CIRCULATION SYSTEM

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1. TYPES OF BOILER CIRCULATION SYSTEM

The 3 systems of circulation (Fig. V-1) adopted in boiler are :

i) Natural circulation system

ii) Controlled circulation system

iii) Combined circulation system

1.1 Natural Circulation System

Water delivered to a steam generator from feed heaters is at a temperature well below the saturation value corresponding to that pressure. Entering first, the economiser, it is heated to much nearer the saturation temperature. From economiser the water enters the drum and thus joins the circulatory system. Water entering the drum flows down through the downcomer and enters bottom of the water wall tubes. In the water wall tubes a part of the water is converted to steam and the mixture flows back to the drum. In the drum, the steam is separated. Remaining water mixes with the incoming water from the economiser, and the cycle is repeated.

The circulation, in this case, takes place on the thermo-siphon principle. The downcomers contain relatively cold water, whereas the water wall tubes contain a steam water mixture, whose density is comparatively less. This density difference is the driving force, for the mixture. Circulation takes place at such a rate that the driving force and frictional resistance are balanced.

As the pressure increases, the difference in density between water and steam reduces (See Fig. V-2). Thus the hydrostatic head available will not be able to overcome the frictional resistance for a flow correspond ing to the minimum requirement of cooling of water wall tubes. Therefore natural circulation is limited to boiler with drum operating pressure around 175 kg /cm^2.

1.2 Controlled Circulation System

Beyond 175 kg/cm^2 of pressure, circulation is to be assisted with mechanical pumps, to overcome frictional losses. To regulate the flow through various tubes, orifice plates are used. This system is applicable in the high sub-critical regions (say 200 kg /cm^2).

1.3 Combined Circulation System

Beyond the critical pressure, phase transformation is absent, and hence a once through system is adopted. However, it has been found that even at supercritical pressures, it is advantageous to recirculate the water through the furnace tubes at low loads. This protects the furnace tubes and simplifies the start-up procedure. A typical operating pressure for such a system is 260 kg/cm^2.

2. CIRCULATION THEORY

The natural circulation is based on thermosiphon principle. Some of the terms, which are of interest in circulation are explained below.

2.1 Nucleate Boiling

As the heat flux increases, the water temperature near the surface increases and reaches saturation temperature. At this point a change from liquid to vapour occurs locally, But since the bulk of water does not reach saturation temperature the steam bubbles collapse giving up their latent heat to raise the temperature of water. When the bulk of water reaches saturation temperature the bubbles do not collapse. This condition is known as nucleate boiling. Nucleate boiling regimes are characterised by high heat transfer coefficients.

Beyond nucleate boiling region (i.e. at still higher heat fluxes) the bubbles coalesce to form a film of superheated steam over part or all the heating surfaces. This condition is known as film boiling. The point, beyond which film boiling occurs is known as Departure from Nucleate Boiling (DNB).

Till the occurrence of DNB, metal temperature is slightly above the water temperature. When water starts boiling the metal temperature is slightly above the saturation temperature. But when DNB occurs, the metal temperature increases much higher than the saturation temperature (See Fig. V-3).
For high heat flux, the DNB point is reached at lower steam quality and peak metal temperature is higher.

3. DESIGN CRITERIA OF A CIRCULATION SYSTEM

The primary requisite of a circulation system design is to ensure that nucleate boiling is maintained for all anticipated operating conditions.

An usual design criteria is the acceptable percent steam by volume (SBV) or the corresponding percent steam by weight (SBW), throughout the fluid flow path. The inverse of SBW is the circulation number, which is the ratio of the quantity of mixture flowing through the circuit to the quantity of steam produced in the circuit. At low pressures circulation is not a critical problem; but at pressures above 80 atm this attains significant importance.

The permissible limit of SBV or SBW is a function of many variables including pressure, heat flux and mass velocity. For each pressure and heat flux, there is a maximum permissible quality which is dependent on mass velocity.

At constant heat flux and mass velocity, the DNB occurs at a lower percentage of steam by volume as pressure increases.

High pressure designs require a detailed analysis of the probable distribution of heat fluxes, throughout the furnace during operation. These fluxes are a function of heat input burner location, type of fuel fired etc. It therefore becomes a necessity to investigate all the factors which affect the quality to ensure that the final circulatory arrangement will have an acceptable percent steam by weight not only on the top of the riser circuit, but also incrementally along its length.

Minimum acceptable internal velocity which is an interdependent variable with quality and heat flux distribution is also an important criterion.

Low velocities in sloping tubes may lead to steam blanketing, and eventual failure. Solid deposition may occur at low velocities, leading to subsequent overheating and failure.

3.1 Design of Circulation Piping

A high shock loss at entrance to the circulating piping at boiler drum is to be avoided when water entering the piping is at saturation temperature. Under these conditions, the entrance loss will reduce the pressure below the vapour pressure of water and a definite portion of the water will immediately flash into steam. This steam will condense again, when the increased pressure due to change in elevation equals the sum of pressure losses due to shock at entrance and friction loss. Condensation of steam bubbles at lower elevation may take place with a sudden collapse having all the characteristics of an explosion thus producing water hammer pressure of great intensity in the piping.

Tubes should have an entrance velocity of not greater than 3m/sec and should have a vertical drop of not less than 1 m before turning in a horizontal plane or connecting to a header. The piping sizes must be selected so that with the desired rate of flow, the friction and shock losses in the downcomers when subtracted from the hydrostatic head will provide an available head equal to friction and hydrostatic head in the heated tubes and risers. The piping size therefore is fixed by the physical arrangement and the desired circulation ratio.

4. FACTOR AFFECTING CIRCULATION

Load on the boiler, operating pressures, disturbance in the system especially Changes in drum water level, and variations in pattern of heat loading inside the furnace affect circulation to a great extent. Lower pressures and lower loads are especially met with during start up and shut-down.

4.1 Heat Input to the Water Walls

In a circulation system, the quantity circulated increases with increase in heat input (with increase in steam output) until a maximum value is reached. After the maximum any further increase in heat input tends to bring down the circulation (Figure V-4). With higher heat inputs, more steam is produced, the increase in specific volume, with associated increase in velocity in riser tubes, increases the losses in the circuit. At a particular stage the losses become more than the gain due to increased density difference and circulation comes down. The objective of a system design should be to design all circuits in the rising part of the curve. In this region a natural circulation boiler tends to be self compensating for numerous variations.

4.2 Operating Pressures

At lower operating pressures, circulation ratio increases mainly because of the increased difference in density between water and steam.

4.3 Disturbances in the System

High and low water levels inside the drum has a pronounced effect on circulation. When the feed flow is increased to raise the drum level temperature of water in the downcomer is reduced. With associated increase in density of water indowncomers, flow in furnace tube increases.

Opposite effect is noticed when feed flow is reduced.

4.4. Pattern of Heat Loading

Heat absorption rate along the riser tubes vary as shown in Figure V-5.

When more heat is added in the lower portion, high quality of steam is reached in the lower portions and the average specific volume of the mixture and hence the velocity is higher over a longer length. This contributes to higher losses and decreased CR. When the quality of steam is increased near the burner, where the heat loading is highest, chances of DNB are more.

5. CIRCULATION PERFORMANCE

Proper circulation is indicated by indices such as :

5.1 Percentage Steam by Volume

This should not exceed 70%.

5.2 Circulation Ratio (CR)

Circulation ratio for utility boilers is between 6 and 9. Industrial boilers usually have a high circulation ratio. Since they should respond to load changes quickly, a higher CR provides a higher thermal inertia in the system which facilitates faster response. The value of CR varies from 8 to 30 in industrial boilers.

5.3 Mass flow

The recommended value is 1100 to 1200 $kg/m^2/sec$.

5.4 Water wall inlet velocity which is approximately 1 m/s.

However the final say in the circulation performance is by the type of boiling i.e. whether nucleate or film boiling.

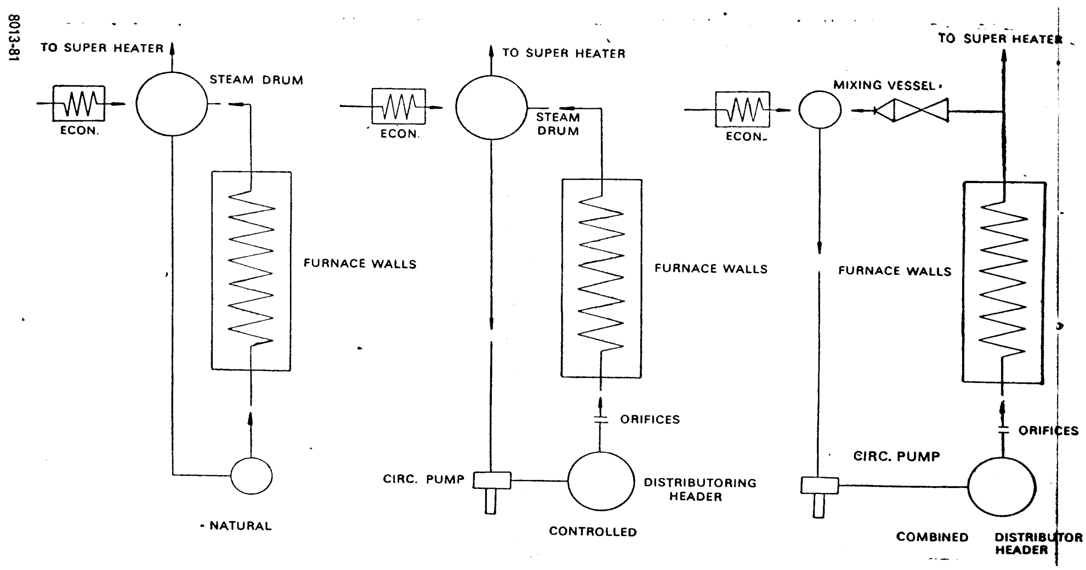

FIG. -1 CIRCULATION SYSTEM

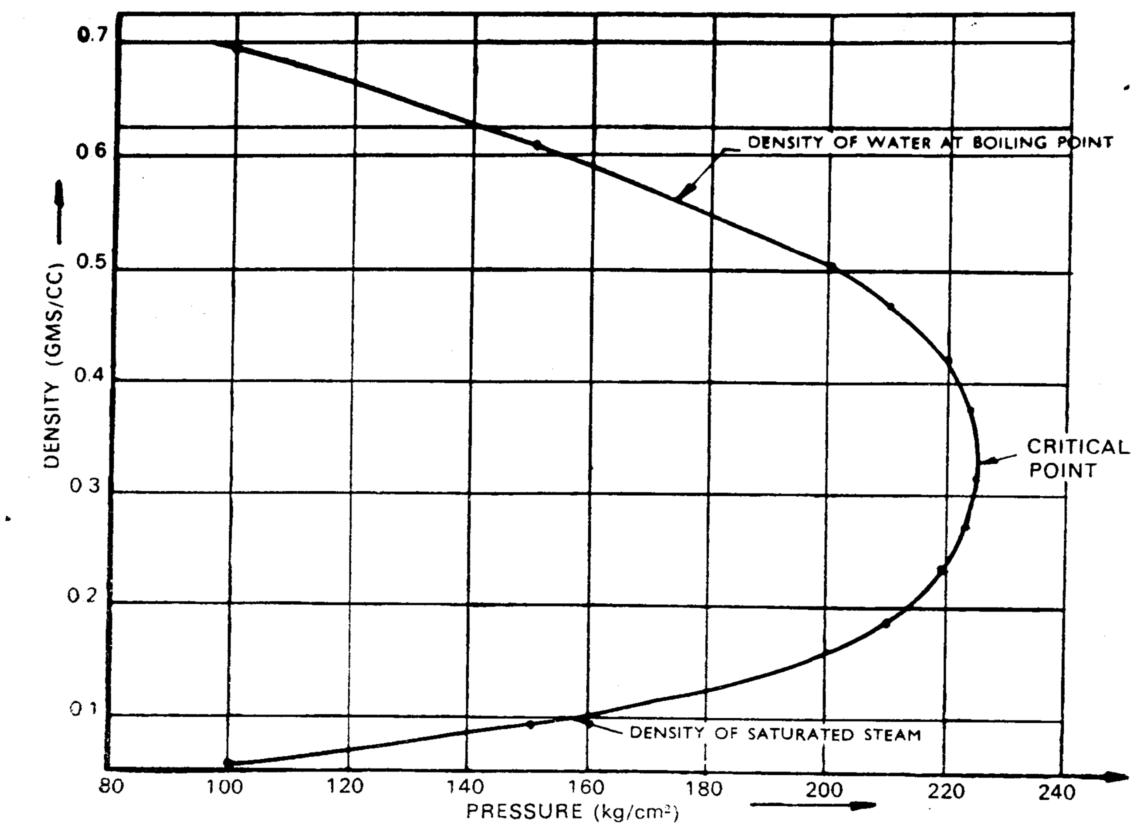

FIG.-2DENSITY DIFFERENCE VARIATION WITH PRESSURE

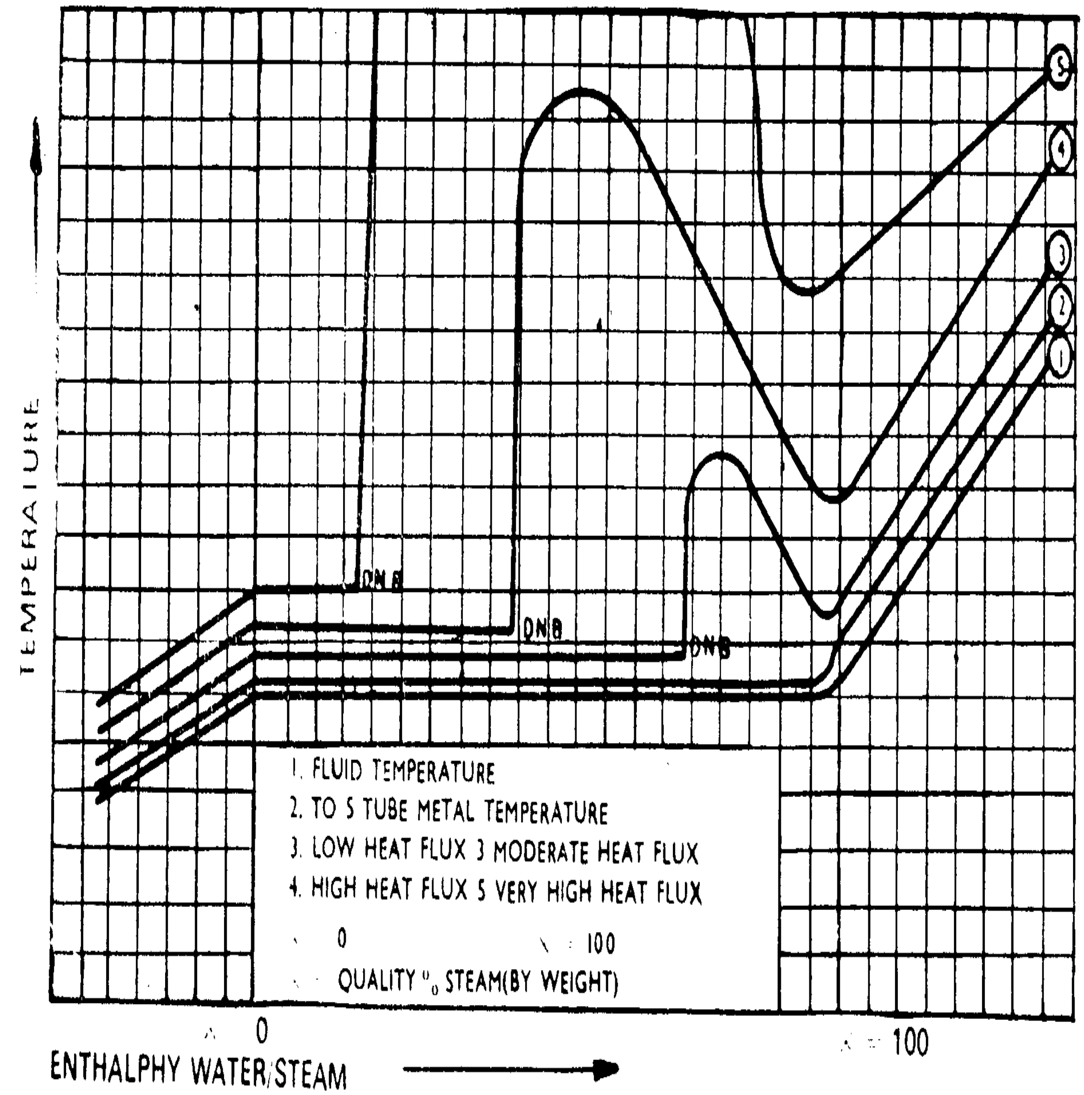

FIG.-3 OCCURRENCE OF DNB WITH DIFFERENCE OF HEAT FLUX

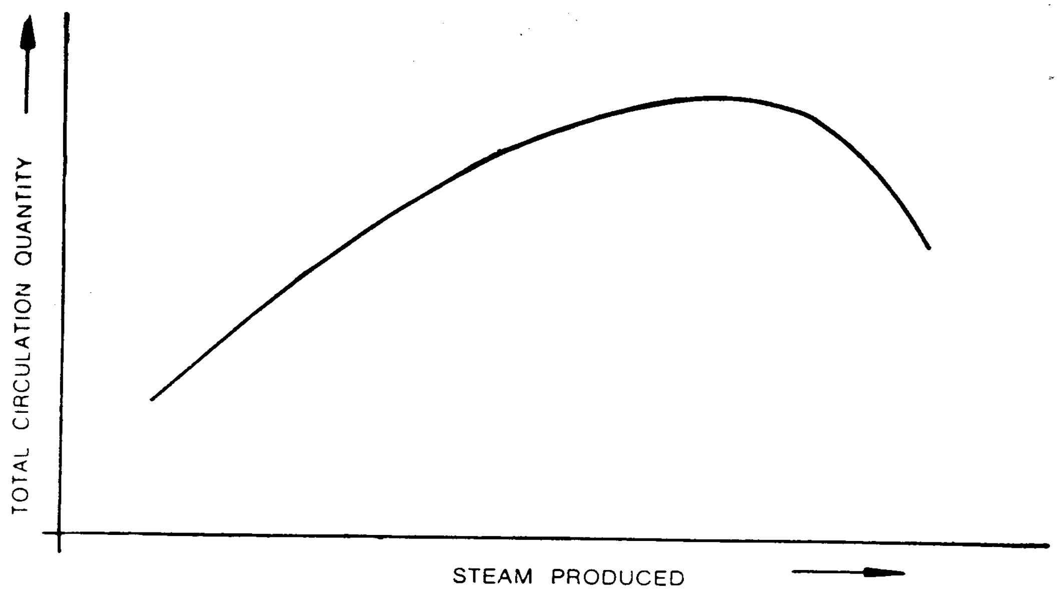

FIG. -4 CIRCULATION QUANTITY VS STEAM PRODUCED

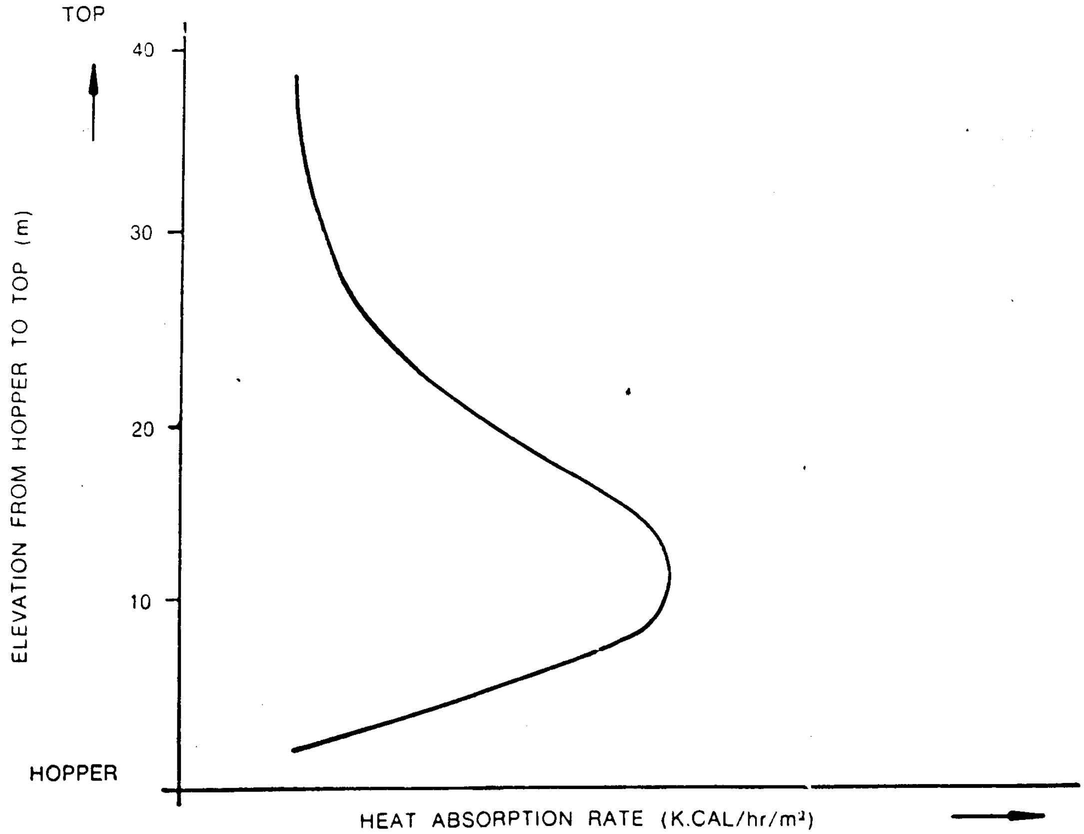

FIG.-5 HEAT ABSORPTION RATE ALONG THE RISER TUBES