Analysis and Optimization of Pressure Reducing and Desuperheating System in Thermal Power Plant

U.Aaditya
Department of Mechanical Engineering,
Velammal Institute of Technology, Chennai, Tamil Nadu, India

K.Arun Prasad
Department of Mechanical Engineering,
Velammal Institute of Technology, Chennai, Tamil Nadu, India

Rishabh Parekh
Department of Mechanical Engineering,
Velammal Institute of Technology, Chennai, Tamil Nadu, India

M.D.Rajkamal
Department of Mechanical Engineering,
Velammal Institute of Technology, Chennai, Tamil Nadu, India

Abstract : Steam Pressure Reducing and Desuperheating System (PRDS) is used for Steam Conditioning Services for reduction of pressure and temperature of steam. Suitably designed pressure reducing valve installed on superheated steam line, reduces steam pressure to desired operating pressure. The steam temperature is reduced close to saturation by injecting water into high velocity steam by controlled water flow through water control valve and often injected into the steam where steam velocity and turbulence are at their highest, which gives quick and efficient cooling. The purpose of this project is to optimize the Pressure reducing and desuperheating system to overcome the current losses such as valve leakage, gland leakage and header leakage. The primary approach to our project is focused on reducing the pressure of the steam in stages and various process parameters such as positioning of nozzles, number of nozzles, positioning of pressure reducing valves, piping material, turbulence developed due to the present design and pipe dimensions with respect to the steam characteristics will be studied. ANSYS for numerical simulations are employed to predict the optimized conditions. Our project deals with the detailed study of PRDS and implementing proper analysis tool to provide a detailed analysis of different components of the system to bring about improvement in design, evaluation, optimization of the system and also to indicate the need for further research.

Keywords: Pressure reducing valve, nozzles, CFD analysis.

I. INTRODUCTION

Steam PRDS is used for Steam Conditioning Services for reduction of pressure and temperature of steam. It is a combination of Control Valve for the pressure reduction purpose and atomizing nozzles through which water is sprayed into steam for reducing the temperature. Typical applications are in Boiler steam, Turbine by-pass, HRSG (Heat recovery steam Generation), and typical Process application where steam temperature and Pressure are critical. Normally steam will be produced in the Boiler with high pressure and temperature and depending on the process requirement, pressure and temperature will be reduced at the consumption point at the plant. This will help to reduce the energy losses during the transmission. PRDS systems are designed to reduce the steam pressure to operating pressure and also bring the outlet steam temperature closer to that of saturation. Suitably designed pressure reducing valve installed on superheated steam line, reduces steam pressure to desired operating pressure. During this process the steam temperature also reduces following superheated steam curve, however the degree of superheat remains unaltered. The steam temperature is reduced close to saturation by injecting water into high velocity steam by controlled water flow through water control valve. Spray water quantity required for the temperature reduction of the steam is controlled by separate spray water valve. The spray water is injected into the steam where steam velocity and turbulence are at their highest, which gives quick and efficient cooling. For PRDS control system, there will be one Pressure loop and one temperature loop.

II. PROJECT BACKGROUND.

The "Self PRDS" system where steam is cut off from the main line into a common bus that can be utilized by the other units is subjected to various losses such as valve leakage, gland leakage, turbulence and vibration. The common factor attributing to this problem is the high pressure drop across the valves. So the main aim of our project is to perform an analysis for evaluation and optimization of the system by reducing the pressure gradually in stages in the main line of the PRDS system and to indicate the need for further research and recommendations for performance comparisons, assessments and improvement in design after identifying the potential areas of improvements. Due to the importance of the pressure reducing and desuperheating system the attention of the designers has been concentrated on this particular topic.

III. APPROACH

The primary approach to our project is focused on reducing the pressure of the steam in stages which overcomes various problems mainly cavitation and aerodynamic noises. It should be noted that cavitation is limited only to liquid applications and aerodynamic noises generally applies to gas applications. When the steam has any condensate particles, cavitation of those particle may occur when the pressure drops below the vapour pressure of those condensate particles.

3.1 Staged Pressure Reduction to avoid Cavitation

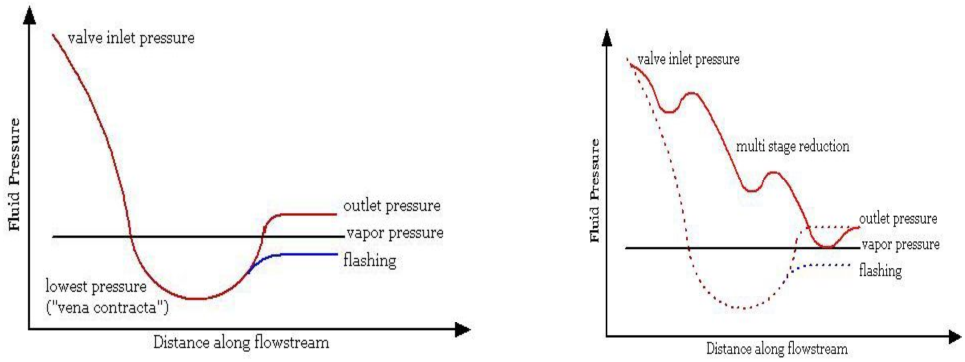


Fig 3.1 shows the advantage of staged pressure reduction which avoids cavitation.

Cavitation is the sudden vaporization and condensation of a liquid downstream of the valve due to localized low pressure zones. When flow passes through a throttled valve, a localized low pressure zone forms immediately downstream of the valve. If the localized pressure falls below the vapor pressure of the fluid, the liquid vaporizes (boils) and forms a vapor pocket. As the vapor bubbles flow downstream, the pressure recovers, and the bubbles violently implode causing a popping or rumbling sound similar to tumbling rocks in a pipe. The sound of cavitation in a pipeline is unmistakable. The condensation of the bubbles not only produces a ringing sound, but also creates localized stresses in the pipe walls and valve body that can cause severe pitting.[1]

$$\sigma = (P_u - P_v) / (P_u - P_d) \qquad (1)$$

where:
σ = cavitation index, dimensionless
P_d = downstream pressure, psig

P_v = vapor pressure adjusted for temperature and atmospheric pressure, psig

= -14.2 psig for water at 60°F, sea level
P^u = upstream pressure, psig

The lower the value for the cavitation index, the more likely cavitation will occur. As a rule of thumb, manufacturers typically suggest that when σ is less than 2.5, cavitation may occur.

From the above equation it is clear that if the downstream pressure is lowered the cavitation index is increased and hence the cavitation is avoided in the application. Hence the pressure differential has to be low in order to avoid cavitation. So, the best possible solution is the staged pressure drop that can be achieved by using two valves in series.

3.2 Staged Pressure reduction to avoid Aerodynamic Noises

Aerodynamic control valve noise is caused by the Reynolds stresses or shear forces that are a property of turbulent flow. Due to the relative velocities, high intensity levels of noise resulting from turbulent flow are generally found in valves handling gas. Sources of turbulence in gas transmission lines include obstructions in the flow path, rapid expansion or deceleration of high velocity gas and directional changes of the fluid stream.[2]

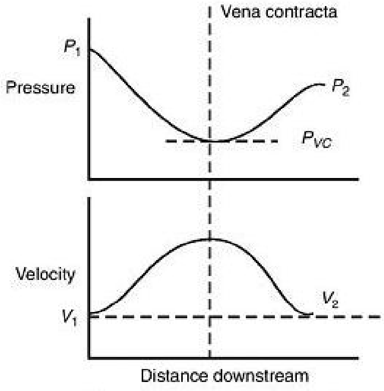


Fig 3.2 shows the relation between the pressure drop and the relative velocity

In general, large pressure differentials create high velocities through a valve and in downstream piping. This in turn creates turbulence, vibration and high noise levels in gas applications. Erosion is a function of steam velocity and higher pressure differential causes **maximum velocity which erodes the valves and causes leakage.**

IV. DESIGN AND ANALYSIS

The techniques that we implemented in bringing the staged pressure reduction are using pressure reducing valves in series, in which the first valve is sized to reduce the 1/3 of the total pressure differential and the second valve is sized to reduce the 2/3 of the total pressure differential. The other technique is the use of nozzles to bring about appreciable pressure drop that is much lesser than that of the pressure drop achieved by the pressure reducing valves. But nozzle is a simple static device and does not require much maintenance and cost effective when compared to pressure reducing valves.

The final optimized design of our project consist of integration of both nozzles and pressure reducing valve in the steam line to bring about the staged pressure reduction. But only the design and analysis of the nozzles is explained in this paper. ANSYS CFD is used for the finite element analysis of the nozzles.

4.1 Sizing of nozzles

The primary equations required for the sizing of the nozzles is given by

$$\frac{V_2^2}{2}-\frac{V_1^2}{2}=\frac{n}{n-1}(p_1v_1-p_2v \tag{2}$$

where
V_2 - Velocity of steam at exhaust
V_1 - Velocity of steam at inlet

- Initial Pressure of Steam
- Specific volume of steam at pressure 1
- Final Pressure of steam
- Specific volume of steam at pressure 2

As the steam passes through the nozzle its pressure is dropped. So the enthalpy is also reduced. This reduction of enthalpy must be equal to the increase in kinetic energy. Hence the work done by the steam upon itself is equal to enthalpy drop. [3]

We also know that,
Mass of steam discharged through nozzle per second

$$m = \frac{\text{Volume of steam flowing per seco}}{\text{specific volume of steam}} \qquad (3)$$

Volume of steam flowing per second = Area x Velocity of steam.
= A x V_2
Specific volume of Steam = v_2

$$\text{Hence, } m = \frac{A\ x}{v} \qquad (4)$$

4.2 Numerical Modeling
4.2.1 First stage pressure reduction:

Inlet Conditions:

Inlet Pressure (bar)	Inlet Density(kg/m3)	Specific Volume(m3/kg)	Area(sq.m)	Inlet Diameter(m)
140	41.09714088	0.024332593	0.004475908	0.075491079

Known Parameters:
The data's are obtained from the Ennore thermal power plant.

Inlet Velocity	***37.75 m/s***
Flow Rate	***6.944 kg / s***
Temperature at inlet	***$540^o c$***

Nozzle Design:
The formulae defined in the 4.1 section is used for determining the exit diameter of the nozzle for the corresponding pressure drop.

outlet Pressure (bar)	outlet velocity V2(m/s)	Density(kg/m3)	Specific Volume(m3/kg)	Area(sq.m)	Outlet Diameter(m)
138	105.8832846	40.447853	0.024723191	0.001621481	0.04543714
137	127.064315	40.12399	0.024922746	0.001362094	0.041644588
136	145.283146	39.800645	0.025125221	0.001200962	0.039103871

It should be noted that the numerical modeling of the nozzle for the first stage is stopped with 136 bar because the velocity at the exit exceeds 152 m/s for the next pressure drop i.e., for pressure from 140 to 135 bar, the exit pressure at the nozzle exceeds 152 m/s[4]. The steam velocity should be maintained within the velocity limits for the safety consideration and also for preventing erosion. Hence only the above three nozzles are taken for analysis whose outlet velocity are within the limits.

4.2.2 Second stage pressure reduction:

Inlet Conditions:
The exit condition for the first stage nozzle will be the inlet condition to the second stage nozzle.

Inlet Pressure (bar)	Inlet Density(kg/m3)	Specific Volume(m3/kg)	Area(sq.m)	Inlet Diameter(m)
136	39.800645	0.025125221	0.001200962	0.039103871

Known Parameters:
The data's are obtained from the Ennore thermal power plant.

Inlet Velocity	***37.75 m/s***
Flow Rate	***6.944 kg / s***
Temperature at inlet	***$540^o c$***

Nozzle Design for second stage:

outlet Pressure (bar)	outlet velocity V2(m/s)	Density(kg/m3)	Specific Volume(m3/kg)	Area(sq.m)	Outlet Diameter(m)
135	161.6497424	39.47781756	0.025330681	0.001088195	0.037222741

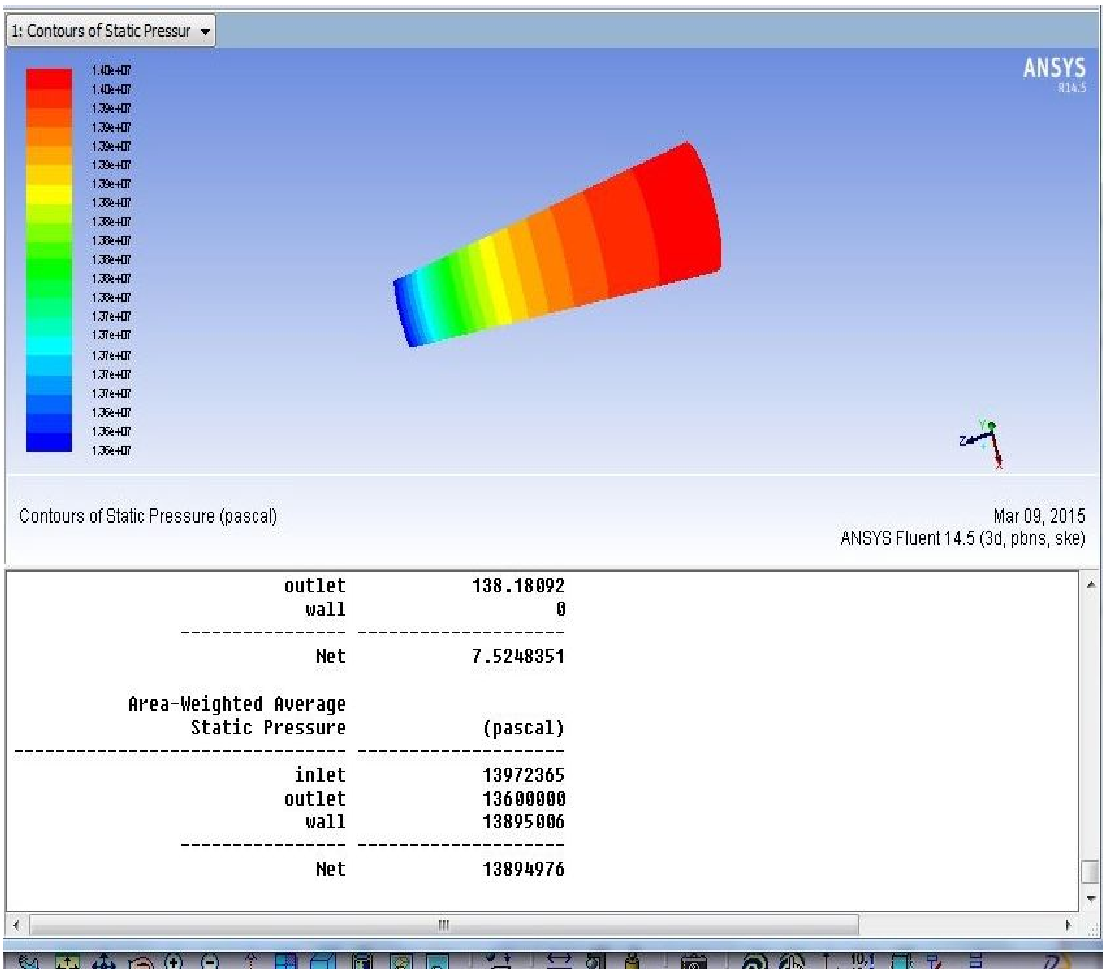
Second stage reduction of pressure using nozzle is practically impossible as the pressure reduction of 136 bar to 135 bar raises the outlet velocity above 152m/s.
Hence second stage nozzle analysis is not carried out.

V. RESULTS

5.1 Analysis result of Nozzle 1:

First stage pressure reduction nozzle with inlet diameter of 76mm, outlet diameter of 39mm and length of 211mm is subjected to CFD analysis. The length of the nozzle varies with the semi cone angle, in our design semi cone angle of 3 to 10^0 is taken as the optimum value.

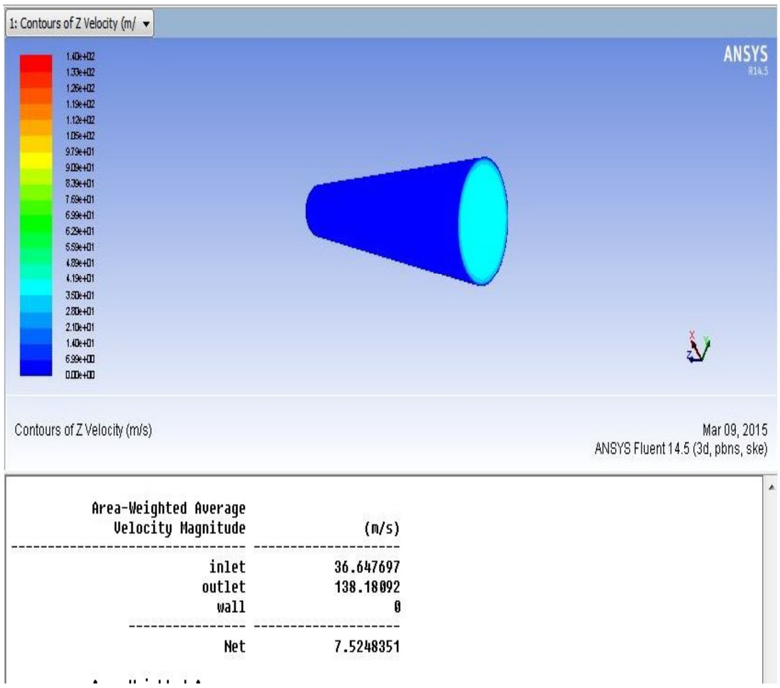
Contours of static pressure:



```
                          outlet            138.18092
                            wall                    0
                ---------------- --------------------
                             Net            7.5248351

          Area-Weighted Average
                 Static Pressure             (pascal)
-------------------------------- --------------------
                           inlet             13972365
                          outlet             13600000
                            wall             13895006
                ---------------- --------------------
                             Net             13894976
```

Contours of Velocity

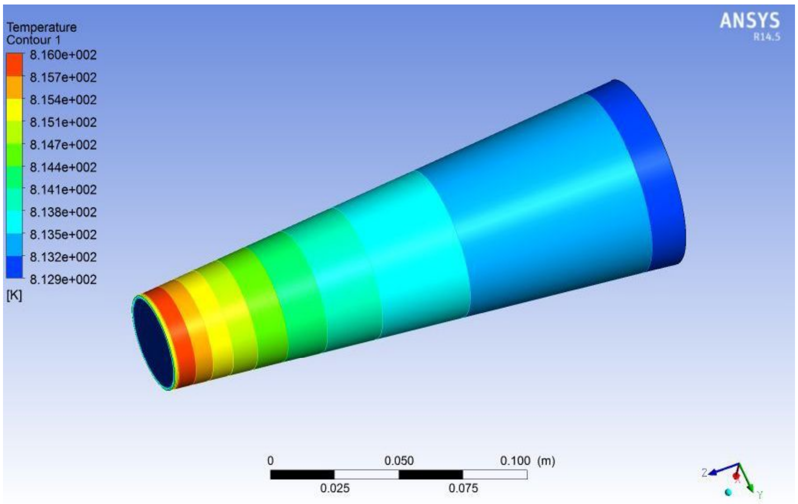


Contours of Z Velocity (m/s)

Mar 09, 2015
ANSYS Fluent 14.5 (3d, pbns, ske)

```
          Area-Weighted Average
             Velocity Magnitude                 (m/s)
-------------------------------- --------------------
                          inlet            36.647697
                         outlet            138.18092
                           wall                    0
                ---------------- --------------------
                            Net            7.5248351
```

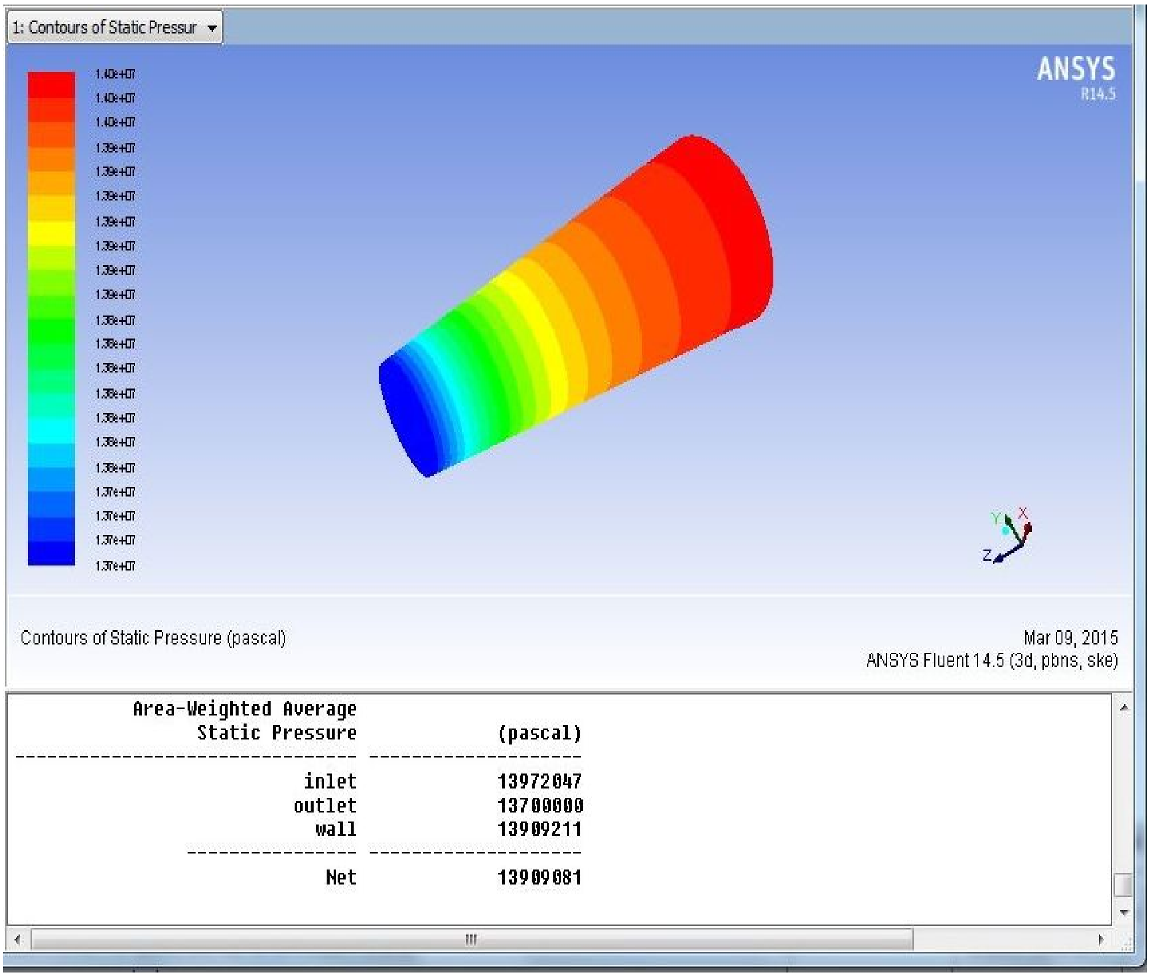
Contours of temperature



5.2 Analysis result of Nozzle 2:

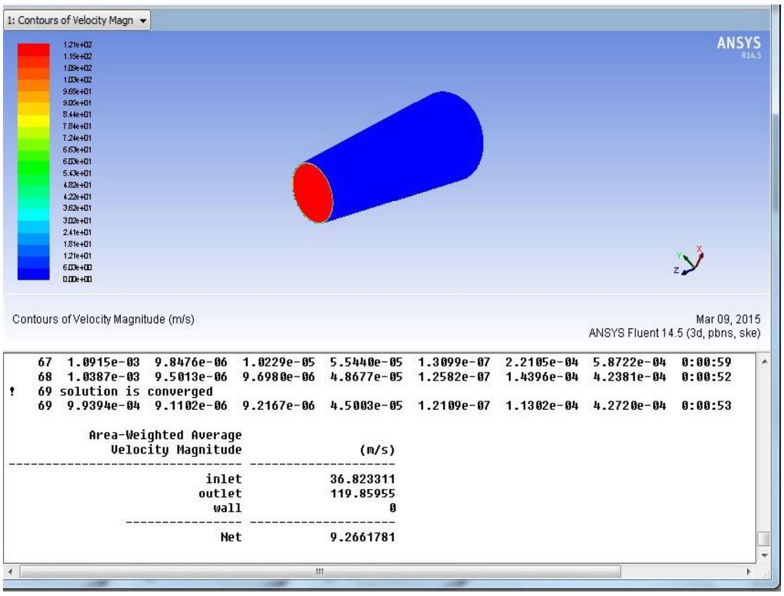
First stage pressure reduction nozzle with inlet diameter of 76mm, outlet diameter of 41mm and length of 166 mm is subjected to CFD analysis. The length of the nozzle varies with the semi cone angle, in our design semi cone angle of 3 to 10^0 is taken as the optimum value.

Contour of Pressure:



```
           Area-Weighted Average
                 Static Pressure             (pascal)
-------------------------------- --------------------
                           inlet             13972047
                          outlet             13700000
                            wall             13909211
                ---------------- --------------------
                             Net             13909081
```

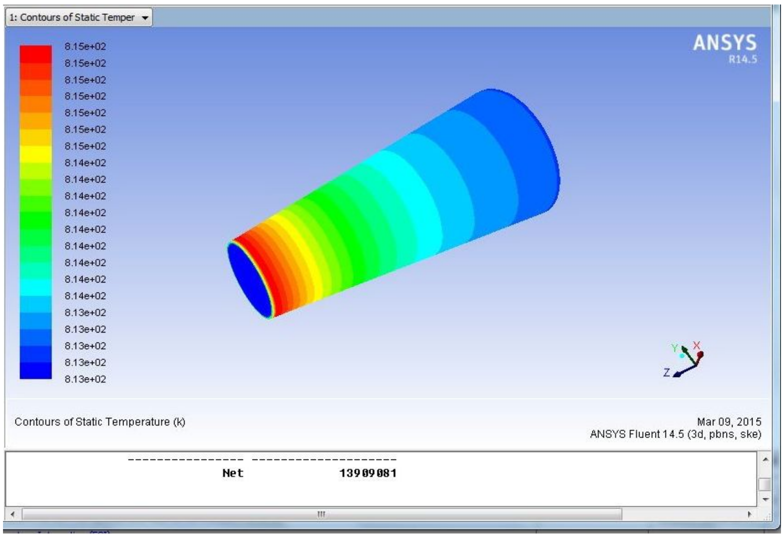
Contour of Velocity:



```
    67  1.0915e-03  9.8476e-06  1.0229e-05  5.5440e-05  1.3099e-07  2.2105e-04  5.8722e-04  0:00:59
    68  1.0387e-03  9.5013e-06  9.6980e-06  4.8677e-05  1.2582e-07  1.4396e-04  4.2381e-04  0:00:52
!   69 solution is converged
    69  9.9394e-04  9.1102e-06  9.2167e-06  4.5003e-05  1.2109e-07  1.1302e-04  4.2720e-04  0:00:53

            Area-Weighted Average
               Velocity Magnitude                 (m/s)
-------------------------------- --------------------
                            inlet             36.823311
                           outlet             119.85955
                             wall                     0
                ---------------- --------------------
                              Net             9.2661781
```

Contour of Temperature:

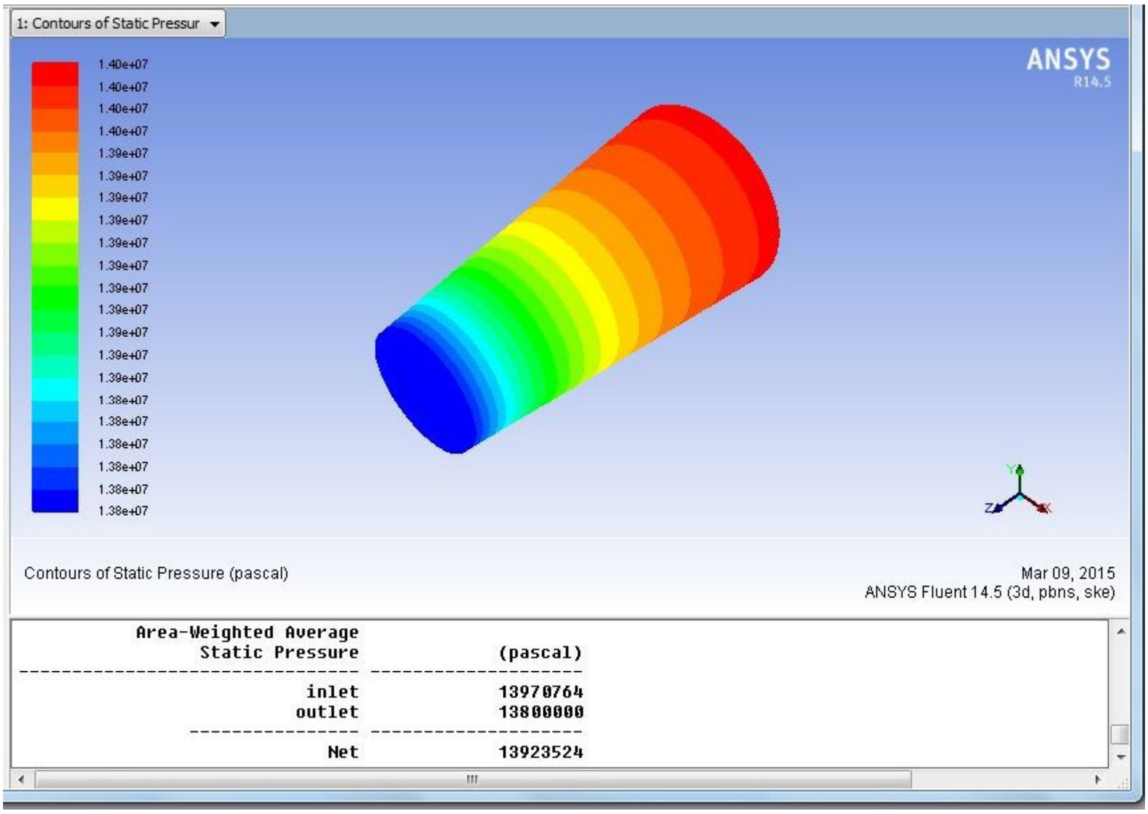


```
                ---------------- --------------------
                              Net              13909081
```

5.3 Analysis result of Nozzle 3:

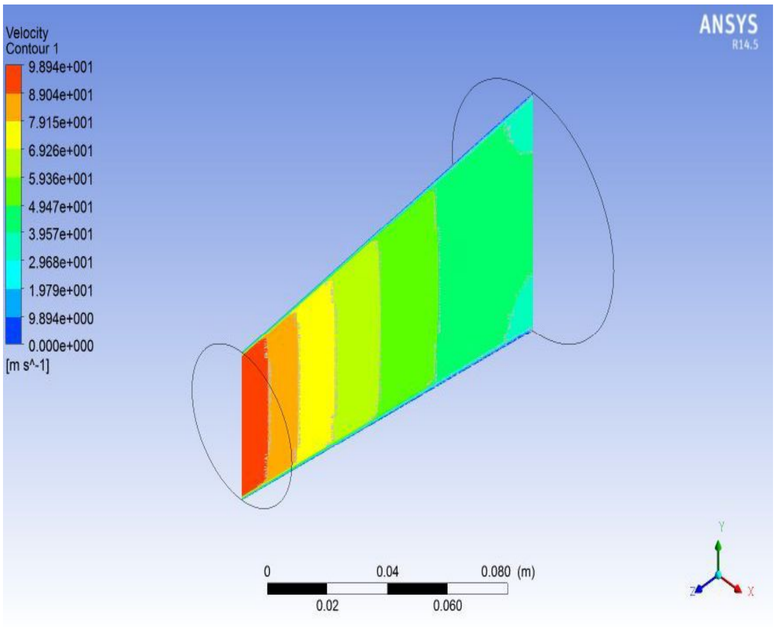
First stage pressure reduction nozzle with inlet diameter of 76mm, outlet diameter of 45 mm and length of 147 mm is subjected to CFD analysis. The length of the nozzle varies with the semi cone angle, in our design semi cone angle of 3 to 10^0 is taken as the optimum value.

Contour of pressure:

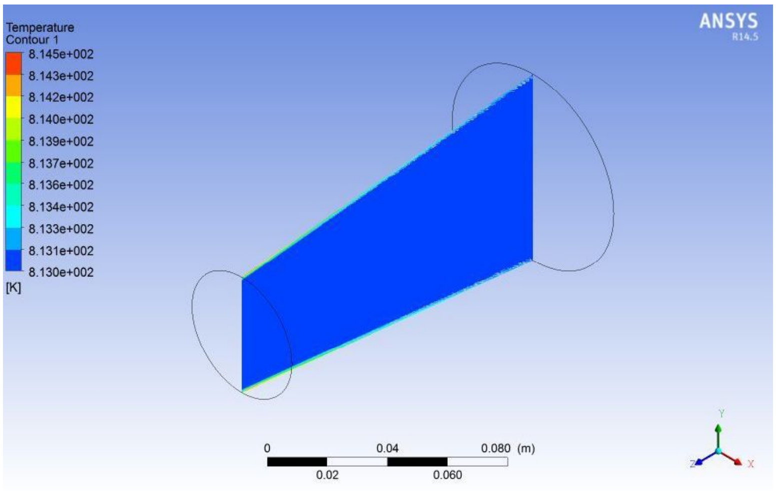


```
             Area-Weighted Average
                   Static Pressure              (pascal)
---------------------------------- --------------------
                             inlet             13970764
                            outlet             13800000
                  ---------------- --------------------
                               Net             13923524
```

Contour of Velocity



Contour of Temperature



The results of the analyses is interpreted in the table

Inlet Diameter	Outlet Diameter	Length of Nozzle (mm)	Output Pressure (bar)	Temperature (Kelvin)	Exit velocity (m/s)	Theoretical Exit Velocity (m/s)
76	39	211	136	814	138.18	145.238
76	41	166	137	814	119.85	127.064

76	45	147	138	814	97.96	105.883

5.4 Graphs

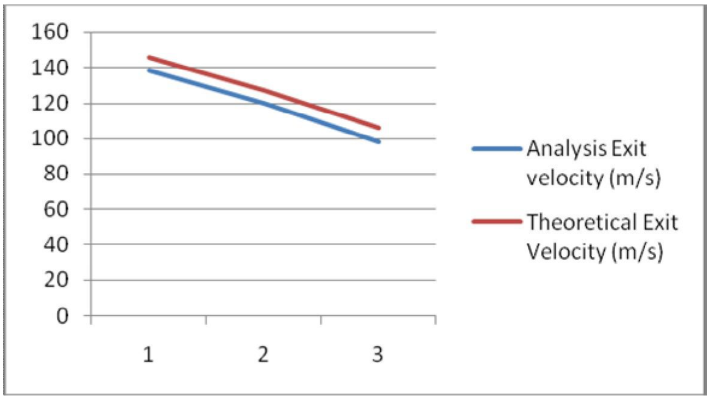


Fig 5.1 Variation of theoretical velocity with the analysis velocity.

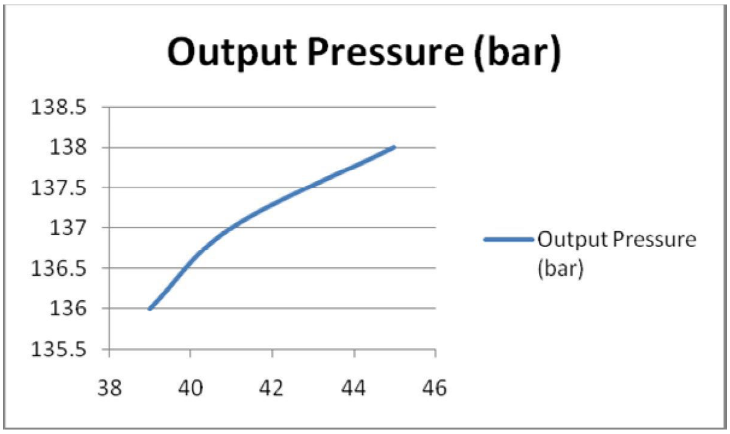


Fig 5.2 Pressure drop vs outlet diameter

5.5 Constraints:

The inlet and the outlet pressure are fixed as the constraints in the design individually for each nozzle to obtain the pressure distribution across the length of the nozzle. After the constraints are applied, velocity and temperature distribution for each nozzle are computed, when the results are converged.

VI. DISCUSSIONS

1) Implementation of nozzles for single stage pressure reduction is only desirable as second stage pressure reduction increases the outlet velocity of nozzle beyond the limit .
2) From the analysis it is observed that increasing the length of the nozzle results in better pressure distribution and avoids back pressure.
3) Nozzle can be implemented for single stage pressure reduction of minimal value between the main steam line and the common bus connecting the PRDS system.
4) There is a variation between the theoretically calculated outlet velocity with the velocity obtained from the analysis.
5) Only a minute change in the temperature contour is observed along the length of the nozzle.

6) Limiting the length of the nozzle by choosing larger semi cone angle results in increasing the possibility of back pressure.
7) Pressure reduction in nozzle also contributes enthalpy drop that is desirable because it reduces the work load on the water spraying nozzle in the PRDS system.
8) Only a maximum of 4 bar pressure differential can be achieved without letting the outlet velocity to exceed 152 m/s.
9) Nozzle can be implemented in vertical steam lines and also helps to reduce piping cost.
10) Pressure drop obtained across the nozzle is less when compared to pressure reducing valves.

VII. CONCLUSION

It is obvious that in order to bring about the staged pressure reduction, in addition to pressure reducing valves, nozzles can also be used along with Pressure reducing valves as the pressure differential obtained by the nozzle is less when compared to pressure reducing valves. The final optimized result of our project includes the integration of both nozzle and Pressure reducing valves to bring about the staged pressure reduction. The analysis of pressure reducing valves and the future research scope of our project will be explained in our next paper.

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