Design of High Pressure Heater to Enhance Efficiency of Boiler by Method of Regenerative Heating

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Abstract - *The most important factor while selection of a boiler is the energy consumption it requires to perform its functionality. The concept of this paper is to enhance the efficiency of boiler by equipping it with high pressure heater. It is observed that the traditional method of multi-stage heating requires relatively large amount of energy which can be avoided by using this technique. The high pressure heater will utilize the steam from turbine to pre-heat condensed water in order to increase its temperature. This method will cause reduction in the input energy to raise the temperature and thus increasing the boiler efficiency. The research indicates that application of high pressure heater yields increase in product life of boilers due to reduction in load upon it. Induction of the high pressure heater will result in elimination of conventional approaches for increasing efficiency such as multi-stage boiling. By employing high pressure heater the boiler efficiency can be improved upto 4 - 7%*

Key Words: Boiler, Feedwater Heater, Energy Management, Heat Exchange, Regenerative Heating

1. INTRODUCTION

A high pressure heater is a type of heat exchanger intended for preheating evaporator feedwater using methods for consolidating steam removed (bleed) from a steam turbine. The heater which is discussed here is classified in category of closed type, since the tube side fluid is encased by the tubes, and thus do not blend with the condensate, as is the case with open type feedwater heaters. They are termed as unfired type due to the thermal transfer inside the vessel does not happen by method of combustion, but instead by convection and conduction. The process of extraction of steam for heating in a closed type feedwater is alluded to as an uncontrolled extraction. The steam flow rate into a high pressure heater is not constrained by measure of accessible steam. The operating parameters on shell side in a high pressure heater are determined by pressure of the steam supplied and not by the amount of surface of heat transfer.

1.1 Relation to power plant cycle

The heating procedure by methods for steam extraction is alluded to as being regenerative category. The pre-heaters are an indispensable segment of the thermodynamic cycle of power plant. Typically, multiple phases of feedwater heating are utilized. Each stage during process relates to an extraction point of turbine. These extraction points happen at varied phases of the steam expansion throughout the turbines.

Fig. 1 shows high pressure heater arrangement which indicates that exhaust steam from turbine is utilized to pre-heat water

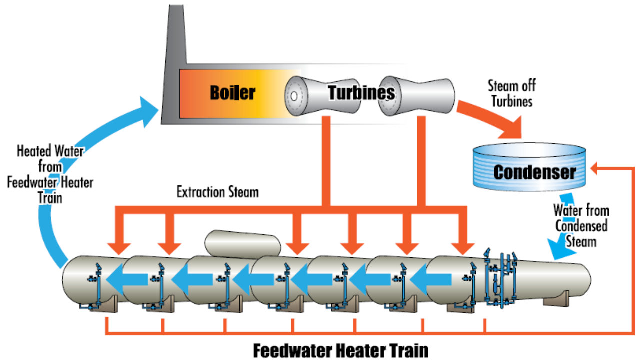

Fig 1.Feedwater heater arrangement

The implementation of the high pressure heaters in heating cycle improves the thermal efficiency of power plant. The more prominent is the quantity of extraction arranged, the lower will be the measure of thermal quantity required to generate a given measure of electrical vitality.

1.2 Literature Review

Rajiv Mukherjee: [1] illustrated the basics of heat exchanger design which included topics as which include STHE components. Data required for thermal design will be tube side design, including tube layout, shell side design and shell side pressure drop. Interrelationships for the optimal conditions are point of focus and are explained with the necessary data in tabulated form. This paper gives overall interpretation in order to design optimal heat exchanger. The optimized thermal design of the heat exchanger is also possible to be compiled by sophisticated computer software such as ANSYS, but a scientific perception of the underlying principles of heat exchanger designs is needed to use this software effectively.

Andre L.H. Costa, Eduardo M. Queiroz:[4] investigated those techniques which were implemented in regards to distinct problems arising in affiliation to: (i) heat transfer area, (ii) constraints such as heat transfer as well as fluid flow equations including pressure drop. This paper accesses the optimization for procedure of design of the shell and tube type heat exchangers. The formulation of this process will investigate the minimal requirement of the thermal surfaces of the heat exchanger. Vital supplementary constraints which were ignored in the previous process of optimization techniques are added so as to obtain the approximate solution to the design.

R. Hosseini, A. Hosseini-Ghaffar, M. Soltani:[7] experimentally achieved the heat transfer coefficient as well pressure drop on shell side heat exchanger for three distant varieties of copper tubes which are i.Smooth, ii.Corrugated and iii.Micro fins. In addition the experimental data which had been attained has been related with theoretical data available. The paper will provide optimum condition which are essential for flow rate (for the least increase of drop in pressure) in reinstating the extant smooth tube which include similar micro-finned tube bundle which was attained for the oil cooler which was in the transformer while under investigation.

José M. Ponce-Ortega et al.: [11] conferred an approach based method upon the genetic algorithms implemented upon optimum design pertaining shell and tube type heat exchanger and also for optimization of geometry which includes the total number of tube-passes, tube layout, pitch, dimensions of of tubes, type of head, baffle were selected. It was concluded that genetic algorithms will grant better expectations in order to detect optimum solutions rather than the gradient methods.

1.3 Thermal transfer zones

The thermal transfer area in the heater can be partitioned into at least one of the accompanying zone are 1) Desuperheating Zone, 2) Condensing Zone and 3) Drain Cooling Zone

The distinctive zones of heater speak to condition of the drained steam which enters the high pressure heater. Inside the desuperheating zone, the steam is condensed from position of superheated state into saturated steam. Inside the condensing zone, the steam will condense to saturated liquid which is called condensate. Finally in drain cooling zone, the condensate is further cooled until desired temperature is achieved. Fig 2 shows the 3 thermal zones in the high pressure heater.

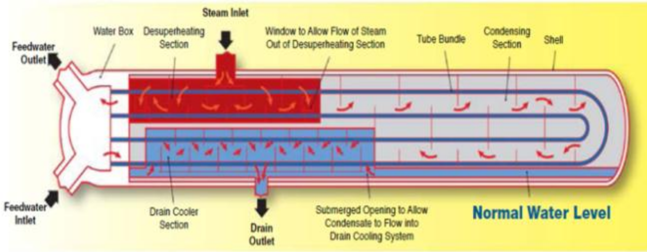

Fig 2. Typical 3 zone horizontal feedwater heater

1.4 Thermal transfer zones

The various operating conditions which affect functionality are:

The Overall Heat Transfer Coefficient i.e., 'U' relies upon tube tidiness, steam concentration in the high pressure heater shell, and the velocity of feed water as well as steam. The surface area of tube which is the heating region i.e., 'A' relies upon the condensate water drains level as well as the total number of tubes inserted. The difference in temparature between the heater tubes mainly relies upon the various operating parameters which are as pursues:

1. The velocity of inlet feed-water and inlet temperature because they play major influence on the mean feedwater temperature which resides within the heater tubes.

2. The temperature and pressure of steam extracted from turbine supplied to the inlet of feed-water heater and subsequently the temperature and flow rate of the falling channels as they influence the normal temperature of steam throughout and the drains which are located outside of the tubes.

In the event that any of these parameters changes, the rate of condensation of steam inside the feed heater changes temporarily, i.e. before another thermal harmony is built up. This amount varies from the extracted flow rate of steam in the steam extraction piping. Due to this shell pressure will change accordingly to it. This, consolidated, with a conceivable change in the steam extraction pressure present at the turbine end of the steam extraction piping, influences the drop of pressure over this channelling, and results in comparing change in the flow rate of steam. These procedures advance until another thermal balance is achieved when the steam extraction stream rate adjusts the steam rate buildup.

2. DESIGN PROCEDURE

2.1 Design Input

For the design a high pressure heater the following information must be specified by the client:

i. Inlet temperature (Feed water)
ii. Inlet pressure(Feed water)

iii. Mass flow rate(Feed water)
iv. Required outlet temperature(Feed water)
v. Inlet bled steam temperature
vi. Inlet bled steam pressure
vii. Mass flow(Flash steam)

In addition to the above requirements the client can also specify other design criteria such as space constraints, tube dimensions, etc.

2.2 Iterative Calculation

After the selection of minimum geometry, the next stage is to calculate the loss in pressure throughout the de-superheating zone so as to determine the new saturation pressure. Repeat the design procedure to calculate until the outcomes converge. Actual heat transfer area and the overall heat transfer coefficient (U) for each of the thermal zones can be calibrated by utilizing the resolved. Thus by implementing the heat transfer coefficient it is viable to calculate the required area for high pressure heater.

2.3 Mechanical Design

The mechanical design procedure of a high pressure heater commences after the process design of heater is accomplished. The structural design entails process of code-based calculations such as IBR codes for the thicknesses of wall of the shell, tube specifications, and tube sheet. The nozzles and their respective reinforcements are determined in accord to the prescribed code in order to ensure that there is availability of sufficient material to compensate for the openings which are present on the shell and water box. The maximum allowable loads i.e., working pressure for the nozzles are also calculated. The strength of the reinforcement such as saddle supports is determined so that the flooded weight of the high can be countered adequately.

3. CALCULATIONS

i. Heat Duty

Heat duty of high pressure heater indicates the performance i.e., the total thermal shift in the duration of its operation.

m = Mass Flow Rate
Cp = Specific Heat Capacity
T1 = Inlet Water Temparature
T2 = Outlet Water Temparature
t1 = Inlet Steam Temparature
t2 = Outlet Steam Temparature

Heat Duty depends upon the amount of heat to be transferred.

$$Q = m.Cp.(T2 - T1)$$

ii. Logarithmic Mean Temparature Difference

Generally the heater is two pass heat exchanger, i.e., A single tube is subjected to steam 2 times

It requires Log Mean Temperature Correction Factor which is given by,

$$LMTD = \frac{(t1 - T2) - (T1 - t2)}{\ln\left(\frac{t1 - T2}{T1 - t2}\right)}$$

iii. Total Area of Contact,A

As the tube is subjected to steam twice, it must include Log Mean Temparature Correction Factor, Ft

$$R = \frac{t1 - t2}{T2 - T1} \qquad S = \frac{T2 - T1}{t1 - T1}$$

$$Ft = \frac{\sqrt{R^2+1}.\ln\left(\frac{1-S}{1-R.S}\right)}{(R-1).\ln\left[\frac{2-S\left(R+1-\sqrt{R^2+1}\right)}{2-S\left(R+1+\sqrt{R^2+1}\right)}\right]}$$

Thus, $A = \frac{Q}{U * LMTD * Ft}$

iv. Total Number of Tubes

The total quantity of tubes depends upon the total heat transferred and geometry of the feedwater heater.

$$\text{Number of Tubes} = \frac{\text{Total Area}}{\text{Surface Area of One Tube}}$$

v. Velocity of Water in Water Inlet Shell

Uniform flow of water determines the proper transfer of heat.

$$\text{Velocity} = \frac{\text{Mass Flow Rate of Water}}{\text{Density} * \text{Cross} - \text{sectional area of inlet}}$$

vi. Shell Design

This stage consists of geometric modelling of shell to ensure its functionality to remain integrated during application of high stresses.

CTP = Tube Count Calculation Constant
CTP depends upon the amount of the tube passes
CL = Tube Layout Constant
CL (Tube Layout Constant) depends upon total number of tubes.
Pt = Tube Pitch
L1 = Length of each tube
d0 = Outside diameter of tube

Generally Triangular Tube Pitch pattern is preferred.

Pr = Tube Pitch Ratio = $\frac{Pt}{d0}$

Ds = Shell Diameter

The dimension of shell which contain heater tubes is given by,

$$Ds = 0.637 * \sqrt{\frac{CL}{CTP}} * \left(\frac{Ao * Pr^2 * do}{L1}\right)^{\frac{1}{2}}$$

vii. Thickness of shell

Thickness of shell determines the reliability of the high pressure heater to not succumb to mechanical as well as thermal stresses

f = Maximum Allowable stress
W.P. = Design Pressure
t = Minimum thickness required
e = Efficiency factor
D = Outside diameter of shell
c = Corrosion allowance

$$W.P = \frac{2 * f * e * (t - c)}{D - t + c}$$

As per IBR Reg. 350 Equation N0. 91

By providing value of Working Pressure of steam and water, their corresponding shell thickness can be calculated

viii. Thickness of heater tubes

Bending of heater tube affects the structural performance and hence it is considered as vital part of the calculations.

Calculation for minimum thickness after bending. Thinning percentage is given by,

$$tp = \frac{100}{4*(R/t)+2}\%$$

Ref: IBR Regulation 338

t = Tube thinning in percentage

R = Tube bending Radius

The minimum thickness of tube is calculated by,

$$Tmin = T*\left(1 - \frac{tp}{100}\right)$$

Where, T = Calculated thickness of heater tube

ix. Dish End Thickness Based on Internal Pressure

T = Design Metal Temparature
H = Height of dish end = 250 mm
D = Outside diameter of shell
K = Shape factor
Value of shape factor depends upon H/D
CA = Corrosion allowance
tp = Dish-end Shell thickness
Calculation of tp is done by equation,

$$W.P. = \frac{2 * f * (tp - c)}{D * K} + C.A$$

However the dish end is subjected to bending bon account of its geometry

Hence generally 15% bending factor is considered

The next stage entails performing x-ray test to detect cracks and hydro test to ensure functionality of high pressure heater.

The design of High Pressure Heater determines the rise of temperature of condensed fluid at inlet of boiler.

4. RESULT AND DISCUSSION

The proposed design is utilized to increase temperature of boiler inlet water by 50°C. The high pressure heater is utilized to heat the water with flow-rate about 80-100 Kg/hr. The initial rate of heat transfer will be very less until stability is achieved. The performance of high pressure heater by varying propeller speed is observed. Immersion probes are used to determine temparatures of inaccessible areas.

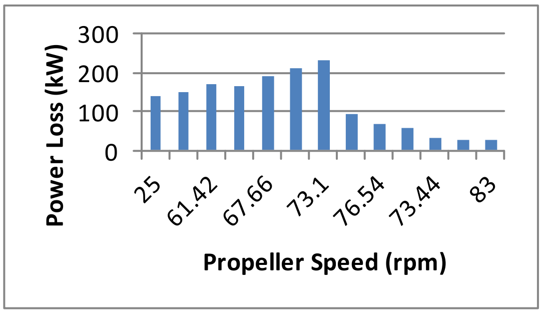

Fig 3 Power loss at varying turbine speed

The power loss in the high-pressure feed water heater for various propulsion propeller speeds is presented in Figure 3.

It is observed that when the propulsion propeller speed is lower than 74.57 rpm, power loss is significantly higher in comparison to the loss at higher steam system loads. This situation arises because at lower loads the high pressure heater is supplied with comparatively excessive amount of energy in order to attain the desired operating temperature as quickly as possible.

When the speed of propeller is greater than 74.57 the power loss is significantly reduced. This occurs because the steam is directly extracted from turbine and this in turn leads to reduction in mass flow. In accords with this range there is noticeable energetic power input reduction, similarly the temperature of the feed water which enters in high pressure heater increases.

CONCLUSIONS

Application of H.P. heater improves the thermal cycle efficiency of boiler by means of regenerative heating. Extraction of steam from the last stages of the turbine will also act as a moisture extractor and thus reduces the blade damage which occurs due to water droplets impact on turbine blades. Considering economic point of view the cost per unit of electrical power is reduced by utilizing high pressure heaters.

The temperature is nearly constant in condensing zone due to the phase change on steam in water is mostly occurring in this region. It is noted that the condensing zone occupies the most amount of area in the high pressure heater. The recirculation of water and steam throughout the process will yield decrease in input energy to raise the initial temperature. It is observed that there is large drop in temperature in desuperheating zone.

If the temperature of the flue gases which is to be extracted attains dew point temperature, it will lead to decrease in the amount of heat extracted from the gas economizer. Thus implementation of high pressure heater will result in recycling of energy and thus increase the overall performance of boiler. Feeding pre-heated water will result in temparature stress arising due to cold feedwater. By observing the operation of high pressure heater it results in conclusion that implementation of high pressure heater yields increase in thermal efficiency by 6.34%.

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BIOGRAPHIES

Himanshu Gaikwad is a second-year student at Rajarambapu Institute of Technology. He received bachelor's degree in Mechanical Engineering at Shivaji University, India. His current field of study is Mechanical Design Engineering. He is interested in Automation, Optimization of product design to enhance efficiency.

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	**Rohan Patil** received his B.E. Degree from NMCE, Peth, Sangli, Maharashtra, India and M. Tech in RIT Rajaramnagar, Sangli, Maharashtra. He has presented/Authored the paper in international Conference on Material Science and Engineering (ICMSE) which is organized by Dr. B.R. Ambedkar National Institute of technology Jalandar (NIT) at June11-12, 2019. " "