Ref # R

- gives SOx data as a function of sodium content of lignite

- high sodium → lower SO2 emiss

~60% 24S

~100%

LIGNITE
COMBUSTION
AP-42 Section 1.7
Reference Number
6

9/81

stack

COMPARISON OF ASH FOULING TENDENCIES OF HIGH- AND LOW-SODIUM LIGNITE FROM A NORTH DAKOTA MINE

Ref 6
Sec 1.7
12/75

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INTRODUCTION

North Dakota lignite has received considerable attention in recent years as a source of low-cost fuel for power generation in the upper Midwest. The major problem associated with its use in power boilers is the tendency to form troublesome ash deposits on boiler tube surfaces—a problem which also occurs with some bituminous coals. This problem varies considerably from one lignite-fired boiler to another and is dependent on such factors as source of lignite, boiler design, load factor, tube-metal temperatures, and soot blowing practices. This report describes the results of a series of tests performed to study one aspect of the problem, namely, the effect of sodium content of the lignite on boiler fouling.

GENERAL BACKGROUND

Until recent years it was generally assumed that North Dakota lignite from a given mine had qualities peculiar to that mine, but that within the mine the lignite was quite uniform. In 1959 the Otter Tail Power Company installed a 53.5 Mw lignite-burning unit at their Hoot Lake Plant, Fergus Falls, Minnesota. During the first years of operation, ash fouling problems were quite severe, but not consistent or predictable. It soon became evident that the fouling tendencies of the lignite being supplied from the Beulah Mine of Knife River Coal Mining Company were quite variable, and dependent upon location in the pit.

- pulverized coal (opposed-firing)
- particulates 5A-8A

By noting the location of the loading shovels during the periods of severe fouling, the mining company was able, over a 2-year period, to outline areas of suspected troublesome coal. These areas were by-passed during the winter high-load period and loaded out during the summer, with an improvement in plant operation, but at the expense of disrupting the normal mining and stripping operations. Results from analysis of the coal did not show large differences in moisture percent, ash percent, heating value, or ash fusion temperature between the troublesome and the less troublesome coals.

Meanwhile, at the plant, the number of soot blowers had been increased from 30 to 55 and a very rigorous blowing schedule had been adopted, resulting in soot blowers operating at least some part of 21 hours per day. Fouling problems continued, with resulting reduction in plant economy and reliability.

Soot blowing increased

During this period, the Federal Bureau of Mines Coal Research Laboratory at Grand Forks, North Dakota, had initiated

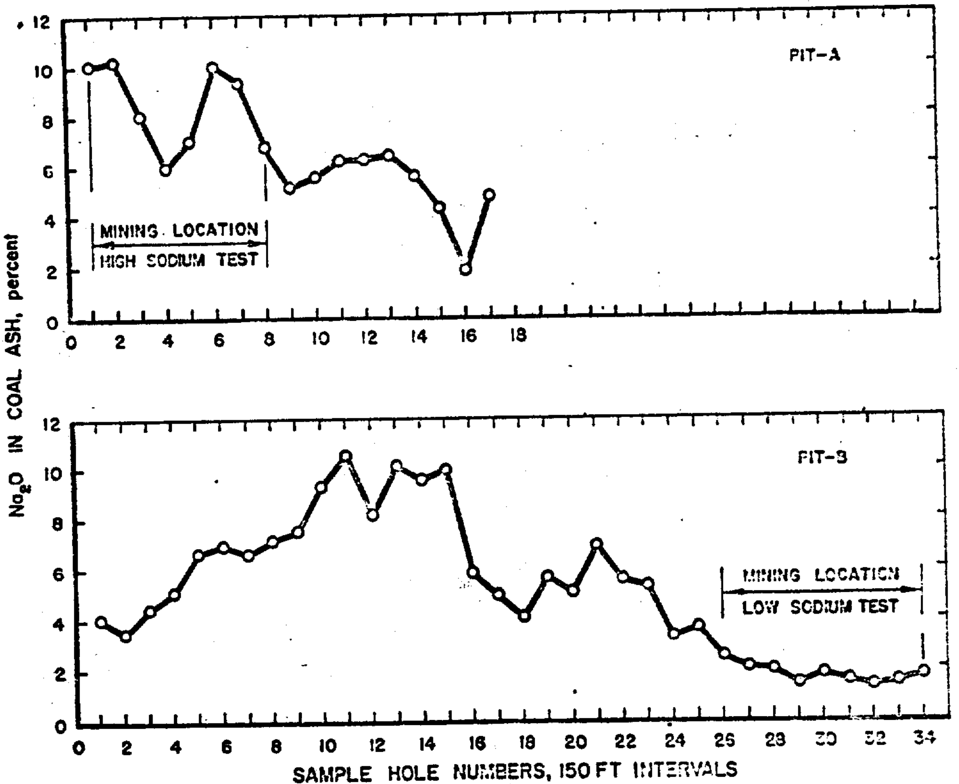


Fig. 1—Sodium oxide content of ash vs. location in two selected strip pits at Beulah Mine.

various research programs relating to the study of lignite ash and ash fouling problems. One project was a survey in which full seam samples were obtained from various locations in all the major lignite producing mines in North Dakota and detailed analyses of the coal and ash were made. This was the first systematic survey[1] of the ash properties of North Dakota lignites. The results showed there were, in fact, large variations in ash characteristics both between and within mines. One of the mines showing the greatest ash variability was the Beulah Mine where, for example, the following variations in ash components were found:

SiO_2 11.4-23.5 percent; Fe_2O_3 7.0-17.3 percent; CaO 16.3-24.7 percent; Na_2O 1.8-11.3 percent; and SO_3 16.1-24.2 percent.

these represent sulfates

The literature on coal ash fouling research from various countries generally shows a high correlation between sodium content of the fuel and degree of fouling, and sodium content had been suggested as a fouling indicator for the Beulah lignite, but no controlled tests had ever been run. As a result of mutual interest in lignite ash research by the Otter Tail Power Company, the Knife River Coal Mining Company, and the Bureau of Mines, it was decided that the three organizations would cooperate in a series of controlled tests on the Hoot Lake No. 2 unit to establish differences in ash fouling tendencies between high- and low-sodium lignite from the Beulah Mine.

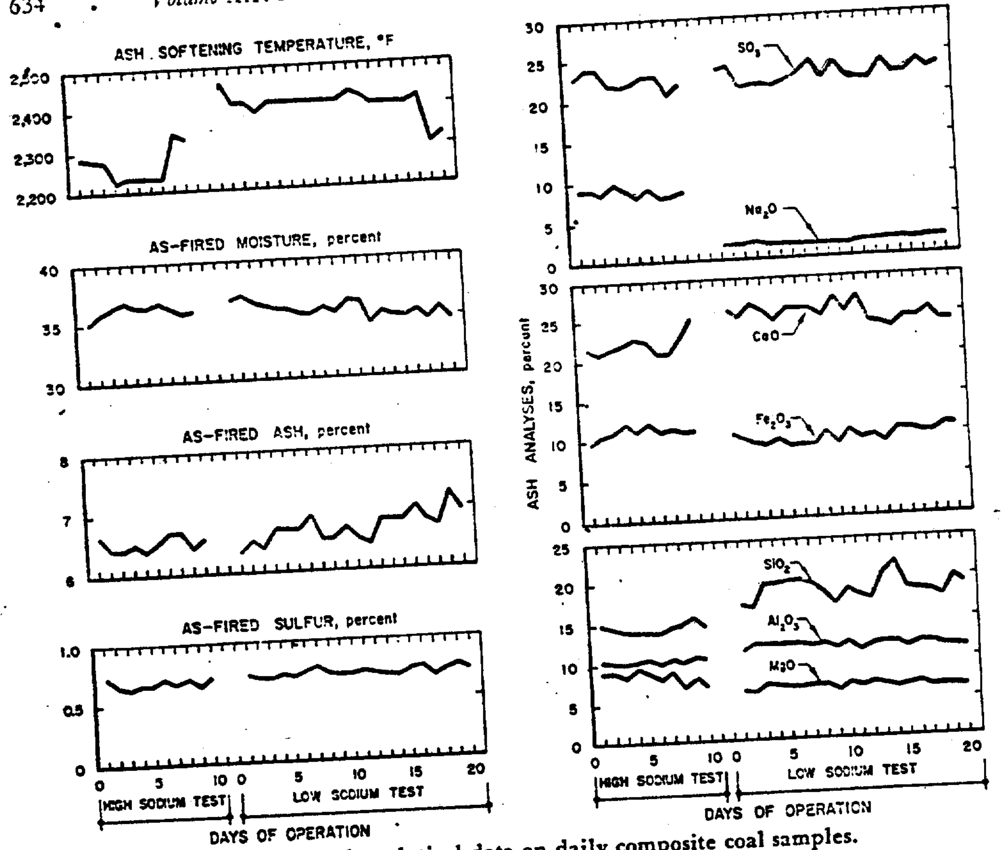


Fig. 2—Selected analytical data on daily composite coal samples.

LIGNITE BURNED

Prior to the boiler tests the coal company collected full seam auger-drilled samples at 150-foot intervals along the length of the various stripped areas at the Beulah Mine. These samples were analyzed for sodium content to permit choosing mining location for the tests. Figure 1 shows the large variations in sodium content in two of the pits and the areas selected for mining during the boiler tests.

Lignite samples were collected from each pulverizer feeder every two hours during the tests and these samples were combined to make 24-hour samples. the analyses of which are shown in Fig. 2. The coal analyses during each period were very consistent and the only significant differences between the coals for the two tests, besides the sodium content, were the somewhat higher calcium oxide, silicon oxide, and ash fusion temperatures for the low-sodium coal. Fortunately for comparative purposes, the predominate variability between the two coals was the sodium content. Because of the inherent coal mixing at the mine tipple and power plants, the sodium content was considerably less variable in the 24-hour samples than in the mine survey samples. *Table I* shows typical analyses of the high- and low-sodium lignites.

BOILER PERFORMANCE

Before the first high-sodium lignite test,

TABLE I
TYPICAL ANALYSIS OF LIGNITES TESTED

	HIGH-SODIUM LIGNITE	LOW-SODIUM LIGNITE
Proximate analysis, percent		
Moisture	35.6	36.6
Volatile matter	26.2	26.4
Fixed carbon	31.6	30.6
Ash	6.6	6.4
Ultimate analysis, percent		
Hydrogen	6.6	6.7
Carbon	42.1	41.8
Nitrogen	0.6	0.4
Oxygen	43.4	44.0
Sulfur	0.7	0.7
Ash	6.6	6.4
Heating value, Btu/lb	6970	6960
Ash fusibility, °F		
Initial deformation	2200	2370
Ash softening	2260	2410
Fluid	2360	2450
Sulfur forms, percent as-fired		
Sulfate	0.03	0.04
Pyritic	0.43	0.30
Organic	0.24	0.35
Chlorine in coal, percent	0.00	0.00
Ash analysis, percent		
SiO_2	14.2	19.7
Al_2O_3	9.8	12.0
Fe_2O_3	11.5	9.2
TiO_2	0.4	0.4
P_2O_5	0.3	0.5
CaO	20.1	26.3
MgO	6.9	7.1
Na_2O	8.2	1.6
K_2O	0.4	0.2
SO_3	25.4	21.3
Total	97.2	93.3

>90% of S available for oxidation (i.e., not in unavailable sulfate form)

after fired in furnace

the Hoot Lake No. 2 boiler, shown in Fig. 3, was shut down and the accumulated bulk deposits removed from the convection tubes. The unit was then put in operation carrying a load of 40 to 50 Mw during most of the day and dropping to about 25 Mw during part of the night. Within [illegible] days the boiler became so badly fouled that draft losses through the reheater were excessive and it was necessary to shut the unit down for cleaning. The ash deposits at the front and rear of the reheater at shutdown are shown in Fig. 3.

For the second high-sodium test the load was reduced to about 40 Mw for most of the day, as shown in Fig. 4. After six days of operation, the load was increased to about 45 Mw. After three days at this load, excessive fouling again caused shutdown.

The low-sodium lignite tests were then run, repeating the load curve and soot blowing schedule from the previous test. A marked decrease in the degree of fouling was experienced, and after nine days the load was increased to 50 Mw, which was continued until the 20th day when the available low-sodium lignite supply was exhausted. A typical daily load curve for the latter part of the low-sodium lignite test is also shown in Fig. 4, and at this condition the fouling was not considered excessive.

PROBE TESTING

As a means of obtaining additional information relating to ash fouling, a series of simultaneous probe tests were run by the Bureau of Mines during the various boiler tests. The location of the sampling points in the boiler are shown in Fig. 3. To obtain meaningful data it was necessary to perform these tests during a 2-hour nonsoot-blowing period in the day.

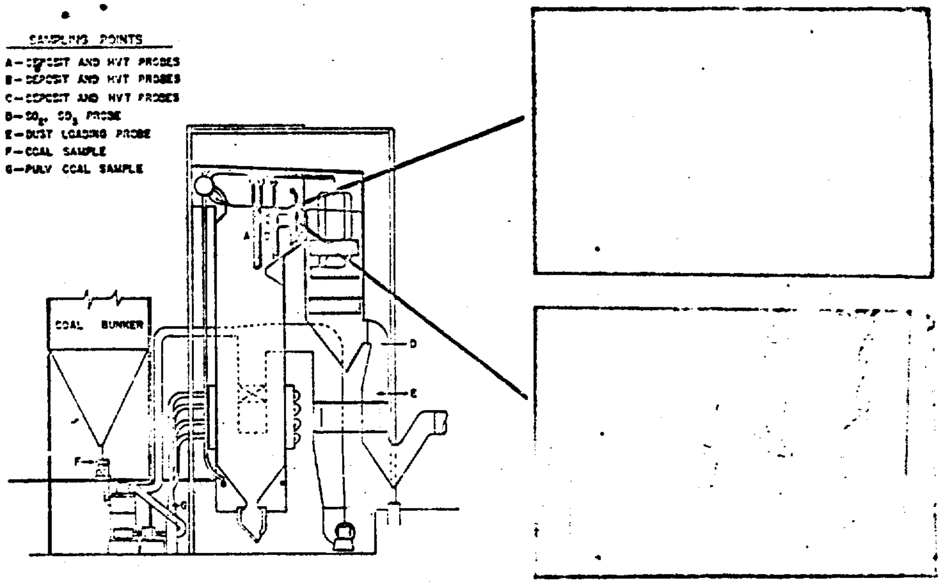
Deposit and HVT Probes

An air-cooled probe was inserted into the boiler at various locations for determination of ash deposition rate. The probe consisted of 10-ft long, ¾-in. Type 310 stainless steel pipe. A chromel alumel thermocouple was embedded in the pipe about 6 in. from the tip, and an automatic temperature controller was used to maintain constant thermocouple temperatures by regulating the air flow through the open-ended pipe.

It was found that measurable quantities of deposits were collected in a 15-min period and this was established as the standard test time for comparison, although some longer tests were also made. The temperature at the probe thermocouple was maintained at 1000 F at positions A and B, and at 800 F at position C. The rate of ash deposition and gas temperatures as determined by a high-velocity thermocouple for the high- and low-sodium lignite tests at a load of about 40 Mw are shown in Fig. 5. The rates of deposition at A and B were about 10 times greater for the high-sodium than for the low-sodium coal. Also shown are deposition rates and temperatures at 49 Mw with the low-sodium coal, and the deposition rates at this higher loading are still only about half that of the high-sodium 40-Mw test.

Figure 6 shows a typical section of the probe after both 15-min and 7 to 8 hour insertions for tests with high- and low-sodium lignites; the differences are quite striking. During the 7 to 8 hour tests, soot blowers located in the vicinity of the probe no doubt removed some of the deposit (note indent in lower left picture).

The probe deposits normally consisted of two layers, a soft, fine, white inner layer adjacent to the tube, and a coarse, brownish, sintered outer layer. The white layer completely surrounded the tube, but the sinter layer only built up on the side facing the gas stream. After each test the two layers were removed from the probe separately and each was weighed and analyzed. Microscopic examination showed that the inner layer consisted of a white amorphous material, which appeared to be a condensation product, and that embedded in this material were glassy flyash spheres similar to those in the outer layer. These inclusions in the inner layer tend to mask what might otherwise be large differences in chemical analysis between the two fractions. Table II shows typical analyses, on a SO_3-free basis, of various ash fractions from different loca-



HOOT LAKE BOILER NO. 2, 400,000 LB/HR, 1,500 PSIG, 1,000°/1,000°F

FOULED REHEATER AFTER HIGH-SODIUM LIGNITE TEST

Fig. 3—Test boiler, showing sampling points and ash deposits.

tions in the boiler and of the original coal ash. The silicon and iron are consistently higher and sodium lower in the sinter deposit than in the original high-sodium coal ash. The inner layer of these deposits is enriched in sodium. The sinter deposits from the low-sodium coal show no large differences from the original coal ash; however, the white deposit is consistently depleted in silicon and iron and enriched in calcium and magnesium. These deposits are being studied further in the laboratory in an attempt to obtain information on the deposition mechanism; however, the scope of this paper does not permit discussion of this phase of the investigation.

The ash softening temperature of the coal fed to the boiler during the deposit probe tests, was about 2000 F for the high-sodium and about 2400 F for the low-sodium coal tests (Fig. 7). Since the flue gas temperatures entering the secondary superheater were 2200 to 2300 F with the high-sodium coal and below 2200 F with the low-sodium coal, it might be assumed that the difference in rate of deposition was due primarily to differences in ash fusion temperatures. However, the flue gas temperature between the secondary superheater and reheater was about 2100 F for both high- and low-sodium coal tests and yet the deposition rate was ten times as great with the high-sodium coal.

Dust Loading Probe

Flyash samples were collected from the flue gas duct to the air heater to determine the percentage of ash passing through the furnace and to obtain samples for laboratory study. The procedure used was essentially that specified in the ASME Power Test Code 27-1957 except that shorter collection periods were used because of the soot blowing schedule. The results of these tests indicated that with the high-sodium lignite only about 25 percent of the input ash passed through the furnace, and that with the low-sodium lignite this percentage in-

5A - high sodium ash
- pulverized coal boiler

TABLE II
TYPICAL ANALYSIS OF ASH DEPOSITS FROM BOILER TESTS

HIGH-SODIUM LIGNITE TEST

LOCATION OF PROBE	DEPOSIT LAYER	SO$_3$—FREE ANALYSIS, PERCENT SiO$_2$	AL$_2$O$_3$	Fe$_2$O$_3$	TiO$_2$	P$_2$O$_5$	CaO	MgO	Na$_2$O	K$_2$O	SO$_3$ PERCENT OF ORIGINAL
A*	Outer	24.6	13.2	19.6	0.3	0.1	24.1	8.3	9.5	0.3	4.6
A	Inner	17.9	12.9	16.9	0.4	0.1	25.8	8.3	16.5	0.7	15.8
B	Outer	24.6	13.5	18.4	0.4	0.1	24.6	9.2	9.0	0.2	4.2
B	Inner	16.6	13.0	13.2	0.5	0.1	27.6	10.0	18.2	0.8	19.1
C	Outer	20.4	14.1	13.9	0.5	0.1	29.5	11.8	9.5	0.2	7.7
C	Inner	16.5	12.9	8.7	0.5	0.1	22.7	19.5	18.5	0.6	21.4
E	Flyash	15.8	12.5	6.7	0.2	0.1	28.0	13.0	22.7	1.0	28.3
Original coal ash		19.2	13.8	13.8	0.4	0.1	30.0	10.0	12.3	0.4	23.4
LOW-SODIUM LIGNITE TESTS											
A	Outer	21.7	15.0	16.2	0.5	0.8	35.0	9.6	1.0	0.2	4.6
A	Inner	17.4	15.6	12.7	0.6	0.9	37.6	12.4	2.4	0.4	9.7
B	Outer	24.5	14.7	15.0	0.4	0.7	31.8	11.5	1.2	0.2	3.3
B	Inner	20.1	16.8	9.4	0.6	0.9	36.8	11.8	3.0	0.6	13.4
C	Inner	22.2	16.4	8.3	0.6	0.8	35.8	12.8	2.7	0.4	8.6
E	Flyash	24.6	16.6	8.4	0.5	0.7	35.3	11.0	2.5	0.4	6.8
Original coal ash		25.7	14.9	15.5	0.4	0.6	33.0	7.2	2.3	0.4	23.9

*See Fig. 3 for probe locations.

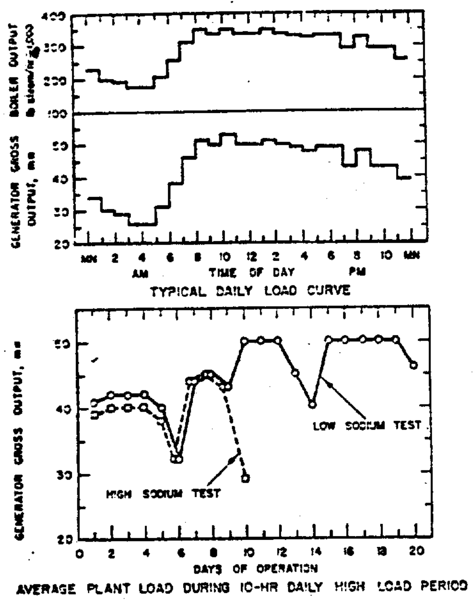


Fig. 4—Hoot Lake No. 2 load curve during ash fouling tests.

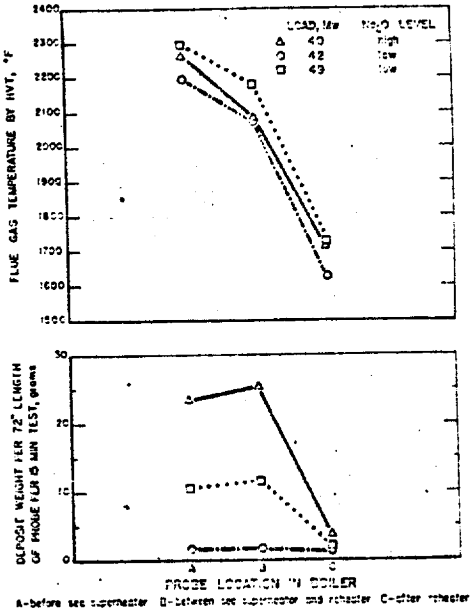
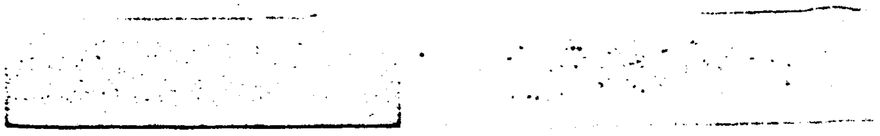
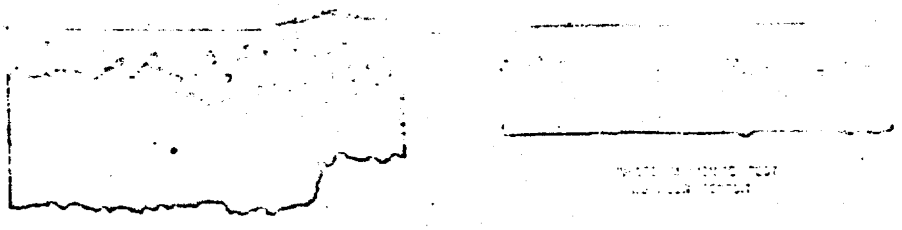


Fig. 5—Probe deposition rate and HVT temperatures as a function of sodium level and load.



HIGH-SODIUM LIGNITE TEST
15 MINUTE DEPOSIT

LOW-SODIUM LIGNITE TEST
15 MINUTE DEPOSIT



HIGH-SODIUM LIGNITE TEST
3 HOUR DEPOSIT

LOW-SODIUM LIGNITE TEST
[illegible] HOUR DEPOSIT

Fig. 6—Comparison of probe deposits using high- and low-sodium coals.

TABLE III
SULFUR BALANCE DATA FROM BOILER TESTS

	INPUT SULFUR	OUTPUT SULFUR					
		SO₂ + SO₃ in flue gas to air heater		In flyash entering air heater		Total accounted for	
	Pound per hour	Pound per hour	Percent of input	Pound per hour	Percent of input	Pound per hour	Percent of input
High-sodium tests							
	410	270	66	89	22	359	88
	460	241	52	116	25	357	77
Low-sodium lignite tests							
	490	523	107	50	10	573	117
	530	523	99	47	9	570	108

8A

low sodium ash

creased to about 40. It is obvious that under these conditions frequent soot blowing is necessary in order to prevent blockage of the tube passes.

Sulfur Oxides in Flue Gas

Determinations of the SO_2 and SO_3 contents in the flue gas to the air heater were also made during the 2-hour test period each day. Two methods were used: the selective condensation method described by Lisle and Sensenbaugh[3] and the absorption method of Berk and Burdick.[4] Agreement between the two methods was good, but the selective condensation method is preferred because of its simplicity. In addition to the SO_2 and SO_3, total sulfur determinations were also made on the samples by titrimetric and gravimetric methods as a check on the above tests.

As shown in Fig. 2, the sulfur content remained essentially constant at 0.6 to 0.7 percent for both the high- and low-sodium lignite. However, the SO_2 content in the flue gas to the air heater increased from about 450 to about 850 ppm when changing from high- to low-sodium lignite and, strangely, the SO_3 content decreased from about 20 ppm to 0. The lower SO_2 in the flue gas with the high-sodium coal would indicate a reaction between the sulfur gases and the high-sodium lignite ash. This effect is seen in the increased SO_3 content of the ash deposits and flyash from the high-sodium coal, as shown in *Table II*. In future laboratory tests, it is hoped that information can be obtained on the end reactions of sodium and sulfur in the flue gas and on the possible catalytic effect of various ash components on the conversion of SO_2 to SO_3.

Table III shows sulfur balance data for tests with high- and low-sodium lignites. The balances for the high-sodium tests show 52 to 66 percent of the input sulfur as sulfur gases and 22 percent in the flyash in the flue gas. Total sulfur accounted for was 77 to 88 percent, but only about 25 percent of the input ash is accounted for. With the low-sodium coal the sulfur in the gas is 99 to 107 percent of the input sulfur, and the total sulfur accounted for is 108 to 117

52-66% of input S goes out stack (for high sodium coal) as SOx gas

99-107% of input S goes up stack for low Na coal percent of the input, with 40 percent of the ash accounted for. The more likely sources of error in these balances are the input coal rate, which is based on pulverizer coal feeder revolutions, the flue gas volume rate, which is based on a pitot tube traverse, or the dust loading determinations.

The percentage of original sulfur retained in the ash during laboratory ashing of the coal samples at 800 C varied from 67 to 98 percent. There has been speculation that this effect of retention of the major portions of the sulfur in the ash might also exist in boiler operation. However, the results of these tests would indicate that with low-sodium coal most of the input sulfur appears as gaseous sulfur oxides and that with high-sodium coal the percentage is also high.

SUMMARY AND CONCLUSIONS

The rate of fouling, as determined both by boiler performance and by probe tests, is much greater when burning lignite having 8 to 10 percent sodium oxide in the ash compared with burning lignite having less than 2 percent sodium oxide in the ash.

The tests indicate a remarkably high ash collection efficiency of the boiler tubes on the unit tested. Based on short-time dust loading tests, only 25 and 40 percent of the input ash can be accounted for in the flue gas for the high- and low-sodium coals, respectively.

5A -8A
- on pulverized
coal fired boiler
- this will
not necessarily
be true for
cyclones
as the ash is
drained out the
bottom

Sulfur oxide determinations indicate that the sodium level has a profound effect on the SO_2 content of the flue gases. The SO_2 increased from about 450 to 850 ppm when changing from high- to low-sodium coal. With low-sodium coal, nearly all the coal sulfur can be expected to appear as SO_2.

Based on the results of these tests, the Otter Tail Power Company and Knife River Coal Mining Company have set up a program designed to supply Hoot Lake Station with lignite containing a predetermined level of sodium. Using two loading shovels at the mine and adjusting the number of trucks serving each shovel, the lignite is blended at the tipple to provide a sodium level determined by the expected electrical load at Hoot Lake. The railroad car numbers are recorded, along with the calculated sodium percentage. These figures are received at Hoot Lake 2 to 5 days in advance of the railroad cars. Minor electrical load adjustments can then be made, if necessary, to accomodate the expected lignite blend. Sampling and analysis at the plant have shown a very good correlation with the expected sodium percentages, as predicted by the blending operation at the mine.

Plant operating results from the first three months using this procedure look very promising.

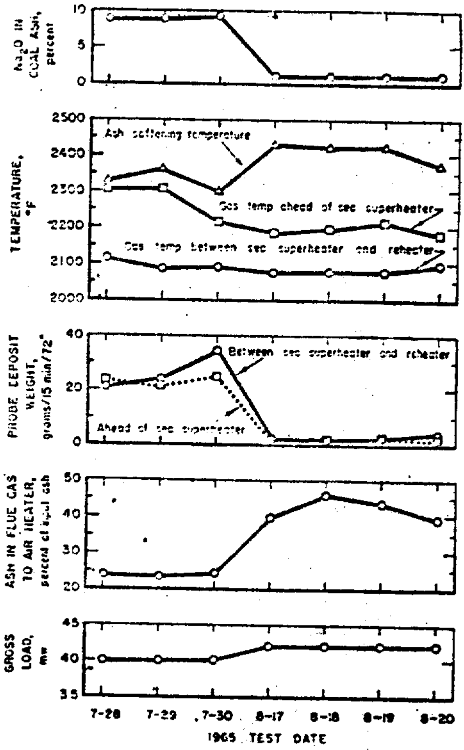


Fig. 7—Sulfur oxides in flue gas using high- and low-sodium lignite.

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PREPARED DISCUSSION

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The Authors have made an outstanding contribution with one of the very early investigations of the fouling characteristics of pulverized lignite. The paper presents data from a thorough study of the fuel properties that affect ash deposition in convection passes and provides a solution to the problem based on their findings. Their work represents the type of effort that is necessary if lignite is to compete successfully as an energy source for electrical power generation. The investigation answers a number of questions and also introduces data that prompt several questions and comments.

One of the more interesting aspects of the investigation is the high retention of flyash in the boiler. Dust loading and rate of deposition figures and the very rapid pluggage of this boiler at reduced loads firing a relatively low-ash fuel all indicate that an extremely high percentage of the ash is deposited on tube banks while firing the high-sodium lignite. The Authors considered the possibility that fusion temperatures might be responsible for differences in deposition rates between these two fuels but discount this possibility, apparently because the flue gas temperatures are 100 degrees F or more below the ash softening temperatures. I would like to suggest, however, that the presence of sticky particles is possible and perhaps likely, particularly with the high-sodium lignite. The initial deformation temperature is 170 degrees F lower for the high sodium ash, and it is possible that molten phases exist at even lower temperatures. In addition, the flyash particle temperature can be higher than surrounding gas temperature, depending on particle size, velocity, etc.

much ash
deposit on
tube banks

high Na ash
more "sticky"

We have had the opportunity of working with Mr. Gronhovd on certain phases of the Hoot Lake Tests and have followed the tests with a great deal of interest. Our work included determination of the sintering characteristics of lignite ashes tested at Hoot Lake and from other sources. The strength of sintered flyash from bituminous coals develops quickly and is related to fouling tendency, but thus far sintering data and probe tests indicate that the deposit from lignite ashes is friable for at least 8 to 15