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Design of diffuser (reducing stage assembly) for superheater and reheater start up vent silencer in super critical once through boilers

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Abstract

In supercritical boiler Startup Vent diffuser is to manage the instant release of huge amounts high pressure of steam to low pressure into atmosphere while cutting of the noise produced while venting the steam in different temperature and pressure conditions. The upstream pressure of startup vent is around 81 kg/sq.cm. so for reducing pressure from 81 kg/cm2 to 3kg/cm2 with constant flow one diffusers (reducing stage assy.) will introduce which will diffuse the pressure. Startup Vent diffuser is a design a reducing stage assembly (called a multistage diffuser) along with study of hydrodynamic parameter like Beta ratio, Mach number, and numerical calculation of orifice plate thickness, size of orifice hole & Bending stress evaluation, reducer etc.

Keywords: Reducing stage assy; Beta ratio; Mach number; Orifice plate; Startup vent

1. Introduction

When boiler is warming up initially the turbine will be matched only a specified temperature and pressure. Till such time the steam produced will be let out to atmosphere. For this purpose, startup vent is required. Its other purpose is for safety valve floating, that is to check the safety valve set pressure. This system includes start up line, regulating and isolating valves, diffuser and silencer, to abate noise.

1.1. Problem identification

In the startup vent line, the silencer inlet pressure has to be maintained within 3 Kg/sq cm for suit to start up vent silencer.

For the super critical boilers, the upstream pressure of startup vent will be at around 81 kg/sq.cm. So for reducing pressure from 81 kg/cm2 to 3kg/cm2 with constant flow one diffusers (reducing stage assy.) will introduce which will diffuse the pressure.

1.2. Remedies

In order to eliminate the problem, we have many remedies such as introducing with multiple pressure reducing valve which leads higher cost, operation & maintence cost & also increasing plant cost. If we design a reducing stage assay, it can replace the pressure reducing valve. It has simple design with very less cost & weight as compared to valve.

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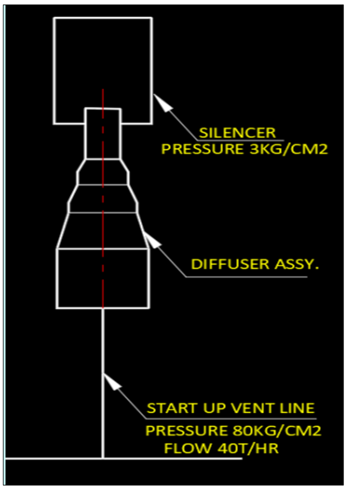

Figure 1 Line diagram for diffuser assembly

2. Methodology of study

Parts of reducing stage assy. are 1. Conical nozzle 2. Orifice meter

2.1. Conical nozzle

The application of a conical nozzle was very common in early rocket engines. The principal appeal of the conical nozzle is that it is easy to manufacture and it has the flexibility of converting an existing design to lower or higher area ratio without much redesign.

The geometry of converging nozzles affects the conditions at which critical-subcritical flow transition occurs. The objective of this is to develop guidelines to identify the optimum nozzle geometry that maximizes critical pressure ratio while minimizing pressure drop across the nozzle. It was determined that a smaller diverging angle and absence of an elongated throat resulted in a higher critical pressure ratio. Length of converging and diverging sections of nozzles did not have as much of an impact on nozzle performance as the throat diameter and shape of converging and diverging sections.

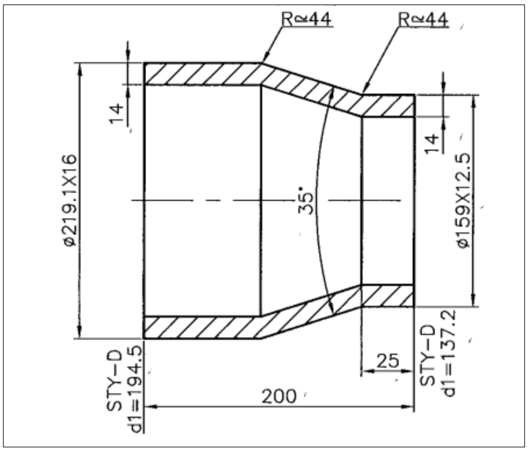

Figure 2 Typical Nozzle/reducer

2.2. Orifice meter

The simplest and most common device for measuring flow rate in a pipe is an orifice meter. An orifice meter is a device with a hole in it, which measures how fast a fluid is flowing, by recording the pressure decrease across the hole. The two most important factors that influence the reading of an orifice meter are the size of the orifice and the diameter of the pipe which it is fitted into. orifice plates are most commonly used to measure flow rates in pipes, when the fluid is singlephase (rather than being a mixture of gases and liquids, or of liquids and solids) and well-mixed, the flow is continuous rather than pulsating, the fluid occupies the entire pipe (precluding silt or trapped gas), the flow.

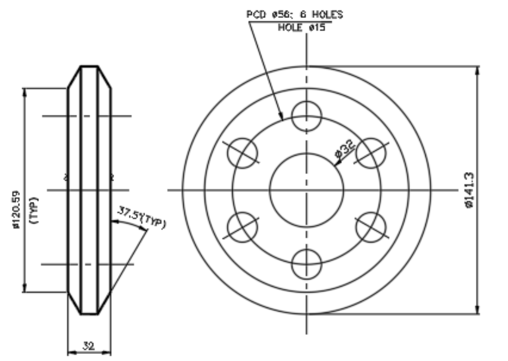

Figure 3 Typical orifice meter

3. Terminology used for designing of reducing stage assay

3.1. Beta Ratio (β)

The orifice plate has a typical bore diameter that ranges from 30% to 75% of the inside diameter of the pipe work in which it is installed. A beta ratio of 0.4 signifies that the orifice bore diameter is 40% of the pipe inside diameter. The Beta ratio (Ratio of orifice whole diameter to Orifice Plate Diameter) is kept around 0.4.

$$(\beta) = \frac{\text{Orifice hole Dia}}{\text{Internal diameter of pipe}}$$

3.2. Mach No

Mach number is an important quantity to compare the speed of any object with a speed of sound. It is a parameter to denote the speed of a flying object in air medium. In fluid dynamics, it has very vast use. Mach number is heavily studied to have a proper idea on the motion of aero planes and rockets.

- When the Mach number is less than unity, the flow is called a sub-sonic flow.
- When the Mach number is equal to unity, the flow is called a sonic flow.
- When the Mach number is between 1 and 6, the flow is called a supersonic flow. Mach number (M or Ma) is a dimensionless quantity in fluid dynamics representing the ratio of flow velocity past a boundary to the local speed of sound.

$$M=u/c$$

M is the local Mach number,

u is the local flow velocity with respect to the boundaries (either internal, such as an object immersed in the flow, or external, like a channel), and

c is the speed of sound in the medium, which in air varies with the square root of the thermodynamic temperature.

3.3. Reynolds no

The Reynolds number (Re) helps predict flow patterns in different fluid flow situations. At low Reynolds numbers, flows tend to be dominated by laminar (sheet-like) flow, while at high Reynolds numbers flows tend to be turbulent.

The Reynolds number (Re) helps predict flow patterns in different fluid flow situations. Types of flow are classified into 2 types: laminar flow and turbulent flow. Reynolds number helps us to determine whether the flow is laminar or turbulent. At high Reynolds numbers, the flow tends to be turbulent.

$$\text{Reynolds Number} = \frac{Þvd}{\mu}$$

Where

þ	=	Density in Kg/m3
v	=	Velocity in m/sec
d	=	Pipe diameter in mm
μ	=	Dynamic viscosity in centipoise

Table 1 Materials selected

Part No.	Part Description	Material
1	Reducer	SA234WP22CL1 Alloy steel Allowable stress -114 MPa Min tensile strength-415MPa Min yield strength-205MPa
2	Orifice plate	SA387GR22CL2 Alloy steel Allowable stress -114 MPa Min tensile strength-415MPa Min yield strength-205MPa

4. Input data /design criteria

4.1. Design validation

- From this design the pressure is achieved from 81kg/cm2 to 3kg/cm2 through 5 reducing stages.
- Pressure drop ratio in each stage is 0.5(Assumed)
- Each stage has one reducer and orifice plate. Selection of reducers and orifice plates depends on requirement and material availability.
- Flow parameters are maintained in each stage which has been showed.
- Calculated value of the MACH number comes in subsonic range in all stages, which means better noise reduction.
- The ratio of orifice plate hole diameter to orifice plate diameter is kept around 0.4

4.2. Calculation for orifice plate thickness

4.2.1. Checking thickness in bending

$$T = FG/2\frac{\sqrt{P}}{S}$$

F	=	0.8 constant
G	=	Orifice Plate diameter in mm
P	=	Design Pressure in Kg/cm2
S	=	Allowable stress in Kg/cm2
T	=	Thickness in mm

4.2.2. Checking thickness in stress

$$\text{t shear} = \frac{0.31\ DL}{\sim} \text{x} \frac{P}{S}$$

$$DL = \frac{4A}{C}$$

A = Area enclosed by Polygon perimeter
C = Perimeter of Polygon formed
~ = Ligament efficiency

4.3. Check for Mach No

Mach number calculated has to be less than 0.4

Z/C = Mach No.
C = Velocity of stress in M/S
Z =Velocity of pressure wave in stream in M/S.
Z = $\sqrt{Ygbt}$
Y = 1.3 for super heater steam
g = 9.81 m/s2
bt = r/m =47.11 for steam
r = Universal gas constant
m = Molecular weight

5. Calculation /experimental details for Start-up Vent Diffuser Reducing stage assy.

Upstream Pressure = 81.0 Kg/cm^2
Upstream Temperature = 430°C
Maximum Flow = 80 TPH
Two Start up vent, so the flow per vent = 40 TPH

5.1. Stage: I

Pressure = 81.0 Kg/cm2
Temperature =430°C
Density = 27.6315 Kg/m3
Sp. volume =0.0361906 m3/Kg
Enthalpy =3219.34 KJ/Kg
Dynamic Viscosity =0.02576 Centipoise
Pressure Drop ratio =0.5 assumed

$$P_1 = 81.0\ Kg/cm^2$$

$$P_2 = 81.0 * 0.5 = 40.5\ Kg/cm^2$$

Diameter of pipe in which Orifice plate is fitted 141.3 mm = 141.3 – (2 x 29.35)

Internal Diameter = 141.3 – (2 x 29.35) = 82.6 mm

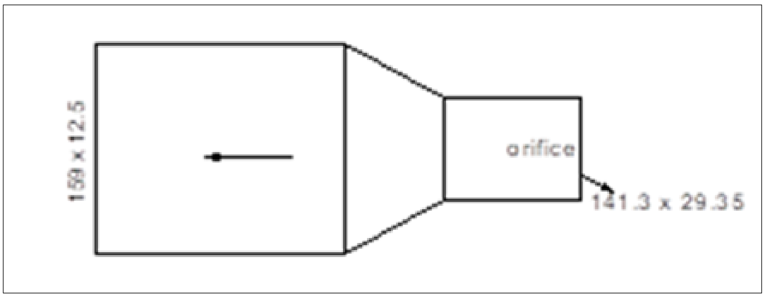

Figure 4 Line diagram diffuser for stage-I

$$\text{Velocity} \quad = \frac{\text{Flow x Specific Volume}}{\text{Area}}$$

Specific Volume at Condition 1 = 0.0361906 m^3/Kg

$$\text{Area} \ = \ \pi \text{ x} \frac{(0.0826)^2}{4} = 5.3586 \text{ x } 10^{-3} \text{ m}^2$$

Velocity = 75.0415 m/sec.

Viscosity at Condition 1 = 0.02575 cp

$$\text{Reynolds Number} = \frac{\text{Þvd}}{\mu}$$

Where,

þ	=	Density in Kg/m^3
v	=	Velocity in m/sec
d	=	Pipe diameter in mm
μ	=	Dynamic viscosity in centipoise

$$\text{Re} = \frac{27.6315 \text{ x } 75.0415 \text{ x } 82.6}{0.02576} = 6.65 \text{ x } 106$$

$$\beta = \frac{\text{Orifice hole Dia}}{\text{Internal diameter of pipe}}$$

$$\beta = \frac{32 \text{ mm}}{82.6 \text{ mm}} = 0.39$$

From Crane Book Page A-20

For β = 0.39

Pressure Ratio = $\Delta P/P_1$ = 0.5

Y – Expansion Factor = 0.850 (Approx.)

Flow Coefficient C is

For $R_e = 6.65 \text{ x } 10^6$

β = 0.39

C = 0.608 (Approx.)

Flow through Orifice whole diameter =

$$\text{CY } \frac{\pi D2^2}{4} \frac{\sqrt{2(P_1 - P_2)}}{þ} = \text{m3 / sec}$$

d_2 = 32 mm

$$= 0.608 \text{ x } 0.850 \text{ x } \pi \text{ x } \frac{(32^2 \text{ x } 10^{-6})}{4} \text{ x } \sqrt{\frac{2\text{x}40.5\text{x}9.8\text{x}10^4}{27.6315}}$$

D_2 = Orifice hole diameter in mm

$(P_1 - P_2)$ = Pressure drop in Pa.
Þ = Density in Kg/m^3 = 0.2228 m^3/sec.

Flow through Orifice of whole diameter 32 mm = 0.2228 x 27.6315 x 3600 = 22162.674 Kg/hr.

Hence Q=.22162.674 Kg/hr.

Total flow = 40,000 Kg/hr.

Flow through 32mm hole orifice = 22162.674 Kg/hr.

Remaining flow =40000 – 22162.674= 17837.326 Kg/hr.

First PCD

Orifice diameter = 15 mm

$^{\beta}$= 15/82.6 = 0.18

Expansion factor 'Y'= 0.861

Flow Coefficient = 0.589

Flow through Orifice hole diameter = 12 mm

$$CY \frac{\pi d_2^2}{4} \sqrt{\frac{2 (P_1 - P_2)}{þ}} = m^3 / sec$$

$$= 0.589 \times 0.861 \times \pi \times \frac{(15^2 \times 10^{-6})}{4} \times \sqrt{\frac{2 \times 40.5 \times 9.8 \times 10^4}{27.6315}}$$

$$= 0.04805\ m^3/sec$$

Flow through orifice hole diameter 12mm

=0.04805 x 27.6315 x 3600 = 4779.7 Kg/hr.

Flow through 32mm orifice hole = 17837.326 Kg/hr.

Flow through 15mm orifice hole = 4779.7 Kg/hr. x 6 holes

=28678.2kg/hr.

First PC diameter is 56mm

5.1.1. Calculation for Orifice Plate thickness

Plate Material = SA387 Gr.22 Cl.2

Design Pressure =1.1 x operating pressure

=1.1 x 81 = 89.1 Kg/cm^2

Design Temperature = 1.1 x 430°

=473°C

Allowable stress at 473°C=11.943 Kg/mm^2 = 1194.3 Kg/cm^2

5.1.2. Checking in Bending

$$t = FG/2 \times \sqrt{\frac{P}{S}}$$

F= 0.8 constant

G= Orifice Plate diameter = 141.3 mm

P =Design Pressure in Kg/cm^2= 89.1

S=Allowable stress in Kg/cm^2= 1194.3 Kg/cm^2

T = Thickness in mm

$$t = \frac{0.8 \times 141.3}{2} \times \sqrt{\frac{89.1}{1194.3}} = 15.43 \text{ mm}$$

5.1.3. Checking thickness in stress

$$t\ shear = \frac{0.31\ DL}{\sim} \times \frac{P}{S}$$

$$DL = \frac{4A}{C}$$

A = Area enclosed by Polygon perimeter
C =Perimeter of Polygon formed

$$\sim = \text{Ligament efficiency} = \frac{28 - 15}{28} = 0.4643$$

$$t\ shear = \frac{0.31 \times 48.5}{0.4643} \times \frac{89.1}{1194.3} = 2.416 \text{ mm}$$

So shear thickness is less than the plate thickness hence design is OK

5.1.4. Check for Mach No.

Mach number calculated has to be less than 0.4

Z/C =Mach No.
C =Velocity of stress in M/S
Z =Velocity of pressure wave in stream in M/S.

$$Z = \sqrt{Ygbt}$$

Y=1.3 for super heater steam
g=9.81 m/s^2
bt=r/m =47.11 for steam
r=Universal gas constant
m=Molecular weight

$$Z = \sqrt{1.3 \times 9.81 \times 47.11} = 24.51$$

$$C = 353.632 \times f \times v / d^2$$

f= Total mass flow in Kg/hr
v = Specific volume in m/Kg
d=Inside diameter of reducer in mm.

$$C = \frac{353.632 \times 40000 \times 0.0361906}{82.6^2} = 75.03212$$

$$\text{Mach No} = \frac{24.51}{75.03212} = 0.32 < 0.4$$

Hence Design is OK.

5.2. Stage II

The same above procedure is applicable for reducing 40.5 Kg/cm^2 to 20.25 Kg/cm^2 with

Assumed Pressure drop= 0.5

5.3. Stage III

The same above procedure is applicable for reducing 20.5 Kg/cm^2 to 10.125 Kg/cm^2 with

Assumed Pressure drop= 0.5

5.4. Stage IV

The same above procedure is applicable for reducing 10.125 Kg/cm^2 to 5.062 Kg/cm^2 with

Assumed Pressure drop= 0.5

5.5. Stage V

The same above procedure is applicable for reducing 5.062 Kg/cm^2 to 2.53 Kg/cm^2 with

Assumed Pressure drop= 0.5

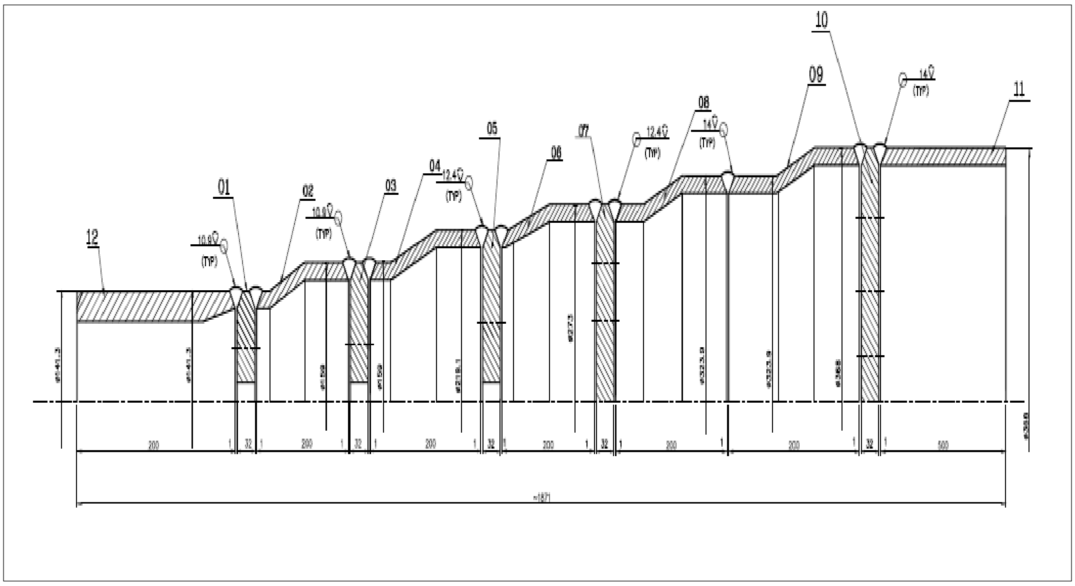

Figure 5 Five stage diffuser assembly

6. Results and discussion

Thereby the problems associated high pressure drop in startup vent line in thermal power plants have been eliminated by designing equipment like diffuser (reducing stage assay) within the existing constraints.

7. Conclusion

This paper proposes a feature-adaptive method called designing of reducing stage assembly which is simple design and also easily fitted at boiler start up vent system. We can conclude that the developed reducing stage assembly can be used for pressure drop with constant steam flow and the efficiency also significant increased.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors certify that they have No Conflict of Interest in the subject matter or materials discussed in this manuscript.

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