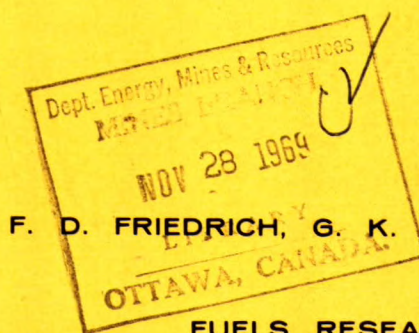




DEPARTMENT OF
ENERGY, MINES AND RESOURCES
MINES BRANCH
OTTAWA

*COMBUSTION AND FOULING
CHARACTERISTICS OF
TWO CANADIAN LIGNITES*



F. D. FRIEDRICH, G. K. LEE AND E. R. MITCHELL

FUELS RESEARCH CENTRE

AUGUST 1969

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COMBUSTION AND FOULING CHARACTERISTICS OF TWO CANADIAN LIGNITES

by

F. D. Friedrich^{*}, G. K. Lee^{**} and E. R. Mitchell^{***}

ABSTRACT

The report describes combustion tests with Bienfait lignite from Saskatchewan and Onakawana lignite from James Bay. These were burned in a pilot-scale pulverized-fired boiler primarily to study combustion performance and fireside fouling tendencies under slag-tap conditions. Flame stability and complete combustion were readily obtained, although satisfactory slag tapping was not achieved with either fuel.

Exhaustive analytical work was carried out on deposit samples representing each fuel, collected from various parts of the boiler. The results indicate that, in the combustion of Bienfait lignite, selective deposition of ash constituents takes place, resulting in an eutectic composition downstream of the furnace exit. Deposit analyses, fusion temperatures and enrichment ratios are given for both fuels.

* Senior Scientific Officer, ** Research Scientist, and *** Head, Canadian Combustion Research Laboratory, Fuels Research Centre, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

Direction des mines
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CARACTÉRISTIQUES DE COMBUSTION ET D'ENCRASSAGE DE
DEUX LIGNITES CANADIENS

par

F.D. Friedrich*, G.K. Lee** et E.R. Mitchell***

RÉSUMÉ

Le présent rapport décrit des essais de combustion pratiqués sur du lignite de Bienfait (Saskatchewan) et d'Onakawana (près de la baie James). Les échantillons ont été brûlés dans une chaudière d'essai à l'état pulvérisé en vue surtout de déterminer l'efficacité de combustion et les tendances à l'encrassage aux environs du foyer sous des conditions propres au décrassage. Les deux types de combustible ont donné une flamme stable et se sont consumés entièrement, bien que ni l'un ni l'autre n'ait permis un décrassage satisfaisant.

Des analyses détaillées ont été pratiquées sur des échantillons de dépôts de chaque combustible, recueillis en divers endroits de la chaudière. Les résultats ont révélé que les constituants de la cendre du lignite de Bienfait se déposent sélectivement et présentent une composition eutectique après la sortie du four. L'analyse des dépôts, les températures de fusion et les taux d'enrichissement sont fournis pour chacun des combustibles.

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1. INTRODUCTION

Saskatchewan lignite, being an important Canadian energy resource, has been of continuing interest to the Canadian Combustion Research Laboratory (CCRL), and in recent years research has been carried out on a rig-scale pulverized-fired boiler to study combustion performance, air pollution emission, low-temperature corrosion potential, and the fireside fouling tendencies for which Saskatchewan lignite fly ash is rather notorious. Concurrently, at the request of the Alberta Coal Company, CCRL carried out similar research on Onakawana lignite from the James Bay area.

The present report summarizes the results for both fuels. Although of the same rank, these two lignites differ substantially in physical structure and, more important, in their fouling characteristics. Extensive analysis of fly-ash samples obtained progressively through the boiler system indicate that this may be due to selective deposition of certain ash constituents, leading to enrichment of others.

2. THE PILOT-SCALE RESEARCH BOILER

The combustion research boiler, schematically illustrated in Figure 1, is a pilot-scale, pulverized-coal-fired boiler that incorporates two opposed burners which tilt downward over a refractory slag chamber. The furnace is of membrane-wall construction and operates at a pressure of about 5 in. W.G. The boiler generates 1600 lb/hr steam at 100 psig which is dissipated in an air condenser.

Crushed coal is supplied from a 5-ton hopper through a variable-speed worm feeder to a ring-and-roller pulverizer, shown in Figure 2, which is normally swept and pressurized by air at any temperature up to 450°F. If necessary, the pulverizer can be also swept and pressurized with a mixture of air and flue gas at any temperature up to 900°F. The pulverizer contains a variable-speed classifier for controlling coal fineness, and a simple splitter at the pulverizer outlet proportions the coal flow to each burner. Secondary air can be supplied to the burners at any temperature up to 500°F.

Combustion gases leave the furnace between 1400°F and 1600°F, pass through a transition section, and then traverse a test air heater which will serve as a simulated superheater for future high-temperature corrosion studies. Finally, the combustion gases pass through a conventional three-pass air heater before entering the stack at 400°F or more.

A forced-draft fan supplies air to the air heater at 26 in. W.G. The air on leaving the air heater is divided into three streams: primary air to the pulverizer, secondary air to the burners, and cooling air to the test air heater. The last stream, after leaving the test air heater, can either be exhausted to atmosphere or be blended with the primary air supply to the pulverizer.

The research boiler is manually controlled, except for some electrical interlocks to ensure that safe start-up and shut-down procedures are followed. It has been possible to operate with as little as 0.6 per cent O_2 , no more than 0.1 per cent CO in the flue gases, and a smoke density of less than No.1 Ringelmann. However, the gas-side pressure drop between the furnace exit and stack limits full-load operation to maximum O_2 levels, in the flue gases, of between 3.5 per cent and 5 per cent, particularly when severe fouling of convective heat transfer surfaces occurs.

The combustion tests were carried out at full-load rating of the research boiler, i.e. 2.5 million Btu/hr input, or a volumetric heat-release rate of 75,000 Btu/cu ft/hr, using two opposed in-shot burners shown schematically in Figure 3. Measurements of air pollutants, corrosion potential and fireside deposits were carried out at excess-oxygen levels of 3% and 5%, as described later.

3. TEST MEASUREMENTS

The following are the principal parameters that were measured during the combustion performance tests with both Onakawana and Bienfait lignite. The stations at which the measurements were taken are designated by numbers as shown in Figure 1.

- (a) Fuel and ash analyses, pulverizer inlet.
- (b) Fineness of coal grind, pulverizer outlet.
- (c) Flame temperature and length of flame, Station 2.
- (d) CO₂, CO and O₂ by continuous monitor, Station 4.
- (e) Acid dewpoint by BCURA dewpoint meter, Station 7.
- (f) SO₃ by Shell-Thornton condensation method, Stations 2 and 7.
- (g) SO₂ by API Method 774-54, Stations 2 and 7.
- (h) NO_x by USBM Method 6970, Stations 2 and 7.
- (i) Rate of iron wastage by corrosion probe at 220°F, Station 7.
- (j) Particulate matter in flue gases by a combined cyclone-filter arrangement, Stations 4 and 7.
- (k) Electrical resistivity of fly ash, Stations 4, 7 and 8.
- (l) Particle-size distribution of fly ash, Stations 4, 7 and 8.
- (m) Chemical analysis, ash fusion determinations, X-ray diffraction and petrographic examinations of combustion residues, Stations 1, 3, 4, 5 and 6.
- (n) Efficiency of fly-ash collection by electrostatic precipitation, Stations 7 and 9.

4. EXPERIMENTAL DATA

4.1 Combustion Performance

The analytical data for the Onakawana and Bienfait lignites tested are given in Table 1. In the as-received state, the Onakawana lignite resembled charred wood, as shown in Figure 4. It was found to have an equilibrium moisture of about 37%, but the sample as received at CCRL was about 48% water. A preliminary trial showed that while the coal in this condition could be burned, passing it through the hammermill crusher was difficult, almost like mashing potatoes. The crushed coal then frequently hung up in the chute to the pulverizer, and even though the pulverizer was swept with air at about 500°F the high moisture content delayed ignition to such an extent that the combustion chamber, the furnace and most of the test air heater were filled with flame. However, after this experience the rest of the six-ton sample

was air-dried to about 27% moisture, whereupon it passed through the crusher readily, was pulverized without difficulty, and burned more or less completely in the combustion chamber.

In designing a large plant to burn Onakawana lignite, it would probably be advantageous to provide for much higher gas or air temperatures to the pulverizer. For example, boilers designed to burn German brown coal, which contains about 60% moisture, commonly use beater mills supplied with a mixture of air and furnace gases, at a temperature of about 1500°F.

Since pre-drying appears to be necessary, in a full-size plant it would probably be most practical to do so with heat from the plant, perhaps using steam coils, or direct heat exchange using waste flue gas. Drying the coal from 48% moisture to 27% moisture represents a heat loss of about 4.3% of heat input. This loss would have to be accepted even if the coal were fired wet; hence it would seem better to accept it in the form of pre-drying and thereby get the benefits of improved combustion and more economical furnace design. Because of the nature of the deposits, surface moisture may on occasion be very high, and the possibility of reducing it by mechanical means such as centrifuging may be worth investigating.

To study the effect of fineness of grind on the combustion performance of Onakawana lignite, the motor-driven classifier which is built into the pulverizer was adjusted to different speeds. At each speed the fineness of grind was measured and related by visual observation to length and stability of the flame. Some of the results are given in Table 2. The optimum classifier setting seemed to be 55 rpm, producing about 72% through 200 mesh, which resulted in a stable, fairly short flame with good burnout. Coarser grinds gave unsteady flames with large quantities of "sparklers" in the test air heater, while finer grinds reduced the capacity of the pulverizer. Optimum flame characteristics of Bienfait lignite seemed to occur at much the same classifier speed but, as can be seen from Table 2, this produced a substantially finer grind. Visual evaluation of the effect of fineness of grind on flame characteristics is admittedly imprecise due to the high turbulence resulting from the furnace configuration. Observations of greater reliability could be obtained from a front-wall-fired furnace, or in a tunnel furnace.

The CCRL ring-and-roller pulverizer is rated at 400 lb/hr of Bienfait lignite, pulverized to 80% through 200 mesh, and no difficulty was experienced in pulverizing 450 lb/hr of Onakawana lignite to 72% through 200 mesh. The differences in grindability and combustion characteristics may be due to the unconsolidated structure and relatively low bulk density of the Onakawana lignite, Table 1. Data from Hardgrove grindability tests on both lignites varied widely, particularly with Onakawana lignite. However, this was not unexpected because it is generally conceded that the Hardgrove index is not a reliable guide to the grindability of lignites that have widely varying organic constituents.

The low ash-fusion temperature of Onakawana lignite suggests the feasibility of slag-tap operation. However, when the lignite was burned alone in the research boiler with flame temperatures ranging from 1935°F to 2095°F, the slag was not rendered sufficiently fluid for continuous tapping. Much of the ash melted in the furnace bottom but it needed the higher temperature of an oil torch for periodic draining (see Figure 5). Possibly in a utility-size furnace a slagging temperature could be achieved with Onakawana lignite at high loads and oil flames could be used to maintain tapping at low loads. On the other hand, there is the possibility that either a unique combustion-chamber design could be developed for long residence time, or moisture-separating burners of a type used in Europe (1) could be adapted to overcome the low flame temperatures that seem to be an inherent drawback of high-moisture coals. Alternatively, the problem of low flame temperatures may be overcome by the use of an indirect firing system in which the pulverized coal is separated from its moisture-laden air in a storage bin before being injected into the furnace with hot primary combustion air. In such a system, the moisture-laden air must be passed through a bag filter before being exhausted to atmosphere to avoid excessive losses of fine coal.

An interesting observation was that Onakawana lignite slag was more fluid than that of the Bienfait lignite tested. The latter had an as-received moisture of 36%, was air-dried to 21% moisture during one year of storage, then was direct-fired and burned with a clean, stable flame at temperatures of 2125°F to 2295°F. Much of the Bienfait ash sintered in the furnace bottom, although some of it slagged, but continuous tapping could not be achieved without the assistance of an oil torch.

Possibly the most significant aspect of the combustion tests carried out with Onakawana lignite is that it produced a lower flame temperature and exhibited none of the massive, tenacious, fireside-fouling tendencies of Bienfait lignite. Normal soot blowing sufficed to keep the furnace exit and air heaters reasonably clean when burning Onakawana lignite.

The observations from the Onakawana combustion tests are based on one six-ton sample and it would be unwise to jump to conclusions without testing samples from many parts of the coal field, because of unexpected inconsistencies. However, if Onakawana lignite does not tend to foul fireside surfaces, it holds an important economic benefit.

4.2 SO₂, SO₃, NO_x, Acid-dewpoint and Corrosion-rate Measurements

Typical SO₂, SO₃, NO_x, acid dewpoint and corrosion rate measurements taken at the breeching with 3% O₂ and 5% O₂ in the flue gases, are given in Table 3. The SO₂ levels are normal for coals containing 0.5% sulphur but the SO₃ levels are relatively high, particularly with 5% O₂ in the flue gases. Fortunately, the corrosive effect of these high SO₃ levels is completely neutralized by cationic ash constituents in both the Onakawana and Bienfait lignite; this is reflected in the absence of an acid dewpoint and in the minimal corrosion rate of iron at 220°F. The Onakawana lignite produced NO_x levels that were significantly lower than those produced by Bienfait lignite, presumably because low NO_x levels are consistent with low flame temperatures.

4.3 Fly Ash, Fireside Deposits and Slag Characteristics

To assess the influence of flame temperature and ash properties on ash-fouling tendency, the combustion residues from Onakawana and Bienfait lignites were subjected to numerous physical and chemical tests, including chemical analyses, petrographic examinations, X-ray diffraction analyses, ash-fusion determinations, and particle-size analyses. The results of tests conducted on selected samples of fly ash, deposits and slag are discussed below.

4.3.1 Fly Ash

Typical chemical analyses of fly ash extracted from flue gases containing 3% O₂ are given in Table 4. These analyses show that the Onakawana fly ash contains a low total alkali and a small amount of water-soluble sulphate whereas the Bienfait fly ash contains a relatively high total alkali and a large amount of water-soluble sulphate. It can also be seen that the ratio of water-soluble alkali to total alkali was only 0.2 for Onakawana fly ash but was over 0.7 for the Bienfait fly ash.

These analyses suggest that fireside fouling is directly related to the following three components of fly ash: (a) total alkali, (b) water-soluble sulphate, (c) water-soluble alkali. Brown et al. (2) stated that the sodium content of lignitic ash deposits is a prime factor in initiating but not in bonding the deposits, while Gronhovd et al. (3) determined that the rate of fouling was a function of total sodium in the lignite ash.

Additional analytical work revealed that nearly all of the alkali was concentrated preferentially in the superfine particles of both Onakawana and Bienfait fly ash. In the case of Bienfait fly ash, the alkali content of the superfine particles was over 50% by weight. Thus, superfine ash particles may be the dominant bonding agent in the formation of massive deposit build-up.

The particle-size analyses, Table 5, together with petrographic examinations of fly-ash samples from Onakawana and Bienfait lignite, revealed that most of the +74 μ particles were composed of char and that the size of the fly-ash particles became progressively smaller between the furnace exit and the breeching. The latter phenomenon, which is clearly illustrated in Figures 6 and 7, suggests that the large particles are being progressively (a) reduced in size by delayed combustion of any unburned carbon, (b) removed from the gas stream by deposition on boiler surfaces, or (c) outnumbered by superfine alkali particles that sublime from vapour phase. Using the apparatus illustrated in Figure 8, the measured electrical resistivities of the fly-ash samples shown in Figures 6 and 7 were all in excess of $\Omega/\text{C.M.} \times \text{ft.}^*$

*Ohms per circular mill foot.

In general, the combustion of high-ash, low-sulphur lignites in slag-tap boilers produces large concentrations of fine dust having high electrical resistivities. This type of dust adheres to and insulates the collecting surfaces of electrostatic precipitators so that collection efficiencies are drastically reduced. However, German experience (4) with brown coals has shown that reasonably high collection efficiencies can be maintained if the electrostatic precipitator is designed with extra-large collecting surfaces and with particle migration velocities of less than 5 cm/sec.

Research work with a small-scale electrostatic precipitator at CCRL confirms the German findings and, as shown in Table 6, the fly ash from Onakawana and Bienfait lignites was collected at efficiencies of 99.5% and 98.0% respectively. The dust residuals, being only 0.03 grains/SCF* or less, are well below rigid standards for air pollution control.

4.3.2 Fireside Deposits

4.3.2.1 Onakawana lignite

The fireside deposits from Onakawana lignite were generally powdery in structure and were readily removed from the tube surfaces by periodic soot blowing. At the end of each test, the furnace walls and screen tubes were covered with about 1/4 in. to 1/2 in. of deposit, while the test air heater and the air heater were relatively clean. The deposits contained mostly quartz, with small amounts of pyroxene and calcium sulphate.

The differences in chemical composition of the Onakawana ash deposits taken from different locations in the boiler are shown in Table 7, and are plotted as a series of enrichment ratios in Figure 9. The enrichment ratio is defined as the ratio of the percentage elemental oxide in the deposit sample to the percentage elemental oxide in the lignite ash, and the series shows that, with the exception of iron and sulphur, all deposits have essentially the same composition as the indigenous ash. The relatively constant chemical and mineral composition of the deposits from different boiler locations suggests that the constituents of Onakawana ash do not readily volatilize or liquefy at the gas temperatures which prevailed downstream of

*Standard cubic foot.

the furnace throat, and that the fly ash passes through the boiler without selective deposition of mineral components. This inference is supported by the friable nature of the deposits, such as the powdery build-up shown in Figure 11, and by the fact that deposit build-up could be controlled by routine soot blowing.

4.3.2.2 Bienfait lignite

The deposits from Bienfait lignite were relatively hard and so strongly sintered that they could not be dislodged by soot blowing. Consequently, the gas passages through the screen tubes bridged rapidly and heavy ash deposits formed on the furnace walls, the tubes of the test air-heater and the air-inlet tubesheet of the main heater.

By the X-ray diffraction method, all of the Bienfait deposits were found to contain minor amounts of quartz, a number of identified complexes, and some amorphous matter. The last is probably a silicate glass, because the chemical analyses and the corresponding enrichment ratios, given in Table 7 and Figure 10 respectively, show little change in silicon content with boiler location.

By referring to Figure 10 it can be seen that the ash deposited between the screen tubes and the test air-heater is characterized by a eutectic which apparently results from a significant depletion of iron and magnesium and a significant enrichment of sodium, calcium and sulphur. Unfortunately, this eutectic occurs immediately downstream of the furnace exit and is in all probability mainly responsible for severe fouling of convective heat transfer surfaces.

The strong tendency of Bienfait lignite to form heavy deposits is evident from Figure 12 which shows a microphotograph of an upstream edge of a deposit taken from the screen tubes. The grey outer layer of this multi-layered deposit is hard and dense, while the black interior core is lightly sintered; the white areas in the outer layer are voids.

The foregoing analytical work indicates that the severe fouling of tube surfaces by ash from Bienfait lignite is due to selective deposition of complex alkali sulphates and silicates on tube surfaces, particularly in the high-temperature region of the boiler. Both of these alkali complexes, which are sticky above 1500°F, will effectively cement particles of ash into a bulky semi-fused mass on tube surfaces.

4.3.2.3 Slag

During tapping of the furnace bottom the highly fluid Onakawana slag drained readily, while the moderately viscous Bienfait slag drained slowly. This difference in flowability is due to the amount and type of the mineral compounds produced in the slag melt and the rate at which these minerals cool. Accordingly, petrographic examinations of slag from both Onakawana and Bienfait lignite were carried out to study the effect of mineral composition and structure on slag flowability.

It was found that the Onakawana slag contained 12 to 18 per cent silica and 45 to 55 per cent voids; the remainder of the slag was a glass with no identifiable phases. In Figure 13, which shows a typical thin section of this slag, the white areas are grains of silica, the grey circular areas are voids and the black background is glassy matter. The relatively uniform pore distribution between the outer and the inner layers of solidified slag "stalactites" that formed while tapping, Figure 14, suggests that the slag solidified gradually.

In contrast, thin sections of Bienfait slag contained a silica content of less than 2 per cent, a massive boxwork of small crystals, and some glassy matter (particularly in the inner layer of the solidified slag "stalactites"). In Figure 15 which shows a thin section of the inner layer of a slag "stalactite", the small, circular white areas are silica grains, and the black areas are glass. The outer slag layer, Figure 16, was characterized by fine silica and box-like crystals and by large voids in the vicinity of the outer surface. These physical features indicate that the Bienfait slag solidifies rapidly during tapping and that its apparent viscosity may be increased significantly by the evolution of gases during cooling.

5. CONCLUSION

While Onakawana lignite is a low-grade energy resource, it is better than many in use throughout the world, and there appears to be no technical obstacles to its utilization that research and sound engineering cannot overcome.

The combustion of Onakawana lignite in a slagging system produced friable deposits that were easily removed by routine soot blowing. In general, deposit build-up was not excessive and deposit composition, with the exception of sulphur, did not change appreciably with location in the boiler.

With Bienfait lignite, slagging combustion produced, in the high-temperature region of the boiler, strongly bonded deposits that were rich in water-soluble alkali sulphates. These deposits, particularly at the furnace exit where a eutectic composition occurred, were difficult to remove by soot blowing. The eutectic composition apparently resulted from a significant depletion of iron and magnesia and a significant enrichment of calcium, sodium and sulphur. Therefore, injection of MgO ahead of the screen tubes may control deposit structure sufficiently to permit removal by soot-blowing.

6. ACKNOWLEDGEMENTS

Dominion Coal Board research grants-in-aid which have supported the CCRL research program for a number of years have been invaluable in making this combustion investigation possible. The technical assistance of the Solid Fuels and the Gas Analysis Sections of the Fuels Research Centre is gratefully acknowledged. Thanks are also due to the Saskatchewan Power Corporation and to Alberta Coal Limited for providing the coal used in the trials.

The combustion-rig tests were carried out under the supervision of R. G. Fohse, assisted by D. G. Savignac, B. C. Post, R. K. Jeffrey, W. D. Shaw and H. Raghunandan, all of the CCRL staff.

7. REFERENCES

1. Froelich, P., "Operating Method and Working Behaviour of a Sulzer Monotube Boiler Firing Brown Coal", Brennstoff-Waerme-Kraft, Vol. 16 (1964), No. 10.
2. Brown, H.R., Durie, R.A., and Taylor, G.H., "Factors Influencing the Formation of Fireside Deposits During the Combustion of Morwell Brown Coal" in The Mechanism of Corrosion by Fuel Impurities (Butterworths, London, 1963), pp 469-483.
3. Gronhovd, G.H., Wagner, R.J., and Wittmaier, A.J., "Comparison of Ash Fouling Tendencies of High- and Low-Sodium Lignite from a North Dakota Mine", Proc. 1966 Amer. Power Conf., Chicago, Ill., Vol. XXVIII, pp 632-644.
4. Engelbrecht, H.L., "Electrostatic Precipitators in Thermal Power Stations Using Low-Grade Coal", Proc. 1966 Amer. Power Conf., Chicago, Ill., Vol. XXVIII, pp 516-524.

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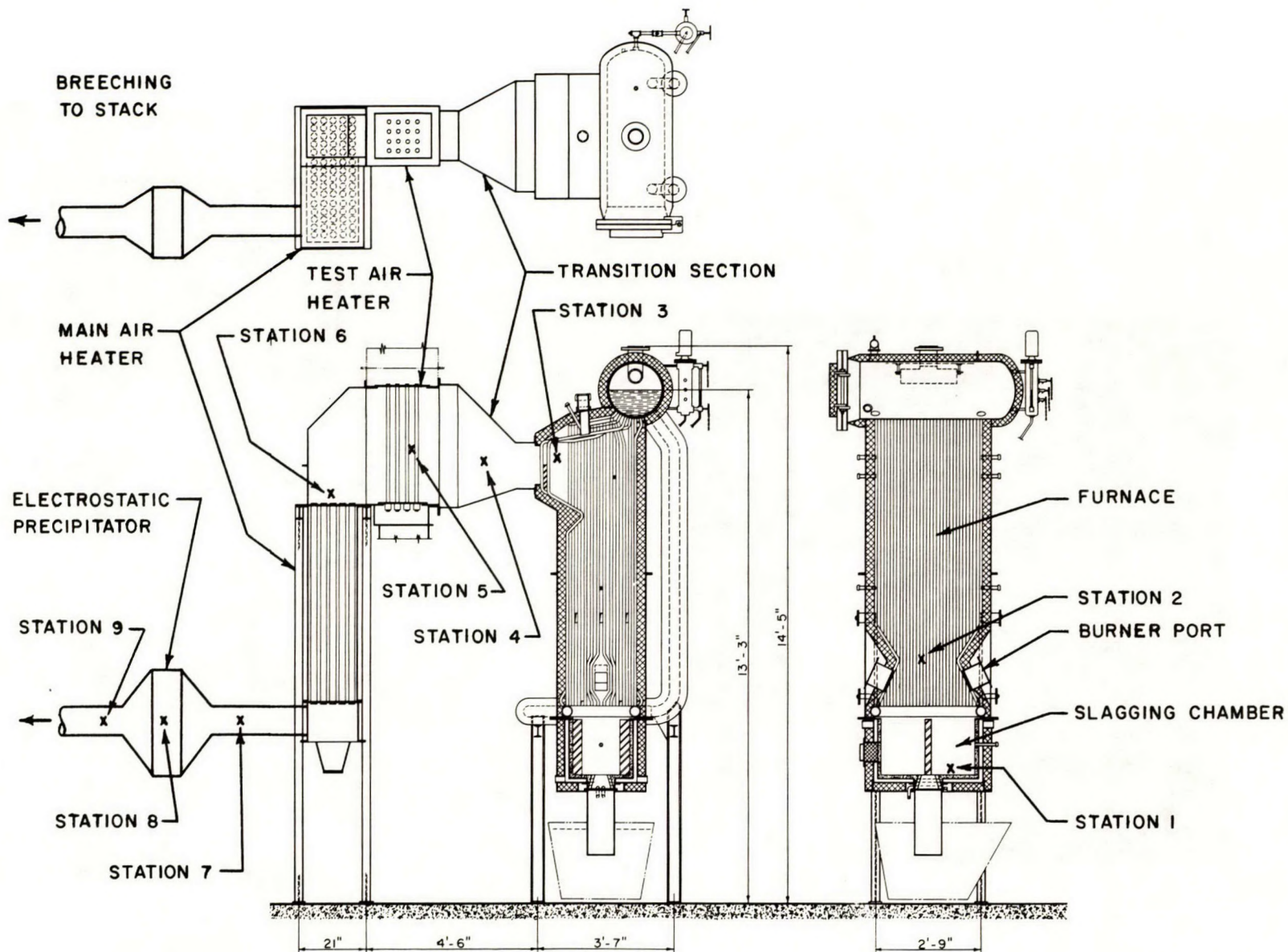


Figure 1. Pilot-scale research boiler, showing location of sampling stations.

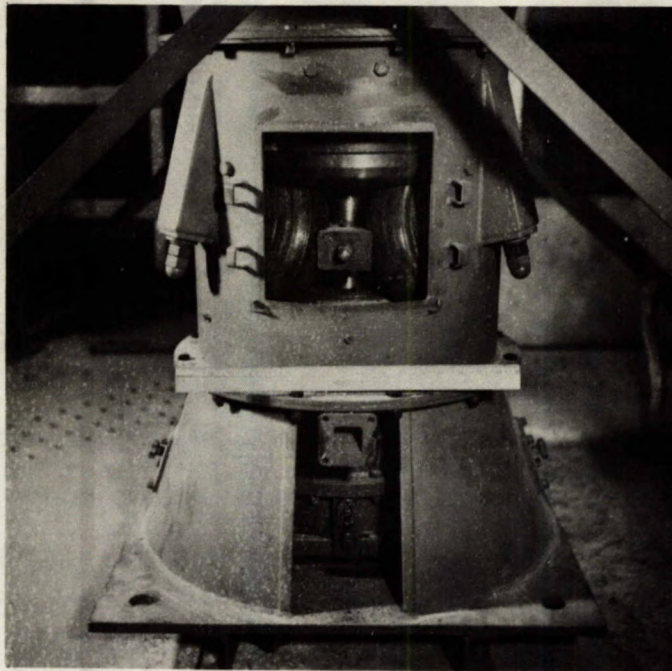


Figure 2. View of ring-and-roller pulverizer.

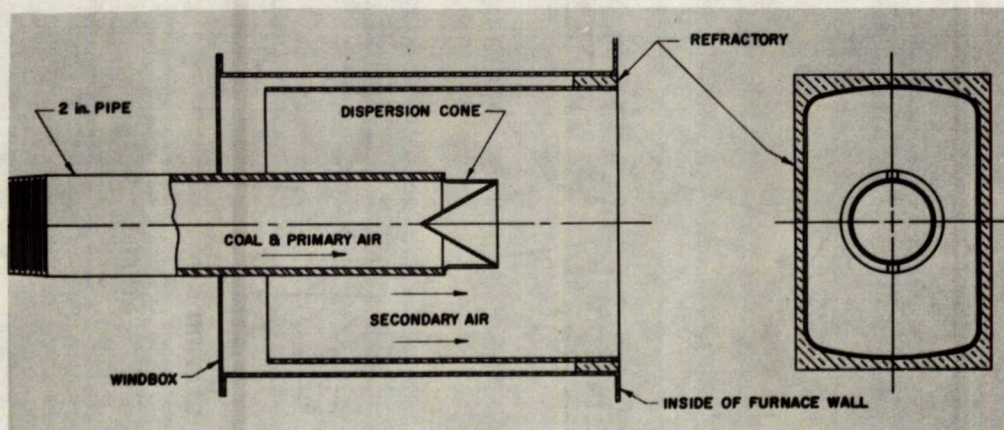


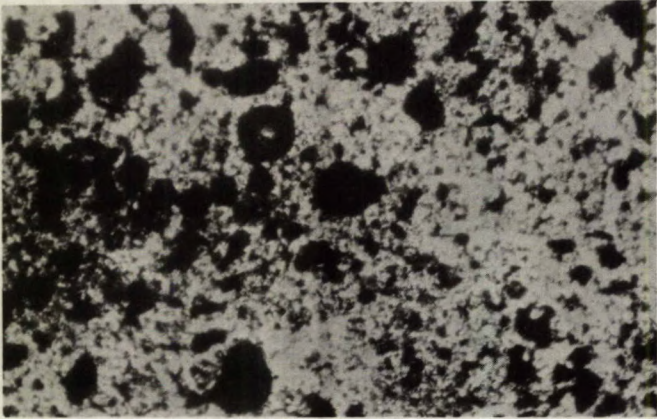
Figure 3. Diagram of coal burner used during tests.



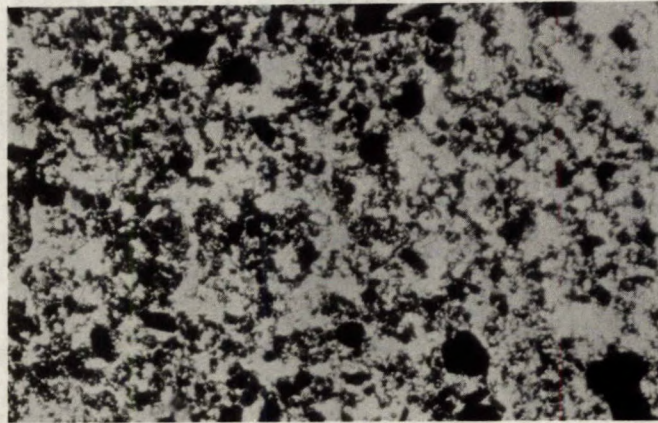
Figure 4. As-received samples of Onakawana lignite.



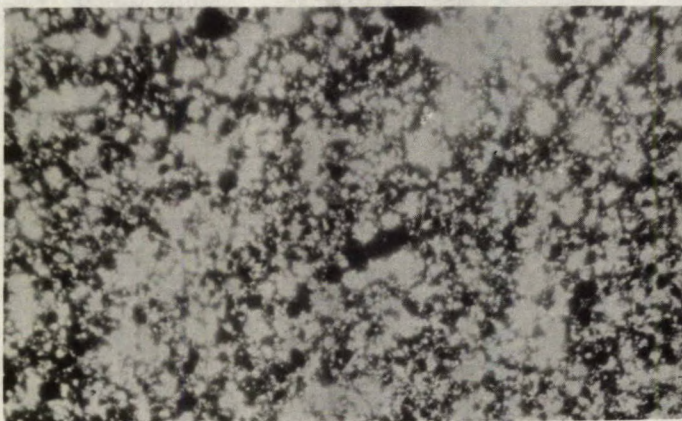
Figure 5. Slag from Onakawana lignite, tapped from the slagging chamber with an oil flame.



(a) Station 4
(Transition section)

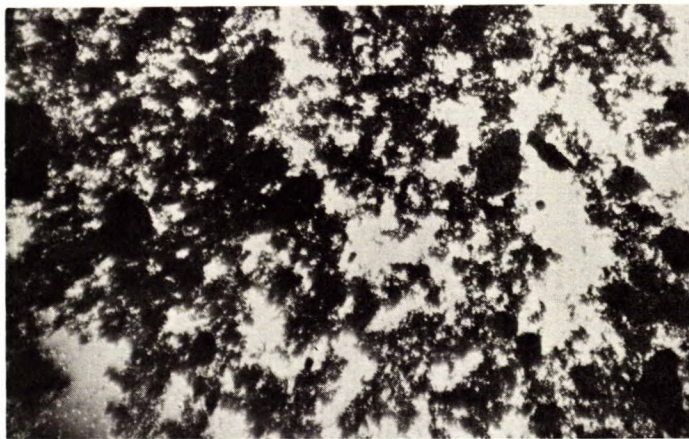


(b) Station 7
(Air-heater exit)

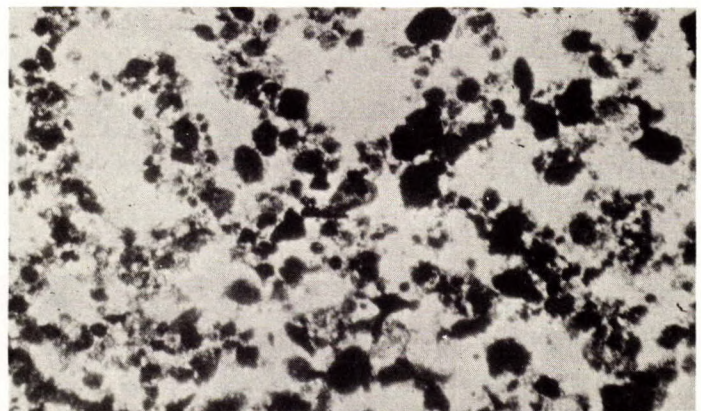


(c) Station 9
(Electrostatic precipitator)

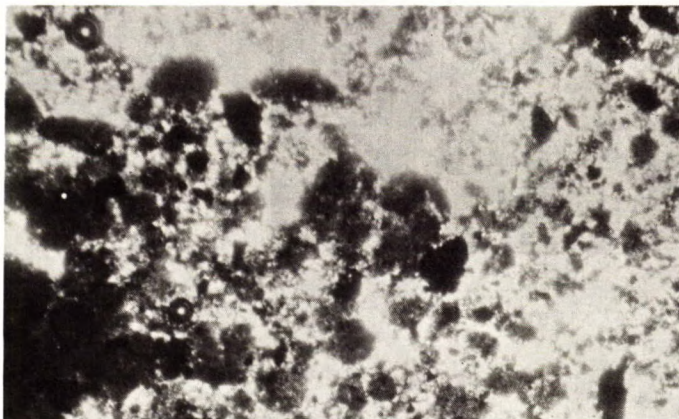
Figure 6. Fly ash from Onakawana lignite.



(a) Station 4
(Transition section)

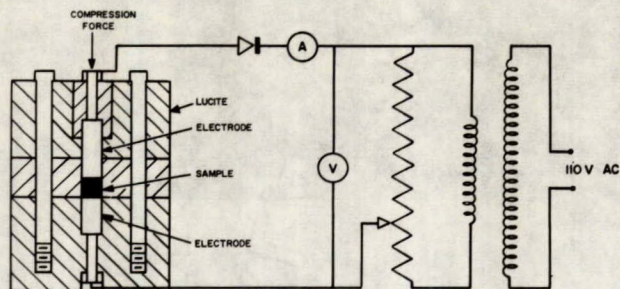


(b) Station 7
(Airheater exit)

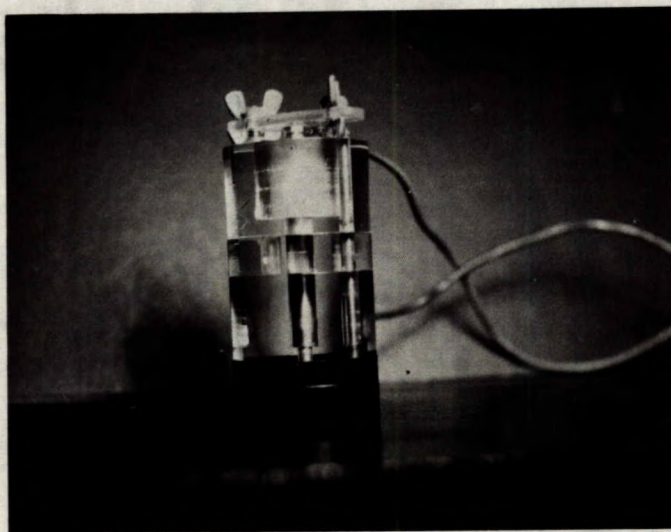


(c) Station 9
(Electrostatic precipitator)

Figure 7. Fly ash from Bienfait lignite.



(a) Schematic illustration.



(b) Measuring cell assembly.
Scale: X0.4.

Figure 8. Electrical-resistivity apparatus.

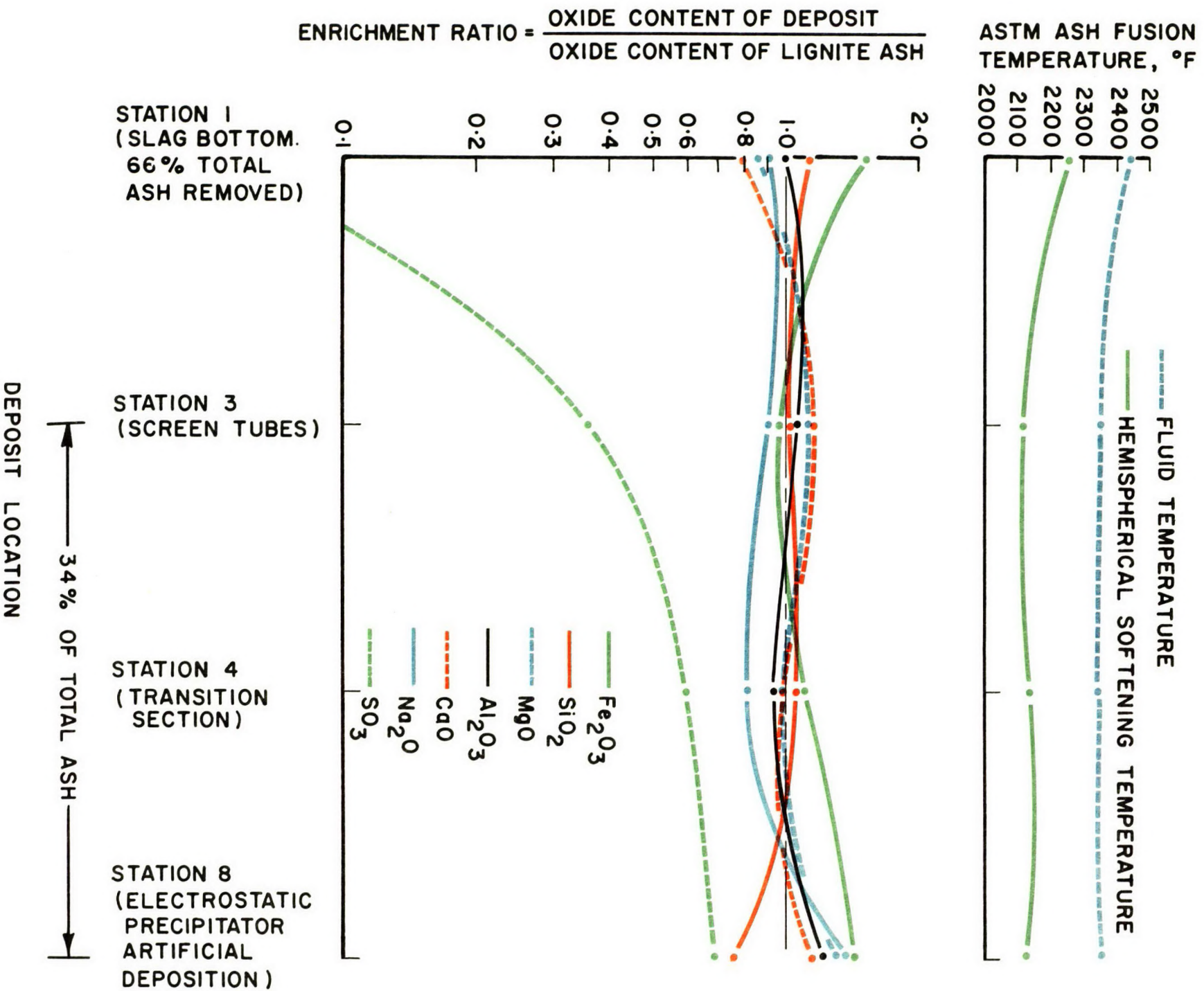
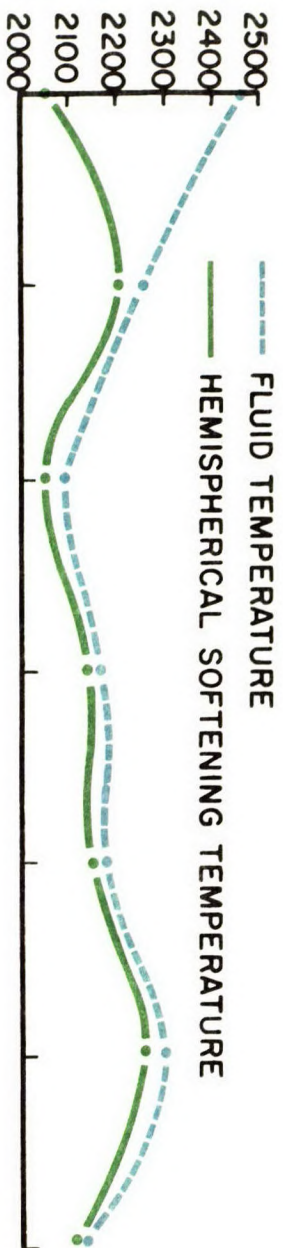


Figure 9. Variation in enrichment ratio and ash fusion temperature of fireside deposits with boiler location when burning Onakawana lignite.

ASTM ASH FUSION
TEMPERATURE, °F



ENRICHMENT RATIO = $\frac{\text{OXIDE CONTENT OF DEPOSIT}}{\text{OXIDE CONTENT OF LIGNITE ASH}}$

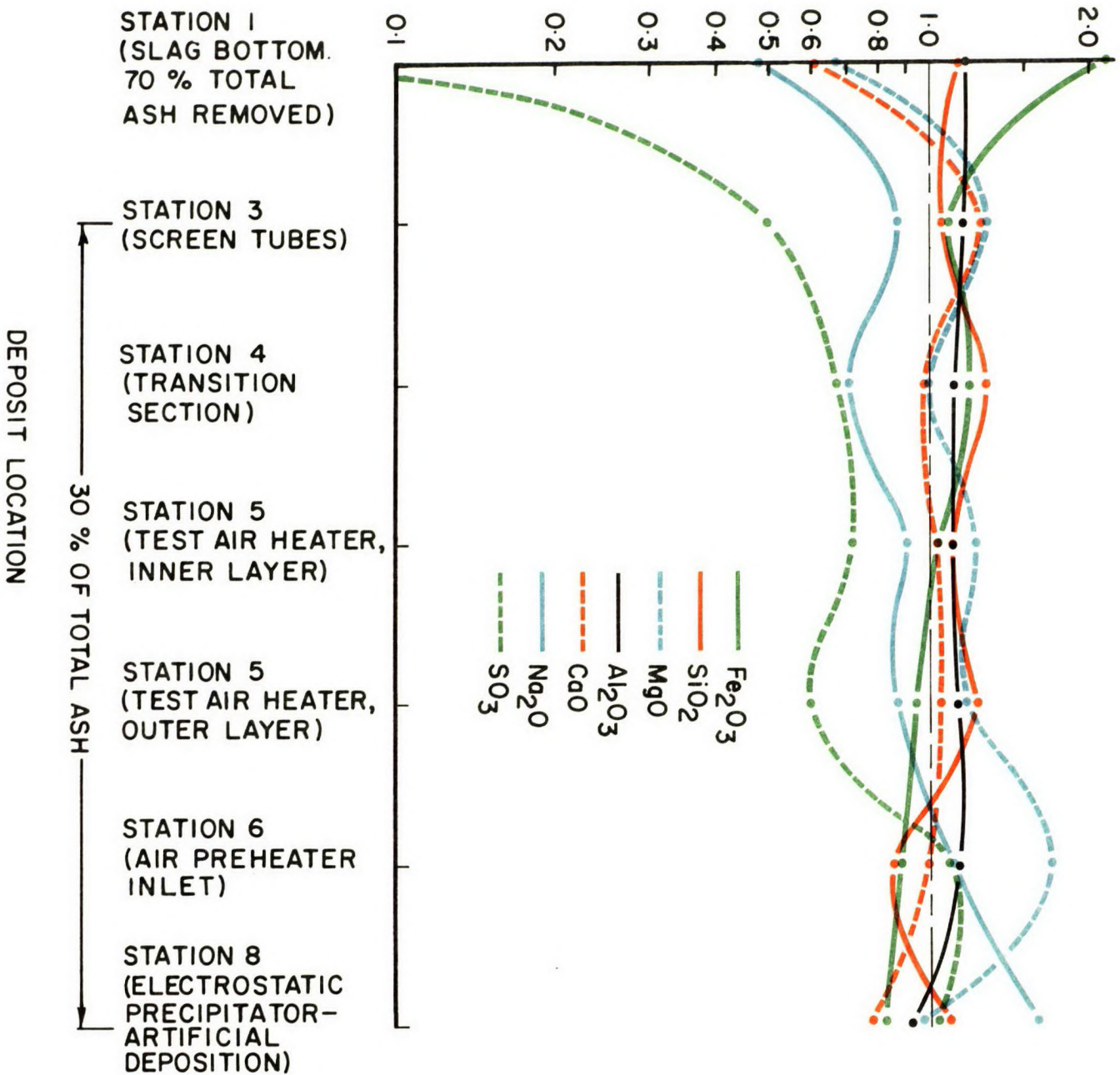


Figure 10. Variation in enrichment ratio and ash fusion temperature of fireside deposits with boiler location when burning Bienfait lignite.

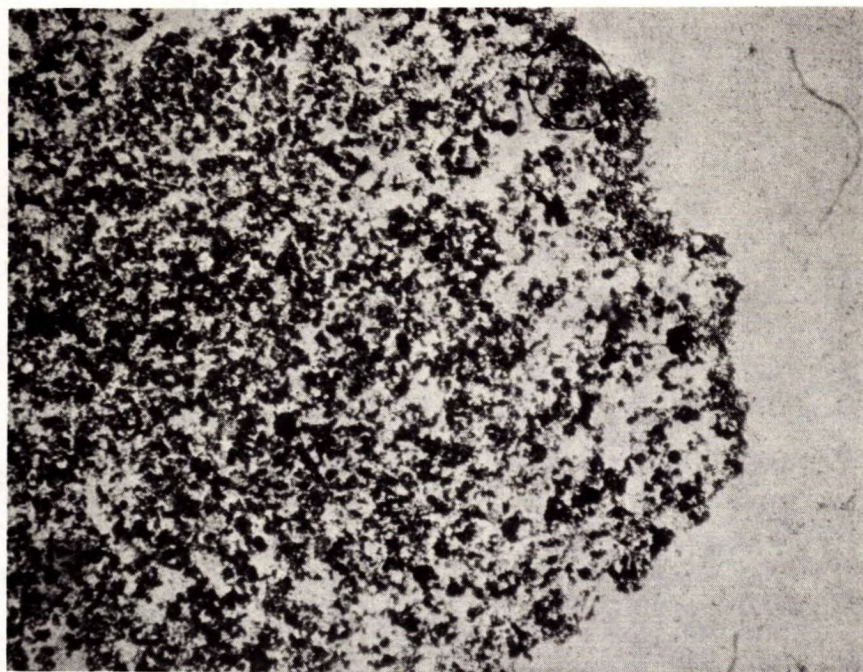


Figure 11. Deposit from screen tubes after burning Onakawana lignite. Thin section X37.

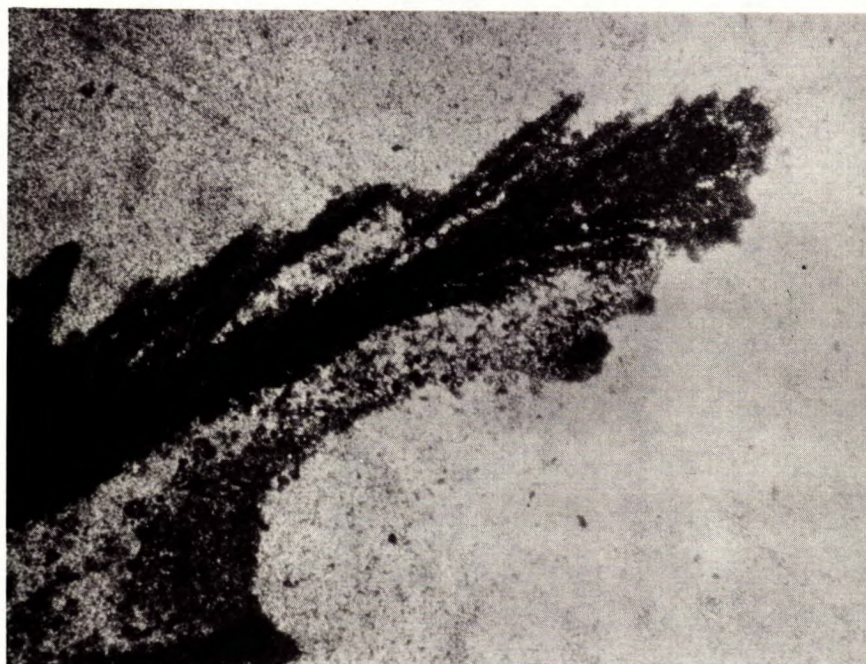


Figure 12. Deposit from screen tubes after burning Bienfait lignite. Thin section X37.

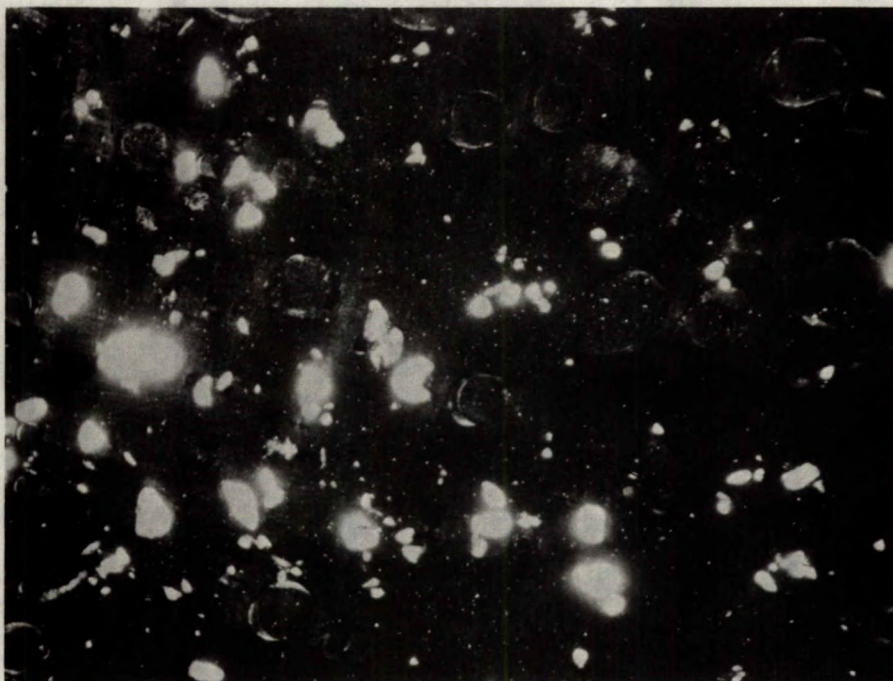


Figure 13. Slag from Onakawana lignite. Thin section X37 under crossed polaroids.

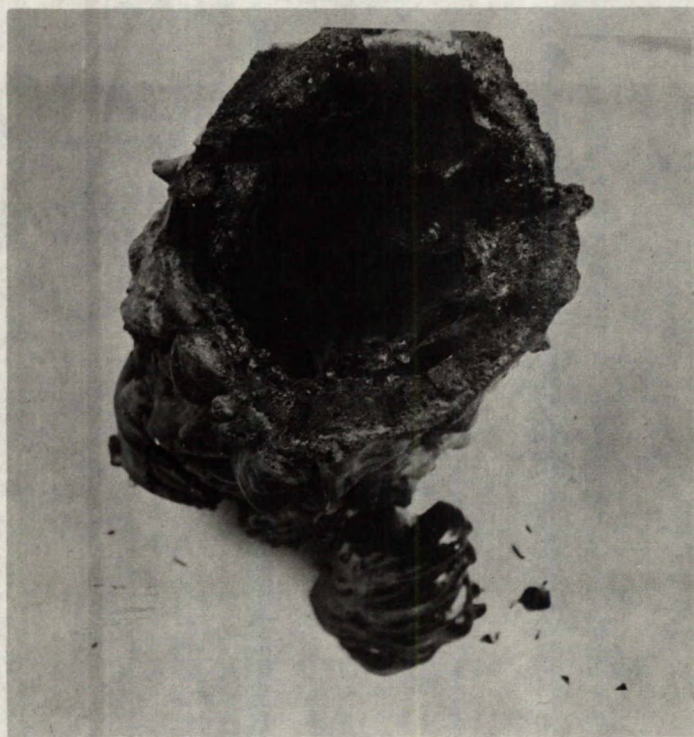


Figure 14. Slag from Onakawana lignite, showing uniform porosity between outer and inner surfaces of "stalactite" which formed during tapping.

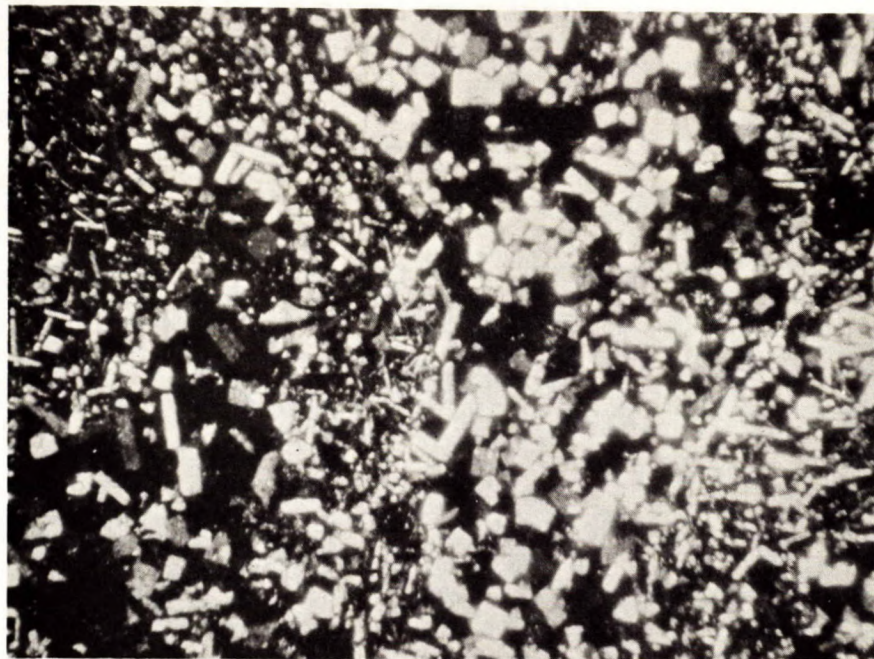
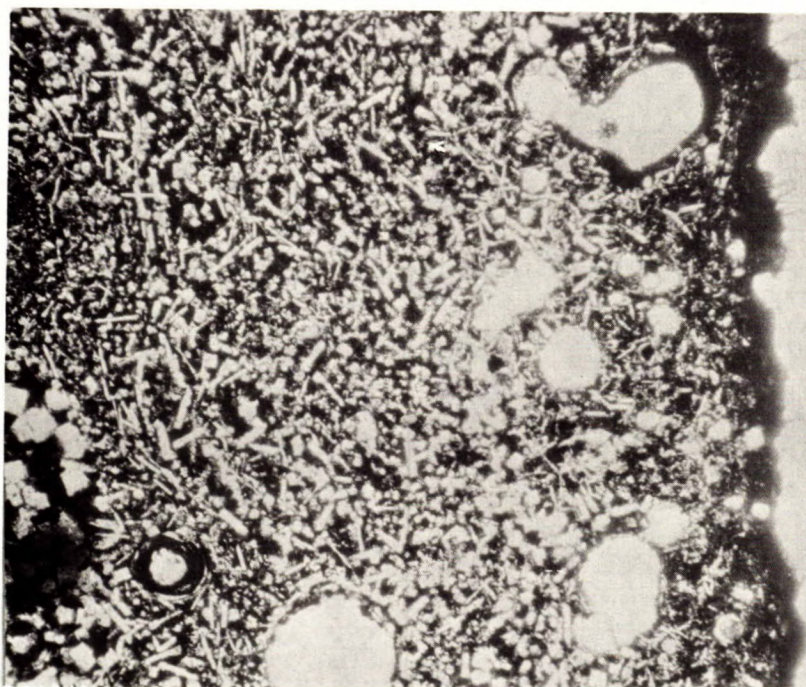


Figure 15. Inner layer of slag "stalactite" from Bienfait lignite.
Thin section X37 under crossed polaroids.



Outside
surface

Figure 16. Outer layer of slag "stalactite" from Bienfait lignite.
Thin section X37 under crossed polaroids.

TABLE 1

Lignite Analytical Data

Lignite	Onakawana		Bienfait	
	As Rec'd	As Fired	As Rec'd	As Fired
Proximate Analysis, %				
Moisture	48.13	26.67	35.85	20.91
Ash	6.78	16.50	6.24	8.79
Volatile Matter	21.44	26.60	27.11	32.52
Fixed Carbon (by diff)	23.65	30.23	30.80	37.78
Ultimate Analysis, %				
Carbon	33.26	42.48	43.45	51.35
Hydrogen	2.04	2.69	2.75	3.44
Sulphur	0.41	0.72	0.44	0.58
Nitrogen	0.55	0.72	0.73	1.01
Ash	6.78	16.50	6.24	8.79
Oxygen (by diff)	8.83	10.22	10.54	13.92
Equilibrium Moisture	35.17			
Gross Calorific Value, Btu/lb	5,340	6,790	7,110	8,440
Bulk Density (moisture-free basis), lb/cu ft	25		35	
Hardgrove Grindability Index	66 - 82		56	
Ash Fusibility, °F	Reducing	Oxidizing	Reducing	Oxidizing
Initial	1900	2020	1870	1910
Spherical Softening	1930	2100	2050	2260
Hemispherical Softening	2000	2110	2110	2280
Fluid	2100	2210	2150	2300
Ash Analysis, %				
SiO ₂	48.85		26.57	
Al ₂ O ₃	14.38		15.77	
Fe ₂ O ₃	7.13		6.43	
TiO ₂	0.97		0.58	
P ₂ O ₅	0.30		0.74	
CaO	14.01		22.54	
MgO	3.82		4.13	
SO ₃	10.22		14.13	
Na ₂ O	0.97		6.78	
K ₂ O	0.81		0.37	

TABLE 2

Sieve Analysis of Pulverized Lignites
(% by Weight)

Lignite	Classifier rpm	Sieve Size, USS Mesh					
		+28	-28	-48	-100	-200	-325
Onakawana	37	0.11	1.70	15.21	17.87	60.54	4.54
	47	0	0.73	13.27	18.45	46.10	21.44
	55	0	0	9.64	18.03	50.35	21.98
Bienfait	56	0	0	20.2		32.8	47.0

TABLE 3

Typical SO₂, SO₃, NO_x, Acid-dewpoint, and Corrosion-rate Measurements
in Flue Gases from Onakawana and Bienfait Lignite

Lignite	O ₂ % vol	SO ₂ ppm vol	SO ₃ ppm vol	NO _x ppm vol	Acid Dewpoint, °F	Corrosion Rate, μg Fe/sq cm/1/2 hr
Onakawana	3	411	17.9	414	Nil	0.05
	5	406	26.7	414	Nil	0.12
Bienfait	3	318	15.0	672	Nil	0.61
	5	157	26.0	743	Nil	0.21

TABLE 4

Chemical Analyses of Fly Ash Extracted from Flue Gases*

Lignite	Onakawana				Bienfait			
Sample Location	4		7		4		7	
Ash Composition, %	Water Extract	Residue	Water Extract	Residue	Water Extract	Residue	Water Extract	Residue
SiO ₂ } Al ₂ O ₃ }		60.7		63.9		3.1		4.3
Fe ₂ O ₃	0.1	11.3	0.1	9.7	0.1	15.9	0.4	0.9
CaO	0.2	4.1	0.5	3.4	0.1	3.9	2.0	4.8
SO ₃	3.8		4.1		21.6		9.8	
Na ₂ O	0.2	0.8	0.2	0.9	3.4	1.6	3.6	1.2
K ₂ O	0.1	0.4	0.1	0.8	0.1	0.5	0.5	0.5
Solubility	3.2		6.8		33.1		18.2	
Loss on Ignition		12.0		8.7		25.2		12.5

*Data for 3% O₂ in flue gases.

TABLE 5

Physical Characteristics of Fly Ash Extracted from Flue Gases*

Lignite	Onakawana			Bienfait		
Sample Location	4	7	9	4	7	9
Ash Particle-size Distribution, μ						
+ 74	24.4	18.7	-	62.8	42.6	-
44 x 74	13.6	6.5	-	31.3	37.5	-
20 x 44	30.2	19.5	-	0.4	9.6	-
10 x 20	16.6	24.4	-	1.4	7.2	-
0 x 10	15.2	30.9	100	4.1	3.1	100
Dust Loading in Flue Gases, gr/SCF	8.62	6.04	0.03	0.60	0.48	0.01
ASTM Ash Fusion Temperature, °F						
Reducing Atmosphere						
Initial	1960	1950		1810	1810	
Hemispherical	2050	2040		2070	2100	
Fluid	2210	2170		2100	2280	
Oxidizing Atmosphere						
Initial	1980	1960		1940	1950	
Hemispherical	2120	2120		2100	2110	
Fluid	2280	2200		2260	2300	

* Data for 3% O₂ in flue gases.

TABLE 6
Collection Efficiency of Lignite Fly Ash
in a Small-scale Electrostatic Precipitator

Lignite	O ₂ % vol	Average Fly Ash Concentration in Flue Gases, gr/SCF		Electrostatic Precipitator Collection Efficiency, %
		Precipitator Inlet	Precipitator Outlet	
Onakawana	3	6.04	0.03	99.5
Bienfait	3	0.48	0.01	98.0

TABLE 7

Physico-chemical Properties of Fireside Deposits

Lignite		Onakawana					Bienfait						
Sample Location		1	3	4	5 and 6	8	1	3	4	5(a)	5(b)	6	8
Ash Composition													
SiO ₂		56.8	49.8	52.8	No Ash	37.3	29.5	27.8	32.7	29.0	32.0	22.4	28.8
Al ₂ O ₃		14.4	15.6	13.8	Build-up	18.0	18.8	18.7	17.7	17.8	18.5	18.1	15.2
Fe ₂ O ₃		10.9	6.9	7.9		10.2	14.0	6.9	7.7	6.9	6.1	5.7	5.3
TiO ₂		0.8	1.1	1.0		1.2	0.7	0.6	0.6	0.6	0.7	0.6	0.8
P ₂ O ₅		0.3	0.3	0.3		0.6	0.6	0.9	0.7	1.0	0.8	0.9	0.7
CaO		11.2	16.2	13.9		17.9	13.5	27.7	21.8	22.7	23.2	22.0	17.3
MgO		3.3	4.4	3.8		5.0	2.7	5.2	4.1	5.1	4.9	7.1	4.0
SO ₃		-	3.7	6.1		7.2	0.1	6.9	9.3	10.2	8.3	15.6	15.0
Na ₂ O		0.9	0.9	0.8		1.3	3.2	6.0	4.8	6.2	6.0	7.6	11.0
K ₂ O		0.6	0.7	0.7		1.0	0.2	-	-	-	-	-	0.4
Combustible		-	0.2	0.5		9.8	-	0.9	0.2	0.2	-	0.1	4.5
Ash Fusion Temperature, °F													
Reducing Atmosphere													
Initial		1890	2000	2000	"	2000	1900	1970	1920	1990	1980	1860	1870
Hemispherical softening		2220	2080	2070		2080	2010	2200	2040	2100	2090	2040	1980
Fluid		2380	2270	2270		2270	2340	2250	2110	2120	2110	2220	2040
Oxidizing Atmosphere													
Initial		1950	2030	2050	"	2030	2050	2120	1970	2060	2080	2170	2010
Hemispherical softening		2270	2130	2140		2130	2080	2220	2070	2150	2170	2270	2120
Fluid		2460	2360	2350		2360	2480	2250	2110	2160	2200	2310	2170
Particle-size Distribution,μ													
+ 74		Glassy	28.0	27.7	No Ash	6.9	Glassy	89.4	38.4	37.4	25.1	71.7	79.8
44 x 74			18.7	14.4	Build-up	2.8		6.2	42.3	25.2	34.1	18.1	14.9
20 x 44			31.7	36.2		23.3		1.6	10.1	15.7	24.4	3.8	2.6
10 x 20			18.0	14.4		22.3		2.4	6.9	15.7	11.5	3.8	1.9
0 x 10			3.6	7.3		44.7		0.4	2.3	6.0	4.9	2.6	0.9

