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Using High Moisture Western Coals in Power Boilers Designed for Pulverized Bituminous Coal Firing

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In the past few years, utility companies operating pulverized coal fired steam generating units in the Midwestern region have experienced problems related to fuel supplies. These include increased curtailment of natural gas and oil as auxiliary fuels, decline in coal reserves due to enforcement of environmental mining restrictions and to increased foreign purchases, and rising cost of spot purchases in the coal market. Present and forecast limitations on SO_2 emissions also caused increased competition and higher prices for bituminous coals of lower sulfur content.

An eastern Iowa utility company beset with these problems investigated a number of alternative coals; one of the more economically attractive substitutes was a high moisture, low sulfur, sub-bituminous coal from a recently developed field in Wyoming. The utility company, with the assistance of the boiler manufacturer, then determined that this coal would be acceptable for test firing the utility's largest unit for a long enough period to verify predicted performance and capacity. Depending upon the test information, the utility company could then make a final decision on a long-term commitment to purchase this coal.

DESCRIPTION OF BOILER AND FIRING EQUIPMENT

The unit tested is of conventional design and rated at 950,000 lbs. steam/hr.; operating pressure is 1975 psi and steam temperature is 1005/1005F. The furnace is pressurized and front-fired with 12 flare-type burners, which are designed to fire pulverized coal and natural gas, either separately or in combination. No gas was fired during the testing of the unit. A cross section of the unit is shown in Figure 1.

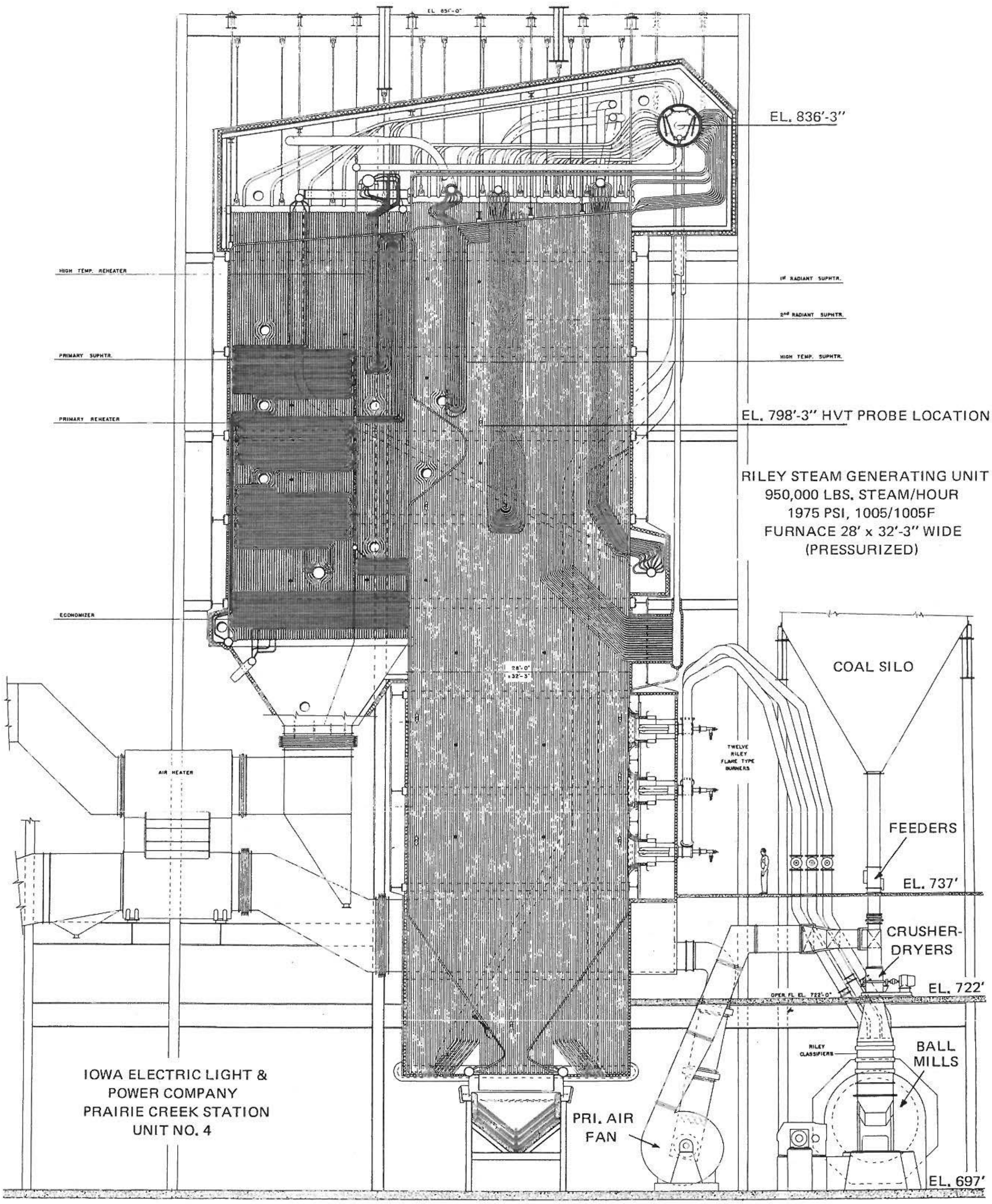

Figure 1 Section Through Test Unit

Two separate but identical mill systems provide pulverized coal for firing, using 11 ft. dia. by 13 ft. long double-ended ball tube mills. The mills are driven at 17.8 rpm by 700 hp motors and gearing. Raw coal flows vertically downward from four separate 1400 ton silos to drum-type feeders located above each end of the two mills. Each mill has its own primary air fan driven by a 350 hp motor. The fan delivers hot air through ducting to both ends of the mill for transport and drying. The pulverized coal and air mixture leaving both ends of the mill passes through bar-type classifiers where oversize particles are rejected to the mill inlets for regrinding. Fine pulverized coal and air are discharged from the classifiers through separate pipelines to six burners, three from each end of the mill.

The foregoing summary lists all of the components usually found in coal pulverizing systems serving power boilers, including feeders, mills, fans, classifiers, and burners. In addition to these elements, mill systems incorporated in the test unit were equipped with hot-air swept impact crushers, through which both raw coal from the feeder and the hot primary air must flow before entering the mills. They are located vertically below the feeders and hot air inlet ducts at each end of the mill, and above the mill inlets. A 40 hp 1200 rpm motor drives each crusher. They were originally designed into the mill system to predry high moisture Illinois coals. The crusher-dryers and other mill system components are shown schematically in Figure 2.

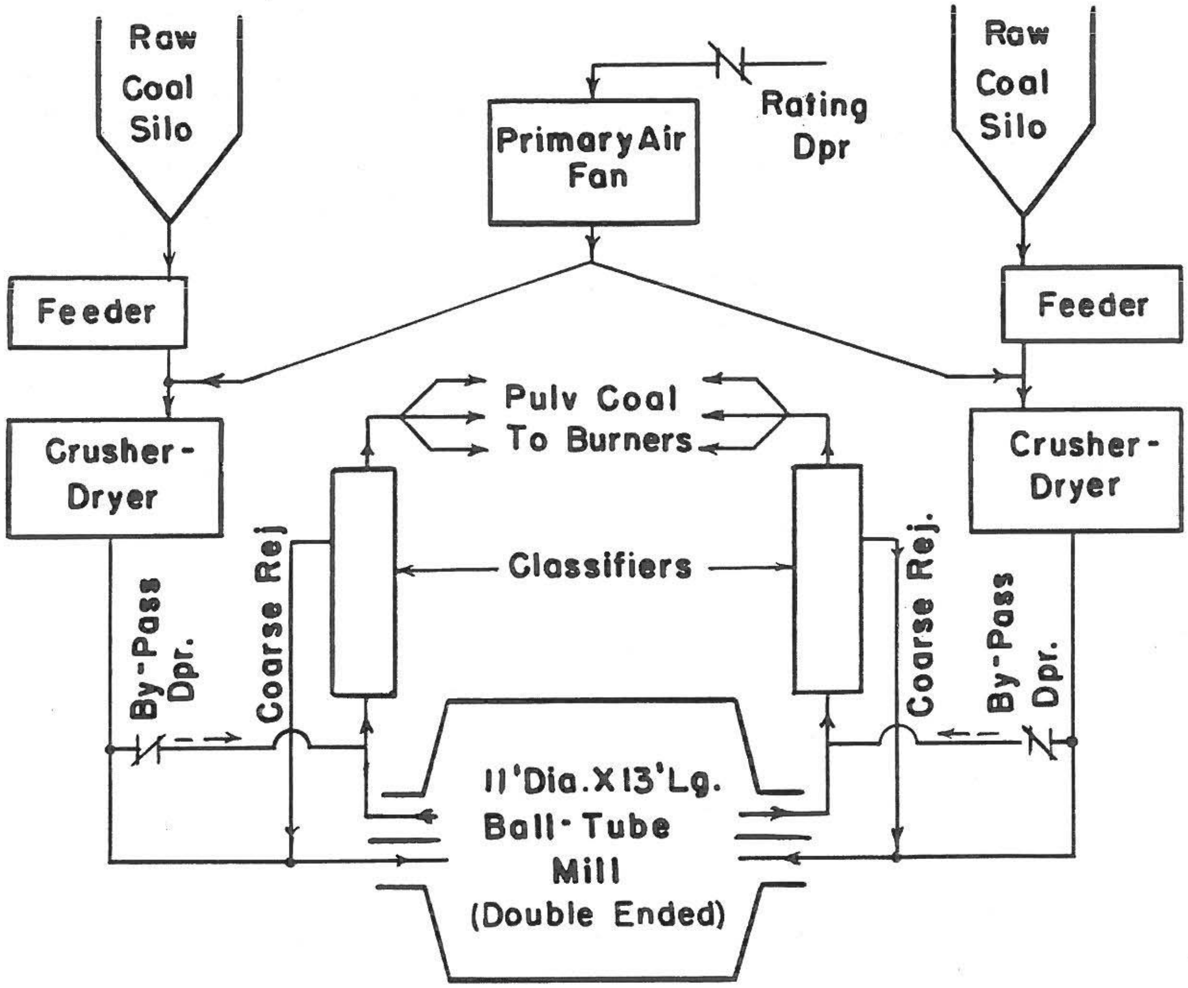

Figure 2 Mill System Components

PREPARATION FOR TESTING

The utility company looked into alternative sources of low-sulfur coal having other characteristics compatible with the design of the unit in which it was to be used. The investigation, along with a coincident evaluation of costs, showed that a western sub-bituminous coal from a newly developed mine in Wyoming would closely satisfy their requirements. Analyses of this coal were reviewed by the manufacturer, who confirmed the selection as a possible alternate fuel for this unit.

Because the manufacturer had no specific experience with this particular coal, the two companies agreed upon a mutual test program to obtain information using a trial lot of 5500 tons. The unit was tested first with the Illinois design coal, then using Wyoming coal, during the latter part of May 1974. A comparison of the physical and chemical properties of both test coals relevant to the performance of the unit is shown in Table I.

COAL SOURCE	Illinois	Wyoming
Total Moisture, %	19.2	31.3
Equil. Moisture, %	17.3	26.3
Btu/Lb A.F.	10,345	8,265
Grindability (Avg.) HGI	56.5	60.5
Ash: B/A Ratio	0.52	0.81
AST (Red.), F	2170	2140
$Na_2O + K_2O$, %	2.5	1.5

Table 1 Test Coal Characteristics

Unit instrumentation was validated before testing and additional test equipment was installed. One of the two mill systems was completely instrumented for detailed analysis. Both mill systems were inspected thoroughly before testing to determine if any mechanical deterioration had occurred since unit start-up in 1967. Nothing requiring correction before testing was found.

COMPARISON OF BOILER AND FURNACE PERFORMANCE

The unit was first tested at ratings of 61% and 100% MCR using the design Illinois coal. The tests were then repeated burning Wyoming sub-bituminous coal at similar ratings, and one additional test was conducted at 79% MCR. The capacity of the unit using sub-bituminous coal was limited to 96% MCR by the mill system transport air flows and static pressures available from the existing primary air fan. For long-term operation on the Wyoming coal at MCR, a re-setting of the mill coal charge level controls would be made to reduce the mill transport air-fuel ratios and flow differentials. This will permit full use of the existing pulverizer capacity, which is in excess of requirements at MCR for the Wyoming coal.

Little difference existed in the performance of the boiler at maximum rating burning either coal, as shown in the first two columns of Table II. The third column shows additional data on operation with the Wyoming coal at 79% MCR. Minor increases in exit steam temperature (superheated steam temperature modified by spray water flow), plus a small rise in gas flow differentials through the boiler passes, were observed at the top ratings on Wyoming coal. These were a result of the following factors:

1. High mass flow rate of combustion gases per pound of steam generated; more fuel must be burned per pound of steam to evaporate moisture in the coal, compared to that in the Illinois coal at a similar rating.

2. The increase in evaporated fuel moisture adds further to the total mass flow of gases/pound of steam generated.

3. At the maximum rating, firing Wyoming coal, more excess air was inadvertently supplied for combustion than for the comparable rating on Illinois coal, as indicated by the %O_2 in the boiler exit gases for each test.

Observation of furnace conditions, limited by high furnace pressures at top loads, indicated similar combustion characteristics for both fuels relative to flame shape, length, absence of wall impingement, and stability. Minor wall slagging noted with Illinois coal firing was absent after one day's operation on Wyoming coal. Molten slag was observed dripping from the bottom of the high-temperature superheater pendant after operating at 96% MCR on Wyoming coal, and probably occurred with Illinois coal too. Furnace exit gas temperatures near this location were about the same for either fuel at maximum ratings. It must be noted that long-term slagging or fouling tendencies could not reliably be evaluated with only four days' operation on Wyoming coal, but preliminary indications were favorable.

Furnace exit gas temperatures were measured by a single line HVT probe traverse across the width of the unit, stopping at 1 ft. intervals. Averaged values for 85% of the furnace width are shown in Table II, and compared to the listed average exit gas temperature calculated by heat balance using boiler test data. The probe values indicate gas temperatures at one location in the flow path.

BOILER:			
Coal Source	Illinois	Wyoming	Wyoming
Steam Flow, lbs/hr	950,000	910,000	750,000
Percent MCR	100	96	79
Superhtr. Out. Press., psi	1885	1835	1880
Superhtr. Out. Temp., F	995	980	990
Superhtr. Spray, lbs/hr	9000	16,000	15,000
Rehtr. Out. Temp, F	975	990	1000
Boiler Eff. (calc.)	88.7	85.6	85.7
FURNACE:			
Firing Rate (Raw Coal) lbs/hr.	124,000	152,500	132,200
F.D. Fan Disch. Pr. "H_2O	24.2	26.8	20.6
F.D. Fan-Furn. Diff. Pr., "H_2O	10.1	11.3	8.6
Furn.-D.C. Outlet Diff. "H_2O	13.1	14.3	11.3
Furnace Exit Gas Temp:			
Heat Balance Calc. F	2147	2157	2125
HVT Probe Traverse, F	2405	2417	2400
Dust Coll. Exit Temp. F	330	342	322
O_2 At Boiler Exit, %	2.2	3.4	3.8

Table II Boiler and Furnace Performance

MILL SYSTEM PERFORMANCE

A summary of test results on the mill system using both Illinois and Wyoming coal is given in Table III, showing separately data on both the drying and pulverizing functions of the system. The capability of the mill system in meeting both requirements when grinding high moisture coals is clearly evident. However, the overall system performance does not define the specific action of the crusher-dryers which insures satisfactory operation of the mill system with extremely high-moisture coals. Furthermore, accurate test data on the drying process or representative samples between the crusher-dryer and the mill inlet cannot be obtained for the following reasons:

1. Raw coal feed into the system varies with time as much as ± 17.5% from an average system discharge rate. The latter is proportional to the transport primary air flow, which is regulated by a demand signal from the master control of the boiler. The primary air flow extracts pulverized coal from a large but active reserve (4-5 tons) in the mill. Changes in the amount of reserve due to demand variations are eventually sensed by level probes. From these, a signal is sent to the controller, which adjusts the raw coal feeder speeds to restore the pre-set level at a rate independent from system delivery. This means that the air-fuel ratio and consequently the degree of drying through the crusher dryer into the mill varies unpredictably with time, although these fluctuations have little overall effect due to mixing of the crusher product with the large reserve in the mill proper.

2. Extreme turbulence, severe flow stratification, widely divergent individual coal particle paths and velocities, and incomplete evaporative processes render sampling of the crusher product by conventional probe methods meaningless at any suitable location in the ducting between the crusher and the mill inlet.

GRINDING:			
Coal Source	Illinois	Wyoming	Wyoming
Unit Output, lbs Steam/hr	950,000	910,000	750,000
Raw Coal to System, lbs/hr	62,200	76,330	66,350
Primary + Seal Air Flow, lbs/hr	104,400	115,000	99,300
Air-Fuel Ratio (Input) lbs/lb.	1.67	1.51	1.50
Power Input to Mill, kW-hr/t	14.4	12.2	13.8
P.A. Fan-Furn. Diff., Ins. H_2O	23.6	31.7	23.8
Pulv. Coal Fineness, %/#200	75.1	73.6	79.5
DRYING:			
Primary Air Temp. to Crusher, F	580	722	703
Classifier Outlet Temp., F	145	145	147
Moisture in Raw Coal, %	18.0	30.9	30.8
Total Moist. Input, lbs/hr	11,200	23,600	20,300
Total Moist. Evaporated, lbs/hr	9,540	13,500	11,120
Moisture in Pulv. Coal, %	3.15	16.1	16.7
Initial Moisture Removed, %	85	57	55

Table III Test Mill System Performance

DRYING PROCESS IN THE CRUSHER

An evaluation of the crusher-dryer function can be made by testing a separate sub-system, which includes a variable-speed feeder, an air supply source controllable as to flow and temperature, a crusher-dryer, thermally insulated ducting and dust collectors, and appropriate test instrumentation. Our Research Division has tested such a sub-system on coals ranging from a pipeline slurry having 1% inherent and 18% surface moisture, to Dakota lignite with 35% inherent moisture. We reviewed these test data to evaluate the pre-drying of the Wyoming test coal when processed through the crusher-dryer with similar air-fuel ratios, inlet air temperatures, and crusher product size. The analysis shows that, of that fraction (± 56%) of moisture evaporated from the Wyoming coal during full-scale testing, approximately two-thirds was removed prior to mill entry, and the remainder in the mill and classifier.

The removal of all free moisture and part of the inherent moisture from the coal ahead of the mill reduces the milling capacity requirement: first, by eliminating the adverse effects of surface moisture in the grinding process, and secondly, by reducing the weight of solids per hour to be pulverized. Considering only the loss in weight/hour due to partial drying, the mill power input for grinding per ton of raw coal feed is reduced by 12%. A decrease in coal grindability of about 5 HGI due to drying is offset by improved mechanical milling efficiency because of the absence of surface moisture in the feed.

A significant increase in milling capacity obtained by partially pre-drying high inherent moisture coals, instead of removing the moisture during the pulverizing process, has been demonstrated for another type of pulverizer.[1]

SIZE REDUCTION IN THE CRUSHER

Along with evaporating 12% of the weight of material to be ground, the crusher-dryers produce a substantial reduction in average coal particle size, which is needed to utilize efficiently the extreme turbulence generated in the crusher-dryer and beyond for fast drying ahead of the mill. The particle size of the crusher product is primarily determined by crusher hammer tip clearance and is only slightly affected by primary air flow rates, coal grindability, and initial feed size. At the maximum test rating, the product size leaving the crusher, expressed as the particle diameter in microns for which 80% of the material is finer, was about 1600 microns. During the same test run, the feed size to the crusher was 8700 microns, or about 3/4" x 0".

Apart from expediting drying, the size reduction in the crusher cuts down the amount of energy consumed by the mill to produce an acceptable fineness in the pulverized coal discharged to the burners. The effect of a decrease in feed particle size on ball mill power consumption in kW-hr/ton can be calculated by a theoretical analysis, which has been extensively verified in practice by the mineral milling industry.[2] For a decrease in mill input feed size from 8700 to 1600 microns, power consumption in kW-hr/ton of finished product at 96 microns (70% passing #200 mesh sieve) is reduced by 15%, assuming that certain mill parameters, such as ball size in the charge, are accordingly adjusted. For a given mill, power input is essentially constant at all ratings so that the reduced kW-hr/ton of product is equivalent to a capacity increase of 18%. This increase will actually be greater since about 30% of the 1600 micron crusher product is already finer than #50 mesh, and some fraction of these fines will be conveyed through the mill and classifier to the burners by the transport air without being subjected to additional grinding. Since the actual amount of this is indeterminate, the effect is not included in the calculation.

EFFECT OF CRUSHER-DRYER ON MILL SIZE REQUIRED

The combination of pre-drying and fine crushing applied to the high-moisture sub-bituminous coal ahead of the ball tube mill produced a reduction of 25% in ball mill power per ton of raw coal from that which would be required without the crusher-dryers in the system. Based on the 12.2 kW-hr/ton recorded during the Wyoming coal test at 96% MCR, the milling power without the crusher-dryers would be 16.3 kW-hr/ton of raw coal. Power consumed by the crushers is 0.8 kW-hr/ton at this rating, so there is a net reduction of 3.3 kW-hr/ton, or about 20%, when the crusher-dryers are used in the mill system. Without crusher-dryers, a larger mill and drive motor would have to be used to obtain the needed capacity, in this case an 11'6" dia. x 15' long mill with a 900 hp drive. This is a prohibitively expensive alternative to the system using crusher-dryers.

SUMMARY

Several steps are necessary in deciding on a change in coal supply, including preliminary economic analysis of the requirement, a survey to determine what particular choice of coals might best suit this analysis, and at least a short trial run using enough of the selected coal to assess its effect on the performance of the equipment in which it is to be fired.

In this particular case, a high inherent moisture Wyoming sub-bituminous coal met initial conditions as an alternative to the Illinois coal for which the unit was designed. Also, since the pulverizing and firing systems were initially designed for coals of somewhat higher total moisture than that usually encountered in coals from the east or midwest, the occurrence of a serious reduction in unit output as a result of mill system limitations using Wyoming coal appeared unlikely.

A four day test run substantially confirmed the preliminary analysis with respect to firing and slagging conditions in the furnace and the capacity of the pulverizing system. The latter was assumed initially to be the most critical element, and for this reason one mill system was tested in detail to compare performance with both the design coal and the selected alternate. The test results showed that the grinding capacity of the mills and crusher-dryers was more than adequate using the Wyoming coal, but that the mill transport air/fuel ratio exceeded design values. This could be readily corrected by re-setting mill level controls if sustained operation with Wyoming coal was required.

The use of crusher-dryers for pre-conditioning high moisture sub-bituminous coals substantially reduces the size and power requirements of the pulverizers needed in the system. Those plants facing conversion to high moisture western coals without adequate milling capacity may well consider the incorporation of crusher-dryers ahead of existing pulverizers, where practical, to avoid substantial loss of capacity. This would be less expensive than installing additional mills, and would use less overall power for grinding.

Since the crusher-dryers account for only a small fraction of the total work in grinding, their maintenance costs are accordingly minor. For the unit tested, grinding high sulfur Illinois coals over a 6-year period, crusher repair costs have averaged 1.7 cents per ton, slightly less than the 1.87 cents/ton chargeable to the ball mills. Recent improvements in design and materials used in the crusher will further reduce maintenance costs.

In contrast to the unit tested, our larger modern pulverized coal-fired units, designed for firing western sub-bituminous coals, utilize directional flame burners arranged for opposed firing downwards into the lower portion of a furnace having a vertical venturi-shaped cross-section. This design achieves higher furnace heat absorption with lower exit gas temperatures and reduced thermal NO_x emission, compared to test unit observations.

Recent mill design and system control improvements have provided significant reductions in grinding power compared to that observed during testing. A new solid state electronic feeder speed control using mill power and sonic signal inputs was developed to maintain precisely the amount of coal in the mill consistent with peak grinding efficiency. Other modifications permit increasing the overall system air-fuel ratio up to as much as 2.25/1, to dry the coal more completely. This permits burning the pulverized sub-bituminous coal efficiently with a fineness of only 65% passing #200 mesh instead of the usual 70% needed for eastern coals. The lower fineness further reduces power needed for grinding.

Ball mills are ordinarily maintained at original design capacity for long periods by simply feeding in new balls at regularly scheduled intervals during normal operation to replace wear losses. This avoids having to put in spare mills initially to avoid losing generating capacity during the time-consuming and relatively frequent outages for maintenance required by other types of mills. Elimination of spare mills and accessories, continuity of operation, and low maintenance costs are primary factors in realistic cost evaluations which are responsible for the increased use of ball mill systems in the industry, particularly for firing high-moisture western coals.

REFERENCES

1. Ellman, R. C., Dockter, L., and Belter, J. W., "Pulverizing Lignite in a Ring-Roller Mill," Bureau of Mines Report of Investigations, RI 7631 (1972)

2. Bond, F. C., "Crushing and Grinding Calculations," Rev. January 2, 1961; published by Allis-Chalmers Manufacturing Company, Industrial Press Department, Milwaukee, Wisconsin.