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Design and Analysis of Boiler Pressure Vessels based on IBR codes

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Abstract

Pressure vessels components are widely used in the thermal and nuclear power plants for generating steam using the philosophy of heat transfer. In Thermal power plant, Coal is burnt inside the boiler furnace for generating the heat. The amount of heat produced through the combustion of pulverized coal is used in changing the phase transfer (i.e. Water into Super-Heated Steam) in the Pressure Parts Component. Pressure vessels are designed as per the Standards and Codes of the country, where the boiler is to be installed. One of the Standards followed in designing Pressure Parts is ASME (American Society of Mechanical Engineers). The mandatory requirements of ASME code must be satisfied by the manufacturer. In our project case, A Shell/pipe which has been manufactured using ASME code has an issue during the drilling of hole. The Actual Size of the drilled holes must be, as per the drawing, but due to error, the size has been differentiate from approved design calculation (i.e. the diameter size has been exceeded). In order to rectify this error, we have included an additional reinforcement pad to the drilled and modified the design of header in accordance with the code requirements.

Key words- Boiler, IRB code, Super critical, Pressure Vessels

1. INTRODUCTION

Boiler codes define a significance of applications. A boiler is a pressure-holding container producing steam at a pressure of generally 2 bar and higher. There is, however, no universal definition. Boilers are also called steam generators. Boilers of the early eighteenth century were no more than large kettles. Since those early days boilers have made great progress in terms of size, variety, flexibility, versatility, reliability, and complexity. An attempt to classify boilers is made in the following sections. The first classification of boilers is based on what flows through the boiler tubes. Fire or smoke or flue tube or shell-type boilers in which flue gases are inside and water is outside. Water tube boilers in which water is inside and flue gases are outside. Combination (combo boiler) in which flue gas and water flow both outside and inside the tubes; the type contains an external furnace and shell-type boiler in a sequence. Fire tube boilers of smaller size are vertical and those of larger size are horizontal. The minimum capacity of a water tube boiler is usually around 5 tph. Combo boilers are generally used for solid fuel firing in lower ranges of up to 30 tph for lower pressures <25 atm

2. TYPES AND PERFORMANCE OF BOILERS

The boilers are classified according the application such as Industrial boilers (Power Boiler), Utility boilers, Marine boilers and Nuclear boilers Type of Industrial Boilers (Power Boiler) CFBC – Coal Fluidised Bed Combustion Boiler, FBC - Fluidised Bed Combustion Boiler, AFBC – Atmospheric Fluidised Bed Combustion Boiler, PCFB – Pulverised Coal Fired Boiler, Oil Fired Boiler. Super critical boiler At drum pressure of ~200 bar and SH/RH temperature of 540/565°C, limits are reached in natural circulation drum-type boilers in respect of steam pressures and temperatures with...
plant thermal efficiency reaching 42% on NCV and 40% on GCV. With the limits for the flue gas exit temperatures and unburnt losses reached long ago, the next improvement could come only by adopting SC conditions. It must be clarified that the SC conditions do not increase the boiler efficiency per se, as the efficiency is governed by stack losses and unburnt losses, neither of which is affected by the steam pressure adopted. The higher steaming conditions basically increase the overall steam cycle efficiency. There is, correspondingly, a reduction in the fuel input that also reduces the CO2 generation and sizing of auxiliaries such as the fans and pumps on per megawatt basis.

The subcritical and SC steam cycles are depicted in Figure 1 (RH is not depicted here for the sake of simplicity.) The difference is in the higher operating cycle pressure, leading to higher cycle efficiency. For the same heat loss in a condenser more work is done in a boiler and a turbine and hence the efficiency is higher. The boiler construction is different, in that there is no longer a drum.

![Subcritical cycle](image1)

Subcritical cycle

![Supercritical cycle](image2)

Supercritical cycle

**Fig 1. Sub and supercritical cycles on T-S chart**

Boilers have classified according to the circulation and draft like Natural circulation or drum-type boilers, Forced circulation boilers and Natural or balanced draft boilers Forced draft (FD) or pressurized fl red boilers, also based on Furnace Construction following are the types Two-pass boilers, One and a half-pass boilers, Single or tower-type boilers, Down-shot boilers. Boiler Component of Pressure Part such as Drum, Furnace Side, Cage Side, Vestibule Side, Primary and Final -Super Heater, Primary and Final – Reheater, Platen Super Heater, Economizer

**Types of Header**

Main function of the boiler header is to collect the fluid (water or steam) from the small diameter tube or the large diameter link and to redistribution, which is called “Collector”. Mostly, it doesn’t transfer heat and located outside of furnace or flue gas path. The header size shall be selected based on the flow, and if the flow from the tube is not surely absorbed due to small in size, pressure loss results overheating of tubes might occur. Boiler headers must be properly trapped in order to prevent carryover from the boiler from being introduced into the steam mains.

**Economizer Header**

The feed water is located in back-pass zone which is coming to the boiler through Economiser and the Economiser headers are located in the entrance and exit of the Economiser, fluid is water, and the material is selected based on design temperature. Mainly carbon steel material will be used.

**Furnace Header**

The water which is coming down through the Down corner or the Economiser Mixing Line is heated in furnace wall and furnace headers are located in the entrance and exit of the furnace wall, and inlet header is mainly located in down side, and outlet header is located in upper side.
Fluid of the inlet header is water and outlet header is both water and steam mixture, and the material is selected based on the design temperature and mainly constituted by carbon steel.

**Super heater Header**

The separated steam from drum or separator is sending to S/H tubes through links, so it is converted to superheated steam. Superheater headers are located in the entrance and exit of S/H tubes, and the fluid is steam. The material is selected based on the design temperature, and its low temperature part is mainly carbon steel, and high temperature part is mainly alloy steel.

**Re heater Header**

The steam which is entered to high pressure turbine is sending to R/H tubes, so it is converted to reheated steam. Reheater headers are located in the entrance and exit of R/H tubes, and the fluid is steam. The material is selected based on the design temperature, and its low temperature part is mainly carbon steel, and high temperature part is mainly alloy steel.

Boiler Specifications - Boilers are always specified by the four most important attributes, in addition to the types of fuel to be fired: Steam flow or evaporation, Steam outlet pressure (SOP), Steam outlet temperature (SOT), Feed water (FW) inlet temperature

Doosan Power Systems India Private Limited in Chennai has mainly involved in designing of Pressure Parts. Since 2011 Doosan Power Systems India Private Limited has adapted the technology of both Designing and Fabrication of Pressure Parts. As of Design, Checking the thickness of Header based on Design Pressure and Temperature is the main criteria followed and these Calculations are performed by Senior Engineer and Header Department pressure parts experienced Engineers. For focusing on fabrication point of view, from preparing raw material indent, purchase order sheet, receipt the inspection activities are carried by our purchase engineers and quality engineers. Finally machining sequence and welding schedule for making the header ready for dispatch has been done by supervising engineers. Check malfunction/human error while fabrication the header (i.e. Drilling of higher hole size instead the lower one), the header shall be scrap. In order to avoid the scrap of the project will provide alternative solution. Introduction of reinforcement calculation (i.e. Weld Pad Introduction) has been done and the following has been briefed in the Calculation Topics with the respective criteria’s.

**Design procedure and calculation**

Based on the design data, thickness of header, tube and nozzle with ligament efficiency have calculated for safe design condition with normal procedure. Preparing raw material indent and bill of material for the header, tube and stub for fabrication has done. The same shall be purchased and check for material testing and inspection. Then end preparation, surface finishing shall be done. After designing of header, the drill marking shall be done for stubs with proper pitch distance as per pressure parts arrangement drawing. While fabrication for a case of putting wrong drill hole diameter which is bigger than required one then the whole header may be a scrap. As per ASME code the available area (example some of header, nozzle and weld should be greater than removed area of a hole). So here we prepare design calculation and manufacturing of platen super heater header of 273 mm diameter and 18.26 mm thickness. Design modification of Header due to wrong drilling while manufacturing and inducing compensation method in nozzle location. The following table -1 show the design parameters and Fig 2 show the header pad design.

<table>
<thead>
<tr>
<th>Table 1. Design parameter</th>
<th>Platen super heater inlet stub heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Maximum allowable Working pressure</td>
<td>10 Mpa (g)</td>
</tr>
<tr>
<td>3. Design temperature</td>
<td>450 C</td>
</tr>
<tr>
<td>4. Hydrostatic head</td>
<td>Nil</td>
</tr>
<tr>
<td>5. Other loading on head</td>
<td>Nil</td>
</tr>
<tr>
<td>6. Service condition</td>
<td>1</td>
</tr>
<tr>
<td>7. Hydro test pressure</td>
<td>15 Mpa (g)</td>
</tr>
<tr>
<td>8. Hydro test temperature</td>
<td>20-40 C</td>
</tr>
<tr>
<td>9. ASME designator</td>
<td>‘S’</td>
</tr>
<tr>
<td>10. Heating surface area</td>
<td>0 mm</td>
</tr>
<tr>
<td>11. Test coupon requirement</td>
<td>Nil</td>
</tr>
<tr>
<td>12. Corrosion allowance</td>
<td>0 mm</td>
</tr>
</tbody>
</table>
Fig. 2. Header Pad design

3. DESIGN PROCEDURE AND CALCULATION

Tube thickness calculation
\[ t = \frac{P_{Do}}{2SE + P} + 0.005 \times Do + e \]
\[ t = \frac{10 \times 38}{2 \times 10^3 \times 1 + 10} \]
\[ t = 1.95 \text{ mm} < 6.8 \text{ mm} \] so Design is safe.

Nozzle thickness calculation
OD based calculation:
\[ t = \frac{P_{Do}}{2SE + 2yP} \]

ID based calculation:
\[ t = \frac{P_{Di}}{2SE - 2(1-y)P} + C \]
\[ Di = OD - 2 \times 0.875 \times AWT \]
\[ Di = 168.3 - 2 \times 0.875 \times 14.27 \]
\[ Di = 143.33 \text{ mm} \]
\[ t = \frac{143.33}{2SE - 2(1-y)P} + C \]
\[ t = \frac{10 \times 143.33}{2 \times 10^3 \times 1-2(1-0.4)10} \]
\[ t = 7.39 \text{ mm} < 14.27 \text{ mm} \] so Design is safe.

Header thickness calculation
OD based calculation:
\[ t = \frac{P_{Do}}{2SE + 2yP} \]
ID based calculation:

\[
T = \frac{P D_i}{2 S E - 2 (1 - y) P} + C
\]

Where:
- \(T\) - Minimum required thickness of the pipe.
- \(P\) - Design pressure (From data sheet).
- \(D_o\) - Outside diameter of the pipe.
- \(D_i\) - Inside diameter of the pipe.
- \(S\) - Allowable stress value (From ASME sec. II part D) on the basis of pipe material and design temperature.
- \(E\) - 1 (For seamless pipe) otherwise efficiency of the ligament.
- \(Y\) - From table according to material type and temperature limit.
- \(C\) - Corrosion allowance (Will be indicated in the contract Document and as per client requirement).

Equivalent Diameter of Holes

\[
de = D_o - 2 \times \text{MWT} \times 1.11
\]

\[
D_e = \text{Equivalent diameter of the hole.}
\]

\[
D_o = \text{Outside diameter of the tube.}
\]

\[
\text{MWT} = \text{Minimum wall thickness.}
\]

\[
de = D_o - 2 \times \text{MWT} = 38 - 2 \times 6.8
\]

\[
de = 24.4 \text{ mm}
\]

Longitudinal ligament Efficiency

The following Fig. 3 - 5 shows ligament efficiency diagram.

Fig. 3 Longitudinal Ligament Efficiency

Formula:

\[
E = \frac{P L - dm}{P L}
\]

\[
dm = \frac{d_{e_1} + d_{e_2}}{2}
\]

Where:
- \(d_{e_1}\) - Equivalent diameter of the hole_1.
- \(d_{e_2}\) - Equivalent diameter of the hole_2.
- \(dm\) - Mean equivalent diameter of the hole.
- \(P L\) - Distance between the two horizontal stubs.
- \(E\) - Ligament efficiency.

Longitudinal Efficiency

\[
dm = \frac{d_{e_1} + d_{e_2}}{2}
\]

\[
dm = \frac{24.4 + 24.4}{2}
\]

\[
dm = \frac{P L - dm}{P L}
\]
\[ E = \frac{172 - 24.4}{172} = 0.86 \]

**Circumferential Efficiency**

\[ P_c = \frac{\theta_1 \times D_c \times \theta_1}{360} \]

\[ = \frac{(273 \times 0.99 - 2 \times 18.26) \times 3.14 \times 80}{360} \]

\[ = \frac{163.11 \text{ mm}}{360} \]

\[ E = \frac{2 \times (P_c - \text{de})}{P_c} = 1.70, \quad \theta_2 = \tan^{-1} \frac{P_c}{PL} \]

**Diagonal Efficiency:**

\[ E = \frac{\text{Sec} \theta_2}{\text{Sec}^2 \theta_2 + 1 - \left( \frac{P_1}{dm} \right) \sqrt{3 + \text{Sec}^2 \theta_2}} \]

\[ = \frac{0.015 + 0.005 \times \text{Sec}^2 \theta_2}{100} \]
Where:

\[ \theta_2 \] - Aligned angle between the two stubs.
\[ d_{e1} \] - Equivalent diameter of the hole 1.
\[ d_{e2} \] - Equivalent diameter of the hole 2.
\[ d_m \] - Mean equivalent diameter of the hole.
\[ PL \] - Length between the two horizontal stubs.
\[ P_1 \] - Length between the PL and Pc.
\[ E \] - Ligament efficiency.

\[
E = \frac{\sec^2 44.825 + 1 - \left( \frac{121.25}{24.4} \right) \times \sqrt{3} + \sec^2 44.825}{121.25/24.4} \times 100 = 0.947.
\]

Headers are allowed to cut for the required length using header cutting machine using a rotating saw as belt drive. In order to make the header and saw safe (in high temperatures), the coolant oil is introduced and for smooth cutting. The required length header with the tolerance is again moved to the facing zone. For example a header of OD 273 x 18.26 thick of length 1200 length, required to cut 1050 length.

**4. DRILLING AND GROOVING OF THE HOLES:**

- i. The header in which the holes to be drilled is sent to the drilling machine
- ii. If the holes are small ranging from (2.5mm to 10mm) the holes are drilled in Radial Drilled machine
- iii. The Schematic representation below shows the drilling of holes in the Radial drilling machine as shown in figures 6 & 7
- iv. This Radial drilling machine is not a numerical controlled one in which humans are required in order to place the drill bit in the hole location.
- v. Such that hole diameter ranging up to 1 meter is drilled In Radial Boring machine is done
- vi. After drilling of holes, the holes are to be faced and made grooved in order that the stub should be inserted in it.
- vii. Then the fittings of nozzles, end cap and other fittings are fitted up in the header

![Fig 6. Drilling bit located](image-url)
5. CONCLUSION

The design of IRB codes have done in this paper with ASME standard, which has followed with proper design calculation and required input data hence the mandatory requirements of ASME code satisfied by the design calculation. The Actual Size of the drilled holes must be, as per the drawing, but due to error, the size has been differentiate from approved design calculation (i.e. the diameter size has been exceeded). In order to rectify this error, designed reinforcement pad has been attached.

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