Technical Publication

# Special Considerations for Coal Fired Cycling Boilers

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# SPECIAL CONSIDERATIONS
# FOR COAL FIRED CYCLING BOILERS

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Electric utility companies in the past handled their high load distribution requirements with what were termed peaking units. The peaking unit was essentially a base loaded unit, but was designed so that by increasing operating pressure and steam flow, decreasing final superheat and reheat temperatures, and decreasing feedwater temperatures by dropping out some feedwater heaters from the cycle, extra megawatts could be obtained from the turbine. Present day load demands dictate that other methods must be utilized to cover these load requirements. Peak load demands are only required for a short portion of the day, and this generally occurs during the working week of Monday through Friday. Large fossil-fired units and nuclear-powered units have given the utilities a solid base load generation.

New units are being designed for fossil fuels utilizing a cycling type of operation. Cycling duty is thought of as daily start-ups and shutdowns during the week, and shutdowns for the weekend. Cycling units therefore will have approximately 250 to 300 start-ups during a year. With the new cycling requirements, modifications in modes of operation, as well as new techniques of design and controls have come into being.

Utilities have also witnessed recently a wide fluctuation in the cost of fuels, as well as cutback in availability of such fuels as natural gas. A short time ago, gas and oil fired cycling units were in demand. Nowadays, fuel availability has prompted the boiler manufacturers and utilities to look at coal fired cycling boilers.

Basic differences between base load and cycling unit designs are not readily apparent when looking at a sectional side elevation of the steam generating unit. Generally, in cycling type operation, the final steam temperatures have been reduced from the normal base load unit figure of approximately 1005° F to 955° F. The superheater outlet pressure is held in the 2000 psig range. Both of these combine to provide thin wall vessels with a minimum of alloy material in an attempt to hold down initial costs and to allow for higher rates of temperature change because of thinner walls. Cycling units can and probably will be designed for the 1005° F and 2600 psig superheater outlet pressures, but the general trend is towards the lower temperatures and pressures.

## DESIGN FEATURES

One example of a coal fired cycling unit design is shown in Figure 1. This unit has the following design features:

1. Stainless steel bumper tubes installed in the area of high heat absorption on the lower portion of the radiant superheater.
2. A drainable superheater is included to facilitate more rapid start-ups and prevent tube failures by water blockage during hot restarts or cold starts. There is only one positive way to insure that all circuits are completely void of condensate before refiring or raising firing rates so that gas temperatures exceed 1005° F, and that is by draining all sections.
3. Higher than usual pressure drops and steam mass flows are utilized as compared to a base loaded unit. For instance, a pressure drop of 180 pounds per square inch would be utilized in place of a normal 140 psi in the superheater.

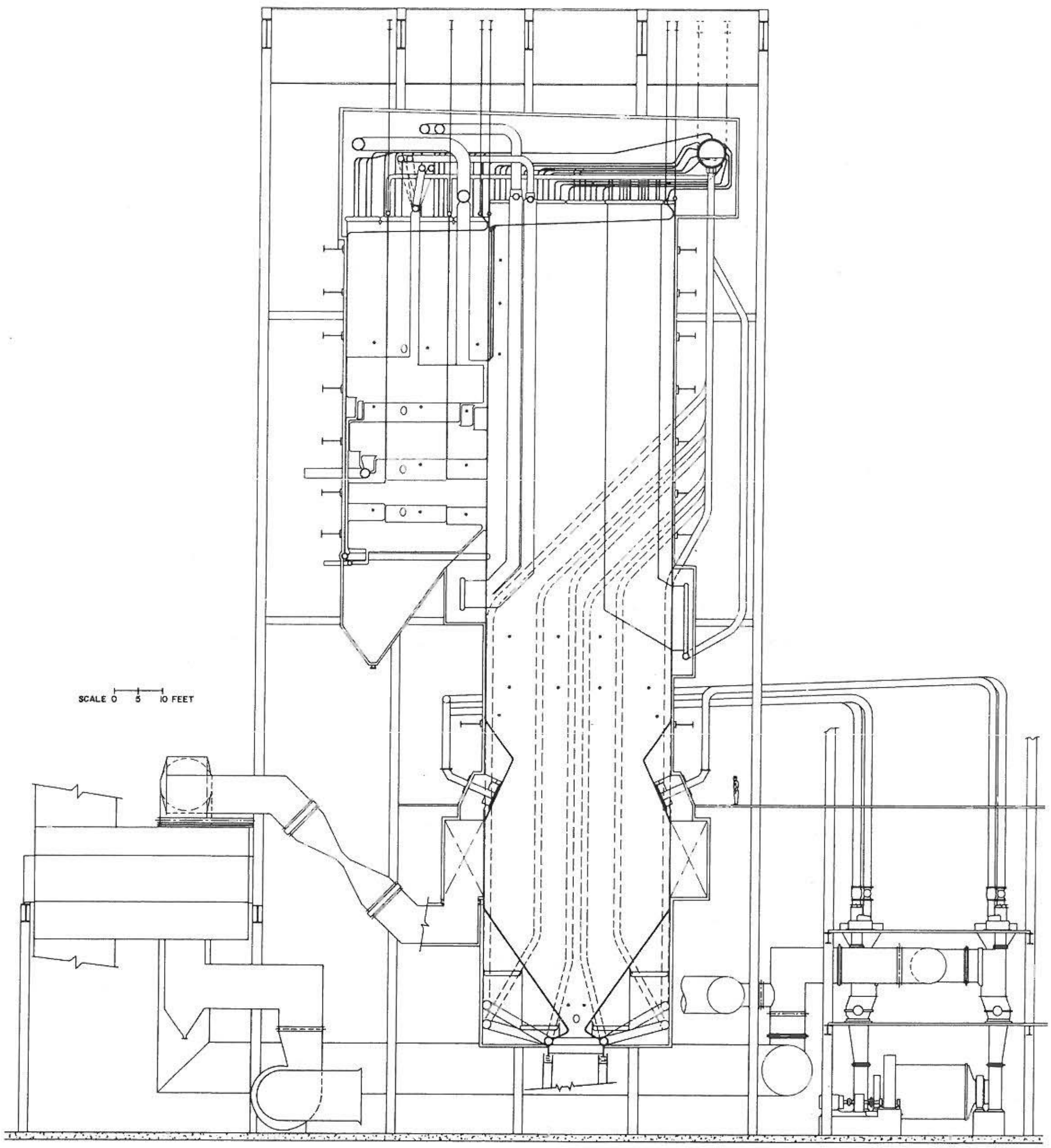


Figure 1 Sectional Side Elevation, Coal Fired Cycling Unit

4. A steam temperature control system, with the ability of avoiding temperature unbalance from side to side caused by sudden load changes, is included. This system also has the ability to maintain superheater and reheater steam temperatures below the control point within a specified range of each other.
5. Oversized spray control systems have been incorporated in the design.
6. A steam bypass has been located before the primary superheater to allow steam to flow straight to the condenser. Control of this bypass flow provides a means of matching turbine temperatures at a lower load during hot and cold restarts.
7. Provisions for flexibility and expansion are provided. This would include, but not be limited to, the distance between superheater and reheater outlet headers and the waterwalls through which the superheater and reheater tubes must penetrate for flexibility, and extra provisions for expansion of casings, penthouse, and ductwork attachments, etc.

## BYPASS SYSTEM

The start-up system for the boiler may incorporate two main features. The first is the bypass between the convective superheater and the steam drum mentioned above. The second is the provision for the addition of pressure control valves between the superheater sections and the drum.

The bypass system, similar to that shown in Figure 2, allows steam flow to be diverted such that for a specific firing rate, high steam temperatures are obtainable to allow turbine matching at low loads. The heat transfer rate in the superheater is influenced more by gas side conditions than by steam flow on the inside. This means varying steam flow within the

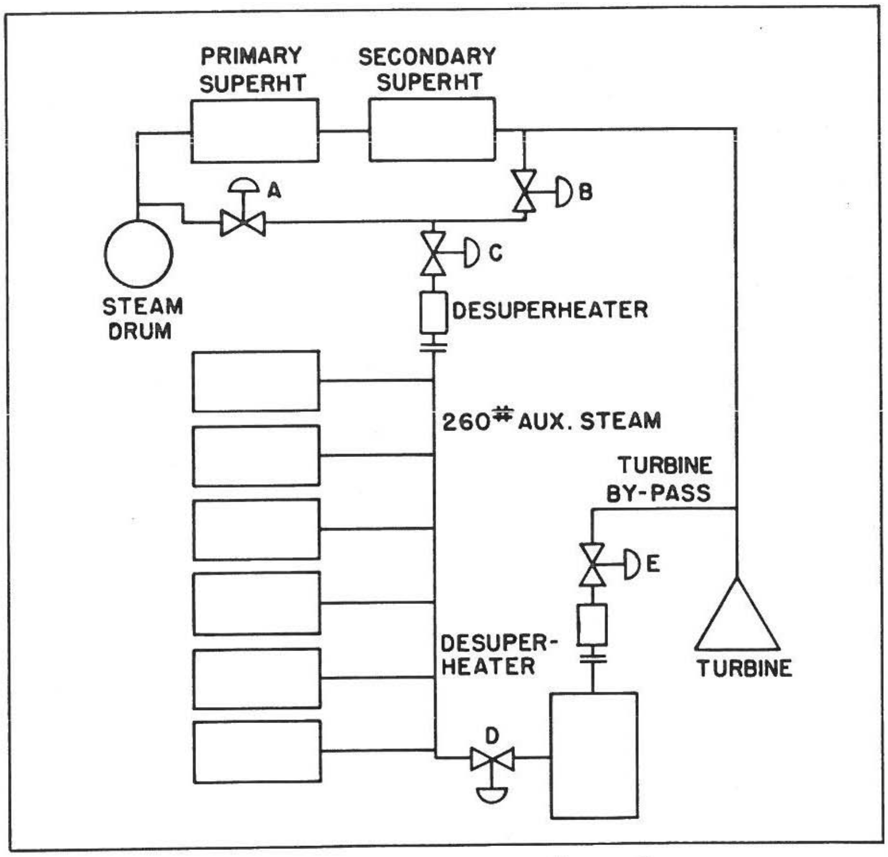


Figure 2 Start-Up System – Steam Bypass

tubes has a minor effect on the total ability of the superheater to pick up heat. By reducing steam flow to the superheater, the same amount of heat pickup can be utilized over a smaller portion of steam, giving correspondingly higher steam temperature. The effect of steam bypassing on superheater outlet temperature is indicated in Figure 3.

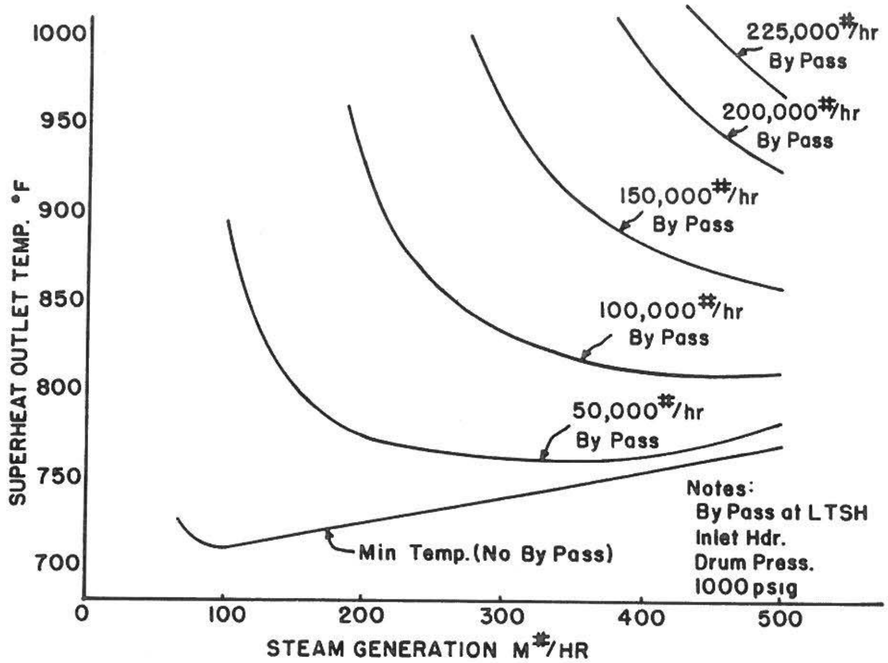


Figure 3 Effect of Steam Bypassing on Steam Temperature

A refinement to the bypass system would be to add a bypass after the superheater to service the various auxiliary steam requirements at times when the bypass system is not used or its use is curtailed due to high individual tube metal temperatures. Figure 4 shows a typical start-up curve for a cycling unit after a ten hour shutdown. The use of the bypass system is incorporated early to enable the unit to get steam to the turbine for roll and synchronization as quickly as possible.

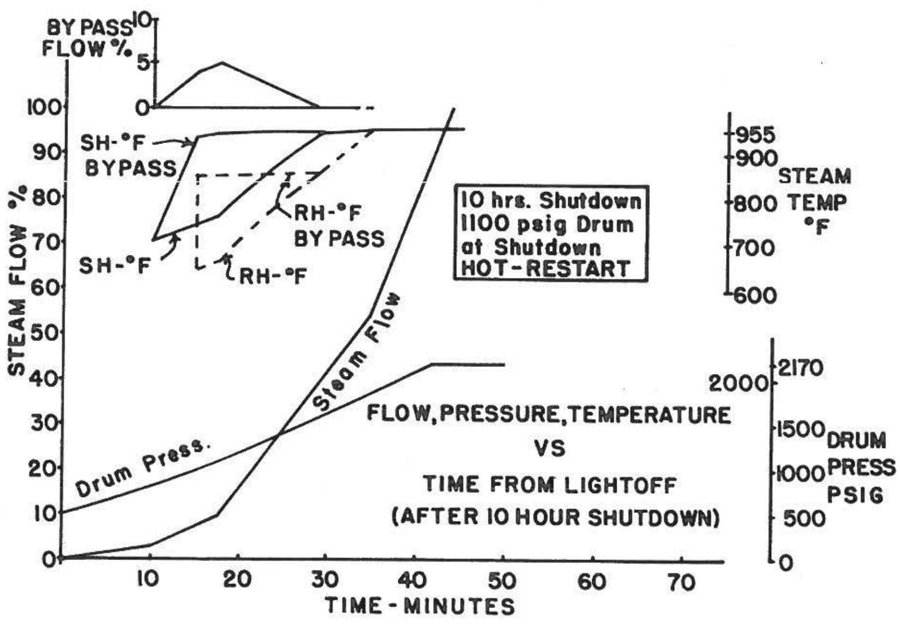


Figure 4 Start-Up Curves, Overnight Shutdown

## VARIABLE PRESSURE OPERATION

Variable pressure operation is another feature of the cycling unit design. At lower loads, the operating pressure is reduced such that the turbine throttle valve can stay wider if not fully open. This produces less of a temperature drop in the high pressure stage of the turbine, allowing a better heat rate. Lower pressure operation also has the effect of raising superheat and reheat steam temperatures. It is harder to generate steam at lower pressures, and so an increase in firing rate occurs which allows more heat in the furnace exit gas temperatures, and a corresponding increase in overall steam temperatures. There is a negligible change in boiler efficiency under the lower pressure operation conditions, and steam quality and circulation are improved.

Variable pressure operation allows the turbine to stay hotter during shutdown so that more rapid restarts can be accomplished after an eight or ten hour shutdown. Utilization of pressure control valves in the superheater system (see Figure 5) allows the drum and circulating system to operate at higher pressures or even full pressure, while maintaining the variable pressure type of operation at the superheater outlet. This allows a cycling unit to shut down with as much residual heat as possible in both the boiler and the turbine. When both the boiler and the turbine are maintained at their highest permissible temperatures, the restart time back to full load/full pressure operation is reduced to a minimum. Offsetting these advantages are the initial cost of the valves and control system, and the additional pressure drop across the valves under normal operation.

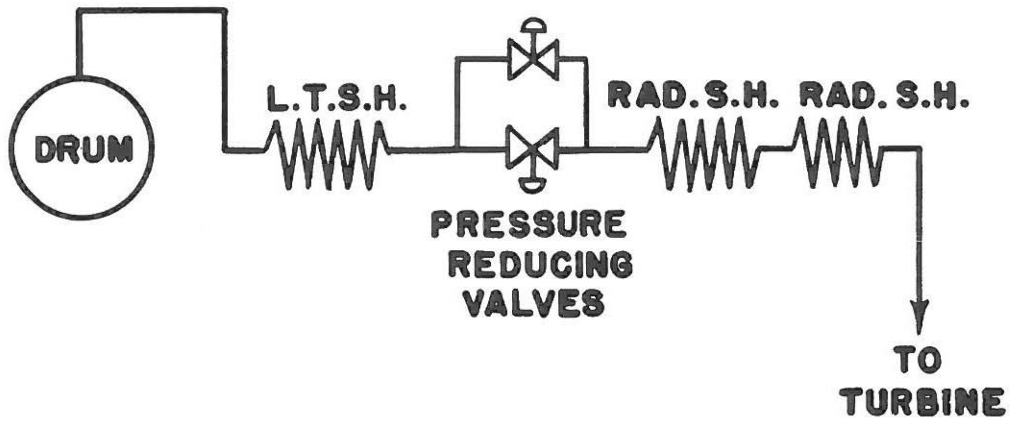


Figure 5 Pressure Reducing Valve Line Schematic

## BALL TUBE MILL SYSTEM

Pulverization equipment for cycling units needs to be dependable, have reproducible performance, and have the ability to react fast, with negligible loss in efficiency or fineness, to rapid load changes. The Riley Ball Tube Mill System is especially suited to this service. See Figure 6.

Riley ball tube mills are available in pulverizing capacities from approximately 10,000 pounds of coal per hour to more than 177,000 pounds of coal per hour. The system consists of the pulverizer, coal feeders, crusher dryers, classifiers, primary air systems, burners and control systems.

Hot primary air and raw coal enter the crusher dryers simultaneously. The purpose of the crusher dryer is to evaporate, through flash drying, the surface moisture of the coal and also

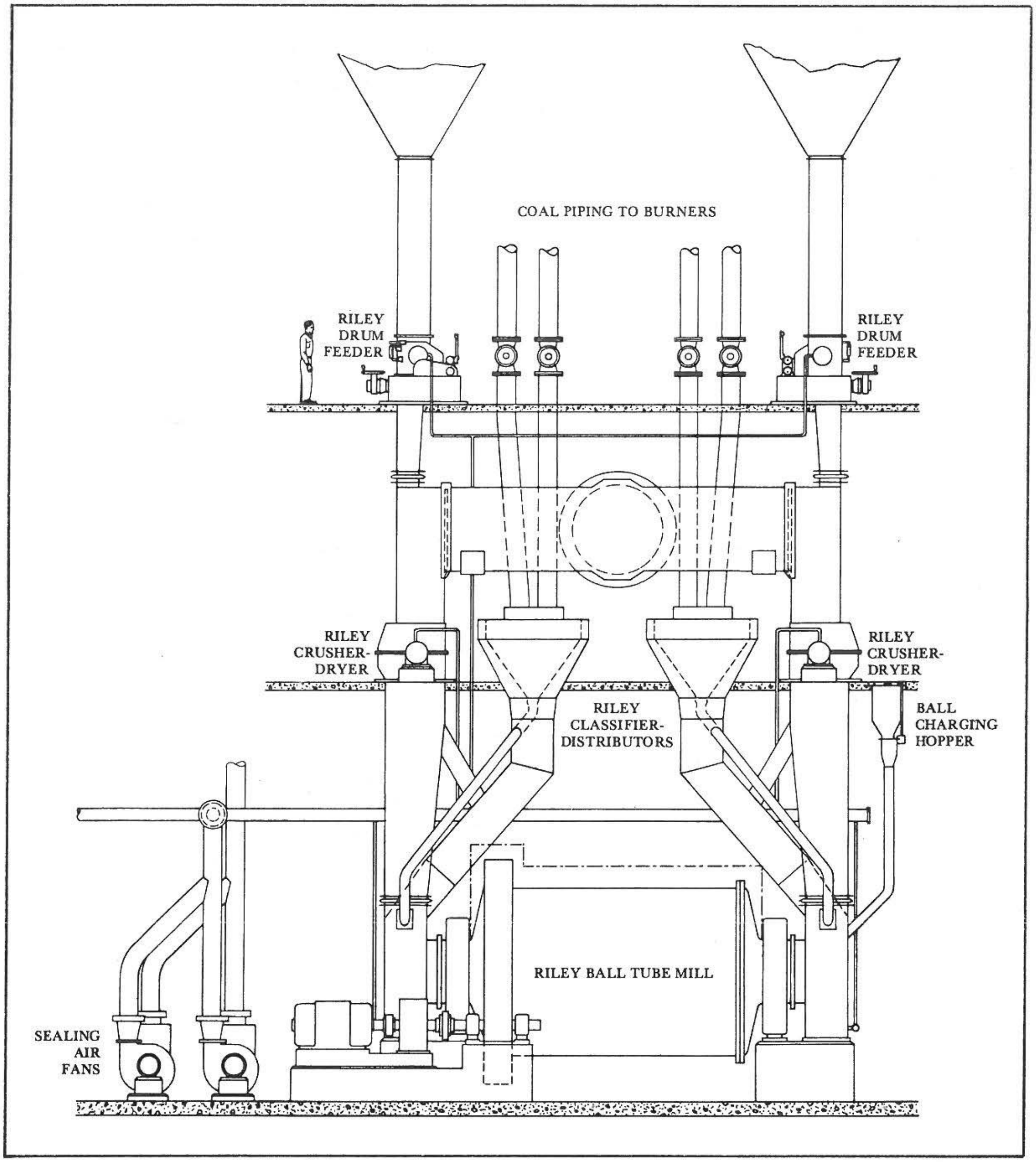


Figure 6 Typical Coal Pulverizing System

a portion of the equilibrium moisture. Simultaneously, the coal size will be reduced to 100% through one-half inch mesh. Unlike other mill systems, the temperature of the coal and air mixture entering the mill is relatively low. This significantly reduces the probability of fires and explosions within the mill system.

Each mill is equipped with two centrifugal type classifiers, which are externally adjustable to maintain the fineness required for low carbon loss, and also to assist in producing optimum furnace performance and reducing slagging potential. Coal charge within the mill is maintained at its most efficient value by transmitting a signal from the coal charge indicator to the coal feeder control, which continuously modulates the feeder output. The feeder control response is thus not directly regulated by the combustion control system. Because of this and the fact that there is always a supply of pulverized coal within the mill, the mill system response to load changes is excellent. To increase or decrease load on the mill, it is necessary only to modulate the primary air damper at the inlet to the mill system.

The Riley ball tube mill system's greatest advantage is that it is unnecessary to shut down the mill for replacement of its grinding elements. Pulverization takes place through the cascading of abrasion and impact resistant alloy balls which are added at regular intervals through external charging hoppers while the mill is in operation. Since the bulk of the pulverization takes place due to the impact and attrition of ball on ball, internal mill wave lift liners exhibit many years of life; in some cases, in excess of fifteen years before replacement is required.

Ball tube mill pulverizers, due to the nature of their design, utilize approximately the same horsepower whether coal is being pulverized or not; therefore, it is prudent to operate ball tube mills only with the necessary ball charge to perform the required pulverizing task, and to remove pulverizers completely from service at reduced system loads such that each individual pulverizer can be operated near its full load capacity. Ball tube mill systems can be operated with only small changes in capacity and efficiency with coals of lower rank than originally specified. Many times, it is not the ball tube mill which limits the use of lower rank coal, but the other aspects of the generating system such as slagging and fouling tendencies in the furnace and boiler sections of the generating facility.

## OIL CONSUMPTION

One of the greatest features of the ball tube mill system in coal fired cycling duty is its ability to come on line early in the start-up sequence, thereby reducing to a minimum the amount of oil fuel required for warmup or sustaining fuel. In Table 1, we have tabulated start-up times and oil consumption for the 600 megawatt coal fired cycling unit shown in Figure 1. We have added other rows of figures to show a comparison between 2000 pound and 2600 pound operating pressures and units with drainable and nondrainable superheaters.

| Operating Pressure (PSI) | Hours to Restart | Superheater Type | Time Required to Full Load (Min.) | #2 Oil Fuel Flow (Gal.) |
|---|---|---|---|---|
| 2000 | 10 | Nondrainable | 75 | 1580 |
| 2000 | 10 | Drainable | 43 | 1580 |
| 2000 | 55 | Nondrainable | 105 | 2220 |
| 2000 | 55 | Drainable | 82 | 2220 |
| 2600 | 10 | Nondrainable | 88 | 1580 |
| 2600 | 10 | Drainable | 55 | 1580 |
| 2600 | 55 | Nondrainable | 117 | 2220 |
| 2600 | 55 | Drainable | 100 | 2220 |

*Note: All times indicated assume a superheat bypass system is incorporated.*

Table 1 Start-Up Times and Oil Consumption (600 MW Unit)

During shutdown of the unit, again the amount of sustaining fuel oil required is held to a minimum. Only two burners are required to be left on to clear the mill of all pulverized coal once the feed has stopped. Therefore, only the ignitors associated with these two burners are required during shutdown procedure. Oil consumption during a shutdown would be approximately 700 gallons.

## OPERATIONAL CRITERIA

The following operational criteria are used on boilers designed for cycling operation:

1. The pressure raising rate shall be such that the temperature rise of the saturated liquid is not more than 200° F per hour. Portions of the boiler such as the windbox and the penthouse casing, as well as flue gas ductwork and breeching which are attached to the boiler, will not expand at the same rate as the waterwalls and/or pressure parts during a start-up and shutdown. This limitation is imposed to prevent tearing of seals and joints.
2. On heating, the temperature differential between the outside top and the outside bottom of the drum shell, plus the differential between the inside bottom and the outside bottom of the drum shell, shall not exceed 150° F. On cooling, the sum of these two temperature differentials shall not exceed 100° F.
3. The gas temperatures in the vicinity of the superheater or reheater must not exceed 1000° F prior to establishing steam flow through the respective superheater or reheater tubing. This is a commonly used criteria for protection of boiler pressure parts exposed to the gas stream. We have found that the 1000° F temperature is not a restrictive temperature as far as time required for hot restart or cold start operation on cycling units.
4. The load (steam flow) pickup should be limited to 5% per minute. While this limitation is imposed on steam flow, it is the result of many other things which are restrictive, primarily by boiler characteristics. Affected by the rate of steam flow pickup are the drum level, individual tube metal temperatures in the superheater and reheater, air flow/fuel flow relationships, steam temperature controls, etc. While most units can move at a load pickup rate greater than 5%, the 5% figure has proven to be a good limitation for a sustained period of time.
5. Overall steam temperatures of approximately 25° F above the design temperature should not be allowed. The unit is more than likely designed to operate within a plus or minus 10° F band. This allows 15 more degrees before special action should be taken to reduce the temperature.
6. Drum level fluctuation should be limited to plus or minus 3 inches. Drum level fluctuations could be caused by control problems or rapid load changes. During start-up, it may be necessary to blow down the lower waterwall headers in addition to the continuous blowdown to prevent excessive drum water level swell.
7. Individual tube metal temperatures will have appropriate limits for protection of the circuit during start-up, shutdown, and regular on-line operation. The limits will be dictated by the materials used throughout the circuit.

## POLLUTION CONTROL

To meet $NO_X$ pollution requirements, Riley utilizes a Turbo® Furnace design as shown in Figure 1. The Turbo Furnace incorporates burners on two walls of the unit aimed downward to promote turbulence and give a longer residence time in the furnace. Directional flame burners utilized in the Turbo Furnace consist of slots formed in the waterwalls by the bending of the furnace tubes. Further measures which can be employed for the reduction of $NO_X$ include gas recirculation through the burners and Off-Stoichiometric firing by the use of overfire air ports. See Figure 7.

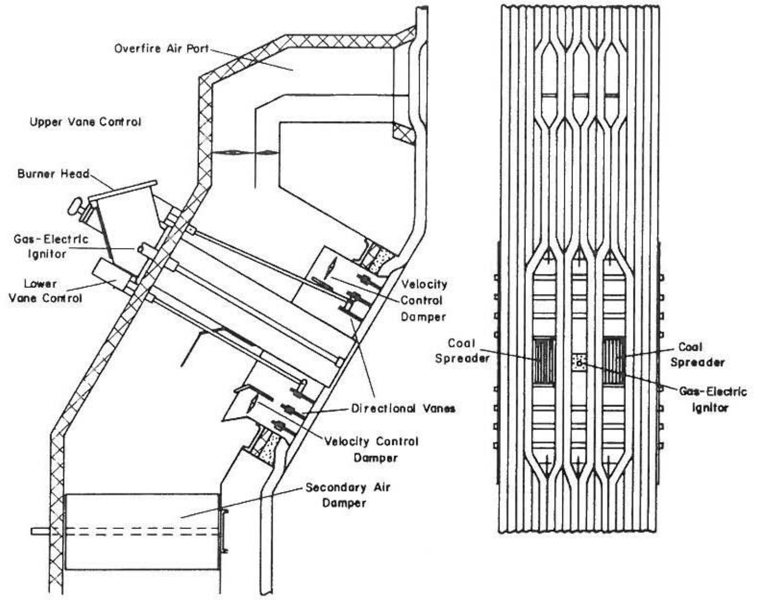


Figure 7 Riley Directional Flame Burner for Coal Firing

The advent of the Western Bituminous and Sub-Bituminous coals has produced greater slagging and fouling tendencies, and so furnaces and convection gas passages are being more generously designed. Heat releases in the order of 60,000 Btu's per hour per square foot are being utilized for coal fired furnaces with severe slagging coals. By the same token, high and severe fouling coals force the boiler designer to increase the tube spacing in the convection passes to prevent bridging over of ash accumulations between tube assemblies. Tube spacing criteria versus gas temperature are shown in Figure 8 for low, medium, high, and severe fouling coals.

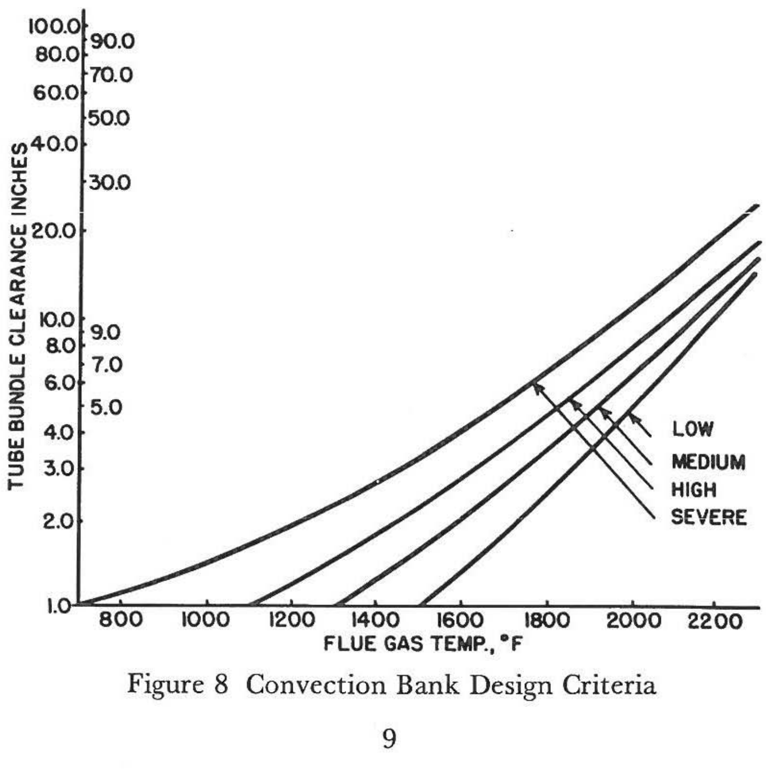


Figure 8 Convection Bank Design Criteria

## COST COMPARISON

Cycling units were originally thought of as less efficient than base loaded units. The reduction in heat recovery equipment reduced the selling price. This concept is no longer compatible with today's inflated fuel prices. The features of the cycling unit, a drainable superheater, slightly higher design pressure, upgraded superheater metals, additional engineering stress studies, etc., all make the cycling unit more expensive. Our estimates show the coal fired cycling unit can be expected to cost approximately 5% more than a base loaded unit.

## SUMMARY

Coal fired cycling steam generating units constitute an advance in the state of the boiler makers' art. They require meticulous design effort and careful operation; but there are no insurmountable problems in either design or operation. As requirements for cycling units grow, so too will the size of these units. It is not unreasonable to expect ratings of 900 or 1000 Mw with 2400 psi throttle pressures. As demand increases, coal fired units will appear more and more for cycling duty along with the gas and oil fired units. Proper coordination is required between manufacturers of major components in the entire power plant, now more than ever, with the advent of coal fired cycling units.