

CFD Analysis of T Pipe Junction in Nuclear Reactor Cooling Circuit

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ABSTRACT: When two fluids at different temperature are mixed, a spatial and time temperature fluctuation occurs. If this fluctuation is high, it may causes damages to the structure due to high cycle thermal fatigue and this is called as thermal stripping phenomena. This phenomenon is important for safety of reactors, which uses liquid metal as the coolant. Now Computational Fluid Dynamics [CFD] is an alternative to reduce the number of experiments required. And CFD reduces cost and time required for the designing process. Further it provides more insight into the flow process. In the present work an elbow is often used near the mixing tee and it brings biased velocity distribution and also the secondary flow, which decays unsteadily. Measured temperature exhibits that fluctuation intensity near the wall was larger in a case with the elbow than in a straight case under a wall jet condition where the jet exiting from the branch pipe was bent down to the pipe wall by high flow velocity in the main pipe. Measured flow velocity exhibits that biased flow velocity distribution and fluctuation due to elbow which influence the water jet in the pipe and the intensity of temperature fluctuation around the jet.

KEYWORDS: Thermal stripping phenomenon, CFD process, impinging jet, Pressure contour, Temperature contour.

I.INTRODUCTION

Streams cause high cycle temperature fluctuations next to piping walls. The temperature fluctuation leads to stress fluctuations. These stresses cause thermal fatigue on the piping system. This occurs in outside region of the nuclear reactor like piping, tee junctions, valves, elbows, particularly the tee pipes in residual heat removing systems

The study of thermal fatigue in piping system of cooling circuit in nuclear power plants is essential because of following issues.

1. Cooling circuit safety
2. To enhance the life of reactors
3. To design future reactors.

The thermal fatigue is caused by uneven mixing of high and low temperature fluids, further it is causes following issues.

1. Fluctuation fluid temperature
2. Fluctuations of stresses in pipe

Following are the phenomena which causes thermal fatigue.

1. Thermal stratification
2. Thermal stripping
3. Turbulent mixing

Many of these phenomena are to be analysed by experimental trails, but the turbulent mixing is not possible and for this a numerical simulations necessary. Fluids meeting at different temperatures can arrive at the pipe wall before reaching

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thermal equilibrium. In this situation, temperature fluctuations occur at near the pipe and cause thermal load. Failures related with thermal fatigue are observed in the pipe materials which are exposed to thermal load for a long time. There are lots of T-junction-type components in which fluids meet at different temperatures in cooling system of nuclear reactor. In these components, occurrence of fractures due to thermal mixing leads to serious disruptions. Such failures occurred in many nuclear power plants. Thereby, accurate prediction of thermal mixing cases that result in failure is essential for safety and operating systems of nuclear reactors. In the tee junction geometry considered in this study, main pipe is located in horizontal plane and cold water is flowing through it. Hot water is flowing through the branch pipe which is located in vertical plane. Momentum ratio, MR, was defined and applied to estimate the flow patterns based on the in flow conditions as follows:

$$M_R = \frac{M_m}{M_b}$$
$$M_m = D_m D_b \rho_m V_m^2$$
$$M_b = \frac{\pi}{4} D_b^2 \rho_b V_b^2$$

Here, the momentum in the main pipe, M_m , considers a projection area ($D_b \times D_m$) of a cylinder with a diameter of D_b and length D_m , which means interaction area between the flow in the main pipe and the jet exiting from the branch pipe. Fluid temperature is considered in the density, figure shows flow pattern map obtained from the flow visualization in axes of the momentums. The flow pattern can be predicted by the momentum ratio, MR as follows;

MR < 0.35: impinging jet,
0.35 < MR < 1.50: deflecting jet,
MR > 1.50: wall jet.

Each flow pattern showed its own temperature distribution and also the fluctuation intensity profile. Results of the temperature measurement are discussed in the next section.

II.LITERATURE SURVEY

In literature review several water experiments to examine the thermal stripping and it was performed in a mixing tee. From the flow visualization test, the patterns are classified in to wall, deflecting and impinging jets. And this is obtained by varying the momentum ratio between the main and branch pipes. For investigation of influence of elbow a water experiment was done in mixing tee, and detailed temperature distribution was performed by using thermocouple tree and the velocity distribution was measured by Particle Image Velocimetry

In this study the analysis was done by comparing the main pipe with and without upstream elbow. To understand this process numerical modelling of mixing tee with and without upstream elbow is studied using discrete phase model within the commercial CFD package environment, FLUENT. An analysis has been carried out by varying the momentum ratio in wall jet, deflective jet and impinging jet conditions.

III.PROPOSED METHODOLOGY AND DISCUSSION

Following are the steps for obtaining of proper solutions in flow of fluids using Fluent.

Pre processing: - in this a geometry construction is done, and meshing of geometry on the volumes or surfaces. These are done with the software Ansys design modular and Ansys meshing, which are linked to the Fluent. Boundary condition: after meshing of model is done. The meshes are checked for errors and import that in the fluent solver. And simulation has been carried out by giving the boundary condition like velocity, pressure, temperature, steady and unsteady, heat flux, heat transfer etc.

Solution: this can be achieved by iterations up to the convergence of variable occurs. Before starting solution the variables are to be initialized then it is computed by giving the starting regions. Then in this stage, the governing equations are solved and it is checked for the convergence until it reaches the given value.

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Post Processing: - in this stage the computed results are analysed. For this there are several choices like Contours, path lines, vectors, X-Y Plots. And in them many variables are analysed like pressure, temperature, velocity, force, density, turbulence and others.

IV. EXPERIMENTAL RESULTS

ANALYSIS OF T-PIPE JUNCTION

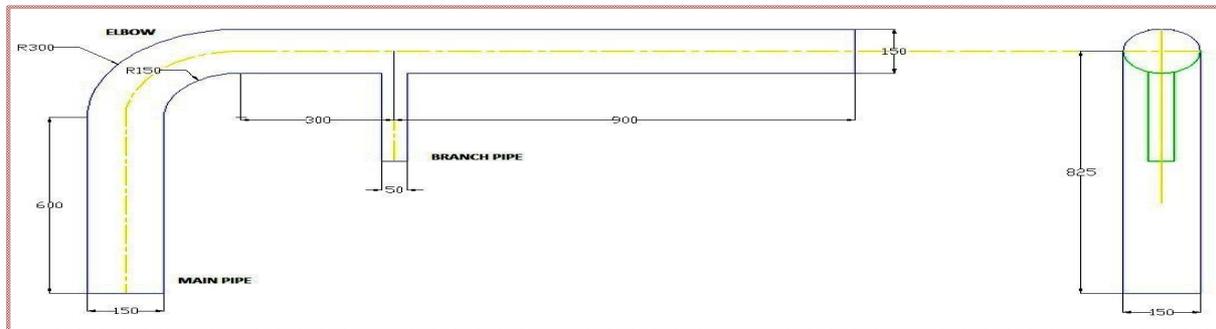


Fig.1 Water model T-Pipe junction

Specification:

- Main pipe diameter (D_m) = 150mm
- Branch pipe diameter (D_b) = 150mm
- Inner Radius of Bend (R) = 150mm
- Outer Radius of Bend ($2R$) = 300mm

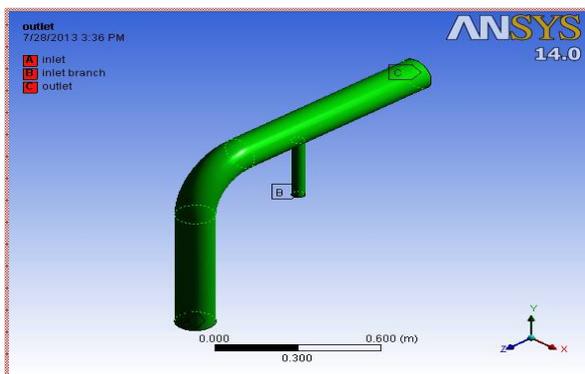


Fig.2 Geometric 3D Model of T-Pipe Junction

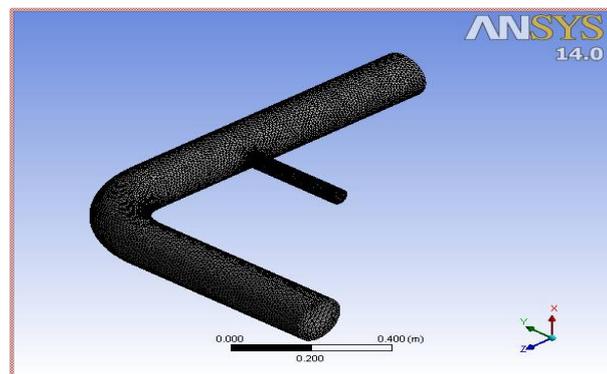


Fig.3 The tetrahedral meshed T-Pipe Junction model

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case	Flow Pattern	Velocity in main pipe V_m (m/s)	Velocity in branch pipe V_b (m/s)	Momentum ratio MR
W-ref	Wall jet	1.46	1.0	8.1
D-ref	Deflecting jet	0.46	1.0	0.8
I-ref	Impinging jet	0.23	1.0	0.2

Table .1: Boundary conditions for a typical T-pipe junction, (Ogawa et.al 2005)

Case	Flow Pattern	Velocity in main pipe V_m (m/s)	Velocity in branch pipe V_b (m/s)	Momentum ratio MR
W-1	Wall jet	2.18	1.5	8.1
D-1	Deflecting jet	0.46	1.5	0.8
I-1	Impinging jet	0.34	1.5	0.2

Table 2. Boundary conditions for a typical T-pipe junction for different momentum ratio

ANALYSIS OF T-PIPE JUNCTION

A T- pipe junction was analysed and simulated by using a CFD software package Ansys FLUENT. The simulation has been done for water model T-pipe. The results presented in this section are velocity contours, velocity vectors, Temperature contours, water volume fraction, and validated against the available literature.

CASE-1 WALL JET CONDITON (W-ref)

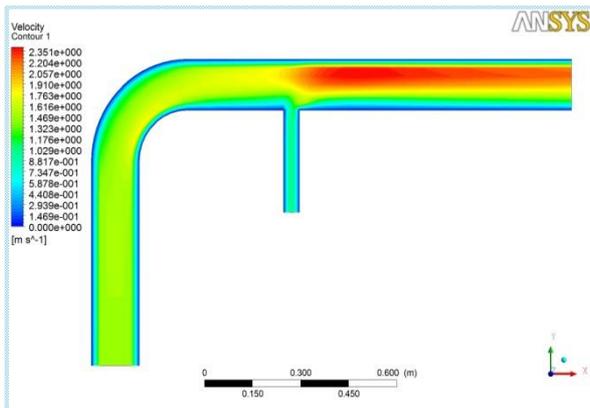


Fig .4 velocity contour at mid plane in elbow case

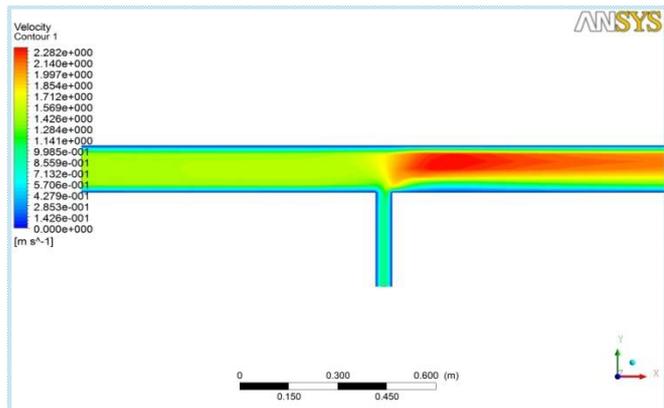


Fig .5 velocity contour at mid plane in straight case

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The above Fig.4 and Fig.5 shows the velocity contours which exhibits the velocity distribution along the T-pipe junction by comparing both of elbow and straight cases. And the peak value of velocities is 2.282 m/s in straight case and 2.351 m/s in elbow case respectively

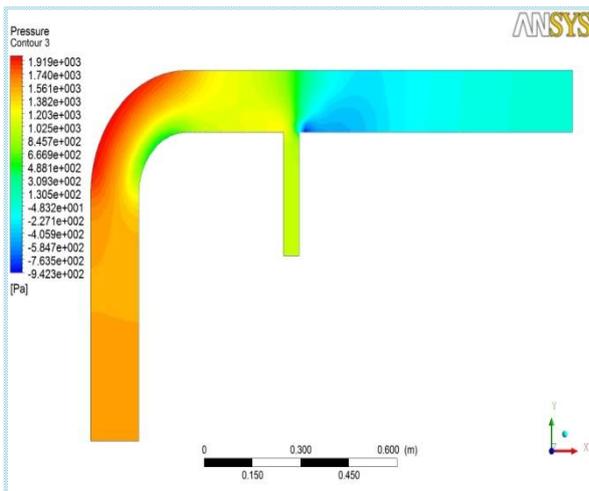


Fig .6 Pressure contour at mid plan in elbow case

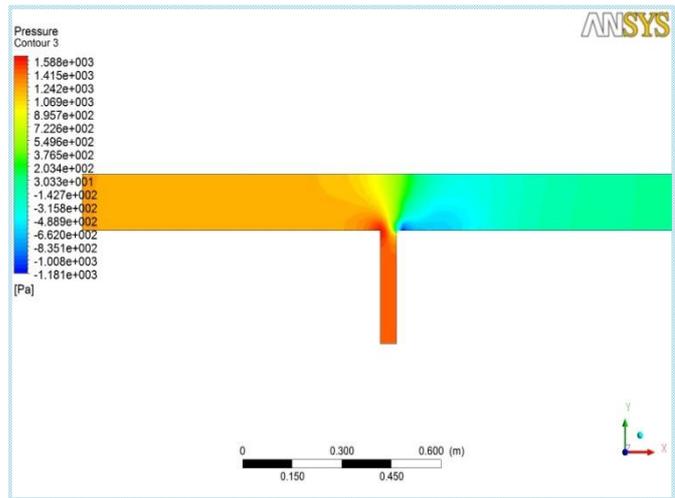


Fig .7 Pressure contour at mid plan in straight case

The above Fig. 6 and Fig .7 shows the pressure contours which exhibit the pressure distribution along the T- pipe junction by comparing both of elbow and straight cases. And the peak value of pressures is 1588 Pa in straight case and 1988 Pa in elbow case respectively.

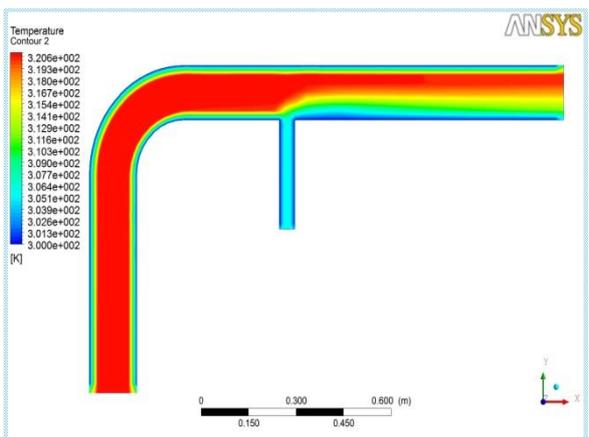


Fig.8 Temperature contour at mid plan in elbow case

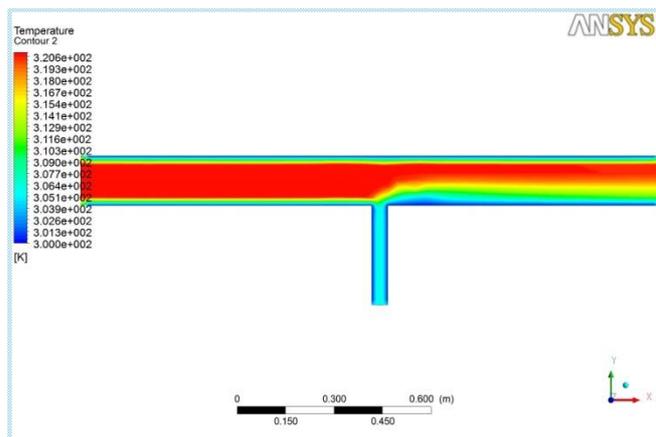


Fig .9 Temperature contour at mid plan in straight case

The temperature contour distribution of T-pipe junction for elbow and straight case are shown in fig.8 and 9. Respectively. The maximum temperature was observed to be 320.6°K in both the cases

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CASE-2 DEFLECTING JET (D-ref)

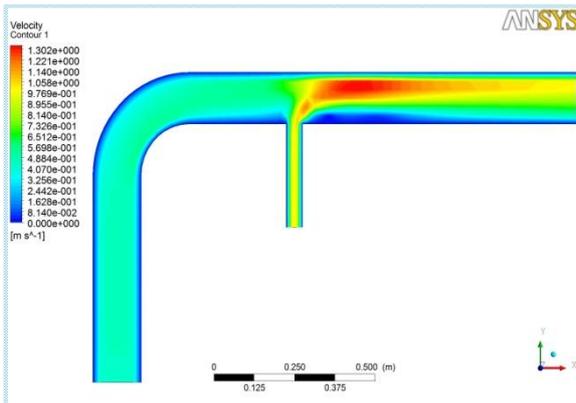


Fig .10 Velocity contour at mid plan in elbow case

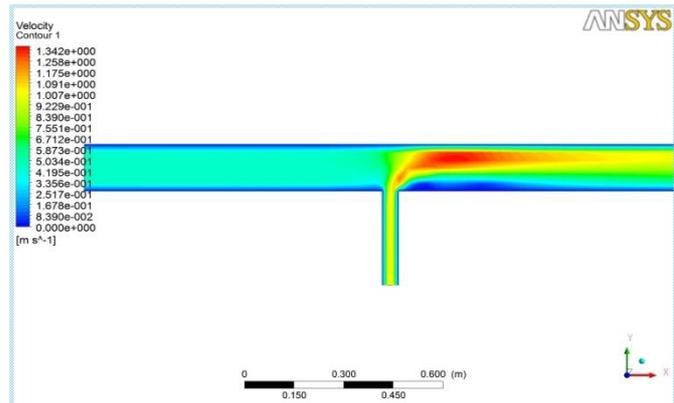


Fig .11 Velocity contour at mid plan in straight case

The above Fig.10 and Fig .11 shows the velocity contours which exhibits the velocity distribution along the T- pipe junction by comparing both of elbow and straight cases. And the peak value of velocities is 1.342 m/s in straight case and 1.302 m/s in elbow case respectively.

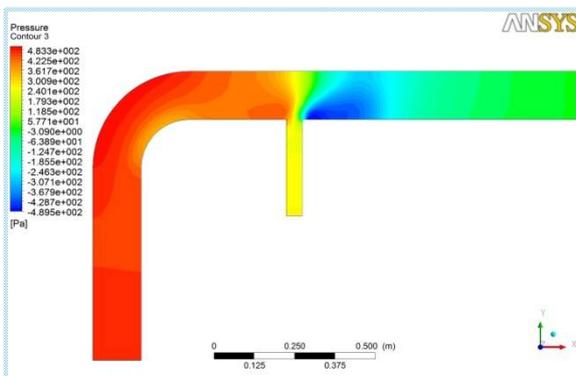


Fig .12 Pressure contour at mid plan in elbow case

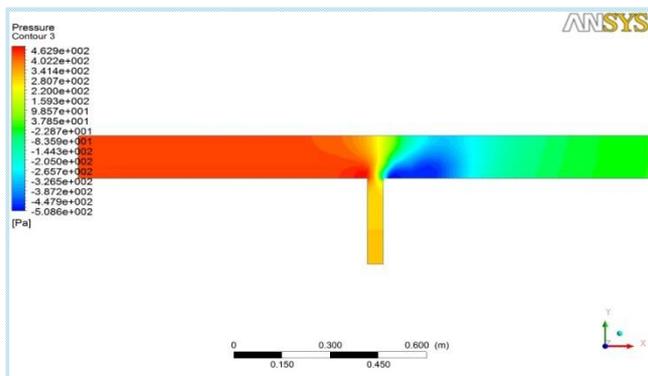


Fig .13 Pressure contour at mid plan in straight case

The above Fig .12 and Fig .13 shows the pressure contours which exhibits the pressure distribution along the T- pipe junction by comparing both of elbow and straight cases. And the peak value of pressures is 462.9 Pa. in straight case and 483.3 Pa. in elbow case respectively.

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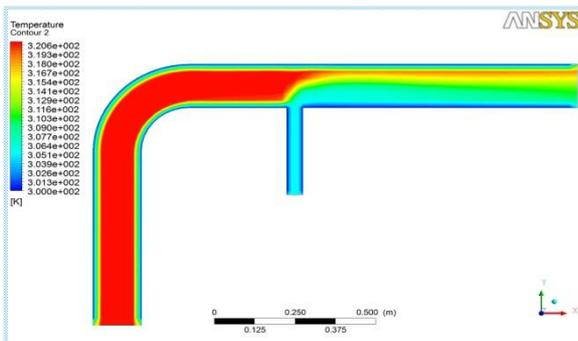


Fig .14 temperature contour at mid plan in elbow case

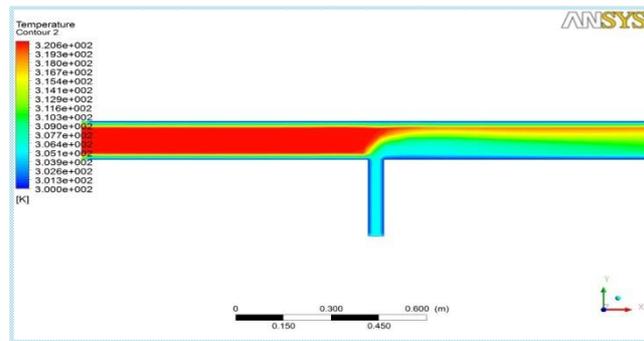


Fig .15 temperature contour at mid plan in straight case

The temperature contour distribution of T-pipe junction for elbow and straight case are shown in fig.14 and .15 respectively. The maximum temperature was observed to be near to 320°K in both the cases

CASE 3: IMPINGING JET (I-ref)

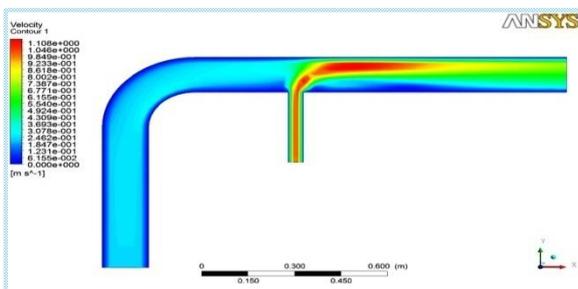


Fig .16 velocity contour at mid plan in elbow case

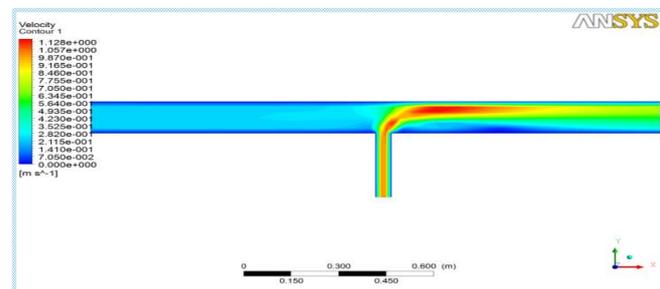


Fig .17 velocity contour at mid plan in straight case

The above Fig .16 and Fig .17 shows the velocity contours which exhibits the velocity distribution along the T- pipe junction by comparing both of elbow and straight cases. And the peak value of velocities is 1.128 m/s in straight case and 1.108 m/s in elbow case respectively.

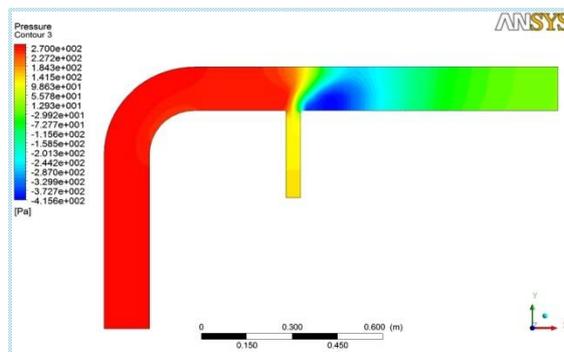


Fig 18 Pressure contours at centre plane in elbow case

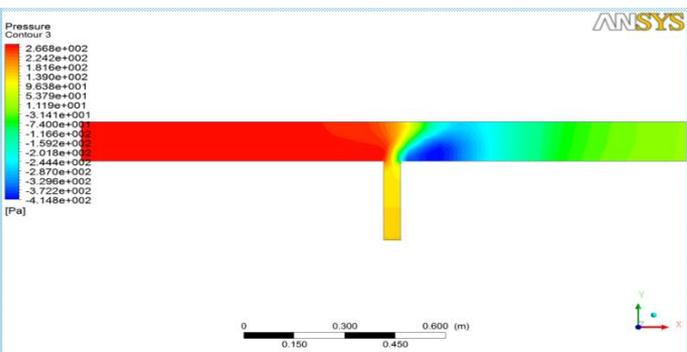


Fig .19 Pressure contours at centre plane in straight case

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The Fig .18 and Fig .19 shows the pressure contours which exhibits the pressure distribution along the T- pipe junction by comparing both of elbow and straight cases. And the peak value of pressures is 266.8 Pa. in straight case and 270.1 Pa. in elbow case respectively.

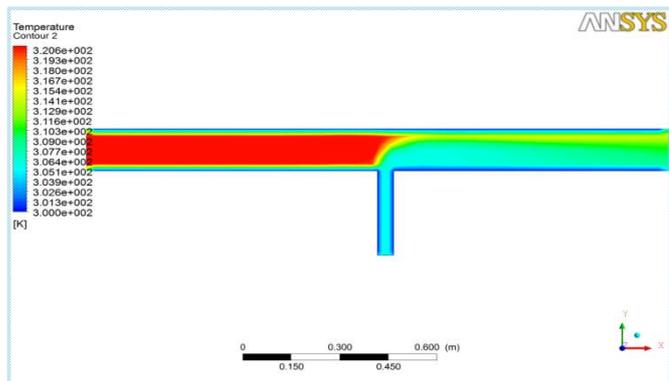
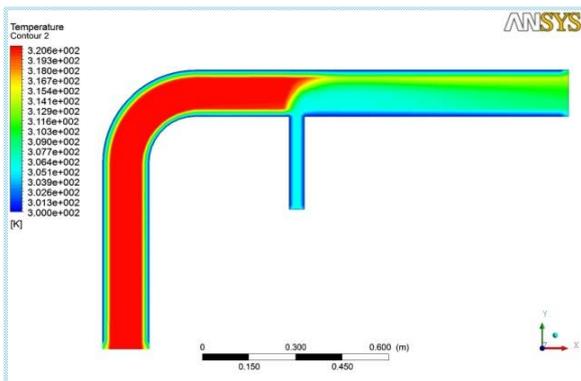


Fig 20 Temperature contours at centre plane in elbow case Fig 21 Temperature contours at centre plane in straight case

The temperature contour distribution of T-pipe junction for elbow and straight case are shown in fig.20 and .21 respectively. The maximum temperature was observed to be 320.6°K in both the cases

COMPARISON OF TEMPERATURE AND VELOCITY FLUCTUATIONS

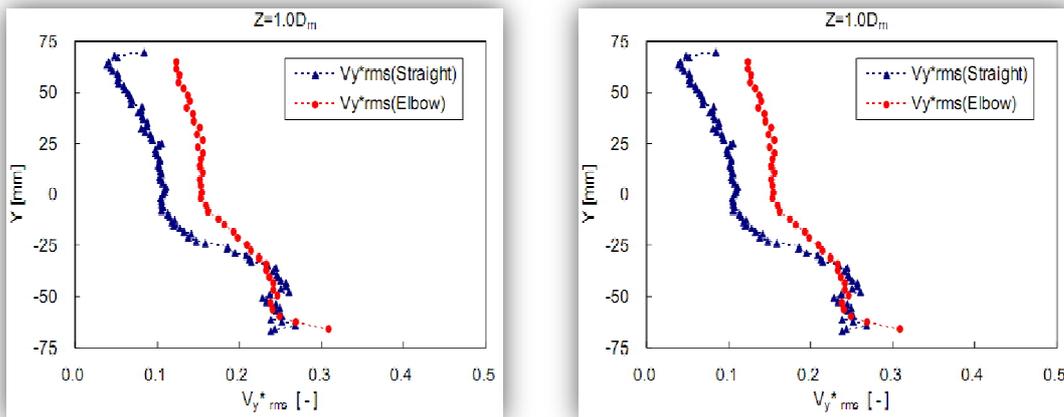


Fig .22 Velocity fluctuation intensity comparisons in wall jet condition

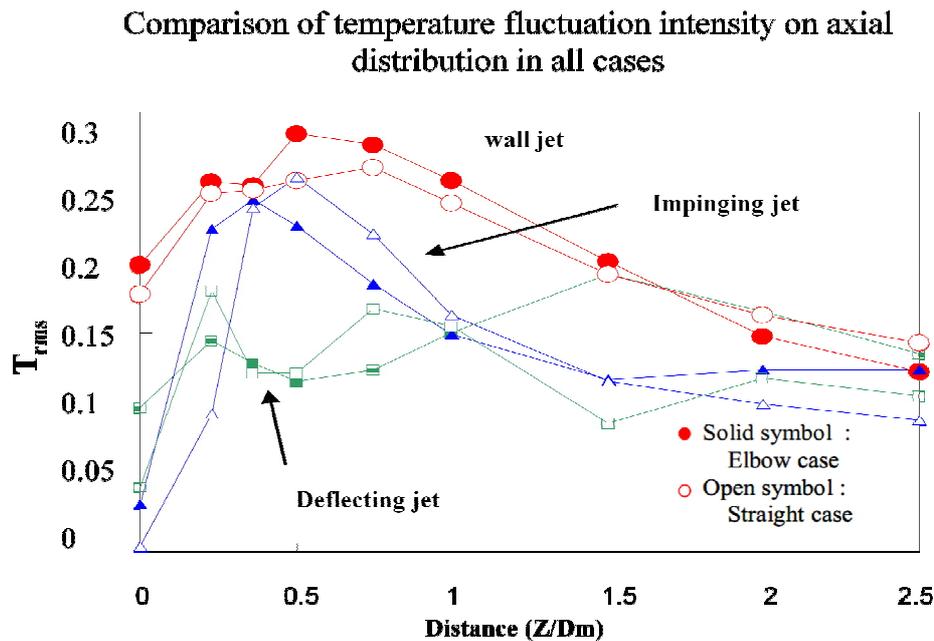


Fig .23 comparison of temperature fluctuation intensity

V. CONCLUSION

A CFD analysis using a simple model of Tee pipe with upstream elbow in main pipe was carried out to investigate thermal stripping. And a detailed analysis was done for Temperature and velocity distribution in the pipe by using upstream elbow and the following observations were made and conclusions were drawn

- The flow pattern of the tee pipe junction was classified in to three patterns; that is wall jet, deflecting jet, impinging jet according to the momentum ratio between main and branch pipes.
- In elbow case the stream of fluids are shifted towards higher momentum in main pipe flow that in wall jet pattern than in straight pipe condition. This occurs because of the biased velocity at outlet of the elbow. It is obtained that the temperature and velocity fluctuation intensity in the wall jet pattern is larger in elbow case than the straight case. And it is observed that the temperature fluctuation intensity and velocity fluctuation intensity in deflecting jet is smaller in elbow case as compared with straight jet.
- The methodology makes use of mathematical optimization and Computational Fluid Dynamics (CFD) to give an optimum design of T-pipe junction based on certain design criteria required for easy flow and to meet the specifications.
- The proposed methodology consist number of steps. . The first step is validation of the CFD results. This can be achieved by either comparing the numerical results to a water model or to a plant trial. In the Second step Numerical modeling is done in line with physical modelling to analyse the flow pattern, velocity and temperature distribution.

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