Technical Publication

Design for High Availability - Boilers

by

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DESIGN FOR HIGH AVAILABILITY—BOILERS

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The energy crisis of the past two or three years has accented the need for increased availability and reliability of steam generating units for utilities. Industry-wide averages for units above 400 megawatts indicate a slowly but steadily declining percentage of availability which is now below 80%. Forced outage rates have shown a gradual increase over the past six or seven years and are presently averaging approximately 15%.

Other industries, such as aerospace, have demonstrated that it is possible to have high reliability and operating availability values. While much effort in the development and application of reliability analysis and testing techniques would be required, there is no reason why this same or similar methods could not be applied to the power industry.

A few definitions are apropos at this point: the "availability" of a steam generating unit is a measure of the proportion of time the system is either operating or operable. In equation form, availability equals operating time over total time, where total time is operating time plus outage time. The "reliability" of a steam generating unit is the probability that it will operate without a single failure over a designated total period of time. The "outage rate" would be defined as the unavailability of the steam generating unit. In equation form, the outage rate would be equal to the outage time over the total time, where again, total time is operating time plus outage time.

The best data we have on steam generating unit availability comes from reports prepared by the Equipment Availability Task Force of the EEI Prime Movers Committee. Using these data, we have produced the Table 1, which indicates the five worst offenders in causing boiler outages. These offenders are categorized by component, with superheaters at the top of the list and economizers and ductwork tied for fifth place. A factor of importance has been established for the components causing outages, which relates each of the

FACTOR OF IMPORTANCE	AVG. NO. OCCUR. PER UNIT YEAR	AVG. HOURS PER OUTAGE	AVERAGE HOURS PER UNIT YEAR	COMPONENT CAUSING OUTAGE
6	0.63	63.88	40.05	SUPERHEATER
4	0.43	71.99	31.06	WATERWALLS
2	0.20	76.71	15.51	GENERATING TUBES
2	0.24	57.53	13.96	REHEATER
1	0.22	32.45	7.00	ECONOMIZER
1	0.14	50.19	6.99	BOILER CASING, BREECHING AND DUCTS

Table 1 Forced Outages of Boiler Equipment
10-Year Summary 1965-1974 (EEI)

offenders to the fifth place component. As can be seen from the table, forced outages caused by the superheaters have six times the average hours per unit year of forced outages caused by the economizers or ductwork.

Unfortunately, the EEI is about the only source of statistics on boiler availability and there are some shortcomings in its methods of reporting. For instance, forced outages caused by the superheater are not defined as to the type of superheater (radiant or convection) whether the failure was one of overheating or erosion or some other cause. To make reliability studies more effective and to produce designs that will obtain higher availability require a better definition of the causes of failure by whomever puts this information together. Generally, the boiler manufacturers have to rely on the utilities or the EEI for information on forced outages and their causes because the boiler manufacturer is generally not on the jobsite 100% of the time after the first year of operation.

Another caution to be exercised in considering data from the EEI is recognition of the fact that the outage duration is based on a common denominator repair crew of ten men. This results in a distortion; i.e., unusually high outage rates for large units and correspondingly low outage rates for small units. For illustration, assume that a large unit is forced out for a period of one week and twenty men were utilized in the repairs to the boiler to put it back on the line. Based on a ten-man common denominator, the outage would be reported in statistical form as a two-week outage. A small unit which has a one-week forced outage but utilizes only two men to do the repair work would be listed as a one-day outage based on ten men.

We feel that the utilities and the boiler manufacturers must work together in partnership to produce more meaningful data that can be turned back into higher reliability and availability by judicious design criteria. We also feel that specifications by the customer and their consulting engineers should be such to result in essentially the same degree of conservatism by each manufacturer bidding so that proposals can be evaluated on an equivalent basis. The specifications should not favor any one manufacturer and should reflect good design practice and conservatism in the areas that may affect reliability and availability.

We would like to comment, at this time, about steps Riley boiler designers are taking to reduce the possibility of forced outages. We will not attempt to discuss all causes of forced outages, but in the interest of time and space, confine our remarks to some of those components listed in the top five.

SUPERHEATERS AND REHEATERS

We are working with customers and their consulting engineers to specify minimum pressure drops at maximum continuous rating of 150 psi on the superheater and 5% of the cold reheat inlet pressure for the reheater. This gives the designer flexibility in his selection of tube materials and steam mass flow to produce a more conservative design. Steam mass flow is one design criterion for keeping individual tube circuits cool that are exposed to the radiant heat of the furnace and/or the high temperatures of the flue gases.

In Figure 1, we are attempting to show that steam mass flow by itself is not the governing criterion for reducing tube metal temperatures. For the same tube O.D., we have indicated a thick wall tube on the right and a thin wall tube on the left. The thick wall tube will have the higher steam mass flow and a corresponding lower drop in temperature across the steam film. This lower drop is offset, however, by a high drop across the tube wall such that the resulting average tube metal temperature and outer skin metal temperature has not changed appreciably over that of a thin wall tube. Average tube metal temperature is used by the designer for strength determinations and outer skin metal temperature is used by the designer for metallurgical selection. The best way to utilize the benefits of increased steam mass flow is by reducing tube O.D. and keeping the wall thickness as thin as possible.

Boiler designers are taking longer and harder looks at gas velocities in tube bundles in

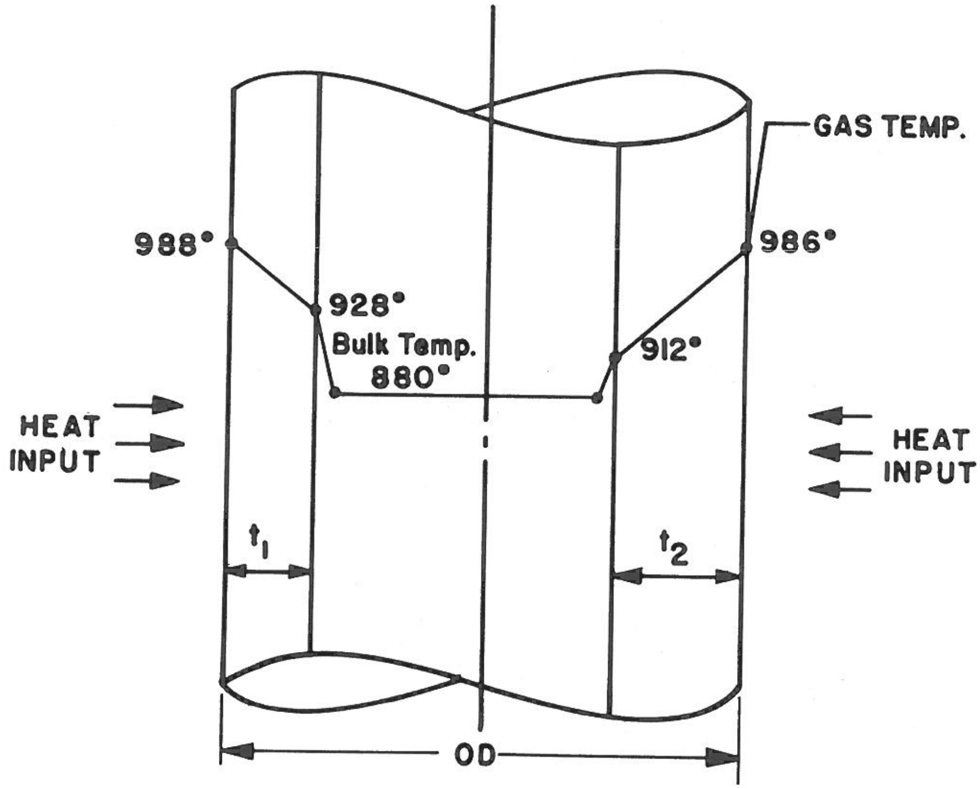


Figure 1 Effect of Wall Thickness on Tube of Constant O.D. on Outside Metal Temperatures

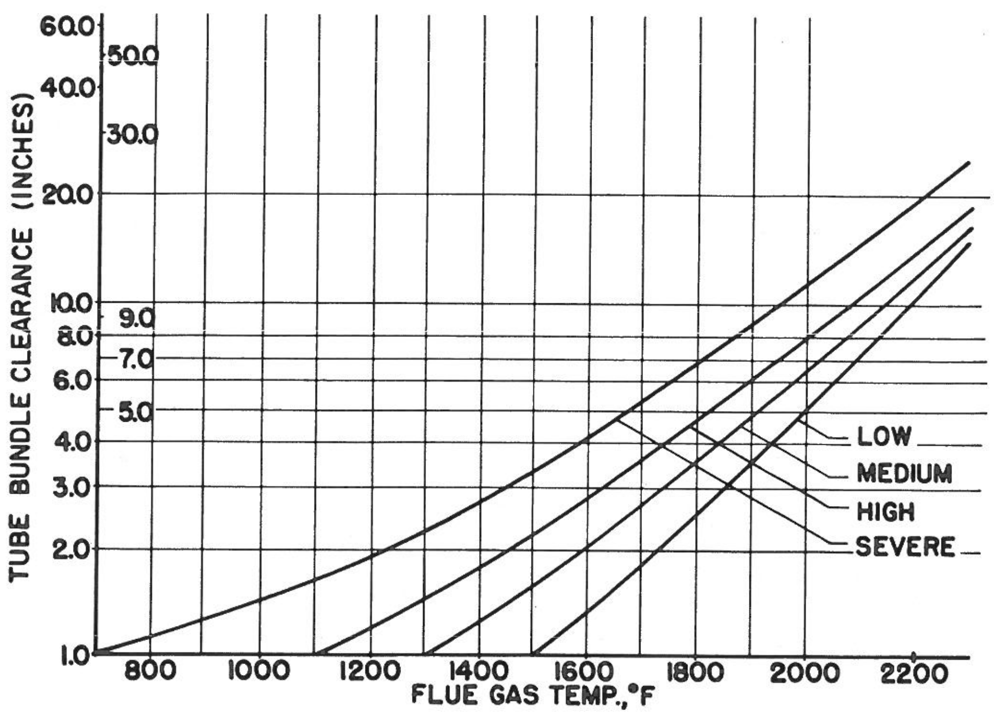


Figure 2 Convection Bank Design Criteria Based on Ash Fouling Index and Gas Temperature

the convection areas of the boilers. Because the current trend is toward lower grade fuels than were used in the past, greater attention is being put on the depth of tube bundles and the side-to-side spacing. Figure 2 indicates that the clear space requirements between tubes increases for both the flue gas temperature in the area of the tube, and the fouling factor attributable to the fuel being fired. Fouling factors are determined from ash analyses and other criteria.

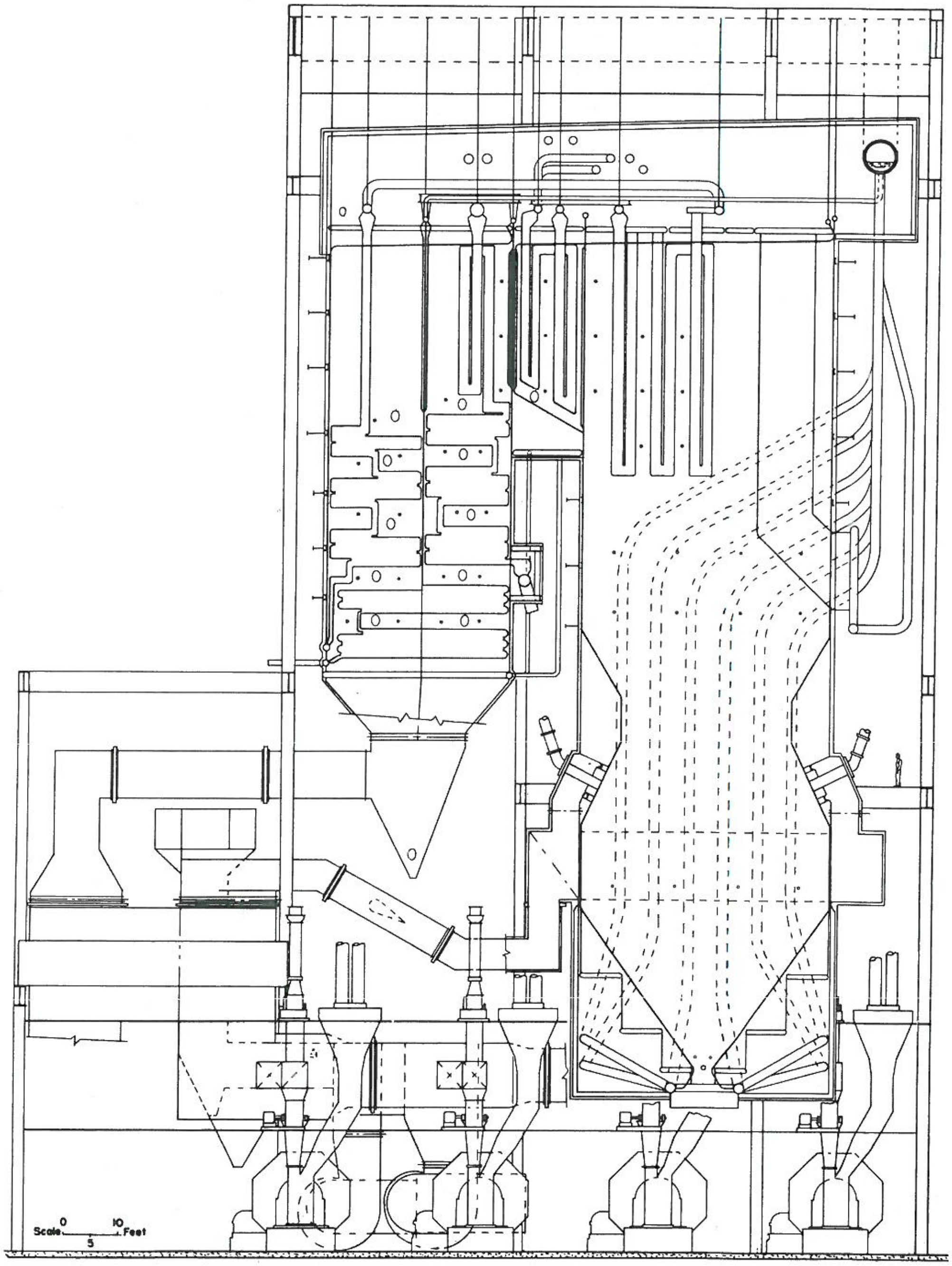


Figure 3 Typical Pulverized Coal Fired, Balanced Draft Utility Steam Generating Unit

Anti-vibration baffles are being installed on large utility units in regions where the flue gas temperature is below 1050° F. as a matter of standard practice. The anti-vibration baffles are also installed above 1050° F. if calculations indicate that there could be a coincidence of vortex-shedding frequencies with the natural frequency of the gas column. More use is being made of superior material such as stainless steels and high nickel alloys for tube supports and alignment straps.

Mean wall and outer skin temperatures are subject to closer scrutiny if meaningful inroads are to be made in availability. Lower limits are now being used by Riley on new proposals which produce more use of superior materials in superheaters, reheaters and waterwalls.

FURNACE AND CIRCULATION SYSTEM

Furnaces for utility units such as that shown in Figure 3 are all of welded-wall construction. We are recommending that users specify balanced draft-designs for coal-fired units, having furnaces designed for plus or minus 20 inches of water at 60% of yield stress. These criteria will supply adequate leeway for upsets such as master fuel trips and control malfunctions. It will not cover every case of fan runaway, especially those where high static pressure induced draft fans are utilized. If a unit is to be designed for fan runaway, the customer and/or consulting engineer should specify this in the pre-sales design stage.

Heat releases at maximum rating should not exceed the values listed below:

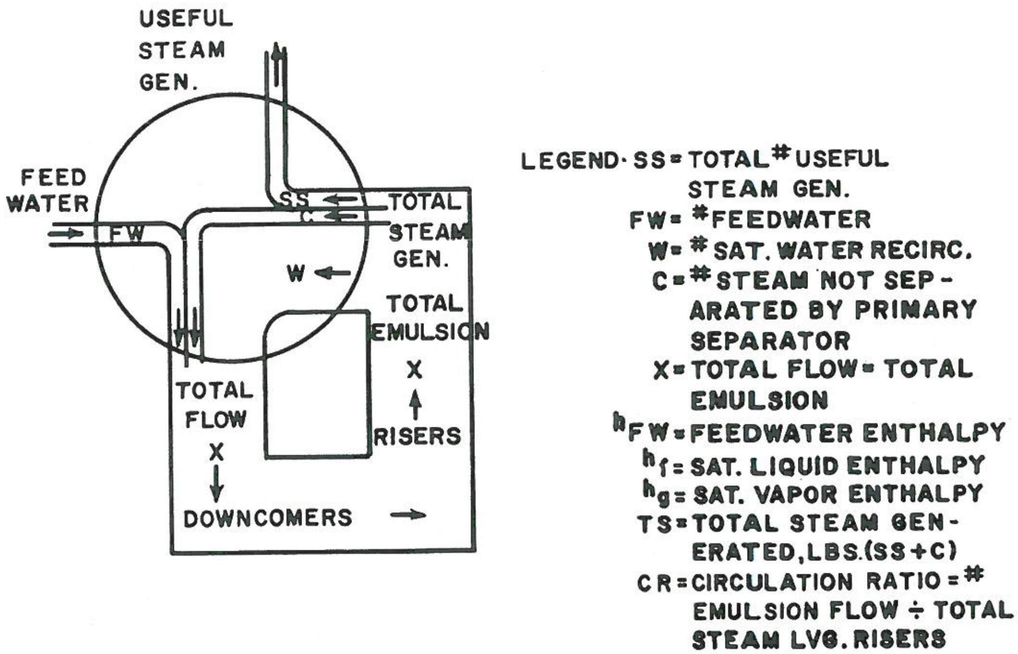
Area Heat Release: BTU/hr/sq. ft.	60,000-75,000
Volume Heat Release: BTU/hr/cu. ft.	10,000-13,000
Furnace Plan Area Heat Release: BTU/hr/sq. ft.	1,250,000-1,500,000

These figures are ranges which depend on the slagging factors, fusion temperatures and other criteria.

In Figure 4, we see a schematic representation of a natural circulation system. A few definitions are given on this figure that are worth reviewing. "Circulation Ratio" is defined as the pounds of emulsion or pounds of water flow in the downcomers divided by the total steam generated in the unit. "Carryover" or "Steam Purity" is defined as the percentage of moisture in the steam leaving the drum and flowing to the superheater. "Carryunder" is defined as the percentage of steam that is not separated from the water and is condensed or entrained and enters the downcomers to follow through the circulation system again. We are concerned with these important operating parameters because reliable operation of the unit depends on good separation of water from steam and also good separation of steam from water.

One of the chief causes of forced outages in high pressure utility units is departure from nucleate boiling within the waterwalls. This phenomenon occurs when small bubbles of steam generated within a furnace tube are not swept away rapidly enough by the emulsion flowing past, and larger bubbles form or the heat input to the tube is so great that large steam bubbles are formed; in either event, the steam acts as an insulator causing overheating and failures of the waterwall tube. In Figure 5, we can see the plotting of circulation criteria that the boiler designer utilizes in the design of the furnace and circulation system. A critical heat flux or, stated simply, the amount of heat necessary to cause failure, can be established based on mass flow and quality criteria. In the design of the furnace and circulation system, we are looking to keep this DNB curve from intersecting with a maximum heat input curve, which is established on the basis of test data and unit configuration.

We have increased the standard O.D. of the tubes that form the waterwalls and furnaces to 2-3/4". As operating pressures creep upwards to the 27- and 2800 psi range, greater flow



ENTHALPY IN DOWNCOMER = $h_{dc} = FW\,(h_{FW}) + W\,(h_f) + (C) \times (h_g)$

IF $h_{DC} > h_f$ WE HAVE ENTRAINMENT $\therefore \dfrac{(h_{DC} - h_f)}{h_{fg}}$ = % STEAM BY WEIGHT ENTRAINED

% CARRY UNDER (BY WT.) = $\dfrac{C}{C + SS}$

Figure 4 Schematic of Natural Circulation System

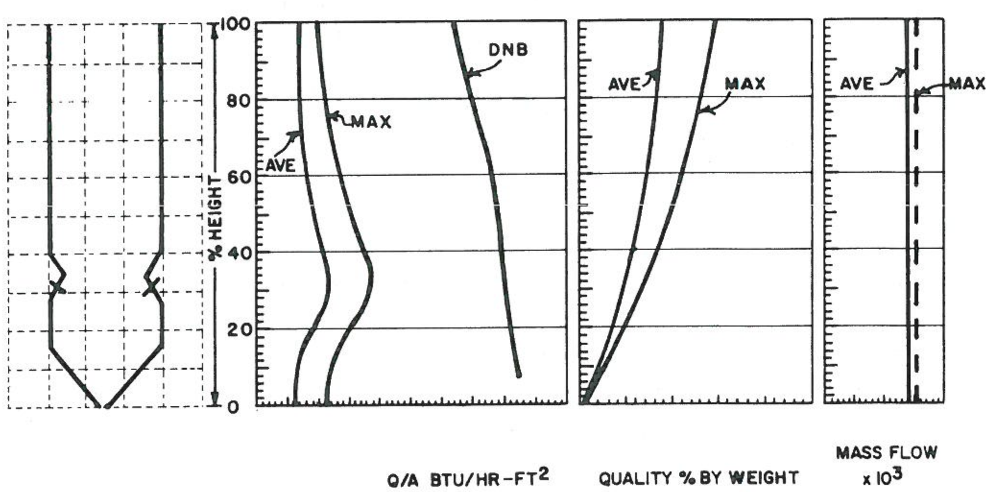


Figure 5

areas are needed in the riser tubes of the furnace to provide less frictional resistance to the emulsion on the inside of the tubes.

To provide the maximum utilization of drum internals, special care is being taken to insure even release of emulsion from side to side and from front to rear on the steam drum. This is important to insure that the internals have the best chance of preventing carryunder and carryover. Further work is needed in the boiler-utility partnership to determine the best means of meeting steam purity requirements of the turbine. Realistic values for steam purity requirements must come from the turbine manufacturer. The customer and/or the consulting engineers must now decide whether the boiler manufacturers' guarantees can produce this purity or whether complete condensate polishing will be required. We say that the boiler-utility partnership must work on this because it is not reasonable to expect the same percentage of efficiency in separating water from steam when boiler water concentration is at 500 parts per billion in the boiler water as when they are 500 parts per million in the boiler water. This subject could be the basis of another whole topic of presentation and so will not be pursued further in this paper.

BOILER CASING, BREECHING, AND DUCTS

Ever-increasing sizes of steam generating units have led to increased failures and forced outages due to breaks and tears in breeching and ductwork. Part of this trouble is attributable to implosions and part to differential expansions and improper use of expansion joints. We have reduced our maximum velocities in ductwork design to 4,000 feet per minute to prevent problems from erosion and/or vibration. The design of the breeching and ducts is for plus or minus 20 inches over the operating pressure. As with the furnaces, stress values are at 60% of yield under these conditions. This gives us good conservatism for all operating conditions except a catastrophic fan runaway. Our Instrument and Controls Group has provided redundant controls and logic to reduce to a bare minimum the possibility of a fan runaway.

Model studies by both our Research and Development Department and companies that specialize in this endeavor aid the designer in the layout of ducts and breeching as well as the turning vanes and expansion joints required. As greater movements are put on these ducts and breechings, superior materials for expansion joints, including stainless steels and fabric joints are being utilized. Greater care is being exercised in keeping shear forces off expansion joints. Where we encounter shear, two or more joints are used to take up this movement.

There is room for improvement in boiler availability within the power industry. The technology for reliability engineering has been developed and is ready for implementation. What is required is a commitment by customers and manufacturers to a solid data exchange program, which can be used in the design, construction, and operational aspects of the boilers.