.)

Total

Specific Gravity in ash: 2.91

ASH ANALYSIS

Component	%	Component	%
SiO_2	48.42	CaO	13.58
Al_2O_3	23.64	MgO	0.93
Fe_2O_3	4.58	SO_3	2.42
Mn_3O_4	1.03	Na_2O	2.45
TiO_2	0.50	K_2O	0.26
P_2O_5	0.20		

Chlorine: 0.00

Trace Mercury:

TEST NO: 1.1

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			0.7	
100M x 140M			4.4	89.3
140M x 200M	17.3	4.0	7.9	86.9
200M x 325M			16.8	85.3
325M x 0			70.1	82.7

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Sundance Coal
Fired as Received, 5% Excess Oxygen

PROGRESS REPORT 1.1C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program.

This progress report (1.1C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 1.1 done on October 5, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 1:1C

Figure 1a

Furnace bottom at end of test. Burners are clear. Friable sinter is loose and easily dislodged. Deposition probes are in foreground air cooled at top (east side) ceramic at bottom (west side). Greatest buildup of sinter is along east side and in north east corner.

Figure 1b

Furnace bottom at end of test. Friable sinter buildup along east side and north east corner can be seen better in this photo.

PROGRESS REPORT 1:1C

Figure 1c

Furnace bottom air cooled deposition probe.

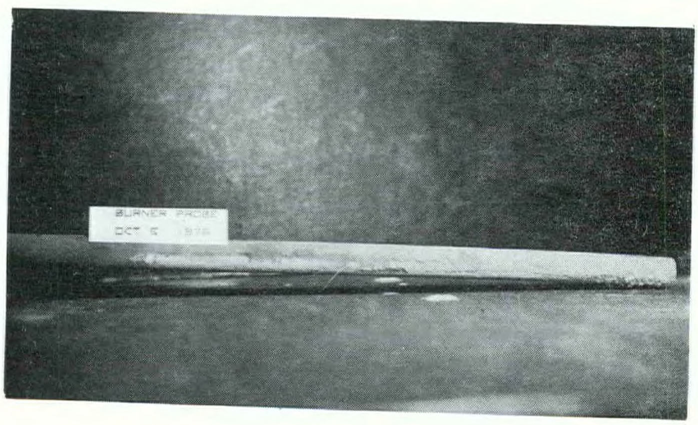


Figure 1d

Burner air cooled deposition probe.

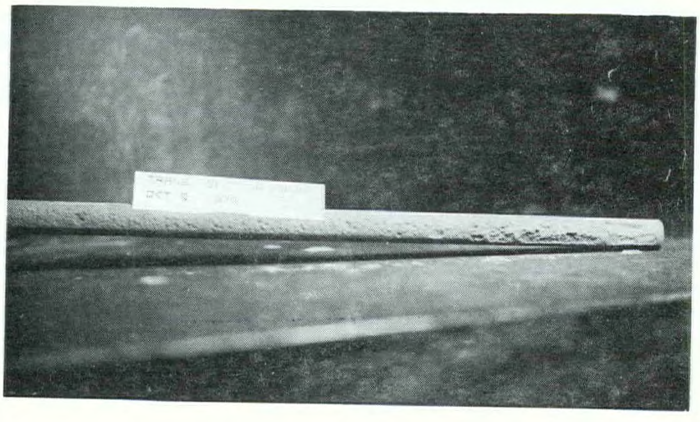


Figure 1e

Transition section air cooled deposition probe

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	131 °C	104 °C	525 °C	451 °C	523 °C
Deposition rate[a/]						
Fe	0.4	0.0	0.4	0.0	2.0	0.6
Mg	0.9	0.4	0.5	2.1	1.7	1.3
Na	1.1	1.1	0.9	16.7	30.7	30.3
Ca	21.3	18.6	20.9	69.1	97.6	81.6
SO_4 (total)	13.8	15.3	15.3	217.7	146.0	261.2
SO_4 (free), by difference				8.6		

[a/] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Progress Report 1.1 C

Sample: Deposit from furnace bottom, Test 1.1, (A 980)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1332	1310
Spherical	°C	1360	1354
Hemispherical	°C	1388	1382
Fluid	°C	1443	1421

Ash Analysis	%
SiO_2	50.25
Al_2O_3	24.31
Fe_2O_3	4.92
Mn_3O_4	----
TiO_2	0.68
P_2O_5	0.34
CaO	12.52
MgO	2.01
SO_3	0.06
Na_2O	1.61
K_2O	0.25
Cl	----

Progress Report 1.1 C

Sample: Deposit from furnace walls, Test 1.1, (A 981)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1282	1210
Spherical	°C	1332	1299
Hemispherical	°C	1360	1360
Fluid	°C	1438	1377

Ash Analysis	%
SiO_2	47.76
Al_2O_3	22.69
Fe_2O_3	6.94
Mn_3O_4	----
TiO_2	0.66
P_2O_5	0.36
CaO	13.28
MgO	1.52
SO_3	3.46
Na_2O	1.53
K_2O	0.24
Cl	----

Sample: Deposit from screen tubes, Test 1.1, (A 982)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1271	1188
Spherical	°C	1299	1271
Hemispherical	°C	1327	1327
Fluid	°C	1393	1366

Ash Analysis	%
SiO_2	44.83
Al_2O_3	21.41
Fe_2O_3	5.06
Mn_3O_4	----
TiO_2	0.85
P_2O_5	0.37
CaO	18.29
MgO	1.99
SO_3	1.63
Na_2O	2.46
K_2O	0.29
Cl	----

Sample: Deposit from transition section, Test 1.1 (A 983)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1343	1266
Spherical	°C	1399	1343
Hemispherical	°C	1432	1360
Fluid	°C	1482	1410

Ash Analysis	%
SiO_2	54.64
Al_2O_3	25.82
Fe_2O_3	4.03
Mn_3O_4	----
TiO_2	0.65
P_2O_5	0.33
CaO	12.46
MgO	1.31
SO_3	1.33
Na_2O	1.22
K_2O	0.28
Cl	----

Sample: Deposit from sheet between 2nd and 3rd pass of air heater
Test 1.1 (A 984)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1277
Spherical	°C	1388	1321
Hemispherical	°C	1416	1332
Fluid	°C	1460	1377

Ash Analysis	%
SiO_2	50.75
Al_2O_3	23.17
Fe_2O_3	5.04
Mn_3O_4	----
TiO_2	0.70
P_2O_5	0.38
CaO	15.01
MgO	1.49
SO_3	0.48
Na_2O	1.22
K_2O	0.26
Cl	----

Progress Report 1.1 C

Sample: Deposit from electrostatic precipitator, Test 1.1, (A 985-6-7)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1182	1143
Spherical	°C	1238	1171
Hemispherical	°C	1271	1254
Fluid	°C	1382	1338

Ash Analysis	%
SiO_2	40.84
Al_2O_3	21.35
Fe_2O_3	5.04
Mn_3O_4	----
TiO_2	0.97
P_2O_5	0.38
CaO	21.79
MgO	2.42
SO_3	1.06
Na_2O	3.53
K_2O	0.39
Cl	----

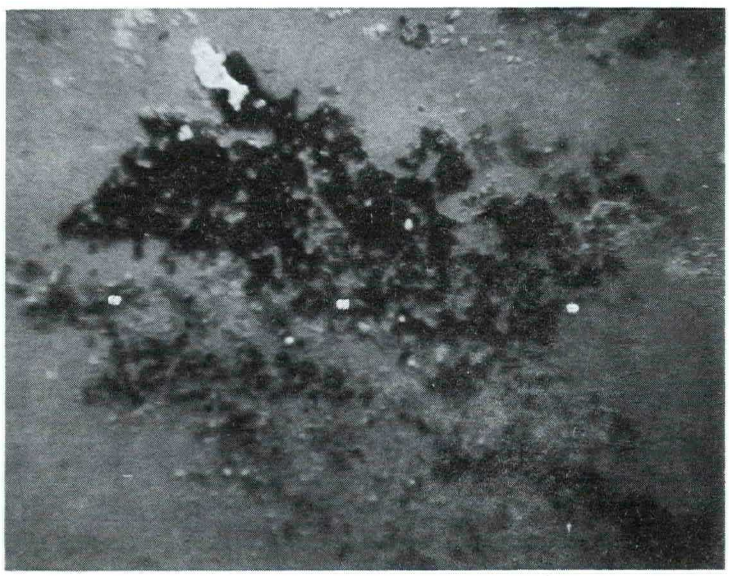


Figure 2. Photomicrograph, x10, of a thin section of sinter which was found attached to the refractory near the burners. The sinter is weak and porous.

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Sundance Coal
Fired as Received, 5% Excess Oxygen

PROGRESS REPORT 1.1D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (1.1D) is the last of the series and presents results of the following detailed analyses of ash produced in test 1.1 done on October 5, 1976.

1. Combustion calculations
2. Particle size distribution of fly-ash
3. X-ray diffraction analyses of fireside deposits
4. Summary of DTA studies on fireside deposits

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

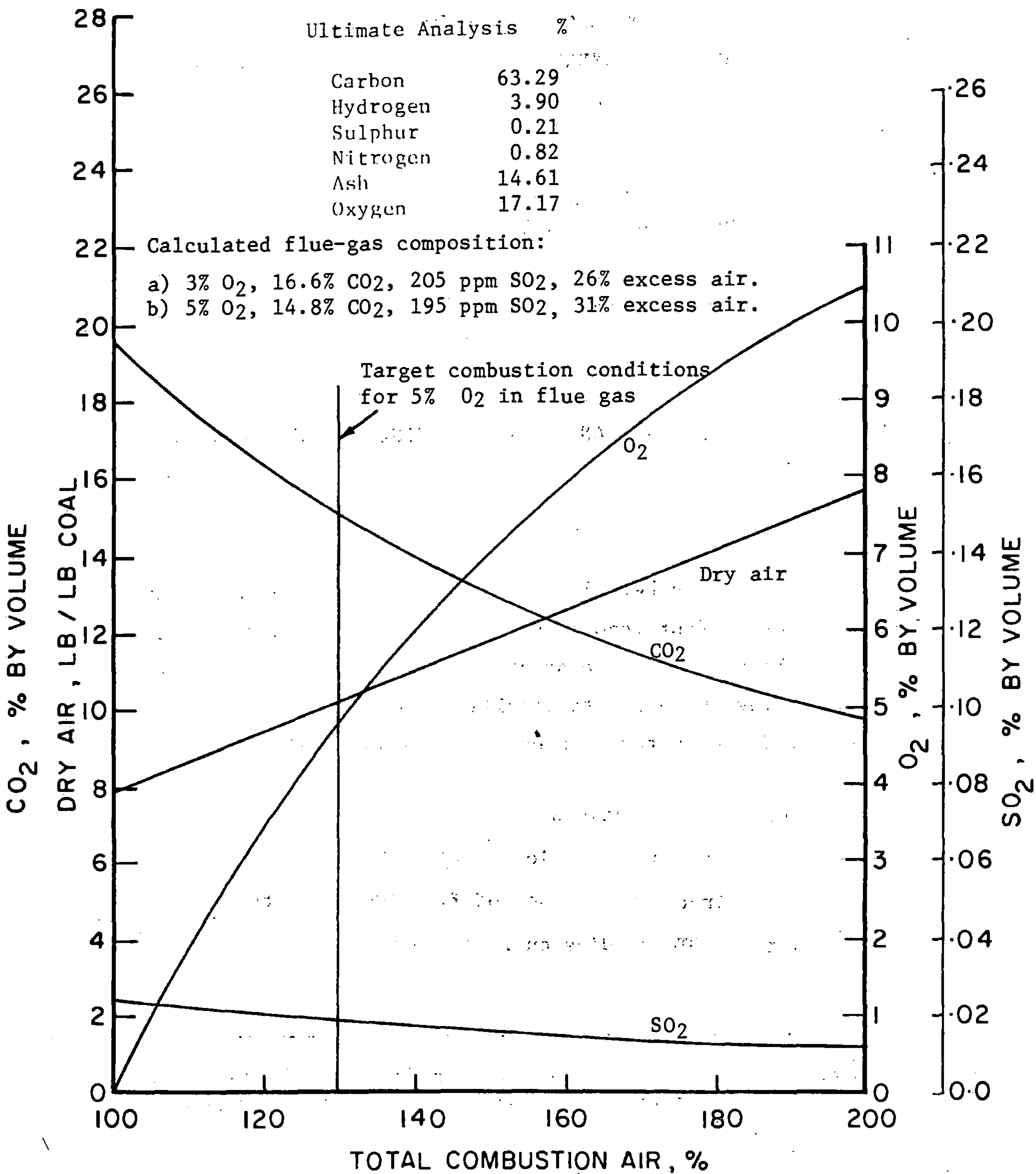


FIGURE 1: Combustion Calculations "Sundance" Coal.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.8
1.59 - 2.00			0.8
2.00 - 2.52			1.3
2.52 - 3.17		0.2	2.0
3.17 - 4.00		0.4	3.5
4.00 - 5.04		0.5	5.4
5.04 - 6.35		0.7	8.0
6.35 - 8.00		1.3	10.2
8.00 - 10.08		2.7	13.1
10.08 - 12.7		4.4	14.5
12.7 - 16.0		7.5	13.5
16.0 - 20.2		11.4	11.7
20.2 - 25.4		15.1	8.6
25.4 - 32.0		17.1	3.4
32.0 - 40.3		13.8	1.6
40.3 - 44.0		4.9	0.4
44.0 - 74.0	Sieve	18.0	1.2
+ 74.0		2.0	0.0

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
X PERCENT

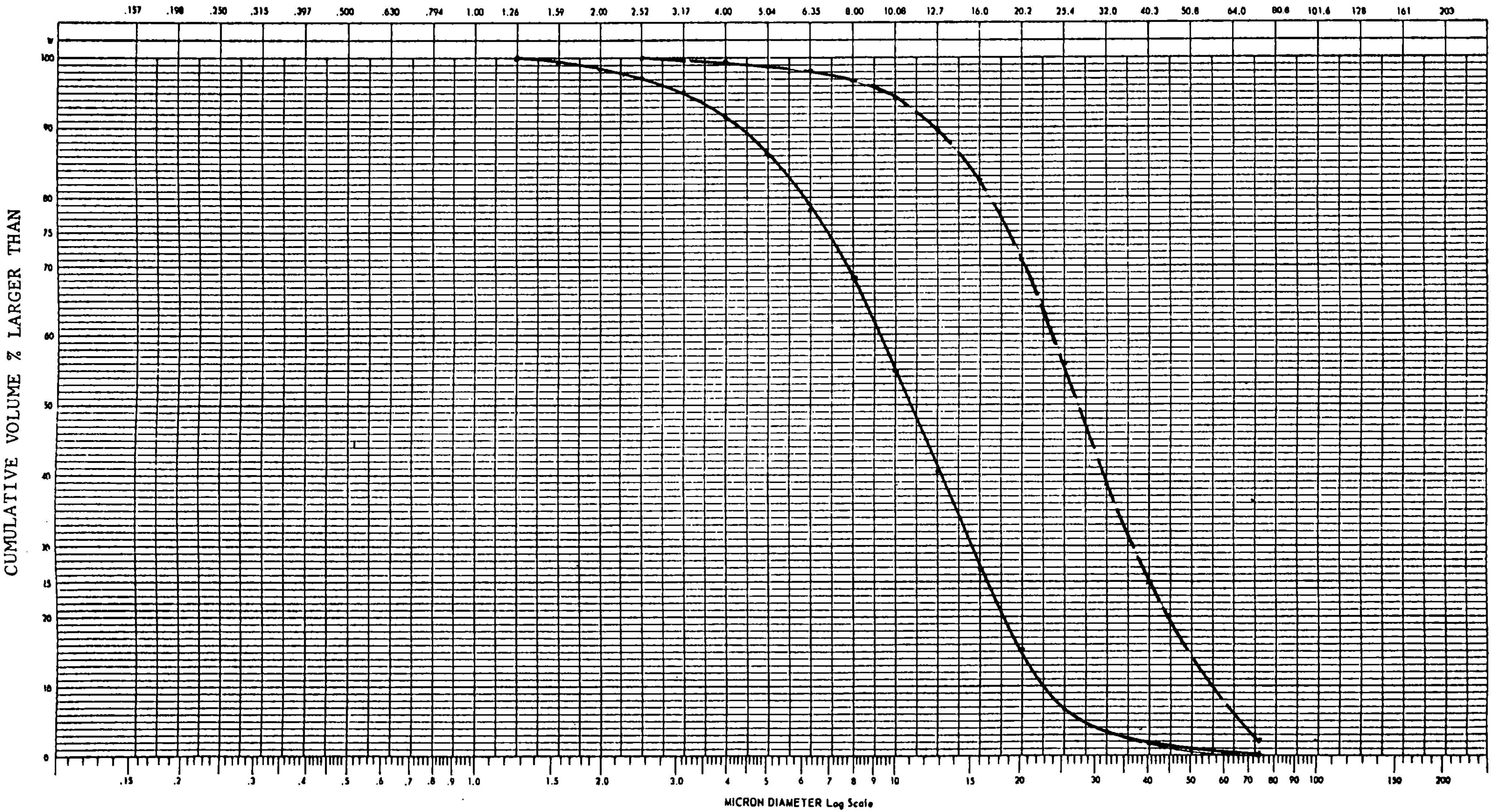
COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION	CCRL - WRL
OPERATOR	
EQUIPMENT	

$k = d\sqrt[3]{2w}$ FOR MODEL T $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$ FOR MODEL TA $\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 1.1	Isoton	Ultrasonic	100μ	6102033									
ESP ————													
AHR - - -													



4221010

X-ray Diffraction Analyses of Fireside Deposits from Test 1.1, Sundance Coal.

Furnace Bottom Ash (980 76-431)	Feld, Qtz, Crist (sm)
Under Flame Probe Deposit (1003 76-442)	Feld, Qtz, Cpd A
Furnace Probe Deposit (1004 76-443)	Qtz, Cpd A, Hem
Transition Probe Deposit (1005 76-444)	Qtz, Cpd A

Abbreviations of Constituents:

Feld	Feldspar (Anorthite) $CaO.Al_2O_3.2SiO_2$
Qtz	Quartz SiO_2
Crist	Cristobalite SiO_2
Hem	Hematite Fe_2O_3
Cpd A	Unidentified with strong 3.50 d-value

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous material.

Most films contain a few faint diffractions that were not identified (in addition to unidentified constituents of significance).

Constituents are listed in decreasing order of abundance. On occasion "small" is used for clarity.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

SUMMARY OF DTA STUDIES ON FIRESIDE DEPOSITS

Samples:

Five samples of ash from the furnace bottom and one sample of ash collected by the CCRL dust sampler were examined.

Sample 1)	CCRL 980	Test 1.1	Sundance bottom ash.
Sample 2)	CCRL 1092	Test 2.1	Hat Creek A-raw, bottom ash
Sample 3)	CCRL 1190	Test 3.1	Hat Creek A-washed, bottom ash
Sample 4)	CCRL 1278	Test 4.1	Hat Creek B-raw, bottom ash
Sample 5)	CCRL 1360	Test 4.3	Hat Creek B-raw, bottom ash
Sample 6)	CCRL 986	Test 1.1	Sundance fly ash.

Procedures:

Samples weighing approximately 50 mg were heated in a static air atmosphere at 12°C/min. to 1500°C. Two platinum foil pans were held in a vertical furnace, one containing the sample and the other containing α-alumina as reference material. Pt: Pt/13% Rh thermocouples were held with their beads denting the bottom of the pans.

Results:

Sample 1) No peaks were observed. The baseline shifted in the exothermic direction at 1360°C. When cool, the sample was dark and glassy.

Sample 2) No peaks were observed. The baseline shifted in the endothermic direction at 1450°C. When cool, the sample was brown-black opaque, and very hard.

Sample 3) No peaks were observed. The baseline shifted in the endothermic direction at 1340°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 4) No peaks were observed. The baseline shifted in the exothermic direction at 1330°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 5) No peaks were observed. The baseline shifted in the endothermic direction at 1160°C. When cool, the sample was brown, opaque, and appeared to have melted.

Sample 6) A sizable exothermic peak was observed in the 400°C to 500°C range and a small endothermic peak was noted at 1160°C. Cooling and reheating in the range 1000°C to 1500°C failed to show any repetition of the latter thermal effect. When cool, the sample was dark and glassy.

Comments:

It seems certain that samples 1), 5) and 6) underwent melting. The other samples probably had some liquid phase present. The lack of DTA peaks is unusual. It most likely indicates that melting occurred over a very broad range. Cooling to 1000°C and reheating gave rise to no peaks either. The exothermic peak for sample 6) was most likely the result of combustion of a small amount of carbonaceous material.

It can be concluded that DTA is not a very usefull technique for studying these materials.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

SUNDANCE COAL

FIRED AS RECEIVED, 3% EXCESS OXYGEN

TEST NO. 1.2

CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/104-107

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Sundance Coal
Fired as Received, 3% Excess Oxygen

PROGRESS REPORT 1.2A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 1.2, which was done on October 7, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 1.2

In this test, Sundance coal, which is an Alberta sub-bituminous coal from the Edmonton formation, was burned to provide baseline data with which the performance of the Hat Creek coals could be compared. The coal was fired with as-received moisture of 16%. The target level of excess oxygen in the flue gas was 3% (approx 15% excess air), and the target coal feed rate was 100 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1 which is a diagram of the research boiler.

Furnace During Test

At 0830 hr, stable, unsupported coal combustion had been in progress for an hour. The flame was observed to be bright yellow, and it tailed out through the furnace into the transition section to the test air heater, where the tubes were plainly visible. From the top of the furnace, the air-cooled deposition probe in the furnace, and the furnace throat were clearly visible, but the deposition probes in the furnace bottom could not be discerned through the flame. The furnace bottom, viewed through the sight ports located there, was transparent; the opposite walls were easily seen.

At 0930 hr, ash deposits were evident on the east and west sides of the furnace at burner level. These grew and by 1330 hr they blocked about 1/3 of the projected throat area, when viewed from the top of the furnace. However, they were located slightly below the throat, and did not excessively interfere with the flame pattern, although the flame was longer and more opaque than formerly. The furnace bottom was still transparent, and only minor deposits of sintered ash were observed to be adhering to the refractory walls.

By 1530 hr the deposits at burner level had grown to the point where they blocked about half of the projected throat area, with the heaviest deposits being in the southwest corner. Their effect on the flame was to lengthen it, and this partly obscured the view of the throat from the top of the furnace. The furnace bottom remained transparent, but a uniform "beard" of sintered ash could be seen covering the refractory walls. Ash had built up on the furnace bottom to half its depth.

At 1600 hr, the test was completed and the furnace was shut down. Furnace bottom ash was not dumped throughout the test.

Deposition Probes During Test

The deposition probes in the furnace and the furnace bottom were visible during the test, and deposits developed on them as follows:

The air-cooled probe in the furnace remained free of sinter throughout the test.

The refractory probe in the furnace developed a heavy deposit of sinter .

The air-cooled probe in the furnace bottom developed a few whiskers of sinter, 5 to 8 mm long, mostly on the bottom surface. These fell off from time to time.

The refractory probe in the furnace bottom developed a 5 to 8 mm beard of sinter all around, which decreased in thickness toward the end of the test, but showed no evidence of slagging.

Furnace After Test

Most of the deposits on the furnace walls had fallen off upon cooling, leaving the refractory around the burners fairly clean. These deposits were removed mostly as large chunks of weak sinter. The furnace water walls were covered by a thin layer of dust. There were approximately 8 mm of dust on the bottom of the transition section (between the furnace and air-heater) and a light dust deposit on the test air-heater tubes.

Deposition Probes After Test

The air-cooled probe in the transition section had a 1 mm layer of tan coloured dust on the trailing surface. The leading surface was clean.

The refractory probe in the transition section had a light layer of tan coloured dust on the leading edge but there were indications that a heavier deposit had fallen off.

The air-cooled probe in the furnace had only a film of tan coloured dust.

The refractory probe in the furnace had tan coloured sintered deposit all around, giving an overall diameter of about 4 cm.

The air-cooled probe in the furnace bottom was bare except for a few whiskers of tan coloured sinter. There were indications that a larger deposit had fallen off.

The refractory probe in the furnace bottom was broken and supported by the sheathed thermocouple. The probe bore nodules of tan coloured sinter about 1 cm thick.

Test No. 1.2

Progress Report 1.2A

Revised 18/11/76

TABLE 1

OPERATING DATA

COAL SUNDANCE AS RECEIVED   EXCESS O_2 3 %

7/10/76

Parameters	Station	Obs. (R.M.S. Dev.)	Comments
Test Duration		7.5 hours	
Firing Rate		96.7(2.1) kg/hr	
Moisture Content of Coal	1	16.0(1.4) %	feed to pulverizer
" " " "	2	3.2(0.3) %	feed to furnace
Combustible " " "	2	84.5(1.6) %	dry weight
Ash Dumping Frequency		once every —— hour	total ash dumped at end of test = 17.7 Kg equivalent to 874 Kg coal
PULVERIZER OPERATING CONDITIONS			
a) Inlet Air Pressure	3	203 (4) mmH_2O	
b) Outlet Air Pressure	2	174 (4) mmH_2O	
c) Inlet Air Temperature	3	206 (5) °C	
d) Outlet Air Temperature	2	92 (3) °C	
e) Coal Fineness	2	93.4% below 200 mesh	oversize, 6.1% 140 mesh " , 6.6% 200 mesh " , 45.4% 325 mesh
BOILER OPERATING CONDITIONS			
a) Steam Flow	6	596 (13) kg/hr	
b) Steam Pressure	6	3.01 (0.05) atmospheres	
c) Combustion Air Temp.	4	198 (6) °C	
d) Furnace Pressures			
Furnace	10	26 (7) mmH_2O	
Inlet	11	27 (6) mmH_2O	
Boiler Exit	12	11 (2) mmH_2O	
Primary (Coal) Air L	5	110 (6) mmH_2O	
" R	5	119 (5) mmH_2O	
Secondary (Windbox) Air L	4	41 (6) mmH_2O	
" R	4	46 (6) mmH_2O	
FLUE GAS ANALYSIS			
a) CO_2	11	17.3 (0.4) %	
b) O_2	11	3.1 (0.2) %	
c) CO	11	46 (3) ppm	
d) NO	13	567 (29) ppm	
e) SO_2	14	88 (3) ppm	
f) SO_3	14	< 1 ppm	
g) Acid dewpoint	14	°C	not detectable
FLUE GAS TEMPERATURE			
a) Furnace Exit	11	671 (19) °C	
b) Boiler Exit	12	298 (22) °C	
c) Precipitator Entry	16	154 (16) °C	
SUCTION PYROMETER TEMPERATURES			
a)	7	1190, 1125 °C	readings taken in second and third two hour period
b)	8	1028, 1075 °C	
c)	9	900, 980 °C	
FLY ASH			
a) Loading	16	310 $mgms/m^3$	measured at 20°C, one measurement
b) Resistivity	15	$4.7(1.1)x10^9$ Ω cm at 280°C	
"	17	8.6×10^9 Ω cm at 156°C,	7.2×10^9 Ω cm at 118°C
c) Precipitator efficiency	18	89(1) %	of three measurements, using a)
d) Combustible content of ash collected from precipitator	18	2.4(0.2)%	

Test No. 1.2
Progress Report 1.2A
7/10/76

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	1135	36	1074	1231	1074	1231	Probe Broken
	stainless	426	29	379	486	406	441	Light tan powder, downstream 1 mm thick, even
Furnace 9	ceramic	815	31	790	853	790	775	Very little light tan powder adheres
	stainless	444	29	396	504	504	459	Light tan powder, 1 mm thick, downstream, even
Transition Section 20	ceramic	682	14	655	705	655	700	Very little light tan powder
	stainless	453	9	453	487	466	477	Light tan powder, 1 mm thick, downstream, easily brushed off

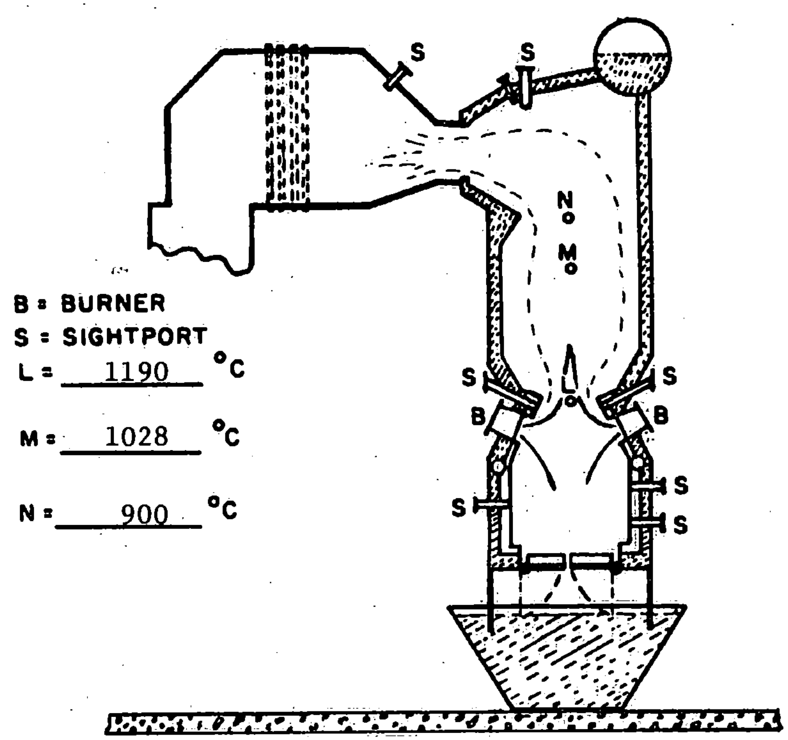


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Sundance Coal
Fired as Received, 3% Excess Oxygen

PROGRESS REPORT 1.2B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (1.2B) presents coal analyses and size distribution of the pulverized coal burned in test 1.2 done on October 7, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

CCRL | 3047-76
Sundance (1.2) 3% Oxygen | A-1015
21-12-76

SAMPLE CONDITION	AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis		
Moisture	14.37	0.00
Ash	12.98	15.16
Volatile Matter	29.44	34.38
Fixed Carbon (by Diff.)	43.21	50.46
Ultimate Analysis		
Carbon %	53.73	62.75
Hydrogen %	3.32	3.88
Sulphur %	0.15	0.18
Nitrogen %	0.74	0.86
Ash %	12.98	15.16
Oxygen (by Diff.) %	14.71	17.17
Calorific Value		
Calories per gram	4901	5723
B.T.U. per Lb. gross	8822	10302
Caking Properties		
By Vol. Button @		
Swelling Properties		
Free Swelling Index (ASTM)		

Ash Fusibility, °F	OXID.	RED
Initial Deformation °F	2390	2330
Softening-Spherical °F	2480	2400
Softening-Hemispherical °F	2530	2530
Fluid °F	2700+	2630

SCREEN ANALYSIS

Mesh Inches	%
1/4 x 3/8	0.00
3/8 x 1/8	4.49
1/8 x 1/16	46.77
1/16 x 1/32	31.12
1/32 x 0	17.62

Grindability Index (Hardgrove): 43

Equilibrium Moist (97% Hum),%: 17.68

Sulphur Forms:
- Sulphate
- Pyritic
- Organic (by Diff.)
- Total

Specific Gravity in ash: 2.92

ASH ANALYSIS

Component	%	Component	%
SiO_2	49.76	CaO	12.60
Al_2O_3	23.96	MgO	0.85
Fe_2O_3	4.35	SO_3	2.50
Mn_3O_4	0.93	Na_2O	2.26
TiO_2	0.47	K_2O	0.26
P_2O_5	0.17		

Chlorine: 0.01

Trace Mercury:

TEST NO: 1.2

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			0.7	
100M x 140M			5.8	89.4
140M x 200M	17.8	0.4	12.9	86.1
200M x 325M			14.0	84.9
325M x 0			66.5	82.6

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Sundance Coal
Fired as Received, 3% Excess Oxygen

PROGRESS REPORT 1.2C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (1.2C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposites collected on probes and the chemical analyses of various ash forms produced in test 1.2 done on October 7, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 1:2C

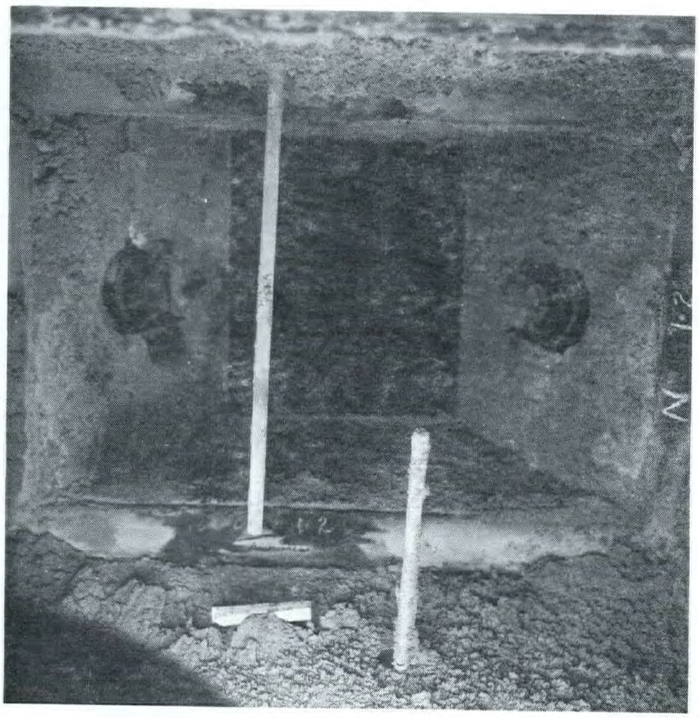


Figure 1a

Furnace bottom at an end of test. Burners are clear. Small buildup of riable sinter in north east and north west corners. Deposition probes in foreground.

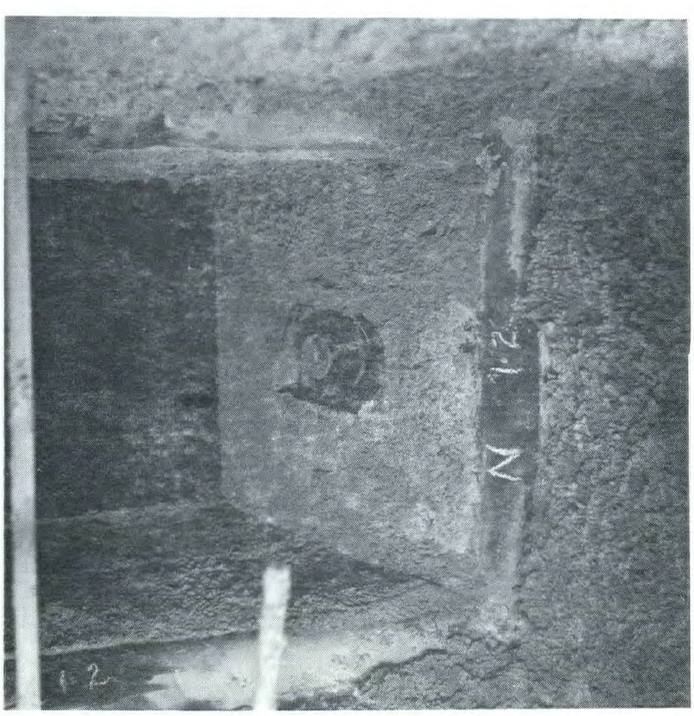


Figure 1b

Friable sinter may be seen more clearly in this photo.

PROGRESS REPORT 1:2C

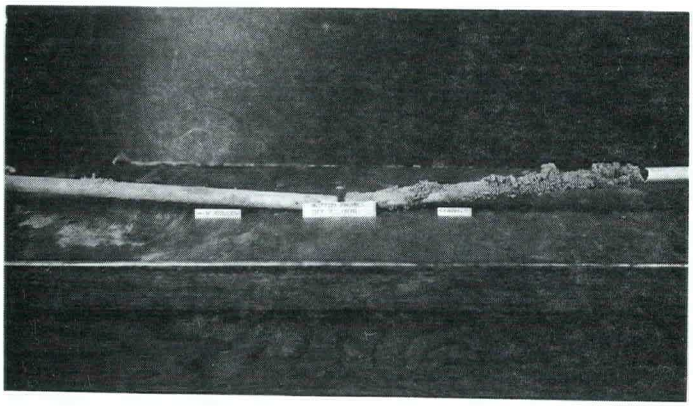


Figure 1c

Furnace bottom deposition probes. Air cooled probe on left. Refractory probe on right.

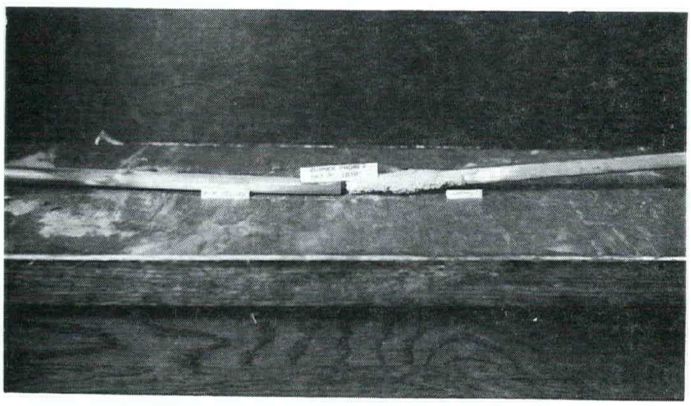


Figure 1d

Burner deposition probes. Air cooled probe of left. Refractory probe on right.

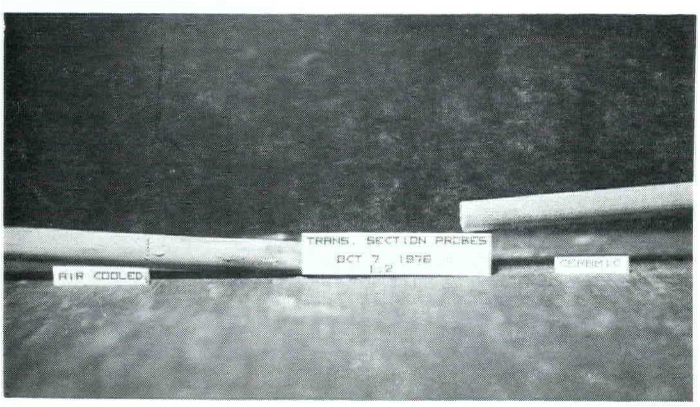


Figure 1e

Transition section deposition probes. Air cooled probe on left. Refractory probe on right.

PROGRESS REPORT 1:2C

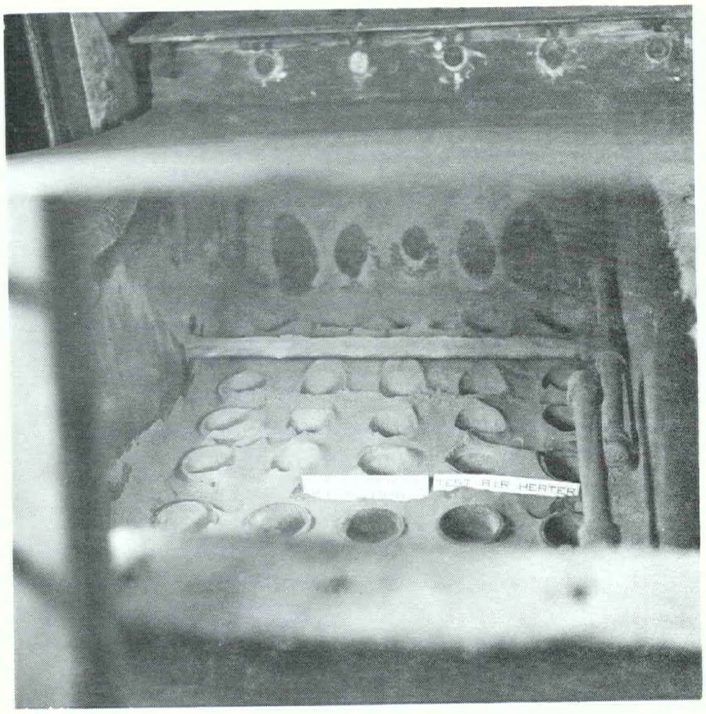


Figure 1f

Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 1:2C

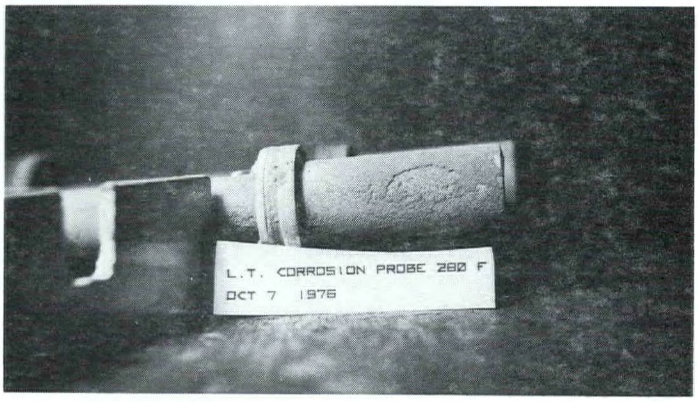


Figure 1g

Low Temperature corrosion probe 138°C.

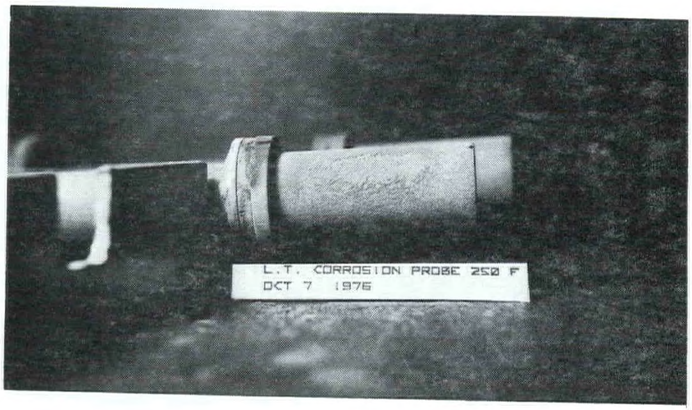


Figure 1h

Low Temperature corrosion probe 121°C.

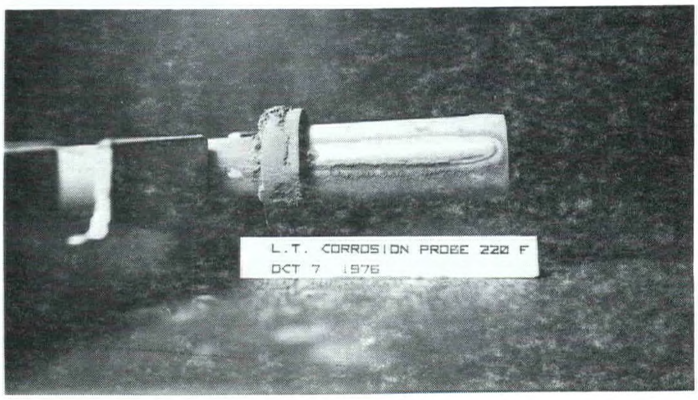


Figure 1i

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	131 °C	104 °C	426 °C	444 °C	473 °C
Deposition rate[a/]						
Fe	0.0	0.4	0.4	0.6	0.6	0.0
Mg	0.4	0.3	0.3	1.6	1.6	1.0
Na	0.9	0.9	1.1	24.3	52.8	44.2
Ca	18.7	12.4	15.0	83.4	84.5	71.8
SO_4 (total)	22.9	26.0	21.5	182.9	287.4	250.3
SO_4 (free), by difference						

[a/] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposition probes, test 1.2

Station	Furnace Bottom				Boiler				Transition Section			
Material	SS		REF		SS		REF		SS		REF	
Mean Temperature °C	219		613		229		435		245		361	
% Water Soluble	4.2		3.3		16.1		5.6		8.0		15.9	
% Acid Insoluble	59.2		80.1		40.0		71.4		49.2		46.5	
Analysis , %	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS
SO_4	1.8		0.0		8.0		2.4		3.6		9.7	
Ca	1.0	7.0	2.1	2.1	1.1	4.0	0.8	4.7	1.6	9.1	3.6	4.7
Fe	1.6	3.5	0.9	0.9	2.4	5.6	0.2	2.1	0.1	3.6	0.2	3.2
Mg	0.1	0.6	--	0.1	0.1	0.7	--	0.4	--	0.8	0.2	0.6
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Na	0.1	1.4	---	0.4	1.1	2.4	---	0.2	0.2	1.8	0.4	1.6

WS = water soluble

AS = acid soluble

--- = trace

Sample: Deposit from Furnace Bottom, Test 1.2, (A1044-76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1338	1332
Spherical	°C	1371	1360
Hemispherical	°C	1393	1388
Fluid	°C	1449	1432

Ash Analysis	%
SiO_2	52.92
Al_2O_3	25.22
Fe_2O_3	4.11
Mn_3O_4	----
TiO_2	0.71
P_2O_5	0.33
CaO	12.31
MgO	1.26
SO_3	0.08
Na_2O	1.15
K_2O	0.27
Cl	----

Sample: Deposit from furnace walls, Test 1.2, (A 1045-76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1338	1299
Spherical	°C	1360	1349
Hemispherical	°C	1382	1382
Fluid	°C	1399	1421

Ash Analysis	%
SiO_2	51.36
Al_2O_3	23.97
Fe_2O_3	4.92
Mn_3O_4	----
TiO_2	0.66
P_2O_5	0.36
CaO	11.80
MgO	1.31
SO_3	2.39
Na_2O	1.35
K_2O	0.24
Cl	----

Sample: Deposit from screen tubes, Test 1.2, (A 1046 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1271	1238
Spherical	°C	1299	1271
Hemispherical	°C	1321	1299
Fluid	°C	1382	1382

Ash Analysis	%
SiO_2	45.52
Al_2O_3	21.97
Fe_2O_3	5.06
Mn_3O_4	----
TiO_2	0.87
P_2O_5	0.38
CaO	17.70
MgO	1.95
SO_3	1.65
Na_2O	2.67
K_2O	0.30
Cl	----

Sample: Deposit from transition section, Test 1.2 (A 1047 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1321
Spherical	°C	1382	1371
Hemispherical	°C	1399	1399
Fluid	°C	1410	1432

Ash Analysis	%
SiO_2	53.27
Al_2O_3	24.80
Fe_2O_3	4.16
Mn_3O_4	----
TiO_2	0.65
P_2O_5	0.35
CaO	11.25
MgO	1.09
SO_3	1.61
Na_2O	1.26
K_2O	0.23
Cl	----

Sample: Deposit from sheet between 2nd and 3rd passes of air heater
Test 1.2 (A 1048 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1310	1288
Spherical	°C	1349	1321
Hemispherical	°C	1377	1388
Fluid	°C	1432	1410

Ash Analysis	%
SiO_2	49.55
Al_2O_3	23.53
Fe_2O_3	4.67
Mn_3O_4	----
TiO_2	0.84
P_2O_5	0.34
CaO	15.51
MgO	1.51
SO_3	0.51
Na_2O	1.57
K_2O	0.28
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Sundance Coal
Fired as Received, 3% Excess Oxygen

PROGRESS REPORT 1.2D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (1.2D) is the last of the series and presents results of the following detailed analyses of ash produced in test 1.2 done on October 7, 1976.

1. Particle size distribution of fly ash

2. Combustion calculations

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter	———	1.1
1.59 - 2.00		———	1.2
2.00 - 2.52		———	1.8
2.52 - 3.17		———	2.5
3.17 - 4.00		0.1	4.1
4.00 - 5.04		0.2	5.6
5.04 - 6.35		0.4	7.5
6.35 - 8.00		0.7	9.2
8.00 - 10.08		1.7	12.3
10.08 - 12.7		3.4	13.4
12.7 - 16.0		6.1	12.3
16.0 - 20.2		9.9	10.7
20.2 - 25.4		12.7	6.9
25.4 - 32.0		15.7	4.2
32.0 - 40.3		13.9	2.2
40.3 - 44.0		5.6	2.0
44.0 - 74.0	Sieve	25.8	2.4
+ 74.0		3.8	0.6

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
% PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL - WRL

OPERATOR:

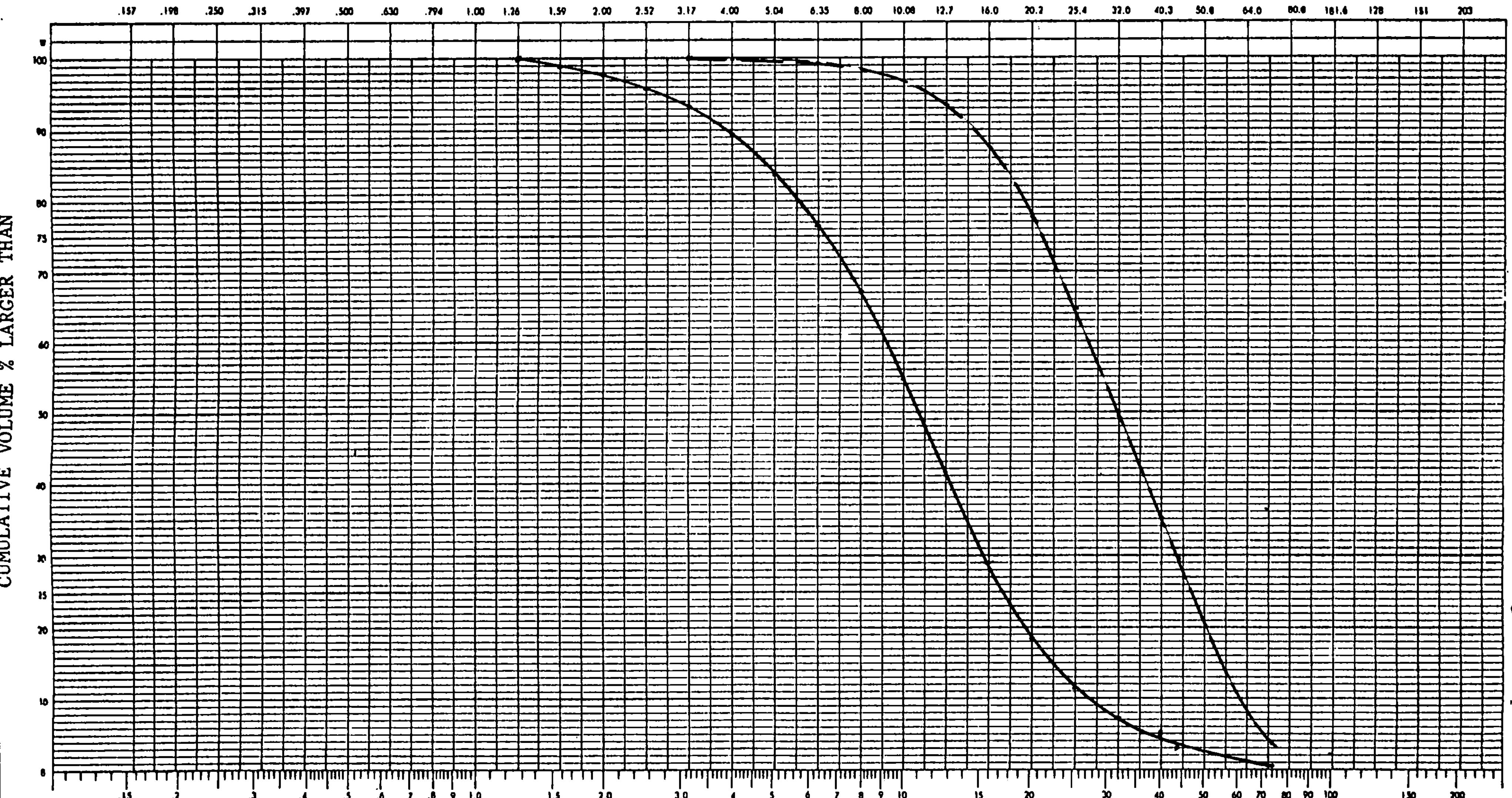
EQUIPMENT:

$k = d\sqrt[3]{2^w}$ — $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$ — FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ — FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 1.2	Isoton	Ultrasonic	100μ	6102033									
ESP ———													
AHR - - -													



4221010

Progress Report 1.2D

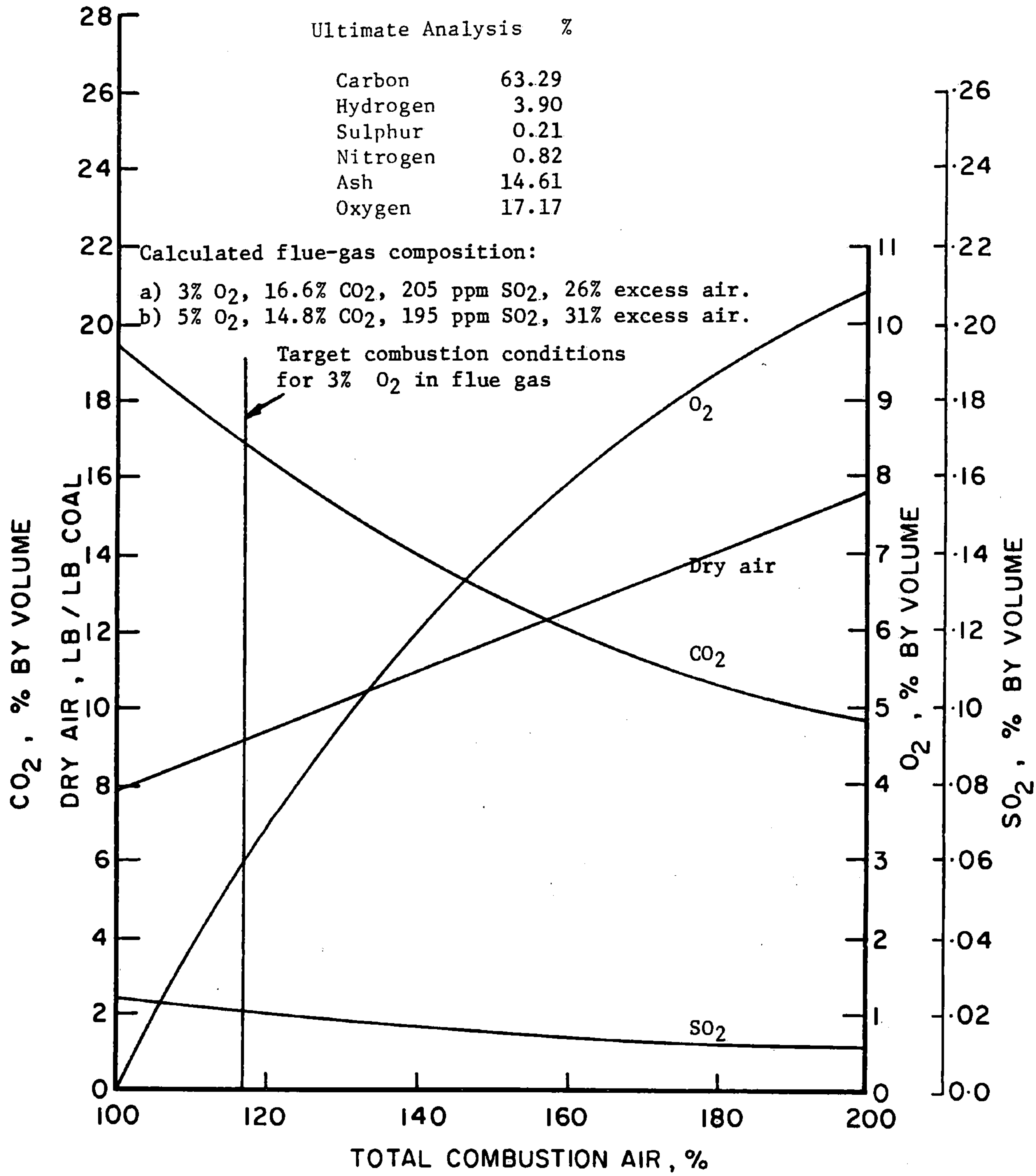


FIGURE 1: Combustion Calculations "Sundance" Coal.

Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology / Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "A" RAW COAL

KILN-DRIED TWICE, 5% EXCESS OXYGEN

TEST NO. 2.1

CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/108 -111

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 2.1A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 2.1, which was done on October 12, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 2.1

In this test, Hat Creek "A" raw coal was burned. The coal had been kiln-dried twice, which reduced the moisture content, as fired, to 7%. The ash content at this moisture level was 58.7%. The target level of excess oxygen in the flue gas was 5% (approx 25% excess air), and the target coal-feed rate was 196 kg/hr, but the actual feed rate was limited by pulverizer capacity to approximately 155 kg/hr. The corresponding heat input was roughly 1.6 Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1 which is a diagram of the research boiler.

Furnace During Test

At 0900 hr, stable, unsupported combustion had been in progress for 1½ hr. The flame was observed to be yellow-orange in colour and to fill the entire furnace. Due to the high dust loading, it was also very opaque. From the top of the furnace, the throat was not visible, nor were the furnace deposition probes. Even the tubes forming the nose at the furnace exit were partly obscured. It was difficult to assess flame length; that is, the flame that appeared to fill the furnace may not have been burning coal particles, but glowing ash particles. The latter possibility is supported by the fact that there was not sufficient light in the transition section (between the furnace and air-heater) to see the tubes in the test air-heater.

At 0930 hr, the furnace bottom appeared to be filled with sintered ash, which blocked one sight port. The first attempt to dump ash into the quench tank failed because the ash bridged across the furnace just below the burners. Initial attempts to loosen it with a poker, working through the top of the furnace and the ports in the furnace bottom, with the furnace in operation, were unsuccessful. The ash rapidly built up to the burner level, and interfered with combustion to the extent that furnace pressure began to pulse.

At 1010 hr, the furnace was shut down and the sintered ash deposits were broken loose with a poker. They had formed a fairly strong bridge, but came away cleanly from the throat refractory.

The furnace was then relit using light oil burners, and the dump plates were left open, i.e., in the dump position. At 1110 hr, unsupported coal combustion was resumed. The flame then had much the same appearance as before, except that the throat was faintly visible from the top of the furnace. The opacity of the flame, or the high dust loading, made it impossible to see across the furnace bottom. Even the deposition probes located there were barely visible. Ash was raked out of the quench tank every 15 min. It had the consistency of fine mud and appeared to be well burned out. There was no evidence of sintering.

At 1120 hr, the dump plates were partly closed to reduce the radiation loss from the flame to the quench tank. The only effect on the appearance of the flame was that the throat could no longer be seen from the top of the furnace. It was occasionally possible to see across the furnace bottom, and these glimpses revealed a moderate layer of sinter on the refractory walls. Dust frequently cascaded into the furnace from the sloped tubes at the furnace exit, indicating heavy deposits of dry fly ash. Ash removed from the quench tank continued to be in the form of fine mud until the test was terminated at 1615 hr. When the oil torch was turned off on shut-down, the furnace was almost immediately black. The glow from the hot refractory and ash was too faint to reveal any details of the furnace interior.

Deposition Probes During Test

Only the air-cooled deposition probe in the furnace bottom was visible during the test. It developed a few deposits of sinter roughly 7 mm thick on the top surface. These fell off from time to time.

Furnace After Test

Inspection of the refractory in the furnace throat revealed one deposit of fairly hard sinter, approximately 25 by 30 cm and 8 to 10 cm thick. The rest of the throat was clean except for a few whiskers of sinter.

The furnace bottom was clean except for one side, which had a deposit of fairly strong sinter, roughly 30 cm square and 8 to 10 cm thick. The furnace water walls had a heavy deposit of dust which fell off readily. There was a layer of dust 20 to 25 cm thick on the bottom of the transition section, and 5 to 8 cm of dust on the 2nd pass tube sheet of the main air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace bottom bore a light layer of dust, and there were indications of a deposit on the upper surface having fallen off.

The refractory probe in the furnace bottom was broken, but bore a few small whiskers of sinter.

The air-cooled probe in the furnace was covered by a 3 mm thick, tan coloured powder on the upstream side and 6 mm thick, grey coloured powder covering a ½ mm thick, tan coloured scale.

The refractory probe in the furnace and the refractory probe in the transition section were of similar appearance. Each was covered lightly by a tan coloured scale.

The air-cooled probe in the transition section was evenly covered by 2 mm thick, tan coloured powder which could be removed by tapping the probe gently.

Test No. 2.1

Progress Report 2.1A

Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "A" RAW, DOUBLE DRIED EXCESS O_2 5 %

12/10/76

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		4	hours	After stable ignition obtained
Firing Rate		155(5)	kg/hr	
Moisture Content of Coal	1	7.1	%	feed to pulverizer
" " " "	2	0.6	%	feed to furnace
Combustible " " "	2	45.2(0.3)	%	dry weight
Ash Dumping Frequency		once every ——	hour	continuous dumping
PULVERIZER OPERATING CONDITIONS				total ash dumped = 86 Kg
a) Inlet Air Pressure	3	291(4)	mmH_2O	equivalent to 1268 Kg coal
b) Outlet Air Pressure	2	245(5)	mmH_2O	
c) Inlet Air Temperature	3	191(3)	^oC	
d) Outlet Air Temperature	2	104(1)	^oC	
e) Coal Fineness	2	76% below 200 mesh		oversize, 14.2% 140 mesh
BOILER OPERATING CONDITIONS				" , 23.9% 200 mesh
a) Steam Flow	6	467(9)	kg/hr	" , 98.2% 325 mesh
b) Steam Pressure	6	2.68(0.05)	atmospheres	
c) Combustion Air Temp.	4	183(5)	^oC	
d) Furnace Pressures				
Furnace	10	42(2)	mmH_2O	
Inlet	11	42(2)	mmH_2O	
Boiler Exit	12	22(2)	mmH_2O	
Primary (Coal) Air L	5	162(5)	mmH_2O	
" R	5	——	mmH_2O	meter error
Secondary (Windbox) Air L	4	50(4)	mmH_2O	
" R	4	50(3)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	14.8(0.4)	%	
b) O_2	11	5.3(0.2)	%	
c) CO	11	191(36)	ppm	
d) NO	13	276(34)	ppm	
e) SO_2	14	909(45)	ppm	
f) SO_3	14	1.3(0.2)	ppm	accuracy limits of 1 ppm
g) Acid dewpoint	18	22	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	612(12)	^oC	
b) Boiler Exit	12	289(9)	^oC	
c) Precipitator Entry	16	201(5)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	980, 1020	^oC	readings taken in second and third two hour period
b)	8	810, 910	^oC	
c)	9	780, 870	^oC	
FLY ASH				
a) Loading	16	34000(11000)	$mgms/m^3$	measured at 20^oC
b) Resistivity	15	$3.6(1.4)x10^{11}$ Ω cm at 257^oC		
"	17	$7.8(2.9)x10^{11}$ Ω cm at 156^oC		
c) Precipitator efficiency	18	91(7)	%	Before duct modification which should prevent jetting of flue gas through plates
d) Combustible content of ash collected from precipitator	18	2.0(0.4)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	928	16	892	943	892	914	Probe broken, no deposit
	stainless	559	20	523	585	523	549	Light tan powder downstream, 2 mm thick. Grey powder adheres upstream, ½ mm thick.
Furnace 9	ceramic	835	40	736	889	736	869	Light tan scale upstream
	stainless	549	34	495	615	552	495	Tan powder downstream, 3 mm thick. Grey powder, 6 mm thick, covers tan crust ½ mm thick, upstream.
Transition Section 20	ceramic	619	16	583	633	583	628	Light tan scale
	stainless	534	29	498	588	534	518	Tan powder, 1 mm thick over entire probe, even, easily removed by tapping.

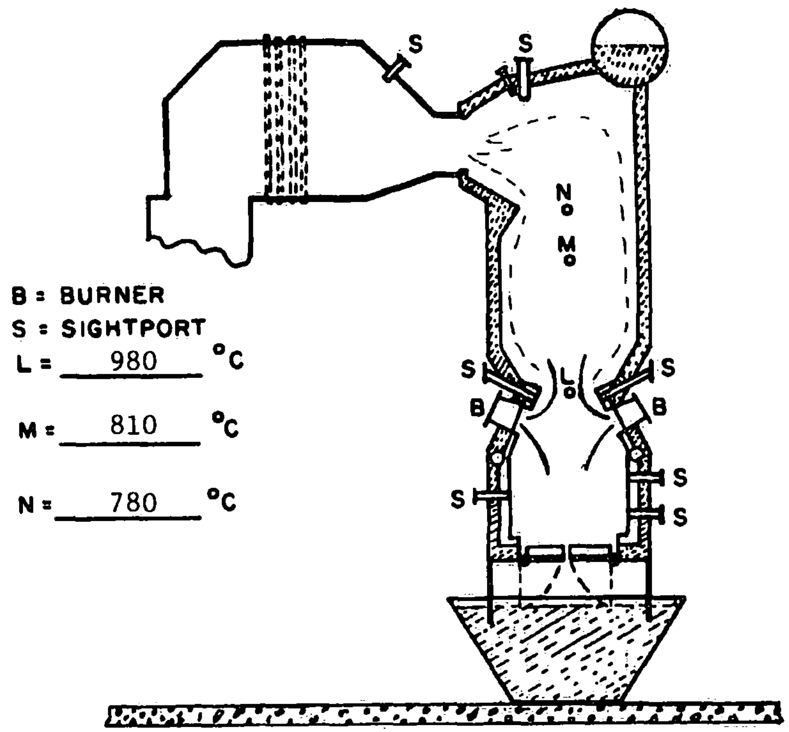


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET
JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 2.1B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (2.1B) presents coal analyses and size distribution of the pulverized coal burned in test 2.1 done on October 12, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

3048-76

A-1053

CCRL

Hat Creek "A-Raw" (2.1) 5% Oxygen

21-12-76

SAMPLE CONDITION		AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis			
Moisture		6.94	0.00
Ash		48.47	52.08
Volatile Matter		23.30	25.04
Fixed Carbon (by Diff.)		21.29	22.88
Ultimate Analysis			
Carbon	%	28.48	30.60
Hydrogen	%	2.40	2.58
Sulphur	%	1.04	1.12
Nitrogen	%	0.58	0.62
Ash	%	48.47	52.08
Oxygen (by Diff.)	%	12.09	13.00
Calorific Value			
Calories per gram		2517	2705
B.T.U. per Lb. gross		4531	4868
Caking Properties			
By Vol. Button @			
Swelling Properties			
Free Swelling Index (ASTM)			
Ash Fusibility, °F		OXID.	RED
Initial Deformation	°F	2700+	2520
Softening-Spherical	°F	2700+	2700+
Softening-Hemispherical	°F	2700+	2700+
Fluid	°F	2700+	2700+

SCREEN ANALYSIS

Mesh Inches	%
1/4 x 3/8	0.00
3/8 x 1/8	0.26
1/8 x 1/16	16.46
1/16 x 1/32	28.09
1/32 x 0	55.19

Grindability Index (Hardgrove): 61

Equilibrium Moist (97% Hum), %: 21.66

Sulphur Forms:

Sulphate	0.12
Pyritic	0.47
Organic (by Diff.)	0.45
Total	1.04

Specific Gravity in ash: 2.64

ASH ANALYSIS

Component	%	Component	%
SiO_2	56.18	CaO	1.23
Al_2O_3	28.26	MgO	1.34
Fe_2O_3	6.69	SO_3	0.97
Mn_3O_4	0.30	Na_2O	0.47
TiO_2	0.89	K_2O	0.94
P_2O_5	0.13		

Chlorine: 0.01

Trace Mercury:

TEST NO: 2.1

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			1.5	
100M x 140M	14.9	0.7	6.8	65.1
140M x 200M	9.3	0.5	9.2	52.9
200M x 325M	54.1	20.8	18.8	49.7
325M x 0	21.9	20.6	63.6	42.2

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 2.1C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program.

This progress report (2.1C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 2.1 done on October 12, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 2:1C

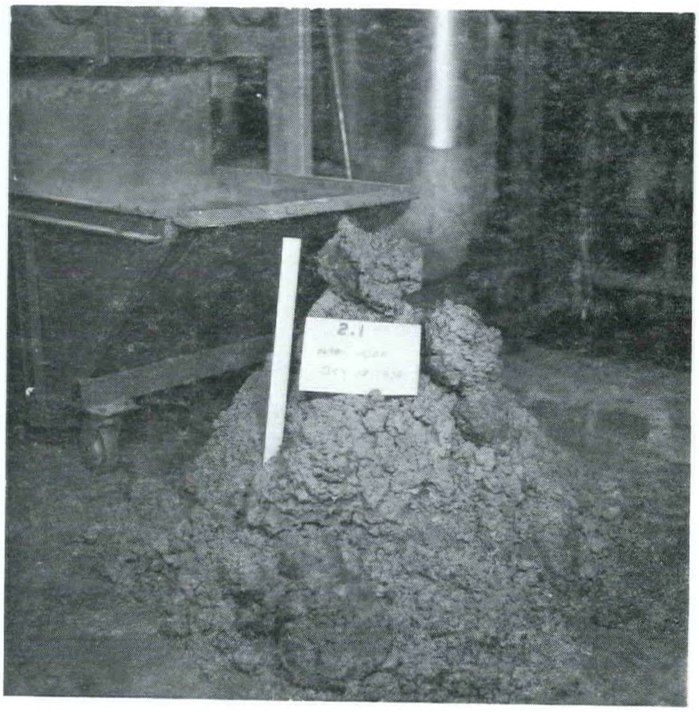


Figure 1a

Quench tank at bottom of burner. Forms a water seal to maintain furnace pressure. Dump plates have been swung open and loose friable sinter has been raked out on the floor.

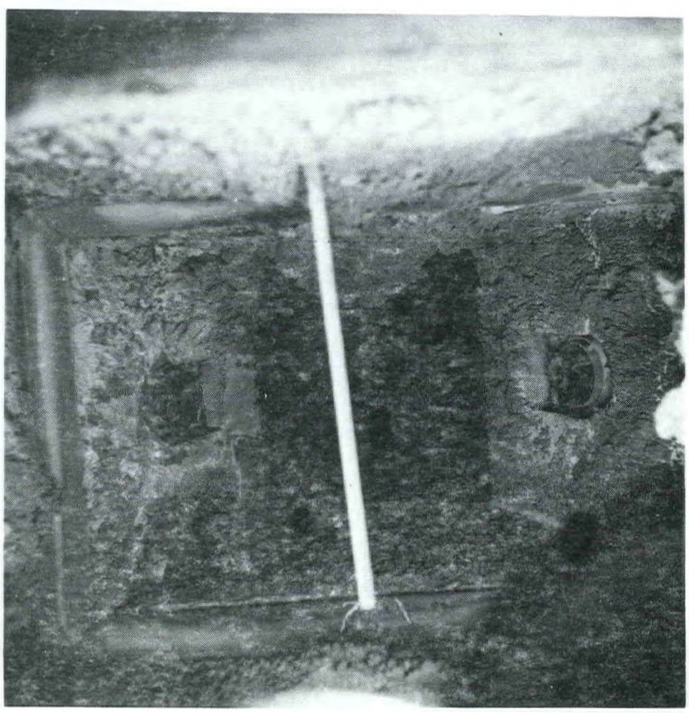


Figure 1b

Furnace bottom at end of test. Loose friable sinter is on east wall (top of photo). Air cooled probe in foreground projects from east wall.

PROGRESS REPORT 2:1C

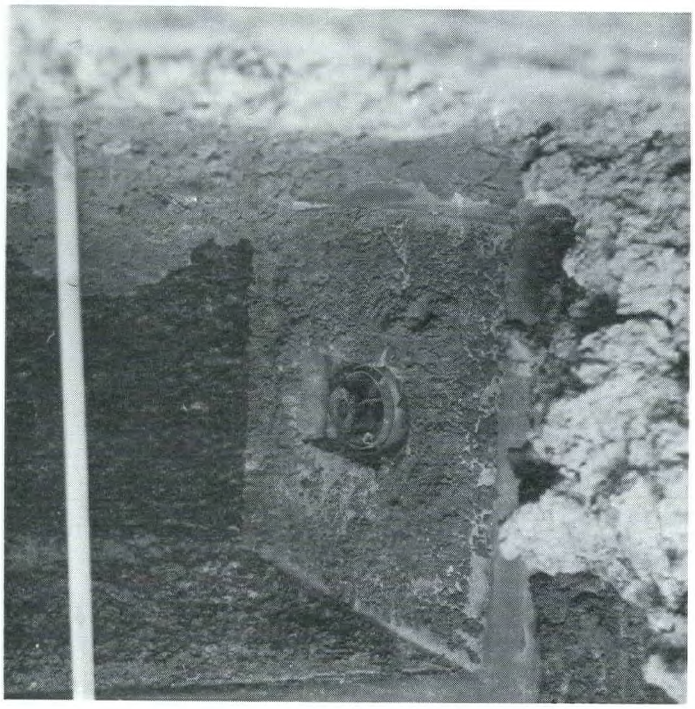


Figure 1c

Furnace bottom at end of test. Burners are clear. Friable sinter is easily dislodged. Large sinter in foreground on north wall above ledge near dump plates is shown more clearly in Figure 1 e.

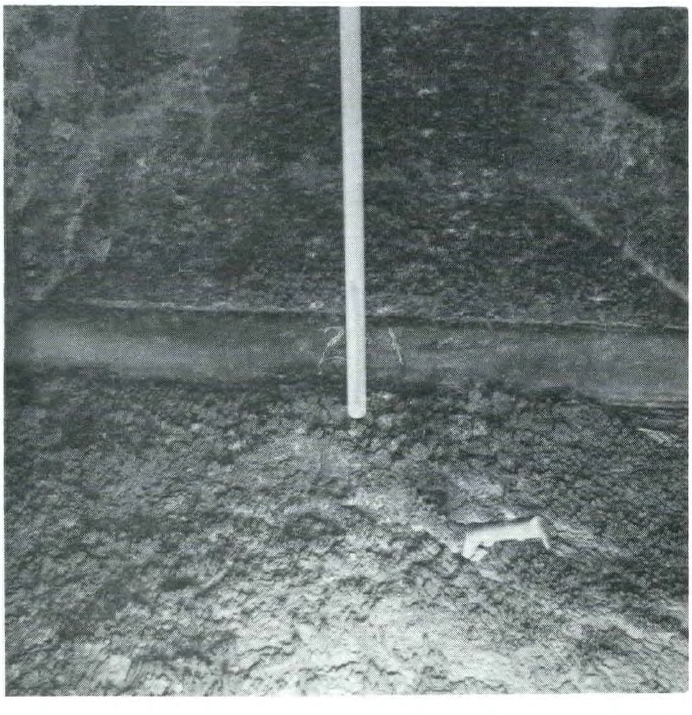


Figure 1d

Furnace bottom at end of test. Refractory probe in foreground is broken and hangs by its thermocouple.

PROGRESS REPORT 2:1C

Figure 1e

Furnace bottom after test. Large sinter in foreground is loose and friable.

PROGRESS REPORT 2.1C

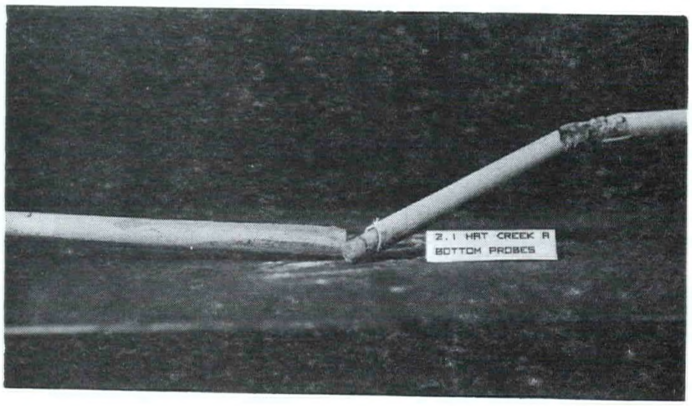


Figure 1f

Furnace bottom deposition probes. Air cooled probe on left. Refractory probe on right.

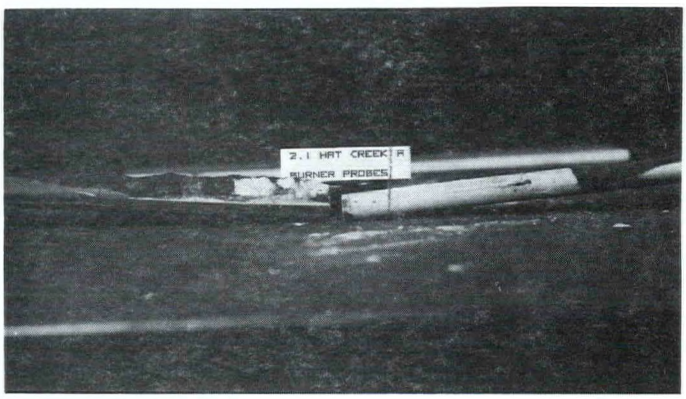


Figure 1g

Burner deposition probes. Air cooled probe of left. Refractory probe on right.

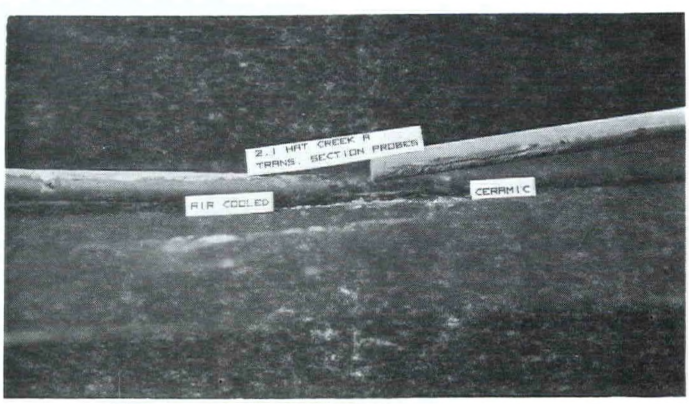


Figure 1h

Transition section deposition probes. Air cooled probe on left. Refractory probe on right.

FIGURE 1i Main air heater tube sheet second pass up to 2 - 3 inches of powder

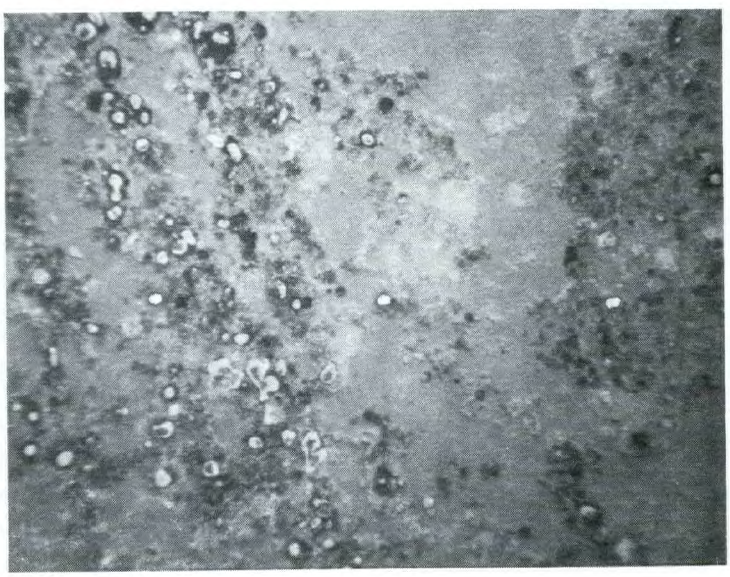


FIGURE 1j Photomicrograph, x 10, of a thin section of sinter which was found attached to the refractory near the burners. The sinter is weak and porous.

PROGRESS REPORT 2:1C

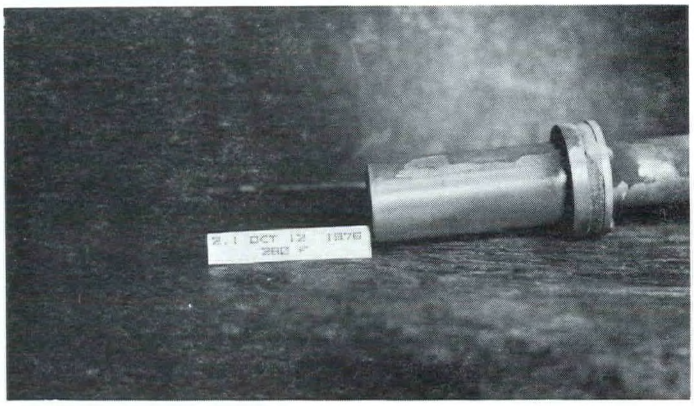


Figure 1k

Low Temperature corrosion probe 138°C.

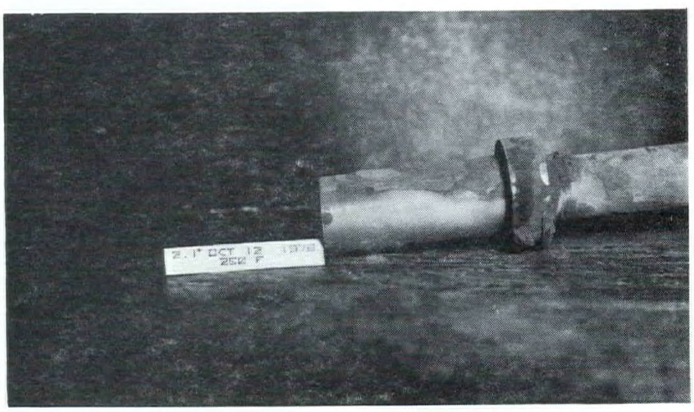


Figure 1L

Low Temperature corrosion probe 121°C.

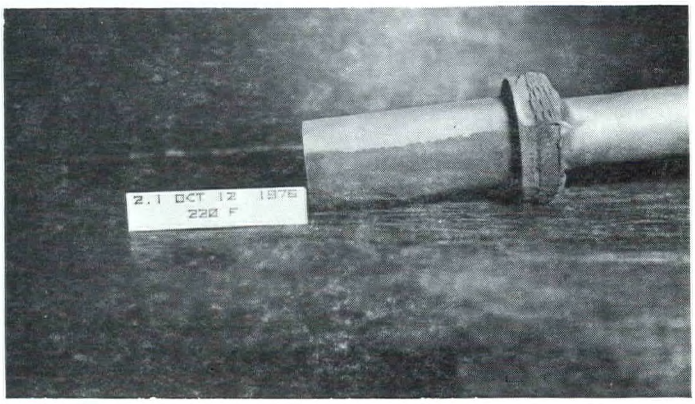


Figure 1m

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	104 °C	121 °C	138 °C	559 °C	549 °C	534°C
Deposition rate[a/]						
Fe	1.0	3.0	1.0	0.0	.6	0.0
Mg	.30	.30	.27	1.5	8.6	1.0
Na	.89	1.12	.66	13.8	32.4	26.6
Ca	16.5	13.4	13.4	110.5	102.5	118.7
SO_4 (total)	58.3	67.3	53.6	84.9	407.1	34.8
SO_4 (free), by difference	13.7	26.5	17.3		58.4	

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposit from the furnace bottom, Test 2.1 (A 1092 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1382	1260
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	60.60
Al_2O_3	29.18
Fe_2O_3	7.58
Mn_3O_4	----
TiO_2	0.99
P_2O_5	0.06
CaO	1.25
MgO	1.01
SO_3	0.44
Na_2O	0.48
K_2O	1.09
Cl	----

Progress Report 2.1 C

Sample: Deposit from the furnace walls, Test 2.1, (A 1093 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1332	1321
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	59.77
Al_2O_3	29.20
Fe_2O_3	7.97
Mn_3O_4	----
TiO_2	1.03
P_2O_5	0.08
CaO	1.41
MgO	1.58
SO_3	1.08
Na_2O	0.47
K_2O	1.04
Cl	----

Progress Report 2.1 C

Sample: Deposit from screen tubes, Test 2.1, (A 1094 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1371	1360
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	58.92
Al_2O_3	28.26
Fe_2O_3	6.53
Mn_3O_4	----
TiO_2	1.10
P_2O_5	0.07
CaO	1.51
MgO	1.32
SO_3	0.97
Na_2O	0.51
K_2O	1.02
Cl	----

Progress Report 2.1 C

Sample: Deposit from transition section, Test 2.1, (A 1095 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1399	1388
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	59.93
Al_2O_3	28.99
Fe_2O_3	7.71
Mn_3O_4	----
TiO_2	0.98
P_2O_5	0.08
CaO	1.15
MgO	1.25
SO_3	0.54
Na_2O	0.43
K_2O	1.06
Cl	----

Sample: Deposit from sheet between 2nd and 3rd passes of air heater

Test 2.1, (A1096 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1299	1188
Spherical	°C	1482+	1471
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	59.74
Al_2O_3	28.96
Fe_2O_3	7.82
Mn_3O_4	----
TiO_2	0.98
P_2O_5	0.07
CaO	1.33
MgO	1.10
SO_3	0.66
Na_2O	0.43
K_2O	1.06
Cl	----

Sample: Deposit from the electrostatic precipitator, Test 2.1, (A1088-9-90-91)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1321	1271
Spherical	°C	1482+	1438
Hemispherical	°C	+	1454
Fluid	°C	+	1482+

Ash Analysis	%
SiO_2	58.76
Al_2O_3	28.19
Fe_2O_3	6.52
Mn_3O_4	----
TiO_2	1.19
P_2O_5	0.08
CaO	1.77
MgO	1.27
SO_3	0.85
Na_2O	0.65
K_2O	1.02
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 2.1D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (2.1D) is the last of the series and presents results of the following detailed analyses of ash produced in test 2.1 done on October 12, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations
3. X-ray diffraction analyses of fireside deposits
4. Summary of DTA studies on fireside deposits

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.3
1.59 - 2.00	Coulter Counter		0.5
2.00 - 2.52	Coulter Counter		0.8
2.52 - 3.17	Coulter Counter		1.1
3.17 - 4.00	Coulter Counter	0.1	1.7
4.00 - 5.04	Coulter Counter	0.2	2.4
5.04 - 6.35	Coulter Counter	0.4	3.3
6.35 - 8.00	Coulter Counter	0.5	4.4
8.00 - 10.08	Coulter Counter	1.2	6.8
10.08 - 12.7	Coulter Counter	2.2	8.9
12.7 - 16.0	Coulter Counter	4.2	10.4
16.0 - 20.2	Coulter Counter	7.9	11.7
20.2 - 25.4	Coulter Counter	12.4	10.6
25.4 - 32.0	Coulter Counter	17.4	8.3
32.0 - 40.3	Coulter Counter	17.3	4.8
40.3 - 44.0	Coulter Counter	4.6	0.9
44.0 - 74.0	Sieve	27.3	14.9
+ 74.0	Sieve	4.3	8.2

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA **PARTICLE SIZE ANALYSIS** .15 – 200μ K PERCENT

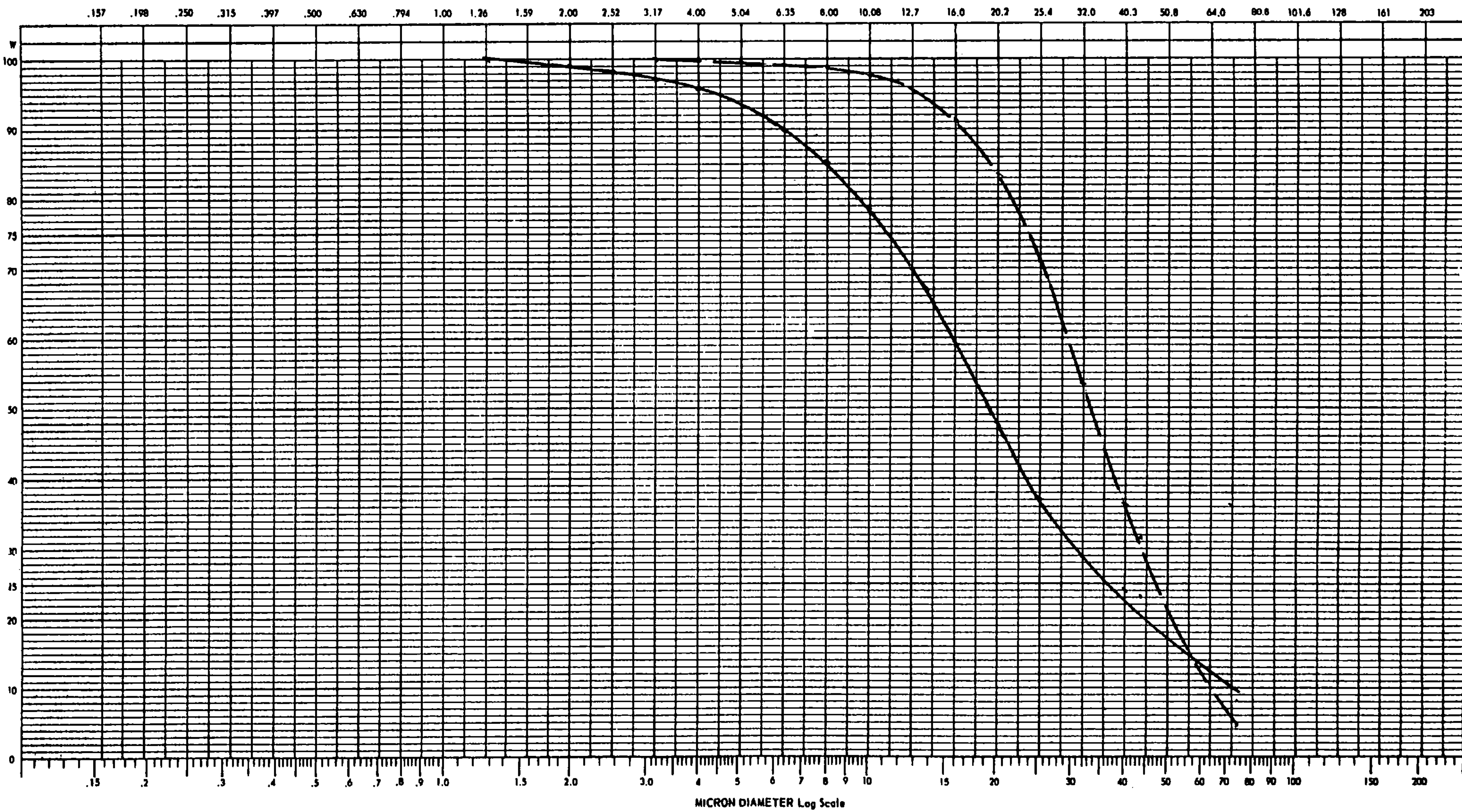
COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION CCRL - WRL				
OPERATOR				
EQUIPMENT				
SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL
TEST No. 2:1	Isoton	Ultrasonic	100μ	6102033
ESP ———				
AH2 — — —				

$k = d\sqrt[3]{2w}$ $\frac{A2}{A1} = \left(\frac{d2}{d1}\right)^3$ when W3 = W1 FOR MODEL T $\frac{A2}{A1} = \left(\frac{d1}{d2}\right)^3$ when W2 = W1 FOR MODEL TA

PART DIA.	W	± IA	A	DIA.	W	± IA	A

SAMPLE SETTINGS



4221010

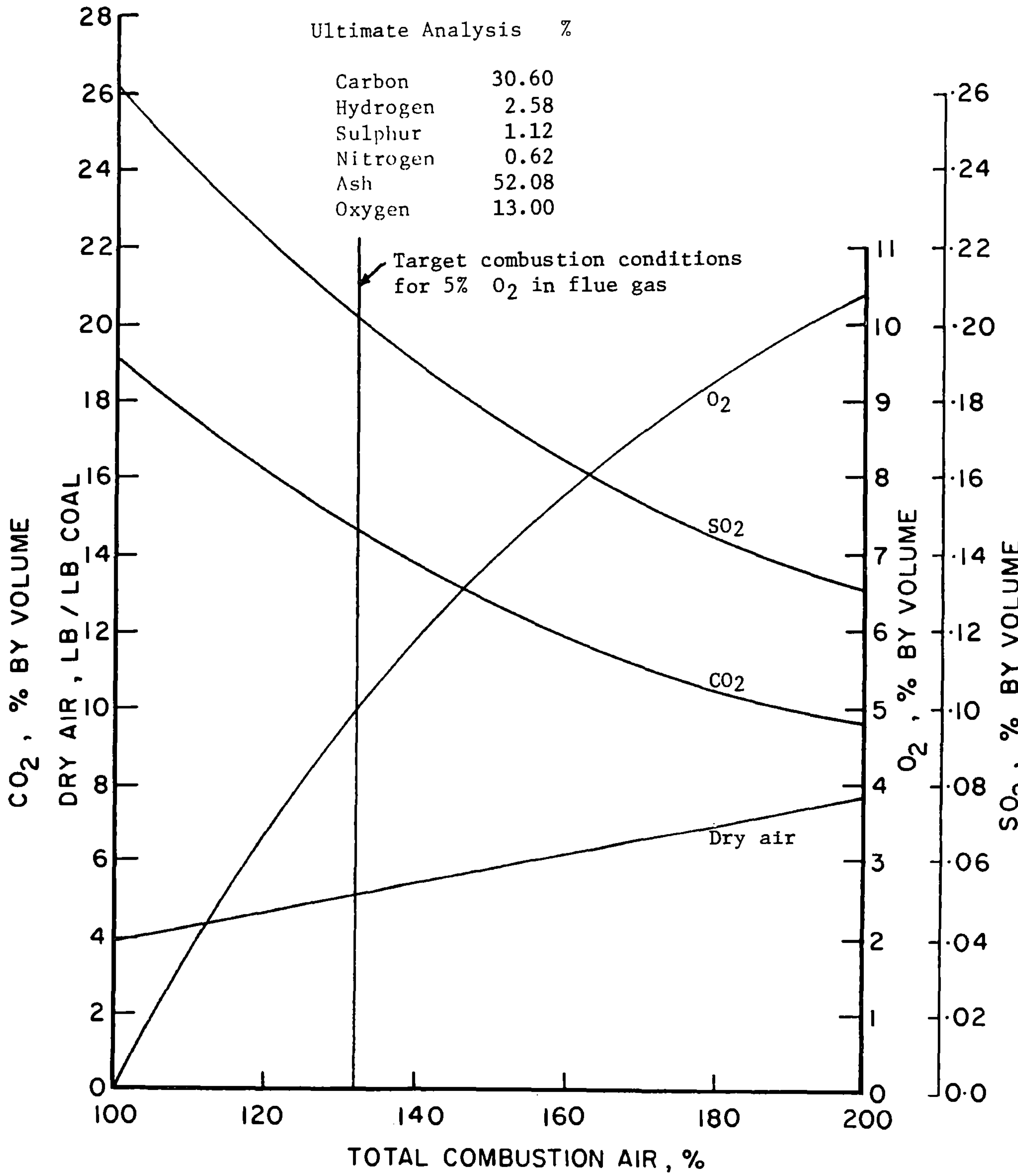


FIGURE 1: Combustion Calculations "A-Raw" Coal.

X-ray Diffraction Analyses of Fireside Deposits from Test 2.1, "A-raw" coal from Hat Creek.

Furnace Bottom Ash (1092 76-433)	Mull, Crist (sm)
Under Flame Probe Deposit (1061 76-463)	Crist, Qtz, Feld, Hem, Mag, Amorph
Furnace Probe Deposit (1062 76-446)	Hem, Crist, Qtz, Mag, Feld
Transition Probe Deposit (1063 76-447)	Hem, Crist, Mull, Qtz, Feld, Amorph

Abbreviations of Constituents:

Feld	Feldspar (Anorthite) $CaO.Al_2O_3.2SiO_2$
Qtz	Quartz SiO_2
Crist	Cristobalite SiO_2
Mull	Mullite $3Al_2O_3.2SiO_2$
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Amorph	Significant amorphous material present

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification.

Constituents are listed in decreasing order of abundance. On occasion "small" is used for clarity.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

SUMMARY OF DTA STUDIES ON FIRESIDE DEPOSITS

Samples:

Five samples of ash from the furnace bottom and one sample of ash collected by the CCRL dust sampler were examined.

Sample 1)	CCRL 980	Test 1.1	Sundance bottom ash.
Sample 2)	CCRL 1092	Test 2.1	Hat Creek A-raw, bottom ash
Sample 3)	CCRL 1190	Test 3.1	Hat Creek A-washed, bottom ash
Sample 4)	CCRL 1278	Test 4.1	Hat Creek B-raw, bottom ash
Sample 5)	CCRL 1360	Test 4.3	Hat Creek B-raw, bottom ash
Sample 6)	CCRL 986	Test 1.1	Sundance fly ash.

Procedures:

Samples weighing approximately 50 mg were heated in a static air atmosphere at 12°C/min. to 1500°C. Two platinum foil pans were held in a vertical furnace, one containing the sample and the other containing α-alumina as reference material. Pt: Pt/13% Rh thermocouples were held with their beads denting the bottom of the pans.

Results:

Sample 1) No peaks were observed. The baseline shifted in the exothermic direction at 1360°C. When cool, the sample was dark and glassy.

Sample 2) No peaks were observed. The baseline shifted in the endothermic direction at 1450°C. When cool, the sample was brown-black opaque, and very hard.

Sample 3) No peaks were observed. The baseline shifted in the endothermic direction at 1340°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 4) No peaks were observed. The baseline shifted in the exothermic direction at 1330°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 5) No peaks were observed. The baseline shifted in the endothermic direction at 1160°C. When cool, the sample was brown, opaque, and appeared to have melted.

Sample 6) A sizable exothermic peak was observed in the 400°C to 500°C range and a small endothermic peak was noted at 1160°C. Cooling and reheating in the range 1000°C to 1500°C failed to show any repetition of the latter thermal effect. When cool, the sample was dark and glassy.

Comments:

It seems certain that samples 1), 5) and 6) underwent melting. The other samples probably had some liquid phase present. The lack of DTA peaks is unusual. It most likely indicates that melting occurred over a very broad range. Cooling to 1000°C and reheating gave rise to no peaks either. The exothermic peak for sample 6) was most likely the result of combustion of a small amount of carbonaceous material.

It can be concluded that DTA is not a very usefull technique for studying these materials.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "A" RAW COAL

KILN-DRIED TWICE, 3% EXCESS OXYGEN

TEST NO. 2.2

CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/112-115

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 2.2A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 2.2, which was done on October 14, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 2.2

In this test, Hat Creek "A" raw coal was burned. The coal had been kiln-dried twice, which reduced the moisture content, as fired, to 7.4%. The ash content at this moisture level was 50.9%. The target level of excess oxygen in the flue gas was 3% (approx 15% excess air), and the target coal feed rate was 196 kg/hr, but the actual feed rate was limited by pulverizer capacity to approximately 155 kg/hr. The corresponding heat input was roughly 1.6 Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is an illustration of the research boiler.

Furnace During Test

At 0830 hr, stable, unsupported coal combustion had been in progress for an hour. The flame was observed to be orange in colour, opaque due to the high dust loading, and appeared to fill the entire furnace. From the top of the furnace the throat was faintly visible on occasion, but the deposition probes in the furnace were not. The tubes forming the nose at the furnace exit were somewhat obscured, and dust frequently cascaded from their upper slope into the furnace. The furnace bottom was fairly clear; through the sight ports the opposite walls were visible and there was no evidence of deposits.

Operation proceeded with the dump plates in the closed position, but ash was dumped every half hour. Ash from the quench tank was mostly in the form of mud and small, weak pieces of sinter. A few larger sinters, roughly 15 cm x 20 cm x 10 cm, appeared from time to time.

The foregoing conditions persisted for the duration of the test, except that after several hours of operation there was some deposit under the throat on the south side of the furnace.

At 1610 hr, support oil burner was inserted prior to shutdown. Some large deposits of sinter could then be seen in the corners of the furnace below the throat.

Deposition Probes During Test

Only the deposition probes in the furnace bottom were visible during the test.

The air-cooled probe developed globules of sinter on the top surface, which would build up to a height of 5 to 15 mm and grow to irregular lengths along the probe. Periodically they would fall off, leaving the probe clean until fresh deposits formed.

The refractory probe was coated all around with a heavy deposit of sinter throughout the test, which gave it an overall diameter that varied with time from 25 mm to 50 mm. The deposit tended to be smooth on top of the probe, and very rough underneath, but there was no indication of melting.

Furnace After Test

Furnace-bottom ash was not dumped during the last hour of the test, and when the dump plates were opened after the boiler had cooled, most of this ash fell, leaving the furnace-bottom walls and the throat refractory clean except for scattered whiskers of sinter 3 to 5 cm long. The ash was in the form of weak sinter, mostly small pieces 1 to 5 cm in diameter, with a few larger pieces, the largest being rougly 30 cm x 30 cm x 20 cm. The furnace water walls were heavily coated with dust; approximately 2 cm thick in the lower half of the furnace and 2 to 4 mm in the upper half. The bottom of the transition section (between the furnace and air-heater) had a layer of fly ash 20 to 25 cm thick, and there were 5 to 8 cm of fly ash on the second-pass tube sheet of the main air-heater. The screen tubes at the furnace exit had a 6 to 12 mm deposit of dust on the downstream side, the test-air-heater tubes had similar but thinner deposits, and there was a 4 mm deposit of dust on the walls of the test air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace-bottom had only light deposits of dust.

The refractory probe in the furnace-bottom was covered with weak sinter whiskers to a total diameter of 2 cm.

The air-cooled probe in the furnace was covered downstream with 1 mm thick, tan coloured powder encased in a friable crust.

The refractory probe in the furnace was clean and appeared to be sand blasted.

The air-cooled probe in the transition section was covered lightly by 1 mm thick, tan coloured dust.

The refractory probe in the transition section was partly covered downstream by an orange coloured scale ($\frac{1}{2}$ mm thick) and some powder adhered near the tip.

Test No. 2.2
Progress Report 2.2A
Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "A" RAW, DOUBLE DRIED EXCESS O_2 3 %

14/10/76

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		156(4)	kg/hr	
Moisture Content of Coal	1	7.4	%	feed to pulverizer
" " " "	2	0.5	%	feed to furnace
Combustible " " "	2	47.4(0.4)	%	dry weight
Ash Dumping Frequency		once every ½	hour	continuous dumping
PULVERIZER OPERATING CONDITIONS				Total ash dumped = 237 kg
a) Inlet Air Pressure	3	295(6)	mmH_2O	equivalent to 1489.5 kg
b) Outlet Air Pressure	2	244(5)	mmH_2O	coal
c) Inlet Air Temperature	3	189(6)	^oC	
d) Outlet Air Temperature	2	97.5(3)	^oC	
e) Coal Fineness	2	76% below 200 mesh		oversize, 15.6% 140 mesh
BOILER OPERATING CONDITIONS				" , 24.4% 200 mesh
a) Steam Flow	6	553(8)	kg/hr	" , 57.7% 325 mesh
b) Steam Pressure	6	2.83(0.06)	atmospheres	
c) Combustion Air Temp.	4	183(6)	^oC	
d) Furnace Pressures				
Furnace	10	42(2)	mmH_2O	
Inlet	11	41(2)	mmH_2O	
Boiler Exit	12	22(2)	mmH_2O	
Primary (Coal) Air L	5	163(4)	mmH_2O	
" R	5	175(3)	mmH_2O	
Secondary (Windbox) Air L	4	46(3)	mmH_2O	
" R	4	46(4)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	17(1)	%	
b) O_2	11	2.9(0.1)	%	
c) CO	11	246(19)	ppm	
d) NO	13	450(24)	ppm	
e) SO_2	14	1158(31)	ppm	
f) SO_3	14	3.4(0.2)	ppm	accuracy 1 ppm
g) Acid dewpoint	18	38(2)	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	572(11)	^oC	
b) Boiler Exit	12	279(5)	^oC	
c) Precipitator Entry	16	149(2)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	1000, 1010	^oC	readings taken in
b)	8	700, 750	^oC	second and third
c)	9	685, 650	^oC	two hour period
FLY ASH				
a) Loading	16	40300(9400)	$mgms/m^3$	measured at 20^oC
b) Resistivity	15	$2.6(1.3)\times10^{11}$ Ω cm at 254^oC		
"	17	$4.8(0.8)\times10^{11}$ Ω cm at 152^oC,		7.4×10^{11} Ω cm at 121^oC
c) Precipitator efficiency	18	96.2(1.3)	%	note comment of 2.1A
d) Combustible content of ash collected from precipitator	18	3.5(0.3)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	1031	(18)	991	1056	1049	1031	Approx 25 mm of crust over most of probe, tan color, friable, easily removed.
	stainless	493	(25)	444	545	545	444	Grey tan powder with isolated lumps of grey crust, slight adherence downstream.
Furnace 9	ceramic	766	(29)	705	828	750	766	75 mm clean tip (sand blasted)
	stainless	527	(36)	437	577	550	545	1 mm tan powder on downstream, some friable crust
Transition Section 20	ceramic	577	(11)	558	595	576	594	Orange scale downstream (½ mm). Some powder adheres near tip.
	stainless	543	(14)	507	563	532	559	Light tan powder, even, 1 mm, no crust.

ADHERES ⇒ NOT EASILY REMOVED BY BRUSH (HAIR)

Test No. 2.2
Progress Report 2.2A
14/10/76

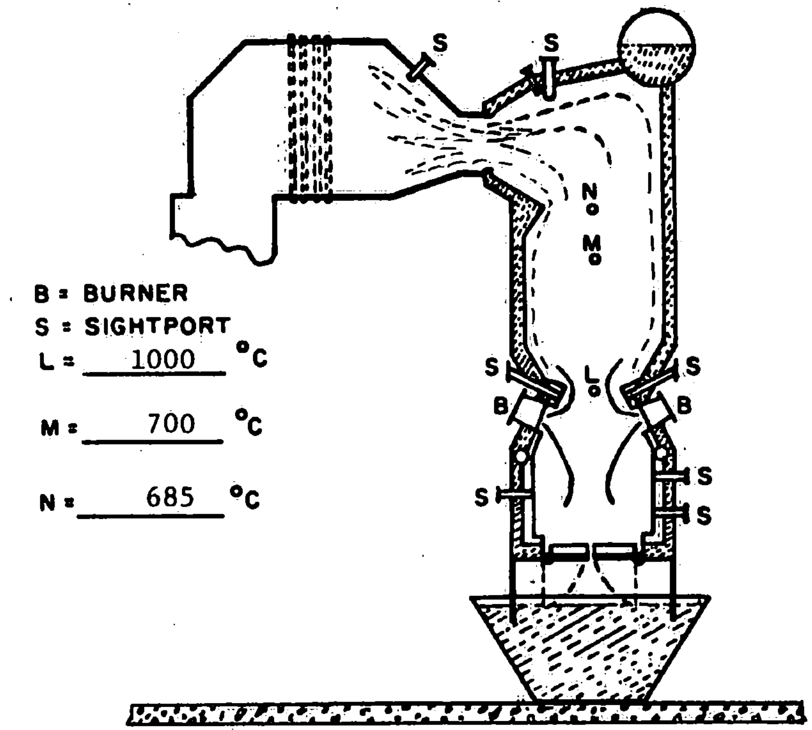


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (2.2B) presents coal analyses and size distribution of the pulverized coal burned in test 2.2 done on October 14, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS 3078-76

CCRL A-1152

Hat Creek (2.2) 21-12-76

SAMPLE CONDITION		AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis			
Moisture		6.69	0.00
Ash		44.22	47.39
Volatile Matter		25.08	26.88
Fixed Carbon (by Diff.)		24.01	25.73
Ultimate Analysis			
Carbon	%	31.88	34.17
Hydrogen	%	2.63	2.82
Sulphur	%	1.01	1.08
Nitrogen	%	0.68	0.73
Ash	%	44.22	47.39
Oxygen (by Diff.)	%	12.89	13.81
Calorific Value			
Calories per gram		2873	3079
B.T.U. per Lb. gross		5171	5542
Caking Properties			
By Vol. Button @			
Swelling Properties			
Free Swelling Index (ASTM)			
Ash Fusibility, °F		OXID.	RED
Initial Deformation	°F	2700+	2570
Softening-Spherical	°F	2700+	2700+
Softening-Hemispherical	°F	2700+	2700+
Fluid	°F	2700+	2700+

SCREEN ANALYSIS

Mesh Inches	%
+ x 1/4	0.00
1/4 x 1/8	0.82
1/8 x 1/16	25.85
1/16 x 1/32	28.70
1/32 x 28M	9.56
28M x 48M	16.61
48M x 0	18.46

Grindability Index (Hardgrove): 58

Equilibrium Moist (97% Hum),%:

Sulphur Forms:

Sulphate	0.13
Pyritic	0.38
Organic (by Diff.)	0.50
Total	1.01

Specific Gravity in ash: 2.64

ASH ANALYSIS

Component	%	Component	%
SiO_2	56.94	CaO	1.51
Al_2O_3	31.38	MgO	1.17
Fe_2O_3	7.53	SO_3	1.10
Mn_3O_4	0.03	Na_2O	0.47
TiO_2	1.31	K_2O	0.79
P_2O_5	0.12		

Chlorine: 0.00

Trace Mercury:

TEST NO: 2.2

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			3.0	
100M x 140M			10.2	66.2
140M x 200M	14.0	2.4	13.0	54.4
200M x 325M			19.9	48.1
325M x 0			53.8	42.3

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 2.2C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (2.2C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 2.2 done on October 14, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

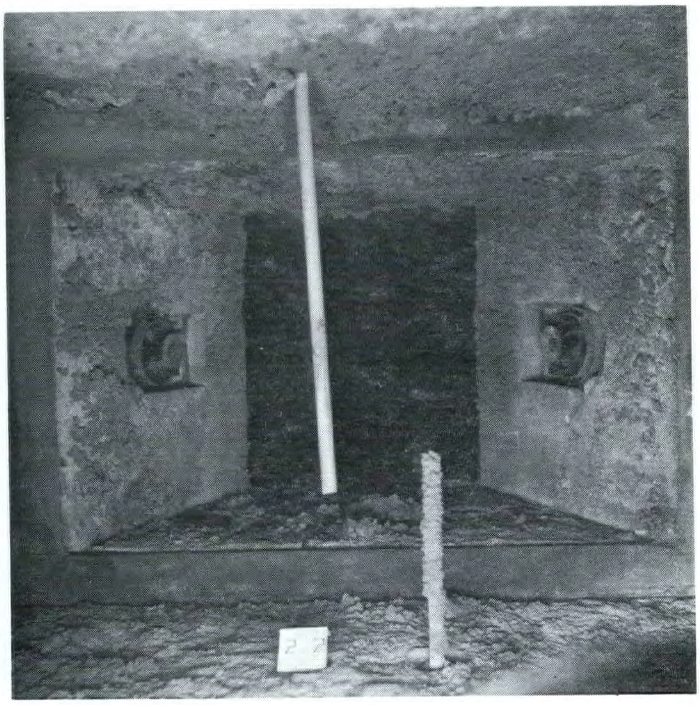


Figure 1a

Furnace bottom at end of test. Burners are clear. Small amount of friable sinter is on east wall (top of photo). Deposition probes are in foreground. Ceramic probe projecting from west wall (bottom of photo) has friable sinter adhereing to it.

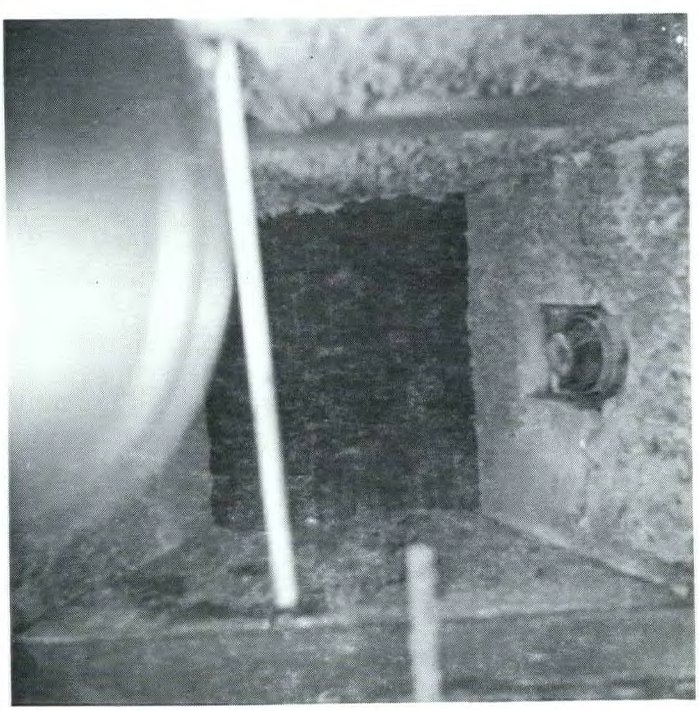


Figure 1b

Furnace bottom at end of test. Throat is clear of sinter.

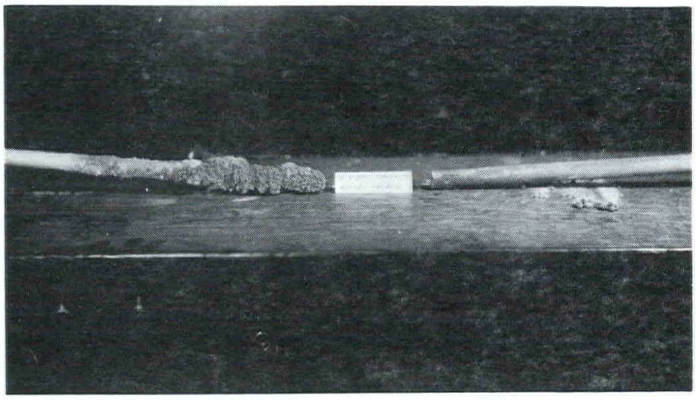


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

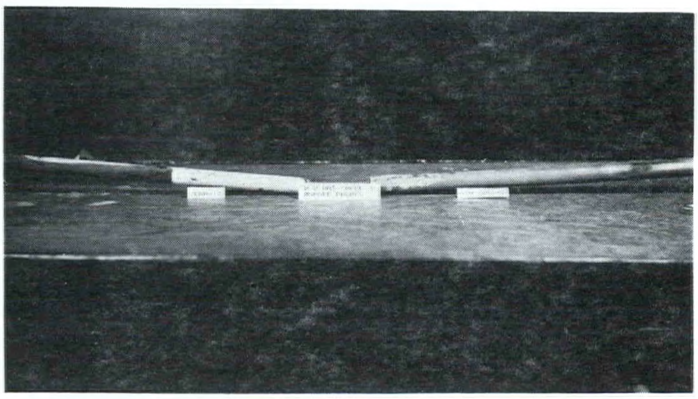


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.

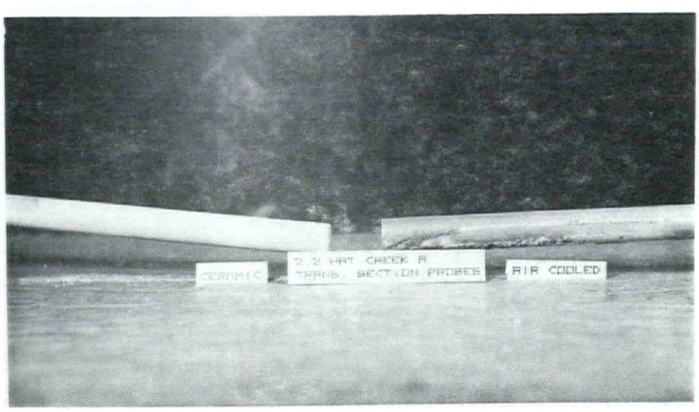


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

PROGRESS REPORT 2:2C

Figure 1f

Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 2:2C

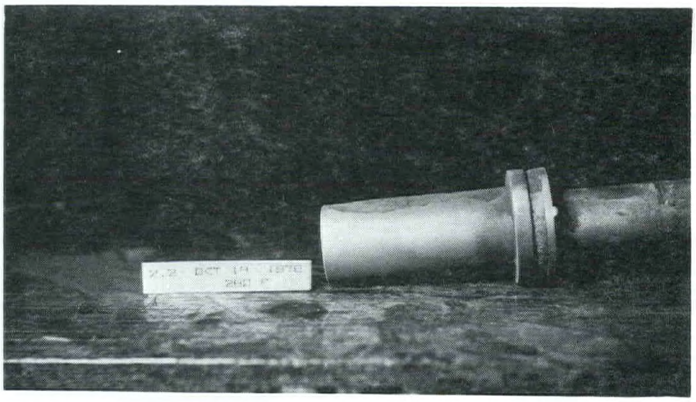


Figure 1g

Low Temperature corrosion probe 138°C.

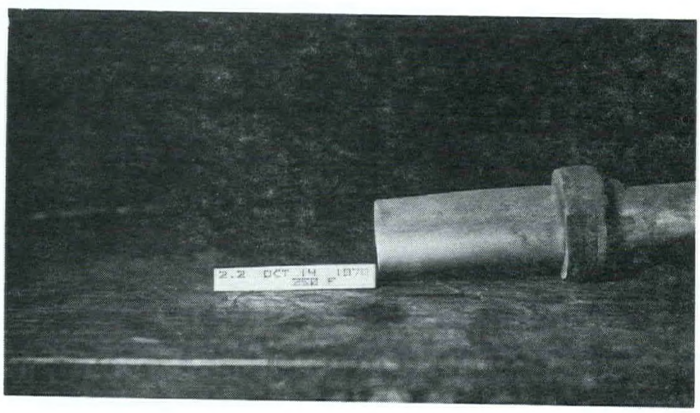


Figure 1h

Low Temperature corrosion probe 121°C.

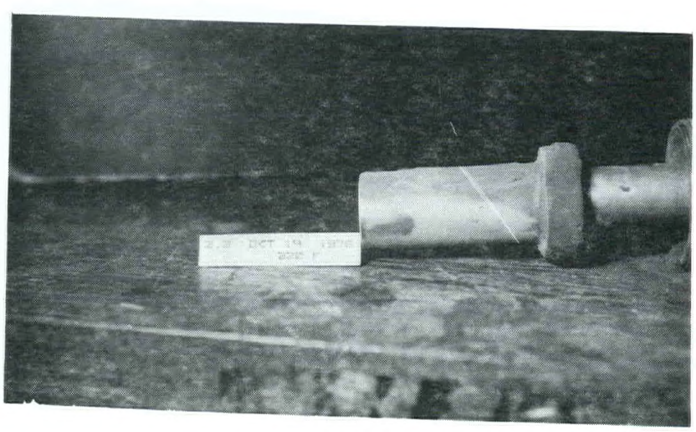


Figure 1i

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138°C	121°C	104°C	493 °C	527°C	543°C
Deposition rate[a]						
Fe	6.9	16.4	8.5	0.0	1.4	0.6
Mg	.35	.33	.32	2.3	12.9	1.0
Na	.66	.45	.45	2.9	4.8	3.9
Ca	11.4	9.4	9.8	103.5	102.5	115.6
SO_4 (total)	39.8	96.5	49.0	109.7	87.1	126.3
SO_4 (free), by difference	NIL	43.5	NIL			

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposition probes, Test 2.2, B. C. Hydro

Station	Furnace Bottom				Boiler				Transition Section			
Material	SS		REF		SS		REF		SS		REF	
Mean Temperature °C	256		555		275		408		284		303	
% Water Soluble	3.5		5.0		3.5		6.5		5.1		---	
% Acid Insoluble	85.0		96.1		72.4		76.2		77.0		---	
Analysis , %	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS
SO_4	1.0		0.0		1.0		0.0		1.8			
Ca	1.2	---	4.4	0.0	1.5	0.0	5.0	0.0	3.6	0.0		
Fe	0.5	4.1	0.6	0.7	1.2	10.6	0.6	4.0	0.2	2.3		
Mg	---	0.2	---	0.1	0.1	0.3	---	0.3	0.1	0.3		
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Na	---	0.1	---	---	0.2	0.1	0.1	0.2	0.2	0.2		

WS = water soluble

AS = acid soluble

--- = trace

Progress Report 2.2 C

Sample: Deposit from the furnace bottom, Test 2.2 (A 1147 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1338	1238
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	61.40
Al_2O_3	30.01
Fe_2O_3	6.54
Mn_3O_4	----
TiO_2	1.08
P_2O_5	0.08
CaO	1.29
MgO	1.40
SO_3	0.14
Na_2O	0.50
K_2O	1.08
Cl	----

Sample: Deposit from the furnace walls, Test 2.2 (A 1148 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1388	1249
Spherical	°C	1482+	1438
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	59.24
Al_2O_3	28.66
Fe_2O_3	8.05
Mn_3O_4	----
TiO_2	0.99
P_2O_5	0.07
CaO	1.34
MgO	1.13
SO_3	0.11
Na_2O	0.53
K_2O	1.05
Cl	----

Progress Report 2.2 C

Sample: Deposit from screen tubes, Test 2.1 (A 1149 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1382	1271
Spherical	°C	1482+	1438
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	59.38
Al_2O_3	28.08
Fe_2O_3	6.84
Mn_3O_4	----
TiO_2	1.13
P_2O_5	0.09
CaO	1.56
MgO	1.56
SO_3	0.83
Na_2O	0.48
K_2O	1.03
Cl	----

Sample: Deposit from transition section, Test 2.2 (A 1150 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1421	1249
Spherical	°C	1482+	1471
Hemispherical	°C	1482+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	58.35
Al_2O_3	27.65
Fe_2O_3	6.86
Mn_3O_4	----
TiO_2	1.01
P_2O_5	0.09
CaO	1.19
MgO	1.48
SO_3	0.37
Na_2O	0.45
K_2O	1.00
Cl	----

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 2.2 (A 1151 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1149
Spherical	°C	1482+	1449
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	57.50
Al_2O_3	27.58
Fe_2O_3	7.22
Mn_3O_4	----
TiO_2	1.05
P_2O_5	0.09
CaO	1.45
MgO	1.13
SO_3	0.55
Na_2O	0.47
K_2O	0.98
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "A" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 2.2D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (2.2D) is the last of the series and presents results of the following detailed analyses of ash produced in test 2.2 done on October 14, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.5
1.59 - 2.00	Coulter Counter		0.7
2.00 - 2.52	Coulter Counter		1.0
2.52 - 3.17	Coulter Counter		1.4
3.17 - 4.00	Coulter Counter	0.3	2.2
4.00 - 5.04	Coulter Counter	0.5	2.9
5.04 - 6.35	Coulter Counter	0.9	3.9
6.35 - 8.00	Coulter Counter	2.2	5.3
8.00 - 10.08	Coulter Counter	5.3	7.7
10.08 - 12.7	Coulter Counter	9.9	10.0
12.7 - 16.0	Coulter Counter	14.9	11.6
16.0 - 20.2	Coulter Counter	18.6	11.2
20.2 - 25.4	Coulter Counter	18.2	9.4
25.4 - 32.0	Coulter Counter	13.3	9.0
32.0 - 40.3	Coulter Counter	6.4	3.9
40.3 - 44.0	Coulter Counter	0.8	0.3
44.0 - 74.0	Sieve	7.7	11.6
+ 74.0	Sieve	1.0	7.4

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA — **PARTICLE SIZE ANALYSIS**

.15 – 200µ X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL - WRL

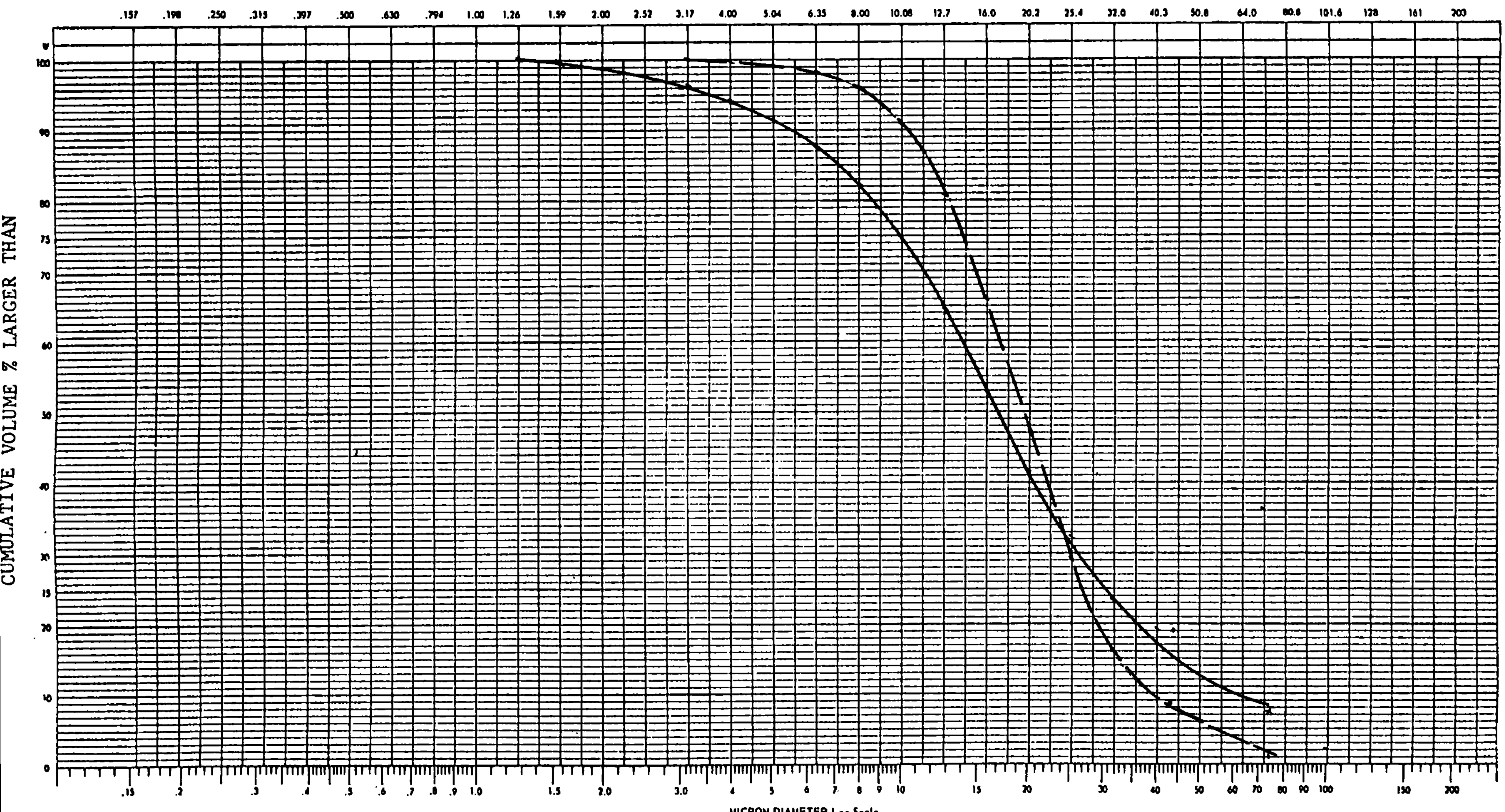
OPERATOR:

EQUIPMENT:

$k = d\sqrt[3]{2w}$ FOR MODEL T; $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$; $\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL	PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 2.2	Isoton	Ultrasonic	100µ	6102033								
ESP ———												
AH2 - - -												



4221010

- 139 -

Progress Report 2.2D

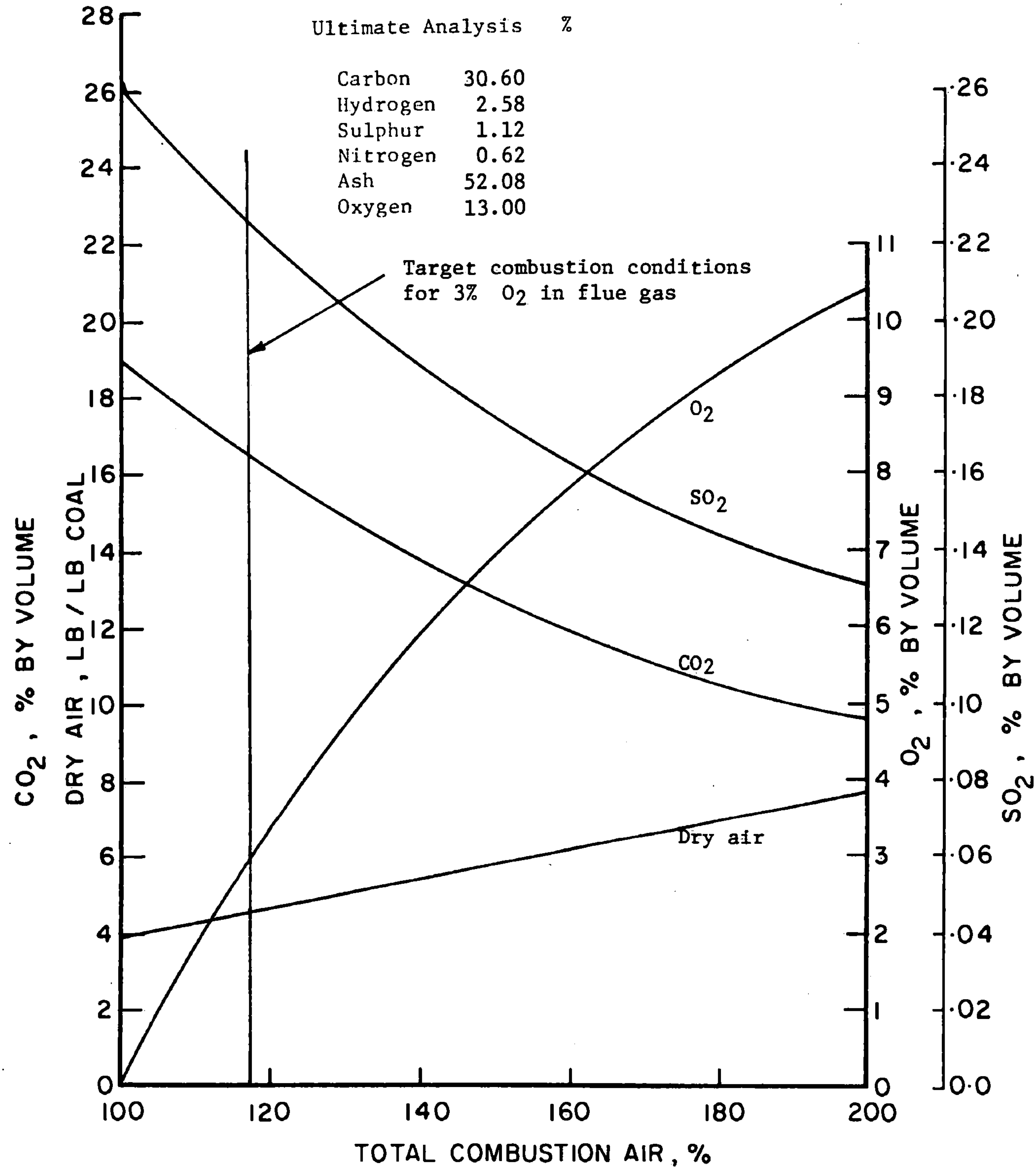


FIGURE 1: Combustion Calculations "A-Raw" Coal.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "A" WASHED COAL

AIR-DRIED AND KILN-DRIED, 5% EXCESS OXYGEN

TEST NO. 3.1

CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/116 -119

PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET
JOINT PROGRAM

TEST NO. 3.1 - HAT CREEK "A" WASHED COAL
AIR-DRIED AND KILN-DRIED, 5% EXCESS OXYGEN

PROGRESS REPORT 3.1A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

INTRODUCTION

By an agreement between the B.C. Hydro and Power Authority (B.C. Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report [2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 3.1, which was done on October 18, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 3.1

In this test, Hat Creek "A" washed coal was burned. The coal had been air-dried and kiln-dried, which reduced the moisture content, as fired, to 16.3%. The target level of excess oxygen in the flue gas was 5% (approx 25% excess air), and the target coal feed rate was 134 kg/hr, which corresponds to a heat input of approximately two Giga Joules per hour.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0830 hr, one hour after stable, unsupported combustion was obtained, the flame was observed to be yellow-orange in colour and fairly opaque. From the top of the furnace the throat was only faintly visible and the furnace deposition probes could not be seen. In the transition section, there was a dull glow by which the tubes of the test air-heater were discernable. The furnace-bottom was bright and transparent; both deposition probes could be seen clearly. Ash was dumped hourly. The ash raked out of the quench tank from the first dump comprised roughly 7 litres and consisted mostly of sinters 2 to 5 cm in diameter.

At 0900 hr, some large pieces of sinter appeared in the furnace-bottom opposite the sight ports. Probably they had fallen off the furnace throat. When these were subsequently removed from the furnace through the dump plates and quench tank, they were found to be three pieces of sinter roughly 20 cm in diameter, and some smaller sinters.

At 1030 hr, sinter could be seen forming under the throat on the south side of the furnace-bottom. From the top of the furnace the flame appeared to be brighter than before. The air-cooled furnace deposition probe was visible, and the furnace throat was visible in detail. Deposits appeared to be developing all around the throat. Combustion occurred mostly below the throat, and only a tail of flame or glowing ash particles was observed in the water cooled portion of the furnace. The deposits on the refractory walls under the furnace throat continued to grow. Occasionally lumps of fairly strong sinter, as large as 40 cm x 35 cm x 20 cm, would fall into the furnace-bottom. When removed by means of normal ash dumping routine, they were found to be dark grey in colour, suggesting a significant carbon content.

At 1045 hr, roughly ¼ of the projected throat area was blocked by sinter, with the heaviest deposits being in the southwest corner and on the west side of the furnace, at or slightly below the level of the burners. Half an hour later, the deposits had almost completely closed the throat from all sides. They were then physically removed with a poker by working through the top of the furnace. They came loose from the walls fairly easily, and about 40 litres of ash were removed in the next ash dumping cycle, although some ash remained on the dump plates. The flame was then hazier, and the radiation pyrometer at the top of the furnace showed a lower flame temperature than earlier.

At 1200 hr, deposits could be seen building anew below the throat on the west wall of the furnace.

At 1250 hr, deposits again blocked roughly ¼ of the projected throat area. The heaviest deposits were on the east wall and in the southwest corner. The furnace-bottom was half filled with ash which had bridged to the extent that when the dump plates were swung open, the ash did not fall into the quench tank until jarred loose with a poker which was inserted through the furnace-bottom ports. A substantial layer of sinter whiskers was visible on the walls of the furnace-bottom.

Combustion conditions continued to be good, but the deposits below the throat continued to grow until the test was completed at 1545 hr. Then, they blocked 2/3 to 3/4 of the projected throat area, and were equally heavy on all sides of the furnace. When an oil support burner was inserted at shut-down, part of the oil spray struck the sinter, and took several minutes to burn off after the oil burner was extinguished. It may be supposed that such heavy deposits similarly affected the pulverized coal jets.

Deposition Probes During Test

Both deposition probes in the furnace-bottom, and the air-cooled deposition probe in the furnace were visible during the test.

The air-cooled probe in the furnace-bottom developed deposits of sinter 3mm to 12 mm thick on the top and whiskers 3 mm to 9 mm on the bottom.

These fell off from time to time, or were knocked off by sinters falling down from the throat. At times the probe was clean.

The refractory furnace-bottom probe had its tip in the field of view in the early part of the test. It had a heavy deposit of sinter all around. It disappeared from view before the deposits under the throat were knocked loose with a poker. Presumably, the probe was broken off by falling sinter.

The air-cooled furnace probe, after it became visible, showed a light layer of dust but there was no evidence of sinter.

Furnace After Test

The refractory in the furnace throat was covered evenly by heavy sinter. The clear projected throat area, from below, was roughly 10 cm x 30 cm. A deposit measuring roughly 40 cm x 40 cm x 40 cm hung from the southwest corner. 15 cm thick deposits hung from the east and west walls, and a 20 cm thick deposit hung from the north wall. The deposit on the east side had broken away from the wall but was supported from below by deposits. Sinter bridged over the top of the south burner. The walls of the furnace-bottom were relatively free of deposit except for the southwest corner.

The furnace water walls bore only a thin layer of dust but approximately 25 mm of dust lay on the upper slope of the nose at the furnace exit. On the bottom of the transition section, there was a layer of grey-brown dust tapering from 10 cm at the furnace exit to 40 cm at the test air-heater. The second-pass tube sheet of the main air-heater bore a 2 to 4 cm layer of charcoal-coloured dust.

Deposition Probes After Test

The air-cooled furnace-bottom probe was clean.

The refractory furnace-bottom probe was broken and hung down the furnace wall from its thermocouple. It bore a 2 cm thick brown coloured sinter all around.

Both furnace probes had a light layer of grey coloured dust on the top surface.

The air-cooled transition section probe had a 1 mm thick deposit of fine, yellow-brown dust all around. There were indications that part of the deposit had fallen off. A thin black layer of dust or soot covered the dust and this was probably due to the distorted oil flame at shutdown.

The refractory transition section probe had a 1 mm thick layer of yellow dust on the downstream side.

Test No. 3.1
Progress Report 3.1A
Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "A" WASHED, DOUBLE DRIED EXCESS O_2 5 %

18/10/76

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		132(5)	kg/hr	
Moisture Content of Coal	1	16.3	%	feed to pulverizer
" " " "	2	3.2(0.6)	%	feed to furnace
Combustible " " "	2	64.2	%	dry weight
Ash Dumping Frequency		once every 1	hour	Total ash dumped 138 kg, equivalent to 1236 kg coal
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	244(14)	mmH_2O	initial 264, final 228
b) Outlet Air Pressure	2	181 (3)	mmH_2O	
c) Inlet Air Temperature	3	191(10)	^oC	
d) Outlet Air Temperature	2	75 (4)	^oC	
e) Coal Fineness	2	87% below 200 mesh		oversize, 8.1% 140 mesh; " , 13.0% 200 mesh; " , 63.2% 325 mesh
BOILER OPERATING CONDITIONS				
a) Steam Flow	6	530(13)	kg/hr	
b) Steam Pressure	6	2.84(0.09)	atmospheres	
c) Combustion Air Temp.	4	182(17)	^oC	
d) Furnace Pressures				
Furnace	10	35(13)	mmH_2O	initial 43, final 23
Inlet	11	34(12)	mmH_2O	" 43, " 23
Boiler Exit	12	16 (6)	mmH_2O	" 20, " 13
Primary (Coal) Air L	5	118 (5)	mmH_2O	
" R	5	127 (4)	mmH_2O	
Secondary (Windbox) Air L	4	53(15)	mmH_2O	initial 63, final 38
" R	4	54(16)	mmH_2O	" 66, " 41
FLUE GAS ANALYSIS				
a) CO_2	11	16.9(0.4)	%	
b) O_2	11	5.1(0.1)	%	
c) CO	11	115(24)	ppm	
d) NO	13	595(57)	ppm	
e) SO_2	14	967(45)	ppm	
f) SO_3	14	3.3(0.4)	ppm	
g) Acid dewpoint	18	34 (4)	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	631(9)	^oC	
b) Boiler Exit	12	236(6)	^oC	
c) Precipitator Entry	16	159(15)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	1054, 960	^oC	readings taken in
b)	8	949, 790	^oC	second and third
c)	9	854, 800	^oC	two hour period
FLY ASH				
a) Loading	16	9100(890)	$mgms/m^3$	measured at 20^{o}C
b) Resistivity	15	$8.3x10^{10}$ Ω cm at 321	^oC	
"	17	$5.4(2.1)x10^{11}$ Ω cm at 157	^oC	, 1.5×10^{11} Ω cm at 120^{o}C
c) Precipitator efficiency	18	90(4)	%	
d) Combustible content of ash collected from precipitator	18	4.0(0.4)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic							Probe broken 25 mm thick brown crust all around.
	stainless	444	43	358	505	484	460	½ mm thick mauve powder, adheres upstream and 1 mm thick, tan powder downstream.
Furnace 9	ceramic	860	58	723	903	855	878	Grey powder, ½ mm thick, adheres weakly.
	stainless	462	92	343	585	469	466	Grey powder, 1 mm thick, adheres weakly upstream.
Transition Section 20	ceramic	626	14	624	666	660	630	Tan powder, 1 mm thick, easily brushed off.
	stainless	505	32	466	543	576	466	Beige dust, 1 mm thick, slightly darker downstream.

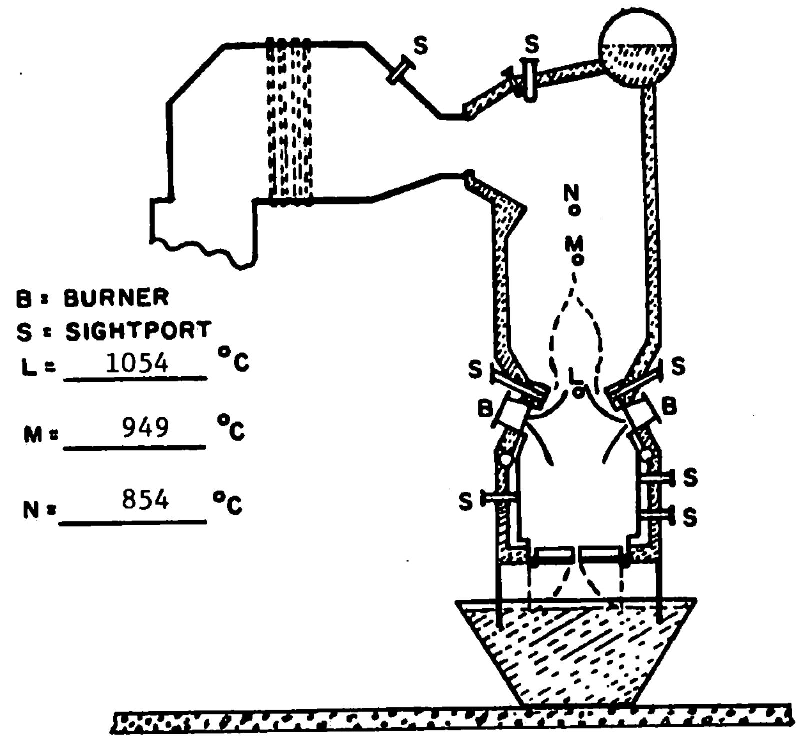


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "A" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 3.1B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make pu the program. This progress report (3.1B) presents coal analyses and size distribution of the pulverized coal burned in test 3.1 done on October 18, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

CCRL
Hat Creek (3.1)

3079-76
A-1152
23/12/76

SAMPLE CONDITION	AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis		
Moisture	15.32	0.00
Ash	25.63	30.27
Volatile Matter	28.07	33.15
Fixed Carbon (by Diff.)	30.98	36.58
Ultimate Analysis		
Carbon %	40.58	47.92
Hydrogen %	2.89	3.41
Sulphur %	1.02	1.20
Nitrogen %	0.81	0.96
Ash %	25.63	30.27
Oxygen (by Diff.) %	13.75	16.24
Calorific Value		
Calories per gram	3771	4453
B.T.U. per Lb. gross	6788	8016
Caking Properties		
By Vol. Button @		
Swelling Properties		
Free Swelling Index (ASTM)		

Ash Fusibility, °F	OXID.	RED
Initial Deformation °F	2660	2510
Softening-Spherical °F	2700+	2670
Softening-Hemispherical °F	2700+	2700+
Fluid °F	2700+	2700+

SCREEN ANALYSIS

Mesh Inches	%
+ x 1/4	0.00
1/4 x 1/8	2.86
1/8 x 1/16	34.02
1/16 x 1/32	32.15
1/32 x 28M	10.13
28M x 48M	11.91
48M x 0	8.93

Grindability Index (Hardgrove): 44

Equilibrium Moist (97% Hum),%:

Sulphur Forms:

Sulphate	0.12
Pyritic	0.29
Organic (by Diff.)	0.61
Total	1.02

Specific Gravity in ash: 2.70

ASH ANALYSIS

Component	%	Component	%
SiO_2	53.57	CaO	2.57
Al_2O_3	28.76	MgO	1.34
Fe_2O_3	8.68	SO_3	1.77
Mn_3O_4	0.02	Na_2O	0.56
TiO_2	1.63	K_2O	0.73
P_2O_5	0.20		

Chlorine: 0.01

Trace Mercury:

TEST NO: 3.1

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			1.9	
100M x 140M			7.2	76.5
140M x 200M	8.4	2.9	8.5	72.5
200M x 325M			33.4	67.4
325M x 0			49.0	58.6

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "A" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 3.1C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (3.1C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash desposits collected on probes and the chemical analyses of various ash forms produced in test 3.1 done on October 18, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 3:1C

Figure 1a

Furnace bottom at end of test. Friable sinter completely fills furnace cross section directly above dump plates.

Figure 1b

Furnace bottom at end of test. Friable sinter bridges across north east corner of furnace. Large friable sinter is in south west corner. The furnace throat is more than ½ blocked. Burners are not visible.

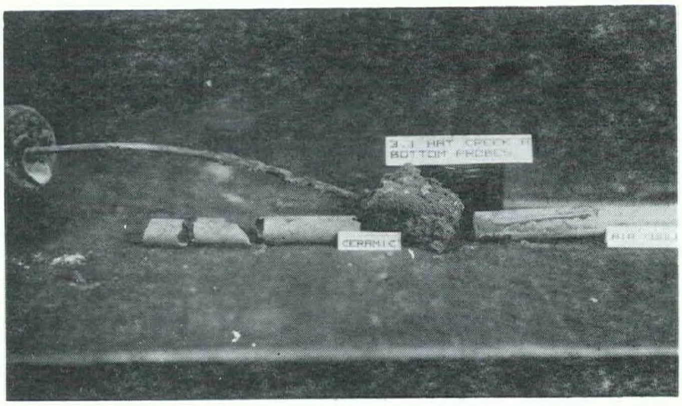


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

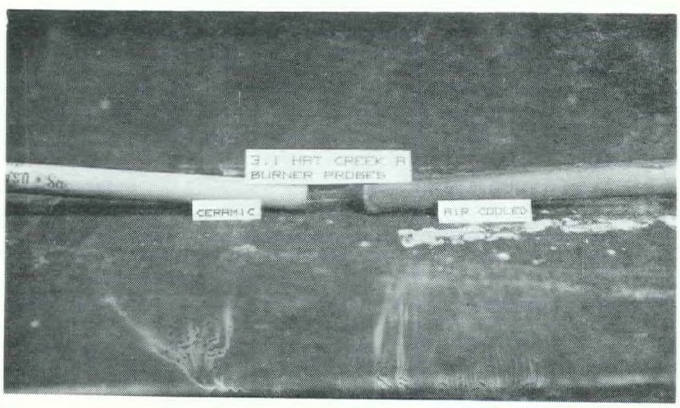


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.

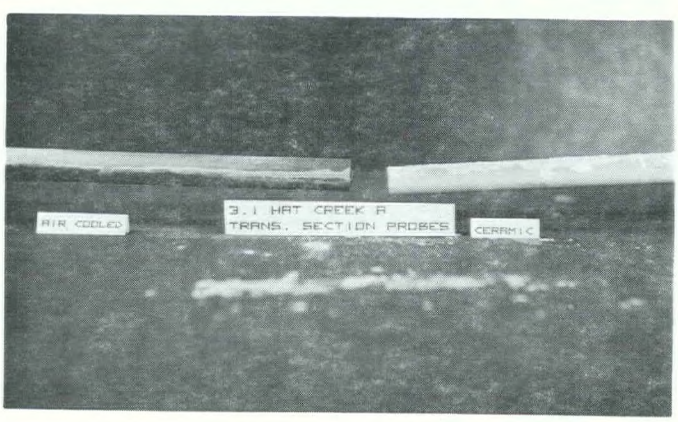


Figure 1e

Transition section deposition probes. Air cooled probe on left. Refractory probe on right.

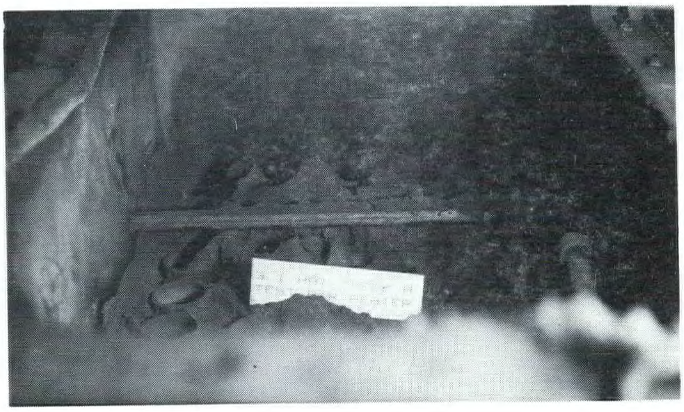


FIGURE 1f Main air heater tube sheet second pass up 2 - 3 inches of powder.

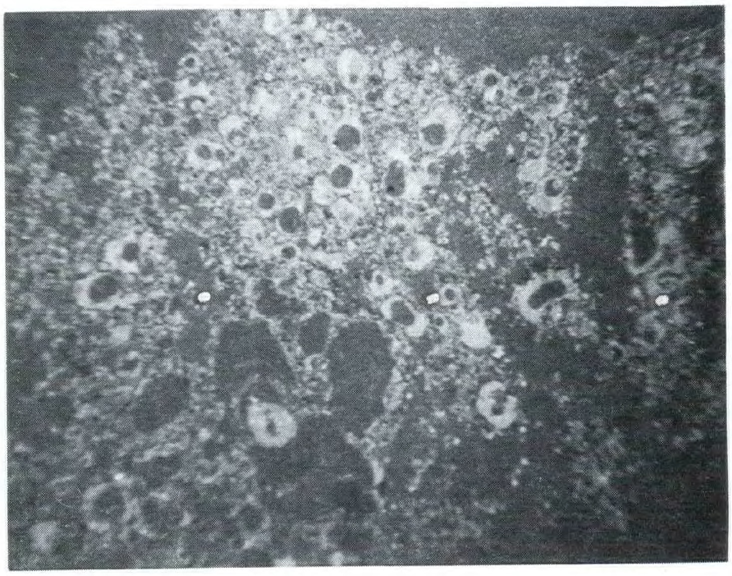


FIGURE 1g Photomicrograph, x 10, of a thin section of sinter which was found attached to the refractory near the burners. The sinter is weak and porous.

PROGRESS REPORT 3:1C

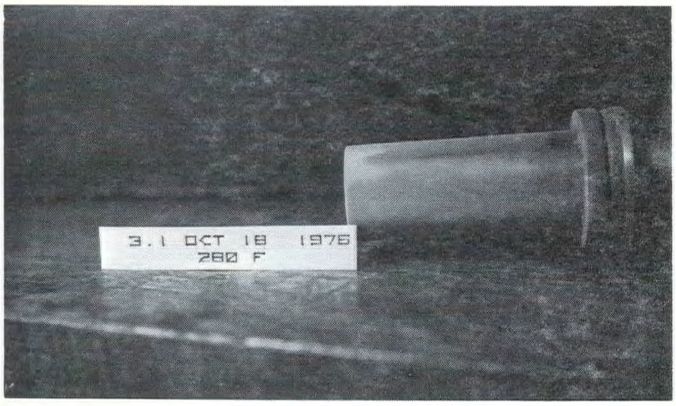


Figure 1h

Low Temperature corrosion probe 138°C.

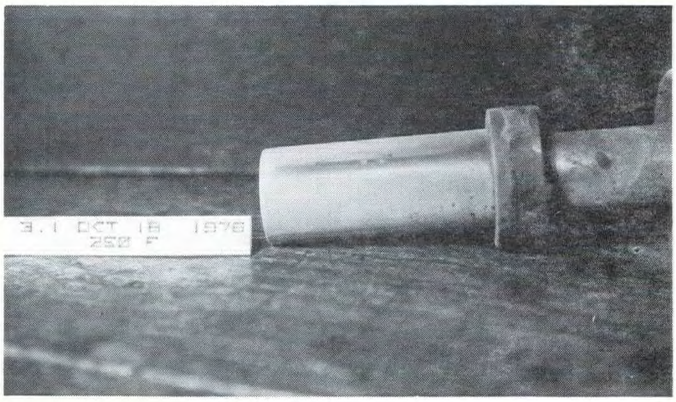


Figure 1i

Low Temperature corrosion probe 121°C.

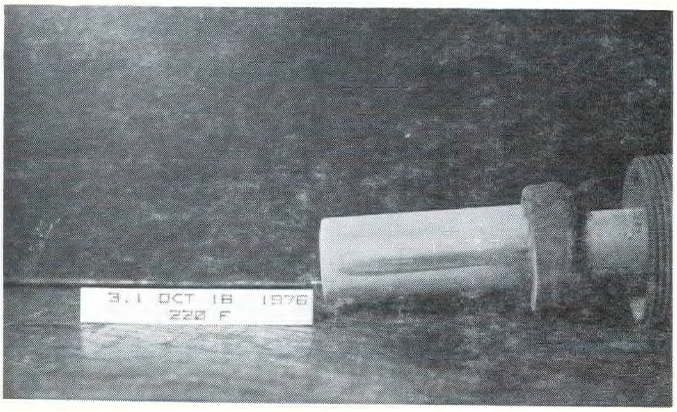


Figure 1j

Low temperature corrosion probe 104°C.

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	444 °C	462 °C	505 °C
Deposition rate[a]						
Fe	18.5	34.8	14.4	0.6	5.7	4.3
Mg	.61	.55	.40	2.5	10.7	1.4
Na	.66	.66	.45	1.6	4.2	2.2
Ca	8.4	5.3	5.9	94.7	102.5	88.2
SO_4 (total)	203.6	202.2	145.5	84.9	152.3	54.5
SO_4 (free), by difference	147.9	125.9	104.1			

[a] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposit from the furnace bottom, Test 3.1 (A 1190 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1288
Spherical	°C	1482+	1432
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	54.69
Al_2O_3	26.15
Fe_2O_3	8.13
Mn_3O_4	----
TiO_2	1.15
P_2O_5	0.12
CaO	2.03
MgO	1.23
SO_3	no sample
Na_2O	0.51
K_2O	0.84
Cl	----

Sample: Deposit from furnace walls, Test 3.1 (A 1191 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C		
Spherical	°C		
Hemispherical	°C		
Fluid	°C		

Ash Analysis	%
SiO_2	56.29
Al_2O_3	27.41
Fe_2O_3	9.28
Mn_3O_4	----
TiO_2	1.16
P_2O_5	0.11
CaO	2.04
MgO	1.13
SO_3	no sample
Na_2O	0.54
K_2O	1.13
Cl	----

Progress Report 3.1 C

Sample: Deposit from Electrostatic Precipitator, Test 3.1 (A 1160-61-62)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1249	1188
Spherical	°C	1454	1349
Hemispherical	°C	1482+	1410
Fluid	°C	+	1471

Ash Analysis	%
SiO_2	55.55
Al_2O_3	25.70
Fe_2O_3	7.29
Mn_3O_4	----
TiO_2	1.56
P_2O_5	0.18
CaO	2.98
MgO	1.39
SO_3	0.96
Na_2O	0.61
K_2O	0.92
Cl	----

Sample: Deposit from tube sheet between 2nd and 3rd passes of air heater, Test 3.1, (A 1194 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1327	1232
Spherical	°C	1477	1377
Hemispherical	°C	1482+	1460
Fluid	°C	+	1482+

Ash Analysis	
SiO_2	55.27
Al_2O_3	25.91
Fe_2O_3	9.80
Mn_3O_4	----
TiO_2	1.31
P_2O_5	0.04
CaO	2.43
MgO	1.90
SO_3	0.61
Na_2O	0.51
K_2O	0.96
Cl	---

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "A" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 3.1D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1]

SUMMARY

As explained elsewhere[2], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (3.1D) is the last of the series and presents results of the following detailed analyses of ash produced in test 3.1 done on October 18, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations
3. X-ray diffraction analyses of fireside deposits
4. Summary of DTA studies on fireside deposits

---

[1] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.6
1.59 - 2.00			0.8
2.00 - 2.52			1.1
2.52 - 3.17			1.7
3.17 - 4.00		0.4	2.9
4.00 - 5.04		0.5	4.2
5.04 - 6.35		0.9	5.9
6.35 - 8.00		1.9	7.5
8.00 - 10.08		4.5	10.5
10.08 - 12.7		8.6	11.9
12.7 - 16.0		14.4	13.2
16.0 - 20.2		18.1	11.8
20.2 - 25.4		18.5	10.5
25.4 - 32.0		14.1	6.4
32.0 - 40.3		6.0	3.8
40.3 - 44.0		1.4	1.1
44.0 - 74.0	Sieve	10.0	4.9
+ 74.0		0.7	1.2

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL - WRL

OPERATOR:

EQUIPMENT:

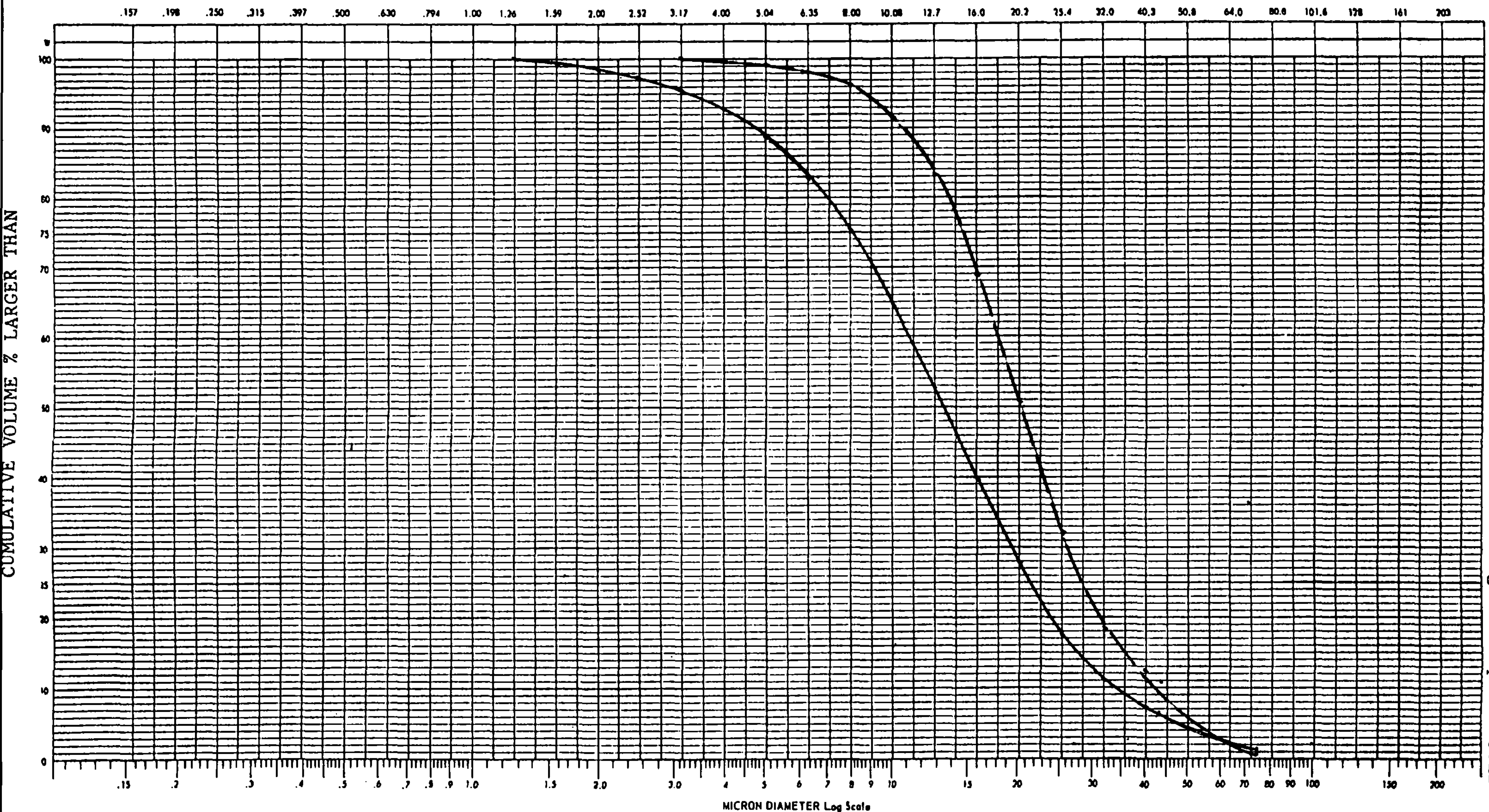
$k = d\sqrt[3]{2w}$ FOR MODEL T

$\frac{A2}{A1} = \left(\frac{d2}{d1}\right)^3$ when W2 = W1

$\frac{A2}{A1} = \left(\frac{d1}{d2}\right)^3$ when W2 = W1 FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 3·1	Isoton	Ultrasonic	100μ	6102033									
ESP ———													
AH2 — — —													



4221010

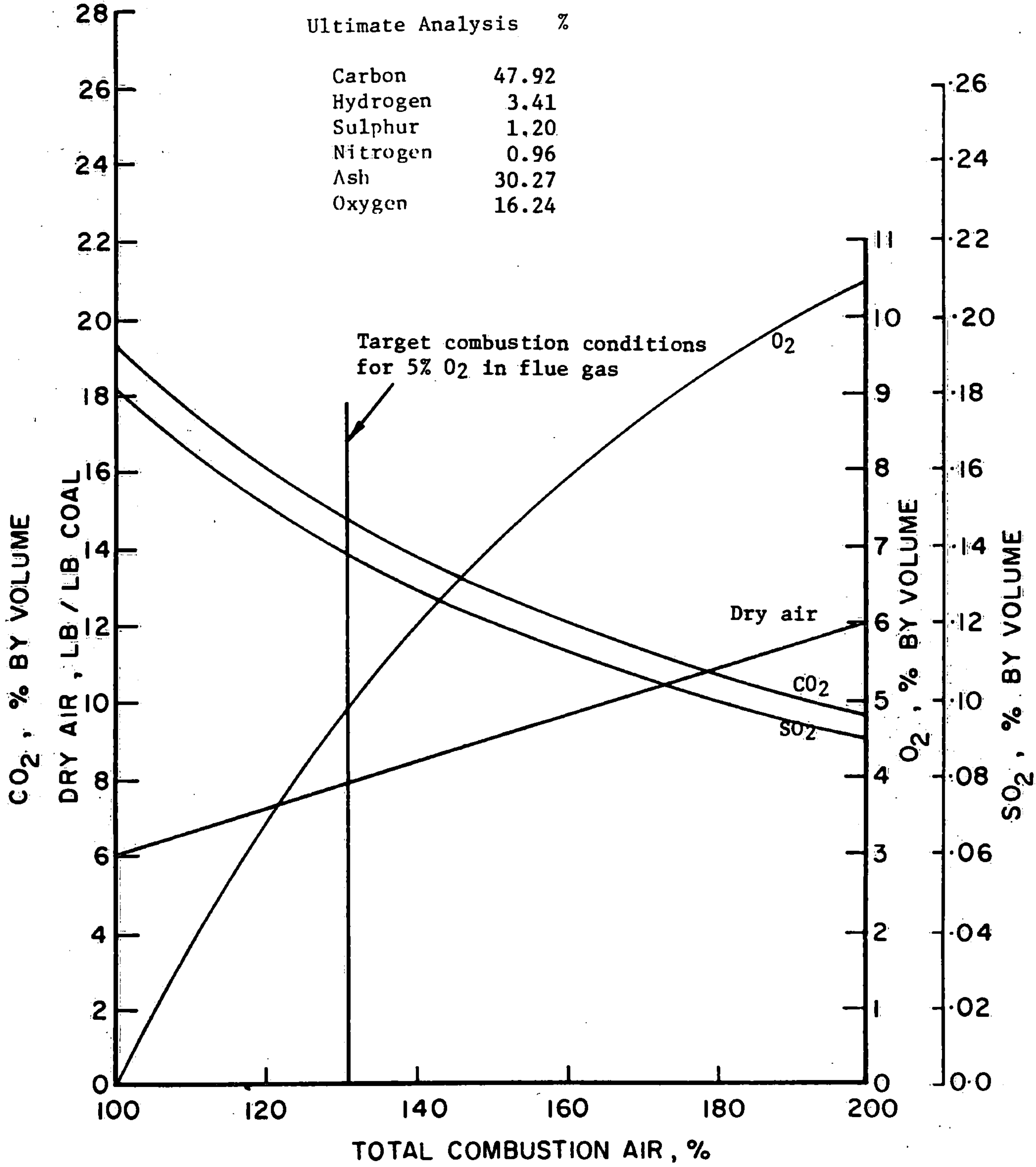


FIGURE 1: Combustion Calculations "A-Washed" Coal.

X-ray Diffraction Analyses of Fireside Deposits from Test 3.1, "A-washed" coal from Hat Creek.

Furnace Bottom Ash (1190 76-434)	Mull, Crist, Lime (tr)
Under Flame Probe Deposit (1184 76-448)	Hem, Mull, Crist, Mag, Feld (tr)
Furnace Probe Deposit (1186 76-449)	Hem, Mag, Mull
Transition Probe Deposit (1188 76-450)	Hem, Crist, Mag, Qtz, Amorph

Abbreviations of Constituents:

Feld	Feldspar (Anorthite) $CaO. Al_2O_3 . 2SiO_2$
Qtz	Quartz SiO_2
Crist	Cristobalite SiO_2
Mull	Mullite $3Al_2O_3.2SiO_2$
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Lime	Lime CaO
Amorph	Significant amorphous material present

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification.

Constituents are listed in decreasing order of abundance. On occasion "trace" is used for clarity.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

SUMMARY OF DTA STUDIES ON FIRESIDE DEPOSITS

Samples:

Five samples of ash from the furnace bottom and one sample of ash collected by the CCRL dust sampler were examined.

Sample 1)	CCRL 980	Test 1.1	Sundance bottom ash.
Sample 2)	CCRL 1092	Test 2.1	Hat Creek A-raw, bottom ash
Sample 3)	CCRL 1190	Test 3.1	Hat Creek A-washed, bottom ash
Sample 4)	CCRL 1278	Test 4.1	Hat Creek B-raw, bottom ash
Sample 5)	CCRL 1360	Test 4.3	Hat Creek B-raw, bottom ash
Sample 6)	CCRL 986	Test 1.1	Sundance fly ash.

Procedures:

Samples weighing approximately 50 mg were heated in a static air atmosphere at 12°C/min. to 1500°C. Two platinum foil pans were held in a vertical furnace, one containing the sample and the other containing α-alumina as reference material. Pt: Pt/13% Rh thermocouples were held with their beads denting the bottom of the pans.

Results:

Sample 1) No peaks were observed. The baseline shifted in the exothermic direction at 1360°C. When cool, the sample was dark and glassy.

Sample 2) No peaks were observed. The baseline shifted in the endothermic direction at 1450°C. When cool, the sample was brown-black opaque, and very hard.

Sample 3) No peaks were observed. The baseline shifted in the endothermic direction at 1340°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 4) No peaks were observed. The baseline shifted in the exothermic direction at 1330°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 5) No peaks were observed. The baseline shifted in the endothermic direction at 1160°C. When cool, the sample was brown, opaque, and appeared to have melted.

Sample 6) A sizable exothermic peak was observed in the 400°C to 500°C range and a small endothermic peak was noted at 1160°C. Cooling and reheating in the range 1000°C to 1500°C failed to show any repetition of the latter thermal effect. When cool, the sample was dark and glassy.

Comments:

It seems certain that samples 1), 5) and 6) underwent melting. The other samples probably had some liquid phase present. The lack of DTA peaks is unusual. It most likely indicates that melting occurred over a very broad range. Cooling to 1000°C and reheating gave rise to no peaks either. The exothermic peak for sample 6) was most likely the result of combustion of a small amount of carbonaceous material.

It can be concluded that DTA is not a very usefull technique for studying these materials.

Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology / Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "A" WASHED COAL

AIR-DRIED AND KILN-DRIED, 3% EXCESS OXYGEN

TEST NO. 3.2

CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/120 -123

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "A" Washed Coal
Air-Dried and Kiln-Dried, 3% Excess Oxygen

PROGRESS REPORT 3.2A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 3.2, which was done on October 20, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 3.2

In this test, Hat Creek "A" washed coal was burned. The coal had been air-dried and kiln-dried, which reduced the moisture content, as fired, to 16.5%. The ash content at this moisture level was 37.3%. The target level of excess oxygen in the flue gas was 3% (approx 15% excess air), and the target coal feed rate was 134 kg/hr, which corresponds to a heat input of approximately two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0850 hr, one hour after stable, unsupported coal combustion was obtained, the flame was observed to be yellow-orange in colour and extended slightly beyond the throat and a short distance into the water-cooled portion of the furnace. The air-cooled furnace probe was plainly visible from the top of the furnace, and the furnace throat was not visible in detail. Substantial deposits could be seen below the throat; they blocked about ¼ of the projected throat area and slightly deflected the flame from the south burner. The deposits were located in the southwest and southeast corners, and along the north side. The furnace-bottom was bright and transparent. Sinter could be seen hanging from the throat, and some large lumps of sinter were lying on the dump plates. The air-cooled furnace-bottom probe was clearly visible, but the refractory probe was not in the field of view. Ash was dumped hourly, and was removed from the quench tank mostly as small sinters.

At 0915 hr, the deposits blocked roughly 1/3 of the projected throat area and they were removed easily with a poker which was thrust through the top of the furnace. Deposits which were hanging on the furnace bottom walls and on the ledges adjacent to the dump plates were removed easily with a poker which was thrust through the furnace-bottom. This ash, which was raked from the quench tank, consisted of weak sinters, dark grey in colour, 2 to 5 cm in size, with one piece roughly 20 cm x 25 cm x 15 cm.

The throat then remained free of deposits for a period of three hours. The flame was fairly transparent and the furnace-bottom walls could be seen intermittently when viewed through the sight port at the top of the furnace. Many small embers could be seen in the furnace-bottom, but none were visible when the rotational speed of the pulverizer classifier was accelerated slightly so that few large particles of coal reached the burner. There was a dull glow in the transition section, by which the test air-heater tubes could be barely discerned. Some ash built up on the furnace-bottom ledges.

At 1300 hr, deposits could be seen in the corners under the furnace throat. Attempts were made to loosen them with a poker through the furnace-bottom ports, but they could not be reached. In the next hour, the deposits grew large enough to be visible from the top of the furnace, and by 1500 hr they blocked approximately half of the projected throat area. They were knocked loose with a poker which was thrust through the top of the furnace and then they filled the furnace-bottom to half its depth. This ash was not dumped into the quench tank because the test was scheduled to end shortly thereafter.

At 1550 hr, the test was terminated and substantial deposits were observed under the throat and on the west wall of the furnace-bottom.

Deposition Probes During Test

The air-cooled deposition probes in the furnace and the furnace-bottom were visible during the test period.

The air-cooled deposition probe in the furnace-bottom had a deposit of sinter 15 mm thick and 25 mm long hanging from the underside of the probe, but it was knocked off while removing deposits from the furnace throat. Then a few 5 mm lumps of sinter deposited on top of the probe, but these were knocked off by falling sinter, which also bent the probe downward.

The air-cooled deposition probe in the furnace remained free of sinter throughout the test.

Furnace After Test

The furnace-bottom was more than half full of orange-brown coloured, weak, dusty sinter. It bridged across the bottom opening, but it was readily dislodged and fell to the floor in lumps ranging from 2 cm to 20 cm in diameter.

Few deposits remained on the throat refractory and the furnace-bottom walls. The furnace water wall tubes were covered by a 2 mm thick layer of dust. The bottom of the transition section was covered by a layer of dust, 6 to 10 cm thick, and this dust was in two distinct layers. The bottom layer was approximately 3 cm thick and coloured grey. The top layer was coloured tan. It may be supposed that the tan coloured layer contained less combustible matter and this condition resulted from the acceleration of the rotational speed of the pulverizer classifier at 1215 hr. The test air-heater tubes were clean on the upstream side, and had a 1 mm layer of dust on the downstream side. There were 12 to 25 mm of charcoal-grey dust on the second-pass tube sheet of the main air-heater.

Deposition Probes After Test

Before being removed from the boiler, the deposition probes appeared as follows:

> The furnace-bottom air-cooled probe was badly bent and the free end was immersed in the ash which remained in the furnace-bottom. The exposed surfaces were clean.
>
> The furnace-bottom refractory probe was broken and hung by its thermocouple. It bore a few small sinters.
>
> The furnace probes appeared to be clean of slag and of sinter.
>
> The deposition probes in the transition section could not be examined in situ.
>
> The air-cooled transition section probe, when it was removed, was found to have a 1 mm layer of light grey coloured dust on the top surface. The bottom surface was clean.
>
> The refractory transition section probe, when it was removed, was clean on the upstream surface. It had a thin layer of dust on the downstream surface, and there were indications that some of the deposit had fallen off.

Test No. 3.2

Progress Report 3.2A

Revise 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "A" WASHED, DOUBLE DRIED EXCESS O_2 3 %

20/10/76

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		6	hours	
Firing Rate		122.5(3.6)	kg/hr	
Moisture Content of Coal	1	16.5	%	feed to pulverizer
" " " "	2	1.8(0.6)	%	feed to furnace
Combustible " " "	2	68(1)	%	dry weight
Ash Dumping Frequency		once every ——	hour	Total ash dumped = 88 kg, equivalent to 1131 kg coal.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	269(5)	mmH_2O	
b) Outlet Air Pressure	2	231(4)	mmH_2O	
c) Inlet Air Temperature	3	181(6)	°C	
d) Outlet Air Temperature	2	77(4)	°C	
e) Coal Fineness	2	74(8)% below 200 mesh		oversize, 22.0% >140 mesh; " , 25.9% >200 mesh; " , 55.0% >325 mesh
BOILER OPERATING CONDITIONS				
a) Steam Flow	6	583(30)	kg/hr	
b) Steam Pressure	6	2.96(0.04)	atmospheres	
c) Combustion Air Temp.	4	185(7)	°C	
d) Furnace Pressures				
Furnace	10	32(5)	mmH_2O	
Inlet	11	33(5)	mmH_2O	
Boiler Exit	12	16(3)	mmH_2O	
Primary (Coal) Air L	5	140(6)	mmH_2O	
" R	5	153(6)	mmH_2O	
Secondary (Windbox) Air L	4	42(9)	mmH_2O	
" R	4	40(7)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	16.4(0.4)	%	
b) O_2	11	3.2(0.3)	%	
c) CO	11	231(82)	ppm	
d) NO	13	608(9)	ppm	
e) SO_2	14	1000(54)	ppm	
f) SO_3	14	2.7(0.5)	ppm	
g) Dewpoint	18	41(2)	°C	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	601(17)	°C	
b) Boiler Exit	12	284(10)	°C	
c) Precipitator Entry	16	153 (7)	°C	
SUCTION PYROMETER TEMPERATURES				
a)	7	930, 1002	°C	readings taken in
b)	8	633, 848	°C	second and third
c)	9	578, 812	°C	two hour period
FLY ASH				
a) Loading at precipitator	16	10400(1100)	$mgms/m^3$	measured at 20°C
b) Resistivity	15	6.0×10^{10} Ω cm at 265°C		
"	17	$2.0(0.1)\times10^{11}$ Ω cm at 150°C		1.2×10^{11} Ω cm at 123°C
c) Precipitator efficiency	18	89.8(1.6)	%	
d) Combustible content of ash collected from precipitator	18	5.6(0.7)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	1058	(74)	930	1162	1076	1162	Orange coloured sinter, 1 mm thick, even, easily brushed off.
	stainless			PROBE BROKEN		246		Beige scale, upstream, washed off easily with H_2O, covered by 1 mm thick tan coloured dust, even.
Furnace 9	ceramic	774	(76)	682	910	910	858	Tan coloured sinter, 1 mm thick, even, easily brushed off.
	stainless	527	(38)	451	576	532	576	Grey scale, upstream, removed by H_2O, and tan powder, 12 mm thick, downstream, easily brushed off, all covered by grey dust, even.
Transition Section 20	ceramic	612	(16)	592	628	594	628	Tan coloured scale, 1 mm thick, easily brushed off, upstream.
	stainless	545	(29)	564	579	464	563	Tan coloured powder, 12 mm thick, downstream, 1 mm thick upstream, easily brushed off.

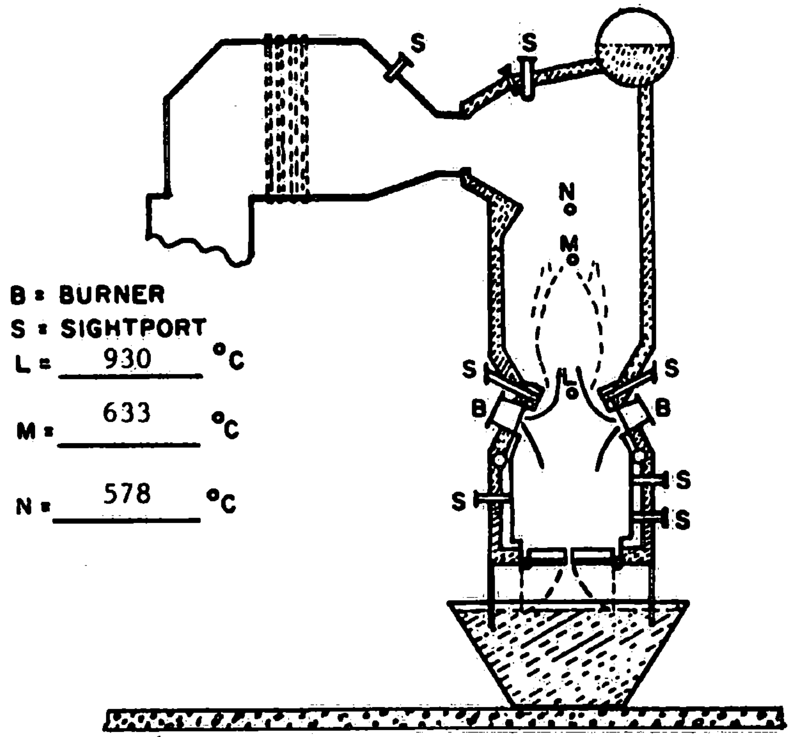


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "A" Washed Coal
Air-Dried and Kiln-Dried, 3% Excess Oxygen

PROGRESS REPORT 3.2B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (3.2B) presents coal analyses and size distribution of the pulverized coal burned in test 3.2 done on October 20, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

CCRL

Hat Creek (3.2)

3080-76

A-1195

23/12/76

SAMPLE CONDITION		AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis			
Moisture		14.18	0.00
Ash		25.53	29.75
Volatile Matter		27.99	32.61
Fixed Carbon (by Diff.)		32.30	37.64
Ultimate Analysis			
Carbon	%	41.36	48.19
Hydrogen	%	2.89	3.37
Sulphur	%	1.03	1.20
Nitrogen	%	0.82	0.96
Ash	%	25.53	29.75
Oxygen (by Diff.)	%	14.19	16.53
Calorific Value			
Calories per gram		3864	4502
B.T.U. per Lb. gross		6955	8104
Caking Properties			
By Vol. Button @			
Swelling Properties			
Free Swelling Index (ASTM)			
Ash Fusibility, °F		OXID.	RED
Initial Deformation	°F	2620	2420
Softening-Spherical	°F	2700+	2690
Softening-Hemispherical	°F	2700+	2700+
Fluid	°F	2700+	2700+

SCREEN ANALYSIS

Mesh Inches	%
+ x 1/4	0.00
1/4 x 1/8	2.78
1/8 x 1/16	35.21
1/16 x 1/32	33.40
1/32 x 28M	9.16
28M x 48M	10.82
48M x 0	8.63

Grindability Index (Hardgrove): 44

Equilibrium Moisture (97% Hum),%:

Sulphur Forms:

Sulphate	0.12
Pyritic	0.31
Organic (by Diff.)	0.60
Total	1.03

Specific Gravity in ash: 2.65

ASH ANALYSIS

Component	%	Component	%
SiO_2	55.63	CaO	2.53
Al_2O_3	30.13	MgO	1.04
Fe_2O_3	8.01	SO_3	2.12
Mn_3O_4	0.02	Na_2O	0.54
TiO_2	1.70	K_2O	0.74
P_2O_5	0.19		

Chlorine: 0.01

Trace Mercury:

TEST NO: 3.2

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			7.4	82.6
100M x 140M	22.0	5.9	21.0	76.7
140M x 200M	3.9	2.2	9.4	73.0
200M x 325M	29.1	6.0	17.5	70.1
325M x 0	45.0	2.5	44.7	61.8

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "A" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 3.2C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1]

SUMMARY

As explained elsewhere[2], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (3.2C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 3.2 done on October 20, 1976.

---

[1] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 3:2C

Figure 1a

Furnace bottom at end of test. Large friable sinter on south wall extends from east wall to west wall. Burners and throat are clear of sinter. Refractory probe in foreground is broken.

Figure 1b

Furnace bottom at end of test. Burner on south wall is clear.

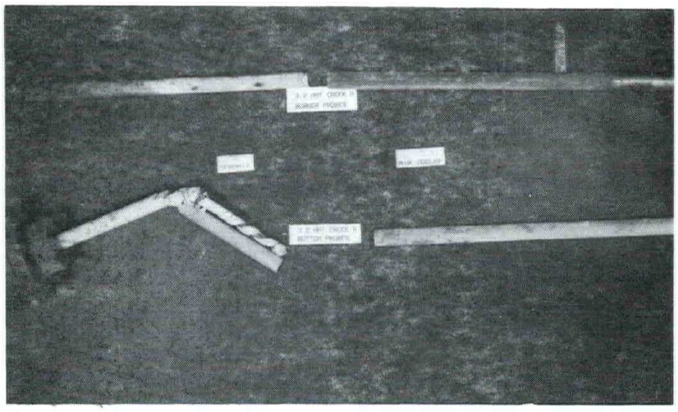


FIGURE 1c Furnace bottom and burner deposition probes. Air cooled probes on right. Refractory probes on left.

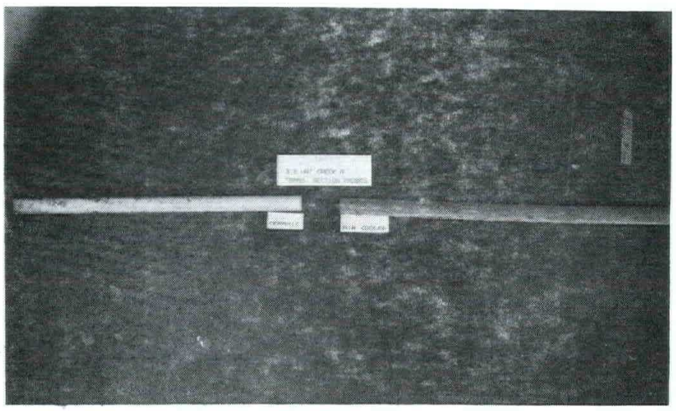


FIGURE 1d Transition section deposition probes. Air cooled probes on right. Refractory probes on left.

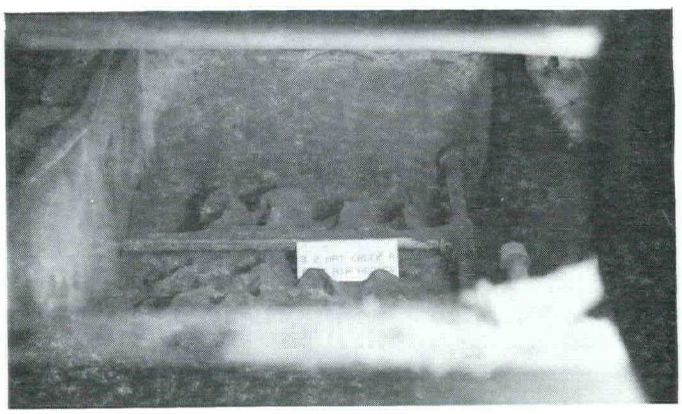


FIGURE 1e Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 3:2C

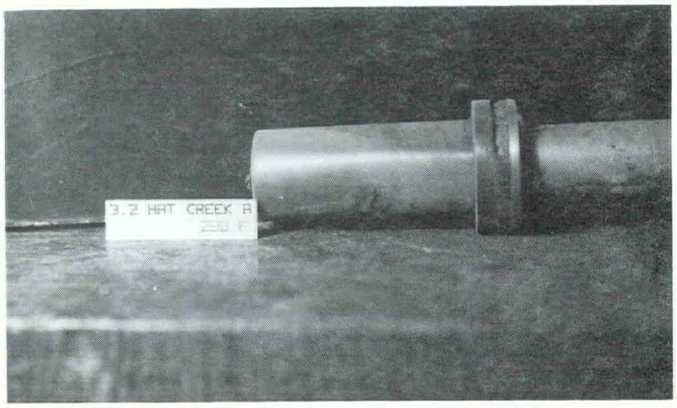


Figure 1f

Low Temperature corrosion probe 138°C.

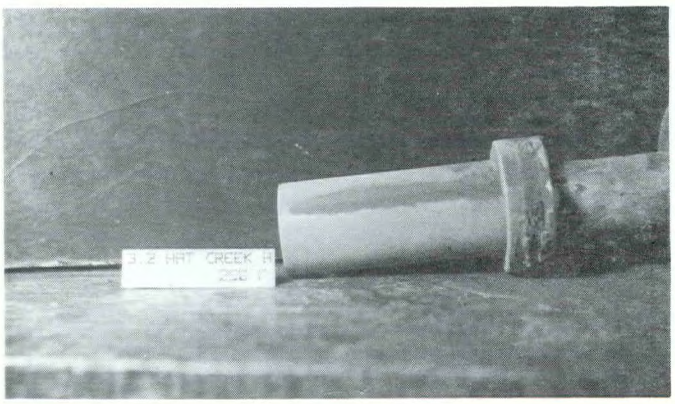


Figure 1g

Low Temperature corrosion probe 121°C.

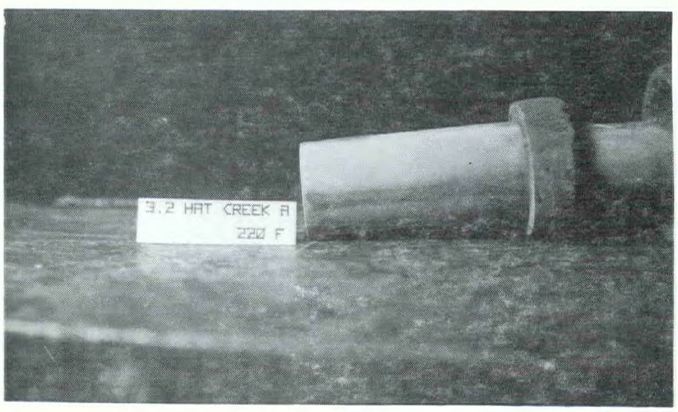


Figure 1h

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	474 °C	527 °C	545 °C
Deposition rate[a]						
Fe	41.8	49.7	30.9	0.0	10.7	4.3
Mg	1.21	.78	.61	2.2	9.6	2.2
Na	.89	.66	.22	1.3	4.5	1.6
Ca	8.8	4.9	6.3	96.8	105.4	83.4
SO_4 (total)	81.2	96.5	42.8	39.2	272.2	69.7
SO_4 (free), by difference	NIL	NIL	NIL			

[a] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposition probes, Test 3.2, B. C. Hydro

Station	Furnace Bottom				Boiler				Transition Section			
Material	SS		REF		SS		REF		SS		REF	
Mean Temperature °C	---		570		275		412		285		322	
% Water Soluble	6.4		---		2.1		---		3.4		---	
% Acid Insoluble	80.1		---		69.3		---		78.5		---	
Analysis , %	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS
SO_4	1.4				1.2				1.8			
Ca	4.1	0.0			0.8	0.1			1.1	0.2		
Fe	0.1	3.9			---	9.2			0.1	3.1		
Mg	---	0.2			---	0.3			---	0.4		
K	0.0	0.0			0.0	0.0			0.0	0.0		
Na	---	0.2			---	0.2			---	0.2		

WS = water soluble

AS = acid soluble

--- = trace

Progress Report 3.2 C

Sample: Deposit from furnace bottom, Test 3.2 (A 1235 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1321	1232
Spherical	°C	1482+	1421
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	56.52
Al_2O_3	26.64
Fe_2O_3	8.04
Mn_3O_4	----
TiO_2	1.22
P_2O_5	0.08
CaO	2.26
MgO	1.55
SO_3	no sample
Na_2O	0.56
K_2O	0.82
Cl	----

Sample: Deposit from furnace walls, Test 3.2 (A 1236 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1260	1199
Spherical	°C	1449	1321
Hemispherical	°C	1482+	1399
Fluid	°C	+	1460

Ash Analysis	%
SiO_2	54.87
Al_2O_3	25.31
Fe_2O_3	8.85
Mn_3O_4	----
TiO_2	1.43
P_2O_5	0.16
CaO	2.76
MgO	1.67
SO_3	1.08
Na_2O	0.68
K_2O	1.10
Cl	----

Progress Report 3.2 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 3.2 (A 1239 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1282	1216
Spherical	°C	1471	1388
Hemispherical	°C	1482+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	56.18
Al_2O_3	27.13
Fe_2O_3	9.26
Mn_3O_4	----
TiO_2	1.36
P_2O_5	0.15
CaO	2.66
MgO	1.50
SO_3	0.58
Na_2O	0.53
K_2O	0.90
Cl	----

Progress Report 3.2 C

Sample: Deposit from electrostatic precipitator, test 3.2 (A 1203-04-05)

Ash Fusibility	Oxidizing	Reducing
Initial °C	1249	1210
Spherical °C	1438	1310
Hemispherical °C	1460	1338
Fluid °C	1482+	1482+

Ash Analysis	%
SiO_2	55.54
Al_2O_3	25.49
Fe_2O_3	6.73
Mn_3O_4	----
TiO_2	1.84
P_2O_5	0.21
CaO	3.49
MgO	1.84
SO_3	0.96
Na_2O	0.78
K_2O	1.10
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "A" Washed Coal
Air Dried and Kiln-Dried, 3% Excess Oxygen

PROGRESS REPORT 3.2D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (3.2D) is the last of the series and presents results of the following detailed analyses of ash produced in test 3.2 done on October 20, 1976.

1. Particle size distribution of fly ash

2. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.6
1.59 - 2.00	Coulter Counter		0.9
2.00 - 2.52	Coulter Counter		1.4
2.52 - 3.17	Coulter Counter		1.9
3.17 - 4.00	Coulter Counter	0.2	3.1
4.00 - 5.04	Coulter Counter	0.3	4.3
5.04 - 6.35	Coulter Counter	0.6	5.8
6.35 - 8.00	Coulter Counter	1.2	7.5
8.00 - 10.08	Coulter Counter	3.2	10.1
10.08 - 12.7	Coulter Counter	6.4	12.5
12.7 - 16.0	Coulter Counter	11.3	13.1
16.0 - 20.2	Coulter Counter	16.7	11.5
20.2 - 25.4	Coulter Counter	17.8	8.8
25.4 - 32.0	Coulter Counter	14.2	4.7
32.0 - 40.3	Coulter Counter	6.0	1.8
40.3 - 44.0	Coulter Counter	0.7	2.8
44.0 - 74.0	Sieve	16.1	5.8
+ 74.0	Sieve	5.3	3.4

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
% PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL - WRL

OPERATOR:

EQUIPMENT:

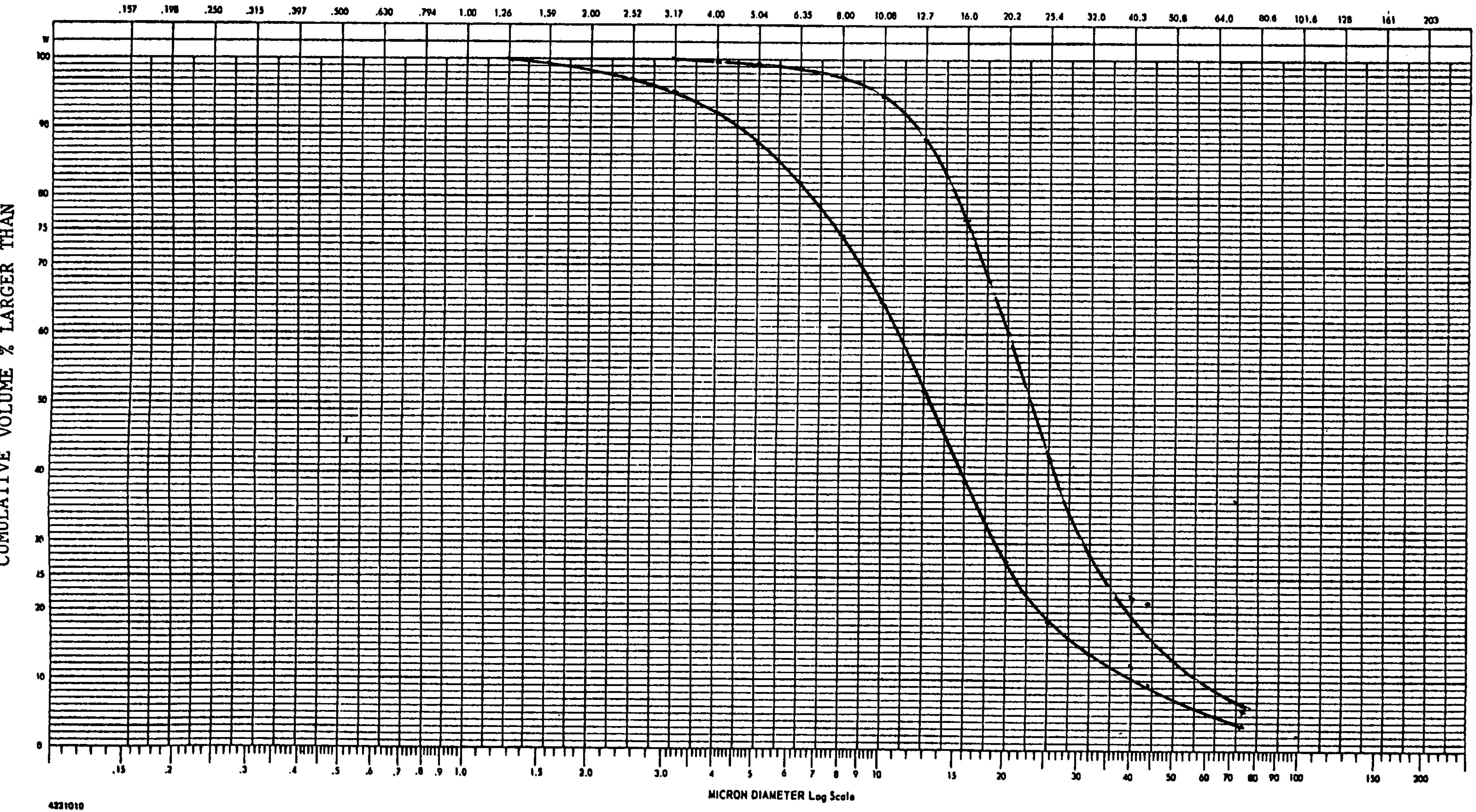
$k = d\sqrt[3]{2w}$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 3·2	Isoton	Ultrasonic	100μ	6102033									
ESP ———													
AH2 — — —													



4321010

Progress Report 3.2 D

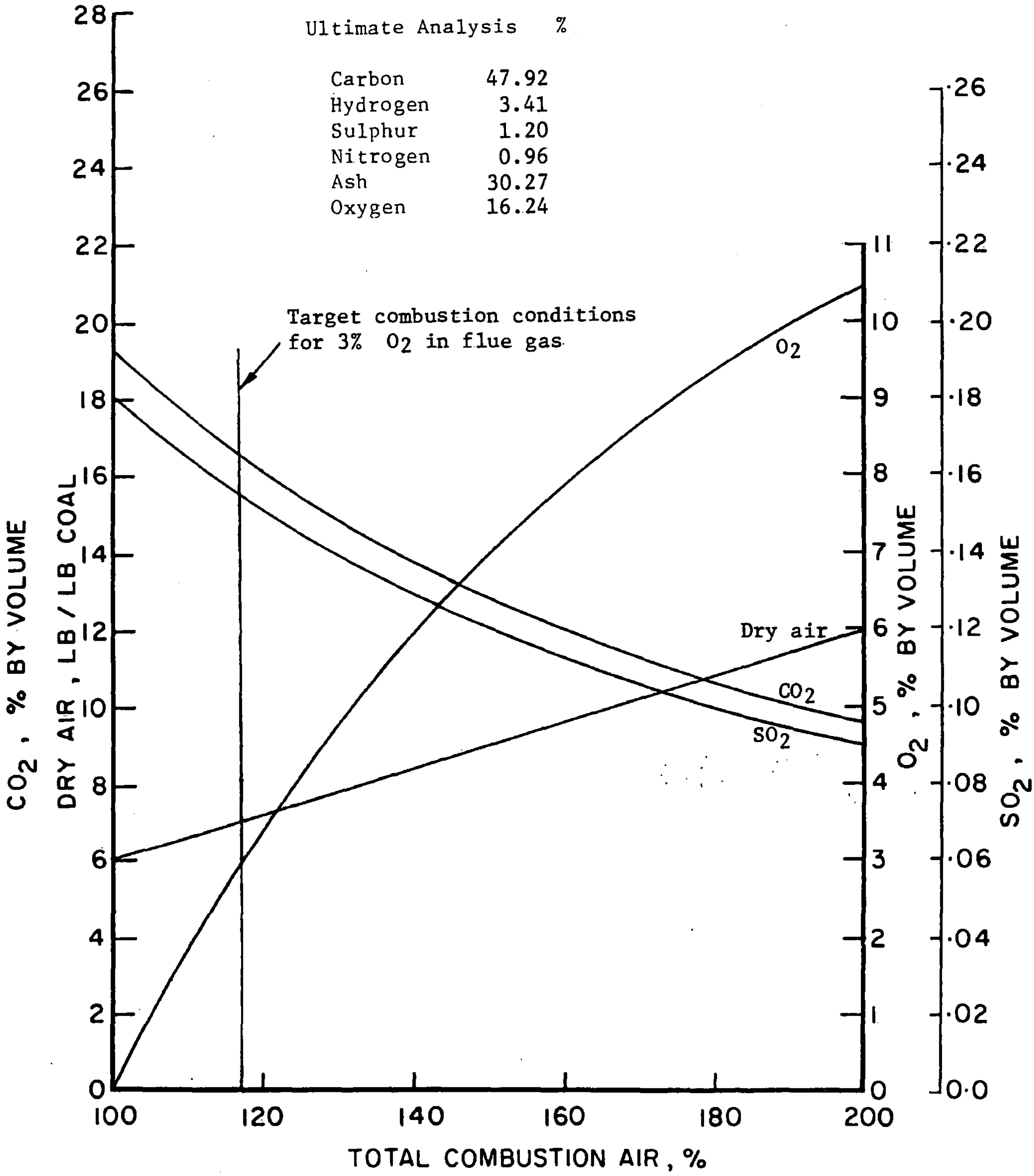


FIGURE 1: Combustion Calculations "A-Washed" Coal .

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "B" RAW COAL

KILN-DRIED TWICE, 5% EXCESS OXYGEN

TEST NO. 4.1

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/124-127

PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET
JOINT PROGRAM
HAT CREEK "B" RAW COAL
KILN-DRIED TWICE, 5% EXCESS OXYGEN

PROGRESS REPORT 4.1A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

INTRODUCTION

By an agreement between the B.C. Hydro and Power Authority (B.C. Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report [2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 4.1, which was done on October 22, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 4.1

In this test, Hat Creek "B" raw coal was burned. The coal had been kiln-dried twice, which reduced the as-fired moisture content to 8.6%. The target level of excess oxygen in the flue gas was 5% (approx 25% excess air), and the target coal-feed rate was 131 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0840 hr, after one hour of stable, unsupported coal combustion, the flame was observed to be yellow-orange in colour, and moderately transparent. The furnace throat was clearly visible from the top of the furnace, as was the air-cooled furnace probe. Large deposits of sinter were visible under the throat. They were heaviest in the southwest and northeast corners of the furnace, but appeared weak. Small pieces of sinter were observed to flutter in the furnace draft. The furnace-bottom was clear. A small flow of burning coal particles could be seen, and a uniform layer of sinter, roughly 3 cm thick, was visible on the furnace-bottom walls.

At 0930 hr, deposits blocked most of the furnace throat, leaving clear a projected throat area which measured 10 cm x 45 cm. All of the sight ports in the furnace-bottom were blocked. Manual removal of the deposits with a poker was delayed a few minutes to permit some measurements to be completed. By then, the throat was blocked completely, and no flame was visible from the top of the furnace. The coal feed was stopped, and the deposits were removed with a poker, which was thrust through the top of the furnace. This was accomplished easily and quickly. The sight ports in the furnace-bottom were cleared and ash was dumped. At 0940 hr, coal feed was resumed with an oil-fired support burner, and at 0945 hr, the support burner was removed.

At 0945 hr, the flame was bright and uniform in colour, and hazy with dust. When viewed through the sight port on the top of the furnace, the air-cooled furnace probe was visible, and the furnace throat was obscured. When viewed through the sight ports in the bottom, the furnace-bottom was clear;

some ash was visible on the bottom ledges, and deposits were visible under the south burner. Also, many burning particles of coal could be seen. When viewed through the sight port in the transition section, there was a dull red glow, which was not of sufficient intensity to make visible the test-air-heater tubes. Ash, which was removed from the quench tank, consisted of very weak, dark-grey sinters, 3 to 10 cm in diameter. Ash was dumped approximately once an hour.

During the next four hours, flame conditions remained stable, and some ash was sintered so firmly to the furnace-bottom walls that, it did not fall when the dump plates were swung open. At 1155 hr, the ash bridged across the bottom, was partly supported by the air-cooled deposition probe, and had to be broken loose with a poker, which was thrust through the furnace-bottom ports. Deposits also gradually built up below the furnace walls until roughly ½ of the projected throat area was blocked.

At 1350 hr, a poker was again thrust through the top of the furnace to remove deposits from the furnace throat. The dump plates were then swung open, and a poker was thrust through the furnace-bottom ports to clear the ash into the quench tank. When this ash was raked from the quench tank, it was found to contain sinters 3 to 10 cm in diameter, and dark-grey in colour.

At 1525 hr, deposits had to be knocked loose from the throat for a third time. They filled most of the furnace-bottom with ash. However, the scheduled end of the test was near, and this ash was not dumped.

At 1550 hr, ¼ of the projected throat area was blocked by a deposit which had formed in the southwest corner of the furnace below the throat.

Deposition Probes During Test

Only the air-cooled deposition probes in the furnace and the furnace-bottom were visible during the test.

The air-cooled furnace-bottom probe developed a few deposits of sinter, roughly 8 mm in diameter, on the top surface. These consolidated to form a continuous line approximately 15 cm long, which was later knocked off by sinters falling from the throat.

The air-cooled furnace probe remained free of sinter throughout the test.

Furnace After Test

When the dump plates were opened, roughly 30 litres of ash fell to the floor. This ash was composed of weak sinters, light-brown in colour; most of the sinters measured 2 to 5 cm in diameter, and some measured 15 cm in diameter. Two larger sinters, roughly 30 cm x 30 cm x 45 cm, remained hanging from the furnace-bottom walls. Some small whiskers of sinter adhered to the throat refractory.

The furnace water walls were covered only by a thin layer of dust except for that portion up to 15 cm above the throat refractory, where some of the dust on the tubes appeared to be sinterd. The upper slope of the tubes forming the nose at the furnace exit was covered by a 1 to 2 cm thick layer of dust. There were 7 to 10 cm of dust on the bottom of the transition section. Most of it was tan-coloured, but a thin layer on the bottom was nearly black. The test air-heater tubes were clean on the upstream side, but a thin layer of dust was visible on the downstream side. The second-pass tube sheet of the main air-heater was covered by a 10 to 25 mm thick layer of dust.

Deposition Probes After Test

The refractory probe in the furnace-bottom, was observed before it was removed. It was covered evenly by a sintered deposit and had a maximum overall diameter of roughly 25 mm. The deposit was thinner at the tip of the probe.

The air-cooled probe in the furnace-bottom, was free of sinter.

The refractory probe in the furnace had some sintered dust on the underside.

The air-cooled probe in the furnace appeared to have 3 to 5 mm of sinter on the underside.

The refractory probe in the transition section had a thin layer of unsintered dust slightly upstream of the top surface, over approximately 60^{o} of the circumference.

The air-cooled probe in the transition section, had a layer of tan-coloured dust, 1 to 2 mm thick, on the downstream surface. There were indications that part of the deposit had fallen off.

Test No. 4.1
Progress Report 4.1A
Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK COAL "B" RAW, DRIED TWICE.   EXCESS O_2 5 %   22/10/76

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		135(2)	kg/hr	
Moisture Content of Coal	1	8.6	%	feed to pulverizer
" " " "	2	0.9	%	feed to furnace
Combustible " " "	2	60.2(0.9)	%	dry weight
Ash Dumping Frequency		once every ——	hour	Continous, knock down every three hours.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	281(5)	mmH_2O	Total ash dumped = 98.7 kg
b) Outlet Air Pressure	2	235(5)	mmH_2O	equivalent to 1253 kg
c) Inlet Air Temperature	3	190(3)	°C	coal
d) Outlet Air Temperature	2	100(2)	°C	
e) Coal Fineness	2	75(7)% below 200 mesh		oversize, 19.9% >140 mesh
BOILER OPERATING CONDITIONS				" , 24.8% >200 mesh
a) Steam Flow	6	608(13)	kg/hr	" , 67.8% >325 mesh
b) Steam Pressure	6	3.03(0.04)	atmospheres	
c) Combustion Air Temp.	4	183(4)	°C	
d) Furnace Pressures				
Furnace	10	40(4)	mmH_2O	
Inlet	11	37(2)	mmH_2O	
Boiler Exit	12	20(2)	mmH_2O	
Primary (Coal) Air L	5	152(6)	mmH_2O	
" R	5	164(6)	mmH_2O	
Secondary (Windbox) Air L	4	60(6)	mmH_2O	
" R	4	59(5)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	14.9(0.3)	%	
b) O_2	11	5.1(0.1)	%	
c) CO	11	218(125)	ppm	
d) NO	13	519(141)	ppm	
e) SO_2	14	937(80)	ppm	
f) SO_3	14	1.8(0.4)	ppm	
g) Acid dewpoint	18	32(2)	°C	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	601(20)	°C	
b) Boiler Exit	12	286(4)	°C	
c) Precipitator Entry	16	157(3)	°C	
SUCTION PYROMETER TEMPERATURES				
a)	7	1006, 1070	°C	readings taken in
b)	8	807, 870	°C	second and third
c)	9	781, 803	°C	two hour period
FLY ASH				
a) Loading	16	12900(3800)	$mgms/m^3$	measured at 20°C
b) Resistivity	15	$3.7(2.2)\times10^{10}\,\Omega$ cm at 260°C		
"	17	$3.2(0.8)\times10^{11}\,\Omega$ cm at 157°C;		$6.7\times10^{10}\,\Omega$ cm at 123°C
c) Precipitator efficiency	18	88.6(4.7)	%	
d) Combustible content of ash collected from precipitator	18	3.8(0.3)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	1101	40	1044	1161	1099	1044	75 mm of probe tip broken, 12 mm thick brown crust, upstream 1 mm thick brown crust, down-stream.
	stainless	534	32	484	579	579	518	Grey scale, upstream, covered by 3 mm tan powder upstream, covered by grey powder ½ mm thick.
Furnace 9	ceramic	784	54	712	860	813	730	grey coloured scale, upstream, 1 mm thick.
	stainless	538	85	405	700	635	576	Grey scale, upstream, 1 mm thick covered by beige powder, 1 mm thick, upstream, covered by ½ mm grey powder, even.
Transition Section 20	ceramic	601	14	577	619	585	619	Grey-tan powder, upstream and top side, 2 mm thick, easily brushed off.
	stainless	536	18	507	561	507	549	Grey glaze upstream, 1 mm, tan powder downstream (some had fallen off), covered by grey powder, 1 mm downstream.

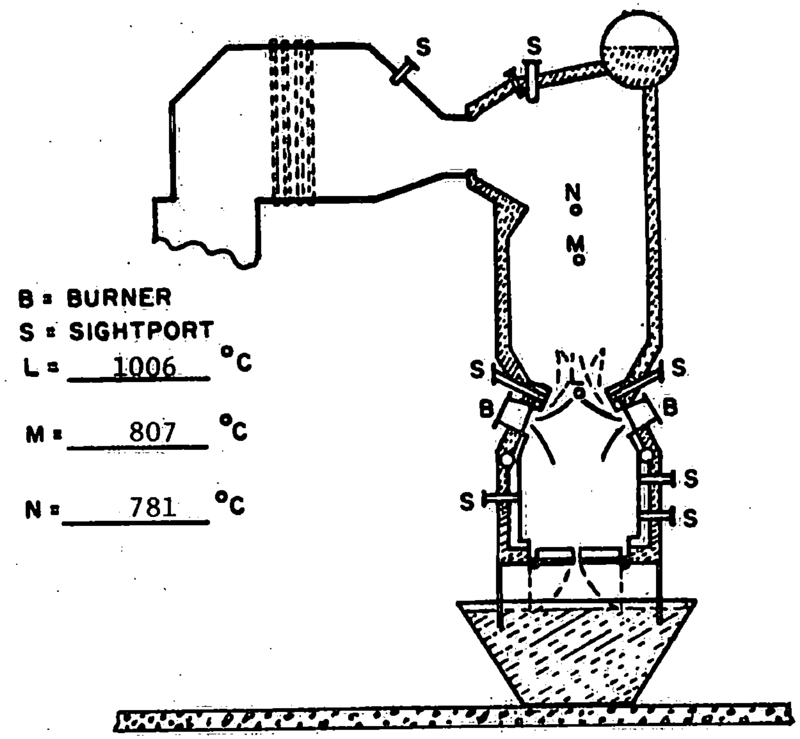


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 4.1B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make pu the program. This progress report (4.1B) presents coal analyses and size distribution of the pulverized coal burned in test 4.1 done on October 22, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

CCRL — 3098-76

A-1240

Hat Creek "B-Raw" (4.1) — 7/1/76

SAMPLE CONDITION	AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis		
Moisture	7.06	0.00
Ash	34.79	37.43
Volatile Matter	30.79	33.13
Fixed Carbon (by Diff.)	27.36	29.44
Ultimate Analysis		
Carbon %	39.13	42.10
Hydrogen %	3.05	3.28
Sulphur %	1.02	1.10
Nitrogen %	0.86	0.93
Ash %	34.79	37.43
Oxygen (by Diff.) %	14.09	15.16
Calorific Value		
Calories per gram	3649	3926
B.T.U. per Lb. gross	6568	7067
Caking Properties		
By Vol. Button @		
Swelling Properties		
Free Swelling Index (ASTM)		

Ash Fusibility, °F	OXID.	RED
Initial Deformation °F	2620	2480
Softening-Spherical °F	2700+	2600
Softening-Hemispherical °F	2700+	2660
Fluid °F	2700+	2700+

SCREEN ANALYSIS

Mesh Inches	%
+ x 1/4	0.00
1/4 x 1/8	0.35
1/8 x 1/16	12.00
1/16 x 1/32	39.35
1/32 x 30M	7.44
30M x 50M	19.95
50M x 0	20.91

Grindability Index (Hardgrove): 48

Equilibrium Moist (97% Hum),%:

Sulphur Forms:

Sulphate	0.11
Pyritic	0.51
Organic (by Diff.)	0.40
Total	1.02

Specific Gravity in ash: 2.76

ASH ANALYSIS

Component	%	Component	%
SiO_2	48.24	CaO	3.82
Al_2O_3	29.14	MgO	1.10
Fe_2O_3	11.11	SO_3	3.62
Mn_3O_4	0.13	Na_2O	0.28
TiO_2	1.18	K_2O	0.37
P_2O_5	0.37		

Chlorine: -

Trace Mercury:

TEST NO: 4.1

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			3.9	79.3
100M x 140M	20.2	2.5	15.1	72.5
140M x 200M	4.0	2.7	9.9	67.0
200M x 325M	40.9	9.5	24.2	60.2
325M x 0	28.0	18.1	46.9	54.6

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 4.1C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (4.1C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 4.1 done on October 22, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 4:1C

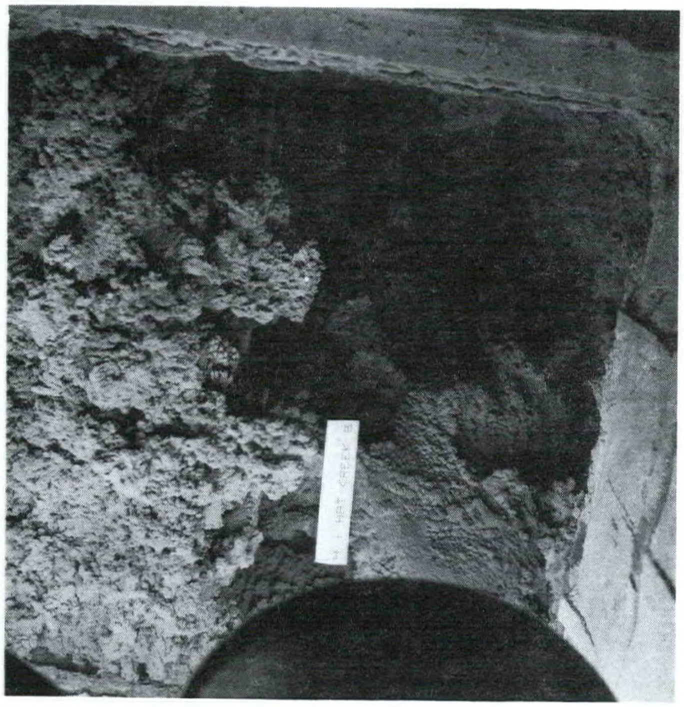


Figure 1a

Furnace bottom at end of test. Friable sinter blocks approximately half of furnace projected bottom area directly above dump plates. Air cooled deposition probe is partly covered with sinter.

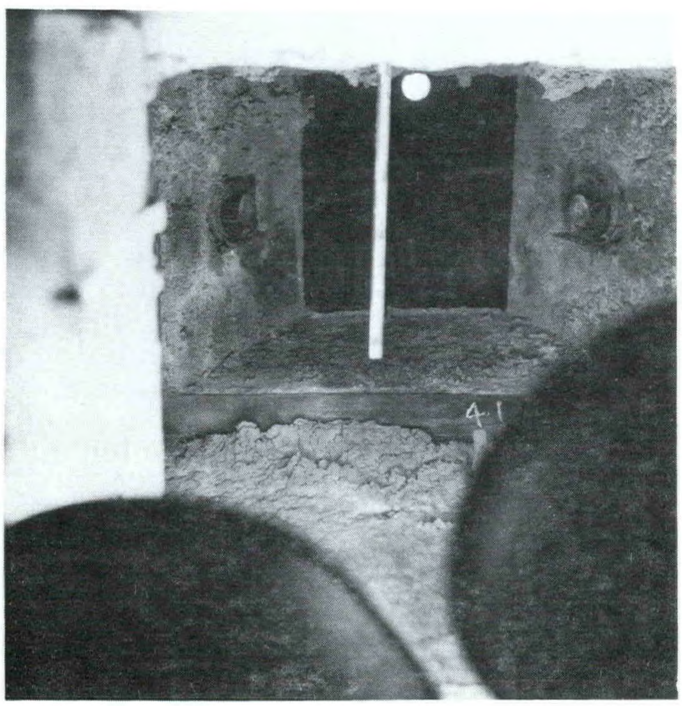


Figure 1b

Furnace bottom at end of test. Sinter has been removed from above dump plates and along west wall of bottom. Burners and throat are clear.

PROGRESS REPORT 4:1C

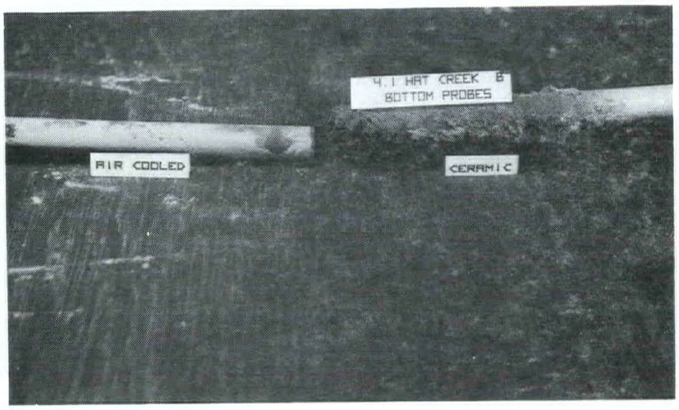


Figure 1c

Furnace bottom deposition probes. Air cooled probe on left. Refractory probe on right.

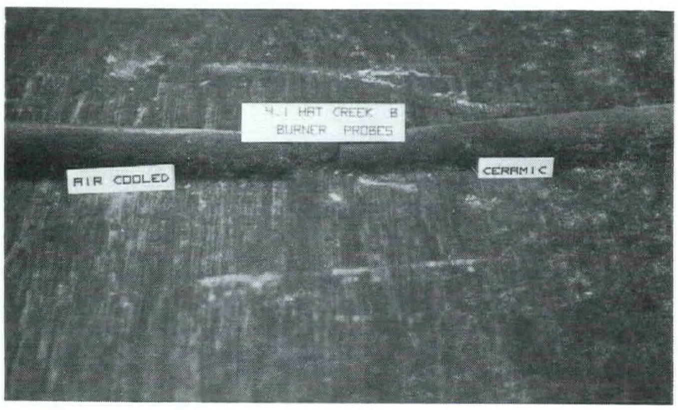


Figure 1d

Burner deposition probes. Air cooled probe on left. Refractory probe on right.

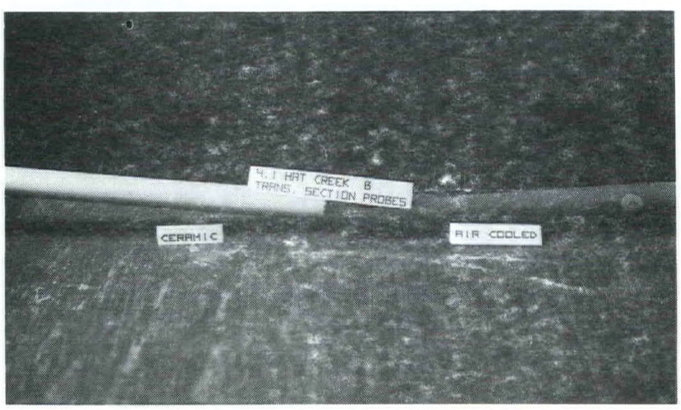


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

FIGURE 1f Main air heater tube sheet second pass up to 2 - 3 inches of powder.

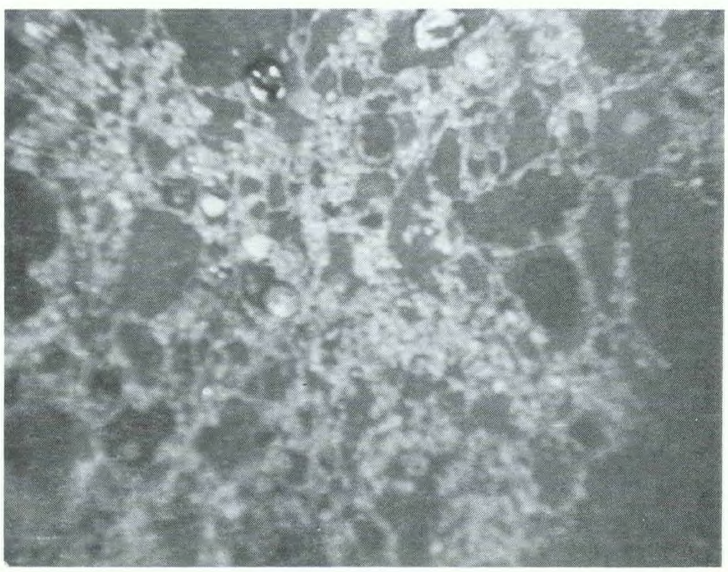


FIGURE 1g Photomicrograph, x 10, of a thin section of sinter which was found attached to the refractory near the burners. The sinter is weak and porous.

PROGRESS REPORT 4:1C

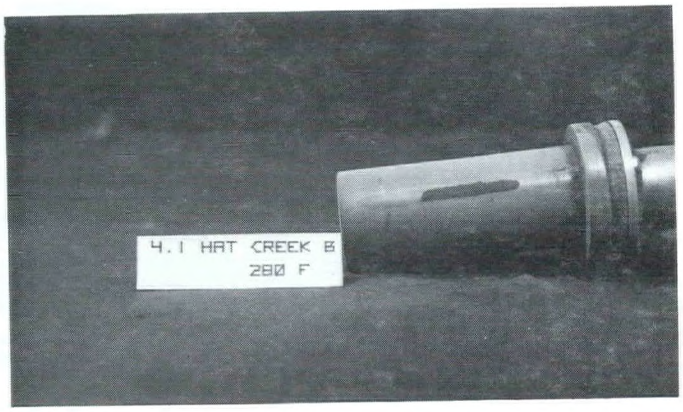


Figure 1h

Low Temperature corrosion probe 138°C.

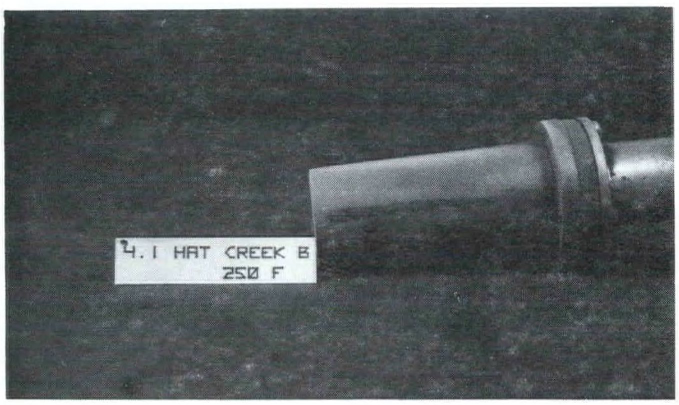


Figure 1i

Low Temperature corrosion probe 121°C.

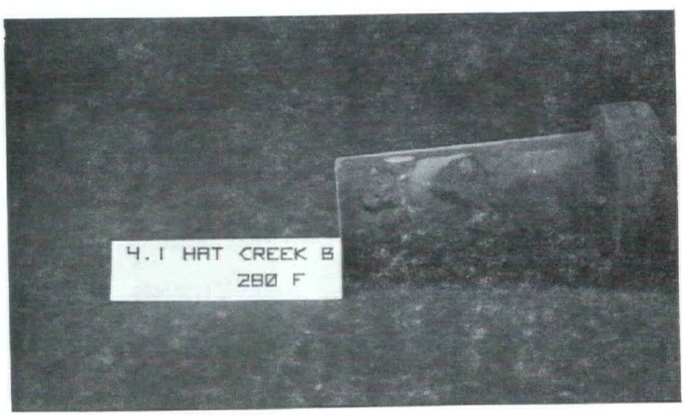


Figure 1j

Low temperature corrosion probe 104°C.
Probe is incorrectly labelled in photograph. Should be 220°F.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

Probe Temperature	Low Temperature 138 °C	Low Temperature 121 °C	Low Temperature 104 °C	High Temperature 534 °C	High Temperature 538 °C	High Temperature 536 °C
Deposition rate[a]						
Fe	48.2	60.7	41.2	2.1	16.8	5.7
Mg	1.34	1.17	.71	2.6	12.2	2.7
Na	1.12	.89	.89	1.3	4.2	1.6
Ca	5.3	3.9	4.3	46.9	89.0	45.3
SO_4 (total)	232.7	203.6	159.2	91.4	392.0	76.3
SO_4 (free), by difference	129.5	83.3	73.4		92.5	

[a] The deposition rate is given in units of $mg/m^2/hour$ and the sampling time is 8½ hours.

Sample: Deposit from the furnace bottom, Test 4.1 (A 1278 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1343	1249
Spherical	°C	1482+	1410
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	52.77
Al_2O_3	28.01
Fe_2O_3	10.79
Mn_3O_4	----
TiO_2	0.96
P_2O_5	0.23
CaO	3.71
MgO	1.44
SO_3	no sample
Na_2O	0.29
K_2O	0.47
Cl	----

Progress Report 4.1 C

Sample: Deposit from the furnace walls, test 4.1 (A 1283 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1271	1199
Spherical	°C	1438	1354
Hemispherical	°C	1466	1421
Fluid	°C	1482+	1449

Ash Analysis	%
SiO_2	51.13
Al_2O_3	27.67
Fe_2O_3	12.73
Mn_3O_4	----
TiO_2	0.95
P_2O_5	0.28
CaO	4.20
MgO	1.42
SO_3	1.64
Na_2O	0.31
K_2O	0.45
Cl	----

Progress Report 4.1 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 4.1 (A 1282 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1310	1221
Spherical	°C	1438	1338
Hemispherical	°C	1460	1449
Fluid	°C	1482+	1482+

Ash Analysis	
SiO_2	50.07
Al_2O_3	27.01
Fe_2O_3	13.31
Mn_3O_4	----
TiO_2	0.96
P_2O_5	0.32
CaO	4.67
MgO	1.22
SO_3	0.91
Na_2O	0.28
K_2O	0.46
Cl	----

Sample: Deposit from electrostatic precipitator, test 4.1 (A 1248-49-50)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1288	1249
Spherical	°C	1432	1343
Hemispherical	°C	1471	1410
Fluid	°C	1482+	1471

Ash Analysis	%
SiO_2	50.26
Al_2O_3	27.03
Fe_2O_3	9.38
Mn_3O_4	----
TiO_2	1.20
P_2O_5	0.35
CaO	5.04
MgO	1.93
SO_3	1.25
Na_2O	0.40
K_2O	0.48
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 4.1D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (4.1D) is the last of the series and presents results of the following detailed analyses of ash produced in test 4.1 done on October 22, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations
3. X-ray diffraction analyses of fireside deposits
4. Summary of DTA studies on fireside deposits

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.8
1.59 - 2.00	Coulter Counter		1.0
2.00 - 2.52	Coulter Counter		1.5
2.52 - 3.17	Coulter Counter		2.2
3.17 - 4.00	Coulter Counter	0.2	3.6
4.00 - 5.04	Coulter Counter	0.3	4.9
5.04 - 6.35	Coulter Counter	0.7	6.7
6.35 - 8.00	Coulter Counter	1.3	8.3
8.00 - 10.08	Coulter Counter	3.2	11.5
10.08 - 12.7	Coulter Counter	6.3	13.1
12.7 - 16.0	Coulter Counter	11.1	13.1
16.0 - 20.2	Coulter Counter	15.7	10.5
20.2 - 25.4	Coulter Counter	17.9	7.8
25.4 - 32.0	Coulter Counter	15.0	4.1
32.0 - 40.3	Coulter Counter	8.0	1.6
40.3 - 44.0	Coulter Counter	1.4	0.3
44.0 - 74.0	Sieve	15.7	5.6
+ 74.0	Sieve	3.2	3.4

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA — PARTICLE SIZE ANALYSIS

.15 – 200μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

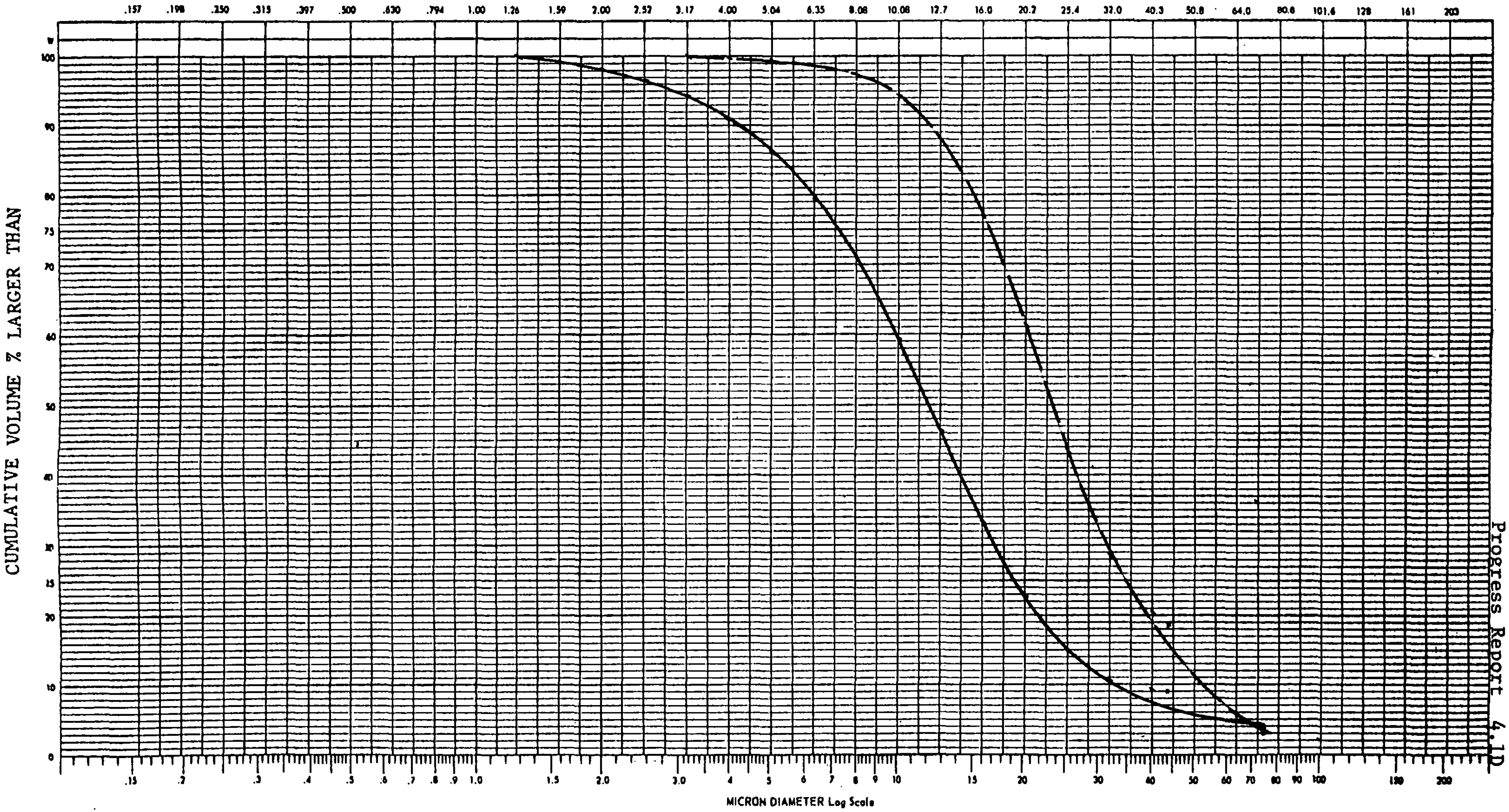
ORGANIZATION: CCRL - WRL

OPERATOR:

EQUIPMENT:

$k = d\sqrt[3]{2W}$ $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$ FOR MODEL T $\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA   SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 4.1	Isoton	Ultrasonic	100μ	6102033									
ESP ———													
AH2 - - -													



4221010

Progress Report 4.1D

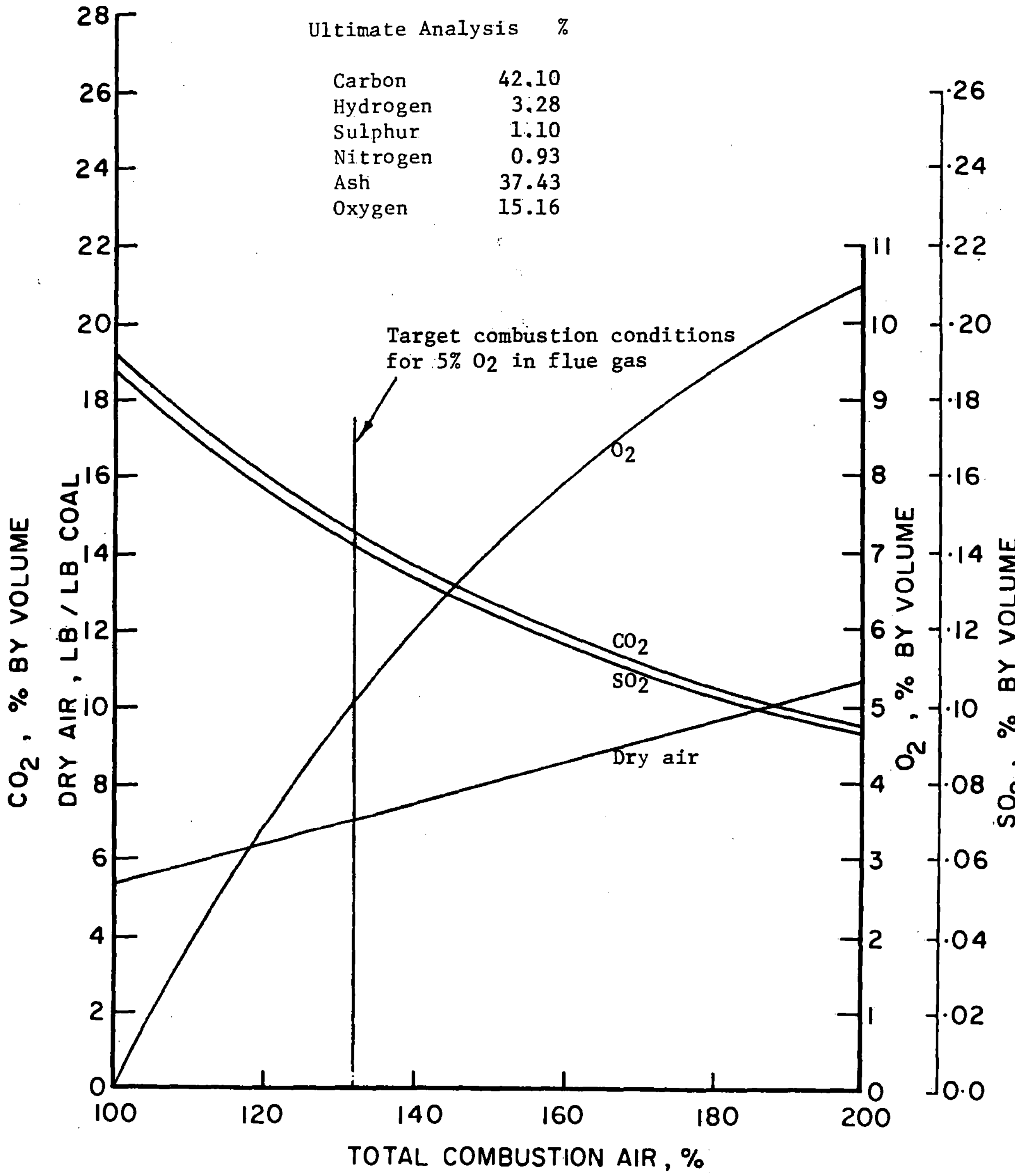


FIGURE 1: Combustion Calculations "B-Raw" Coal.

X-ray Diffraction Analyses of Fireside Deposits from Test 4.1, "B-raw" coal from Hat Creek.

Furnace Bottom Ash (1278 76-435)	Mull, Crist
Under Flame Probe Deposit (1272 76-451)	Hem, Mag, Mull, Sill
Furnace Probe Deposit (1274 76-452)	Mag, Hem, Mull, Unid (tr), Amorph
Transition Probe Deposit (1276 76-453)	Hem, Mull, Qtz, Amorph

Abbreviations of Constituents:

Qtz	Quartz SiO_2
Crist	Cristobalite SiO_2
Mull	Mullite $3Al_2O_3.2SiO_2$
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Sill	Sillimanite $Al_2O_3.SiO_2$
Unid	Unidentified material of significance
Amorph	Significant amorphous material present

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification.

Constituents are listed in decreasing order of abundance. On occasion "trace" is used for clarity.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

SUMMARY OF DTA STUDIES ON FIRESIDE DEPOSITS

Samples:

Five samples of ash from the furnace bottom and one sample of ash collected by the CCRL dust sampler were examined.

Sample 1)	CCRL 980	Test 1.1	Sundance bottom ash.
Sample 2)	CCRL 1092	Test 2.1	Hat Creek A-raw, bottom ash
Sample 3)	CCRL 1190	Test 3.1	Hat Creek A-washed, bottom ash
Sample 4)	CCRL 1278	Test 4.1	Hat Creek B-raw, bottom ash
Sample 5)	CCRL 1360	Test 4.3	Hat Creek B-raw, bottom ash
Sample 6)	CCRL 986	Test 1.1	Sundance fly ash.

Procedures:

Samples weighing approximately 50 mg were heated in a static air atmosphere at $12^{\circ}C$/min. to $1500^{\circ}C$. Two platinum foil pans were held in a vertical furnace, one containing the sample and the other containing α-alumina as reference material. Pt: Pt/13% Rh thermocouples were held with their beads denting the bottom of the pans.

Results:

Sample 1) No peaks were observed. The baseline shifted in the exothermic direction at $1360^{\circ}C$. When cool, the sample was dark and glassy.

Sample 2) No peaks were observed. The baseline shifted in the endothermic direction at $1450^{\circ}C$. When cool, the sample was brown-black opaque, and very hard.

Sample 3) No peaks were observed. The baseline shifted in the endothermic direction at $1340^{\circ}C$. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 4) No peaks were observed. The baseline shifted in the exothermic direction at $1330^{\circ}C$. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 5) No peaks were observed. The baseline shifted in the endothermic direction at 1160°C. When cool, the sample was brown, opaque, and appeared to have melted.

Sample 6) A sizable exothermic peak was observed in the 400°C to 500°C range and a small endothermic peak was noted at 1160°C. Cooling and reheating in the range 1000°C to 1500°C failed to show any repetition of the latter thermal effect. When cool, the sample was dark and glassy.

Comments:

It seems certain that samples 1), 5) and 6) underwent melting. The other samples probably had some liquid phase present. The lack of DTA peaks is unusual. It most likely indicates that melting occurred over a very broad range. Cooling to 1000°C and reheating gave rise to no peaks either. The exothermic peak for sample 6) was most likely the result of combustion of a small amount of carbonaceous material.

It can be concluded that DTA is not a very usefull technique for studying these materials.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "B" RAW COAL

KILN-DRIED TWICE, 3% EXCESS OXYGEN

TEST NO. 4.2

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/128 -131

PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET
JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 4.2A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarized the data immediately available from Test No. 4.2, which was done on October 26, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 4.2

In this test, Hat Creek "B" raw coal was burned. The coal had been kiln-dried twice, which reduced the as-fired moisture content to 9.3%. The target level of excess oxygen in the flue gas was 3% (approx 15% excess air), and the target coal feed rate was 131 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0840 hr, stable, unsupported coal combustion had been in progress for over an hour. The flame was observed to be yellow-orange coloured, and moderately opaque. The view of the furnace throat from the top of the furnace was partly obscured by flame or glowing ash particles. The air-cooled deposition probe in the furnace was intermittently visible but the refractory deposition probe was not. Deposits could be seen on all of the furnace walls below the throat, and they blocked roughly 1/3 of the projected throat area. The furnace-bottom was fairly transparent but many burning particles of coal were visible. The air-cooled deposition probe in the furnace-bottom was clearly visible. A deposit of sinter on the north wall of the furnace was visible through one of the sight ports. The transition section between the furnace and the test air-heater showed only a faint glow by which the test air-heater tubes could barely be discerned.

At 0900 hr, the deposits under the furnace throat were removed by thrusting a poker through the top of the furnace. Ash was then dumped, and when raked from the quench tank it was observed to be formed of nearly black coloured, small, weak sinters. The flame was more transparent. From the top of the furnace it was possible to observe part of the west wall of the furnace-bottom and the air-cooled probe in the furnace-bottom.

At 1000 hr, a poker was again used to remove deposits from the walls below the furnace throat. Then ash was dumped and raked out of the quench tank.

A few pieces of sinter 15 to 20 cm in diameter and some small sinters were found in the ash. The flame was bright and its colour was closer to yellow than to orange. Some burning or glowing coal particles were being swept into the furnace exit, and there was a 5 to 8 cm layer of sinter whiskers on the furnace-bottom walls.

At 1135 hr, deposits were removed from the furnace throat by thrusting a poker through the top of the furnace, and ash was removed from the ledges adjacent to the dump plates by thrusting a poker through a sight port in the bottom. This was repeated at 1310 hr, and a large sinter, 15 to 20 cm thick remained adhering to the south wall of the furnace-bottom.

By 1410 hr, deposits under the throat had built up afresh and they blocked nearly 1/4 of the projected throat area. All visible walls of the furnace-bottom had a layer of sinter, which was 5 to 10 cm thick. By 1450 hr, the throat was nearly blocked with deposit, but the deposits were not removed until 1460 hr, when measurements were completed. A poker was thrust through the top of the furnace, and ash was dumped.

At 1530 hr, the furnace-bottom was ½ full of ash. The air-cooled deposition probe in the furnace was badly bent by falling sinters, and was partly immersed in the ash. Heavy deposits of sinter on the south wall of the furnace-bottom and below the furnace throat were evident.

At 1553 hr, the test was completed. Deposits were visible on the north side and part of the west side of the furnace throat. The furnace-bottom walls were heavily coated with whiskers of sinter. After "shutdown", a flame persisted for several minutes. This was caused by oil from the support burner which had struck and soaked into the deposits of sinter. However, the ash in the furnace-bottom very soon ceased to radiate visible light.

Deposition Probe During the Test

Only the air-cooled deposition probes in the furnace and the furnace-bottom were visible during the test.

The air-cooled deposition probe in the furnace-bottom initially developed a beard of sinter, 6 to 12 mm thick, on all of the top surface. Some of this sinter was knocked off and the probe was bent downward when the throat was first cleaned. The probe then became bearded evenly with sinter, 6 mm thick, and again this was knocked off when the throat was cleaned at 1310 hr. This pattern of deposit development and their accidental removal did not change until the end of the test. Then the free end of the probe was buried in the ash on the furnace-bottom and the exposed portion was clean except for a continuous deposit, 4 mm thick, along the top surface.

The air-cooled deposition probe in the furnace remained free of massive deposits throughout the test.

Furnace After Test

When the dump plates were swung open, only a small quantity of ash fell. A large sinter, roughly 30 cm square x 15 cm thick, remained hanging in the furnace-bottom, partly supported by the air-cooled deposition probe. The furnace-bottom walls and the throat refractory were covered with sinter, 5 cm thick, and with some deposits less than 20 cm thick. The heaviest deposits were in the southwest and northeast corners. The ash ranged in colour from tan to rust-brown, with the former predominating. Some of the sinter was moderately strong.

The furnace water walls bore some dust and at the lower end there were a few 3 to 4 mm globules of sinter. There were roughly 2 cm of dust on the upper slopes of the tubes forming the furnace throat and the nose of the furnace exit.

There was a layer of dust 7 to 10 cm thick on the bottom of the transition section and the test air-heater. It was mostly tan coloured, with a thin charcoal-grey coloured layer on top. The test air-heater tubes were clean on the upstream surface, but had a 1 to 2 mm deposit of tan-coloured dust on the downstream surface. The main air-heater had 1 to 4 cm of charcoal-grey coloured dust on the second-pass tube sheet.

Deposition Probes After Test

Before it was removed, the air-cooled probe in the furnace-bottom was clean. The ash which covered the free end did not adhere.

The refractory probe in the furnace-bottom had broken off during the test and had been raked out of the quench tank.

Before they were removed, both of the probes in the furnace were clean, except for a thin layer of dust.

The refractory transition probe was clean on the upstream surface and was covered by $1\frac{1}{2}$ mm of tan coloured dust on the downstream surface.

The air-cooled transition probe was covered evenly by 3 mm thick, grey coloured dust.

Test No. 4.2

Progress Report 4.2A

Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "B" RAW, DRIED TWICE EXCESS O_2 3 %

26/10/76

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		132.5(4.1)	kg/hr	
Moisture Content of Coal	1	9.3	%	feed to pulverizer
" " " "	2	0.8	%	feed to furnace
Combustible " " "	2	65.1(2.7)	%	dry weight
Ash Dumping Frequency		once every ½	hour	continuous dumping
PULVERIZER OPERATING CONDITIONS				Total ash dumped=155 kg(dry)
a) Inlet Air Pressure	3	278(5)	mmH_2O	equivalent to 1238.5 kg
b) Outlet Air Pressure	2	227(6)	mmH_2O	coal.
c) Inlet Air Temperature	3	199(6)	°C	
d) Outlet Air Temperature	2	103(2)	°C	
e) Coal Fineness	2	83.6% below 200 mesh		oversize, 15.3% 140 mesh
BOILER OPERATING CONDITIONS				" , 16.4% 200 mesh
a) Steam Flow	6	649(16)	kg/hr	" , 47.9% 325 mesh
b) Steam Pressure	6	3.07(0.08)	atmospheres	
c) Combustion Air Temp.	4	188(7)	°C	
d) Furnace Pressures				
Furnace	10	34(9)	mmH_2O	
Inlet	11	34(9)	mmH_2O	
Boiler Exit	12	18(3)	mmH_2O	
Primary (Coal) Air L	5	145(8)	mmH_2O	
" R	5	157(8)	mmH_2O	
Secondary (Windbox) Air L	4	53(11)	mmH_2O	
" R	4	52 (9)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	17.1(0.4)	%	
b) O_2	11	3.1(0.2)	%	
c) CO	11	149(30)	ppm	
d) NO	13	580(123)	ppm	
e) SO_2	14	1016(22)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	24(3)	°C	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	628(18)	°C	
b) Boiler Exit	12	292(12)	°C	
c) Precipitator Entry	16	156(12)	°C	
SUCTION PYROMETER TEMPERATURES				
a)	7	1110, 1008	°C	readings taken in
b)	8	907, 844	°C	second and third
c)	9	873, 845	°C	two hour period
FLY ASH				
a) Loading	16	11600(2600)	$mgms/m^3$	measured at 20°C
b) Resistivity	15	$1.5(1.4)\times10^{10}\,\Omega$ cm at 262°C		
"	17	$2.6(1.0)\times10^{11}\,\Omega$ cm at 158°C;		$1.8\times10^{11}\,\Omega$ cm at 114°C
c) Precipitator efficiency	18	92.0(0.9)	%	
d) Combustible content of ash collected from precipitator	18	4.5(0.7)	%	

TABLE 2

DEPOSITION PROBES

Station		Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom	19	ceramic	1220	175	957	1648	961	1263	Probe Broken Tan and grey sinter, 6 mm thick, uneven.
		stainless	711	(68)	545	847	781	675	Tan scale, uneven, upstream. Tan powder, even, ½ mm thick, downstream
Furnace	9	ceramic	781	(59)	723	876	856	673	Black scale, uneven, upstream.
		stainless	482	(58)	397	568	426	428	Grey dust, 2 mm thick, over dark grey scale, upstream. Dark grey powder, 2 mm thick, downstream.
Transition Section	20	ceramic	640	(20)	592	666	592	631	Tan coloured dust, 1½ mm thick, downstream.
		stainless	504	(27)	423	538	423	496	Grey powder, 1 mm thick, all around, over tan powder, 2 mm thick, downstream and grey scale, upstream.

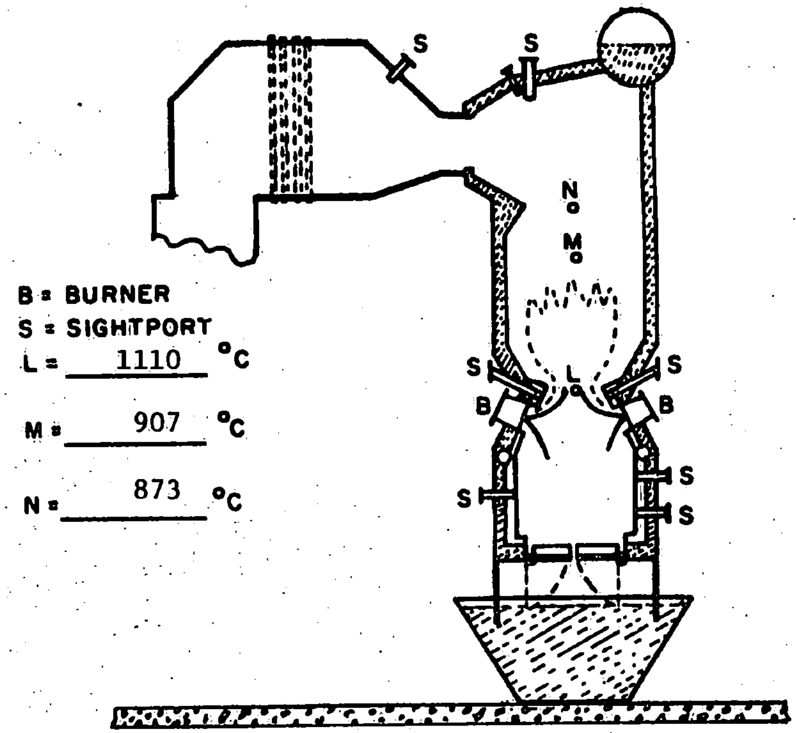


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 4.2B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (4.2B) presents coal analyses and size distribution of the pulverized coal burned in test 4.2 done on October 26, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

3099-76
A-1284
7/1/77

CCRL
Hat Creek "B-Raw" (4.2)

SAMPLE CONDITION		AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis			
Moisture		7.81	0.00
Ash		28.43	30.84
Volatile Matter		32.59	35.35
Fixed Carbon (by Diff.)		31.17	33.81
Ultimate Analysis			
Carbon	%	44.07	47.80
Hydrogen	%	3.34	3.62
Sulphur	%	0.84	0.91
Nitrogen	%	0.92	1.00
Ash	%	28.43	30.84
Oxygen (by Diff.)	%	14.59	15.83
Calorific Value			
Calories per gram		4113	4461
B.T.U. per Lb. gross		7403	8030
Caking Properties			
By Vol. Button @			
Swelling Properties			
Free Swelling Index (ASTM)			

Ash Fusibility, °F		OXID.	RED
Initial Deformation	°F	2700+	2580
Softening-Spherical	°F	2700+	2690
Softening-Hemispherical	°F	2700+	2700+
Fluid	°F	2700+	2700+

SCREEN ANALYSIS

Mesh Inches	%
+ x 1/4	0.00
1/4 x 1/8	0.89
1/8 x 1/16	32.34
1/16 x 1/32	38.53
1/32 x 30M	9.02
30M x 50M	10.51
50M x 0	8.71

Grindability Index (Hardgrove): 47

Equilibrium Moist (97% Hum),%:

Sulphur Forms:

Sulphate	0.06
Pyritic	0.32
Organic (by Diff.)	0.46
Total	0.84

Specific Gravity in ash: 2.76

ASH ANALYSIS

Component	%	Component	%
SiO_2	50.85	CaO	4.11
Al_2O_3	29.84	MgO	0.94
Fe_2O_3	9.36	SO_3	3.17
Mn_3O_4	0.12	Na_2O	0.31
TiO_2	1.31	K_2O	0.36
P_2O_5	0.37		

Chlorine: 0.01

Trace Mercury:

TEST NO: 4.2

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			3.8	84.1
100M x 140M	15.3	3.4	16.8	76.6
140M x 200M	1.2	1.3	8.6	70.5
200M x 325M	31.5	8.2	23.3	66.6
325M x 0	52.0	12.1	47.4	60.2

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 4.2C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (4.2C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various eash forms produced in test 4.2 done on October 26, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 4:2C

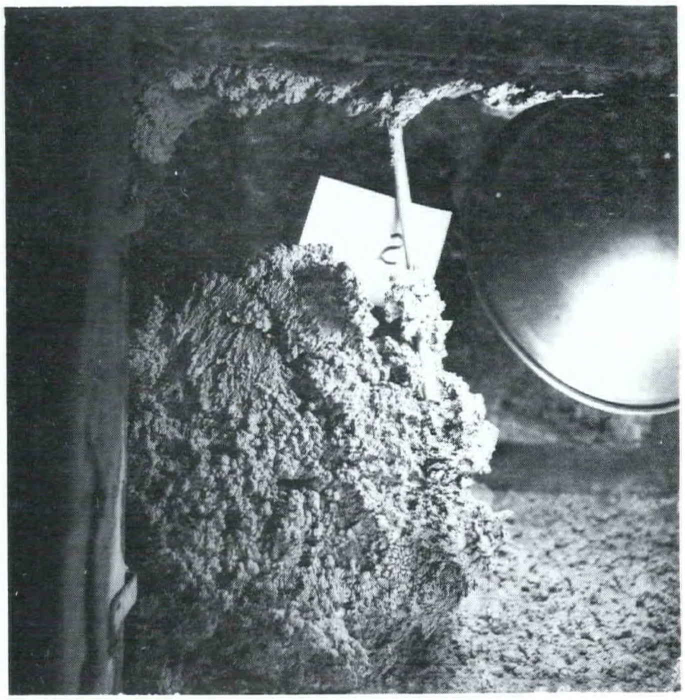


Figure 1a

Furnace bottom at end of test. Large friable sinter in south west corner immediately above dump plates. Air cooled deposition probe extends into sinter.

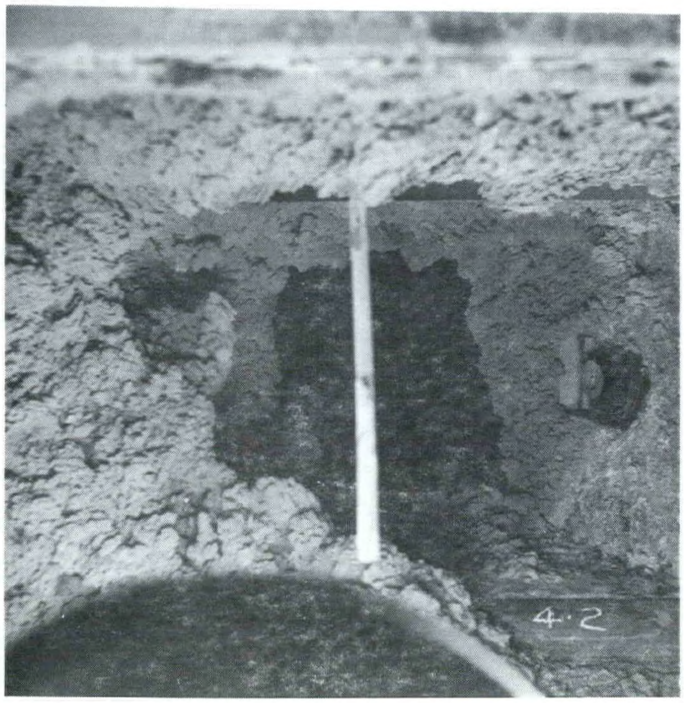


Figure 1b

Furnace bottom at end of test. Sinter immediately above dump plates has been removed. Large sinter extends from half way on west wall to south east corner of furnace bottom. Sinter along north and south walls partially blocks furnace throat. Burner on north side is clear of sinter.

PROGRESS REPORT 4:2C

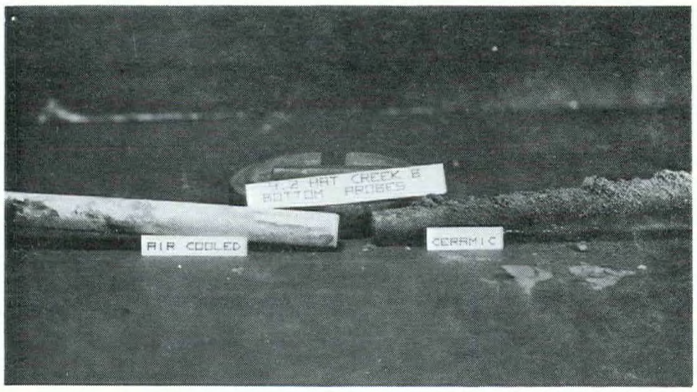


Figure 1c

Furnace bottom deposition probes. Air cooled probe on left. Refractory probe on right.

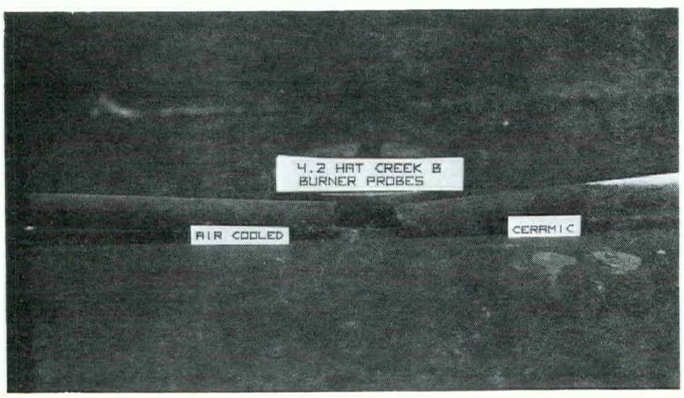


Figure 1d

Burner deposition probes. Air cooled probe of left. Refractory probe on right.

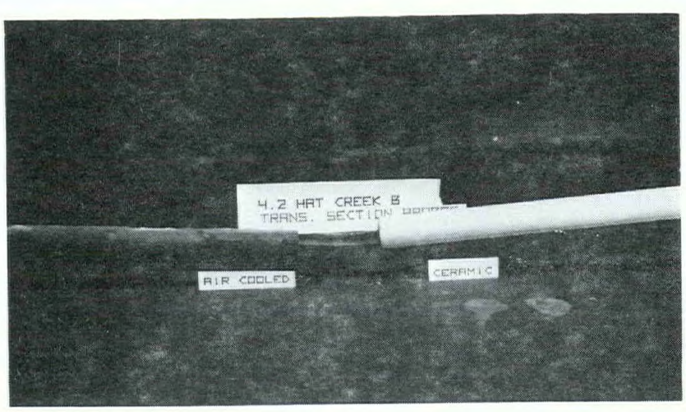


Figure 1e

Transition section deposition probes. Air cooled probe on left. Refractory probe on right.

PROGRESS REPORT 4:2C

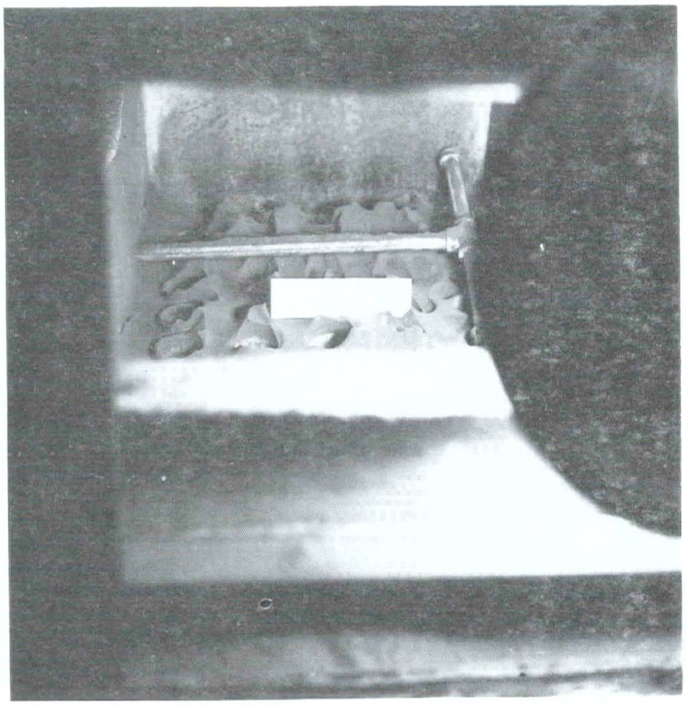


Figure 1f

Main air heater tube sheet second pass up to 2 - 3 inches of powder.

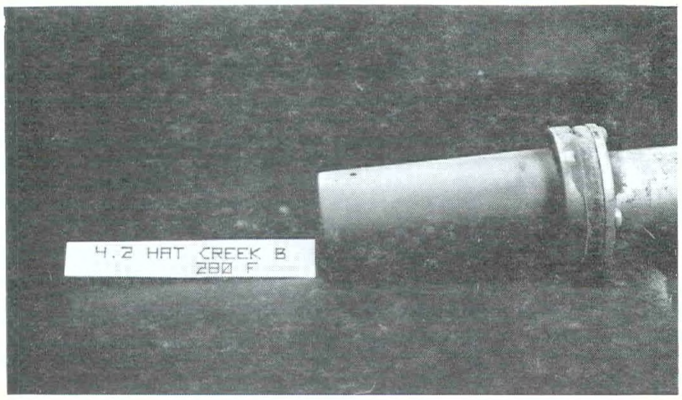


Figure 1g

Low Temperature corrosion probe 138^{o}C.

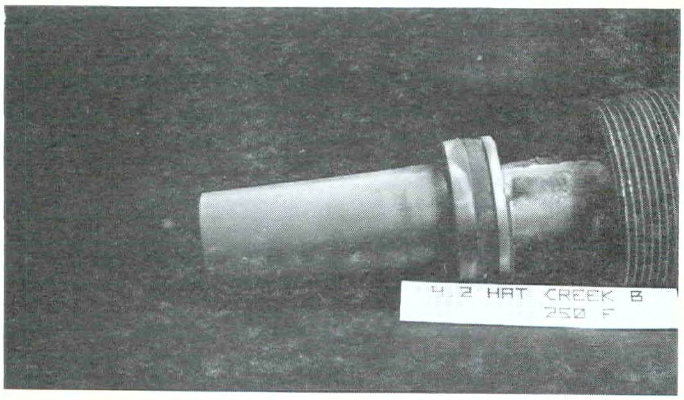


Figure 1h

Low Temperature corrosion probe 121^{o}C.

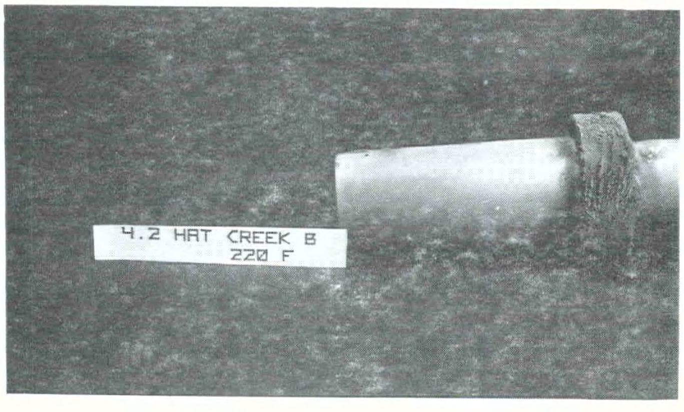


Figure 1i

Low temperature corrosion probe 104^{o}C.

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	711 °C	482 °C	504 °C
Deposition rate[a/]						
Fe	62.6	60.7	31.8	2.1	13.5	4.3
Mg	2.0	1.7	0.5	1.8	14.5	2.6
Na	1.3	0.9	0.7	0.9	4.2	1.3
Ca	5.3	3.5	3.5	15.6	70.7	9.8
SO_4 (total)	165.4	102.7	111.8	80.6	289.5	36.9
SO_4 (free), by difference	34.3		27.8	30.8	30.5	

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposition probes, Test 4.2, B. C. Hydro

Station	Furnace Bottom				Boiler				Transition Section			
Material	SS		REF		SS		REF		SS		REF	
Mean Temperature °C	377		660		250		416		262		338	
% Water Soluble	6.4		2.7		4.8		3.4		4.6		---	
% Acid Insoluble	83.8		90.6		69.1		60.8		75.4		---	
Analysis , %	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS
SO_4	2.4		0.0		1.3		1.4		2.1			
Ca	4.1	0.0	2.5	0.4	2.2	0.3	0.7	0.4	2.0	0.2		
Fe	1.0	3.6	0.1	0.8	0.7	11.4	---	17.5	---	3.6		
Mg	0.1	0.3	---	0.1	0.1	0.6	---	0.5	---	0.6		
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Na	---	0.1	---	---	---	0.1	0.0	0.0	0.0	0.1		

WS = water soluble

AS = acid soluble

--- = trace

Progress Report 4.2 C

Sample: Deposit from the furnace bottom, Test 4.2 (A 1312 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1332	1238
Spherical	°C	1482+	1438
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	55.17
Al_2O_3	30.02
Fe_2O_3	8.34
Mn_3O_4	----
TiO_2	1.02
P_2O_5	0.28
CaO	3.66
MgO	1.25
SO_3	no sample
Na_2O	0.31
K_2O	0.45
Cl	----

Sample: Deposit from the furnace walls, Test 4.2 (A 1312 - B)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1410	1143
Spherical	°C	1421	1154
Hemispherical	°C	1421	1171
Fluid	°C	1438	1249

Ash Analysis	%
SiO_2	21.47
Al_2O_3	11.11
Fe_2O_3	57.02
Mn_3O_4	----
TiO_2	0.50
P_2O_5	0.31
CaO	3.84
MgO	0.99
SO_3	2.12
Na_2O	0.26
K_2O	0.31
Cl	----

Sample: Deposit from transition section, Test 4.2 (A 1312E)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1316	1260
Spherical	°C	1471	1399
Hemispherical	°C	1482+	1460
Fluid	°C	+	1482+

Ash Analysis	
SiO_2	52.30
Al_2O_3	28.72
Fe_2O_3	8.94
Mn_3O_4	----
TiO_2	1.11
P_2O_5	0.32
CaO	4.55
MgO	1.64
SO_3	0.58
Na_2O	0.31
K_2O	0.47
Cl	----

Progress Report 4.2 C

Sample: Deposit from electrostatic precipitator, test 4.2 (A 1292-93-94)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1288	1249
Spherical	°C	1449	1371
Hemispherical	°C	1477	1432
Fluid	°C	1482+	1471

Ash Analysis	%
SiO_2	53.25
Al_2O_3	29.15
Fe_2O_3	7.37
Mn_3O_4	----
TiO_2	1.28
P_2O_5	0.30
CaO	4.97
MgO	1.48
SO_3	0.81
Na_2O	0.42
K_2O	0.50
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 4.2D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY 1/

SUMMARY

As explained elsewhere 2/, the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (4.2D) is the last of the series and presents results of the following detailed analyses of ash produced in test 4.2 done on October 26, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa. Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle <u>volume</u> to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.4
1.59 - 2.00	Coulter Counter		0.5
2.00 - 2.52	Coulter Counter		0.8
2.52 - 3.17	Coulter Counter		1.2
3.17 - 4.00	Coulter Counter	0.2	2.2
4.00 - 5.04	Coulter Counter	0.3	3.3
5.04 - 6.35	Coulter Counter	0.9	4.9
6.35 - 8.00	Coulter Counter	1.9	6.6
8.00 - 10.08	Coulter Counter	4.5	10.1
10.08 - 12.7	Coulter Counter	8.2	12.3
12.7 - 16.0	Coulter Counter	13.1	13.6
16.0 - 20.2	Coulter Counter	16.5	11.9
20.2 - 25.4	Coulter Counter	16.9	9.0
25.4 - 32.0	Coulter Counter	13.9	5.9
32.0 - 40.3	Coulter Counter	6.2	3.3
40.3 - 44.0	Coulter Counter	1.1	1.2
44.0 - 74.0	Sieve	13.3	7.9
+ 74.0	Sieve	3.0	4.9

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA — **PARTICLE SIZE ANALYSIS**

.18 – 200 µ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL - WRL

OPERATOR:

EQUIPMENT:

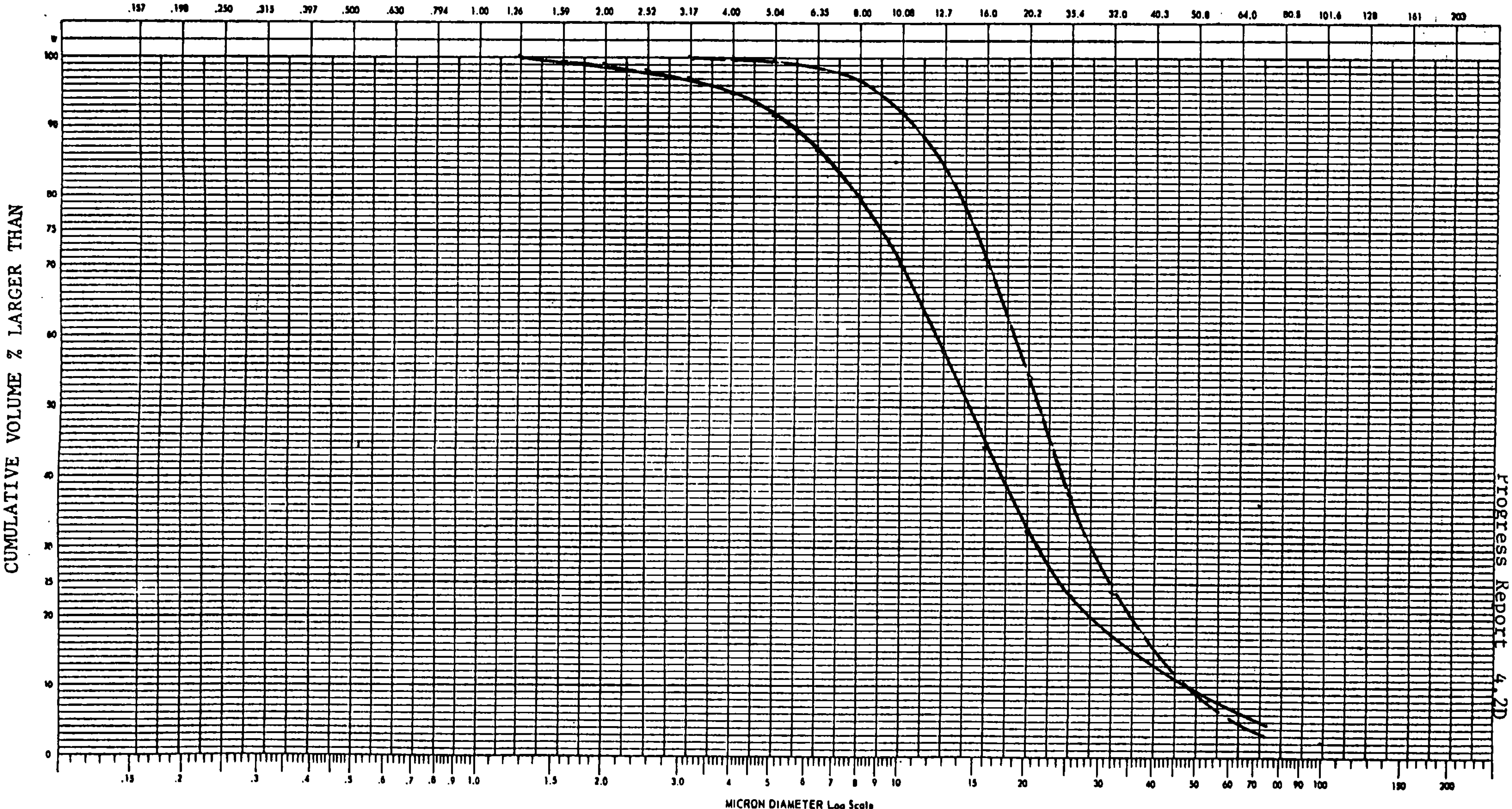
$h = d\sqrt[3]{2W}$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± ΣA	A	DIA.	W	± ΣA	A
TEST No. 4.2	Isoton	Ultrasonic	100µ	6102033									
ESP ———													
AH2 - - -													



4321010

Progress Report 4.2D

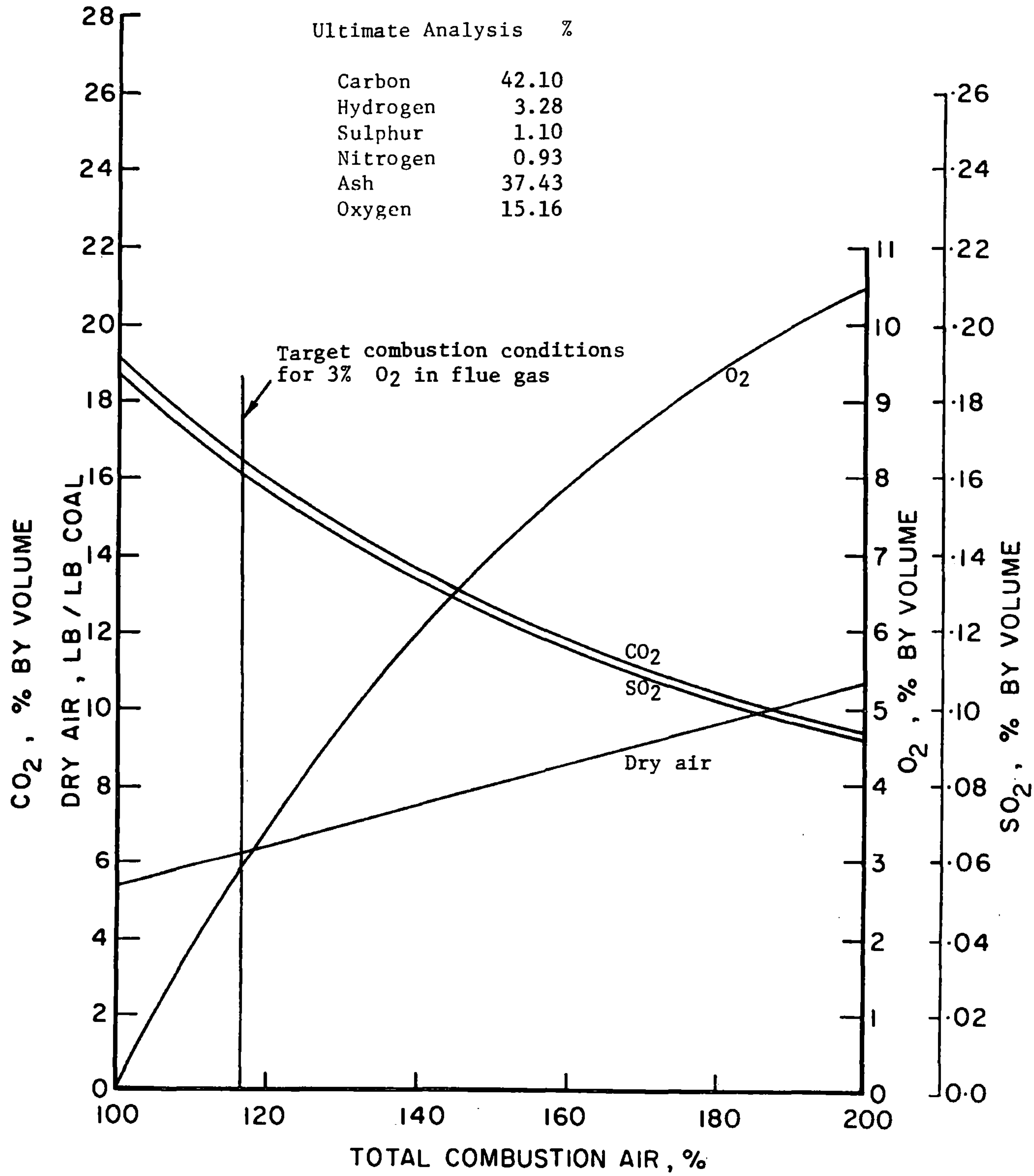


FIGURE 1: Combustion Calculations "B-Raw" Coal.

Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology / Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "B" RAW COAL

KILN-DRIED, 5% EXCESS OXYGEN

TEST NO. 4.3

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/132-135

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 4.3A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET, a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 4.3, which was done on October 28, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 4.3

In this test, Hat Creek "B" raw coal was burned. The coal had been kiln-dried once, which resulted in an as-fired moisture content of 16.6%. The target level of excess oxygen in the flue gas was 5% (approx. 25% excess air), and the target coal feed rate was 142 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0845 hr, stable, unsupported coal combustion had been in progress for over an hour. From the top of the furnace the flame appeared yellow-orange to orange in colour, and was fairly opaque. The furnace throat was visible but hazy, and a deposit of sinter was evident in the southwest corner below the throat. The flame extended above the throat, and some burning particles were carried into the furnace exit. When viewed from the top of the furnace, the air-cooled furnace-deposition probe was visible, but the refractory probe was not. The transition section between the furnace and the test air-heater showed only a dull glow by which the test air-heater tubes could be discerned. The furnace-bottom was bright and transparent. There was a heavy deposit of sinter in the southwest corner, and a light layer on the other walls. The air-cooled deposition probe in the furnace-bottom was clearly visible.

At 0915 hr, the deposits below the furnace throat had grown sufficiently to block approximately 1/3 of the projected throat area. The throat, when viewed from the top of the furnace, was partly obscured by flame and glowing ash particles, and the refractory deposition probe in the furnace was visible intermittently.

At 0945 hr, the deposits below the throat were knocked loose with a poker, which was thrust through the top of the furnace. The dump plates were swung open, and ash was cleared out of the furnace-bottom with a poker, which was thrust through the furnace-bottom ports. The furnace throat then appeared to be clean but was partially obscured by flame and embers. The refractory deposition probe in the furnace was not visible from the top of the furnace. The furnace-bottom was transparent and the walls were fairly clean, but many burning particles of coal were visible.

Conditions remained stable for the remainder of the test. Ash was dumped approximately every hour during periods when no measurements were in progress. The ash, which was raked from the quench tank, was composed of small sinters and mud. Large flakes of agglomerated dust or sinter and a substantial quantity of burning coal particles were being blown about in the furnace. A faint, flickering light was visible in the transition section, by which the test air-heater tubes were barely discernable. A large deposit of sinter developed in the southwest corner of the furnace-bottom, and by 1500 hr, deposits were visible under all sides of the furnace throat. These deposits blocked approximately 1/10 of the projected throat area. Substantial quantities of ash were in the corners of the furnace-bottom.

When the test was completed at 1600 hr, the furnace-bottom was nearly ½ full of ash. Large whiskers of sinter adhered to the walls. Burned-out particles of coal lay lightly on and covered the rough sinter surfaces. The ash in the furnace-bottom very soon ceased to radiate visible light.

Deposition Probes During Test

The deposition probes in the furnace, and the air-cooled deposition probe in the furnace-bottom, were visible during the test.

The air-cooled probe in the furnace-bottom developed a beard of sinter roughly 10 mm thick and 10 cm long along the top surface. Later another lump of sinter 2 cm in diameter was observed to be on the bottom surface. Both deposits fell off when the deposits below the throat were removed. The probe then remained clean until the test was completed.

The air-cooled probe and the refractory probe in the furnace appeared to have only minor deposits throughout the test. The refractory probe was only visible intermittently.

Furnace After Test

When the dump plates were swung open, approximately 50 litres of tan to rust-brown coloured sinter fell to the floor. Two lumps measured approximately 25 cm x 20 cm x 7 cm. The remainder consisted of smaller sinters, and all were friable. The furnace-bottom had a rough layer of sinter 5 to 8 cm thick on the walls and in the lower corners. The upper corners of the furnace-bottom were fairly clean.

The furnace water walls were clean and shiny. The transition section walls were clean, but the bottom bore a 10 cm layer of granular or sandy material which was uniformly light tan coloured. The furnace screen tubes had a layer of grey powder on the downstream surface.

Deposition Probes After Test

Before it was removed, the refractory probe in the furnace-bottom, had a thin layer of tan coloured sinter at the tip and approximately 3 cm of tan coloured sinter on the top and sides near the wall.

Before it was removed, the air-cooled probe in the furnace-bottom had a thin layer of tan coloured dust on the bottom surface and a thin layer of grey and black sinter on the top surface.

The refractory probe in the furnace, before it was removed, appeared to have a thin layer of dark grey sinter on the bottom surface.

The air-cooled probe in the furnace, before it was removed, appeared to have a substantial layer of tan coloured dust on the top surface and a thin layer of dark grey sinter on the bottom surface.

The refractory probe in the transition section, after it was removed, was clean and appeared to have been polished.

The air-cooled probe in the transition section, after it was observed to have a thin layer of weakly adhering, tan coloured dust on the downstream surface. Some of the deposit had fallen off. The upstream surface appeared to have been sandblasted.

Test No. 4.3

Progress Report 4.3A

Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "B" RAW, SINGLE DRIED EXCESS O_2 5 %

28/10/76

Parameters	Station	Obs. (R.M.S. Dev.)	Comments
Test Duration		7 hours	
Firing Rate		150(10) kg/hr	
Moisture Content of Coal	1	16.6 %	feed to pulverizer
" " " "	2	2.1(0.3) %	feed to furnace
Combustible " " "	2	62(3) %	dry weight
Ash Dumping Frequency		once every 1 hour	Total ash dumped = 102 kg, equivalent to 1210 kg coal.
PULVERIZER OPERATING CONDITIONS			
a) Inlet Air Pressure	3	283(14) mmH_2O	
b) Outlet Air Pressure	2	240(6) mmH_2O	
c) Inlet Air Temperature	3	198(4) °C	
d) Outlet Air Temperature	2	71(5) °C	
e) Coal Fineness	2	81.8% below 200 mesh	oversize, 17.6% 140 mesh
BOILER OPERATING CONDITIONS			" , 18.2% 200 mesh
a) Steam Flow	6	634(56) kg/hr	" , 48.8% 325 mesh
b) Steam Pressure	6	3.05(0.10) atmospheres	
c) Combustion Air Temp.	4	184(5) °C	
d) Furnace Pressures			
Furnace	10	39(8) mmH_2O	
Inlet	11	39(7) mmH_2O	
Boiler Exit	12	19(4) mmH_2O	
Primary (Coal) Air L	5	151(10) mmH_2O	
" R	5	167(8) mmH_2O	
Secondary (Windbox) Air L	4	56(12) mmH_2O	
" R	4	57(12) mmH_2O	
FLUE GAS ANALYSIS			
a) CO_2	11	15.1(0.5) %	
b) O_2	11	5.0(0.2) %	
c) CO	11	202(46) ppm	
d) NO	13	587(78) ppm	
e) SO_2	14	1076(83) ppm	
f) SO_3	14	1.9(0.3) ppm	
g) Acid dewpoint	18	34 °C	
FLUE GAS TEMPERATURE			
a) Furnace Exit	11	609(10) °C	
b) Boiler Exit	12	285(8) °C	
c) Precipitator Entry	16	155(6) °C	
SUCTION PYROMETER TEMPERATURES			
a)	7	960, 1079 °C	readings taken in
b)	8	855, 880 °C	second and third
c)	9	780, 704 °C	two hour period
FLY ASH			
a) Loading	16	14100(3100) $mgms/m^3$	measured at 20°C
b) Resistivity	15	$1.2(0.4)\times10^{11}$ Ω cm at 256°C	
"	17	$6.3(0.8)\times10^{11}$ Ω cm at 154°C;	3.0×10^{11} Ω cm at 119°C
c) Precipitator efficiency	18	93.6(1.0) %	
d) Combustible content of ash collected from precipitator	18	3.3(0.5) %	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C						Description of Deposit
		mean	RMS Dev.	min.	max.	initial	final	
Furnace Bottom 19	ceramic	1123	63	1020	1285	1020	1285	Tan coloured sinter, uneven, 12 mm thick, friable, adheres.
	stainless	486	32	442	538	538	532	Mauve coloured scale, even, upstream, grey coloured powder, 1 mm thick, downstream.
Furnace 9	ceramic	829	32	806	889	889	847	Grey coloured scale upstream, covered by 1 mm thick, grey coloured powder upstream and downstream.
	stainless	496	56	394	648	531	477	Mauve coloured scale, upstream, beige powder, 2 mm thick, downstream, both covered by 1 mm thick, grey powder.
Transition Section 20	ceramic	617	22	570	657	577	657	Clean polished surface.
	stainless	415	72	370	550	448	414	Black scale, upstream, beige powder, 1 mm thick, downstream, both covered by grey powder ½ mm thick.

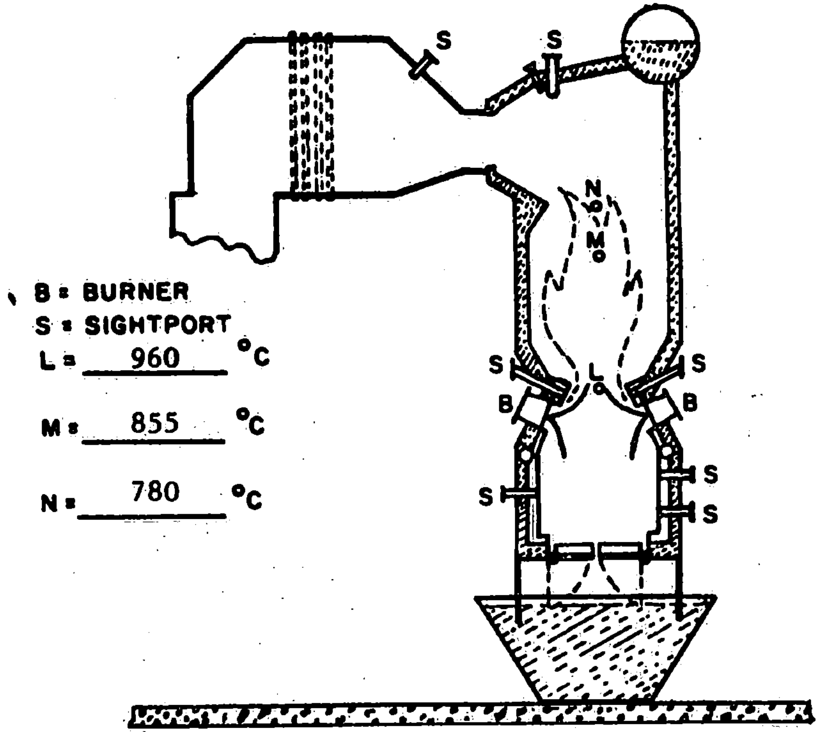


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 4.3B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (4.3B) presents coal analyses and size distribution of the pulverized coal burned in test 4.3 done on October 28. 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

RECORD OF ANALYSIS

CCRL	3100-76
Hat Creek "B-Raw" (4.3)	A1313
	7/1/77

SAMPLE CONDITION	AIR DRIED	DRIED 107 ± 3°C
Proximate Analysis		
Moisture	17.33	0.00
Ash	23.81	28.80
Volatile Matter	29.72	35.95
Fixed Carbon (by Diff.)	29.14	35.25
Ultimate Analysis		
Carbon %	40.68	49.21
Hydrogen %	3.03	3.67
Sulphur %	0.76	0.92
Nitrogen %	0.85	1.03
Ash %	23.81	28.80
Oxygen (by Diff.) %	13.54	16.37
Calorific Value		
Calories per gram	3805	4603
B.T.U. per Lb. gross	6849	8285
Caking Properties		
By Vol. Button @		
Swelling Properties		
Free Swelling Index (ASTM)		

Ash Fusibility, °F	OXID.	RED
Initial Deformation °F	2650	2500
Softening-Spherical °F	2700+	2680
Softening-Hemispherical °F	2700+	2700+
Fluid °F	2700+	2700+

SCREEN ANALYSIS

Mesh Inches	%
+ x 1/4	0.00
1/4 x 1/8	4.78
1/8 x 1/16	49.18
1/16 x 1/32	24.27
1/32 x 30M	5.58
30M x 50M	7.19
50M x 0	9.00

Grindability Index (Hardgrove): 42

Equilibrium Moist (97% Hum),%:

Sulphur Forms:

Sulphate	0.08
Pyritic	0.24
Organic (by Diff.)	0.44
Total	0.76

Specific Gravity in ash: 2.76

ASH ANALYSIS

Component	%	Component	%
SiO_2	50.82	CaO	4.06
Al_2O_3	30.53	MgO	1.29
Fe_2O_3	8.43	SO_3	3.31
Mn_3O_4	0.10	Na_2O	0.33
TiO_2	1.29	K_2O	0.38
P_2O_5	0.35		

Chlorine: -

Trace Mercury:

TEST NO: 4.3

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			16.9	77.7
100M x 140M	17.6	4.7	12.8	72.5
140M x 200M	0.6	0.3	6.4	66.2
200M x 325M	30.6	7.8	16.2	60.6
325M x 0	51.2	4.9	47.7	53.8

1/ The mesh openings for the sieves are as follows: 250µ for 60 mesh, 149µ for 100 mesh, 105µ for 140 mesh, 74µ for 200 mesh and 44µ for 325 mesh and where 1µ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 4.3C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (4.3C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 4.3 done on October 28, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 4:3C

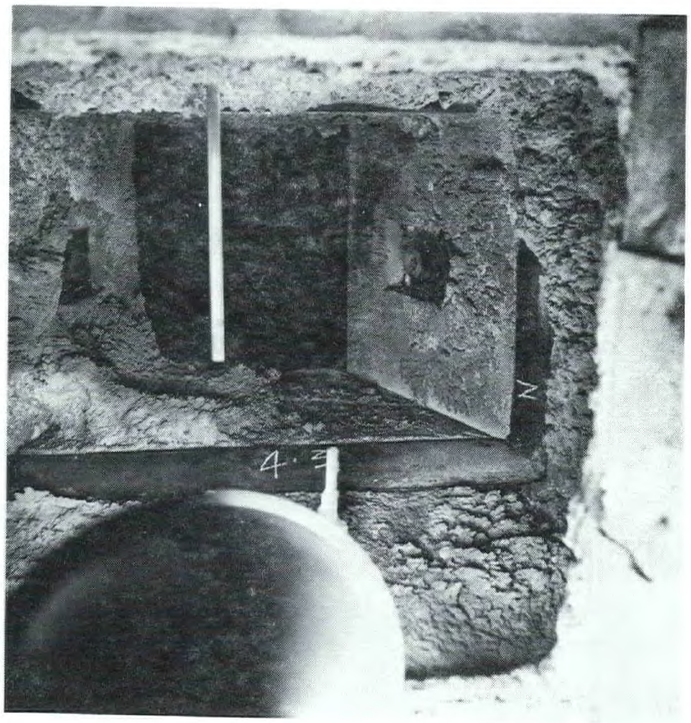


Figure 1a

Furnace bottom at end of test. Burners are clear of sinter. Furnace throat is clear excepting a small accumulation of sinter in the south west corner. Deposition probes are in foreground.

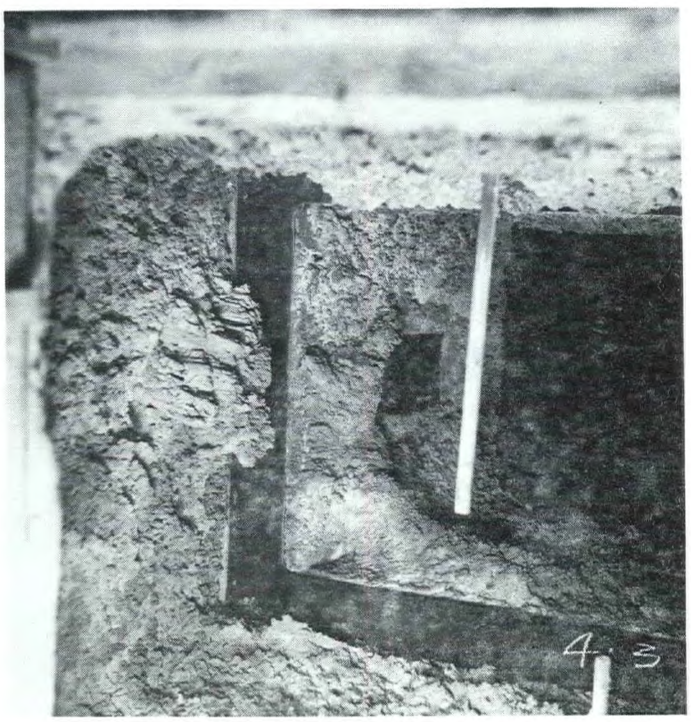


Figure 1b

Furnace bottom at end of test. Closer view of south side of furnace where sinter accumulation is greatest.

PROGRESS REPORT 4:3C

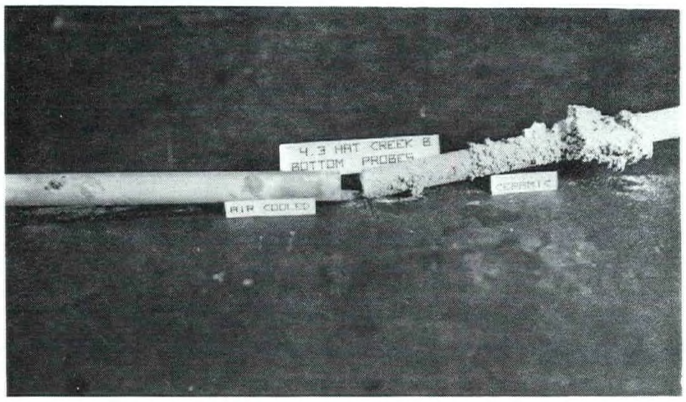


Figure 1c

Furnace bottom deposition probes. Air cooled probe on left. Refractory probe on right.

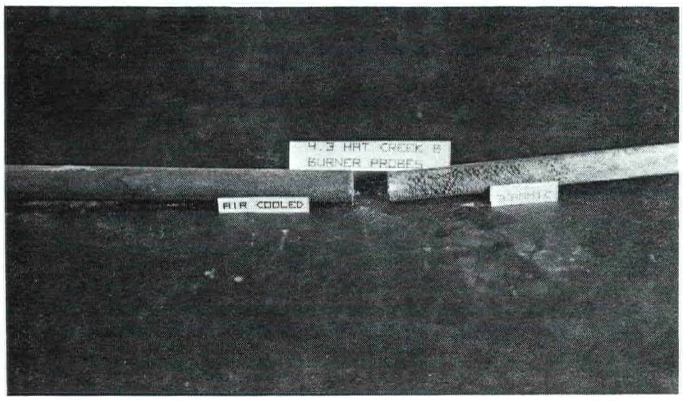


Figure 1d

Burner deposition probes. Air cooled probe of left. Refractory probe on right.

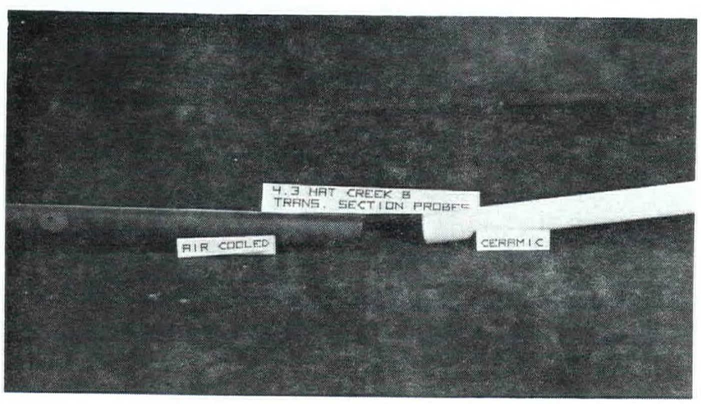


Figure 1e

Transition section deposition probes. Air cooled probe on left. Refractory probe on right.

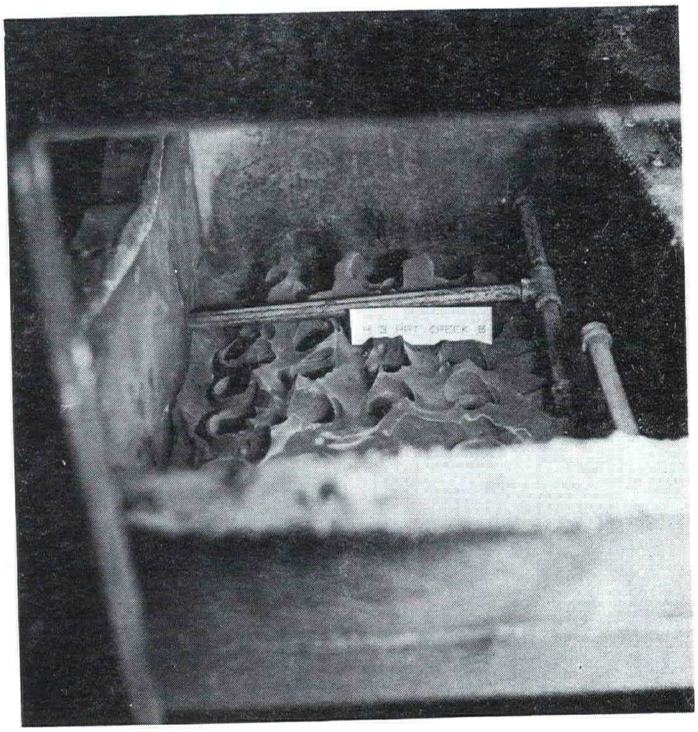


Figure 1f

Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 4:3C

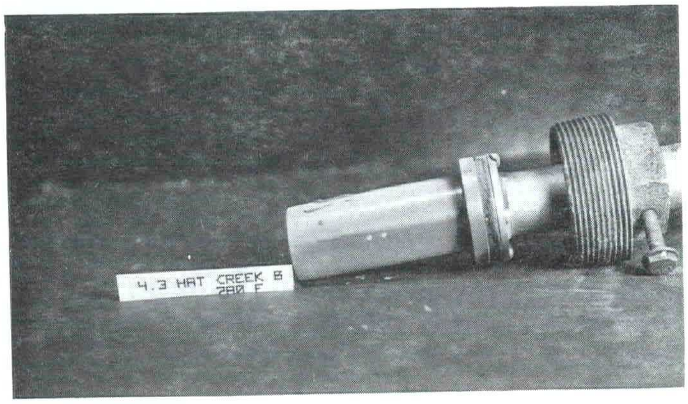


Figure 1g

Low Temperature corrosion probe 138°C.

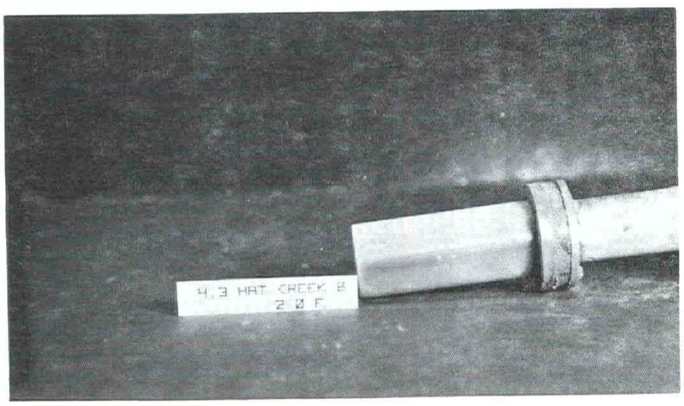


Figure 1h

Low Temperature corrosion probe 121°C.

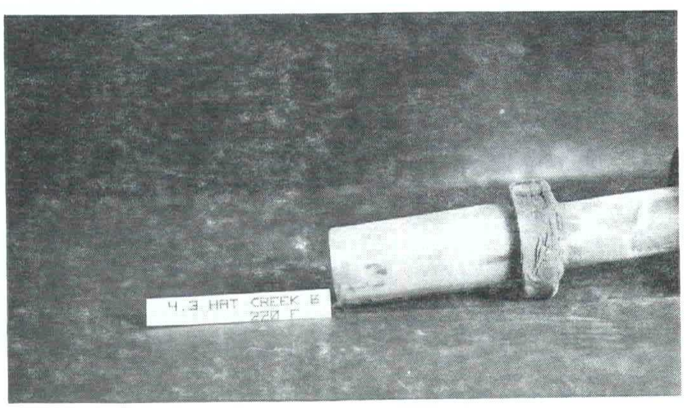


Figure 1i

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	486 °C	496 °C	415 °C
Deposition rate[a]						
Fe	62.6	46.7	36.3	3.5	10.0	3.5
Mg	2.5	1.6	0.5	1.7	15.6	2.0
Na	1.1	0.4	0.4	1.3	3.5	1.6
Ca	4.9	3.5	2.9	30.3	90.0	21.3
SO_4 (total)	139.3	125.6	76.6	117.7	827.4	635.5
SO_4 (free), by difference	6.1	29.7	4.3	29.5	525.0	40.4

[a] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposit from the furnace bottom, Test 4.3 (A 1360 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C		
Spherical	°C		
Hemispherical	°C		
Fluid	°C		

Ash Analysis	%
SiO_2	55.18
Al_2O_3	29.51
Fe_2O_3	9.29
Mn_3O_4	----
TiO_2	1.03
P_2O_5	0.24
CaO	3.70
MgO	1.35
SO_3	no sample
Na_2O	0.31
K_2O	0.52
Cl	----

Sample: Deposit from the furnace walls, Test 4.3 (A 1361 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1354	1238
Spherical	°C	1482+	1388
Hemispherical	°C		1454
Fluid	°C		1482+

Ash Analysis	%
SiO_2	52.19
Al_2O_3	28.11
Fe_2O_3	10.68
Mn_3O_4	----
TiO_2	1.00
P_2O_5	0.29
CaO	3.69
MgO	1.22
SO_3	1.60
Na_2O	0.31
K_2O	0.61
Cl	----

Progress Report 4.3 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 4.3 (A 1364 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1338	1188
Spherical	°C	1438	1382
Hemispherical	°C	1454	1432
Fluid	°C	1482+	1482+

Ash Analysis	
SiO_2	50.54
Al_2O_3	27.33
Fe_2O_3	12.85
Mn_3O_4	----
TiO_2	0.92
P_2O_5	0.30
CaO	4.16
MgO	1.19
SO_3	1.01
Na_2O	0.26
K_2O	0.44
Cl	----

Progress Report 4.3 C

Sample: Deposit from electrostatic precipitator, Test 4.3 (A 1321-22-23)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1360	1221
Spherical	°C	1466	1343
Hemispherical	°C	1482+	1360
Fluid	°C	+	1382

Ash Analysis	%
SiO_2	52.51
Al_2O_3	28.94
Fe_2O_3	7.91
Mn_3O_4	----
TiO_2	1.27
P_2O_5	0.32
CaO	4.73
MgO	1.50
SO_3	1.14
Na_2O	0.40
K_2O	0.63
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Raw Coal
Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 4.3D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (4.3D) is the last of the series and presents results of the following detailed analyses of ash produced in test 4.3 done on October 28, 1976.

1. Particle size distribution of fly-ash
2. Combustion calculations
3. X-ray diffraction analyses of fireside deposits
4. Summary of DTA studies on fireside deposits

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter	______	0.5
1.59 - 2.00		______	0.6
2.00 - 2.52		______	1.1
2.52 - 3.17		______	1.6
3.17 - 4.00		______	2.7
4.00 - 5.04		0.2	3.8
5.04 - 6.35		0.4	5.3
6.35 - 8.00		0.7	7.0
8.00 - 10.08		1.7	10.3
10.08 - 12.7		3.3	12.2
12.7 - 16.0		6.9	14.0
16.0 - 20.2		11.6	12.2
20.2 - 25.4		15.9	9.3
25.4 - 32.0		16.8	5.2
32.0 - 40.3		11.2	1.9
40.3 - 44.0		2.1	0.4
44.0 - 74.0	Sieve	22.8	7.2
+ 74.0		6.4	4.7

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
% PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL - WRL

OPERATOR:

EQUIPMENT:

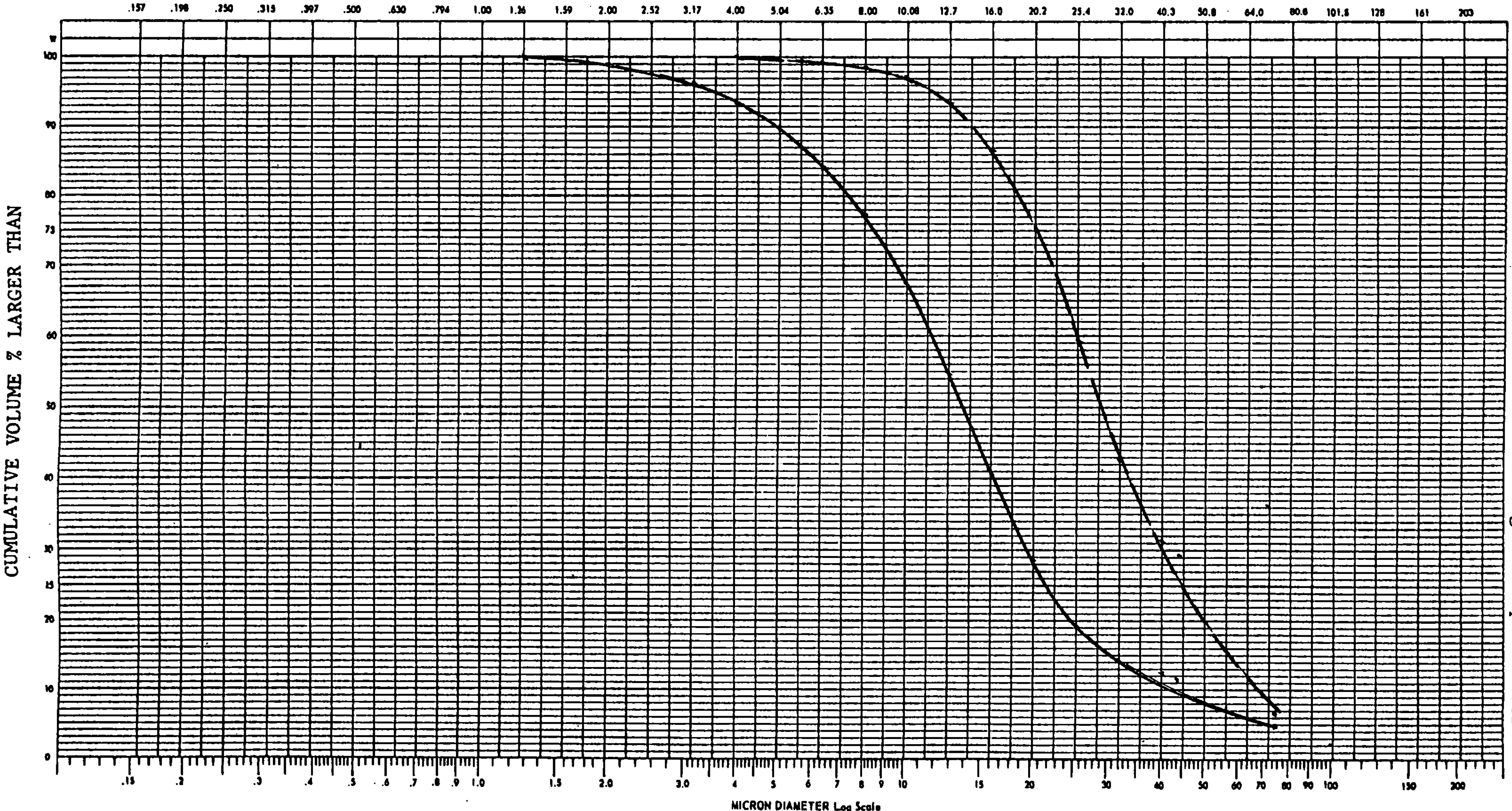
$k = d\sqrt[3]{\frac{2w}{}}$ FOR MODEL T

$\frac{A2}{A1} = \left(\frac{d2}{d1}\right)^3$ when $W_2 = W_1$

$\frac{A2}{A1} = \left(\frac{d1}{d2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 4.3	Isoton	Ultrasonic	100μ	6102033									
ESP ———													
AH2 — — —													



4221016

Progress Report 4.3D

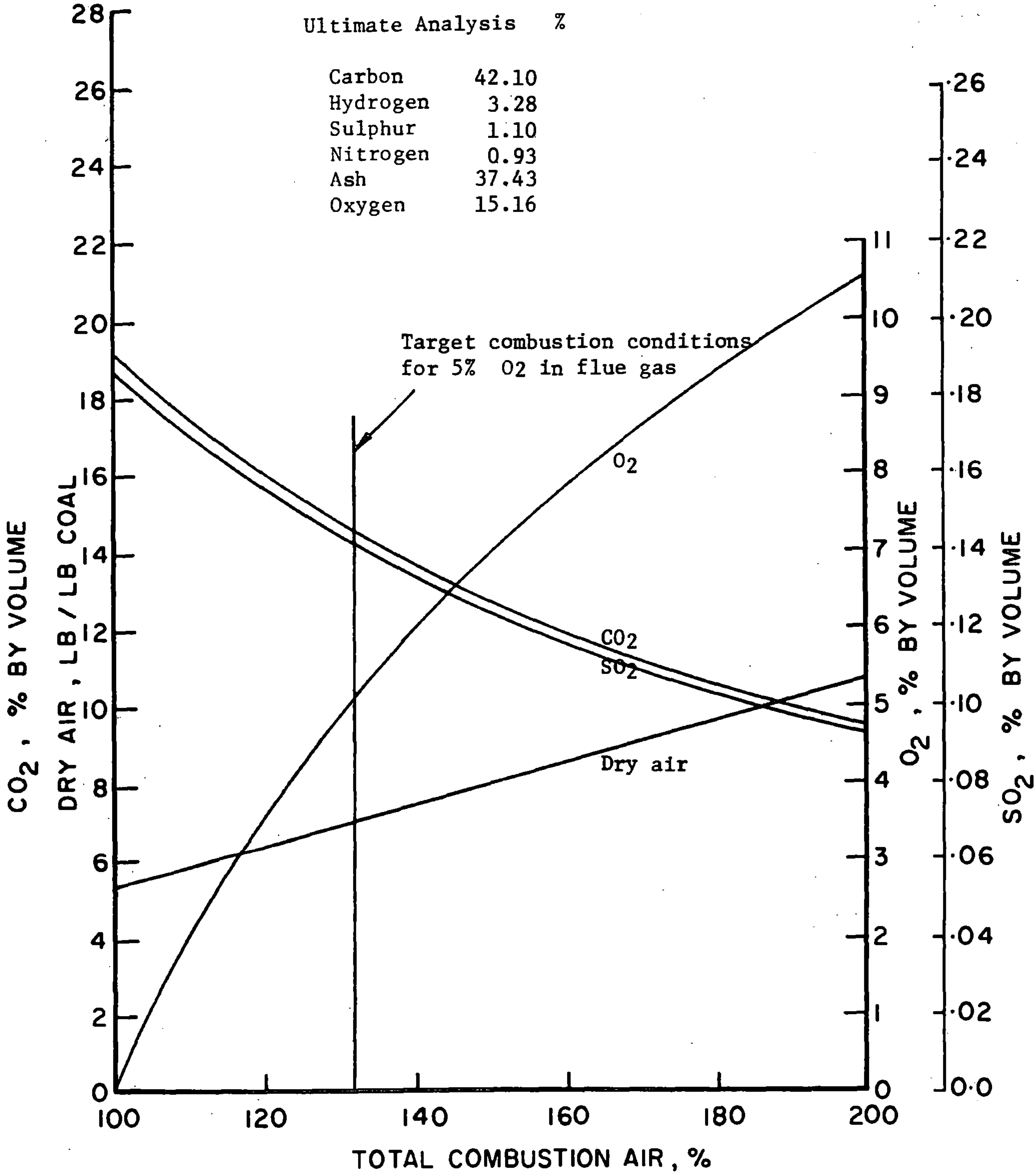


FIGURE 1: Combustion Calculations "B-Raw" Coal .

X-ray Diffraction Analyses of Fireside Deposits from Test 4.3, "B-raw" coal from Hat Creek.

Furnace Bottom Ash (1360 76-436)	Mull, Crist
Under Flame Probe Deposit (1355 76-454)	Hem, Mag(sm), Mull(sm)
Furnace Probe Deposit (1357 76-455)	Hem, Mull, Mag
Transition Probe Deposit (1359 76-464)	Hem, Mull, Mag

Abbreviations of Constituents:

Crist	Cristobalite SiO_2
Mull	Mullite $3Al_2O_3.2SiO_2$
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification.

Constituents are listed in decreasing order of abundance. On occasion "small" is used for clarity.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

SUMMARY OF DTA STUDIES ON FIRESIDE DEPOSITS

Samples:

Five samples of ash from the furnace bottom and one sample of ash collected by the CCRL dust sampler were examined.

Sample 1)	CCRL 980	Test 1.1	Sundance bottom ash.
Sample 2)	CCRL 1092	Test 2.1	Hat Creek A-raw, bottom ash
Sample 3)	CCRL 1190	Test 3.1	Hat Creek A-washed, bottom ash
Sample 4)	CCRL 1278	Test 4.1	Hat Creek B-raw, bottom ash
Sample 5)	CCRL 1360	Test 4.3	Hat Creek B-raw, bottom ash
Sample 6)	CCRL 986	Test 1.1	Sundance fly ash.

Procedures:

Samples weighing approximately 50 mg were heated in a static air atmosphere at 12°C/min. to 1500°C. Two platinum foil pans were held in a vertical furnace, one containing the sample and the other containing α-alumina as reference material. Pt: Pt/13% Rh thermocouples were held with their beads denting the bottom of the pans.

Results:

Sample 1) No peaks were observed. The baseline shifted in the exothermic direction at 1360°C. When cool, the sample was dark and glassy.

Sample 2) No peaks were observed. The baseline shifted in the endothermic direction at 1450°C. When cool, the sample was brown-black opaque, and very hard.

Sample 3) No peaks were observed. The baseline shifted in the endothermic direction at 1340°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 4) No peaks were observed. The baseline shifted in the exothermic direction at 1330°C. When cool, the sample was black with brown spots, opaque, and very hard.

Sample 5) No peaks were observed. The baseline shifted in the endothermic direction at 1160°C. When cool, the sample was brown, opaque, and appeared to have melted.

Sample 6) A sizable exothermic peak was observed in the 400°C to 500°C range and a small endothermic peak was noted at 1160°C. Cooling and reheating in the range 1000°C to 1500°C failed to show any repetition of the latter thermal effect. When cool, the sample was dark and glassy.

Comments:

It seems certain that samples 1), 5) and 6) underwent melting. The other samples probably had some liquid phase present. The lack of DTA peaks is unusual. It most likely indicates that melting occurred over a very broad range. Cooling to 1000°C and reheating gave rise to no peaks either. The exothermic peak for sample 6) was most likely the result of combustion of a small amount of carbonaceous material.

It can be concluded that DTA is not a very usefull technique for studying these materials.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "B" WASHED COAL

AIR-DRIED AND KILN-DRIED, 5% EXCESS OXYGEN

TEST NO. 5.1

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/136-139

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.1A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 5.1, which was done on November 1, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 5.1

In this test, Hat Creek "B" washed coal was burned. The coal had been air-dried and then kiln-dried, which reduced the as-fired moisture to 8.6%. The target level of excess oxgyen in the flue gas was 5% (approx 25% excess air), and the target coal-feed rate was 120 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0830 hr, stable, unsupported coal combustion had been in progress for an hour. The flame, when viewed from the top of the furnace, was orange-yellow coloured, and fairly short. There appeared to be little active combustion above the furnace throat. The flame was so transparent that the air-cooled deposition probe in the furnace bottom was faintly visible when viewed from the top of the furnace, and it was possible to see well down the west wall of the furnace bottom. The air-cooled deposition probe in the furnace was visible but the refractory probe was not. Deposits which were below the furnace throat on the east wall and in the southwest corner blocked approximately 1/10 of the projected throat area. Burning coal particles were carried by the flue gas into the furnace exit, through the transition section, and into the test air-heater. There was sufficient light in the transition section to permit the test air-heater tubes to be seen clearly. The furnace bottom was transparent; the walls opposite the sight ports were visible in detail. There were deposits of ash on the ledges and in the corners of the furnace bottom. Much of this deposit remained in place when the dump plates were swung open. Then, the ash which was raked from the quench tank consisted of mud and small, weak sinters.

At 0925 hr, the deposits below the throat had grown sufficiently to block nearly half the projected throat area, extending primarily from the southwest and northeast corners.

At 0940 hr, the deposits were easily dislodged by thrusting a poker, through the top of the furnace. Then a poker was thrust through the furnace bottom ports to remove ash from the corners and the ledges. When the ash was raked from the quench tank, it was found to be mostly small sinters, and a few large ones, 10 cm in diameter. All were coloured black.

Combustion conditions then appeared to be very good. The flame was bright, short and fairly transparent. The furnace bottom was transparent, and few burning particles were observed.

At 1030 hr, flame conditions appeared to be very good, and deposits below the furnace throat were evident. A heavy layer of sinter on the south wall of the furnace bottom blocked the sight port located there. A deposit under the south burner was also visible. At 1120 hr, the deposits blocked approximately 1/3 of the projected throat area, and at 1150, after some measurements had been completed, more than ½ of the projected throat area was blocked. The furnace bottom sight ports were also blocked with ash. A poker was thrust through the top of the furnace to dislodge the deposits, the dump plates were swung open, and a poker was used to clear the ash from the furnace bottom. A heavy deposit remained on the south wall and ledge of the furnace bottom. Approximately 50 litres of black sinters, measuring from 1 cm to 10 cm were raked from the quench tank.

At 1405 hr, deposits were removed again from below the throat and above the burners. Ash was dumped. However, a poker was not applied through the furnace bottom ports, and therefore, much ash remained on the ledges and in the corners of the furnace bottom. Combustion conditons did remain stable. At 1600 hr, when the test was completed and the furnace was "shut-down", deposits again blocked approximately ¼ of the projected throat area. A large sinter was in the southwest corner of the furnace bottom, and sinters roughly 5 cm thick were on the north wall of the furnace bottom.

Deposition Probes During Test Period

The air-cooled deposition probes in the furnace and the furnace bottom were visible during the test.

The air-cooled probe in the furnace bottom was clean during the early part of the test. Later, it developed a 3 mm beard of sinter along part of the top surface. When the throat deposits were first removed a piece of sinter, measuring approximately 8 cm and resembling spanish moss, lay on the probe. This sinter did not appear to be plastic, but remained in place until throat deposits were next removed. Afterwards, the probe remained clean.

Tha air-cooled probe in the furnace did not develop deposits of significant size in the test.

Furnace After Test

Approximately 25 litres of ash fell to the floor when the dump plates were swung open. The ash consisted of tan and black coloured, small, weak sinters, and one large sinter which was approximately 30 cm x 40 cm x 8 cm. A sinter adhering to the southwest corner of the furnace bottom was roughly 30 cm x 50 cm x 25 cm. Part of the east wall had a layer of sinter 12 cm thick, the remaining walls had isolated whiskers of sinter roughly 3 cm thick, and some sinters, 3 cm thick, were on the throat refractory. All of the sinter was fairly friable.

The furnace water walls bore a light layer of dark grey dust over most of their length, but there was a heavier layer of dust and small sinters for 15 cm above the furnace throat. There were 3 to 10 cm of tan-coloured, sandy dust on the bottom of the transition section. Tubes of the test air-heater were clean on the upstream surfaces but they had a thin layer of dust on their downstream surfaces. The furnace-exit tubes had a heavy layer of dust on the downstream surfaces. There were 2 to 7 cm of dark grey dust on the second pass tube sheet of the main air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed, bore only a thin layer of sintered dust.

The refractory probe in the furnace bottom, before it was removed, had a ragged deposit of sinter, approximately 3 cm thick, projecting from one side and the bottom.

Both probes in the furnace, before they were removed, showed no deposits of significant size.

The air-cooled probe in the transition section, after it was removed, appeared polished on the upstream surface and had a thin layer of tan-coloured dust on the downstream surface.

The refractory probe in the transition section, after it was removed, had a very thin layer of dust on the downstream surface.

Test No. 5.1
Progress Report 5.1A
Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "B" WASHED, DOUBLE DRIED EXCESS O_2 5 %

1/11/76

Parameters	Station	Obs. (R.M.S. Dev.)	Comments
Test Duration		7 hours	
Firing Rate		118.0(4.6) kg/hr	
Moisture Content of Coal	1	8.6 %	feed to pulverizer
" " " "	2	0.2 %	feed to furnace
Combustible " " "	2	72.9(0.9) %	dry weight
Ash Dumping Frequency		once every —— hour	continuous, 77 kg ash dumped, equivalent to 1143.5 kg coal.
PULVERIZER OPERATING CONDITIONS			
a) Inlet Air Pressure	3	271(6) mmH_2O	
b) Outlet Air Pressure	2	238(4) mmH_2O	
c) Inlet Air Temperature	3	202(2) °C	
d) Outlet Air Temperature	2	108(2) °C	
e) Coal Fineness	2	72.8% below 200 mesh	oversize, 26.4% 140 mesh , 27.2% 200 mesh , 58.5% 325 mesh
BOILER OPERATING CONDITIONS			
a) Steam Flow	6	647(43) kg/hr	
b) Steam Pressure	6	3.07(0.09) atmospheres	
c) Combustion Air Temp.	4	190(6) °C	
d) Furnace Pressures			
Furnace	10	36(4) mmH_2O	
Inlet	11	36(4) mmH_2O	
Boiler Exit	12	17(4) mmH_2O	
Primary (Coal) Air L	5	145(5) mmH_2O	
" R	5	162(5) mmH_2O	
Secondary (Windbox) Air L	4	63(3) mmH_2O	
" R	4	64(5) mmH_2O	
FLUE GAS ANALYSIS			
a) CO_2	11	14.8(0.3) %	
b) O_2	11	5.0(0.1) %	
c) CO	11	152(22) ppm	
d) NO	13	563(42) ppm	
e) SO_2	14	731(38) ppm	
f) SO_3	14	< 1 ppm	
g) Acid dewpoint	18	32 °C	
FLUE GAS TEMPERATURE			
a) Furnace Exit	11	638(19) °C	
b) Boiler Exit	12	298(12) °C	
c) Precipitator Entry	16	160(9) °C	
SUCTION PYROMETER TEMPERATURES			
a)	7	1056, 947 °C	readings taken in
b)	8	863, 854 °C	second and third
c)	9	825, 845 °C	two hour period
FLY ASH			
a) Loading	16	6980(1050) $mgms/m^3$	measured at 20°C
b) Resistivity	15	$2.8(0.9) \times 10^{10}$ Ω cm at 277°C	
"	17	$5.9(1.3) \times 10^{11}$ Ω cm at 159°C	5.7×10^{11} Ω cm at 121°C
c) Precipitator efficiency	18	94(2) %	
d) Combustible content of ash collected from precipitator	18	6.3(0.3) %	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	1080	47	984	1162	1056	1018	Tan and orange coloured sinter, 25 mm thick, mostly downstream.
	stainless	579	45	487	648	552	487	Grey coloured scale, even, upstream.
Furnace 9	ceramic	743	97	615	864	864	637	Grey coloured scale, uneven, upstream.
	stainless	516	50	428	588	565	484	Grey powder, 1 mm thick, even, all around and over mauve coloured scale, upstream.
Transition Section 20	ceramic	621	20	586	653	601	640	Beige coloured powder, 2 mm thick, downstream, uneven.
	stainless	493	18	460	522	507	505	Beige coloured powder, 2 mm thick, uneven, downstream.

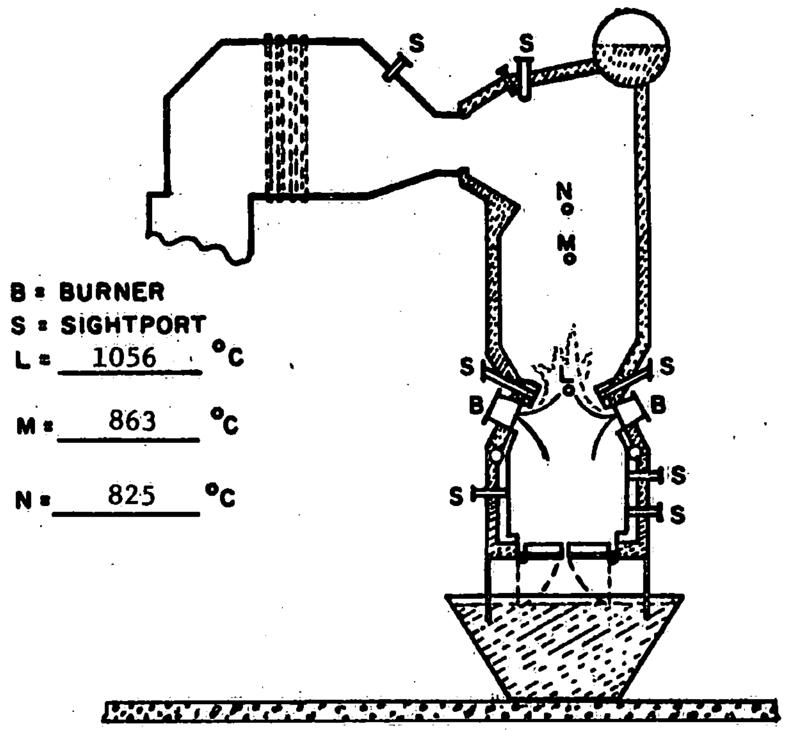


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.1B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (5.1B) presents coal analyses and size distribution of the pulverized coal burned in test 5.1 done on November 1, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 5.1

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			12.4	80.6
100M x 140M	26.4	4.2	17.4	78.8
140M x 200M	0.8	0.4	8.2	76.4
200M x 325M	31.3	5.2	14.0	75.3
325M x 0	41.6	3.6	48.0	68.2

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: B Washed, Test 5.1, B. C. Hydro (A1365)

Analysis	
Screen Analysis	
+ ¼	0.00
¼ * 1/8	3.93
1/8 * 1/16	30.18
1/16 * 1/32	33.23
1/32 * 28M	11.03
28M * 48M	13.04
48M * 0	8.59
Grindability	
Hardgrove Index	45
Classification of Coal	
Rank (ASTM)	
Eq. Moisture % (97% Humidity)	

Sample B Washed, Test 5.1, B. C. Hydro (A1365)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	7.45	0.00
Ash	22.04	23.81
Volatile Matter	49.69	53.69
Fixed Carbon (by Diff.)	20.82	22.50
Ultimate Analysis %		
Carbon	49.26	53.23
Hydrogen	3.49	3.77
Sulphur	0.72	0.78
Nitrogen	0.09	0.10
Ash	22.04	23.81
Oxygen (by Diff.)	16.95	18.31
Calorific Value		
Calories/gram	4652	5026
Btu/lb gross	8374	9048
Megajoules/kilogram	19.48	21.05
Sulphur Forms %		
Sulphatic	0.05	
Pyritic	0.17	
Organic (by Diff.)	0.50	
	0.72	
TOTAL		
Chlorine	0.00	

Sample: B Washed, Test 5.1, B. C. Hydro (A1365)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1427	1382
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	48.28
Al_2O_3	31.41
Fe_2O_3	6.80
Mn_3O_4	0.06
TiO_2	1.42
P_2O_5	0.38
CaO	4.54
MgO	1.30
SO_3	2.70
Na_2O	0.29
K_2O	0.37
Cl	0.00
Specific gravity	2.75

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.1C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1]

SUMMARY

As explained elsewhere[2], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (5.1C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 5.1 done on November 1, 1976.

---

[1] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 5:1C

Figure 1a

Furnace bottom at end of test. Friable sinter extends from half way along west wall to south east corner immediately above dump plates. Refractory deposition probe in foreground is covered with sinter.

Figure 1b

Furnace bottom at end of test. Burners and furnace throat are clear of sinter.

PROGRESS REPORT 5:1C

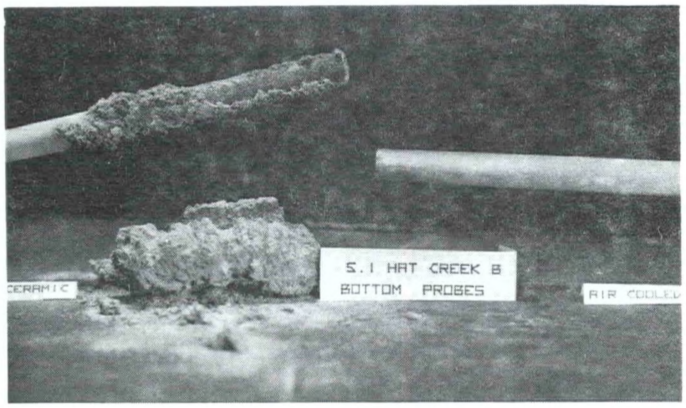


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

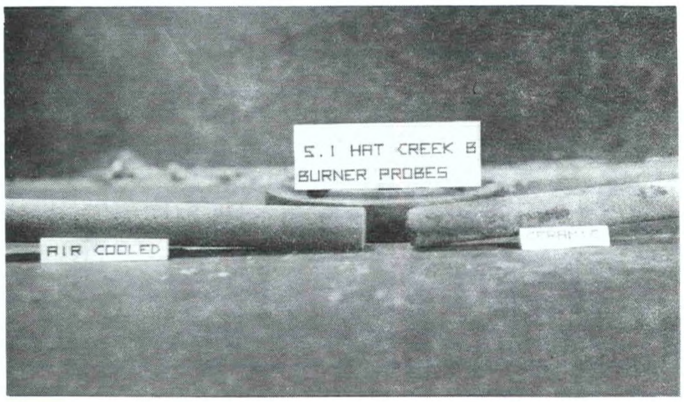


Figure 1d

Burner deposition probes. Air cooled probe on left. Refractory probe on right.

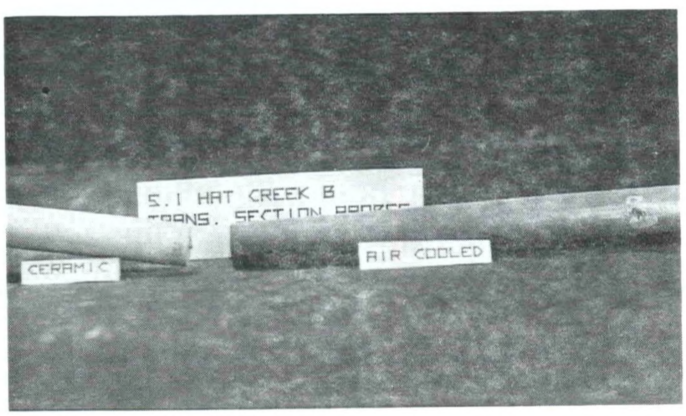


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory rpobe on left.

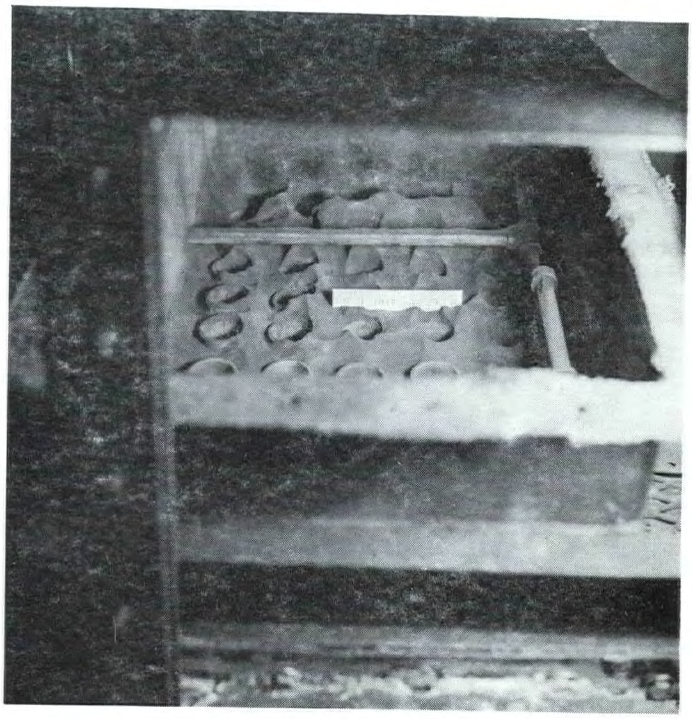


FIGURE 1f Main air heater tube sheet second pass up to 2 - 3 inches of powder.

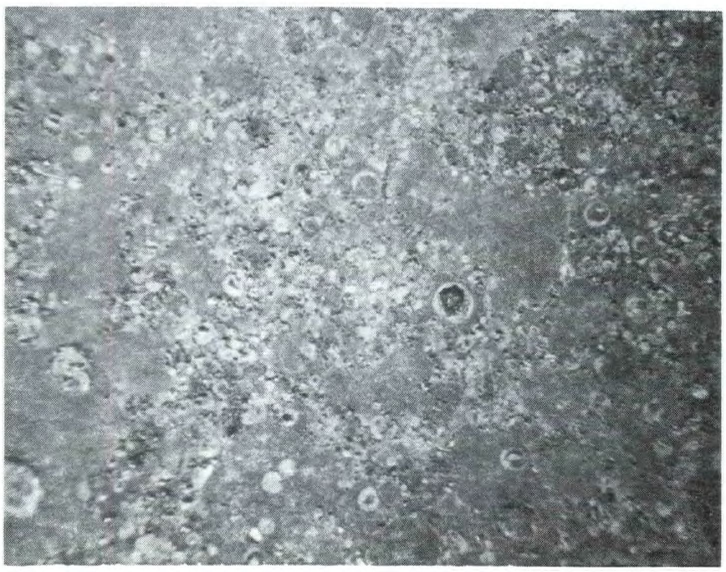


FIGURE 1g Photomicrograph, x 10, of a thin section of sinter which was found attached to the refractory near the burners. The sinter is weak and porous.

PROGRESS REPORT 5:1C

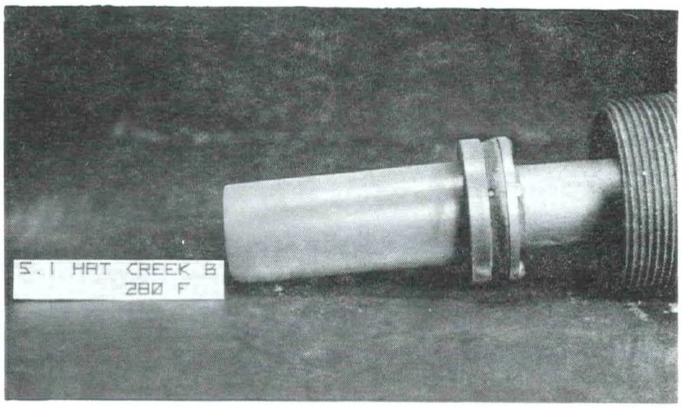


Figure 1h

Low Temperature corrosion probe 138°C.

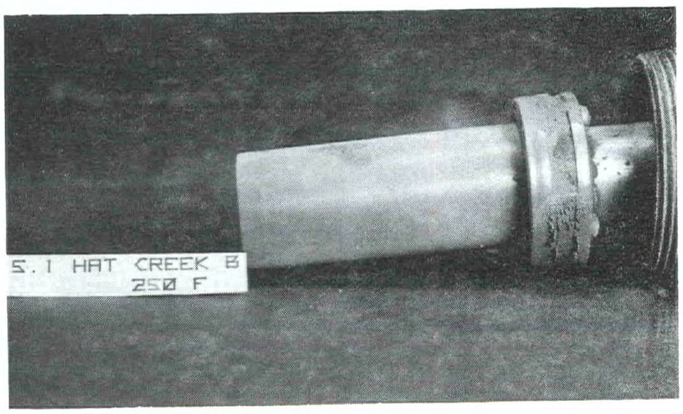


Figure 1i

Low Temperature corrosion probe 121°C.

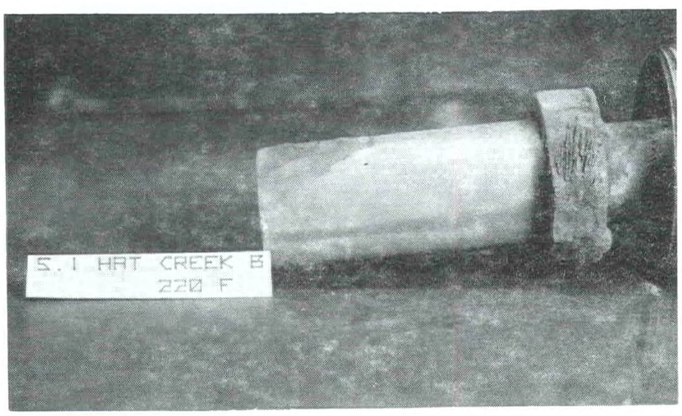


Figure 1j

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

TABLE

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	579 °C	516 °C	493 °C
Deposition rate[a/]						
Fe	55.7	53.6	41.8	5.7	16.8	6.4
Mg	2.0	1.4	0.6	1.8	19.8	2.9
Na	2.5	3.6	1.3	2.2	6.2	2.9
Ca	4.3	3.9	2.5	28.1	121.8	20.7
SO_4 (total)	295.6	153.1	99.5	58.8	304.8	60.9
SO_4 (free), by difference	176.2	38.4	16.6			

[a/] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Progress Report 5.1 C

Sample: Deposit from the furnace bottom, Test 5.1 (A 1403 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1310	1277
Spherical	°C	1482+	1399
Hemispherical	°C	+	1460
Fluid	°C	+	1482+

Ash Analysis	%
SiO_2	52.17
Al_2O_3	29.38
Fe_2O_3	7.69
Mn_3O_4	----
TiO_2	1.06
P_2O_5	0.36
CaO	3.99
MgO	1.77
SO_3	0.27
Na_2O	0.37
K_2O	0.47
Cl	----

Progress Report 5.1 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 5.1 (A 1407)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1338	1238
Spherical	°C	1460	1388
Hemispherical	°C	1482+	1449
Fluid	°C	+	1482+

Ash Analysis	
SiO_2	50.82
Al_2O_3	29.08
Fe_2O_3	9.93
Mn_3O_4	----
TiO_2	1.23
P_2O_5	0.40
CaO	4.73
MgO	1.53
SO_3	0.59
Na_2O	0.33
K_2O	0.48
Cl	----

Sample: Deposit from electrostatic precipitator, Test 5.1 (A 1373-74-75)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1282	1260
Spherical	°C	1438	1349
Hemispherical	°C	1482+	1443
Fluid	°C	+	1477

Ash Analysis	%
SiO_2	50.78
Al_2O_3	29.35
Fe_2O_3	6.49
Mn_3O_4	----
TiO_2	1.56
P_2O_5	0.44
CaO	5.58
MgO	1.75
SO_3	0.60
Na_2O	0.45
K_2O	0.68
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried and Kiln-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.1D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (5.1D) is the last of the series and presents results of the following detailed analyses of ash produced in test 5.1 done on November 1, 1976.

1. Particle size distribution of fly ash
2. X-ray diffraction analyses of fireside deposits
3. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.2
1.59 - 2.00	Coulter Counter		0.3
2.00 - 2.52	Coulter Counter		0.8
2.52 - 3.17	Coulter Counter		1.3
3.17 - 4.00	Coulter Counter	0.2	2.4
4.00 - 5.04	Coulter Counter	0.3	3.4
5.04 - 6.35	Coulter Counter	0.6	4.7
6.35 - 8.00	Coulter Counter	1.2	6.1
8.00 - 10.08	Coulter Counter	3.0	8.9
10.08 - 12.7	Coulter Counter	5.5	11.2
12.7 - 16.0	Coulter Counter	9.3	13.4
16.0 - 20.2	Coulter Counter	14.5	13.1
20.2 - 25.4	Coulter Counter	17.0	9.8
25.4 - 32.0	Coulter Counter	15.4	6.0
32.0 - 40.3	Coulter Counter	7.6	2.0
40.3 - 44.0	Coulter Counter	1.0	0.8
44.0 - 74.0	Sieve	16.8	7.4
+ 74.0	Sieve	7.6	8.2

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
% PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL - WRL

OPERATOR:

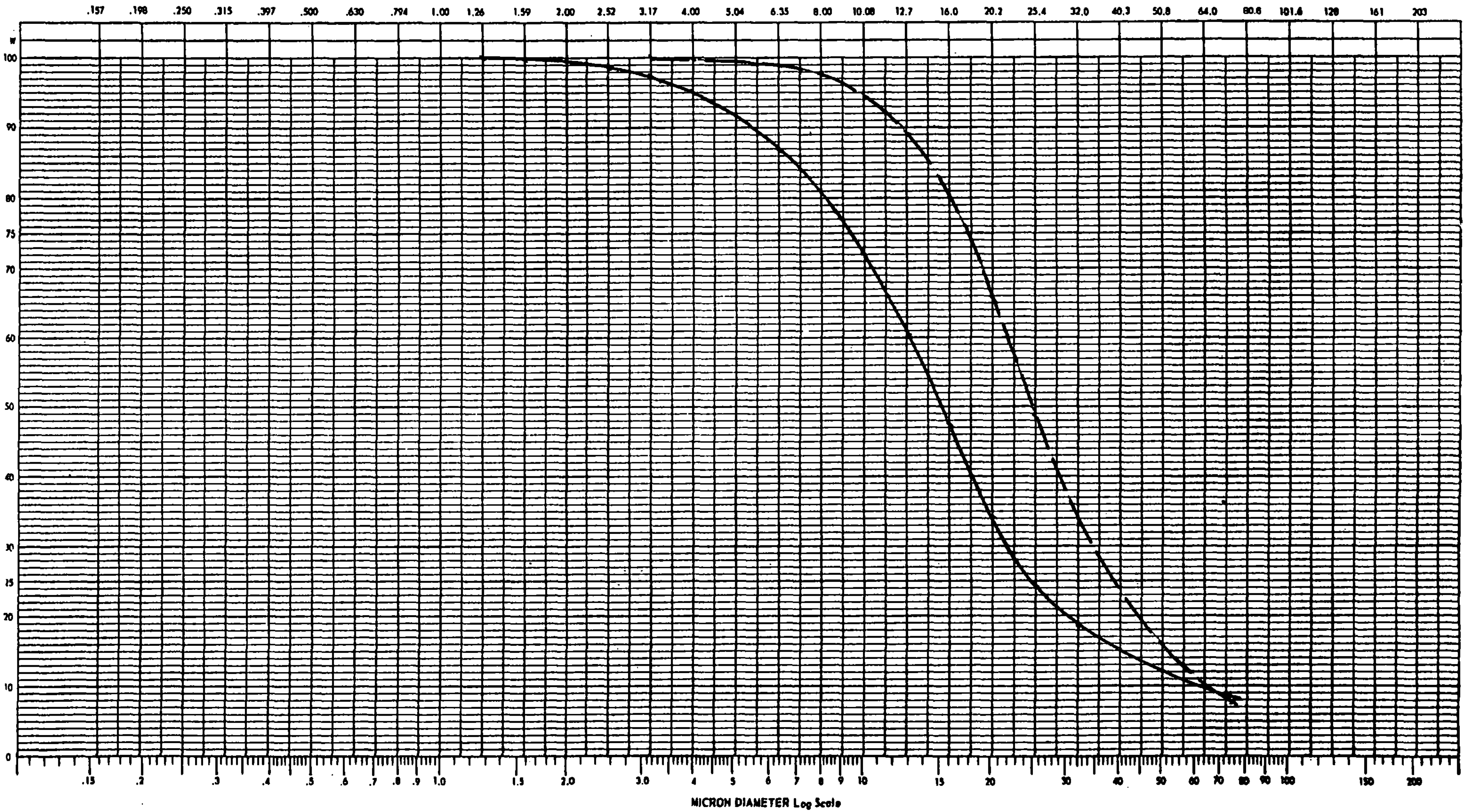
EQUIPMENT:

$k = d \sqrt[3]{2w}$ — $\frac{A2}{A1} = \left(\frac{d2}{d1}\right)^3$ when $W2 = W1$ — FOR MODEL T

$\frac{A2}{A1} = \left(\frac{d1}{d2}\right)^3$ when $W2 = W1$ — FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No 5.1	Isoton	Ultrasonic	100μ	6102033									
ESP ———													
AH2 - - -													



4221010

- 310 -

Progress Report 5.1D

X-ray Diffraction Analyses of Fireside Deposits from Test 5.1, "B-washed" coal from Hat Creek

Under Flame Probe Deposit (1397 76-457)	Hem, Mag, Mull (tr)
Furnace Probe Deposit (1399 76-458)	Hem, Mull, Mag
Transition Probe Deposit (1401 76-462)	Hem, Mull, Unid(tr), Amorph

Abbreviations of Constituents:

Mull	Mullite $3Al_2O_3.2SiO_2$
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Unid	Unidentified material of significance
Amorph	Significant amorphous material present

Notes:

All samples appear to contain some amorphous material, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification.

Constituents are listed in decreasing order of abundance. On occasion, "trace" is used for clarity.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

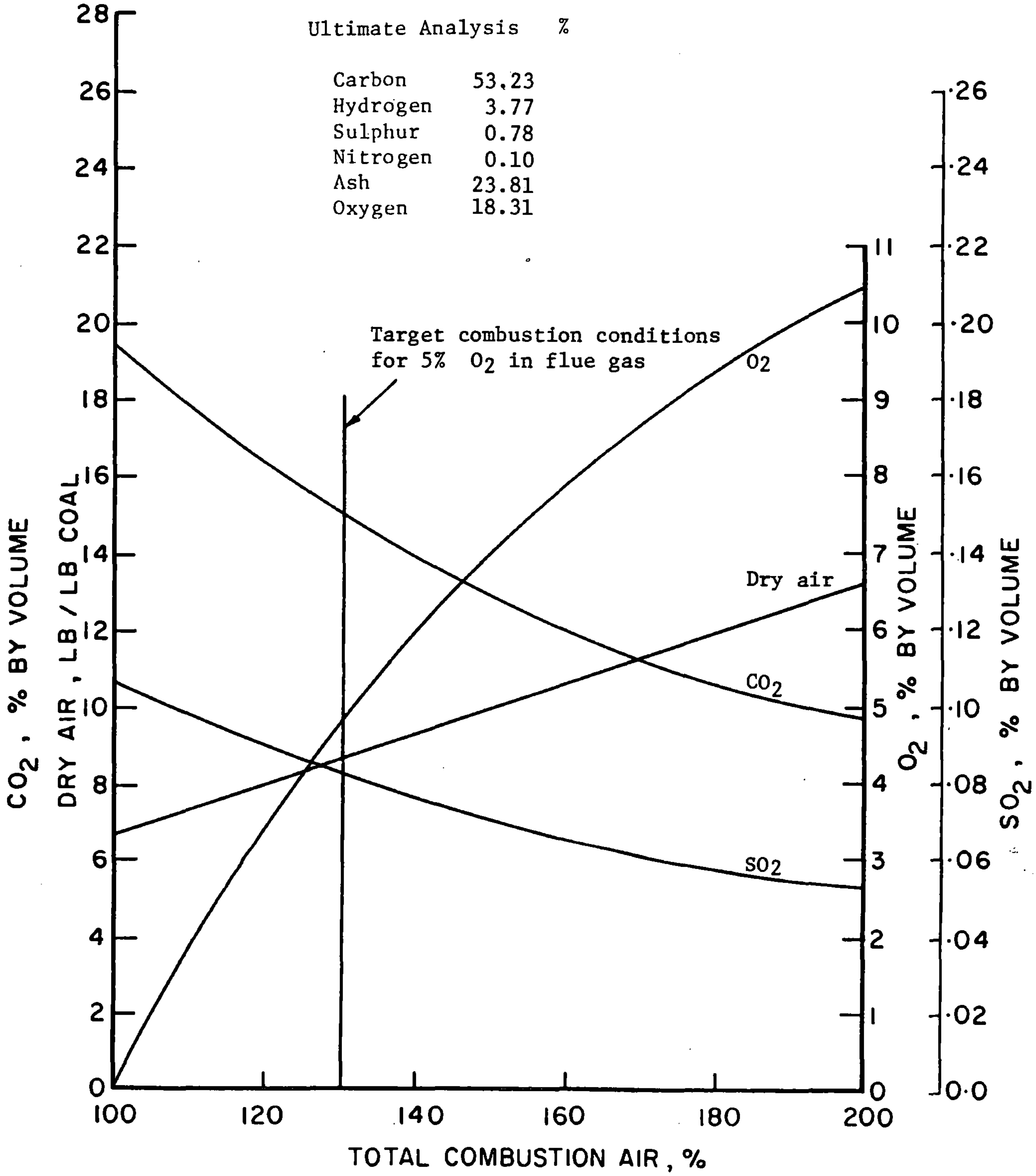


FIGURE 1: Combustion Calculations "B-Washed" Coal .

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des mineraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "B" WASHED COAL

AIR-DRIED AND KILN-DRIED, 3% EXCESS OXYGEN

TEST NO. 5.2

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/140 -143

PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "B" WASHED COAL
AIR-DRIED AND KILN-DRIED, 3% EXCESS OXYGEN

PROGRESS REPORT 5.2A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

INTRODUCTION

By an agreement between the B.C. Hydro and Power Authority (B.C. Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report [2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 5.2, which was done on November 3, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 5.2

In this test Hat Creek "B" washed coal was burned. The coal had been air-dried and then kiln-dried, which reduced the as-fired moisture to 8.6%. The target level of excess oxygen in the flue gas was 3% (approx 15% excess air) and the target coal feed rate was 120 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0840 hr, stable, unsupported coal combustion had been in progress for more than one hour. The flame, when it was observed from the top of the furnace, was yellow-orange coloured and it appeared to end a short distance above the furnace throat. When it was viewed from the top of the furnace, the flame was so transparent that the air-cooled deposition probe in the furnace bottom was intermittently visible and both of the deposition probes in the furnace were visible. Some deposits were below the throat in the south-west corner and on the east wall of the furnace. Many burning coal particles were carried through the furnace exit, but most of them were extinguished before they reached the test air-heater. Large quantities of faintly glowing ash particles were carried through the transition section. The test air-heater tubes were clearly visible by the flickering light from the furnace.

The furnace bottom was transparent but many burning coal particles were evident. Deposits of sinter were on the south wall of the furnace bottom and below the south burner. Ash on the south ledge of the furnace bottom blocked the sight port, which was cleared later with a poker. The air-cooled deposition probe in the furnace bottom was clearly visible.

By 0930 hr, the south sight port in the furnace bottom was blocked again by sinter. Much ash lay on the furnace bottom, and this sloped upwards to the end walls. The deposits below the throat had grown, but they blocked less than ¼ of the projected throat area. At 1000 hr, ash was dumped, but much ash remained on the furnace bottom ledges. The ash which was raked from the quench tank consisted of small sinters and mud.

At 1030 hr, the deposits below the furnace throat blocked rougly 1/3 of the projected throat area. The flame appeared to be uneven, and to be deflected by the deposits. The deposits were removed without difficulty by means of a poker which was thrust through the top of the furnace. The dump plates were swung open, and a poker was thrust through the ports in the furnace bottom to remove ash from the ledges. The ash which was removed later from the quench tank consisted of small sinters and mud. The throat was then clean. The flame was uniform, and was coloured orange-yellow. From the top of the furnace, it was no longer possible to see the air-cooled deposition probe in the furnace bottom. However, it was possible to observe much of the west wall and some deposits on the west side of the furnace bottom. The furnace bottom was bright and transparent, and some burning coal particles were evident. Also, fairly heavy deposits of sinter were on the south wall, in the southwest corner and under the south burner.

By 1300 hr, deposits had developed below the throat on the east wall and in the southwest corner of the furnace. They were removed by thrusting a poker through the top of the furnace and through the south ports in the furnace bottom. Ash was dumped. Then, the furnace throat was fairly clean, but the west wall of the furnace bottom was rough with sinter, and heavy deposits remained under the south burner and on the south wall of the furnace bottom.

At 1400 hr, when it was observed from the top of the furnace, the furnace throat was still clean except for small deposits in the northeast and southwest corners. However, a bright spot in the flame near the south burner indicated that the fuel-air stream was striking a deposit. The furnace bottom was bright and transparent as it was before, but only a few burning coal particles were evident. At 1430 hr, most of the furnace throat was closed by rough, massive deposits on all sides, and a poker was thrust through the top of the furnace to remove the deposits for the third time. This left the furnace bottom approximately half full of ash, which was not dumped. Then, conditions remained unchanged until the test was completed at 1555 hr, when deposits blocked approximately 1/5 of the projected throat area. After "shutdown," the ash in the furnace bottom glowed visibly for approximately 15 min., which showed that the furnace temperatures had been relately high compared to most of the other tests.

Deposition Probes During Test Period

Both probes in the furnace, and the air-cooled probe in the furnace bottom, were visible during the test.

The air-cooled probe in the furnace bottom, when it was first observed at 0840 hr, bore one lump of sinter, approximately 2 cm in diameter. This deposit adhered to the top and one side of the probe. By the deposition of burning coal particles during the next two hours, this deposit grew approximately 7 cm in diameter, and maintained its eccentric location on the probe. It fell off when the furnace was cleaned at 1055 hr. The probe then developed a few small sinters on the top surface, which consolidated to form a beard roughly 7 mm thick by 2 cm long on top of the probe. Most of this fell off when the furnace was cleaned at 1430 hr. The probe was clean at the end of the test.

The air-cooled probe in the furnace showed no large deposits in the test.

The refractory probe in the furnace appeared to be clean until 1400 hr, when some sinter was observed on it. This sinter fell off later, and the probe bore no evident deposit at the end of the test.

Furnace After Test

When the dump plates were swung open approximately 20 litres of tan-coloured, friable sinters, 2 cm to 12 cm in diameter, fell to the floor. Approximately twice that volume remained in the furnace bottom, either adhering to the walls or bridging across and being partly supported by the air-cooled deposition probe. One piece of sinter thus supported was approximately 50 cm x 25 cm x 20 cm. Two deposits which measured approximately 15 cm in diameter, adhered to a vertical refractory wall of the furnace throat, which was generally rough with sinter. The colour of the sinter varied from tan to black, and all of it was friable.

The furnace water walls were covered by a few millimeters of black dust and some nodules, approximately 5 mm in diameter of sinter. The upper slope of the tubes forming the nose at the furnace exit was covered by a heavy layer of grey and black dust. Fine sandy tan-coloured deposit, 5 to 12 cm thick, was in the bottom of the transition section. The downstream surface of the furnace screen tubes bore a thin tan-coloured powder which was covered by a thin layer of black coloured dust. The upstream surfaces of the test air-heater tubes were clean, and the downstream surfaces had a layer of tan-coloured dust roughly 1 mm thick. There were 1 to 4 cm of dark grey coloured dust on the second pass tube sheet of the main air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed, bore no deposits of substantial size.

The refractory probe in the furnace bottom was broken during the test, and was lost in the bottom ash.

The air-cooled probe in the furnace, before it was removed, appeared to be clean.

The refractory probe in the furnace, before it was removed, bore some nodules of sinter, roughly 5 mm in diameter, on the bottom surface.

The air-cooled probe in the transition section, after it was removed, was clean and dull black coloured on the upstream surface. The downstream surface was covered by light tan-coloured dust, 2 to 3 mm thick.

The refractory probe in the transition section, after it was removed, was clean on the upstream surface and on the downstream surface, it had a layer of fine light tan-coloured dust, approximately 1 mm thick.

Test No. 5.2
Progress Report 5.2A
Revised 18/11/75

TABLE 1

OPERATING DATA

COAL HAT CREEK "B" WASHED, DOUBLE DRIED EXCESS O_2 3 %

3 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		111(2)	kg/hr	
Moisture Content of Coal	1	8.6	%	feed to pulverizer
" " " "	2	1.4(1.7)	%	feed to furnace
Combustible " " "	2	75.4	%	dry weight
Ash Dumping Frequency		once every ——	hour	76 kg Ash dumped; equivalent to 1042 kg coal.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	263(3)	mmH_2O	
b) Outlet Air Pressure	2	231(2)	mmH_2O	
c) Inlet Air Temperature	3	198(5)	^oC	
d) Outlet Air Temperature	2	107(3)	^oC	
e) Coal Fineness	2	73.6% below 200 mesh		oversize, 25.9% 140 mesh
BOILER OPERATING CONDITIONS				" , 26.4% 200 mesh
a) Steam Flow	6	658(18)	kg/hr	" , 54.3% 325 mesh
b) Steam Pressure	6	3.14(0.04)	atmospheres	
c) Combustion Air Temp.	4	186(8)	^oC	
d) Furnace Pressures				
Furnace	10	33(1)	mmH_2O	
Inlet	11	33(1)	mmH_2O	
Boiler Exit	12	17(1)	mmH_2O	
Primary (Coal) Air L	5	140(3)	mmH_2O	
" R	5	153(1)	mmH_2O	
Secondary (Windbox) Air L	4	48(4)	mmH_2O	
" R	4	47(3)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	15.8(0.4)	%	
b) O_2	11	3.0(0.2)	%	
c) CO	11	151(54)	ppm	
d) NO	13	667(85)	ppm	
e) SO_2	14	718(23)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	28	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	631(28)	^oC	
b) Boiler Exit	12	289(11)	^oC	
c) Precipitator Entry	16	153(6)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	1107, 942	^oC	readings taken in
b)	8	912, 821	^oC	second and third
c)	9	816, 799	^oC	two hour period
FLY ASH				
a) Loading	16	6970(810)	$mgms/m^3$	measured at 20°C
b) Resistivity	15	$1.0(0.5)x10^{10}$ Ω cm at 264°C		
"	17	$6.8(1.1)x10^{10}$ Ω cm at 160°C		9.3×10^{10} Ω cm at 121°C
c) Precipitator efficiency	18	94.4(0.7)	%	
d) Combustible content of ash collected from precipitator	18	8.6	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic					1036		Thermocouple defective Tan-orange coloured sinter, 2 mm thick, uneven, upstream.
	stainless	495	(36)	433	552	552	538	Grey coloured scale, even, upstream. Light grey powder, 2 mm thick, uneven, downstream.
Furnace 9	ceramic	768	(67)	675	869	748	675	Tan coloured loose sinter, 13 mm thick, uneven, easily falls off, upstream.
	stainless	552	(27)	514	579	543	574	Grey coloured scale, even, upstream. Grey coloured powder, uneven, 2 mm thick, downstream.
Transition Section 20	ceramic	624	(18)	581	655	604	626	Light tan coloured dust, uneven, 2 mm thick, downstream.
	stainless	550	(32)	471	595	482	576	Black coloured scale, uneven, upstream. Tan coloured powder, 2 mm thick, uneven, downstream.

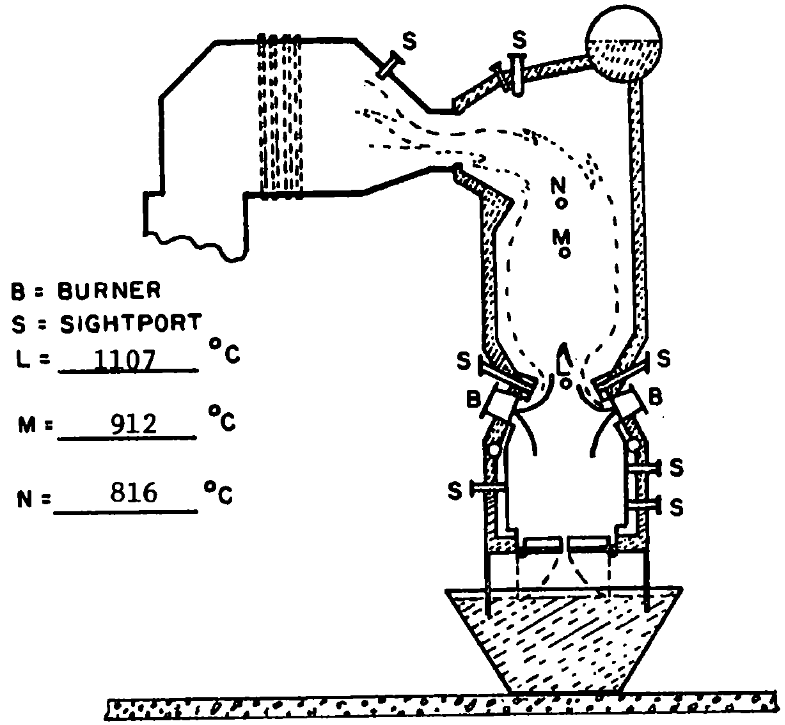


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried and Kiln-Dried, 3% Excess Oxygen

PROGRESS REPORT 5.2B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (5.2B) presents coal analyses and size distribution of the pulverized coal burned in test 5.2 done on November 3, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 5.2

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			11.2	80.3
100M x 140M	25.9	4.0	17.5	80.6
140M x 200M	0.5	0.1	8.2	78.7
200M x 325M	27.9	3.7	14.9	77.7
325M x 0	45.7	6.2	48.2	71.2

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: B Washed, Test 5.2, B. C. Hydro (A1408)

Analysis	
Screen Analysis	
+ ¼	0.00 %
¼ * 1/8	6.14 %
1/8 * 1/16	40.06 %
1/16 * 1/32	31.08 %
1/32 * 28M	8.16 %
28M * 48M	8.80 %
48M * 0	5.76 %
Grindability	
Hardgrove Index	44
Classification of Coal	
Rank (ASTM)	
Eq. Moisture % (97% Humidity)	

Sample B Washed, Test 5.2, B. C. Hydro (A1408)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	8.41	0.00
Ash	20.07	21.91
Volatile Matter	43.69	47.70
Fixed Carbon (by Diff.)	27.83	30.39
Ultimate Analysis %		
Carbon	50.29	54.91
Hydrogen	3.60	3.93
Sulphur	0.82	0.90
Nitrogen	0.99	1.08
Ash	20.07	21.91
Oxygen (by Diff.)	15.82	17.27
Calorific Value		
Calories/gram	4720	5153
Btu/lb gross	8496	9276
Megajoules/kilogram	19.76	21.58
Sulphur Forms %		
Sulphatic	0.04	
Pyritic	0.14	
Organic (by Diff.)	0.64	
TOTAL	0.82	
Chlorine	0.00	

Progress Report 5.2 B

Sample: B. C. Hydro, B. Washed, Test 5.2 (A1408)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1410	1354
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	48.42
Al_2O_3	31.07
Fe_2O_3	6.61
Mn_3O_4	0.07
TiO_2	1.45
P_2O_5	0.37
CaO	4.47
MgO	1.64
SO_3	3.12
Na_2O	0.29
K_2O	0.35
Cl	0.00
Specific gravity	2.78

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried and Kiln-Dried, 3% Excess Oxygen

PROGRESS REPORT 5.2C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (5.2C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chmical analyses of various ash forms produced in test 5.2 done on November 3, 1976

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 5:2C

Figure la

Furnace bottom at end of test. South wall above dump plates is blocked by friable sinter extending from each wall to west wall of furnace. Above this wall is a ridge of sinter on the west wall of the furnce.

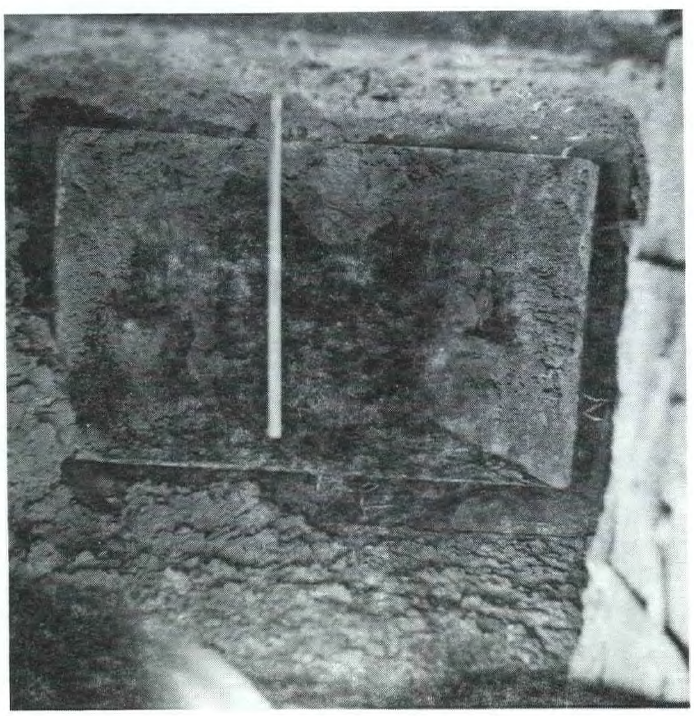


Figure lb

Furnace bottom at end of test. Burners are clear. Throat of furnace is partially blocked by sinter extending in from centre of east side of furnace.

PROGRESS REPORT 5:2C

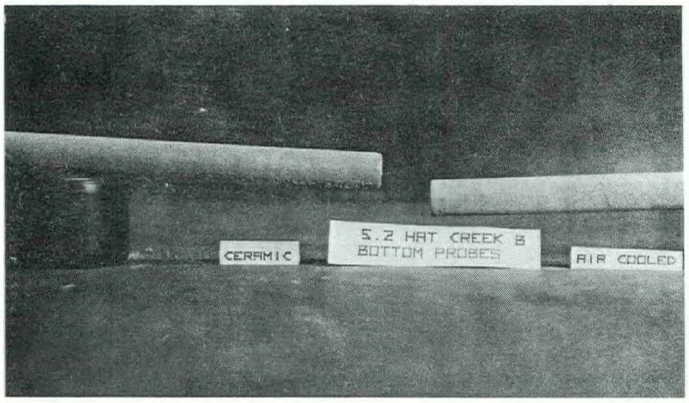


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

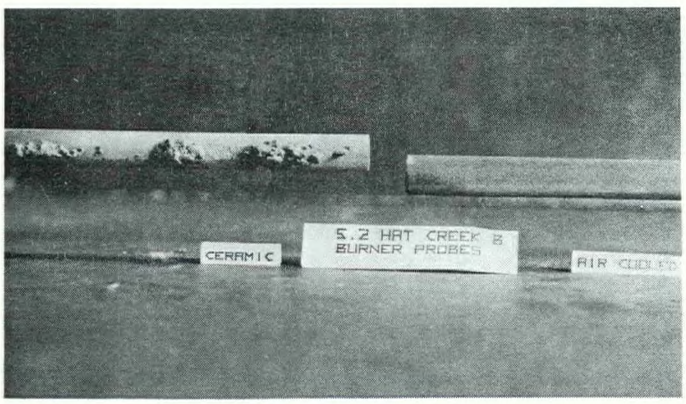


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.

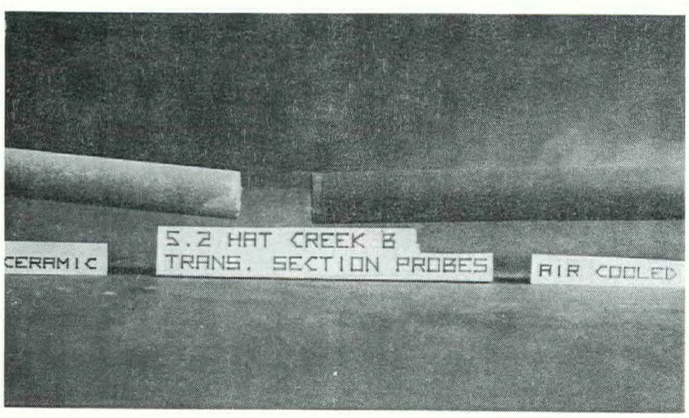


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

PROGRESS REPORT 5:2C

Figure 1f

Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 5:2C

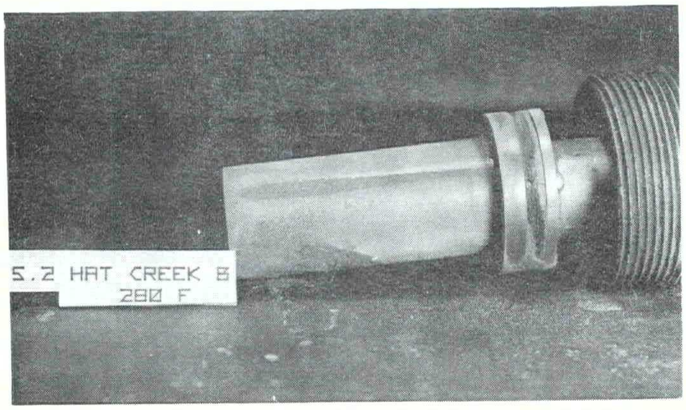


Figure 1g

Low Temperature corrosion probe 138°C.

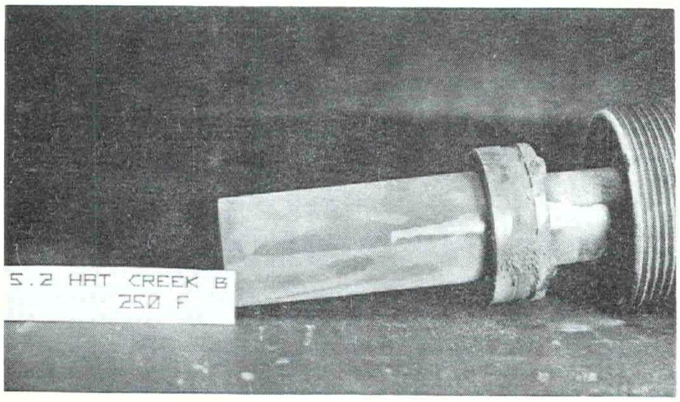


Figure 1h

Low Temperature corrosion probe 121°C.

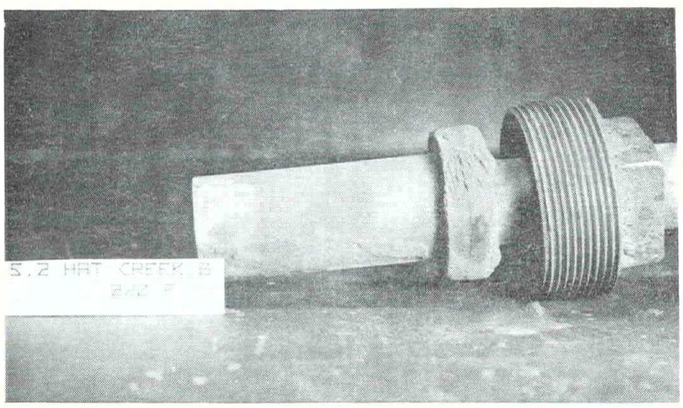


Figure 1i

Low temperature corrosion probe 104°C.

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	495 °C	552 °C	550 °C
Deposition rate[a]						
Fe	70.1	59.1	40.7	7.0	24.8	6.4
Mg	2.8	1.4	0.6	1.4	17.3	2.6
Na	2.0	2.0	1.1	1.3	3.5	2.2
Ca	6.9	5.3	1.9	25.8	154.8	13.9
SO_4 (total)	108.7	104.1	59.7	0.0	259.1	115.4
SO_4 (free), by difference						56.2

[a] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposition probes, B. C. Hydro

Station	Furnace Bottom				Boiler				Transition Section			
Material	SS		REF		SS		REF		SS		REF	
Mean Temperature °C	257		---		289		409		288		329	
% Water Soluble	5.9		3.4		3.5		2.4		4.7		---	
% Acid Insoluble	74.2		85.6		72.6		85.8		75.0		---	
Analysis , %	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS
SO_4	0.0		0.0		1.2		0.8		1.8			
Ca	5.7	0.0	2.9	0.2	2.4	0.1	1.4	0.2	3.3	0.1		
Fe	0.7	3.7	0.1	0.5	0.4	4.0	---	2.2	---	2.2		
Mg	0.1	0.4	---	0.1	---	0.7	---	0.4	0.1	0.6		
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Na	---	0.1	---	0.1	---	0.1	---	---	0.1	0.1		

WS = water soluble

AS = acid soluble

--- = trace

Progress Report 5.2 C

Sample: Deposit from electrostatic precipitator, Test 5.2 (A 1443-44-45)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1288	1249
Spherical	°C	1438	1360
Hemispherical	°C	1482+	1438
Fluid	°C		1432+

Ash Analysis	%
SiO_2	51.37
Al_2O_3	29.85
Fe_2O_3	5.58
Mn_3O_4	----
TiO_2	1.61
P_2O_5	0.45
CaO	5.79
MgO	1.94
SO_3	0.84
Na_2O	0.43
K_2O	0.50
Cl	----

Progress Report 5.2 C

Sample: Deposit from the furnace bottom, Test 5.2 (A 1446 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1299	1277
Spherical	°C	1482+	1460
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	55.14
Al_2O_3	31.71
Fe_2O_3	5.55
Mn_3O_4	----
TiO_2	1.22
P_2O_5	0.38
CaO	4.24
MgO	1.60
SO_3	0.10
Na_2O	0.33
K_2O	0.46
Cl	----

Progress Report 5.2 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 5.2 (A 1450 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1299
Spherical	°C	1482+	1410
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	50.78
Al_2O_3	30.31
Fe_2O_3	6.98
Mn_3O_4	----
TiO_2	1.33
P_2O_5	0.37
CaO	4.97
MgO	1.90
SO_3	0.54
Na_2O	0.31
K_2O	0.43
Cl	----

Progress Report 5.2 C

Sample: Deposit from the furnace walls, Test 5.2 (A 1447 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C		
Spherical	°C		
Hemispherical	°C		
Fluid	°C		

Ash Analysis	%
SiO_2	50.63
Al_2O_3	28.98
Fe_2O_3	11.11
Mn_3O_4	----
TiO_2	1.17
P_2O_5	0.45
CaO	4.34
MgO	1.67
SO_3	1.75
Na_2O	0.40
K_2O	0.46
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried and Kiln-Dried, 3% Excess Oxygen

PROGRESS REPORT 5.2D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY 1/

SUMMARY

As explained elsewhere 2/, the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (5.2D) is the last of the series and presents results of the following detailed analyses of ash produced in test 5.2 done on November 3, 1976.

1. **Particle size distribution of fly ash**
2. **Combustion calculations**

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle <u>volume</u> to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59			0.5
1.59 - 2.00			0.5
2.00 - 2.52			0.9
2.52 - 3.17			1.4
3.17 - 4.00		0.3	2.6
4.00 - 5.04		0.4	4.3
5.04 - 6.35	Coulter	1.0	6.7
6.35 - 8.00	Counter	2.0	8.9
8.00 - 10.08		5.0	11.4
10.08 - 12.7		9.1	10.8
12.7 - 16.0		14.6	9.8
16.0 - 20.2		18.7	8.2
20.2 - 25.4		17.9	6.5
25.4 - 32.0		11.8	3.4
32.0 - 40.3		4.3	1.4
40.3 - 44.0		0.5	1.2
44.0 - 74.0	Sieve	10.8	9.5
+ 74.0		3.6	12.0

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA

PARTICLE SIZE ANALYSIS

.15 – 200μ
% PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL – WRL

OPERATOR:

EQUIPMENT:

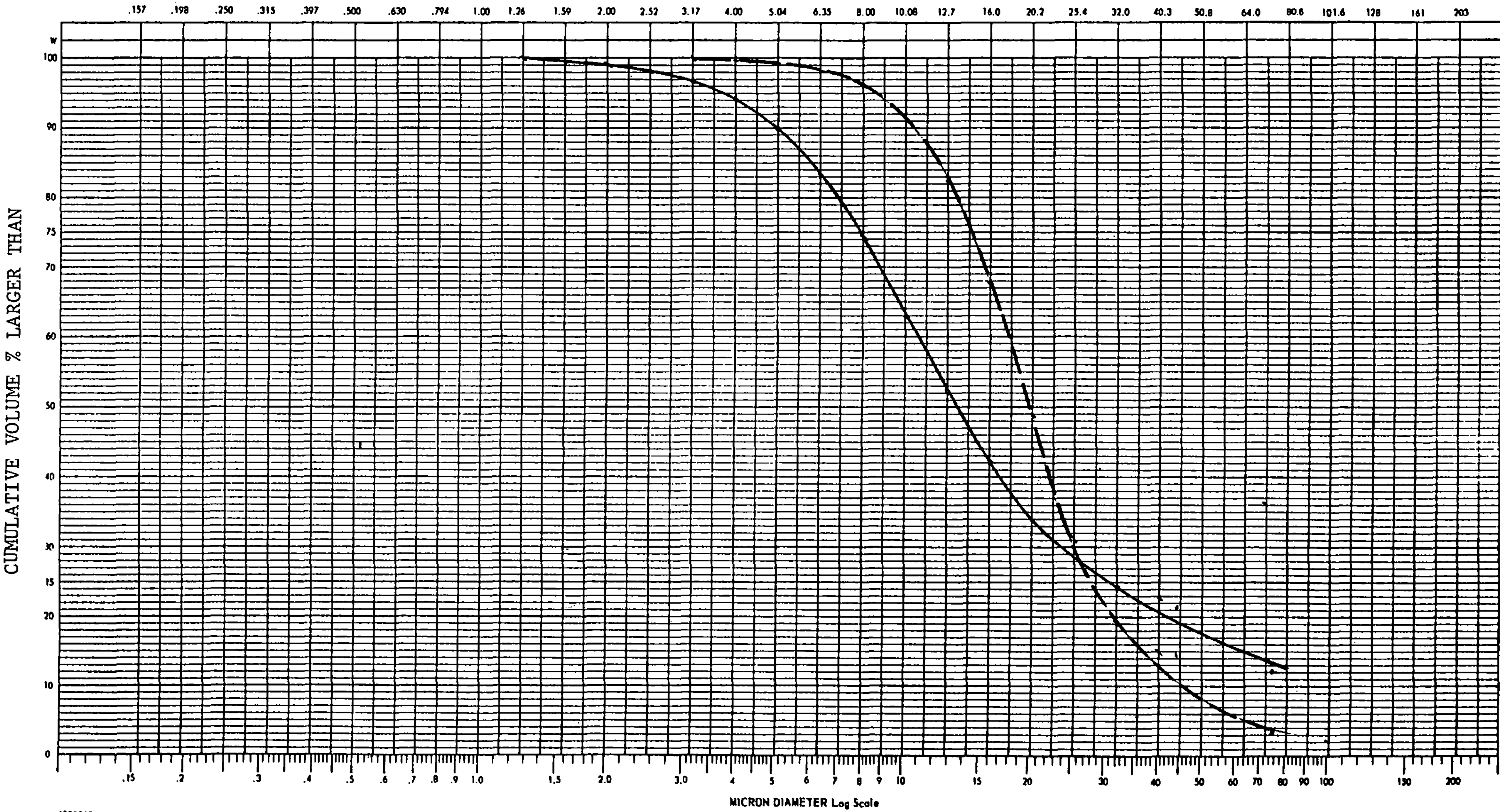
$k = d\sqrt[3]{2W}$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_3 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± ΣA	A	DIA.	W	± ΣA	A
TEST No. 5.2	Isoton	Ultrasonic	100μ	6102033									
ESP ————													
AH2 – – –													



4221010

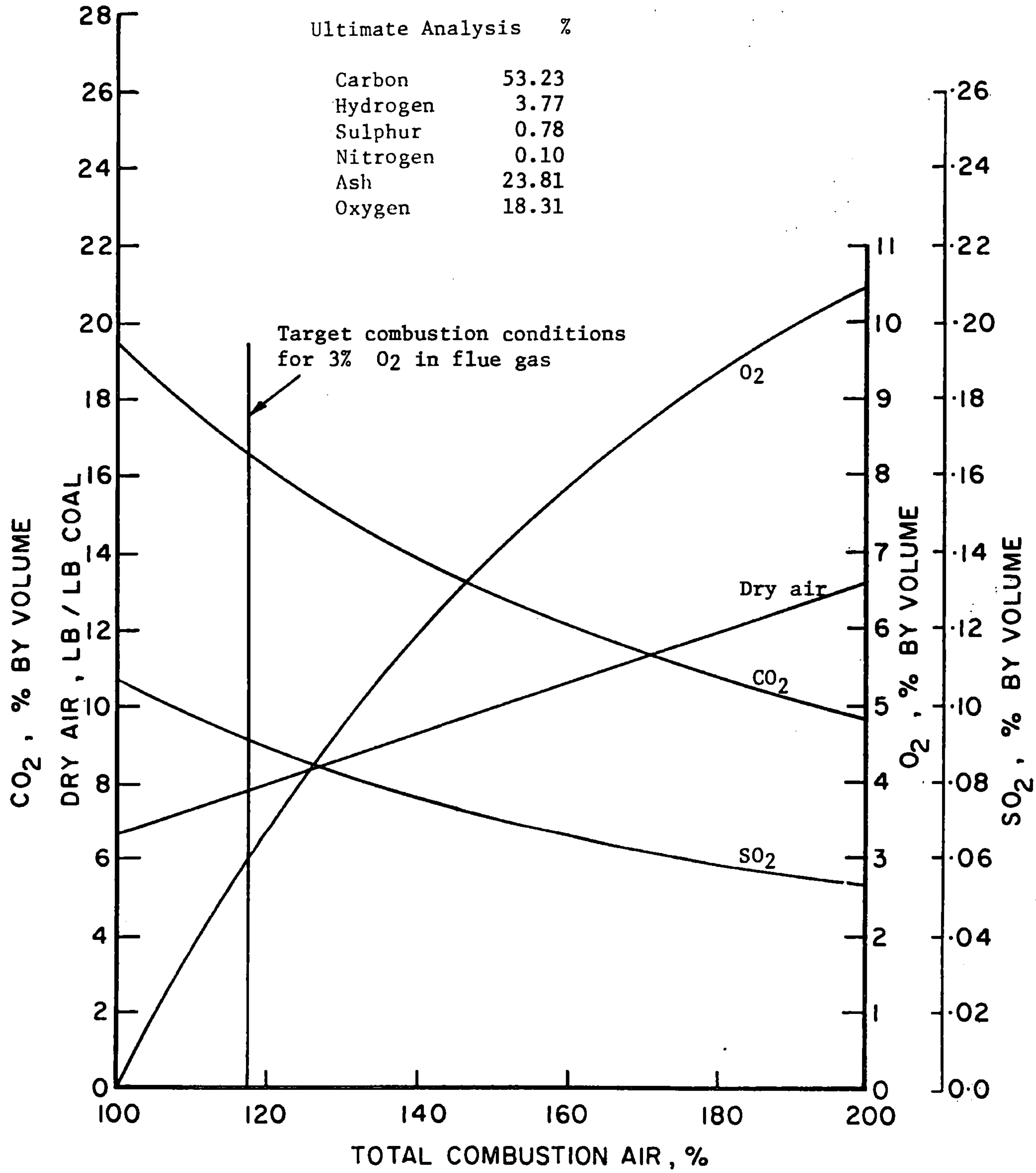


FIGURE 1: Combustion Calculations "B-Washed" Coal.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "B" WASHED COAL

AIR-DRIED, 5% EXCESS OXYGEN

TEST NO. 5.3

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/144-147

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.3A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 5.3, which was done on November 5, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 5.3

In this test Hat Creek "B" washed coal was burned. The coal had been air-dried only, which reduced the as-fired moisture to 20.3%. The target level of excess oxygen in the flue gas was 5% (approx 25% excess air), and the target coal feed rate was 120 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0840 hr, stable, unsupported coal combustion had been in progress for more than one hour. When it was viewed from the top of the furnace, the flame appeared to be yellow-orange coloured, and it was so transparent that it was possible to see fairly well down the walls of the furnace bottom, although the air-cooled deposition probe located there was not visible. The flame appeared to end a short distance above the furnace throat, and there were very few burning coal particles at the furnace exit. Both deposition probes in the furnace were visible. There were deposits on all sides of the furnace below the throat, blocking approximately 1/10 of the projected throat area. The test air-heater tubes were barely visible in the flickering light from the furnace. The furnace bottom was bright and transparent, very few burning coal particles were evident, there were 2 to 4 cm of sinter on the walls of the furnace bottom, and some ash was visible on the ledges adjacent to the dump plates. The air-cooled deposition probe in the furnace bottom was clearly visible through the sight ports located there.

At 0930 hr, the view of the throat from the top of the furnace was hazy. The deposits in the southwest and northeast corners below the furnace throat blocked nearly ½ of the projected throat area. A large sinter was also visible on the north wall of the furnace bottom. At 0940 hr, the deposits were knocked loose with a poker which was thrust through the top of the furnace. Ash was dumped. The ash, which later was raked from the quench tank, consisted mostly of small sinters. A few sinters measured 10 cm in diameter, and all were medium grey coloured. Then, the furnace throat was clean but somewhat obscured by flame or dust, and the refractory deposition probe in the furnace was barely visible. The flame appeared brighter than before, but the appearance of the test air-heater was the same as before. The furnace bottom was fairly clean, and some ash remained on the ledges. The air-cooled deposition probe in the furnace bottom was bent downward.

Combustion conditions were relatively constant until the end of the test. At 1415 hr, deposits were visible below the furnace throat, and they blocked approximately 1/10 of the projected throat area. The furnace bottom was nearly half-full of ash, which blocked the south sight port. Ash had not been dumped since 1000 hr, therefore, this was done again at 1420 hr. The ash fell readily, although large quantities remained on the ledges and in the corners. The ash removed from the quench tank consisted of fine, tan-coloured sand and small, weak sinters.

At 1525 hr, large quantities of dust were observed to be cascading off the nose at the furnace exit. Just before an oil-fired support burner was inserted at 1615 hr, the air-cooled deposit probe in the furnace bottom was faintly visible from the top of the furnace. There were heavy deposits on the east and west walls of the furnace, below the throat, and these blocked approximately ¼ of the projected throat area. When the support oil burner was turned off and the furnace was "shut-down" at 1618 hr, a flame presisted for a few minutes from oil that had struck the deposits in the furnace. The ash deposits ceased to glow very quickly, although the refractory behind them was visible for a few minutes after shut-down.

Deposition Probes During Test Period

Both probes in the furnace, and the air-cooled probe in the furnace bottom were visible.

The air-cooled probe in the furnace bottom first developed a few sinters approximately 5 mm in diameter. These fell off during cleaning of the furnace, and were replaced by somewhat larger sinters on the top surface. These gradually consolidated to form a beard 7 mm thick on most of the probe but they fell off later and only a thin layer of sinter remained at the end of the test.

The air-cooled probe in the furnace did not develop any evident deposits during the test

The refractory probe in the furnace at 0930 hr, had a lump of sinter, measuring 2½ cm in diameter, on the bottom surface at the outer end. Later, this sinter fell off and there were no noticeable deposits for the remainder of the test.

Furnace After Test

When the dump plates were swung open, approximately 40 litres of ash fell to the floor. With the exception of one sinter, 25 x 20 x 15 cm, and a few pieces, 10 cm in diameter, the ash consisted of small sinters and dust. Its colour ranged from tan to grey. The sinters were very friable and when broken up, had the consistency of fine sand. A small number of sinters 2 to 5 cm in diamater, adhered to the furnace bottom walls and the throat refractory.

The furnace water walls were fairly heavily coated with dust. There were 1 to 2 mm of dust on the exposed surfaces of the tubes, and the grooves between them were partly filled with dust from the throat to the furnace exit. There was also a heavy layer of tan-coloured, sandy material on the upper slopes of tubes forming the throat and the nose at the furnace exit.

The bottom of the transition section bore 5 to 8 cm of fine, tan-coloured sand. The walls of the transition section were clean. On their downstream surfaces, the furnace screen tubes had a 3 to 4 mm layer of dust, coloured various shades of grey. The test air-heater tubes appeared to have been sand blasted on their upstream surfaces, but there was a layer of tan-coloured dust, 1 to 2 mm thick, on their downstream surfaces. The second pass tube sheet of the main air-heater bore a 2 to 5 cm layer of dust which was dark grey except for a thin surface layer which was tan-coloured.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed bore only a thin layer of dust and sintered particles.

The refractory probe in the furnace bottom, before it was removed, was almost hidden by a sinter, which measured approximately 5 cm in diameter and which adhered to the top of the probe and the furnace wall.

Both of the probes in the furnace, before they were removed, appeared to have no evident deposits.

The air-cooled probe in the transition section, after it was removed, was polished on the upstream surface. On the downstream surface, tan-coloured dust, 3 mm thick, covered most of the surface. Approximately half of the dust had fallen off and left some clean surface.

The refractory probe in the transition section, after it was removed, had a layer of tan-coloured dust, 1 to 2 mm thick, over 90% of the probe circumference on the downstream surface. Much of it had fallen off.

Test No. 5.3

Progress Report 5.3A

Revised 18/11/76

TABLE 1

OPERATING DATA

COAL HAT CREEK "B" WASHED, AIR-DRIED   EXCESS O_2 5 %

5 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)	Comments
Test Duration		4 hours	
Firing Rate		124(4) kg/hr	
Moisture Content of Coal	1	20.3 %	feed to pulverizer
" " " "	2	3.0(0.7) %	feed to furnace
Combustible " " "	2	74.5(0.8) %	dry weight
Ash Dumping Frequency		once every 6 hour	67 kg Ash dumped, equivalent to 1222 kg coal.
PULVERIZER OPERATING CONDITIONS			
a) Inlet Air Pressure	3	266(5) mmH_2O	
b) Outlet Air Pressure	2	220(2) mmH_2O	
c) Inlet Air Temperature	3	199(2) ^oC	
d) Outlet Air Temperature	2	73(4) ^oC	
e) Coal Fineness	2	82.5% below 200 mesh	oversize, 16.7% 140 mesh " , 17.5% 200 mesh " , 55.4% 325 mesh
BOILER OPERATING CONDITIONS			
a) Steam Flow	6	592(14) kg/hr	
b) Steam Pressure	6	2.97(0.5) atmospheres	
c) Combustion Air Temp.	4	181(4) ^oC	
d) Furnace Pressures			
Furnace	10	31(1) mmH_2O	
Inlet	11	31(1) mmH_2O	
Boiler Exit	12	15(2) mmH_2O	
Primary (Coal) Air L	5	130(6) mmH_2O	
" R	5	148(3) mmH_2O	
Secondary (Windbox) Air L	4	51(4) mmH_2O	
" R	4	50(3) mmH_2O	
FLUE GAS ANALYSIS			
a) CO_2	11	14.7(1.5) %	
b) O_2	11	5.0(0.1) %	
c) CO	11	80(10) ppm	
d) NO	13	644(62) ppm	
e) SO_2	14	690(5) ppm	
f) SO_3	14	< 1 ppm	
g) Acid dewpoint	18	32 ^oC	
FLUE GAS TEMPERATURE			
a) Furnace Exit	11	648(9) ^oC	
b) Boiler Exit	12	283(2) ^oC	
c) Precipitator Entry	16	152(2) ^oC	
SUCTION PYROMETER TEMPERATURES			
a)	7	976, 890 ^oC	readings taken in second and third two hour period
b)	8	835, 785 ^oC	
c)	9	799, 727 ^oC	
FLY ASH			
a) Loading	16	6710(500) $mgms/m^3$	measured at 20^oC
b) Resistivity	15	$2.6(0.1)\times10^{10}$ Ω cm at 253^oC	
"	17	$2.4(0.3)\times10^{11}$ Ω cm at 154^oC	8.7×10^{10} Ω cm at 129^oC
c) Precipitator efficiency	18	94.8(0.6) %	
d) Combustible content of ash collected from precipitator	18	4.0(0.4) %	

TABLE 2

DEPOSITION PROBES

Station		Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom	19	ceramic	990	(36)	905	1045	1045	941	Tan coloured scale, upstream. Tan powder, 15 mm upstream, 1 mm downstream covered up-stream by light brown crust.
		stainless	561	(45)	466	615	615	511	Grey scale upstream, grey dust all around, 1 mm thick.
Furnace	9	ceramic	745	(29)	703	790	790	765	Grey scale upstream covered by black dust, 2 mm thick, all around.
		stainless	441	(16)	405	462	462	423	Grey scale, even, upstream. Grey dust, ½ mm thick all around.
Transition Section	20	ceramic	622	(13)	603	640	608	630	Beige dust, even, 1 mm thick, downstream.
		stainless	586	(4)	579	594	581	585	Grey being dust, even, all around.

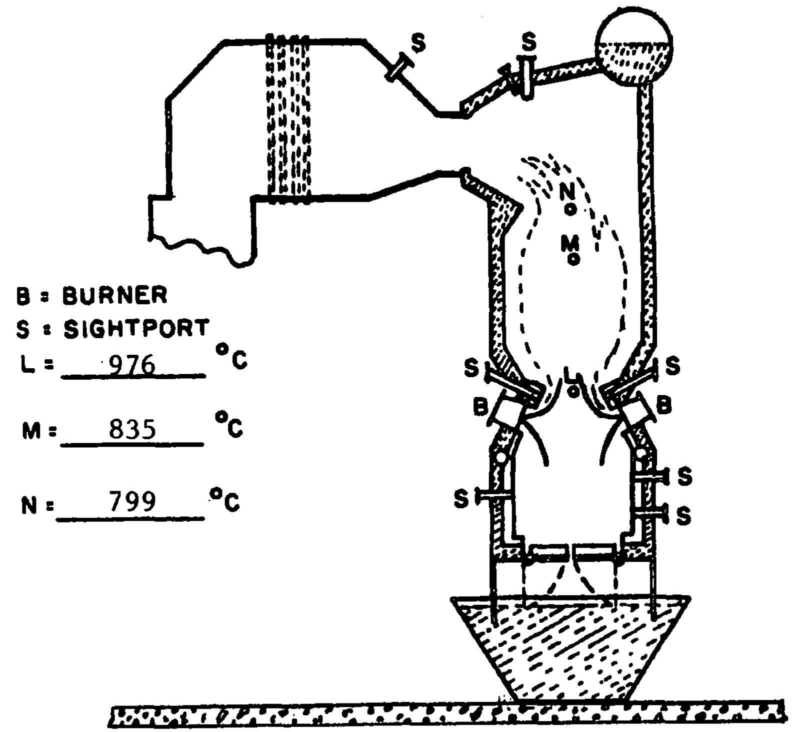


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.3B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (5.3B) presents coal analyses and size distribution of the pulverized coal burned in test 5.3 done on November 5, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 5.3

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size [1/]	Grab Samples [2/]		Composite Sample	
	Wt %	R.M.S. Deviation [3/]	Wt %	LOI % [4/]
60M				
60M x 100M			3.1	
100M x 140M	16.7	3.8	17.1	83.0
140M x 200M	0.8	0.3	9.7	79.9
200M x 325M	37.9	3.2	23.7	76.2
325M x 0	44.6	1.2	46.4	69.1

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: B Washed, Test 5.3, B. C. Hydro (A1451)

Analysis	
Screen Analysis	
+ ¼	0.00 %
¼ * 1/8	15.36 %
1/8 * 1/16	51.75 %
1/16 * 1/32	19.00 %
1/32 * 28M	3.76 %
28M * 48M	4.56 %
48M * 0	5.57 %
Grindability	
Hardgrove Index	39
Classification of Coal	
Rank (ASTM)	
Eq. Moisture % (97% Humidity)	

Sample B Washed, Test 5.3, B.C. Hydro (A1451)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	18.07	0.00
Ash	16.94	20.68
Volatile Matter	37.68	45.99
Fixed Carbon (by Diff.)	27.31	33.33
Ultimate Analysis %		
Carbon	45.99	56.13
Hydrogen	3.18	3.88
Sulphur	0.63	0.77
Nitrogen	0.90	1.10
Ash	16.94	20.68
Oxygen (by Diff.)	14.29	17.44
Calorific Value		
Calories/gram	4203	5130
Btu/lb gross	7565	9233
Megajoules/kilogram	17.60	21.48
Sulphur Forms %		
Sulphatic	0.04	
Pyritic	0.10	
Organic (by Diff.)	0.49	
	0.63	
TOTAL		
Chlorine	0.00	

Progress Report 5.3 B

Sample: B Washed, Test 5.3, B.C. Hydro (A1451)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1482+	1399
Spherical	°C	+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	49.43
Al_2O_3	31.85
Fe_2O_3	6.57
Mn_3O_4	0.06
TiO_2	1.52
P_2O_5	0.41
CaO	4.66
MgO	1.51
SO_3	3.00
Na_2O	0.31
K_2O	0.36
Cl	0.00
Specific gravity	2.79

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.3C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (5.3C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 5.3 done on November 5, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 5:3C

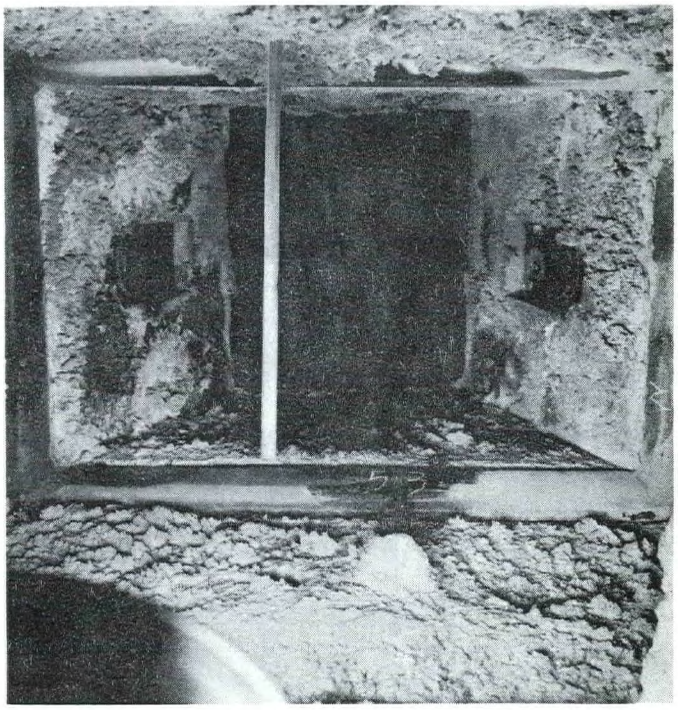


FIGURE 1a Furnace bottom at end of test. Burners and furnace throat are clear of sinter. Refractory deposition probe, in foreground is covered by sinter.

FIGURE 1b Main air heater tube sheet second pass up to 2 - 3 inches powder.

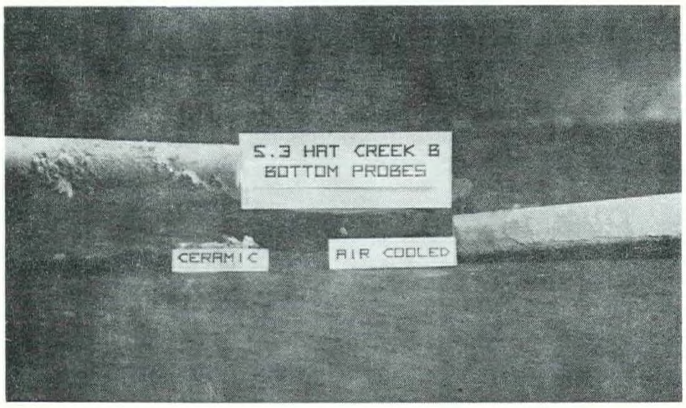


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

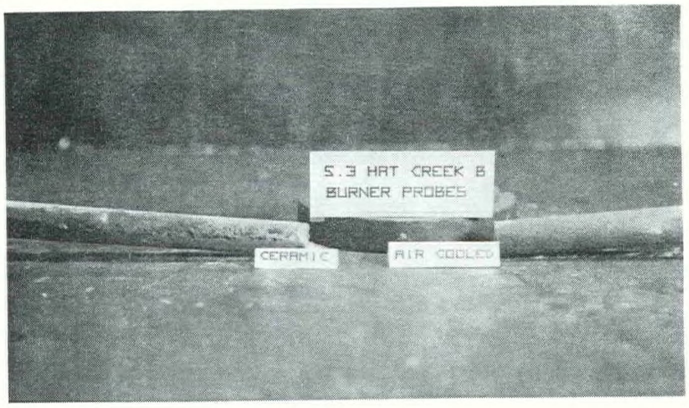


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.

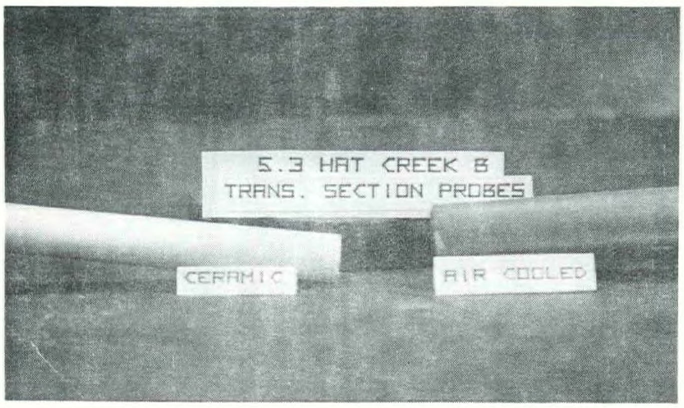


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

PROGRESS REPORT 5:3C

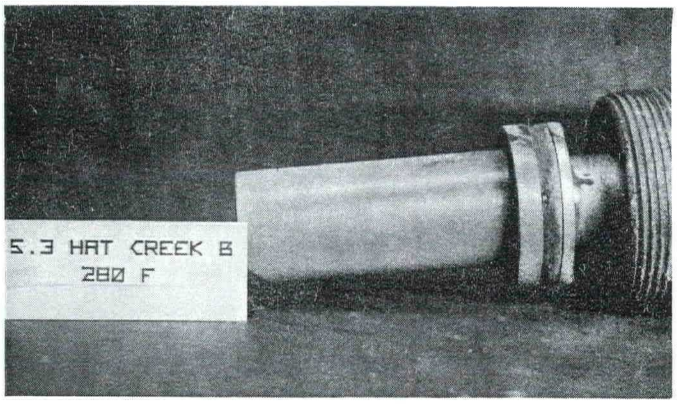


Figure 1f

Low Temperature corrosion probe 138^{o}C.

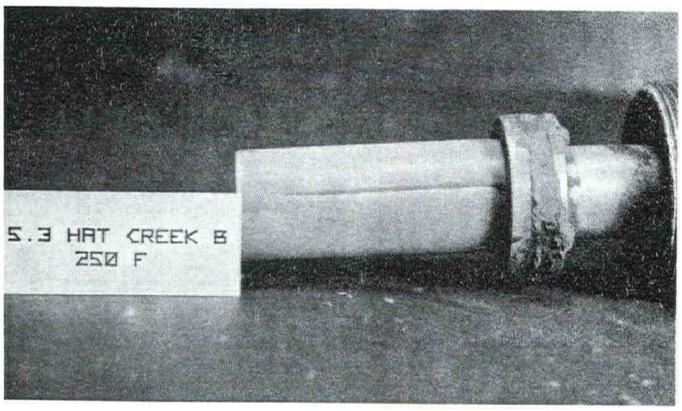


Figure 1g

Low Temperature corrosion probe 121^{o}C.

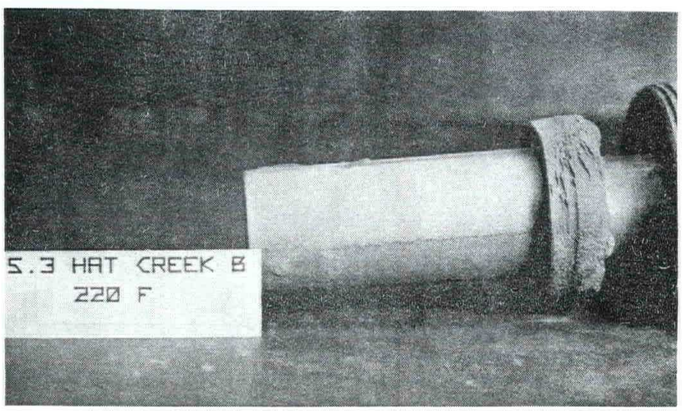


Figure 1h

Low temperature corrosion probe 104^{o}C.

Test No. 5.3
Progress Report 5.3C

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121°C	104°C	561°C	441°C	586°C
Deposition rate[a/]						
Fe	70.1	56.2	33.3	4.9	16.2	7.6
Mg	2.9	1.3	0.7	1.1	11.3	2.8
Na	0.7	0.4	0.2	0.8	2.9	2.2
Ca	6.9	4.3	1.9	23.6	143.5	11.1
SO_4 (total)	110.3	110.3	62.7	71.8	198.0	169.7
SO_4 (free), by difference				0.4		114.0

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposit from electrostatic precipitator, Test 5.3 (A 1490-A-B-C)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1288	1299
Spherical	°C	1438	1382
Hemispherical	°C	1482+	1432
Fluid	°C	+	1482+

Ash Analysis	%
SiO_2	51.77
Al_2O_3	30.25
Fe_2O_3	5.97
Mn_3O_4	----
TiO_2	1.55
P_2O_5	0.46
CaO	5.57
MgO	1.84
SO_3	0.10
Na_2O	0.38
K_2O	0.49
Cl	----

Progress Report 5.3 C

Sample: Deposit from the furnace bottom, Test 5.3 (A 1486 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1338	1321
Spherical	°C	1482+	1477
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	54.78
Al_2O_3	30.97
Fe_2O_3	6.88
Mn_3O_4	----
TiO_2	1.19
P_2O_5	0.33
CaO	4.29
MgO	1.39
SO_3	0.17
Na_2O	0.31
K_2O	0.49
Cl	----

Sample: Deposit from the furnace walls, Test 5.3 (A 1487 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1288
Spherical	°C	1482+	1432
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	51.84
Al_2O_3	29.62
Fe_2O_3	8.41
Mn_3O_4	----
TiO_2	1.15
P_2O_5	0.39
CaO	4.09
MgO	1.61
SO_3	1.19
Na_2O	0.29
K_2O	0.49
Cl	----

Progress Report 5.3 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 5.3 (A 1490)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1310	1282
Spherical	°C	1449	1371
Hemispherical	°C	1482+	1477
Fluid	°C	+	1482+

Ash Analysis	
SiO_2	50.66
Al_2O_3	29.55
Fe_2O_3	9.40
Mn_3O_4	----
TiO_2	1.31
P_2O_5	0.42
CaO	5.09
MgO	1.86
SO_3	0.49
Na_2O	0.28
K_2O	0.46
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "B" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 5.3D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (5.3D) is the last of the series and presents results of the following detailed analyses of ash produced in test 5.3 done on November 5, 1976.

1. Particle size distribution of fly ash
2. X-ray diffraction analyses of fireside deposits
3. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.4
1.59 - 2.00	Coulter Counter		0.8
2.00 - 2.52	Coulter Counter		1.1
2.52 - 3.17	Coulter Counter		1.5
3.17 - 4.00	Coulter Counter	0.3	2.6
4.00 - 5.04	Coulter Counter	0.3	3.7
5.04 - 6.35	Coulter Counter	0.6	5.4
6.35 - 8.00	Coulter Counter	1.2	7.3
8.00 - 10.08	Coulter Counter	3.0	11.0
10.08 - 12.7	Coulter Counter	5.8	13.3
12.7 - 16.0	Coulter Counter	10.5	14.4
16.0 - 20.2	Coulter Counter	16.3	12.4
20.2 - 25.4	Coulter Counter	21.7	8.4
25.4 - 32.0	Coulter Counter	17.0	5.7
32.0 - 40.3	Coulter Counter	10.1	3.0
40.3 - 44.0	Coulter Counter	2.0	1.0
44.0 - 74.0	Sieve	8.4	3.3
+ 74.0	Sieve	2.8	4.7

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA **PARTICLE SIZE ANALYSIS**

.15 – 200 μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION CCRL – WRL

OPERATOR

EQUIPMENT

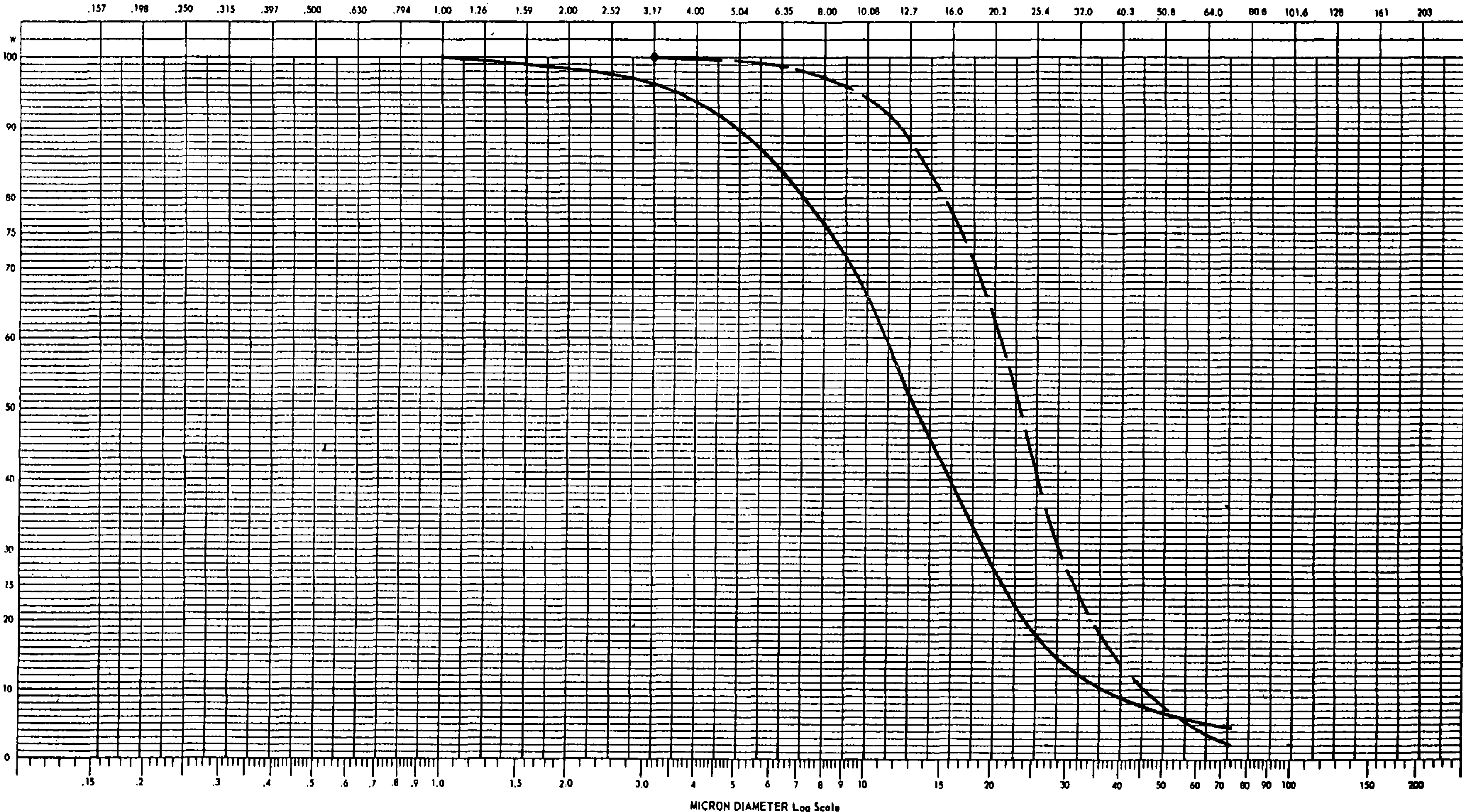
$k = d\sqrt[3]{2w}$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 5.3	ISOTON	ULTRASONIC	100μ	6102033									
ESP ———													
AH2 — — —													



4221010

X-ray Diffraction Analyses of Fireside Deposits from Test 5.3, "B-washed" coal from Hat Creek.

Furnace Bottom Ash (1486 76-480)	Mull, Crist, Feld, Hem, Qtz
Under Flame Probe Deposit (1480 76-481)	Hem, Mull, Crist, Feld, Mag
Furnace Probe Deposit (1482 76-482)	Mag, Hem, Qtz, Amorph
Transition Probe Deposit (1484 76-483)	Hem, Qtz, Crist, Mull, Amorph

Abbreviations of Constituents:

Crist	Cristobalite SiO_2
Mull	Mullite ($3Al_2O_3.2SiO_2$) or Sillimanite ($Al_2O_3.SiO_2$)
Feld	Feldspar (Anorthite) $CaO.Al_2O_3.2SiO_2$
Qtz	Quartz SiO_2
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Amorph	Significant amorphous material present

Notes:

All samples appear to contain some amorphous material, particularly where indicated. There is little indication of amorphous material in Furnace Bottom Ash samples.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification. Mullite and sillimanite give very similar diffraction patterns. It is very doubtful that they can (or should) be distinguished in mixtures such as these.

Constituents are listed in decreasing order of abundance.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

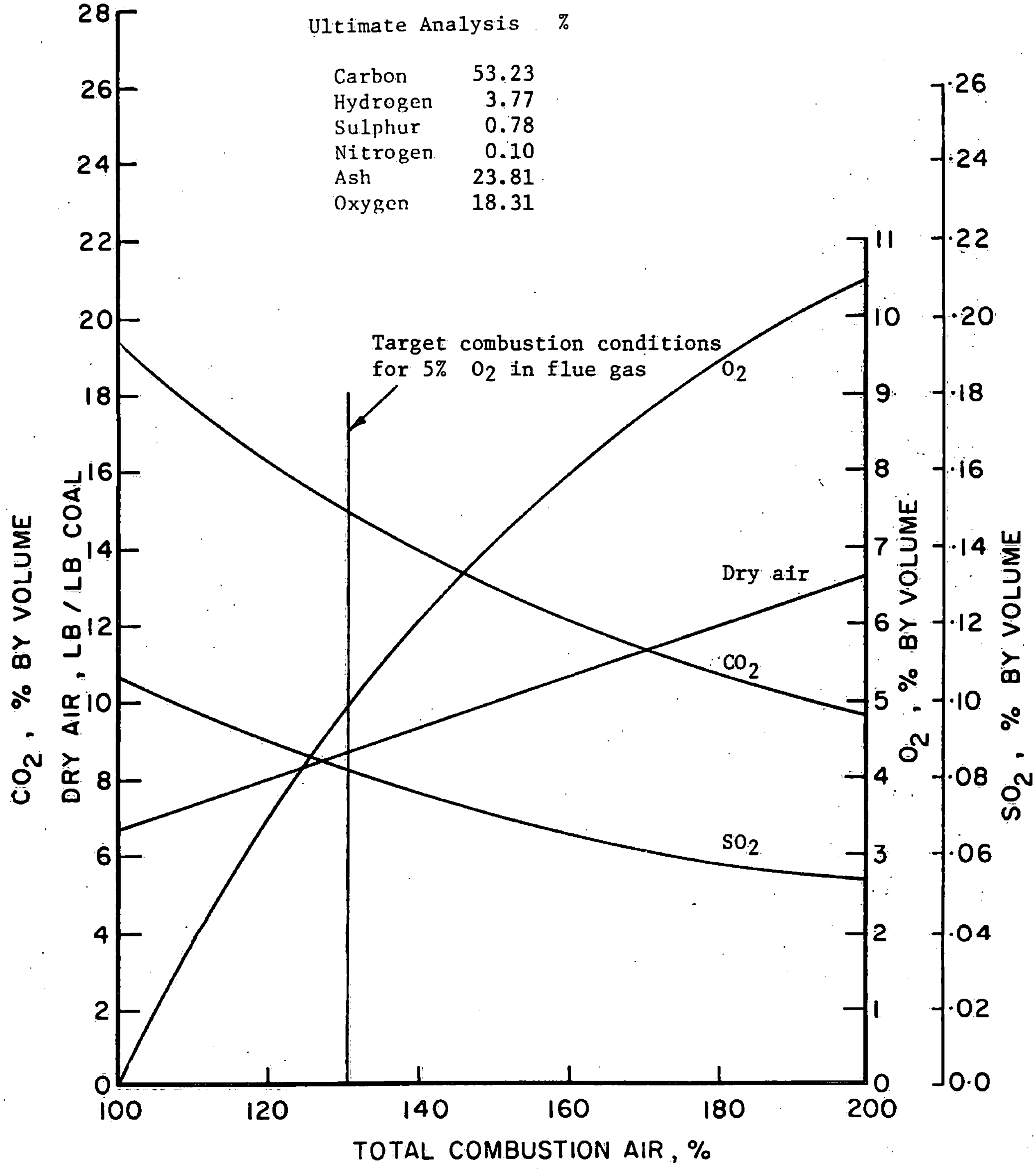


FIGURE 1: Combustion Calculations "B-Washed" Coal .

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "C" RAW COAL

KILN-DRIED TWICE, 5% EXCESS OXYGEN

TEST NO. 6.1

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/148-151

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 6.1A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 6.1, which was done on November 9, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 6.1

In this test Hat Creek "C" raw coal was burned. The coal had been kiln-dried twice, which reduced the as-fired moisture content to 11%. The target level of excess oxygen in the flue gas was 5% (approx 25% excess air) and the target coal feed rate was 110 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0840 hr, stable, unsupported coal combustion had been in progress for over an hour. When it was viewed from the top of the furnace, the flame was yellow-orange coloured and active combustion appeared to end a short distance above the throat. Some deposits were visible below the throat, with the heaviest concentration being in the southwest corner, but pieces of sinter were observed to fall at frequent intervals. There were only a few particles of burning coal at the furnace exit. Both deposition probes in the furnace were visible. There was a dull red glow in the transition section by which the test air-heater tubes were faintly visible. The furnace bottom was bright and transparent. Many small particles of burning coal were evident. There appeared to be 5 to 7 cm of rough sinter on the south wall of the furnace bottom, the south sight port was blocked with sinter, and there was a considerable quantity of dusty ash on the ledges adjacent to the dump plates. Both deposition probes in the furnace bottom were clearly visible. Ash had been dumped twice, and when raked from the quench tank it was light grey coloured and it had the consistency of mud.

During the next hour the deposits below the furnace throat grew to the point where they blocked roughly ¼ of the projected throat area. The flame, when it was observed from the top of the furnace, appeared to be less uniform than before. A small increase of CO content of the flue gas was noted. At 0945 hr, the deposits were removed with a poker which was thrust through the top of the furnace, and ash was dumped. Then, the flame was bright and uniform, and the furnace throat appeared to be clean. A large deposit of sinter remained on the south wall of the furnace bottom and on the south ledge, although the north wall of the furnace bottom appeared to be fairly clean. The ash which was removed from the quench tank consisted of small, grey sinters.

Conditions remained stable for several hours. At 1140 hr, ash was dumped again. At that time the flame was bright, uniform and orange-yellow coloured. The furnace throat was clean except for a deposit 7 to 10 cm thick in the southwest corner, and there was still a heavy deposit of sinter and ash on the south wall and ledge of the furnace bottom.

At 1310 hr, approximately 1/3 of the projected throat area was blocked by sinter which projected from the southwest and northeast corners. The south sight port in the furnace bottom was again blocked by sinter. A few minutes later, the deposits below the furnace throat fell, damaged the deposition probes in the furnace bottom, but left the throat clean. Ash was dumped at 1330 hr, and a poker was thrust through the south ports in the furnace bottom to remove ash from the ledge. The sight port was also cleared with a poker. The ash which was raked from the quench tank consisted of light grey mud and small sinters.

Good combustion conditions persisted for the remainder of the test. No further deposits developed below the furnace throat, and the glow in the transition section was a little brighter than before. Large quantities of dust cascaded from the upper slope of the nose at the furnace exit. At 1535 hr, when a support oil burner was inserted prior to shutdown, the furnace throat was clean, but a heavy deposit of sinter was observed below the sight port, on the south wall of the furnace bottom. After shutdown, the ash and refractory in the furnace bottom maintained a visible glow for approximately ten minutes.

Deposition Probes During Test Period

The probes in the furnace, and the air-cooled probe in the furnace bottom, were visible throughout the test. The refractory probe in the furnace bottom was visible until 1330 hr.

The air-cooled probe in the furnace bottom remained clean for the first hour of the test, then it developed one sinter, 5 mm in diameter on the underside, which remained until the end of the test. No change occurred until 1310 hr, when a few millimeters of deposit along the top surface were observed. Later, this deposit was knocked off when deposits falling from the furnace throat struck the probe and bent it downward. No evident deposits developed in the remainder of the test.

The refractory probe in the furnace bottom, when first observed, had a ragged beard of sinter, approximately 3 cm long, hanging from the bottom surface. Pieces periodically fell off and new deposits grew in their stead. While the shape of the deposits changed constantly, the dimensions remained fairly stable. The probe disappeared from view at approximately 1330 hr, when large deposits fell from the furnace throat.

The probes in the furnace had no evident deposits on them throughout the test. At times the refractory probe was difficult to see through the haze of glowing ash particles.

Furnace After Test

When the dump plates were swung open, approximately 15 litres of ash fell to the floor. This material was tan coloured. Nearly half of it was unsintered, and had the consistency of fine sand. The largest sinter was approximately 25 x 15 x 7 cm, and there were a few pieces approximately 10 cm in diameter. The furnace bottom walls were clean, but some unsintered ash lay on the ledges adjacent to the dump plates. There were patches of sinter approximately 3 cm thick covering one-half of the east and west walls of the throat refractory, and a few small patches of sinter on the refractory walls containing the burners. The furnace water walls had a 1 to 2 mm thick layer of grey and black dust on the outer surfaces of the tubes; the grooves between the tubes had heavier deposits of dust. There were also heavy deposits of grey dust on the upper slopes of the furnace throat and on the nose at the furnace exit.

The floor of the transition section was covered by a layer of tan and grey coloured dust, 5 to 10 cm thick, and on top of this was a thin layer of dark grey coloured dust. The walls of the transition section were clean but there was a thin layer of dust on the walls of the test air-heater. The furnace screen tubes had a few millimeters of tan and grey dust on the downstream surfaces. The upstream surfaces of the test air-heater tubes were clean, and the downstream surfaces bore a thin layer of tan-coloured dust. There were 1 to 5 cm of fine, dark grey dust on the second pass tube sheet of the main air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed, bore a thin layer of sintered deposit and one strongly adhering lump of sinter approximately 5 mm in diameter.

The refractory probe in the furnace bottom, before it was removed was broken at the furnace wall. It was pointed down at 45° and was supported by its thermocouple. It bore only a thin layer of sintered deposit.

Both probes in the furnace, before they were removed, had no deposits of significant size.

The air-cooled probe in the transition section, after they were removed, was clean and had a dull black finish on the upstream surface. The downstream surface had a deposit of tan-coloured dust, 1 to 3 mm thick, most of which had fallen off.

The refractory probe in the transition section, after it was removed, was clean on the upstream surface, and had a 2 mm layer of light tan-coloured dust on the downstream surface. This deposit adhered very weakly, and some of it had fallen.

Test No. 6.1

Progress Report 6.1A

TABLE 1

OPERATING DATA

COAL HAT CREEK "G" RAW, DOUBLE DRIED EXCESS O_2 5 %

9 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		115.4(4.5)	kg/hr	
Moisture Content of Coal	1	11.0	%	feed to pulverizer
" " " "	2	1	%	feed to furnace
Combustible " " "	2	68.0(0.8)	%	dry weight
Ash Dumping Frequency		once every	hour	26.0 kg Ash dumped, equivalent to 943.5 kg coal
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	272(4)	mmH_2O	
b) Outlet Air Pressure	2	240(5)	mmH_2O	
c) Inlet Air Temperature	3	196(5)	^oC	
d) Outlet Air Temperature	2	99(2)	^oC	
e) Coal Fineness	2	73.6(4.9) below 200 mesh		oversize, 19.9 >140 mesh " , 26.4 >200 mesh " 57.7 >325 mesh
BOILER OPERATING CONDITIONS				
a) Steam Flow	6	597(17)	kg/hr	
b) Steam Pressure	6	2.97(0.07)	atmospheres	
c) Combustion Air Temp.	4	183(6)	^oC	
d) Furnace Pressures				
Furnace	10	42(7)	mmH_2O	
Inlet	11	42(7)	mmH_2O	
Boiler Exit	12	21(4)	mmH_2O	
Primary (Coal) Air L	5	150(5)	mmH_2O	
" R	5	164(7)	mmH_2O	
Secondary (Windbox) Air L	4	56(8)	mmH_2O	
" R	4	56(8)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	14.8(0.5)	%	
b) O_2	11	5.1(0.1)	%	
c) CO	11	133(36)	ppm	
d) NO	13	581(38)	ppm	
e) SO_2	14	745(13)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	22	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	574(19)	^oC	
b) Boiler Exit	12	279(11)	^oC	
c) Precipitator Entry	16	150(5)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	950, 926	^oC	readings taken in second and third two hour period
b)	8	810, 861	^oC	
c)	9	730, 854	^oC	
FLY ASH				
a) Loading	16	10600(500)	$mgms/m^3$	measured at 20^oC
b) Resistivity	15	$4.1(0.4)\times10^9\Omega$ cm at 262	^oC	
"	17	$4.0(1.0)\times10^{10}\Omega$ cm at 148	^oC	; $1.4 \times 10^{11}\Omega$ cm at 119^oC
c) Precipitator efficiency	18	94.9(0.2)	%	
d) Combustible content of ash collected from precipitator	18	4.6(0.4)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	1000	(27)	934	1042	1011	1002	Grey coloured scale covered by < ½ mm thick grey dust, upstream.
	stainless	549	(23)	498	577	574	552	Grey scale, uneven, upstream, grey powder, 1 mm thick, downstream.
Furnace 9	ceramic	761	(85)	658	860	860	703	Grey scale, upstream.
	stainless	543	(27)	394	588	588	565	Grey scale, upstream. Grey-beige powder, 2 mm thick, downstream.
Transition Section 20	ceramic	581	(16)	556	603	559	603	Beige coloured powder, 3 mm thick, downstream.
	stainless	556	(23)	531	583	540	583	Grey-beige powder, 2 mm thick, downstream.

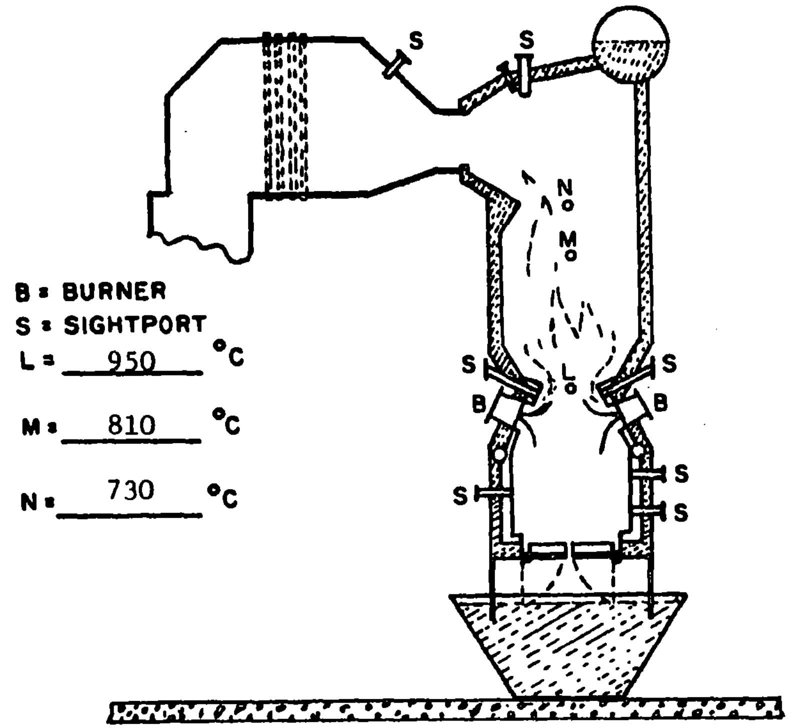


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET
JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 6.1B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (6.1B) presents coal analyses and size distribution of the pulverized coal burned in test 6.1 done on November 9, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 6.1

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			9.2	80.0
100M x 140M	19.9	3.2	15.0	75.3
140M x 200M	6.5	6.0	7.0	71.1
200M x 325M	31.2	10.8	16.0	69.6
325M x 0	42.4	13.6	52.8	63.9

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: C Raw, Test 6.1, B.C. Hydro (A1491)

Analysis	
Screen Analysis	
+ ¼	0.00 %
¼ * 1/8	2.60 %
1/8 * 1/16	20.38 %
1/16 * 1/32	28.07 %
1/32 * 28M	11.23 %
28M * 48M	18.87 %
48M * 0	18.85 %
Grindability	
Hardgrove Index	45
Classification of Coal	
Rank (ASTM)	
Eq. Moisture % (97% Humidity)	

Sample C Raw, Test 6.1, B.C. Hydro (A1491)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	10.55	0.00
Ash	25.33	28.32
Volatile Matter	31.68	35.42
Fixed Carbon (by Diff.)	32.44	36.26
Ultimate Analysis %		
Carbon	43.49	48.62
Hydrogen	3.24	3.62
Sulphur	0.63	0.70
Nitrogen	0.11	0.12
Ash	25.33	28.32
Oxygen (by Diff.)	16.65	18.61
Calorific Value		
Calories/gram	4142	4631
Btu/lb gross	7456	8335
Megajoules/kilogram	17.34	19.39
Sulphur Forms %		
Sulphatic	0.05	
Pyritic	0.12	
Organic (by Diff.)	0.46	
TOTAL	0.63	
Chlorine	0.00	

Progress Report 6.1 B

Sample: C Raw, Test 6.1, B.C. Hydro (A1491)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1482+	1454
Spherical	°C	+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	49.98 %
Al_2O_3	32.10 %
Fe_2O_3	7.89 %
Mn_3O_4	0.16 %
TiO_2	1.30 %
P_2O_5	0.18 %
CaO	2.59 %
MgO	1.43 %
SO_3	1.37 %
Na_2O	0.50 %
K_2O	0.47 %
Cl	0.00 %
Specific gravity	2.75

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 6.1C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make pu the program.

This progress report (6.1C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 6.1 done on November 9, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 6:1C

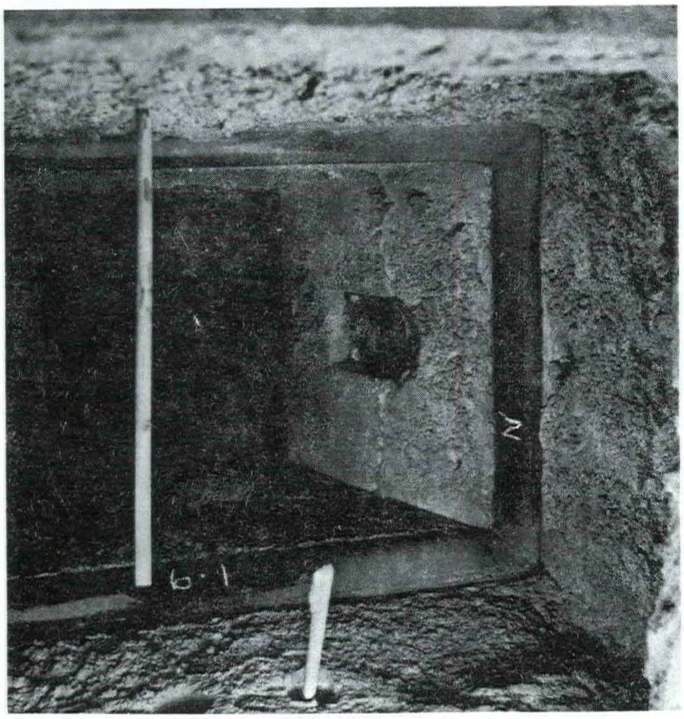


Figure 1a

Furnace bottom at end of test. Burners and furnace throat are clear of sinter. Air cooled deposition probe projects from east wall, refractory deposition probe from west wall. There is a small accumulation of friable sinter on west wall at same elevation as burners.

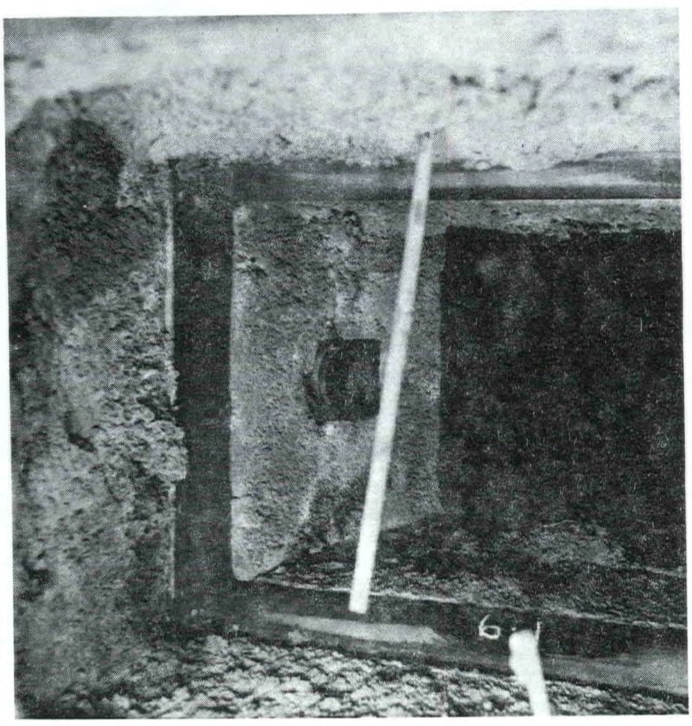


Figure 1b

Furnace bottom at end of test. A small accumulation of friable sinter extends along the south wall.

PROGRESS REPORT 6:1C

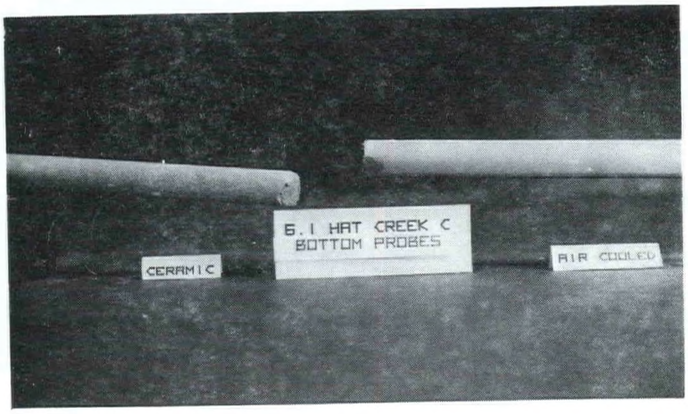


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

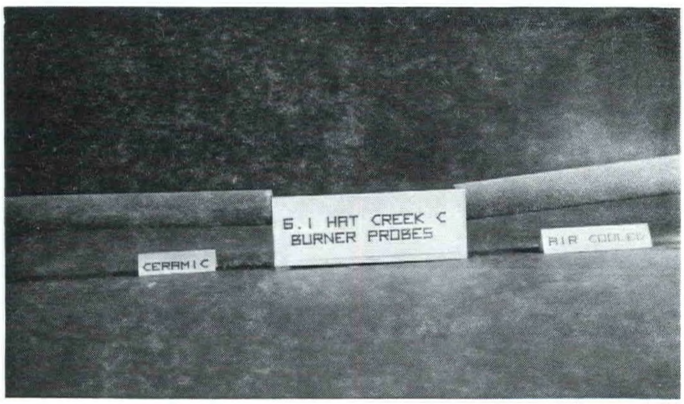


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.

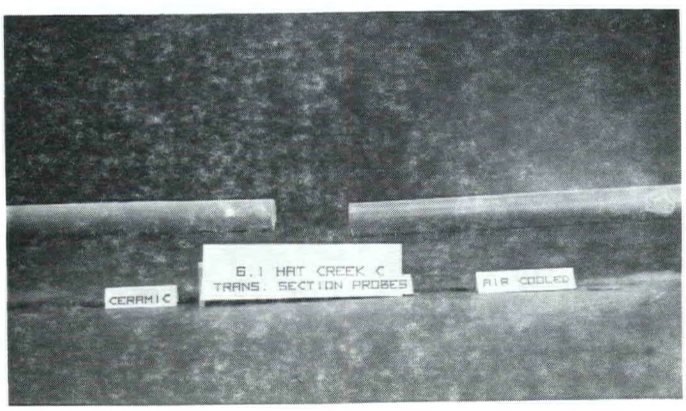


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

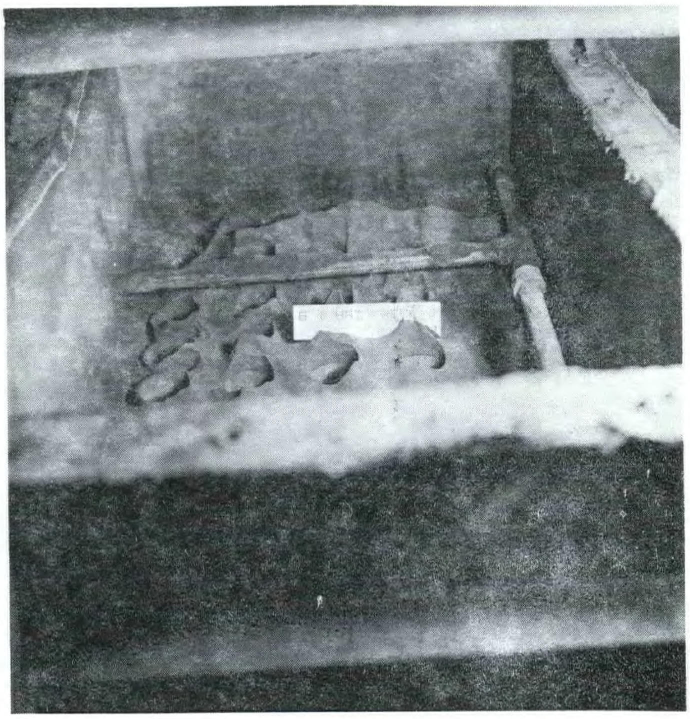


FIGURE 1f Main air heater tube sheet second pass up to 2 - 3 inches of powder.

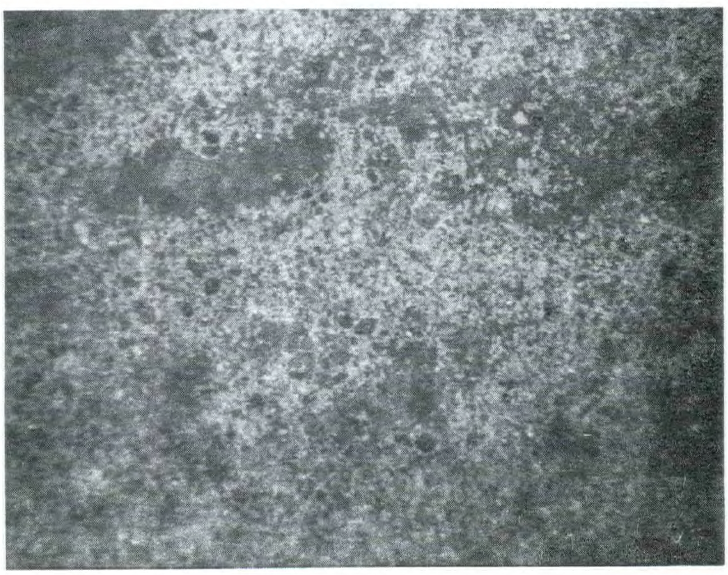


FIGURE 1g Photomicrograph, x 10, of a thin section of sinter which was found attached to the refractory near the burners. The sinter is weak and porous.

PROGRESS REPORT 6:1C

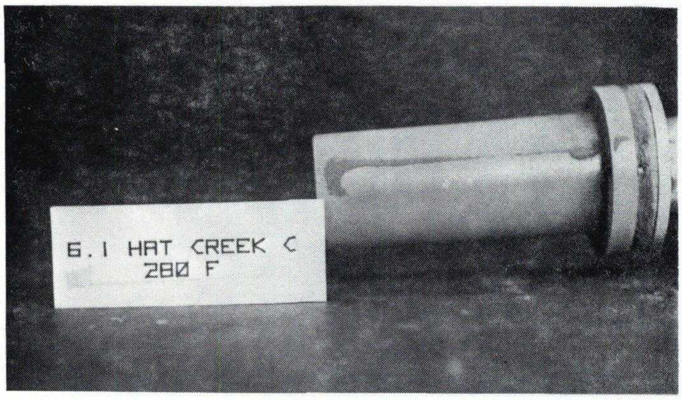


Figure 1h

Low Temperature corrosion probe 138°C.

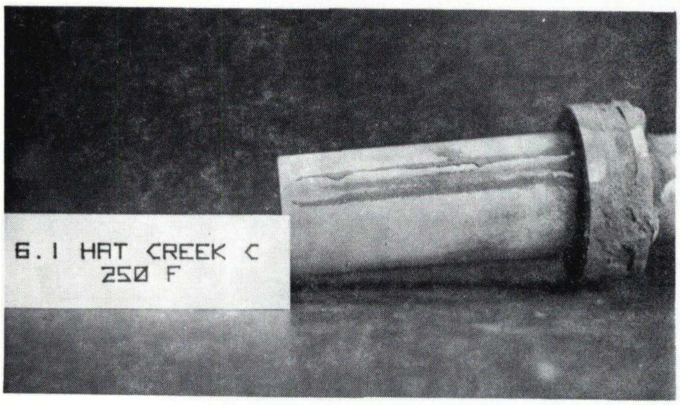


Figure 1i

Low Temperature corrosion probe 121°C.

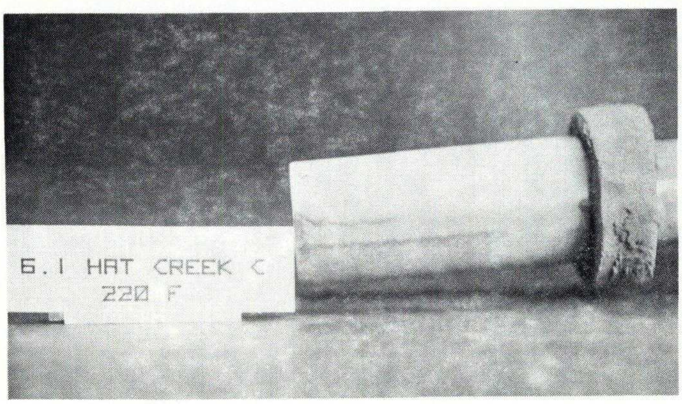


Figure 1j

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

Probe Temperature	Low Temperature 138 °C	121 °C	104 °C	High Temperature 549°C	543°C	556°C
Deposition rate[a/]						
Fe	62.6	54.2	30.3	9.2	14.1	14.1
Mg	2.6	1.3	0.7	2.3	12.4	4.0
Na	0.9	0.7	0.4	4.2	4.5	3.2
Ca	7.8	4.3	1.9	12.5	160.7	7.6
SO_4 (total)	55.1	58.3	58.3	394.0	263.4	209.1
SO_4 (free), by difference				330.3		143.7

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposit from the furnace bottom, Test 6.1 (A 1529 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1421	1199
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	55.49
Al_2O_3	31.31
Fe_2O_3	7.95
Mn_3O_4	----
TiO_2	1.03
P_2O_5	0.19
CaO	2.38
MgO	1.37
SO_3	0.23
Na_2O	0.47
K_2O	0.61
Cl	----

Progress Report 6.1 C

Sample: Deposite from the furnace walls, Test 6.1 (A 1530 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1449	1204
Spherical	°C	1482+	1460
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	53.83
Al_2O_3	30.47
Fe_2O_3	9.07
Mn_3O_4	----
TiO_2	1.07
P_2O_5	0.24
CaO	2.64
MgO	1.26
SO_3	0.12
Na_2O	0.50
K_2O	0.60
Cl	----

Progress Report 6.1 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 6.1 (A 1533 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1288	1232
Spherical	°C	1482+	1438
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	52.68
Al_2O_3	30.14
Fe_2O_3	10.61
Mn_3O_4	----
TiO_2	1.09
P_2O_5	0.28
CaO	3.13
MgO	1.27
SO_3	0.43
Na_2O	0.45
K_2O	0.57
Cl	----

Progress Report 6.1 C

Sample: Deposit from electrostatic precipitator, Test 6.1 (A 1505-06-07)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1388	1310
Spherical	°C	1482+	1449
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	53.26
Al_2O_3	30.91
Fe_2O_3	6.53
Mn_3O_4	----
TiO_2	1.38
P_2O_5	0.36
CaO	3.77
MgO	1.74
SO_3	0.69
Na_2O	0.67
K_2O	0.61
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 5% Excess Oxygen

PROGRESS REPORT 6.1D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (6.1D) is the last of the series and presents results of the following detailed analyses of ash produced in test 6.1 done on November 9, 1976.

1. Particle size distribution of fly ash
2. X-ray diffraction analyses of fireside deposits
3. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.4
1.59 - 2.00	Coulter Counter		0.5
2.00 - 2.52	Coulter Counter		0.8
2.52 - 3.17	Coulter Counter		1.4
3.17 - 4.00	Coulter Counter	0.2	2.4
4.00 - 5.04	Coulter Counter	0.4	3.5
5.04 - 6.35	Coulter Counter	0.7	5.1
6.35 - 8.00	Coulter Counter	1.6	6.8
8.00 - 10.08	Coulter Counter	3.9	10.0
10.08 - 12.7	Coulter Counter	7.4	11.9
12.7 - 16.0	Coulter Counter	11.9	13.0
16.0 - 20.2	Coulter Counter	16.3	11.6
20.2 - 25.4	Coulter Counter	17.3	8.7
25.4 - 32.0	Coulter Counter	14.5	6.3
32.0 - 40.3	Coulter Counter	7.0	3.0
40.3 - 44.0	Coulter Counter	3.5	1.1
44.0 - 74.0	Sieve	9.0	4.3
+ 74.0	Sieve	6.3	9.2

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA

PARTICLE SIZE ANALYSIS

.15 – 200μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL-WRL

OPERATOR:

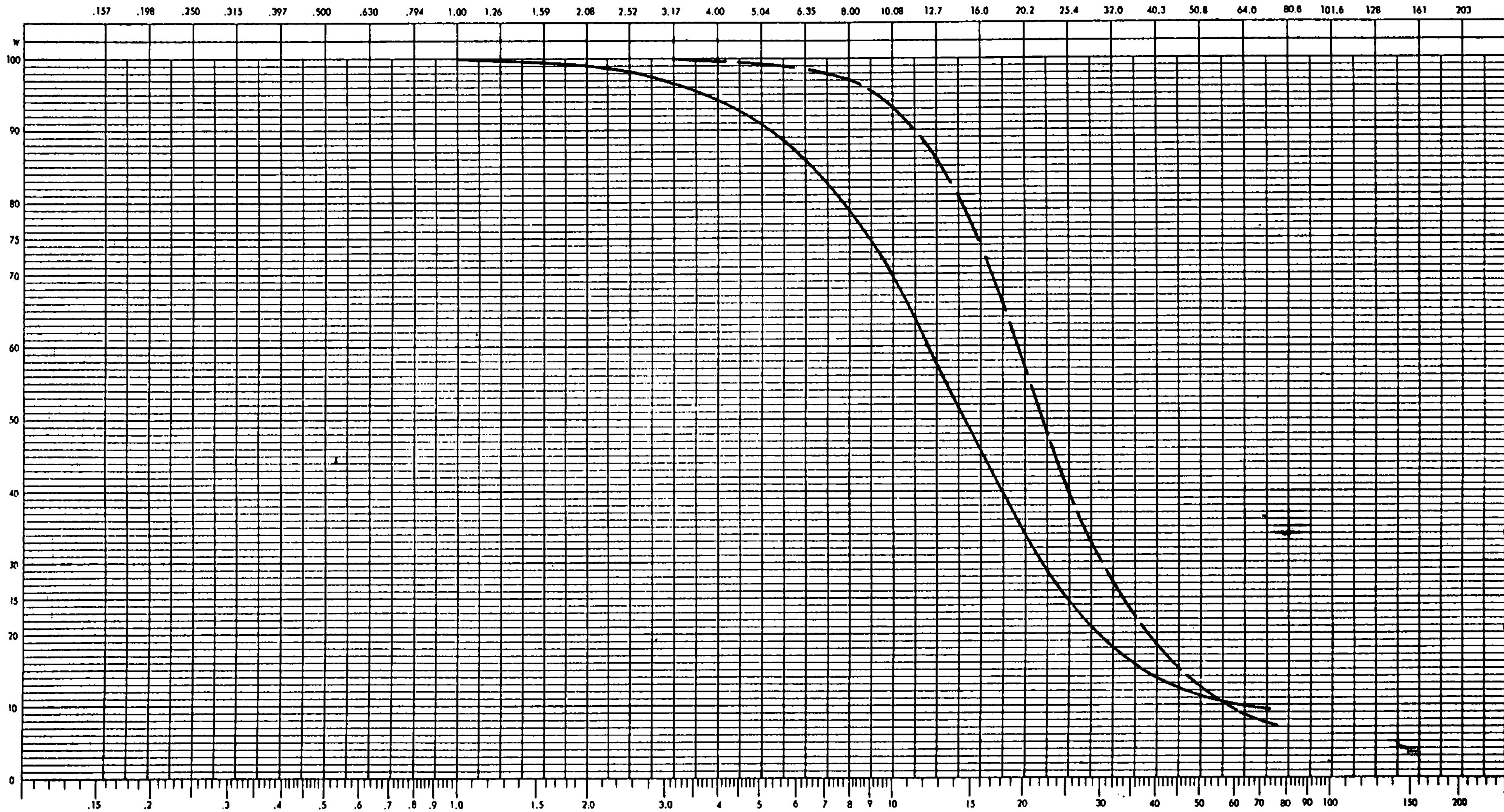
EQUIPMENT:

$k = d\sqrt[3]{2w}$ $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 6.1	ISOTON	ULTRASONIC	100μ	6102033									
ESP ————													
AH2 – – – –													



4221010

X-ray Diffraction Analyses of Fireside Deposits from Test 6.1, "C-raw" coal from Hat Creek.

Furnace Bottom Ash (1529 76-484)	Hem, Mull, Feld, Qtz
Under Flame Probe Deposit (1499 76-485)	Hem, Qtz, Mag, Crist, Amorph
Furnace Probe Deposit (1501 76-486)	Hem, Qtz, Mag, Amorph

Abbreviations of Constituents:

Feld	Feldspar (Anorthite) $CaO.Al_2O_3.2SiO_2$
Qtz	Quartz SiO_2
Mullite	Mullite ($3Al_2O_3.2SiO_2$) or Sillimanite ($Al_2O_3.SiO_2$)
Crist	Cristobalite SiO_2
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Amorph	Significant amorphous material present.

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification. Mullite and sillimanite give very similar diffraction patterns. It is very doubtful that they can (or should) be distinguished in mixtures such as these.

Constituents are listed in decreasing order of abundance.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

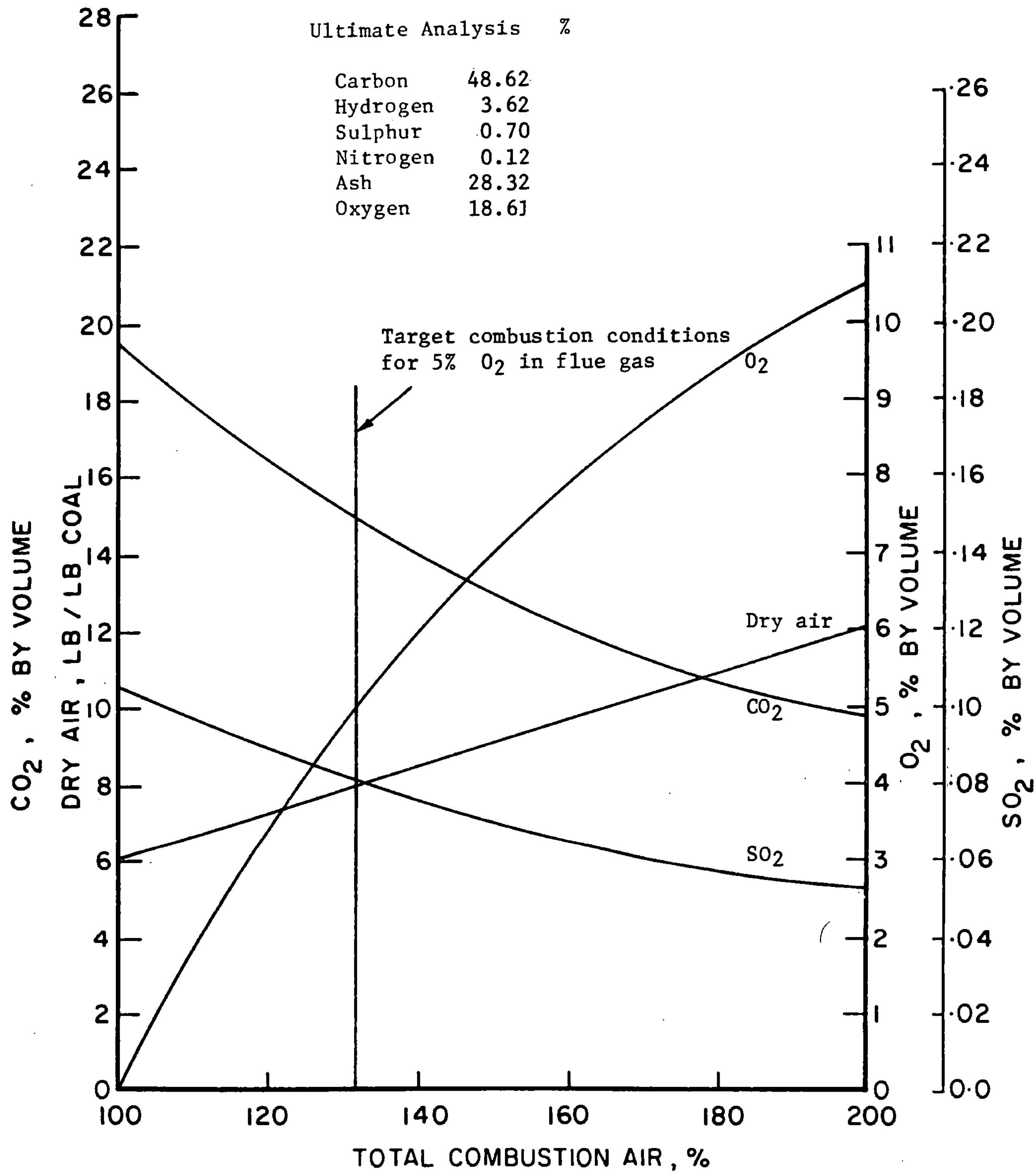


FIGURE 1: Combustion Calculations "C-Raw" Coal .

Energy Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "C" RAW COAL

KILN-DRIED TWICE, 3% EXCESS OXYGEN

TEST NO. 6.2

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/152 -155

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 6.2A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 6.2, which was done on November 12, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 6.2

In this test, Hat Creek "C" raw coal was burned. The coal had been kiln-dried twice, which reduced the as-fired moisture to 13.0%. The target level of excess oxygen in the flue gas was 3% (approx 15% excess air), and the target coal feed rate was 110 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler. An illustration of the pattern of the flame is shown in Figure 2.

Furnace During Test

At 0845 hr, stable, unsupported coal combustion had been in progress for more than one hour. When it was viewed from the top of the furnace, the flame was uniformly yellow-orange or orange in colour, and was so transparent that the air-cooled deposition probe in the furnace bottom was intermittently visible. Active combustion appeared to end a short distance above the furnace throat. A small deposit of sinter was evident below the throat on the north side. Very few particles of burning coal were evident at the furnace exit. Both deposition probes in the furnace were visible. There was very little light in the transition section and nothing could be seen in the test air-heater. The furnace bottom was bright, transparent and full of small particles of burning coal. The north wall of the furnace bottom appeared to be clean but there was a large deposit of sinter on the south wall and much ash on the south ledge adjacent to the dump plates. The air-cooled deposition probe in the furnace bottom was clearly visible.

Furnace conditions remained fairly stable. At 1000 hr, the flame was uniform yellow-orange coloured, and 1/10 of the projected throat area was blocked by deposits on the north side and in the southwest corner. Ash was dumped and when it was raked from the quench tank, it consisted of mud and yellow-grey coloured small sinters. By 1045 hr, most of the deposit under the north side of the furnace throat had fallen. The deposit in the southwest corner was still there. Heavy deposits of sinter covered the south wall of the furnace bottom, and blocked the sight port located there. Fewer particles of burning coal were evident than before.

By 1130 hr, deposits had built up below the furnace throat on the north and east walls, and in the southwest corner, and they blocked more than 1/10 of the projected throat area. Ash was dumped and a poker was thrust through the ports in the south side of the furnace bottom to clear ash from the ledge adjacent to the dump plates. However, much of the ash remained because it could not be reached in this manner. Only small sinters and mud appeared in the ash removed from the quench tank.

Deposits below the furnace throat continued to grow and fall until at 1420 hr, they blocked approximately ½ of the projected throat area. The heaviest deposits were in the southwest corner and on the east wall of the furnace bottom. They were removed with a poker which was thrust through the top of the furnace. Then, the furnace bottom was half-full of ash, and much of this ash did not fall when the dump plates were swung open later.

At 1500 hr, the furnace throat was fairly clean and the flame was bright and uniform. The furnace bottom was bright, transparent, and free of burning coal particles. By 1530 hr, however, the projected area of the furnace throat was 1/3 blocked with sinter on the southwest and northeast corners. Flame appeared to be striking the sinter, but the flue gas analysis did not show any deterioration of combustion conditions. Some flame was visible in the furnace bottom, which was half full of ash and had a heavy deposit of sinter on the south wall. The north wall of the furnace bottom was fairly clean.

By 1600 hr, one-half of the projected area of the furnace throat was blocked, but combustion conditions were good and the flame temperature, which was measured by a radiation pyrometer at the top of the furnace was higher than at any other time during the test. The test air-heater was brighter than earlier in the test, but it was still not possible to see the tubes. There was sufficient flame in the furnace bottom to make it fairly opaque.

At 1615 hr, an oil torch was inserted and it was observed that sinter blocked nearly 3/4 of the projected throat area. Much of this sinter was above the burners. After "shutdown" the ash in the furnace bottom glowed brightly for several minutes.

Deposition Probes During Test Period

The air-cooled probe in the furnace bottom and both probes in the furnace were visible in the test.

The air-cooled probe in the furnace bottom remained clean until 1000 hr, when a few small sinters were observed on the top surface. These fell a short time later, but were gradually replaced and at 1300 hr, the probe bore a beard of sinter rougly 7 mm thick on part of the top surface. At 1400 hr, this beard covered the top 120^{o} of the probe's circumference, and sinter whiskers were also forming randomly on the sides and bottom. When the furnace throat was cleaned at 1420 hr, falling sinter bent the probe and dislodged most of the deposits. The free end of the probe was buried in the ash lying on the furnace bottom, and only a small quantity of deposit remained on the top surface of the exposed portion of the probe. A fresh layer of sinter then began to develop and at the end of the test at 1415 hr, a beard of sinter was 7 mm thick on the top surface of the probe, and 3 mm thick around the remainder of the probe's circumference.

The air-cooled probe in the furnace was clean throughout the test.

The refractory probe in the furnace showed no evident deposit until 1340 hr, when a ragged deposit of sinter was observed to be on the bottom surface.At 1410 hr, this deposit had grown to a diameter of approximately 4 cm, but it was observed to fall off suddenly, leaving the probe clean. At 1600 hr, a fresh deposit, approximately 4 cm in diameter had developed.

Furnace After Test Period

When the dump plates were swung open, approximately 60 litres of ash fell to the floor. It consisted mostly of sinters, ranging in size from 1 cm in diameter to 35 cm x 25 cm x 15 cm, and with most of them being 8 to 12 cm in diameter. They ranged in colour from medium grey to tan and orange-brown. Some of them were strong enough to bear a man's weight without being crushed. Another 40 litres of ash remained in the furnace bottom as two large sinters supported by the air-cooled probe and large sinters on the northwest and southwest corners of the furnace bottom. Small surface areas of these sinters had the appearance of slag and this was caused most likely by the oil support burner which was inserted at shutdown. These sinters ranged in colour from tan to orange-brown. There were also very weak sinter whiskers, 2 to 7 cm long, on most of the furnace bottom walls. The throat refractory was clean except for small patches of sinter whiskers, 2 to 7 cm long, under the south burner and in the northeast corner of the throat.

The furnace water walls were covered with grey dust, and there were heavy layers of grey ash on the upper slopes of the furnace throat and on the nose at the furnace exit. The bottom of the transition section was covered by 4 to 10 cm of dust which lay in three layers of different colours: a black coloured bottom layer, a pale-tan coloured middle layer and a dark grey coloured top layer which was also thin. On the downstream surfaces, the furnace screen tubes had a few millimeters of dust which was layered dark grey and tan. The test air-heater had 2 mm of dust on the walls, the upstream surfaces of the tubes were clean, and the downstream surfaces bore 2 to 3 mm of tan-coloured dust. There were 1 to 5 cm of dark grey dust on the second pass tube sheet of the main air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed, had no large deposits of sinter.

The refractory probe in the furnace bottom, before it was removed, had a 10 to 12 mm layer of sinter on the top and one side.

The air-cooled probe in the furnace, before it was removed, appeared to have a layer of dust on the top surface.

The refractory probe in the furnace, before it was removed, had whiskers of sinter, 12 to 15 mm thick, on the bottom surface and on the free end.

The air-cooled probe in the transition section, after it was removed, had a very thin layer of dust on the upstream surface, and a layer of pale tan coloured dust, 2 to 3 mm thick, covered by a thin layer of dark grey coloured dust on the downstream surface. Part of the deposit on the downstream surface had fallen off.

The refractory probe in the transition section, after it was removed, was clean on the upstream surface and had a weakly adhering pale tan coloured layer of dust, 2 to 3 mm thick, on the downstream surface. This covered 120° of the probe's circumference.

Test No. 6.2

Progress Report 6.2A

TABLE 1

OPERATING DATA

COAL: HAT CREEK "C" RAW, DOUBLE DRIED EXCESS O_2 3 %

12 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		104(5)	kg/hr	
Moisture Content of Coal	1	13.0	%	feed to pulverizer
" " " "	2	0.8(0.4)	%	feed to furnace
Combustible " " "	2	72.4(0.9)	%	dry weight
Ash Dumping Frequency		once every —	hour	78.1 kg ash dumped, equivalent to 1014 kg coal.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	268(4)	mmH_2O	
b) Outlet Air Pressure	2	233(4)	mmH_2O	
c) Inlet Air Temperature	3	184(7)	°C	
d) Outlet Air Temperature	2	92(5)	°C	
e) Coal Fineness	2	66.7(5.8) below 200 mesh		oversize, 20.6 > 140 mesh
BOILER OPERATING CONDITIONS				" , 33.3 > 200 mesh
a) Steam Flow	6	597(23)	kg/hr	" , 61.7 > 325 mesh
b) Steam Pressure	6	2.93(0.05)	atmospheres	
c) Combustion Air Temp.	4	177(10)	°C	
d) Furnace Pressures				
Furnace	10	35(5)	mmH_2O	
Inlet	11	35(5)	mmH_2O	
Boiler Exit	12	18(2)	mmH_2O	
Primary (Coal) Air L	5	143(1)	mmH_2O	
" R	5	156(4)	mmH_2O	
Secondary (Windbox) Air L	4	41(5)	mmH_2O	
" R	4	40(5)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	16.6(0.5)	%	
b) O_2	11	3.0(0.2)	%	
c) CO	11	169(57)	ppm	
d) NO	13	693(183)	ppm	
e) SO_2	14	768 (47)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	35	°C	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	570(29)	°C	
b) Boiler Exit	12	274(11)	°C	
c) Precipitator Entry	16	150(5)	°C	
SUCTION PYROMETER TEMPERATURES				
a)	7	1104, 1104	°C	readings taken in
b)	8	820, 912	°C	second and third
c)	9	805, 808	°C	two hour period
FLY ASH				
a) Loading	16	8160(870)	$mgms/m^3$	measured at 20°C
b) Resistivity	15	—	Ω cm at °C	
"	17	$3.7(0.6)\times10^{10}$	Ω cm at 147°C;	4.5×10^{10} Ω cm at 122°C
c) Precipitator efficiency	18	94.0(0.3)	%	
d) Combustible content of ash collected from precipitator	18	4.3(0.4)	%	

TABLE 2

DEPOSITION PROBES

Station		Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom	19	ceramic	1008	41	939	1078	995	939	Grey scale (and sinter), even, all around, covered by 8 mm friable sinter on upstream and downstream.
		stainless	545	23	482	570	565	482	Black scale, upstream. Grey-white powder, 1 mm thick, downstream.
Furnace	9	ceramic	792	85	631	991	702	991	Grey scale, even, upstream. Grey powder, even, 12 mm thick, downstream.
		stainless	529	14	502	556	545	511	Clean upstream. Grey sinter, even, covered by grey powder, uneven, 2mm, downstream.
Transition Section	20	ceramic	572	29	532	615	534	615	Clean upstream. Grey-white powder, 3 mm thick, uneven, downstream, some fallen.
		stainless	559	16	529	576	529	570	Clean upstream. Grey-beige powder, 3 mm thick, uneven, downstream, some fallen.

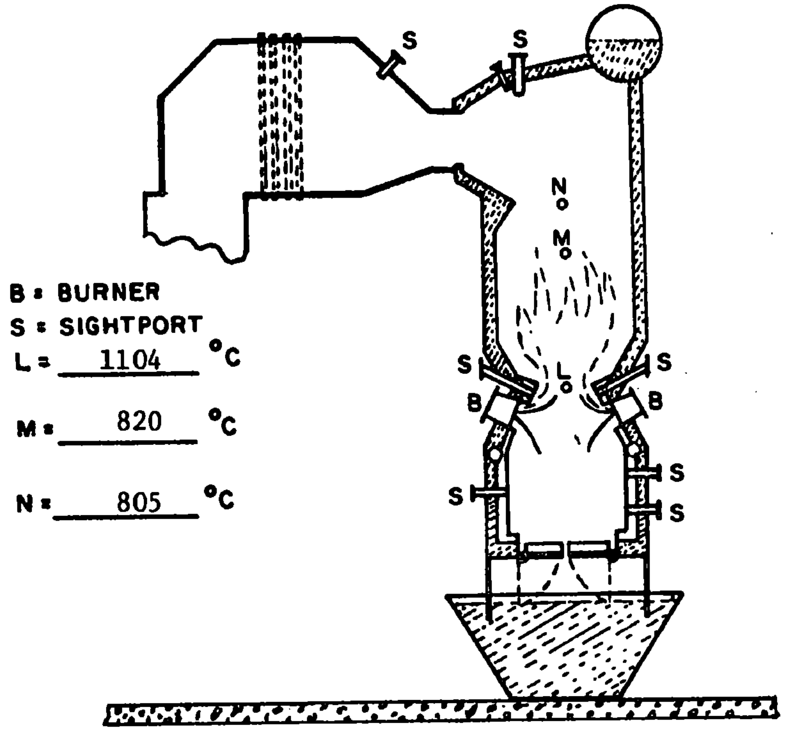


Figure 2. Illustration of flame pattern (——) and burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 6.2B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (6.2B) presents coal analyses and size distribution of the pulverized coal burned in test 6.2 done on November 12, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 6.2

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			8.5	84.2
100M x 140M	20.6	6.7	15.2	79.4
140M x 200M	12.6	1.0	6.7	76.8
200M x 325M	28.4	14.6	17.2	74.9
325M x 0	38.5	17.4	52.5	68.6

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: C Raw, Test 6.2, B.C. Hydro (A1534)

Analysis	
Screen Analysis	
+ ¼	0.00 %
¼ * 1/8	4.51 %
1/8 * 1/16	41.22 %
1/16 * 1/32	29.53 %
1/32 * 28M	7.27 %
28M * 48M	9.31 %
48M * 0	8.16 %
Grindability	
Hardgrove Index	43
Classification of Coal	
Rank (ASTM)	
Eq. Moisture % (97% Humidity)	

Sample C Raw, Test 6.2, B.C. Hydro (A1534)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	10.15	0.00
Ash	23.22	25.84
Volatile Matter	32.38	36.03
Fixed Carbon (by Diff.)	34.27	38.13
Ultimate Analysis %		
Carbon	46.18	51.39
Hydrogen	3.35	3.73
Sulphur	1.05	1.17
Nitrogen	0.99	1.11
Ash	23.22	25.84
Oxygen (by Diff.)	15.08	16.76
Calorific Value		
Calorics/gram	4354	4845
Btu/lb gross	7837	8720
Megajoules/kilogram	18.23	20.28
Sulphur Forms %		
Sulphatic		
Pyritic		
Organic (by Diff.)		
TOTAL		
Chlorine	0.00	

Progress Report 6.2 B

Sample: C Raw, Test 6.2, B.C. Hydro (A1534)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1471	1388
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	51.20 %
Al_2O_3	29.06 %
Fe_2O_3	6.78 %
Mn_3O_4	0.10 %
TiO_2	1.10 %
P_2O_5	0.16 %
CaO	2.81 %
MgO	1.20 %
SO_3	2.67 %
Na_2O	0.54 %
K_2O	0.60 %
Cl	0.00 %
Specific gravity	2.69

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 6.2C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (6.2C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 6.2 done on November 12, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 6:2C

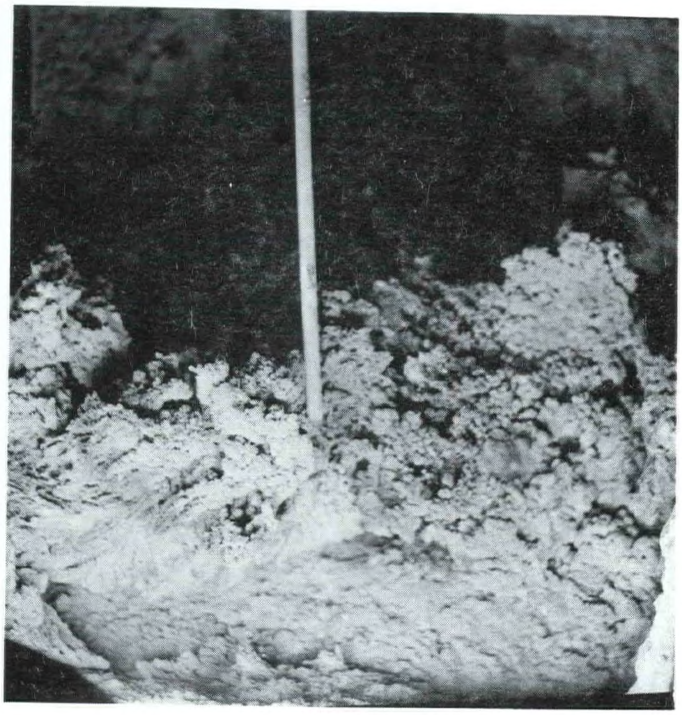


Figure 1a

Furnace bottom at end of test. Friable sinter extends from west wall of furnace at the elevation of the air cooled deposition probe blocking about half the projected area of the furnace bottom.

Figure 1b

Furnace bottom after part of the sinter has been removed. Burners and furnace throat are clear of sinter.

PROGRESS REPORT 6.2C

Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

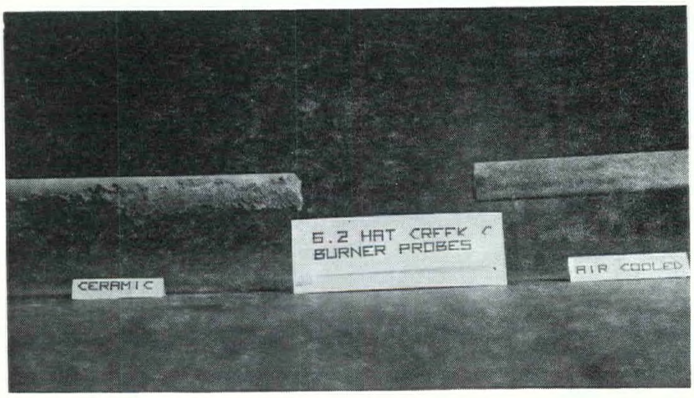


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.

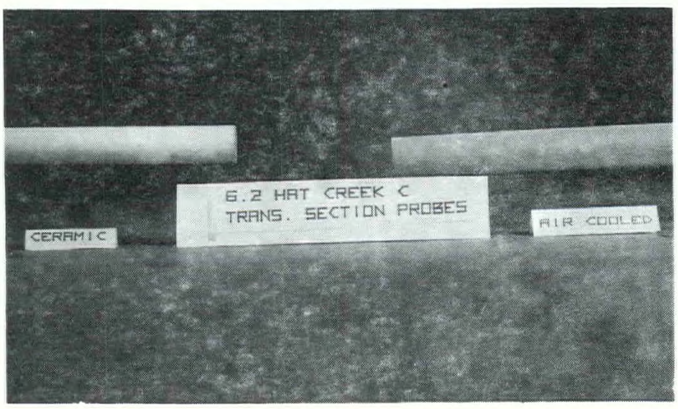


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

PROGRESS REPORT 6:2C

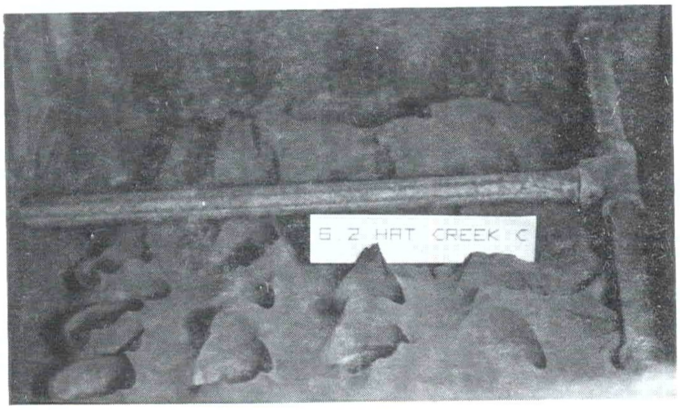


Figure 1f

Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 6:2C

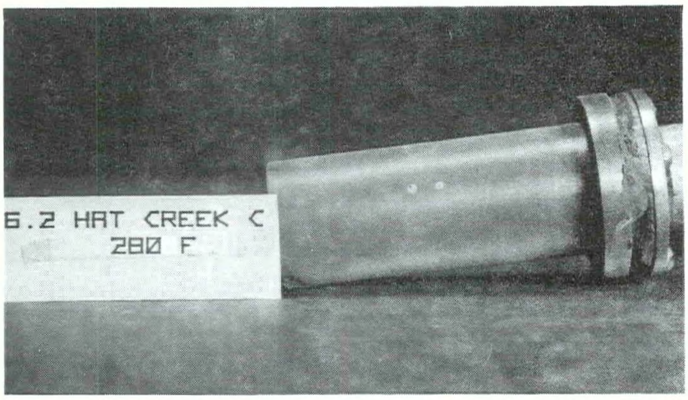


Figure 1g

Low Temperature corrosion probe 138°C.

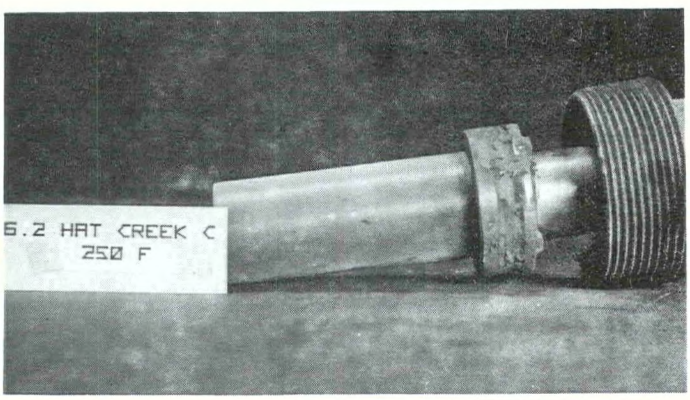


Figure 1h

Low Temperature corrosion probe 121°C.

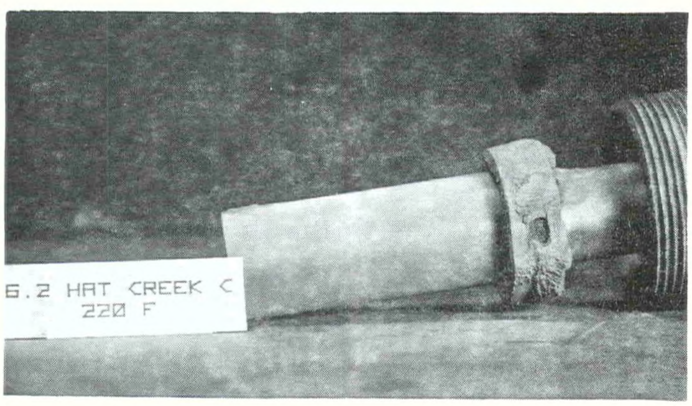


Figure 1i

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

Probe Temperature	Low Temperature 138°C	Low Temperature 121°C	Low Temperature 104°C	High Temperature 545°C	High Temperature 529°C	High Temperature 559°C
Deposition rate[a]						
Fe	50.2	33.7	27.4	22.6	12.1	15.6
Mg	1.9	0.7	0.5	2.6	13.2	4.4
Na	1.1	1.1	0.7	3.2	3.9	4.2
Ca	9.4	3.9	2.3	17.0	168.9	10.5
SO_4 (total)	114.8	78.2	61.3	167.7	182.9	115.4
SO_4 (free), by difference		5.8	5.0	71.1		

[a] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposition probes, Test 6.2, B. C. Hydro

Station	Furnace Bottom		Boiler		Transition Section	
Material	SS	REF	SS	REF	SS	REF
Mean Temperature °C	285	542	276	422	293	300
% Water Soluble	6.9	2.4	---	5.2	---	6.0
% Acid Insoluble	78.9	92.5	---	73.5	---	69.6

Analysis , %	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS
SO_4	1.3		0.0				1.6				0.0	
Ca	4.8	0.0	2.1	0.1			3.6	0.0			6.1	0.0
Fe	0.2	2.6	---	0.7			0.4	3.6			0.1	3.2
Mg	---	0.4	0.0	0.1			0.1	0.5			0.1	0.3
K	0.0	0.0	0.0	0.0			0.0	0.0			0.0	0.0
Na	---	0.2	0.0	---			0.2	0.1			0.1	0.1

WS = water soluble

AS = acid soluble

--- = trace

Progress Report 6.2 C

Sample: Deposit from the furnace bottom, Test 6.2 (A 1572 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1388	1299
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	53.61
Al_2O_3	30.85
Fe_2O_3	6.97
Mn_3O_4	----
TiO_2	1.08
P_2O_5	0.24
CaO	2.68
MgO	1.91
SO_3	0.14
Na_2O	0.48
K_2O	0.61
Cl	----

Progress Report 6.2 C

Sample: Deposit from the furnace walls, Test 6.2 (A 1573 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1382	1299
Spherical	°C	1482+	1477
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	53.34
Al_2O_3	30.23
Fe_2O_3	7.31
Mn_3O_4	----
TiO_2	1.08
P_2O_5	0.30
CaO	2.71
MgO	1.51
SO_3	0.61
Na_2O	0.51
K_2O	0.58
Cl	----

Progress Report 6.2 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 6.2 (A 1576)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1382	1288
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	53.18
Al_2O_3	30.91
Fe_2O_3	7.25
Mn_3O_4	----
TiO_2	1.23
P_2O_5	0.23
CaO	3.34
MgO	1.50
SO_3	0.39
Na_2O	0.53
K_2O	0.59
Cl	----

Progress Report 6.2 C

Sample: Deposit from electrostatic precipitator, Test 6.2 (A 1542-43-44)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1188
Spherical	°C	1482+	1449
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	52.31
Al_2O_3	30.80
Fe_2O_3	5.85
Mn_3O_4	----
TiO_2	1.46
P_2O_5	0.43
CaO	3.97
MgO	1.86
SO_3	0.63
Na_2O	0.74
K_2O	0.60
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Twice, 3% Excess Oxygen

PROGRESS REPORT 6.2D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (6.2D) is the last of the series and presents results of the following detailed analyses of ash produced in test 6.2 done on November 12, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.4
1.59 - 2.00	Coulter Counter		0.4
2.00 - 2.52	Coulter Counter		0.7
2.52 - 3.17	Coulter Counter		1.0
3.17 - 4.00	Coulter Counter	0.2	1.9
4.00 - 5.04	Coulter Counter	0.3	2.7
5.04 - 6.35	Coulter Counter	0.6	4.0
6.35 - 8.00	Coulter Counter	1.2	5.6
8.00 - 10.08	Coulter Counter	2.9	9.1
10.08 - 12.7	Coulter Counter	5.7	12.6
12.7 - 16.0	Coulter Counter	10.4	14.6
16.0 - 20.2	Coulter Counter	15.8	13.8
20.2 - 25.4	Coulter Counter	19.3	9.7
25.4 - 32.0	Coulter Counter	15.8	6.9
32.0 - 40.3	Coulter Counter	8.7	3.5
40.3 - 44.0	Coulter Counter	3.0	1.1
44.0 - 74.0	Sieve	10.8	2.7
+ 74.0	Sieve	5.3	9.3

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL – WRL

OPERATOR:

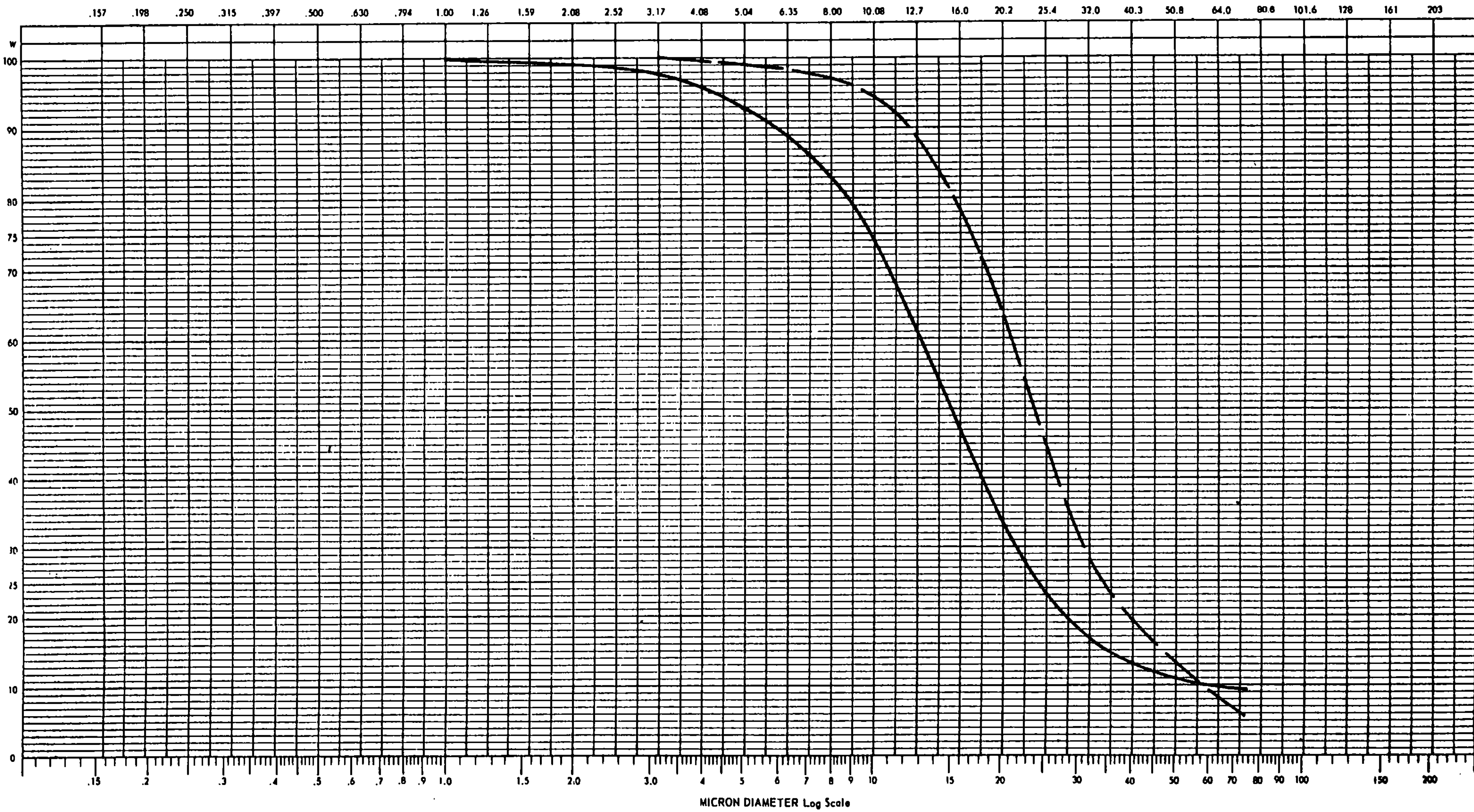
EQUIPMENT:

$k = d\sqrt[3]{2w}$ $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 6-2	ISOTON	ULTRASONIC	100μ	6102033									
ESP ———													
AH2 – – – –													

SAMPLE SETTINGS



4221010

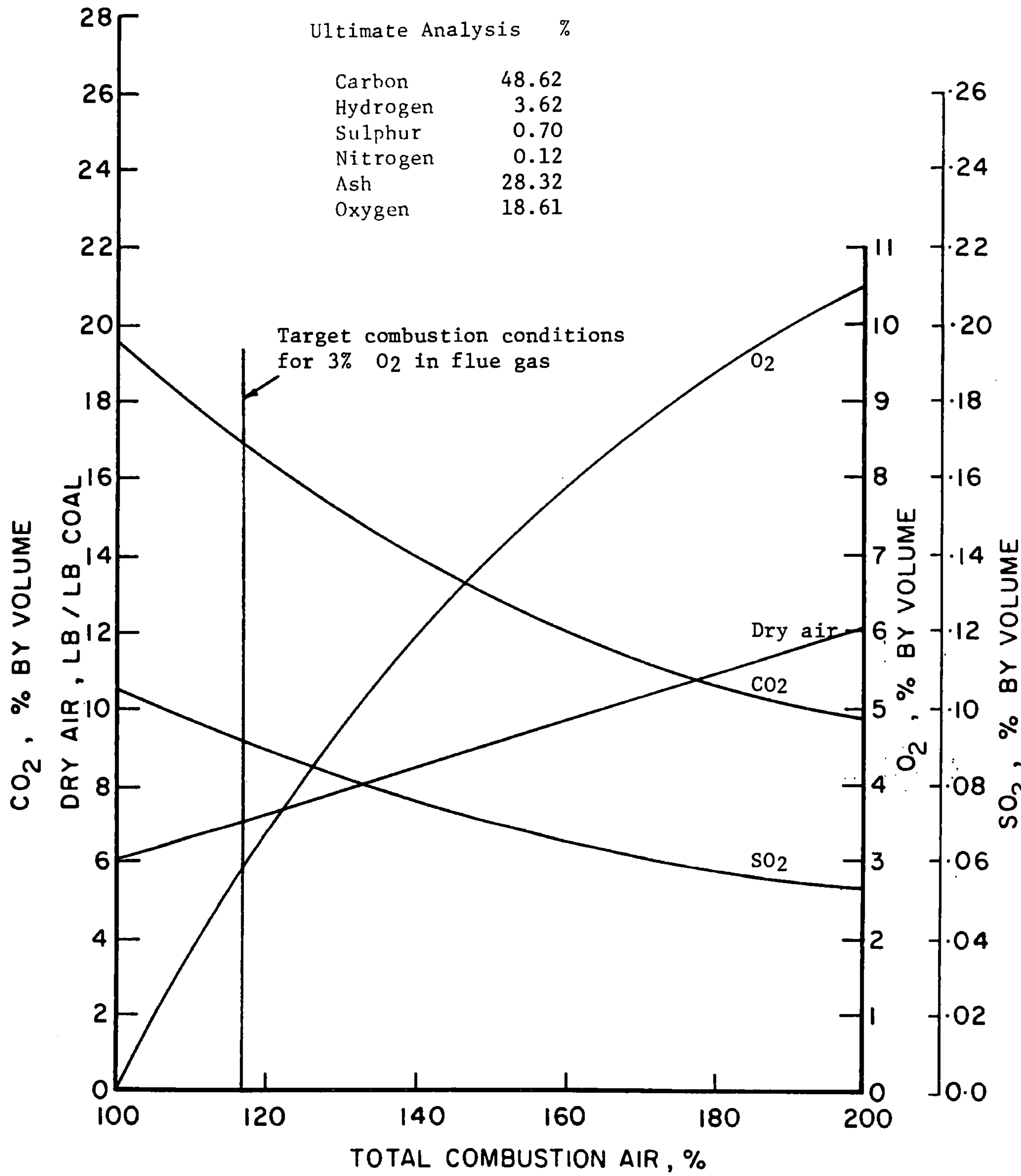


FIGURE 1: Combustion Calculations "C-Raw" Coal.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "C" RAW COAL

KILN-DRIED ONCE, 5% EXCESS OXYGEN

TEST NO. 6.3

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/156-159

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 6.3A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 6.3, which was done on November 16, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 6.3

In this test Hat Creek "C" raw coal was burned. The coal had been kiln-dried once, which reduced the as-fired moisture to 19.6%. The target level of excess oxygen in the flue gas was 5% (approx 25% excess air), and the target coal feed rate was 120 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0845 hr, stable, unsupported coal combustion had been in progress for over an hour. When it was observed from the top of the furnace, the flame was uniformly yellow-orange in colour. Active combustion appeared to end a short distance above the furnace throat. Fairly heavy deposits of sinter under the furnace throat blocked approximately ¼ of the projected throat area. The heaviest deposits were in the southwest corner, and there were deposits on the east and north sides. The air-cooled deposition probe in the furnace was visible but the refractory probe was not. No burning particles of coal were evident at the furnace exit. There was not sufficient light in the transition section to discern any features of the test air-heater. When it was viewed through the sight port in the furnace bottom, the furnace bottom was bright and clear and some flame was visible near the top of it. All the walls of the furnace bottom bore sinter whiskers approximately 2 cm long, and a heavy deposit of sinter was observed to be under the south burner. The air-cooled deposition probe in the furnace bottom was visible in detail.

At 0925 hr, when the furnace was again inspected from the top, most of the deposits had fallen from the furnace throat, leaving it fairly clean. A large quantity of ash was visible in the furnace bottom. Otherwise, conditions were unchanged.

At 1000 hr, fresh deposits, which had formed below the furnace throat, in the southwest corner and above the north burner, blocked roughly 1/10 of the projected throat area. Ash was dumped. However, much ash remained in the furnace bottom where it had bridged across the south end. The ash, which was raked from the quench tank consisted of small sinters, mud, and a few large sinters, approximately 15 cm in diameter. All were friable, and ranged in colour from grey to brown.

Combustion conditions remained stable for the next two hours. At 1145 hr, the deposits below the throat blocked ¼ of the projected throat area, but the flame was bright and uniform. No burning particles of coal were evident at the furnace throat. The transition section was faintly illuminated by flickering light from the furnace; sampling probes in the test air-heater were visible but the tubes were not. The furnace bottom was bright, transparent, and filled with small particles of burning coal. Ash was dumped but most of it remained where it had bridged across the south end of the furnace bottom. The material removed from the quench tank consisted of small grey-brown coloured sinters and mud.

At 1300 hr, the furnace throat above the burners was almost completely blocked by very porous and light sinter. Combustion conditions in the furnace bottom appeared to be unaffected. The deposits were easily removed with a poker which was thrust through the top of the furnace. This left the throat clean and the flame uniform. The furnace bottom was more than half full of ash, and most of the air-cooled deposition probe located there was buried in ash. Ash was not dumped because some measurements were incomplete.

At 1340 hr, ash was dumped, and a poker was thrust through the ports in the furnace bottom to dislodge and break the bridge of sinter which lay across the furnace bottom and to push the broken pieces into the quench tank. Some ash still remained on the south ledge adjacent to the dump plates. A 5 to 8 cm beard of sinter was on the south wall of the furnace bottom. The north wall of the furnace bottom had only a light deposit of sinter. The material which was raked from the quench tank was small, weak sinters, tan-brown and grey coloured, and one fairly strong sinter, approximately 25 cm in diameter.

The flame remained bright and uniform for the remainder of the test. At 1440 hr, when it was viewed from the top of the furnace, the throat had much sinter on all sides, but it was not significantly blocked. Many burning coal particles were at the furnace exit, and dust was cascading from the upper slope of the tubes forming the exit nose. The furnace bottom remained bright and clear, many burning coal particles were visible, the south wall was heavily layered with sinter, and the north wall was fairly clean. Conditions were similar at 1535 hr, when the boiler was shut down. The refractory and sinter in the furnace bottom cooled below the visible temperature range in approximately five minutes.

Deposition Probes During Test Period

Only the air-cooled probes in the furnace and the furnace bottom were visible during the test period. Both the refractory probes were too short to be in the field of view.

At 0845 hr, the air-cooled probe in the furnace bottom had a beard of sinter 3 to 10 mm long on the top surface. Deposits falling from the burner throat knocked this off soon after. Isolated lumps of sinter, approximately 10 mm in diameter, then developed on the top surface, and were in turn knocked off by falling deposits which also bent the probe downward. A few small lumps remained on the probe. At 1300 hr, fresh deposits had formed an irregular beard of sinter on the top surface of the probe, but when the furnace throat was cleaned at 1305 hr, the probe was bent further, and most of it was buried in ash. Some sinter remained on the top surface of the exposed portion. After the furnace bottom was cleaned at 1340 hr, the probe was clean. Only a few small sinters had developed on the top surface at the time the test was ended.

The air-cooled probe in the furnace remained free of large deposits throughout the test.

Furnace After Test

When the dump plates were swung open, approximately 30 litres of ash fell to the floor. It consisted of sinters ranging up to 12 cm in diameter. All were very weak, and ranged in colour from tan to grey. This left the furnace bottom clean except for some dust and sinters on the ledges adjacent to the dump plates. The throat refractory under each burner bore a deposit of sinter, approximately 15 cm in diameter and 2 to 5 cm thick. There were also small deposits of sinter in the corners, and the walls were rough with small, thin patches of sinter.

Most of the furnace water walls were covered with a thin layer of grey dust, but one area on the east wall, approximately 30 cm in diameter, had a layer of dust thick enough to fill the grooves between the tangent tubes. There were also heavy deposits of grey and sandy dust on the upper slopes of the furnace throat, and on the upper slope of the nose at the furnace exit.

On the bottom of the transition section there were 4 to 5 cm of tan and grey coloured dust covered by a thin layer of dark grey dust. The furnace screen tubes bore 2 to 3 mm of dark grey dust on the downstream surfaces. 2 mm of grey dust were on the walls of the test air-heater. The tubes of the test air-heater were clean on the upstream surfaces, and had a 1 mm layer of tan-coloured dust on the downstream surfaces. 1 to 5 cm of grey coloured dust were on the second pass tube sheet of the main air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed, bore only thin layers of deposit.

The refractory probe in the furnace bottom, before it was removed, was broken at the furnace-bottom wall. Part of the broken portion hung from the thermocouple and bore small deposits of sinter.

Both the air-cooled probe and the refractory probe in the furnace, before they were removed, appeared to have only thin layers of deposit.

The air-cooled probe in the transition section, after it was removed, was smooth, clean and black on the upstream surface. The downstream surface, over 120° of the probe's circumference, bore a 1 to 2 mm layer of tan-coloured dust which was covered by a thin layer of grey dust. The deposit adhered only weakly to the probe, and some of it had fallen.

The refractory probe in the transition section, after it was removed, was clean on the upstream surface and very clean on most of the downstream surface because much deposit had fallen. Evidence of the deposit was visible on both sides of the probe, at 90° to the direction of gas flow, and part of the deposit was in place near the tip of the probe. From this it was determined that the deposit was a tan-coloured dust, and had been approximately 3 mm thick.

Test No. 6.3

Progress Report 6.3A

TABLE 1

OPERATING DATA

COAL : HAT CREEK "C" RAW, DRIED ONCE EXCESS O_2 5 %

16 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		6	hours	
Firing Rate		119(3)	kg/hr	
Moisture Content of Coal	1	19.6	%	feed to pulverizer
" " " "	2	1.3(0.2)	%	feed to furnace
Combustible " " "	2	68.9(1.8)	%	dry weight
Ash Dumping Frequency		once every —	hour	57.5 Kg ash dumped, equivalent to 1107 Kg coal.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	274(3)	mmH_2O	
b) Outlet Air Pressure	2	235(3)	mmH_2O	
c) Inlet Air Temperature	3	195(3)	^oC	
d) Outlet Air Temperature	2	76(2)	^oC	
e) Coal Fineness	2	72(3) below 200 mesh		oversize, 12.7% >140 mesh " , 28.0% >200 mesh " , 63.0% >325 mesh
BOILER OPERATING CONDITIONS				
a) Steam Flow	6	578(10)	kg/hr	
b) Steam Pressure	6	2.93(0.02)	atmospheres	
c) Combustion Air Temp.	4	189(7)	^oC	
d) Furnace Pressures				
Furnace	10	46(3)	mmH_2O	
Inlet	11	45(3)	mmH_2O	
Boiler Exit	12	23(2)	mmH_2O	
Primary (Coal) Air L	5	154(3)	mmH_2O	
" R	5	166(4)	mmH_2O	
Secondary (Windbox) Air L	4	61(3)	mmH_2O	
" R	4	61(3)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	15.4(0.2)	%	
b) O_2	11	4.9(0.2)	%	
c) CO	11	94(7)	ppm	
d) NO	13	690(56)	ppm	
e) SO_2	14	707(39)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	36	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	597(18)	^oC	
b) Boiler Exit	12	289(4)	^oC	
c) Precipitator Entry	16	158(2)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	1074 , 1250	^oC	readings taken in
b)	8	955 , 1192	^oC	second and third
c)	9	909 , 702	^oC	two hour period
FLY ASH				
a) Loading	16	9050(1180)	$mgms/m^3$	measured at 20^oC
b) Resistivity	15	$8.1(0.5)\times10^{9}$ Ω cm at 262^oC		
"	17	$4.1(0.4)\times10^{10}$ Ω cm at 158^oC;		7.5×10^{10} Ω cm at 118^oC
c) Precipitator efficiency	18	93(1)	%	
d) Combustible content of ash collected from precipitator	18	4.5(1.4)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C						Description of Deposit
		mean	RMS Dev.	min.	max.	initial	final	
Furnace Bottom 19	ceramic	1114	(38)	982	1137	1036	982	Probe shattered, no sample.
	stainless	469	(67)	325	583	583	325	Grey coloured scale, uneven, covered by light grey powder, ½ mm thick, downstream.
Furnace 9	ceramic	655	(70)	513	693	693	513	Grey coloured scale, upstream. Dark grey coloured powder, 2 mm thick, on one side, easily brushed off.
	stainless	502	(79)	307	588	516	588	Black coloured sinter, upstream. Grey coloured powder, uneven, 2 mm thick, downstream.
Transition Section 20	ceramic	563	(18)	522	592	559	592	Grey powder, uneven, 2 mm thick on sides, trace downstream as if most of deposit (> 3 mm) were lost.
	stainless	424	(14)	396	457	419	457	Grey powder, uneven, 3 mm thick, downstream, some lost.

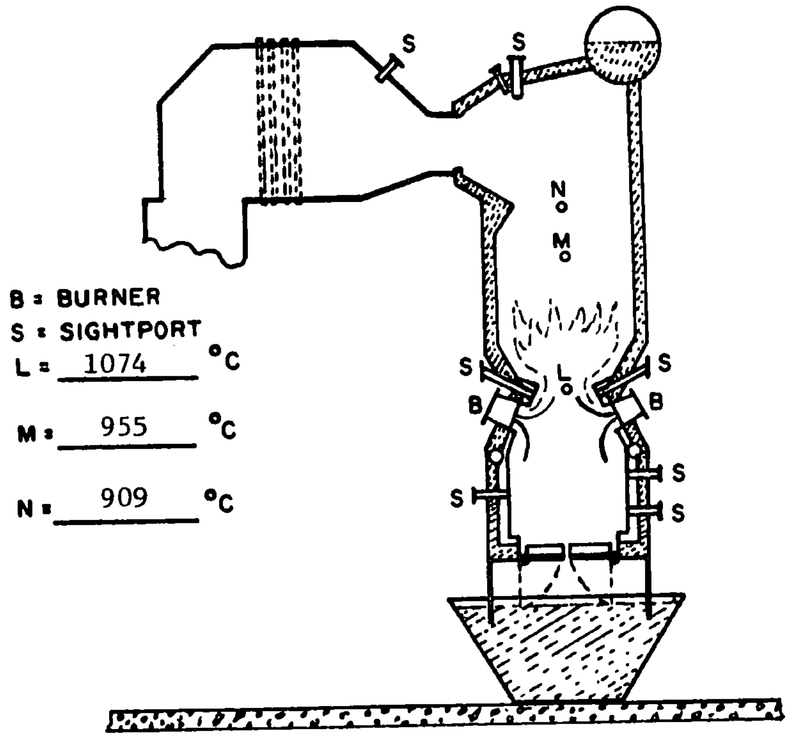


Figure 2. Illustration of flame pattern (——) and of burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 6.3B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion Tests which mak up the program. This progress report (6.3B) presents coal analyses and size distribution of the pulverized coal burned in test 6.3 done on November 16, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 6.3

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			2.3	
100M x 140M	12.8	3.2	12.2	82.2
140M x 200M	15.3	0.5	10.9	75.0
200M x 325M	35.0	20.2	17.1	72.2
325M x 0	37.0	19.8	57.5	65.5

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: C Raw, Test 6.3, B. C. Hydro (A1577)

Analysis	
Screen Analysis	
+ ¼	0.00 %
¼ * 1/8	1.55 %
1/8 * 1/16	15.91 %
1/16 * 1/32	24.77 %
1/32 * 28M	11.49 %
28M * 48M	22.00 %
48M * 0	24.28 %
Grindability	
Hardgrove Index	43
Classification of Coal	
Rank (ASTM)	
Eq. Moisture %	
(97% Humidity)	

Sample C Raw. Test 6.3, B.C. Hydro (A1577)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	13.89	0.00
Ash	26.06	30.26
Volatile Matter	29.86	34.68
Fixed Carbon (by Diff.)	30.19	35.06
Ultimate Analysis %		
Carbon	41.87	48.62
Hydrogen	2.99	3.47
Sulphur	0.53	0.62
Nitrogen	0.93	1.08
Ash	26.06	30.26
Oxygen (by Diff.)	13.73	15.95
Calorific Value		
Calories/gram	3919	4551
Btu/lb gross	7054	8192
Megajoules/kilogram	16.41	19.05
Sulphur Forms %		
Sulphatic		
Pyritic		
Organic (by Diff.)		
TOTAL		
Chlorine	0.00%	

Progress Report 6.3 B

Sample: C Raw, Test 6.3, B.C. Hydro (A1577)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1460	1332
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	51.22 %
Al_2O_3	29.00 %
Fe_2O_3	6.84 %
Mn_3O_4	0.09 %
TiO_2	1.03 %
P_2O_5	0.14 %
CaO	2.33 %
MgO	1.39 %
SO_3	2.87 %
Na_2O	0.48 %
K_2O	0.59 %
Cl	0.00 %
Specific gravity	2.75

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 6.3C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (6.3C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 6.3 done on November 16, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

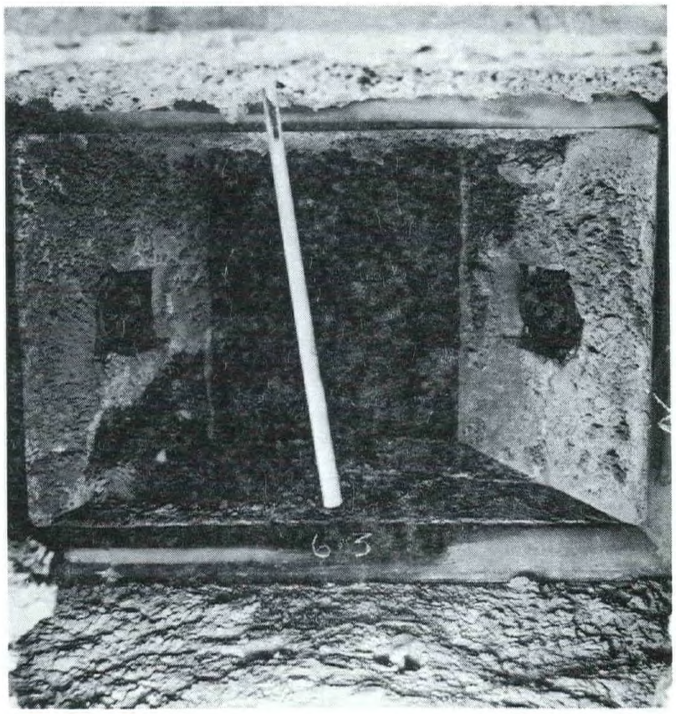


FIGURE 1a Furnace bottom at end of test. Burners and furnace throat are clear of sinter. Air cooled deposition probe in foreground projects from east wall. Remains of refractory deposition probe may be seen across from it on west wall.

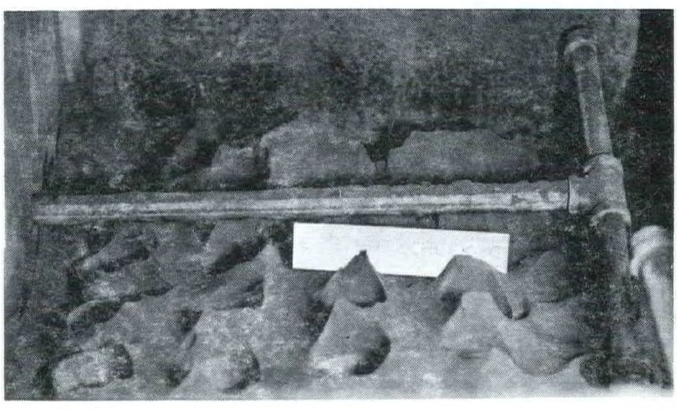


FIGURE 1b Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 6:3C

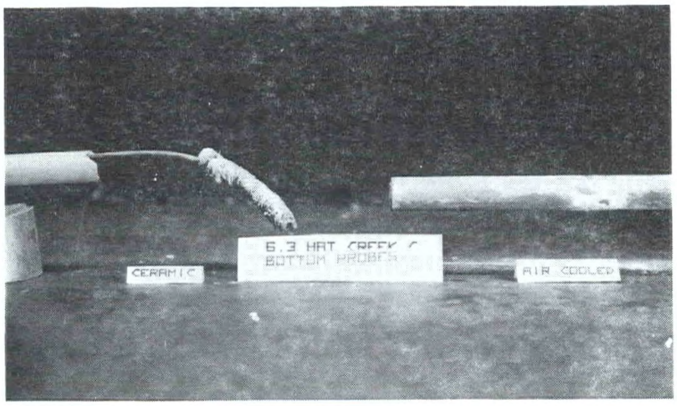


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

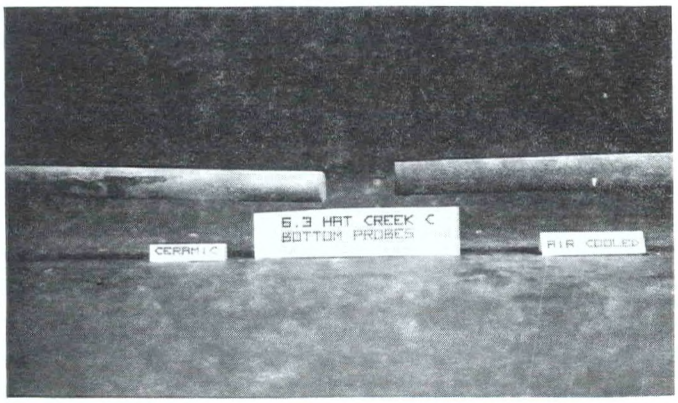


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.
Burner probes are incorrectly labelled as Bottom probes.

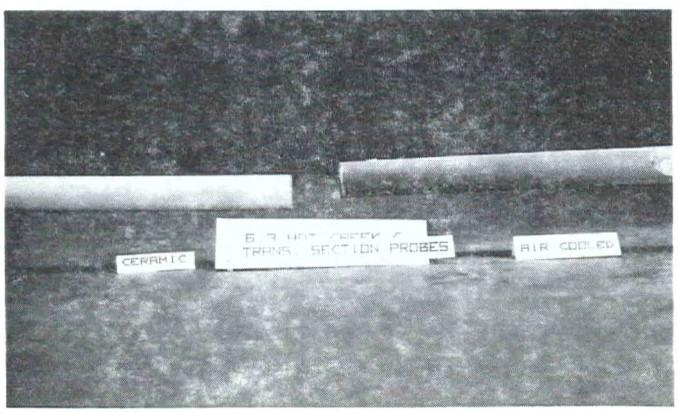


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

PROGRESS REPORT 6:3C

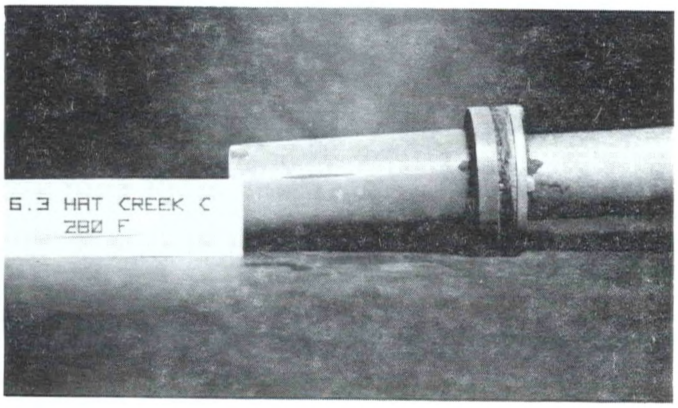


Figure 1f

Low Temperature corrosion probe 138°C.

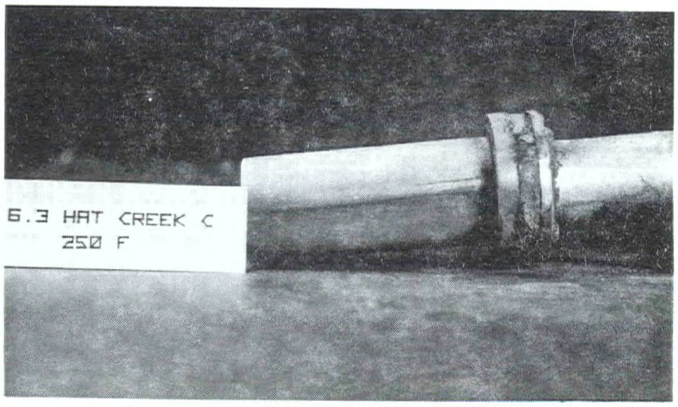


Figure 1g

Low Temperature corrosion probe 121°C.

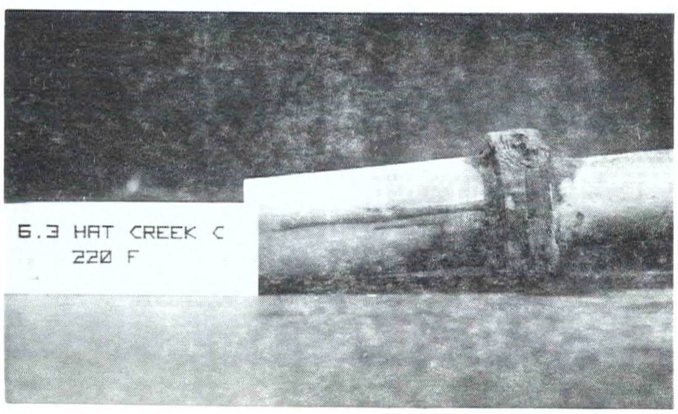


Figure 1h

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	469 °C	502 °C	424 °C
Deposition rate[a/]						
Fe	40.8	31.9	10.4	27.5	6.4	11.3
Mg	1.5	0.6	0.5	2.0	8.6	3.9
Na	0.7	0.4	0.4	1.6	3.5	1.6
Ca	7.8	4.3	2.5	17.6	107.4	11.1
SO_4 (total)	61.3	47.4	33.7	84.9	139.4	19.7
SO_4 (free), by difference			7.2			

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposit from the furnace bottom, Test 6.3 (A 1616 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1360	1288
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	54.16
Al_2O_3	30.80
Fe_2O_3	6.93
Mn_3O_4	----
TiO_2	1.03
P_2O_5	0.17
CaO	2.44
MgO	1.09
SO_3	0.15
Na_2O	0.51
K_2O	0.58
Cl	----

Progress Report 6.3 C

Sample: Deposit from the furnace walls, Test 6.3 (A 1617 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1371	1249
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	54.25
Al_2O_3	31.22
Fe_2O_3	7.58
Mn_3O_4	----
TiO_2	1.06
P_2O_5	0.25
CaO	2.44
MgO	1.16
SO_3	0.62
Na_2O	0.48
K_2O	0.57
Cl	----

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 6.3 (A 1620 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1366	1271
Spherical	°C	1482+	1471
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	53.29
Al_2O_3	30.46
Fe_2O_3	9.17
Mn_3O_4	----
TiO_2	1.11
P_2O_5	0.26
CaO	3.04
MgO	1.48
SO_3	0.39
Na_2O	0.47
K_2O	0.59
Cl	----

Progress Report 6.3 C

Sample: Deposit from electrostatic precipitator, Test 6.3 (A1585-86-87)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1304
Spherical	°C	1482+	1438
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	51.41
Al_2O_3	29.81
Fe_2O_3	6.20
Mn_3O_4	----
TiO_2	1.36
P_2O_5	0.28
CaO	3.60
MgO	1.65
SO_3	0.72
Na_2O	0.70
K_2O	0.58
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Raw Coal
Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 6.3D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (6.3D) is the last of the series and presents results of the following detailed analyses of ash produced in test 6.3 done on November 16, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations
3. X-ray diffraction analyses of fireside deposits

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.4
1.59 - 2.00	Coulter Counter		0.6
2.00 - 2.52	Coulter Counter		1.1
2.52 - 3.17	Coulter Counter		1.6
3.17 - 4.00	Coulter Counter	0.2	2.7
4.00 - 5.04	Coulter Counter	0.3	3.7
5.04 - 6.35	Coulter Counter	0.7	5.4
6.35 - 8.00	Coulter Counter	1.2	7.2
8.00 - 10.08	Coulter Counter	2.9	10.3
10.08 - 12.7	Coulter Counter	5.6	12.4
12.7 - 16.0	Coulter Counter	10.8	13.5
16.0 - 20.2	Coulter Counter	16.1	11.5
20.2 - 25.4	Coulter Counter	19.1	8.3
25.4 - 32.0	Coulter Counter	16.0	6.7
32.0 - 40.3	Coulter Counter	8.9	3.3
40.3 - 44.0	Coulter Counter	3.1	1.3
44.0 - 74.0	Sieve	10.3	5.0
+ 74.0	Sieve	4.8	5.0

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL – WRL

OPERATOR:

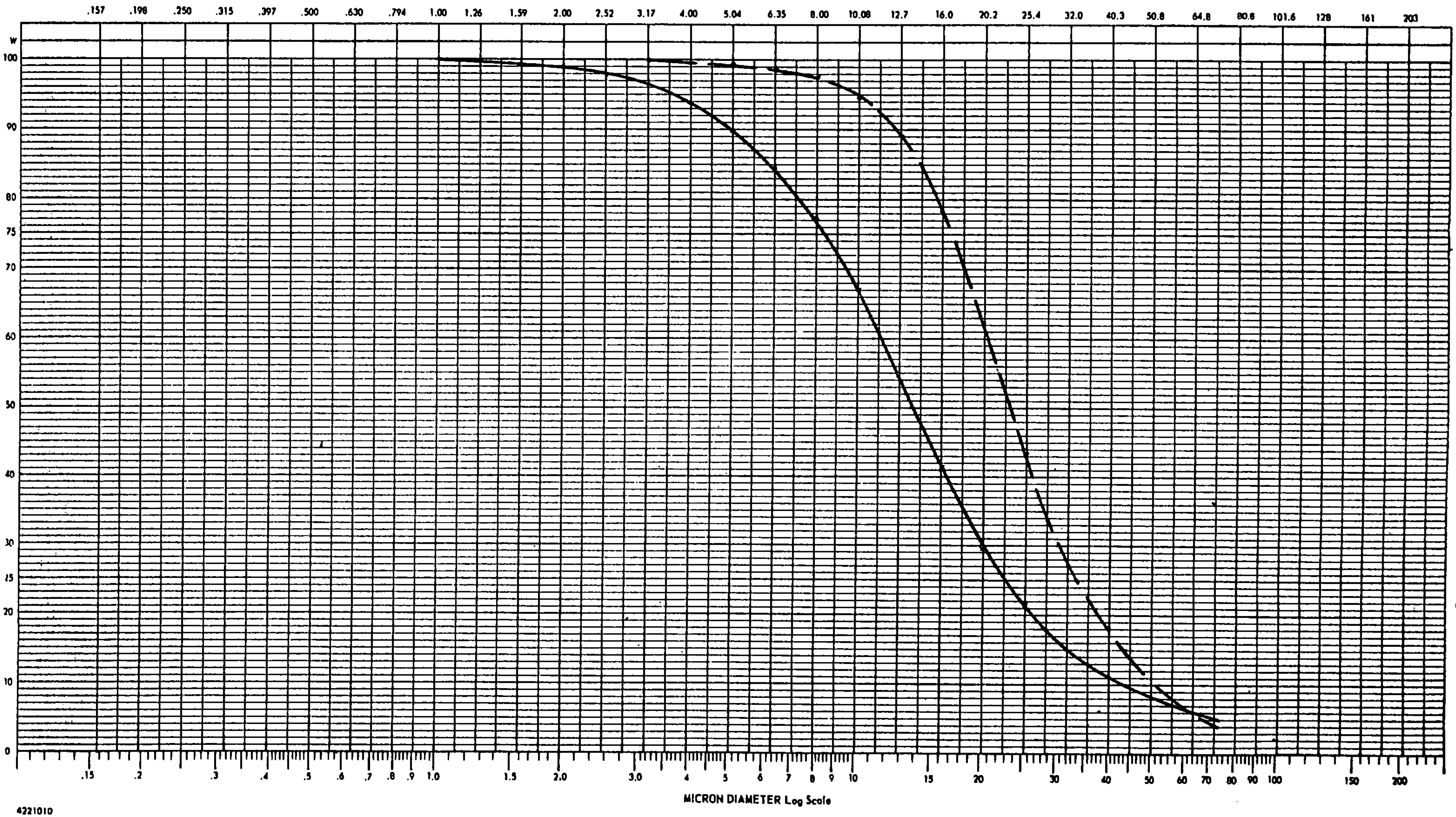
EQUIPMENT:

$k = d\sqrt[3]{2^w}$ $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 6.3	ISOTON	ULTRASONIC	100μ	6102033									
ESP ———													
AH2 – – –													



4221010

- 459 -

Progress Report 6.3D

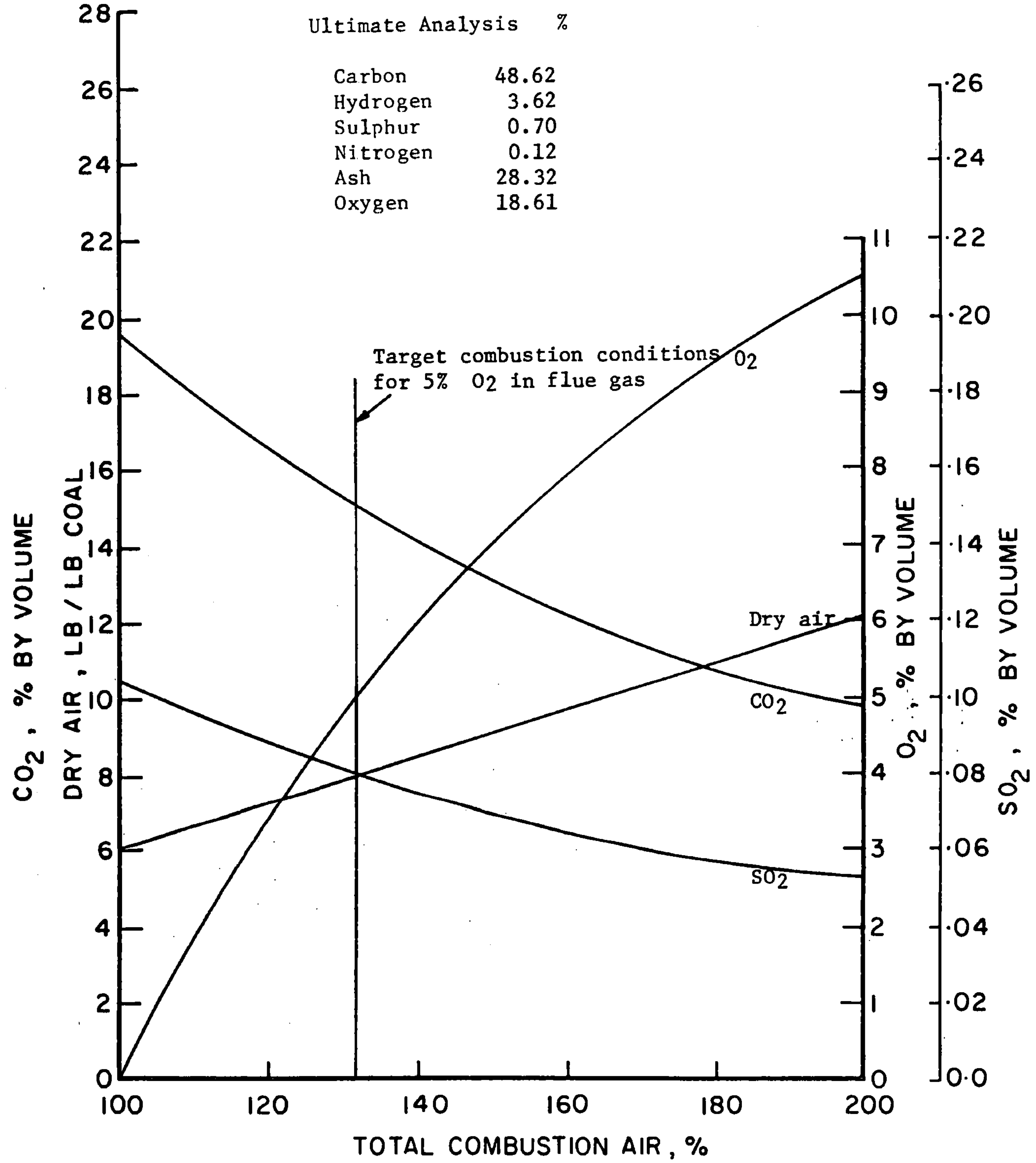


FIGURE 1: Combustion Calculations "C-Raw" Coal.

X-ray Diffraction Analyses of Fireside Deposits from Test 6.3, "C-raw" coal from Hat Creek.

Furnace Bottom Ash (1616 76-487)	Mull, Crist, Qtz, Feld, Hem, Amorph
Under Flame Probe Deposit (1589 76-488)	Hem, Qtz, Crist (tr), Feld (tr), Mull (tr), Amorph
Transition Probe Deposit (1593 76-489)	Hem, Mull, Feld, Qtz

Abbreviations of Constituents:

Feld	Feldspar (Anorthite) $CaO.Al_2O_3.2SiO_2$
Qtz	Quartz SiO_2
Crist	Cristobalite SiO_2
Mull	Mullite $(3Al_2O_3.2SiO_2)$ or Sillimanite $(Al_2O_3.SiO_2)$
Hem	Hematite Fe_2O_3
Amorph	Significant amorphous material present.

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification. Mullite and sillimanite give very similar diffraction patterns. It is very doubtful that they can (or should) be distinguished in mixtures such as these.

Constituents are listed in decreasing order of abundance.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "C" WASHED COAL

AIR-DRIED AND KILN-DRIED ONCE, 5% EXCESS OXYGEN

TEST NO. 7.1

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/160-163

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 7.1A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 7.1, which was done on November 18, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 7.1

In this test Hat Creek "C" washed coal was burned. The coal had been air-dried and kiln-dried once, which reduced the as-fired moisture to 12.8%. The target level of excess oxygen in the flue gas was 5%, and the target coal feed rate was 110 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data, shown in Tables 1 and 2, are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test Period

At 0845 hr, stable, unsupported coal combstion had been in progress for more than one hour. When it was observed from the top of the furnace, the flame was orange-yellow coloured, and uniform. Active combustion appeared to end a short distance above the throat. Sinter had formed all around the furnace throat, and blocked ¼ of the projected throat area. The heaviest deposits were located in the southwest corner. The air-cooled deposition probe in the furnace was clearly visible, but the refractory deposition probe was not, because it was too short to be in the field of view. There were no particles of burning coal evident at the furnace exit. The transition section was fairly bright with light reflected from the furnace. Gas sampling probes in the test air-heater were clearly visible, and the test air-heater tubes were faintly visible. The furnace bottom was very bright and clear; no particles of burning coal were visible. The furnace bottom walls appeared to be uniformly covered with sinter whiskers 2 to 3 cm long. There were a few centimetres of ash on the ledges adjacent to the dump plates. The air-cooled deposition probe in the furnace bottom was clearly visible.

At 0915 hr, ½ the projected area of the furnace throat was blocked with sinter which had formed in the southwest and northeast corners, but combustion conditions in the furnace bottom appeared to be unaffected.

At 0925 hr, the laboratory experienced a power failure which forced a "shutdown" of the research boiler. Power was restored at 0932 hr and the boiler was immediately relit on oil. While combustion conditions were being stabilized the deposits at the furnace throat were knocked loose with a poker which was thrust through the top of the furnace, and ash was dumped. Stable, unsupported coal combustion was quickly achieved and measurements were resumed at 1020 hr. Combustion conditions were comparable to those observed at 0845 hr.

At 1050 hr, sinter deposits were evident on all sides of the furnace throat, but they were the heaviest in the southwest corner. Approximately 1/10 of the projected throat area was blocked. When it was observed from the top of the furnace, the flame appeared to diverge from each burner, and ranged in colour from yellow at the centre to orange-yellow at the edges, rather than the previously-observed pattern of a uniform colour across the entire cross-section of the furnace. Conditions at the test air-heater were unchanged. The furnace bottom was bright, transparent, and a small quantity of burning coal particles were evident. The furnace bottom walls bore a moderately heavy layer of sinter whiskers.

At 1122 hr, the projected area of the furnace throat was 1/3 blocked with sinter which had formed mainly in the southwest and northeast corners. Test measurements in progress precluded removal of the deposits at that time, and by 1135 hr, the furnace throat was 3/4 blocked.

At 1140 hr, a poker was thrust through the top of the furnace to remove the deposits at the furnace throat. This was accomplished with a little difficulty; the deposits appeared to be plastic rather than dry and brittle, and therefore did not break away from the walls readily. After cleaning, a small deposit was evident in the northwest corner below the furnace throat. Ash was then dumped and approximately 45 litres of ash were raked from the quench tank. This material consisted mostly of sinters 2 to 8 cm in diameter. There were several pieces 12 to 20 cm in diameter, and one piece 25 cm in diameter. Some of the sinters were moderately strong. The flame was then bright and mostly yellow in colour. The furnace bottom was also bright and transparent, but many small particles of burning coal were evident. Some ash remained on the south ledge adjacent to the dump plates.

At 1200 hr, the furnace throat was ragged with sinter, and by 1240 hr, 1/10 of the projected area of the furnace throat was blocked. Otherwise, combustion conditions were unchanged. At 1320 hr, the furnace throat was more than ½ blocked with sinter, mostly from the east and west sides. The furnace bottom had become slightly opaque with flame.

At 1325 hr, a poker was thrust through the top of the furnace to remove the deposits from the furnace throat. They were cleared away without difficulty, and subsequently the furnace bottom was transparent. Ash was not dumped at this time because a measurement of electrostatic precipitator efficiency was in progress.

At 1405 hr, the furnace throat was still fairly clean, the flame was bright yellow in colour, and clearly shaped. The test air-heater was bright and the tubes were clearly visible. Conditions in the furnace bottom were unchanged. At 1440 hr, deposits below the furnace throat were again evident and they blocked 1/5 of the projected throat area. At this time some of the ash in the furnace bottom was clearly observed to be plastic.

At 1520 hr, the furnace throat was ¾ blocked with sinter, which had again formed in the southwest and northeast corners. No burning particles of coal were evident at the furnace exit, and only a small quantity was visible in the furnace bottom. The furnace bottom was approximately 1/3 filled with ash. At 1528 hr, the furnace throat was cleaned for the fourth time by thrusting a poker through the top of the furnace and it was observed that the deposits were tacky. The furnace bottom was then more than half full of ash which buried the air-cooled deposition probe located there, but ash was not dumped because a fly ash resistivity measurement was in progress.

From 1540 hr, to the end of the test, deposits on the throat refractory interfered with and deflected the flame but no massive blockage of furnace throat occurred. At 1607 hr, an oil support burner was inserted, and the boiler was "shut-down" shortly thereafter. A small flame from oil-soaked sinter persisted for a few minutes, and the ash and refractory in the furnace bottom maintained a visible glow for approximately fifteen minutes.

<u>Deposition Probes During Test Period</u>

Only the air-cooled deposition probes in the furnace and in the furnace bottom were visible during the test.

The air-cooled probe in the furnace bottom, when it was first observed at 0845 hr, had a beard of sinter 8 mm long on most of the top surface. There were also shorter whiskers randomly located around the probe, and a few larger pieces of sinter, 8 mm to 25 mm in diameter, adhering to the top and sides. At 1020 hr, the probe was clean except for a deposit of sinter 3 cm in diameter, shaped like a wasp's nest, with a hole in the centre of it. Closer examination showed that the deposit was centred around a small hole in the probe where the thermocouple had been silver-soldered in place. The silver solder had melted, leaving a small air leak. The probe subsequently developed a few small deposits of sinter, randomly located, and at 1135 hr, had also developed a beard of sinter, 2 to 8 mm long on the bottom surface. After the furnace throat was cleaned at 1140 hr, the probe was clean. At 1240 hr, a few 1 cm lumps of sinter were observed on the top surface of the probe, and a small wasp's nest had been re-established around the leak in the probe. By 1320 hr, the probe bore whiskers, 5 mm long, all around the circumference, but most of these sinters were knocked off when the throat deposits were removed a few minutes later. At 1405 hr, the probe had an intermittent beard of sinter 8 mm long on the top surface, and some shorter whiskers on the bottom surface. These grew gradually until the throat deposits were removed at 1530 hr. Then the probe was buried in ash and could no longer be observed.

The air-cooled probe in the furnace appeared to be clean throughout the test.

<u>Furnace After Test</u>

When the dump plates were swung open approximately 15 litres of small sinters, tan to dark brown coloured, fell to the floor. These were all friable. However, the furnace bottom was completely bridged with sinter which, when it was dislodged, comprised an additional volume of roughly 80 litres, mostly in the form of large sinters, up to 30 cm in diameter. Some of them were strong enough to bear a man's weight. They also ranged in colour from tan to dark brown. The walls of the furnace bottom were fairly uniformly covered with sinter whiskers, 5 cm long and light tan coloured. The furnace throat refractory was also covered with sinter whiskers, 5 to 7 cm long. These appeared to be tan-coloured underneath, with a grey or black surface layer that probably was caused by the oil support burner used during shut-down. Some of the sinters showed evidence of partial slagging. The refractory on the west wall of the throat at the burner level bore a deposit, 20 cm in diameter and 8 cm thick and which had a slagged surface. The furnace water walls were moderately coated with grey and black dust. There were heavy layers of grey and tan-coloured dust on the upper slopes of the furnace throat and on the nose at the furnace exit.

The bottom of the transition section had a layer of fine dust, pale tan coloured, 2 to 4 cm thick. The downstream surfaces of the furnace screen tubes bore a layer of tan-coloured dust, 2 to 3 mm thick, with a thin layer of black dust on top. The walls of the test air-heater bore a 2 mm layer of dust, the tubes were clean on the upstream surfaces, and they had a thin layer of red-tan coloured dust on the downstream surfaces. The second pass tube sheet of the main air-heater had a deposit of grey dust 1 to 5 cm thick.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, appeared to have a thin layer of sintered dust on the bottom surface.

The refractory probe in the furnace bottom, projected only 3 cm beyond the inside wall. The exposed portion bore a deposit of sinter a few millimetres thick on two sides, but there were indications that part of the deposit had been knocked off.

The air-cooled probe in the furnace, appeared to be clean.

The refractory probe in the furnace did not project into the furnace for enough to be visible from either the top or the bottom of the furnace.

The air-cooled probe, after it was removed from the transition section, was clean on the upstream surface, and had a deposit of weakly adhering pale-tan coloured dust, up to 3 mm thick, on the downstream surface. Some of the deposit had fallen off.

The refractory probe, after it was removed from the transition section, was clean on the upstream surface. On the downstream surface it bore a layer of tan-coloured dust, 1 mm thick, over 180^{o} of the probe's circumference.

Test No. 7.1

Progress Report 7.1A

TABLE 1

OPERATING DATA

COAL: HAT CREEK "C" RAW, AIR-DRIED AND KILN-DRIED   EXCESS O_2 5 %

16 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		4	hours	
Firing Rate		108(2)	kg/hr	
Moisture Content of Coal	1	12.8	%	feed to pulverizer
" " " "	2	< 0.1	%	feed to furnace
Combustible " " "	2	79.2(0.6)	%	dry weight
Ash Dumping Frequency		once every ——	hour	57.8 Kg ash dumped, equivalent to 1016 Kg coal.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	264(2)	mmH_2O	
b) Outlet Air Pressure	2	227(3)	mmH_2O	
c) Inlet Air Temperature	3	202(2)	^oC	
d) Outlet Air Temperature	2	97(1)	^oC	
e) Coal Fineness	2	70.4% below 200 mesh		oversize, 12.3% >140 mesh " , 29.6% >200 mesh " , 49.2% >325 mesh
BOILER OPERATING CONDITIONS				
a) Steam Flow	6	619(7)	kg/hr	
b) Steam Pressure	6	3.06	atmospheres	
c) Combustion Air Temp.	4	193(6)	^oC	
d) Furnace Pressures				
Furnace	10	39(3)	mmH_2O	
Inlet	11	41(2)	mmH_2O	
Boiler Exit	12	21(3)	mmH_2O	
Primary (Coal) Air L	5	147(3)	mmH_2O	
" R	5	159(4)	mmH_2O	
Secondary (Windbox) Air L	4	64(2)	mmH_2O	
" R	4	66(4)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	15.9(0.3)	%	
b) O_2	11	5.0(0.2)	%	
c) CO	11	61(11)	ppm	
d) NO	13	958(18)	ppm	
e) SO_2	14	685(21)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	29	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	650(10)	^oC	
b) Boiler Exit	12	297(9)	^oC	
c) Precipitator Entry	16	157(4)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	1070, 973	^oC	readings taken in second and third two hour period
b)	8	888, 773	^oC	
c)	9	875, 715 *	^oC	
FLY ASH				
a) Loading	16	5060(800)	$mgms/m^3$	measured at 20^oC
b) Resistivity	15	$6.3(0.7)\times10^9$ Ω cm at 269^oC		
"	17	$9.6(4.6)\times10^{10}$ Ω cm at 157^oC;		2.4×10^{10} Ω cm at 118^oC.
c) Precipitator efficiency	18	94.8(1.2)	%	
d) Combustible content of ash collected from precipitator	18	4.1(0.6)	%	

*The suction pyrometer became partially blocked by dust in this reading.

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	990	22	955	1020	982	1000	Black scale upstream covered by beige sinter, 12 mm thick, uneven and 100 mm thick beige sinter on sides and downstream, uneven.
	stainless	Thermocouple partly unsoldered 442	23	414	489	433	453	Grey scale covered by beige powder, ½ mm thick, all around.
Furnace 9	ceramic	489	25	457	540	457	480	Grey scale upstream. Black powder, 1 mm thick, downstream.
	stainless	Thermocouple broken						Black scale upstream covered by dark grey powder, 3 mm thick, all around.
Transition Section 20	ceramic	628	5	617	648	617	626	Clean upstream. Grey-beige powder, 3 mm thick, downstream.
	stainless	565	13	552	586	577	586	Clean upstream. Light grey powder, 3 mm thick, downstream.

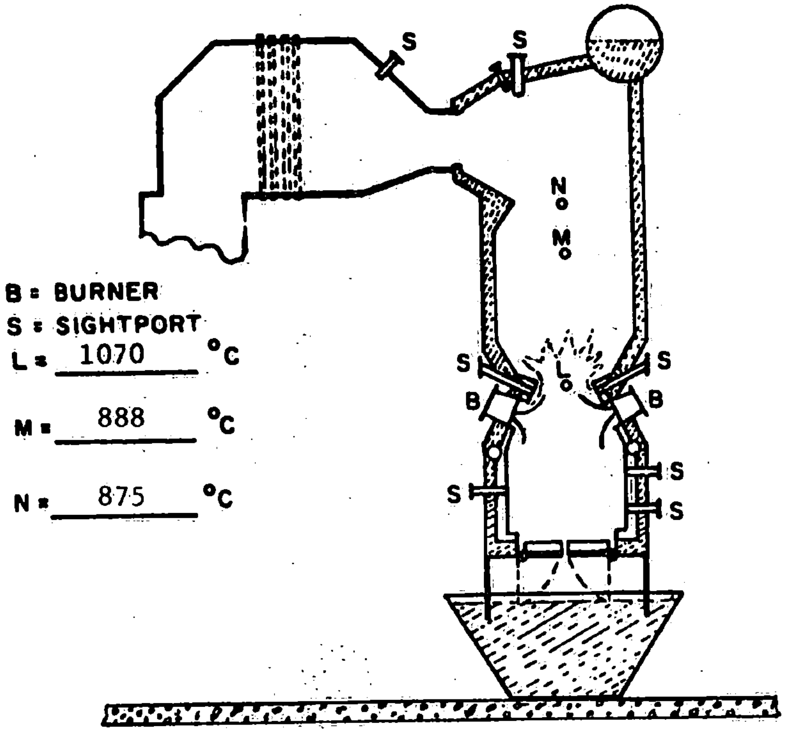


Figure 2. Illustration of the flame pattern (——) and of the burnout pattern(----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 7.1B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (7.1B) presents coal analyses and size distribution of the pulverized coal burned in test 7.1 done on November 18, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 7.1

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M				
60M x 100M			2.5	
100M x 140M	12.3	3.1	13.3	84.0
140M x 200M	17.4	0.3	10.7	81.2
200M x 325M	19.6	0.9	18.6	81.4
325M x 0	50.8	2.3	55.0	76.9

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: C Washed, Test 7.1, B. C. Hydro (A1621)

Analysis	
Screen Analysis	
+ ¼	0.00 %
¼ * 1/8	2.96 %
1/8 * 1/16	32.08 %
1/16 * 1/32	34.77 %
1/32 * 28M	11.17 %
28M * 48M	12.28 %
48M * 0	6.74 %
Grindability	
Hardgrove Index	40
Classification of Coal	
Rank (ASTM)	
Eq. Moisture % (97% Humidity)	

Sample C Washed, Test 7.1, B. C. Hydro (A1621)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	12.25	0.00
Ash	16.75	19.09
Volatile Matter	33.00	37.61
Fixed Carbon (by Diff.)	38.00	43.30
Ultimate Analysis %		
Carbon	50.31	57.33
Hydrogen	3.57	4.07
Sulphur	0.62	0.71
Nitrogen	1.06	1.21
Ash	16.75	19.09
Oxygen (by Diff.)	15.44	17.59
Calorific Value		
Calories/gram	4763	5428
Btu/lb gross	8573	9770
Megajoules/kilogram	19.94	22.73
Sulphur Forms %		
Sulphatic		
Pyritic		
Organic (by Diff.)		
TOTAL		
Chlorine	0.00 %	

Progress Report 7.1 B

Sample: C Washed, Test 7.1, B. C. Hydro (A1621)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1438	1282
Spherical	°C	1482+	1460
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	50.61 %
Al_2O_3	29.57 %
Fe_2O_3	5.28 %
Mn_3O_4	0.07 %
TiO_2	1.26 %
P_2O_5	0.27 %
CaO	3.48 %
MgO	1.50 %
SO_3	3.66 %
Na_2O	0.60 %
K_2O	0.58 %
Cl	0.00 %
Specific Gravity	2.92

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 7.1C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (7.1C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 7.1 done on November 18, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PROGRESS REPORT 7:1C

Figure 1a

Furnace bottom at end of test. Friable sinter completely bridges bottom of furnace directly above dump plates.

Figure 1b

Furnace bottom at end of test. Sinter bridge has been removed. Burner on north side is surrounded by heavy sinter whiskers.

PROGRESS REPORT 7:1C

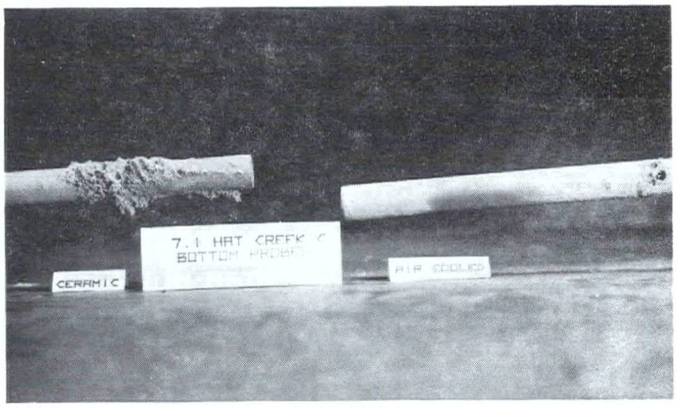


Figure 1c

Furnace bottom deposition probes. Air cooled probe on right. Refractory probe on left.

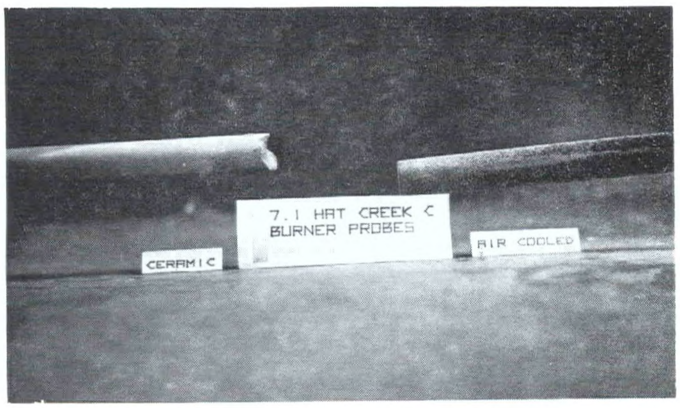


Figure 1d

Burner deposition probes. Air cooled probe on right. Refractory probe on left.

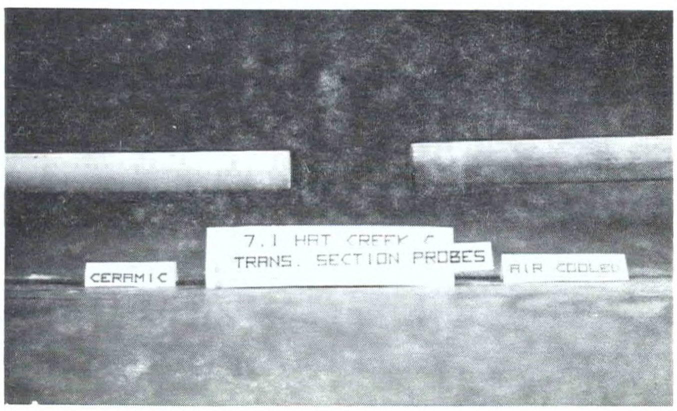


Figure 1e

Transition section deposition probes. Air cooled probe on right. Refractory probe on left.

Figure 1f Main air heater tube sheet second pass up to 2 - 3 inches of powder.

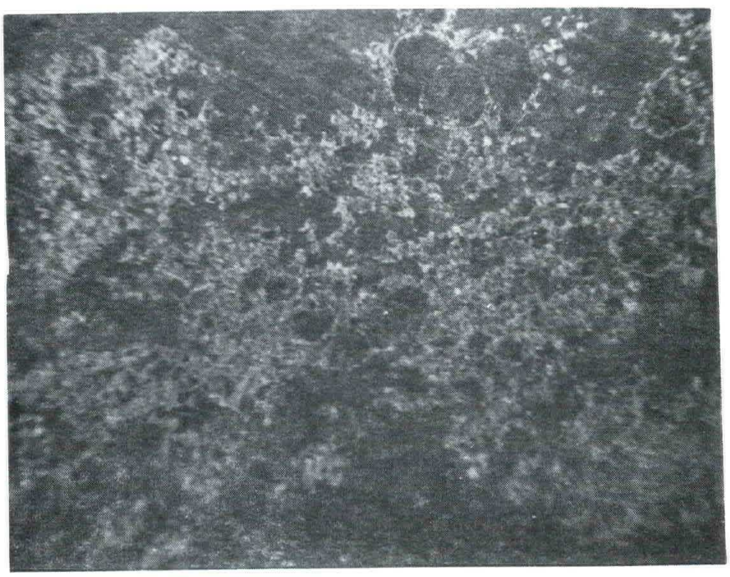


Figure 1g Photomicrograph, x 10, of a thin section of sinter which was found attached to the refractory near the burners. The sinter is weak and porous.

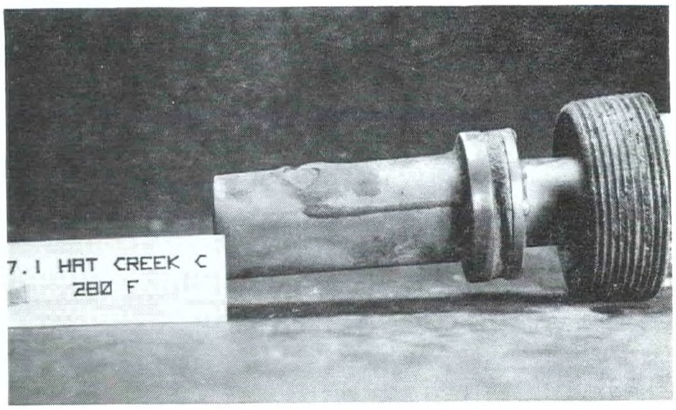


Figure 1h

Low Temperature corrosion probe 138°C.

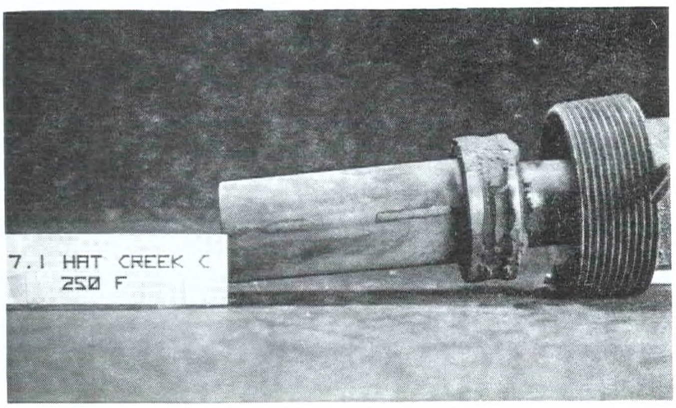


Figure 1i

Low Temperature corrosion probe 121°C.

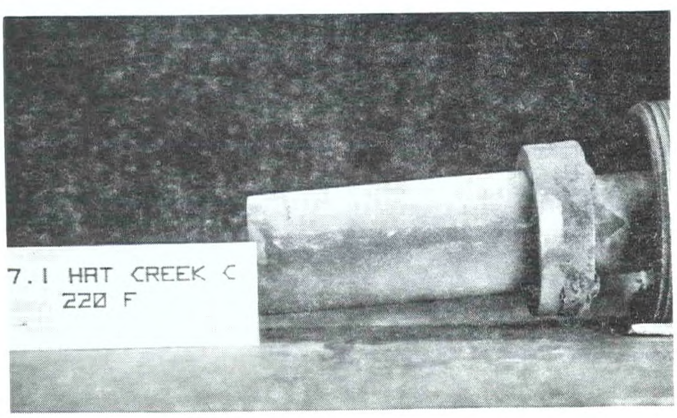


Figure 1j

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	442 °C	°C	565 °C
Deposition rate[a/]						
Fe	51.8	40.2	31.9	26.9	16.2	8.4
Mg	0.6	0.2	0.5	1.8	8.3	3.2
Na	1.8	0.9	0.7	1.9	8.9	1.6
Ca	5.9	3.5	2.9	16.2	110.5	12.7
SO_4 (total)	45.6	52.2	52.2	249.3	209.3	167.5
SO_4 (free), by difference				153.3		106.6

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Progress Report 7.1 C

Sample: Deposit from the furnace bottom, Test 7.1 (A 1656 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1399	1288
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	55.56
Al_2O_3	32.44
Fe_2O_3	6.07
Mn_3O_4	----
TiO_2	1.16
P_2O_5	0.30
CaO	3.33
MgO	1.58
SO_3	0.12
Na_2O	0.54
K_2O	0.68
Cl	----

Progress Report 7.1 C

Sample: Deposit from the furnace walls, Test 7.1 (A 1657 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1349	1304
Spherical	°C	1482+	1449
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	53.31
Al_2O_3	30.69
Fe_2O_3	7.56
Mn_3O_4	----
TiO_2	1.22
P_2O_5	0.29
CaO	3.49
MgO	1.37
SO_3	0.71
Na_2O	0.56
K_2O	0.59
Cl	----

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 7.1 (A 1660 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1310	1243
Spherical	°C	1482+	1460
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	51.31
Al_2O_3	29.34
Fe_2O_3	8.86
Mn_3O_4	----
TiO_2	1.11
P_2O_5	0.15
CaO	3.20
MgO	2.50
SO_3	0.37
Na_2O	0.47
K_2O	0.65
Cl	----

Progress Report 7.1 C

Sample: Deposit from electrostatic precipitator, Test 7.1 (A 1629-30-31)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1310	1271
Spherical	°C	1438	1388
Hemispherical	°C	1482+	1471
Fluid	°C	+	1482+

Ash Analysis	%
SiO_2	50.88
Al_2O_3	30.14
Fe_2O_3	6.23
Mn_3O_4	----
TiO_2	1.73
P_2O_5	0.46
CaO	5.07
MgO	1.99
SO_3	0.69
Na_2O	0.85
K_2O	0.64
Cl	---

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 5% Excess Oxygen

PROGRESS REPORT 7.1D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY 1/

SUMMARY

As explained elsewhere 2/, the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (7.1D) is the last of the series and presents results of the following detailed analyses of ash produced in test 7.1 done on November 18, 1976.

1. Particle size distribution of fly ash
2. X-ray diffraction analyses of fireside deposits
3. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.6
1.59 - 2.00	Coulter Counter		0.9
2.00 - 2.52	Coulter Counter		1.2
2.52 - 3.17	Coulter Counter		1.9
3.17 - 4.00	Coulter Counter		3.1
4.00 - 5.04	Coulter Counter	0.1	4.2
5.04 - 6.35	Coulter Counter	0.3	5.8
6.35 - 8.00	Coulter Counter	0.5	7.0
8.00 - 10.08	Coulter Counter	1.2	10.1
10.08 - 12.7	Coulter Counter	2.3	11.8
12.7 - 16.0	Coulter Counter	4.7	12.6
16.0 - 20.2	Coulter Counter	9.1	11.8
20.2 - 25.4	Coulter Counter	15.2	9.8
25.4 - 32.0	Coulter Counter	18.4	7.0
32.0 - 40.3	Coulter Counter	12.3	2.9
40.3 - 44.0	Coulter Counter	5.6	1.2
44.0 - 74.0	Sieve	22.3	4.0
+ 74.0	Sieve	8.0	4.1

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA — **PARTICLE SIZE ANALYSIS**

.15 - 200μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL-WRL

OPERATOR:

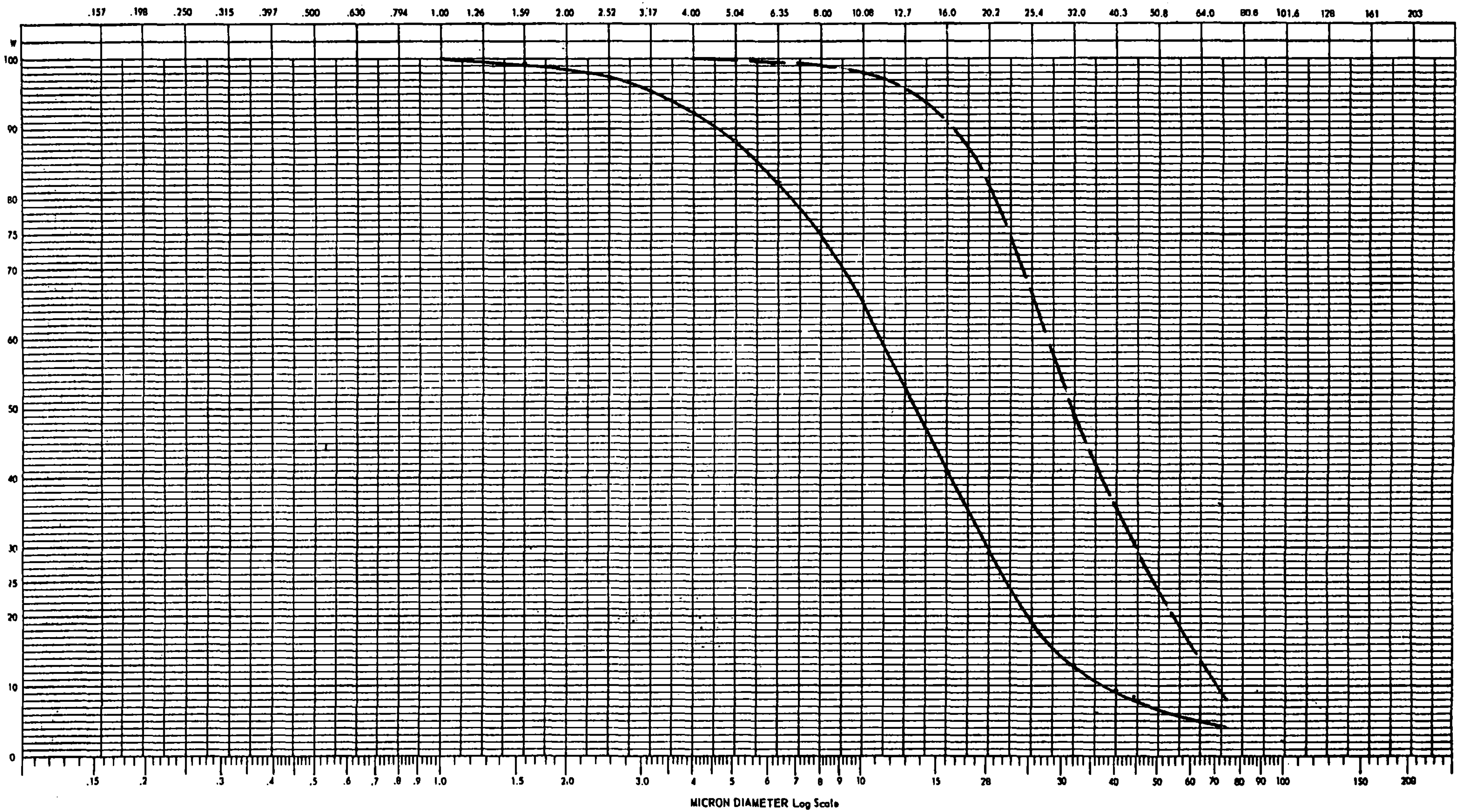
EQUIPMENT:

$k = d\sqrt[3]{2w}$ $\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^3$ when $W_2 = W_1$ FOR MODEL T

$\frac{A_2}{A_1} = \left(\frac{d_1}{d_2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST NO. 7.1	ISOTON	ULTRASONIC	100μ	6102035									
ESP ————													
AH2 - - - -													



4221010

X-ray Diffraction Analyses of Fireside Deposits from Test 7.1, "C-washed" coal from Hat Creek.

Furnace Bottom Ash (1656 76-490)	Mull, Crist, Feld, Hem
Under Flame Probe Deposit (1632 76-491)	Hem, Mull, Feld, Mag, Amorph
Transition Probe Deposit (1636 76-492)	Hem, Mull, Amorph

Abbreviations of Constituents:

Feld	Feldspar (Anorthite) $CaO.Al_2O_3.2SiO_2$
Crist	Cristobalite SiO_2
Mull	Mullite ($3Al_2O_3.2SiO_2$) or Sillimanite ($Al_2O_3.SiO_2$)
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Amorph	Significant amorphous material present.

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous material, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification. Mullite and sillimanite give very similar diffraction patterns. It is very doubtful that they can (or should) be distinguished in mixtures such as these.

Constituents are listed in decreasing order of abundance.

The sampling method is not representative and the order of abundance may be different from that of other larger samples.

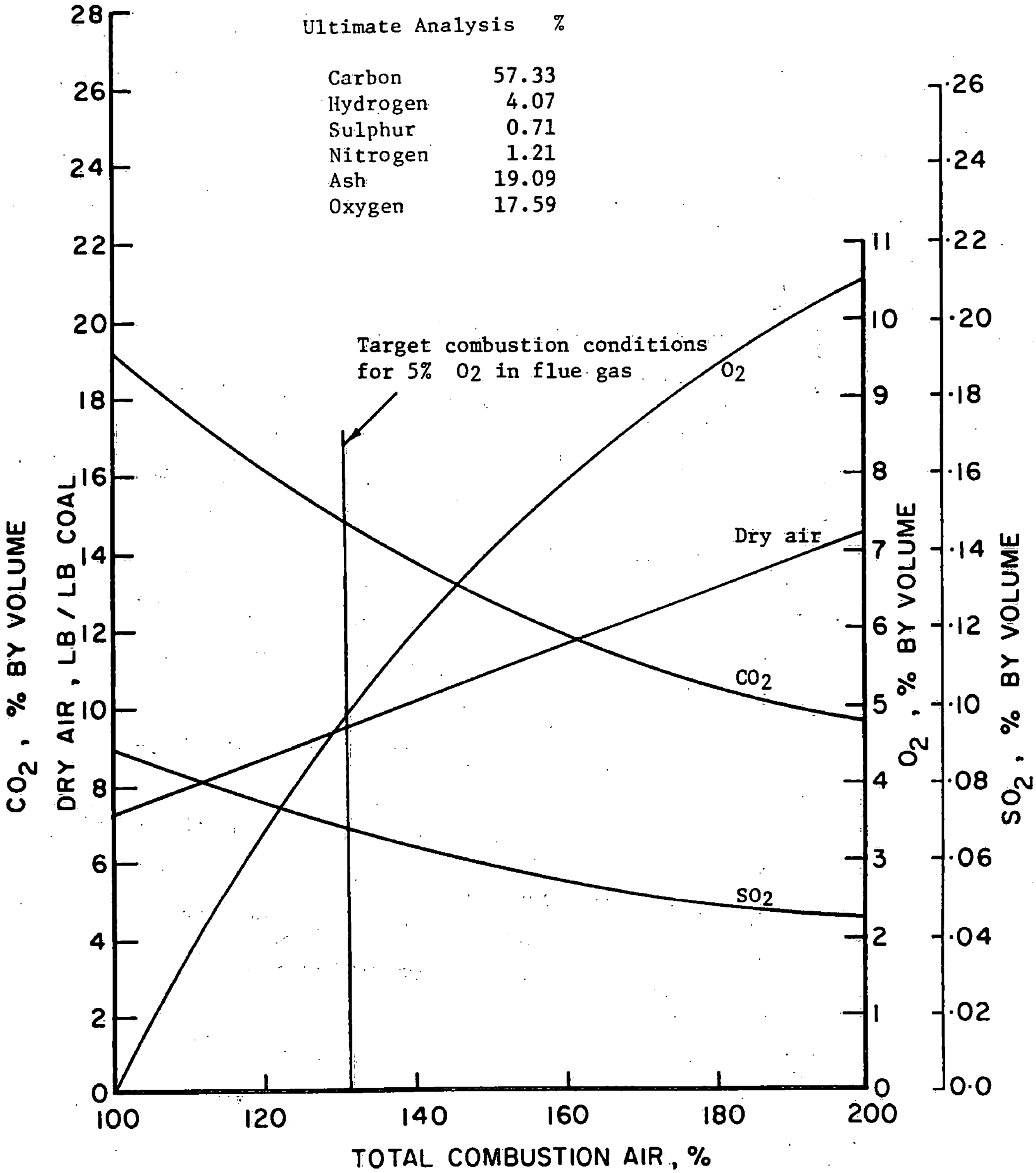


FIGURE 1: Combustion Calculations "C-Washed" Coal.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "C" WASHED COAL

AIR-DRIED AND KILN-DRIED ONCE, 3% EXCESS OXYGEN

TEST NO. 7.2

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/164 -167

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 3% Excess Oxygen

PROGRESS REPORT 7.2A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Laboratory (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 7.2, which was done on November 22, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 7.2

In this test Hat Creek "C" washed coal was burned. The coal had been air-dried and kiln-dried once, which reduced the as-fired moisture to 13.8%. The target level of excess oxgyen in the flue gas was 3%, and the target coal feed rate was 110 kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During the Test Period

At 0845 hr, stable, unsupported coal combustion had been in progress for more than one hour, and ¾ of the furnace's projected throat area was blocked with deposits of sinter. These were immediately removed by means of a poker, which was thrust through the top of the furnace. The deposits came loose easily and left the furnace throat cleanly. The flame was then observed to be bright yellow and diamond-shaped, diverging from each burner and meeting at the centre of the furnace. The edges of the flame were orange-yellow. Active combustion ended a short distance above the furnace throat. From the top of the furnace it was possible to see well down the west wall of the furnace bottom and both deposition probes in the furnace were clearly visible. No burning particles of coal were evident at the furnace exit. The transition section was fairly bright with flickering light reflected from the furnace; the gas sampling probe in the test air-heater was clearly visible, and the test air-heater tubes were faintly visible. The furnace bottom was bright and transparent. Many burning coal particles were evident. The furnace bottom walls were uniformly covered with sinter whiskers, and a large quantity of sinter, which had been knocked loose from the furnace throat, was on the dump plates. The air-cooled deposition probe in the furnace bottom was visible in detail.

During the next hour deposits again built up in the southwest and northwest corners below the furnace throat, blocking 1/5 of the projected throat area. When it was observed from the top of the furnace, the flame had a less distinct shape than before and it was fairly uniformly yellow coloured.

At 0940 hr, ash was dumped and when it was raked from the quench tank, it was found to consist of sinters from 2 to 25 cm in size and to range in colour from medium sand to grey. All of the sinters were friable; the large ones broke into several pieces when they fell from the quench tank to the floor.

At 1030 hr, the projected area of the furnace throat was observed to be 1/3 blocked with sinter, mostly from the southwest and northeast corners. Combustion conditions were nevertheless good, and no burning particles of coal were at the furnace exit. The furnace bottom was bright and transparent, only a small quantity of burning coal particles could be seen, and the furnace bottom walls were uniformly bearded with sinters approximately 5 cm long.

At 1032 hr, a poker was thrust through the top of the furnace and the deposits at the throat were removed easily. When it was viewed from the top of the furnace, the flame was observed to resume the diamond shape noted previously. Ash was dumped, and was removed from the quench tank. The ash consisted of weak sinters, 5 to 12 cm in diameter, and dark grey coloured. Some ash remained on the ledges adjacent to the dump plates. Combustion conditions in the furnace bottom were unchanged.

For the next 1½ hours, conditions remained stable. At 1150 hr, the furnace throat appeared ragged with sinter but blockage was minor. At 1245 hr, the throat was found to be ¾ blocked with sinter which had again formed in the southwest and northeast corners, and a few particles of burning coal were at the furnace exit. The furnace bottom was slightly hazy with flame, and no burning coal particles were visible.

At 1255 hr, the deposits at the furnace throat were removed for the third time by thrusting a poker through the top of the furnace. The deposits broke loose readily but they were observed to be somewhat plastic. Ash was dumped and grey sinters up to 25 cm in diameter were removed from the quench tank. Some were moderately strong. The diamond-shaped flame pattern noted previously was re-established, and no burning coal particles were evident at the furnace exit. The furnace bottom was again transparent, and large quantities of burning coal particles were visible.

At 1400 hr, the furnace throat was again somewhat ragged with sinter, and a deposit of sinter approximately 20 cm thick was visible on the west wall of the furnace bottom. The transition section was brighter than before, and the tubes of the test air-heater were clearly visible. Heavy deposits of sinter, slightly plastic on the surface, were observed on the walls of the furnace bottom. The upper sight port on the north wall of the furnace bottom was largely blocked with sinter.

By 1430 hr, sinter had again formed below the furnace throat, more or less equally on all sides and blocking ½ of the projected throat area. Combustion conditions were not noticeably affected. The deposits were removed at 1440 hr, and ash was dumped. Weak sinters up to 25 cm in diameter, ranging in colour from grey to black, were raked from the quench tank. From the top of the furnace, the air-cooled deposition probe in the furnace bottom was intermittently visible.

By 1520 hr, the furnace throat was again rough with sinter, and a large deposit was in the southwest corner below the furnace throat. By 1550 hr, this deposit and another on the north side of the furnace had grown to block 1/3 of the projected throat area. The air-cooled deposition probe in the furnace bottom was faintly visible from the top of the furnace. Otherwise combustion conditions were unchanged.

At 1552 hr, the test was completed and an oil support burner was inserted. At 1536 hr, the boiler was "shut down". A flame from oil spray which had impinged on the sinter deposits persisted briefly but by 1558 hr the furnace was dark.

<u>Deposition Probes During Test</u>

The air-cooled probe in the furnace bottom and both probes in the furnace were visible in the test.

The air-cooled probe in the furnace bottom, when first observed at 0850 hr, had whiskers of sinter 1 to 3 mm in length on the top and bottom surfaces. By 0935 hr, these had formed a beard 10 mm long on the top surface and 5 cm long on the bottom surface. There was also a wasp's-nest-like deposit centred on the thermocouple junction in the side of the probe. After the furnace throat was cleaned at 1032 hr, the probe was bent downward and bore only a 5 mm long beard of sinter along part of the top surface. This had doubled in length by 1115 hr, but by 1150 hr part of it had fallen off, leaving a 2 mm long beard of sinter on the top surface, a few lumps of sinter approximately 1 cm in diameter, and a wasp's nest at the thermocouple junction

25 mm in diameter. At 1245 hr, the probe was bearded all around with sinters 5 mm long, but part of this deposit fell off when the furnace throat was cleaned a few minutes later. At 1400 hr, part of the probe was sintered all around to a diameter of 25 mm, but a portion at the free end, 20 cm in length, was clean except for some isolated lumps of sinter roughly 1 cm in diameter, and a deposit at the thermocouple junction, 2 cm in diameter. At 1430 hr, the deposits on the probe were reduced to a thin layer on the top surface, and a 7 mm long beard on part of the bottom surface. 15 cm of the free end of the probe was clean except for a deposit 25 mm in diameter at the thermocouple junction. There was no further change until the test was completed.

The air-cooled probe in the furnace was clean throughout the test period.

The refractory probe in the furnace, when it was first observed at 0845 hr, bore sinter whiskers 1 cm long on the bottom surface and on the free end. This stayed until 1245 hr, when the probe appeared to be clean. At 1430 hr, sinter whiskers 1 to 2 cm long were again observed on the bottom surface and free end of the probe, and these remained in place until the test was completed.

Furnace After Test

When the dump gates were swung open approximately two litres of ash, consisting of sinters up to 10 cm in diameter, fell to the floor. The sinters were tan and brown coloured, and some were fairly strong. A large sinter, roughly 50 cm x 30 cm x 15 cm, remained in the furnace bottom, where it had bridged across the south end. It was grey-tan coloured, was moderately strong, and was partially slagged on the side exposed to the flame. The furnace bottom walls were uniformly bearded with sinters 1 to 3 cm long except the north wall, which bore a deposit of sinter up to 10 cm thick. The furnace throat refractory was heavily sintered all around, particularly above the burners, where the sinters were up to 15 cm thick. These deposits were tan and brown coloured and were slagged on the surface by the oil support burner which was operated prior to "shutdown". Some of the deposit was covered with soot from the burning oil which had struck it. The furnace water walls bore a thin layer of dark grey-black dust. The upper slopes of the furnace throat and the nose at the furnace exit had a heavy layer of grey and black dust.

A layer of fine dust, 2 to 5 cm thick and light tan in colour and covered by thin layer of grey dust, lay on the bottom of the transition section. The downstream surfaces of the furnace screen tubes had a deposit of fine, tan-coloured dust, approximately 2 mm thick, covered by black soot. There were 2 mm of tan-coloured dust on the walls of the test air-heater. This deposit fell off readily when the walls were rapped with a hammer. The test air-heater tubes were clean on the upstream surfaces, but had a weakly adhering deposit of dust, 2 mm thick and light tan in colour, on the downstream surfaces. There were 1 to 4 cm of medium grey dust on the second pass tube sheet of the main air-heater.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed, had a thin layer of dust on the top surface, and a thin layer of tan-coloured scale on the bottom surface. Some whiskers of sinter, 3 to 5 mm long adhered to the scale on the bottom of the probe.

The refractory probe in the furnace bottom, before it was removed, bore rough, weak sinter all around and had an overall diameter of 4 cm. The deposit was thickest on the bottom surface.

The air-cooled probe in the furnace, before it was removed, appeared to be clean except for some dust on the top surface.

The refractory probe in the furnace, before it was removed, had a layer of dust on the top surface, and there appeared to be some sinter whiskers on the bottom surface. This could not be confirmed because the probe was not visible from the bottom of the furnace.

The air-cooled probe in the transition section, after it was removed, was found to have a clean, black, sand blasted upstream surface. The downstream surface had a weakly adhering layer of tan-coloured dust, 1 mm thick. It appeared that some of the deposit had fallen off.

The refractory probe in the transition section, after it was removed, was clean and shiny on the upstream surface. The downstream surface bore a deposit of tan-coloured dust, 3 to 4 mm thick, which fell off readily.

Test No. 7.2
Progress Report 7.2A

TABLE 1

OPERATING DATA

COAL: HAT CREEK "C" WASHED, DOUBLE DRIED. EXCESS O_2 3 %

22 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		104(2)	kg/hr	
Moisture Content of Coal	1	13.8	%	feed to pulverizer
" " " "	2	< 0.1	%	feed to furnace
Combustible " " "	2	80.3(0.3)	%	dry weight
Ash Dumping Frequency		once every ——	hour	79.5 Kg of ash dumped, equivalent to 983 Kg coal.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	267(4)	mmH_2O	
b) Outlet Air Pressure	2	224(3)	mmH_2O	
c) Inlet Air Temperature	3	203(3)	^oC	
d) Outlet Air Temperature	2	99(3)	^oC	
e) Coal Fineness	2	75.4% below 200 mesh		oversize, 13.2% >140 mesh
BOILER OPERATING CONDITIONS				" , 24.6% >200 mesh
a) Steam Flow	6	626(18)	kg/hr	" , 47.0% >325 mesh
b) Steam Pressure	6	3.04(0.03)	atmospheres	
c) Combustion Air Temp.	4	199(4)	^oC	
d) Furnace Pressures				
Furnace	10	41(4)	mmH_2O	
Inlet	11	41(4)	mmH_2O	
Boiler Exit	12	20(2)	mmH_2O	
Primary (Coal) Air L	5	146(3)	mmH_2O	
" R	5	155(4)	mmH_2O	
Secondary (Windbox) Air L	4	56(4)	mmH_2O	
" R	4	55(4)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	16.8(0.2)	%	
b) O_2	11	3.0(0.2)	%	
c) CO	11	73(4)	ppm	
d) NO	13	741(62)	ppm	
e) SO_2	14	677(34)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	32	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	636(17)	^oC	
b) Boiler Exit	12	301(5)	^oC	
c) Precipitator Entry	16	155(3)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	985, 1086	^oC	readings taken in
b)	8	754, 1001	^oC	second and third
c)	9	707, 907	^oC	two hour period
FLY ASH				
a) Loading	16	5400(800)	$mgms/m^3$	measured at 20^oC
b) Resistivity	15	$0.9(1.2)\times10^{11}$ Ω cm at 278^oC;		10^9 to 10^{12} Ω cm readings
"	17	$8(4)\times10^{10}$ Ω cm at 153^oC;		4.8×10^{10} Ω cm at 122^oC.
c) Precipitator efficiency	18	92.4(1.4)	%	
d) Combustible content of ash collected from precipitator	18	4.5(0.5)	%	

TABLE 2

DEPOSITION PROBES

Station		Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom	19	ceramic	1051	25	1018	1107	1080	1054	Dark grey scale upstream covered unevenly by 25 mm grey-beige friable sinter, all around.
		stainless	462	56	397	509	509	451	Grey brown scale all around covered by 6 mm beige grey sinter and crust upstream, 4 mm sinter downstream.
Furnace	9	ceramic	750	47	680	858	788	680	Grey scale covered by 1 mm grey-black powder, upstream, uneven.
		stainless	500	58	385	588	477	534	Black scale upstream covered by 3 mm grey-black powder, uneven, all around.
Transition Section	20	ceramic	630	13	610	646	610	646	Grey-black scale covered unevenly by beige grey powder, 3 mm thick, upstream.
		stainless	496	14	477	527	477	527	Grey-beige powder, 1 mm thick, downstream.

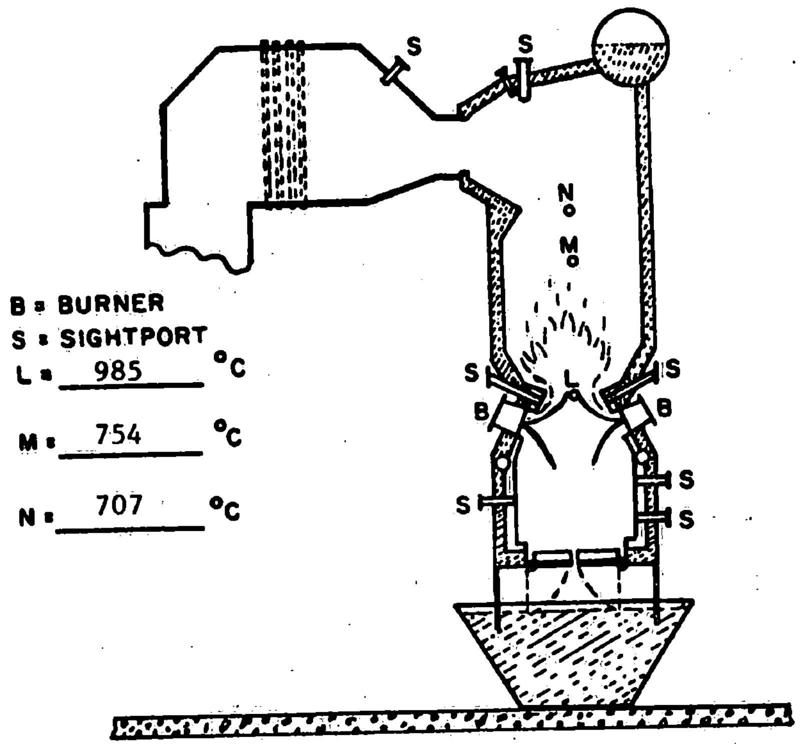


Figure 2. Illustration of flame pattern (——) and of burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 3% Excess Oxygen

PROGRESS REPORT 7.2B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (7.2B) presents coal analyses and size distribution of the pulverized coal burned in test 7.2 done on November 22, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 7.2

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M	0.3	0.0		
60M x 100M	1.3	0.4	1.6	87.8
100M x 140M	11.6	1.8	11.6	85.3
140M x 200M	11.3	0.7	11.3	82.6
200M x 325M	22.5	1.8	22.5	81.3
325M x 0	53.0	1.4	53.0	78.4

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: C Washed, Test 7.2, B. C. Hydro (A1661)

Analysis	
Screen Analysis	
+ ¼	0.00
¼ * 1/8	6.75
1/8 * 1/16	55.33
1/16 * 1/32	25.12
1/32 * 28M	4.79
28M * 48M	4.83
48M * 0	3.18
Grindability	
Hardgrove Index	38
Classification of Coal	
Rank (ASTM)	
Eq. Moisture % (97% Humidity)	

Sample C Washed, Test 7.2, B. C. Hydro (A1661)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	11.91	0.00
Ash	16.00	18.16
Volatile Matter	33.79	38.36
Fixed Carbon (by Diff.)	38.30	43.48
Ultimate Analysis %		
Carbon	50.84	57.71
Hydrogen	3.51	3.98
Sulphur	0.66	0.75
Nitrogen	1.09	1.24
Ash	16.00	18.16
Oxygen (by Diff.)	15.99	18.16
Calorific Value		
Calories/gram	4766	5410
Btu/lb gross	8579	9739
Megajoules/kilogram	19.95	22.65
Sulphur Forms %		
Sulphatic		
Pyritic		
Organic (by Diff.)		
TOTAL		
Chlorine	0.02 %	

Sample: C Washed, Test 7.2, B. C. Hydro (A1661)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1482+	1410
Spherical	°C	+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	51.23 %
Al_2O_3	30.19 %
Fe_2O_3	5.11 %
Mn_3O_4	--
TiO_2	1.26 %
P_2O_5	0.36 %
CaO	3.64 %
MgO	1.44 %
SO_3	2.96 %
Na_2O	0.64 %
K_2O	0.63 %
Cl	---
Specific Gravity	2.54

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 3% Excess Oxygen

PROGRESS REPORT 7.2C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (7.2C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 7.2 done on November 22, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

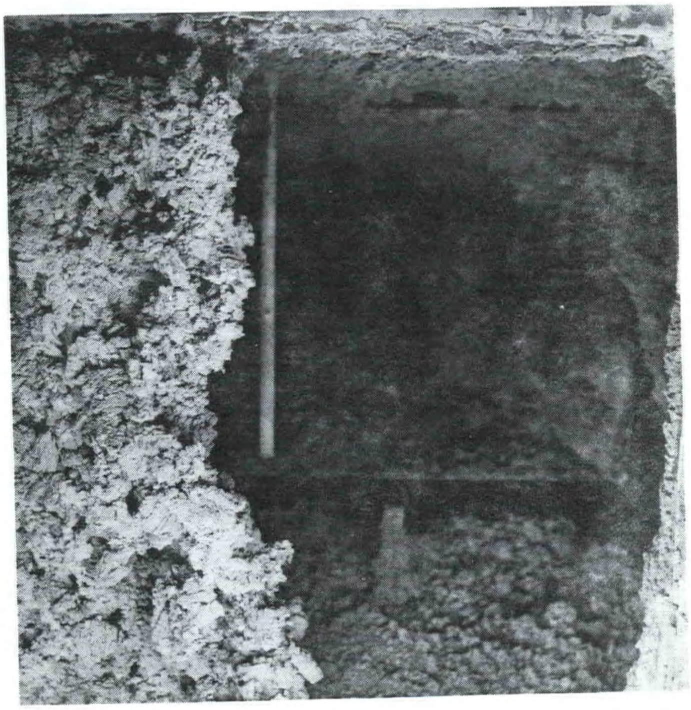


Figure 1a

Furnace bottom at end of test. Friable sinter bridges south side of bottom.

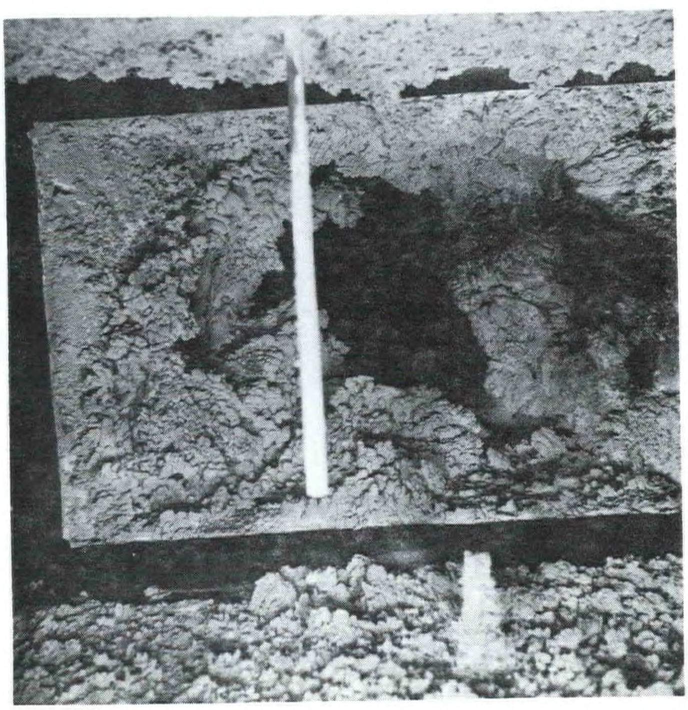


Figure 1b

Furnace bottom at end of test. Loose friable sinter blocks nearly ½ of the throat area. Sinter has developed mainly from NE and SW corners. Air cooled probe projects from E wall above in photograph, refractory probe projects from W wall.

PROGRESS REPORT 7:2C

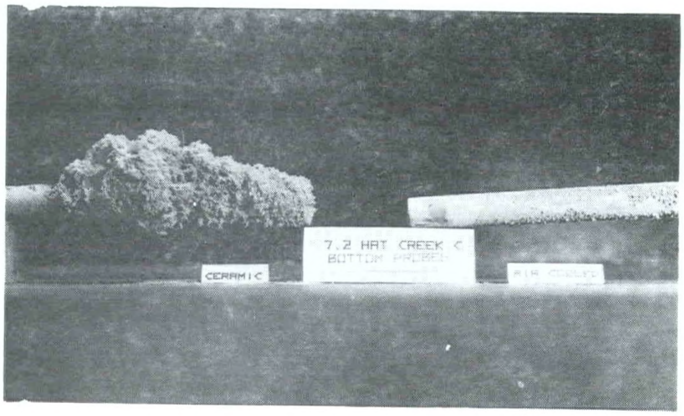


Figure 1c

Furnace bottom deposition probes. Air cooled probe on left. Refractory probe on right.

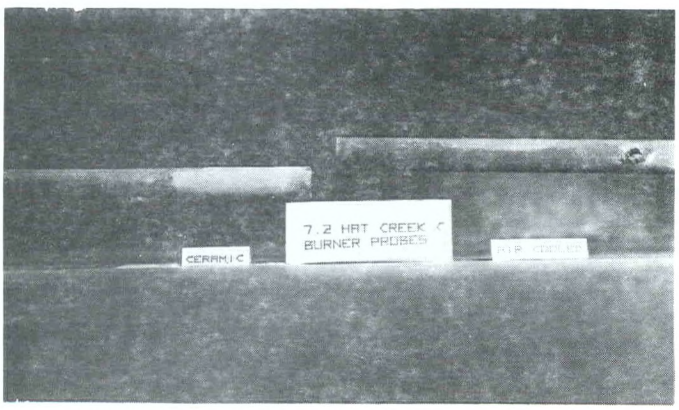


Figure 1d

Burner deposition probes. Air cooled probe of left. Refractory probe on right.

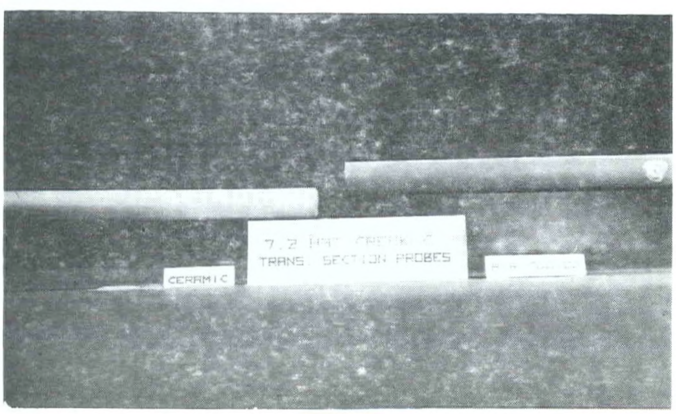


Figure 1e

Transition section deposition probes. Air cooled probe on left. Refractory probe on right.

PROGRESS REPORT 7:2C

Figure 1f

Main air heater tube sheet second pass up to 2 - 3 inches of powder.

Figure 1g

Low Temperature corrosion probe 138°C.

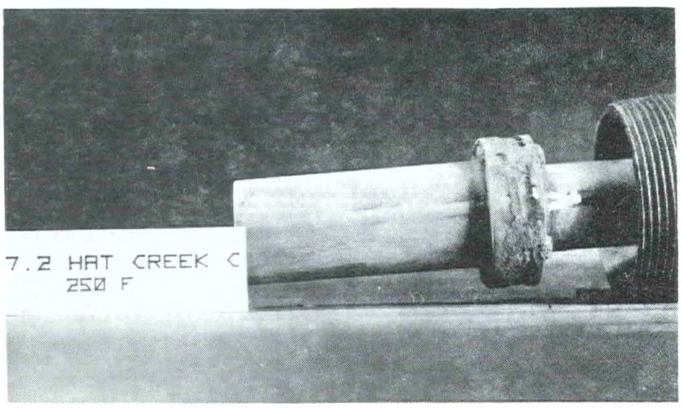


Figure 1h

Low Temperature corrosion probe 121°C.

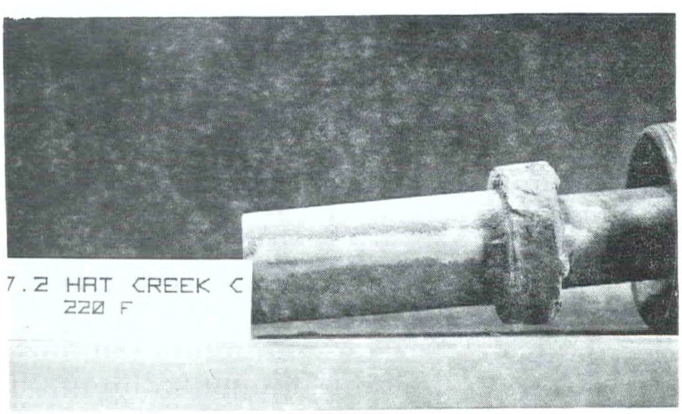


Figure 1i

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	462 °C	500 °C	496 °C
Deposition rate[a]						
Fe	55.2	63.2	35.3	26.9	7.8	7.8
Mg	1.9	0.9	0.6	1.4	7.1	2.4
Na	2.9	1.1	0.7	1.6	6.5	2.9
Ca	6.3	3.9	2.5	18.2	116.6	12.7
SO_4 (total)	104.4	73.5	61.3	182.9	186.6	129.6
SO_4 (free), by difference						
	9.1			84.1		70.1

[a] The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Sample: Deposition probes, Test 7.2, B. C. Hydro

Station	Furnace Bottom				Boiler				Transition Section			
Material	SS		REF		SS		REF		SS		REF	
Mean Temperature °C	239		566		260		399		258		332	
% Water Soluble	2.5		1.6		4.8		---		---		6.5	
% Acid Insoluble	88.2		93.0		65.7		---		---		72.1	
Analysis , %	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS	WS	AS
SO_4	0.0		0.0		0.0						1.6	
Ca	2.3	0.2	1.3	0.2	4.3	0.0					2.5	0.3
Fe	0.1	1.4	---	0.2	0.3	12.8					0.3	1.8
Mg	---	0.2	---	0.1	0.1	0.7					---	0.6
K	0.0	0.0	0.0	0.0	0.0	0.0					0.0	0.0
Na	---	---	---	---	---	0.1					0.1	0.2

WS = water soluble

AS = acid soluble

--- = trace

Sample: Deposit from the furnace bottom, Test 7.2 (A 1701 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1366	1332
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	%
SiO_2	52.26
Al_2O_3	31.20
Fe_2O_3	5.63
Mn_3O_4	----
TiO_2	1.73
P_2O_5	0.38
CaO	5.28
MgO	1.97
SO_3	0.06
Na_2O	0.53
K_2O	0.67
Cl	----

Sample: Deposit from the furnace walls, Test 7.2 (A 1702 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1238	1182
Spherical	°C	1454	1382
Hemispherical	°C	1482+	1438
Fluid	°C	+	1477

Ash Analysis	%
SiO_2	49.02
Al_2O_3	28.44
Fe_2O_3	13.75
Mn_3O_4	----
TiO_2	1.11
P_2O_5	0.35
CaO	3.50
MgO	1.39
SO_3	1.41
Na_2O	0.68
K_2O	0.59
Cl	----

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 7.2 (A 1705 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1310	1266
Spherical	°C	1482+	1438
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	50.70
Al_2O_3	29.79
Fe_2O_3	6.13
Mn_3O_4	----
TiO_2	1.47
P_2O_5	0.41
CaO	4.30
MgO	3.36
SO_3	0.39
Na_2O	0.56
K_2O	0.63
Cl	----

Progress Report 7.2 C

Sample: Deposit from electrostatic precipitator, Test 7.2 (A 1675-76-77)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1332	1299
Spherical	°C	1443	1399
Hemispherical	°C	1482+	1477
Fluid	°C	+	1482+

Ash Analysis	%
SiO_2	56.06
Al_2O_3	32.78
Fe_2O_3	5.56
Mn_3O_4	----
TiO_2	1.18
P_2O_5	0.25
CaO	3.35
MgO	1.25
SO_3	0.64
Na_2O	0.87
K_2O	0.63
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried and Kiln-Dried Once, 3% Excess Oxygen

PROGRESS REPORT 7.2D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1/]

SUMMARY

As explained elsewhere [2/], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (7.2D) is the last of the series and presents results of the following detailed analyses of ash produced in test 7.2 done on November 22, 1976.

1. Particle size distribution of fly ash
2. Combustion calculations

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle <u>volume</u> to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.4
1.59 - 2.00	Coulter Counter		0.7
2.00 - 2.52	Coulter Counter		1.0
2.52 - 3.17	Coulter Counter		1.4
3.17 - 4.00	Coulter Counter	0.3	2.5
4.00 - 5.04	Coulter Counter	0.4	3.5
5.04 - 6.35	Coulter Counter	0.9	4.8
6.35 - 8.00	Coulter Counter	1.8	6.4
8.00 - 10.08	Coulter Counter	4.1	9.5
10.08 - 12.7	Coulter Counter	7.4	12.0
12.7 - 16.0	Coulter Counter	12.2	13.5
16.0 - 20.2	Coulter Counter	17.8	12.1
20.2 - 25.4	Coulter Counter	20.0	9.5
25.4 - 32.0	Coulter Counter	16.0	6.6
32.0 - 40.3	Coulter Counter	9.2	3.5
40.3 - 44.0	Coulter Counter	1.6	1.2
44.0 - 74.0	Sieve	5.9	3.8
+ 74.0	Sieve	2.4	7.6

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T & TA

PARTICLE SIZE ANALYSIS

.15 – 200μ
X PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL – WRL

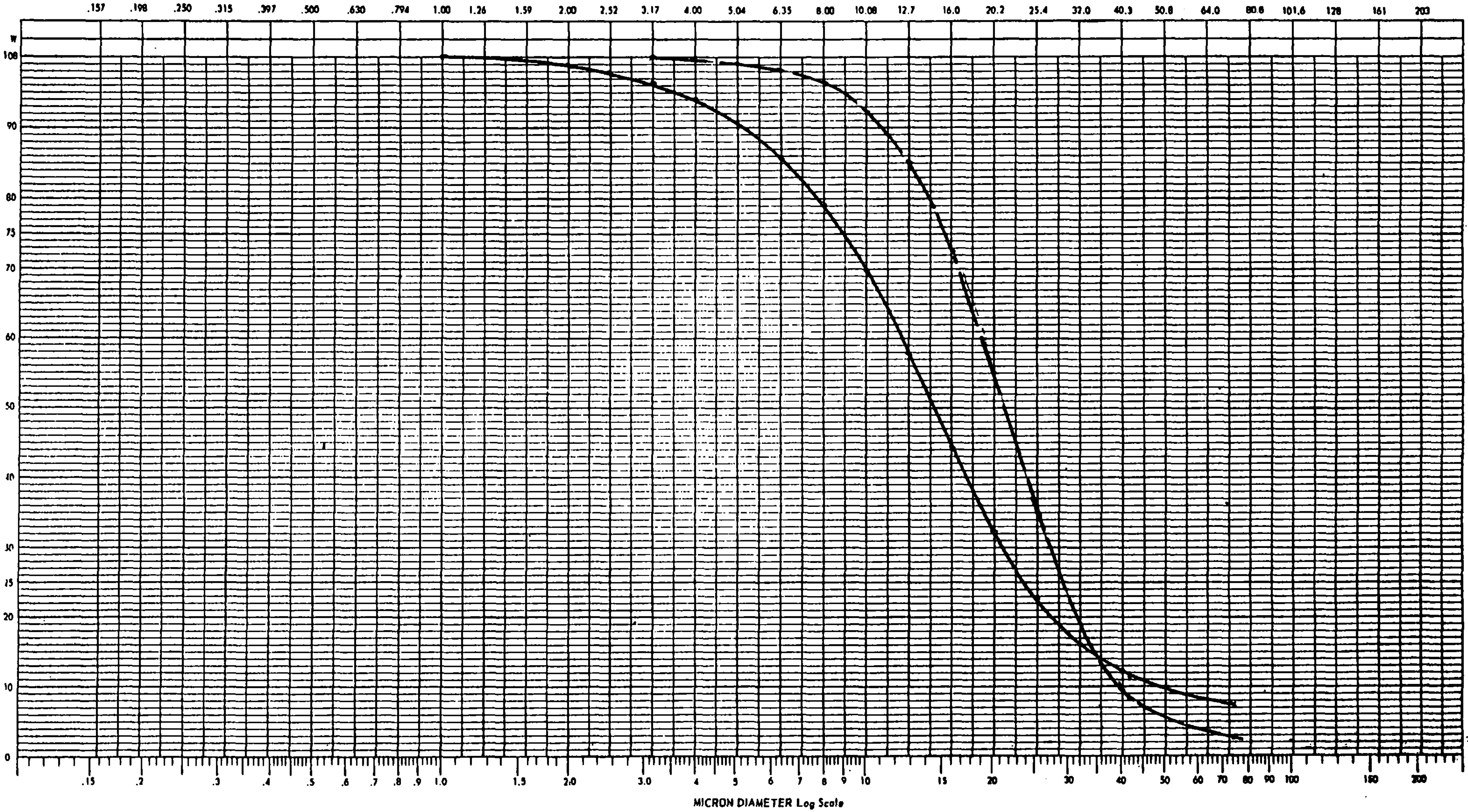
OPERATOR

EQUIPMENT

$k = d\sqrt[3]{2w}$ $\frac{A2}{A1} = \left(\frac{d2}{d1}\right)^3$ when $W2 = W1$ FOR MODEL T $\frac{A2}{A1} = \left(\frac{d1}{d2}\right)^3$ when $W2 = W1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 7.2	ISOTON	ULTRASONIC	100μ	6102033									
ESP ———													
AHR – – – –													



- 524 -

Progress Report 7.2D

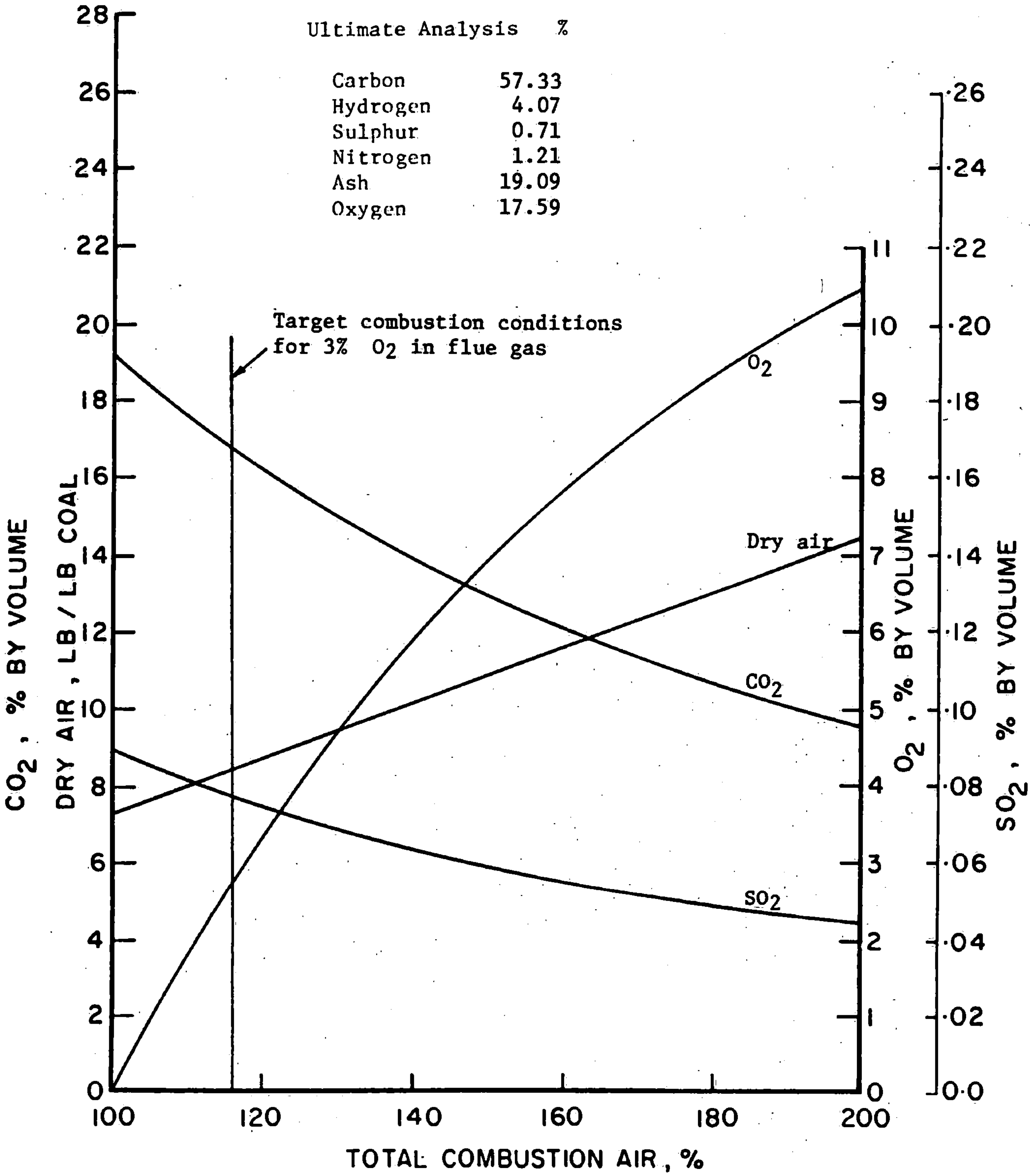


FIGURE 1: Combustion Calculations "C-Washed" Coal.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

HAT CREEK "C" WASHED COAL

AIR-DRIED, 5% EXCESS OXYGEN

TEST NO. 7.3

CANADIAN COMBUSTION RESEARCH LABORATORY

NOVEMBER 1976

ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 76/168-171

PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 7.3A

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

INTRODUCTION

By an agreement between the B. C. Hydro and Power Authority (BC Hydro) and the Canada Centre for Mineral and Energy Technology (CANMET), a series of combustion tests are being done at the Canadian Combustion Research Research (CCRL) to assess the suitability of Hat Creek coal as a boiler fuel for thermo-electric generation. A previous report[2/] describes the objectives of the program, the pilot-scale equipment, the procedures and method of reporting results.

This progress report summarizes the data immediately available from Test No. 7.3, which was done on November 24, 1976.

[1/] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2/] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure ". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

CONTROL PARAMETERS FOR TEST NO. 7.3

In this test Hat Creek "C" washed coal was burned. The coal had been air-dried, which reduced the as-fired moisture to 21.8%. The target level of excess oxygen in the flue gas was 5%, and the target coal feed rate was 110 Kg/hr, which represents a heat input of two Giga Joules/hr.

TEST DATA AND DESCRIPTION

The operating data shown in Tables 1 and 2 are self-explanatory. The locations of the measuring stations are shown in Figure 1, which is a diagram of the research boiler.

Furnace During Test

At 0830 hr, stable, unsupported coal combustion had been in progress for more than one hour. From the top of the furnace, deposits of sinter were observed all around the furnace throat, and they blocked 1/5 of the projected throat area. The flame was uniformly orange-yellow coloured, and active combustion appeared to end a few inches above the furnace throat. Flakes of sinter were blowing about in the furnace, but there were no burning coal particles at the furnace exit. Both deposition probes in the furnace were clearly visible. The transition section was aglow with light reflected from the furnace by which the flue gas sampling probe in the test air-heater was clearly visible and the tubes were only dimly visible. The furnace bottom was bright and transparent. Large quantities of burning coal particles were visible, and flickers of flame were observed in the upper levels. The furnace bottom walls were fairly clean and the air-cooled deposition probe was visible in detail.

Conditions changed very little during the next hour, except that deposits of sinter began to form on the furnace bottom walls, and the deposits in the furnace throat slowly grew until they blocked 1/3 of the projected throat area.

At 0950 hr, a poker was thrust through the top of the furnace to easily remove the deposits at the throat. Ash was dumped and the material removed from the quench tank consisted of small, weak sinters, grey to tan coloured. The flame was then observed to diverge from the burners to form a diamond shape, which was coloured yellow in the centre and orange-yellow at the edges. Some ash remained on the south ledge of the furnace bottom.

By 1035 hr, the throat was again ragged with sinter, and deposits up to 10 cm thick were on the west and north sides. The characteristics of the flame remained unchanged. At 1115 hr, a 15 cm thick deposit was above the north burner, but it fell later. Combustion conditions remained stable.

At 1340 hr, the projected area of the furnace throat was 1/5 blocked with sinters in the southwest and northeast corners and on the east side. The flame was fairly uniform and orange-yellow coloured. The air-cooled deposition probe in the furnace bottom was intermittently visible, when it was viewed from the top of the furnace. The transition section was brighter than when first observed, but the test air-heater tubes were still only dimly visible. The furnace bottom continued to be bright and transparent. It was filled with a cloud of burning coal particles. A large quantity of ash lay on the dump plates, mostly at the south end of the furnace bottom. A uniform layer of sinter whiskers, 2 to 4 cm long covered the walls of the furnace bottom.

During the next half-hour, the deposits in the furnace throat rapidly grew to block half of the projected throat area. The deposits were removed at 1410 hr by thrusting a poker through the top of the furnace. Ash was dumped. Approximately 40 litres of small sinters, with a few pieces measuring 12 cm diameter, were removed from the quench tank. All were weak, and ranged in colour from grey to brown. The furnace throat was then clean, the flame was yellow and approximately diamond-shaped, and a small quantity of ash remained on the south ledge of the furnace bottom.

Within an hour the furnace throat was again ragged with sinter and fairly large deposits were visible on the west wall and above the north burner. The flame was bright, but neither uniform nor of a clearly defined shape. Through the sight ports in the furnace bottom it was possible to see a large deposit on the south wall below the burner. By 1600 hr, ½ the projected area of the furnace throat was blocked with rough sinter deposits which had formed on all sides. The flame was orange-yellow coloured and was uniform.

At 1611 hr, when an oil support burner was inserted prior to "shut-down," some of the deposits fell from the furnace throat. They appeared to be plastic. At 1616 hr, the oil support burner was removed and the boiler was "shut-down". Flame from oil spray had struck the sinter deposits and a small flame remained for approximately five minutes. The ash and refractory in the furnace glowed brightly for several minutes and was still glowing at 1625 hr.

Deposition Probes During Test Period

The air-cooled probe in the furnace bottom and both probes in the furnace were visible in the test.

The air-cooled probe in the furnace bottom, when it was first observed at 0830 hr, was bearded along part of the top surface with lumps of sinter. These lumps, which measured up to 10 mm in diameter were joined together. Sinters 3 to 5 mm long formed a beard along part of the bottom surface. These deposits stayed until the furnace throat was cleaned at 0950 hr, when most of the deposits were dislodged. At 1035 hr, the last 15 cm of the probe were clean, but the remainder bore deposits up to 20 mm thick on the top surface, and a few small whiskers on the bottom surface. These deposits were not as large at 1115 hr. At 1340 hr, the probe was observed to bear randomly-placed whiskers of sinter 3 to 5 mm long, with an irregular deposit on the top surface, up to 10 mm thick. After the furnace throat was cleaned at 1410 hr, the probe was clean. At 1510 hr a rough deposit, 5 to 12 mm thick, was observed on part of the top surface. At 1600 hr, the probe bore some randomly-placed whiskers of sinter 3 to 8 mm long, a few lumps of sinter 15 mm in diameter. It also bore a deposit 15 mm in diameter, shaped like a wasp's nest and centred over a small air leak at the thermocouple junction in the probe.

The air-cooled probe in the furnace appeared to remain clean throughout the test.

The refractory probe in the furnace did not develop any visible deposits until 1115 hr, when some whiskers of sinter were observed on the tip and the bottom surface. By 1210 hr, these had grown to form a rough deposit with an overall diameter of approximately 4 cm. Shortly thereafter, this fell off and left only a few whiskers on the bottom surface. By 1340 hr, sinter had again formed, mostly on the bottom surface, to an overall diameter of 4 cm. At 1600 hr, the deposits were estimated to be 6 cm in diameter, and extended 7 or 8 cm beyond the tip of the probe. When the oil support burner was inserted at "shut-down", most of the deposits fell off the probe.

Furnace After Test

When the dump plates were swung open, approximately 15 litres of tan coloured ash fell to the floor. This ash consisted of dust, small, weak sinters, and a few pieces of fairly strong sinter, 12 cm in diameter. The furnace bottom was fairly clean. Only a few litres of dust and small sinters remained on the ledges adjacent to the dump plates and the walls were lightly layered with sinter whiskers 1 to 3 cm long. The south wall of the furnace bottom, had a sinter up to 5 cm thick. The furnace throat refractory bore deposits of sinter up to 15 cm thick all around. This material was orange-brown coloured and was mostly slagged on the fire side, presumably from the oil support burner which was operated during "shut-down". The furnace water walls were lightly layered with grey dust except for a band, 30 to 45 cm wide, halfway up the water walls, where deposits of grey dust filled the grooves between the tubes. There were also heavy layers of light grey dust on the upper slopes of the furnace throat and on the nose at the furnace exit.

There were approximately 3 cm of light grey-tan coloured dust lying on the bottom of the transition section. The downstream surfaces of the furnace screen tubes bore a loose layer of dust, 2 to 3 mm thick and coloured various shades of grey. A similar layer of dust, part of which had fallen off, was on the walls of the test air-heater. The upstream surfaces of the test air-heater tubes were clean, but the downstream surfaces bore a weakly adhering layer of dust, approximately 2 mm thick and tan-grey coloured. The second pass tube sheet of the main air-heater had a layer of grey dust 1 to 4 cm thick.

Deposition Probes After Test

The air-cooled probe in the furnace bottom, before it was removed, had a thin layer of weakly adhering tan-coloured scale on the bottom surface, and a thin layer of dust on the top surface.

The refractory probe in the furnace bottom, before it was removed, had rough, tan-coloured, friable sinters, up to 3 cm long on the top and bottom surfaces.

Neither the air-cooled probe nor the refractory probe in the furnace, before they were removed, had large deposits.

The air-cooled probe in the transition section, after it was removed, was clean and polished on the upstream surface. The downstream surface had a weakly adhering layer of tan-coloured dust, up to 3 mm thick and much more dust had fallen off than remained.

The refractory probe in the transition section, after it was removed, was clean and shiny on both the upstream and downstream surfaces. However, a thin line of tan-coloured dust was on each side of the probe, normal to the direction of gas flow. This appeared to be the roots of a deposit which had fallen off the downstream surface.

Test No. 7.3

Progress Report 7.3A

TABLE 1

OPERATING DATA

COAL: HAT CREEK "C" WASHED, SINGLE DRIED

EXCESS O_2 5 %

24 November 1976

Parameters	Station	Obs. (R.M.S. Dev.)		Comments
Test Duration		7	hours	
Firing Rate		112(5)	kg/hr	
Moisture Content of Coal	1	21.8	%	feed to pulverizer
" " " "	2	< 0.1%	%	feed to furnace
Combustible " " "	2	79.4(1.4)	%	dry weight
Ash Dumping Frequency		once every ——	hour	46.1 Kg Ash dumped, equivalent to 1002.5 Kg coal.
PULVERIZER OPERATING CONDITIONS				
a) Inlet Air Pressure	3	268(5)	mmH_2O	
b) Outlet Air Pressure	2	217(4)	mmH_2O	
c) Inlet Air Temperature	3	200(4)	^oC	
d) Outlet Air Temperature	2	65(6)	^oC	
e) Coal Fineness	2	72.4% below 200 mesh		oversize, 11.5% >140 mesh
BOILER OPERATING CONDITIONS				" ,27.6% >200 mesh
a) Steam Flow	6	563(16)	kg/hr	" ,39.7% >325 mesh
b) Steam Pressure	6	2.86(0.05)	atmospheres	
c) Combustion Air Temp.	4	191(7)	^oC	
d) Furnace Pressures				
Furnace	10	41(6)	mmH_2O	
Inlet	11	40(6)	mmH_2O	
Boiler Exit	12	21(3)	mmH_2O	
Primary (Coal) Air L	5	142(4)	mmH_2O	
" R	5	151(3)	mmH_2O	
Secondary (Windbox) Air L	4	56(6)	mmH_2O	
" R	4	57(6)	mmH_2O	
FLUE GAS ANALYSIS				
a) CO_2	11	14.4(0.1)	%	
b) O_2	11	5.0(0.1)	%	
c) CO	11	44(11)	ppm	
d) NO	13	653(26)	ppm	
e) SO_2	14	612(39)	ppm	
f) SO_3	14	< 1	ppm	
g) Acid dewpoint	18	29	^oC	
FLUE GAS TEMPERATURE				
a) Furnace Exit	11	628(22)	^oC	
b) Boiler Exit	12	297(6)	^oC	
c) Precipitator Entry	16	157(6)	^oC	
SUCTION PYROMETER TEMPERATURES				
a)	7	1060, 1080	^oC	readings taken in second and third two hour period
b)	8	895, 910	^oC	
c)	9	770, 866	^oC	
FLY ASH				
a) Loading	16	5200(400)	$mgms/m^3$	measured at 20^oC
b) Resistivity	15	$6.2(1.2)\times10^9\ \Omega$ cm at 268	^oC	
"	17	$3.0(2.9)\times10^{11}\ \Omega$ cm at 157	^oC	; $4.6 \times 10^{11}\ \Omega$ cm at 135^oC
c) Precipitator efficiency	18	96.4(0.6)	%	
d) Combustible content of ash collected from precipitator	18	2.2(0.2)	%	

TABLE 2

DEPOSITION PROBES

Station	Deposition	Temperature °C mean	RMS Dev.	min.	max.	initial	final	Description of Deposit
Furnace Bottom 19	ceramic	968	38	919	1045	972	919	Grey mauve scale, even, all around covered by 12 mm thick, grey-cream, friable sinter, mostly downstream.
	stainless	529	23	496	581	522	500	Grey sinter, uneven, upstream covered by 2 mm thick grey-beige powder, all around, uneven.
Furnace 9	ceramic	858	41	820	927	820	774	Rose-beige scale, even, upstream covered by 6 mm thick, yellow-beige powder, uneven, all around.
	stainless	523	49	482	637	538	487	Grey scale upstream covered by 3 mm thick grey powder, uneven, all around
Transition Section 20	ceramic	635	11	615	649	615	646	Polished upstream. Light grey-beige powder, uneven, 2 mm thick, downstream.
	stainless	525	9	505	559	522	534	Polished upstream. Light-grey powder, 2 mm thick, downstream on sides. Evidence that some deposit has fallen.

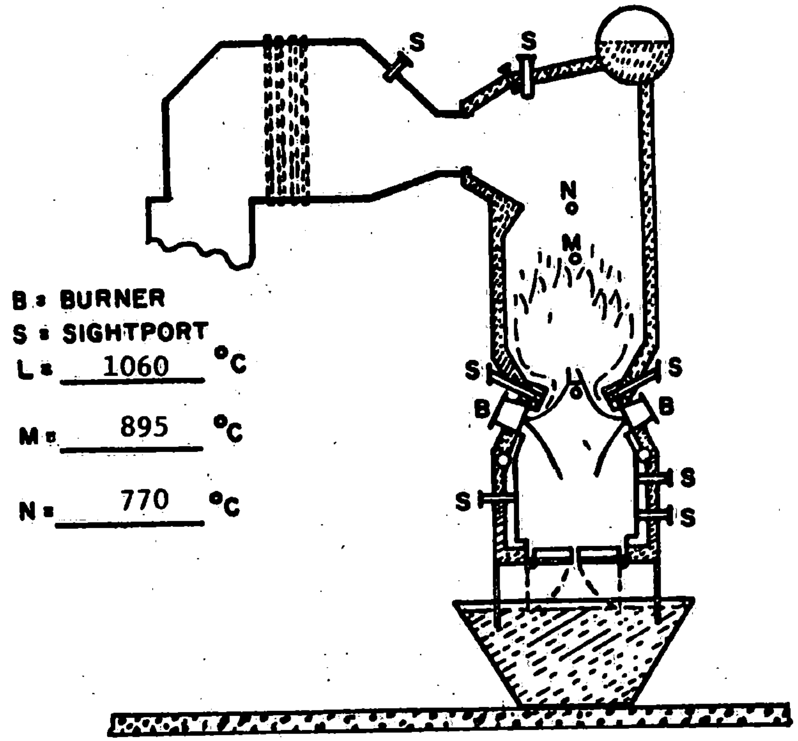


Figure 2. Illustration of flame pattern (——) and of burnout pattern (----).

COAL ANALYSES FOR PILOT-SCALE COMBUSTION TESTS

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET

JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 7.3B

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program. This progress report (7.3B) presents coal analyses and size distribution of the pulverized coal burned in test 7.3 done on November 24, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

TEST NO: 7.3

B. C. Hydro - CANMET Joint Program

TABLE 2

Size Analysis of Pulverized Coal

Size 1/	Grab Samples 2/		Composite Sample	
	Wt %	R.M.S. Deviation 3/	Wt %	LOI % 4/
60M	0.7	0.1		
60M x 100M	1.3	0.4	2.1	84.6
100M x 140M	9.5	2.1	9.5	85.5
140M x 200M	16.1	2.0	16.1	83.7
200M x 325M	12.1	1.0	12.1	83.0
325M x 0	60.4	1.3	60.4	76.2

1/ The mesh openings for the sieves are as follows: 250μ for 60 mesh, 149μ for 100 mesh, 105μ for 140 mesh, 74μ for 200 mesh and 44μ for 325 mesh and where 1μ = 10^{-6} metres.

2/ Grab samples were taken at 1 hour intervals during the test.

3/ R.M.S: Root Mean Square Deviation.

4/ Loss on ignition, ASTM 3174-73.

Sample: C Washed, Test 7.3, B. C. Hydro (A1706)

Analysis	
Screen Analysis	
+ ¼	0.00 %
¼ * 1/8	5.76 %
1/8 * 1/16	33.15 %
1/16 * 1/32	25.11 %
1/32 * 28M	8.72 %
28M * 48M	14.17 %
48M * 0	13.09 %
Grindability	
Hardgrove Index	36
Classification of Coal	
Rank (ASTM)	
Eq. Moisture %	
(97% Humidity)	

Sample C Washed, Test 7.3, B. C. Hydro (A1706)

Analysis	Air Dried	Dried at 107 ± 3°C
Proximate Analysis %		
Moisture	20.30	0.00
Ash	15.14	19.00
Volatile Matter	30.57	38.36
Fixed Carbon (by Diff.)	33.99	42.64
Ultimate Analysis %		
Carbon	46.14	57.89
Hydrogen	3.16	3.96
Sulphur	0.59	0.74
Nitrogen	0.96	1.20
Ash	15.14	19.00
Oxygen (by Diff.)	13.71	17.21
Calorific Value		
Calories/gram	4302	5398
Btu/lb gross	7744	9716
Megajoules/kilogram	18.01	22.60
Sulphur Forms %		
Sulphatic		
Pyritic		
Organic (by Diff.)		
TOTAL		
Chlorine	0.02 %	

Sample: C Washed, Test 7.3, B. C. Hydro (A1706)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1399	1288
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	50.20 %
Al_2O_3	28.66 %
Fe_2O_3	6.88 %
Mn_3O_4	--
TiO_2	1.24 %
P_2O_5	0.43 %
CaO	3.63 %
MgO	1.81 %
SO_3	2.98 %
Na_2O	0.67 %
K_2O	0.63 %
Cl	---
Specific Gravity	2.62

FIRESIDE FOULING AND CHEMICAL ANALYSES OF ASH PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 7.3C

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY[1/]

SUMMARY

As explained elsewhere[2/], the results of this joint program are reported in a series of four reports numbered A to D for each of the 18 combustion tests which make up the program.

This progress report (7.3C) presents a photographic record of the fireside fouling of the research boiler surfaces, the properties of ash deposits collected on probes and the chemical analyses of various ash forms produced in test 7.3 done on November 24, 1976.

1/ Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

2/ "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedures". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

FIGURE 1a Furnace bottom at end of test. Furnace throat is about half blocked by friable sinter. Burners appear to be clear. Refractory probe in foreground on west wall is covered with sinter.

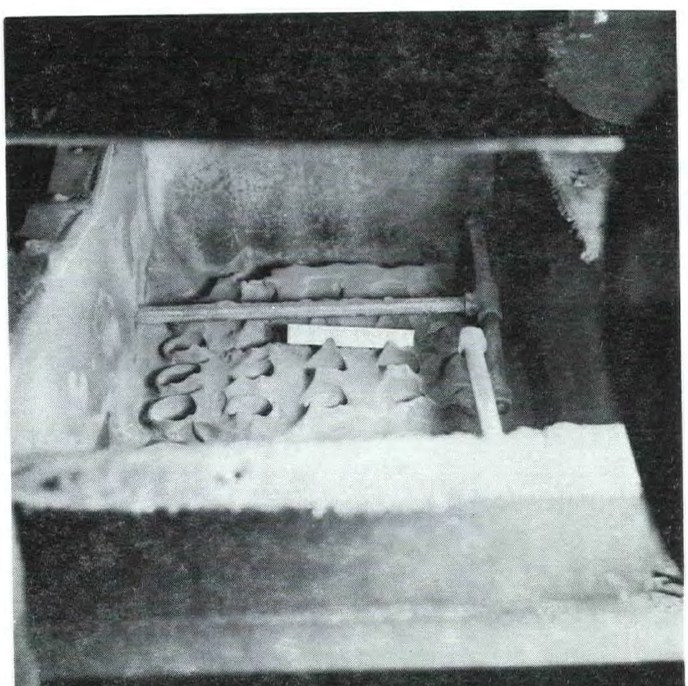


FIGURE 1b Main air heater tube sheet second pass up to 2 - 3 inches of powder.

PROGRESS REPORT 7:3C

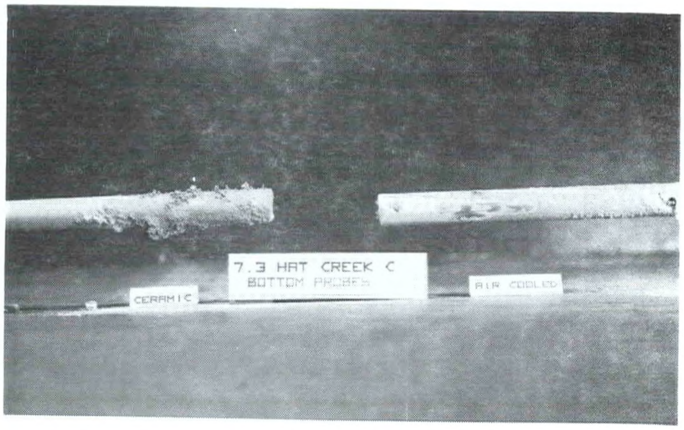


Figure 1c

Furnace bottom deposition probes. Air cooled probe on left. Refractory probe on right.

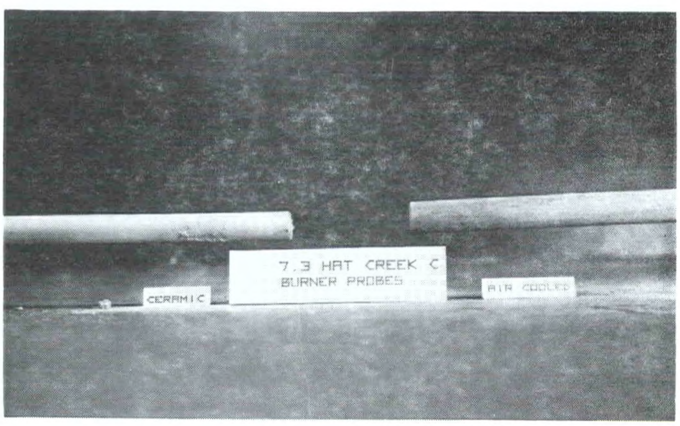


Figure 1d

Burner deposition probes. Air cooled probe of left. Refractory probe on right.

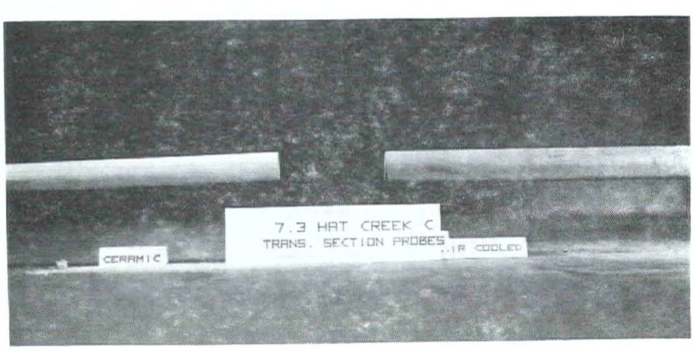


Figure 1e

Transition section deposition probes. Air cooled probe on left. Refractory probe on right.

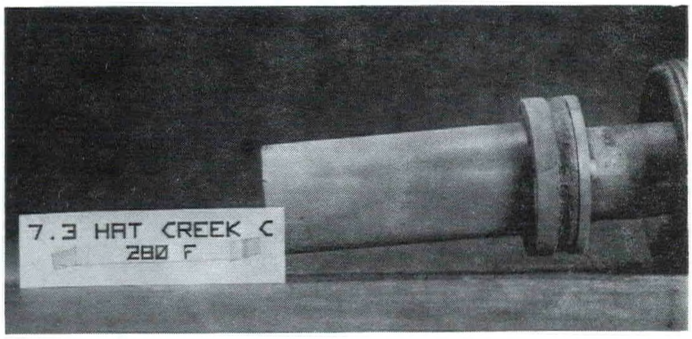


Figure 1f

Low Temperature corrosion probe 138°C.

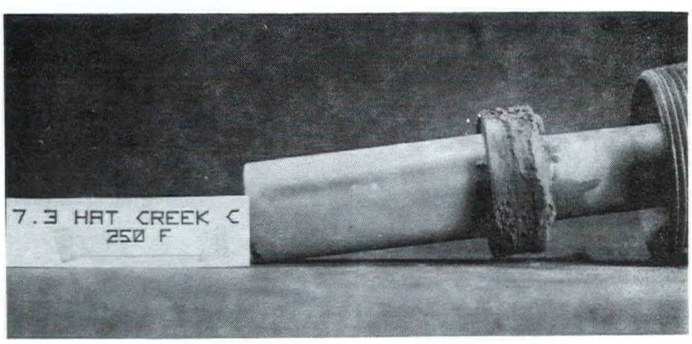


Figure 1g

Low Temperature corrosion probe 121°C.

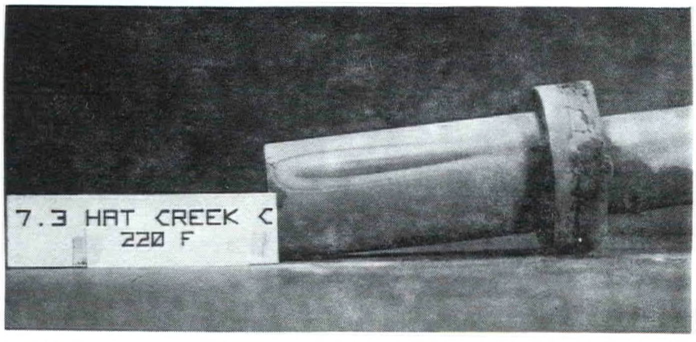


Figure 1h

Low temperature corrosion probe 104°C.

B. C. Hydro - CANMET Joint Program

RATE OF DEPOSITION OF WATER SOLUBLE MATERIALS ON CORROSION AND DEPOSITION PROBES

	Low Temperature			High Temperature		
Probe Temperature	138 °C	121 °C	104 °C	529 °C	523 °C	525 °C
Deposition rate[a]						
Fe	18.9	37.3	27.8	9.2	9.8	3.5
Mg	1.2	1.0	1.1	0.7	3.0	2.0
Na	2.2	2.0	2.0	1.3	3.5	2.9
Ca	3.9	17.2	6.3	20.7	67.2	14.8
SO_4 (total)	53.6	44.7	41.2	81.2	126.3	49.2
SO_4 (free), by difference	2.2			10.5		

a/ The deposition rate is given in units of mg/m^2/hour and the sampling time is 8½ hours.

Progress Report 7.3 C

Sample: Deposit from the furnace bottom, Test 7.3 (A 1747 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1377	1338
Spherical	°C	1482+	1482
Hemispherical	°C	+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	54.78
Al_2O_3	31.34
Fe_2O_3	6.84
Mn_3O_4	----
TiO_2	1.17
P_2O_5	0.32
CaO	3.39
MgO	1.52
SO_3	0.07
Na_2O	0.54
K_2O	0.67
Cl	----

Progress Report 7.3 C

Sample: Deposit from the furnace walls, Test 7.3 (A 1748 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1399	1327
Spherical	°C	1482+	1482+
Hemispherical	°C	+	+
Fluid	°C	+	+

Ash Analysis	
SiO_2	54.91
Al_2O_3	31.36
Fe_2O_3	7.52
Mn_3O_4	----
TiO_2	1.08
P_2O_5	0.30
CaO	2.96
MgO	1.33
SO_3	0.88
Na_2O	0.48
K_2O	0.62
Cl	----

Progress Report 7.3 C

Sample: Deposit from sheet between 2nd and 3rd passes of air heater, Test 7.3 (A 1751 - 76)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1321	1266
Spherical	°C	1460	1399
Hemispherical	°C	1482+	1482+
Fluid	°C	+	+

Ash Analysis	
SiO_2	50.11
Al_2O_3	29.04
Fe_2O_3	7.56
Mn_3O_4	----
TiO_2	1.48
P_2O_5	0.33
CaO	4.49
MgO	2.86
SO_3	0.43
Na_2O	0.59
K_2O	0.63
Cl	----

Sample: Deposit from electrostatic precipitator, Test 7.3 (A 1720-21-22-22A)

Ash Fusibility		Oxidizing	Reducing
Initial	°C	1332	1299
Spherical	°C	1482+	1410
Hemispherical	°C	+	1477
Fluid	°C	+	1482+

Ash Analysis	
SiO_2	52.23
Al_2O_3	30.99
Fe_2O_3	6.26
Mn_3O_4	----
TiO_2	1.63
P_2O_5	0.40
CaO	4.87
MgO	1.66
SO_3	0.63
Na_2O	0.81
K_2O	0.68
Cl	----

DETAILED ANALYSES OF ASH FORMS PRODUCED IN PILOT-SCALE COMBUSTION TESTS BRITISH COLUMBIA HYDRO AND POWER AUTHORITY - CANMET JOINT PROGRAM

Hat Creek "C" Washed Coal
Air-Dried, 5% Excess Oxygen

PROGRESS REPORT 7.3D

by

THE STAFF OF THE CANADIAN COMBUSTION RESEARCH LABORATORY [1]

SUMMARY

As explained elsewhere [2], the results of this joint program are reported in a series of four reports numbered A to D for each of 18 combustion tests which make up the program. This progress report (7.3D) is the last of the series and presents results of the following detailed analyses of ash produced in test 7.3 done on November 24, 1976.

1. Particle size distribution of fly ash
2. X-ray diffraction analyses of fireside deposits
3. Combustion calculations

---

[1] Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (former Mines Branch), Department of Energy, Mines and Resources, Ottawa, Canada.

[2] "Pilot-Scale Combustion Tests with Coals from the Hat Creek Area of British Columbia, British Columbia Hydro and Power Authority - CANMET Joint Program. Objectives and Procedure". Report ERP/ERL 76/99 Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada. October 1976.

PARTICLE SIZE DISTRIBUTION OF FLY ASH

In the Table below and in the Figure on the following page are given the particle size analyses for fly ash collected from the tube sheet between the second and third passes of the air heater and for fly ash collected from the electrostatic precipitator. The analyses have been done using a combines sieve-Coulter-Counter technique, wherein the fraction passing 325 mesh (-44 micrometers)has been analyzed on the Coulter Counter. It must be remembered that the Coulter Counter, unlike most particle size-analysis techniques, relates particle volume to equivalent spherical diameter.

PARTICLE SIZE (Micrometers)		AIR HEATER	PRECIPITATOR
1.26 - 1.59	Coulter Counter		0.6
1.59 - 2.00	Coulter Counter		0.9
2.00 - 2.52	Coulter Counter		1.4
2.52 - 3.17	Coulter Counter		2.0
3.17 - 4.00	Coulter Counter	0.2	3.3
4.00 - 5.04	Coulter Counter	0.3	4.4
5.04 - 6.35	Coulter Counter	0.7	5.8
6.35 - 8.00	Coulter Counter	1.6	7.0
8.00 - 10.08	Coulter Counter	3.9	9.3
10.08 - 12.7	Coulter Counter	7.6	10.8
12.7 - 16.0	Coulter Counter	12.7	12.0
16.0 - 20.2	Coulter Counter	19.3	11.9
20.2 - 25.4	Coulter Counter	21.2	10.5
25.4 - 32.0	Coulter Counter	18.0	6.2
32.0 - 40.3	Coulter Counter	8.8	3.0
40.3 - 44.0	Coulter Counter	1.4	1.2
44.0 - 74.0	Sieve	3.1	4.1
+ 74.0	Sieve	1.2	5.6

The values given represent differential volume per cent and in the absence of information about variation of density with particle size, may be taken as weight per cent.

COULTER COUNTER® Model T&TA — **PARTICLE SIZE ANALYSIS**

.15 – 200μ
% PERCENT

COULTER ELECTRONICS INC.
590 W 20 ST.
HIALEAH, FLA. 33010

ORGANIZATION: CCRL – WRL

OPERATOR:

EQUIPMENT:

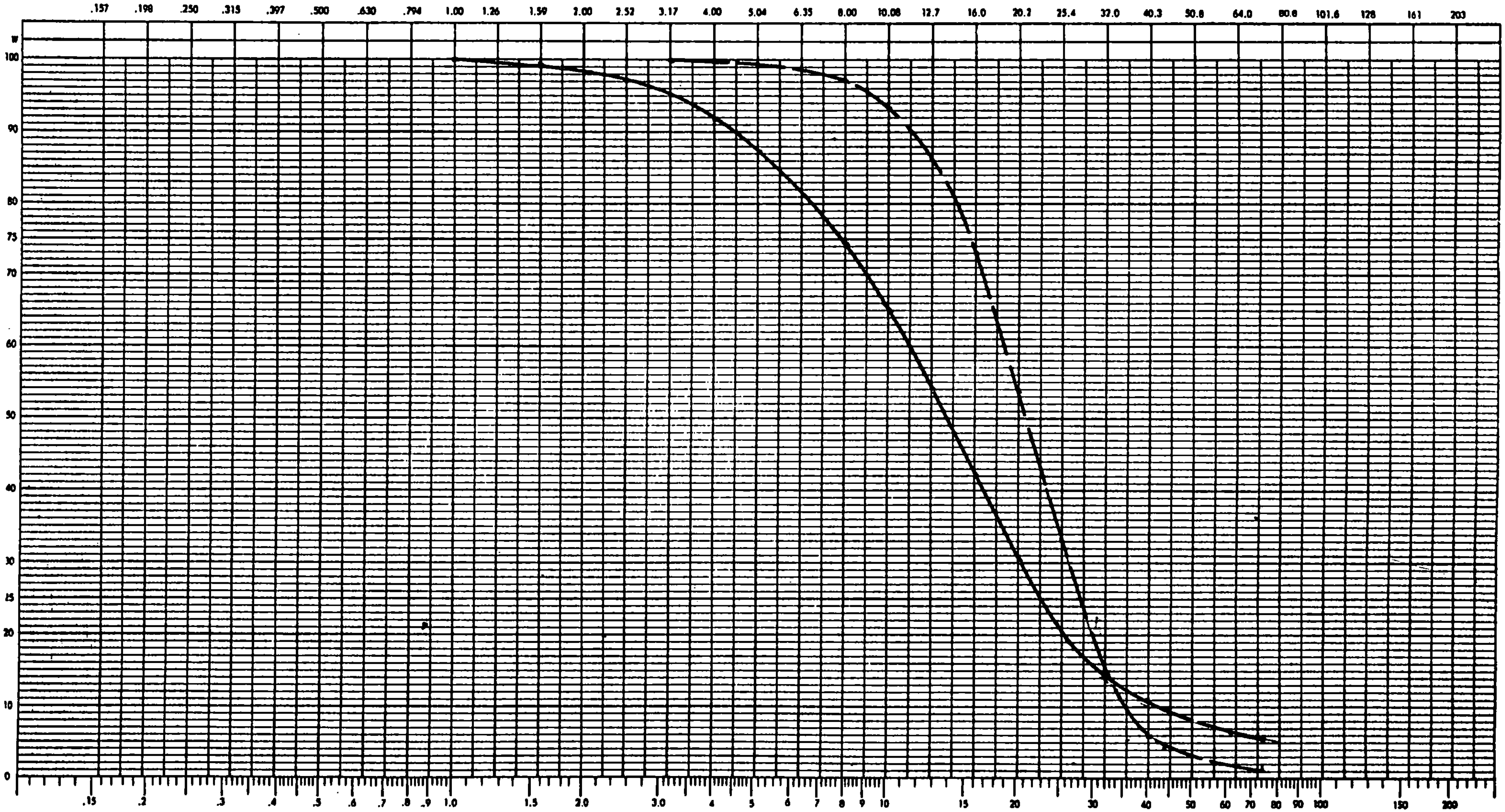
$k = d\sqrt[3]{2w}$ FOR MODEL T

$\frac{A2}{A1} = \left(\frac{d2}{d1}\right)^3$ when $W_2 = W_1$

$\frac{A2}{A1} = \left(\frac{d1}{d2}\right)^3$ when $W_2 = W_1$ FOR MODEL TA

SAMPLE SETTINGS

SAMPLE	ELECTROLYTE	DISPERSANT	APER. SIZE	SERIAL		PART DIA.	W	± IA	A	DIA.	W	± IA	A
TEST No. 7·3	ISOTON	ULTRASONIC	100μ	6102033									
ESP ————													
AH2 - - - -													



4221010

X-ray Diffraction Analyses of Fireside Deposits from Test 7.3, "C-washed" coal from Hat Creek.

Furnace Bottom Ash (1747 76-493)	Mull, Feld, Crist, Hem
Under Flame Probe Deposit (1714 76-494)	Hem, Mull, Mag, Feld, Amorph
Furnace Probe Deposit (1716 76-495)	Mag, Hem, Mull (tr), Amorph
Transition Probe Deposit (1718 76-496)	Hem, Mull, Crist (tr), Amorph

Abbreviations of Constituents:

Feld	Feldspar (Anorthite) $CaO.Al_2O_3.2SiO_2$
Crist	Cristobalite SiO_2
Mull	Mullite ($3Al_2O_3.2SiO_2$) or Sillimanite ($Al_2O_3.SiO_2$)
Hem	Hematite Fe_2O_3
Mag	Magnetite Fe_3O_4 (or spinel-type close to this composition)
Amorph	Significant amorphous material present.

Notes:

There is little indication of amorphous material in Furnace Bottom Ash samples. All others appear to contain some amorphous material, particularly where indicated.

Most films contain a few faint diffractions that were not identified.

A combination of cristobalite and quartz is similar to mullite, causing some ambiguity in identification. Mullite and sillimanite give very similar diffraction patterns. It is very doubtful that they can (or should) be distinguished in mixtures such as these.

Constituents are listed in decreasing order of abundance.

The sampling method is not representative and the oreder of abundance may be different from that of other larger samples.

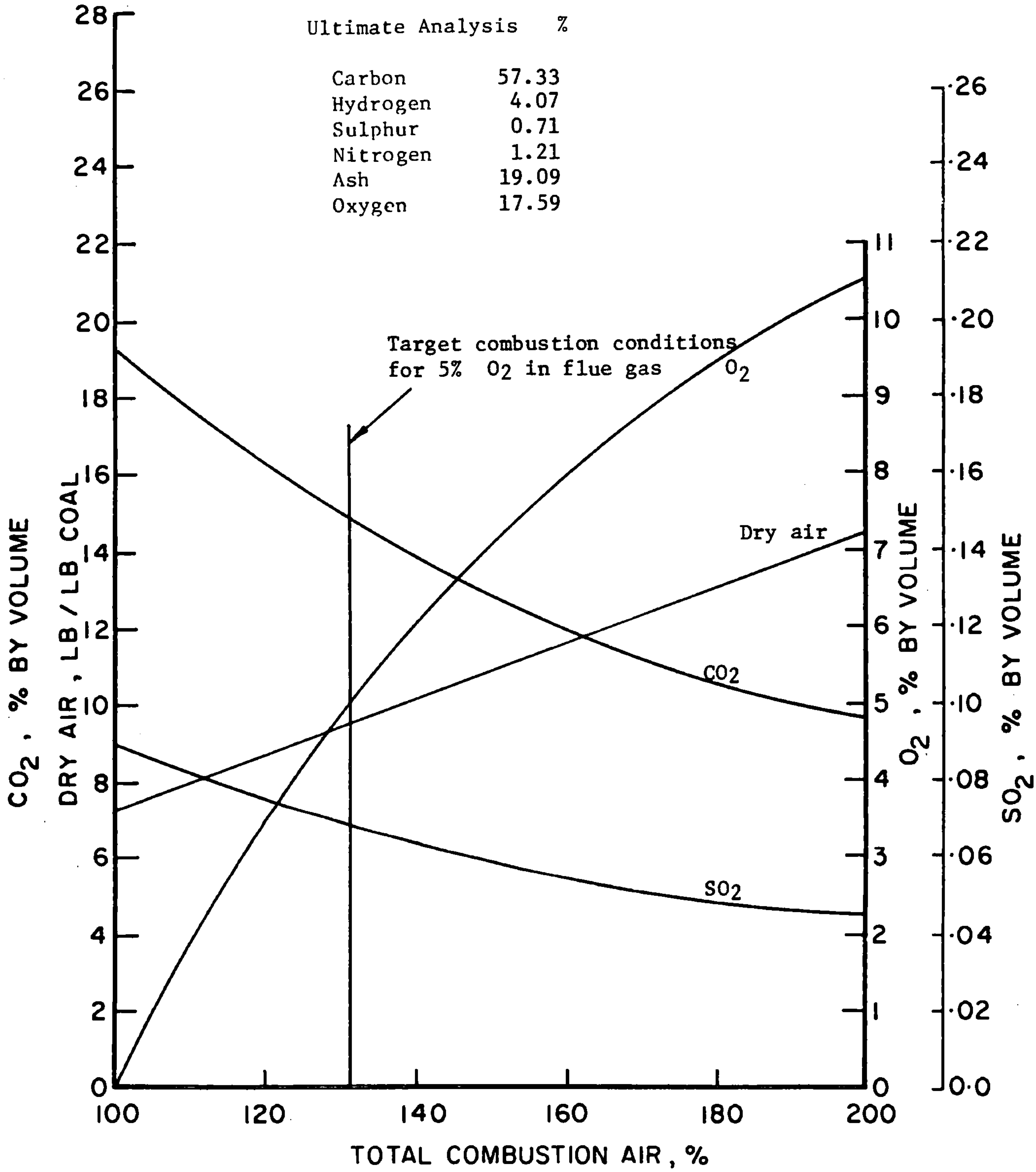


FIGURE 1: Combustion Calcultions, "C-Washed" Coal.

ACKNOWLEDGEMENTS

The authors wish to express their sincere appreciation for the generous support provided by both CANMET and B. C. Hydro throughout this research project. In particular, the effective co-operation and invaluable assistance received from the pilot-plant staff of CCRL and M. H. French of B. C. Hydro is gratefully acknowledged. Special thanks are also due to the following CANMET personnel: B. N. Nandi for petrographic examinations, W. J. Montgomery for coal and ash analyses, D. C. Harris for X-ray diffraction and differential thermal analyses and Mrs. A. Splett for assistance in report preparation.