Behaviour and Effect of Temperature over Pressure Tube of Nuclear Reactor

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ABSTRACT
Radiation is responsible for heat transfer from fuel rods to the Pressure tube during loss of coolant. The temperature distribution of the pressure tube is obtained through experimental test runs.

A Finite Difference Method and ANSYS are applied to predict the axial temperature distribution and its effect on a pressure tube by incorporating the radiative and convective boundary conditions. The results obtained using FDM and ANSYS are compared well with the experimental results. Prediction of the temperature distribution of a cylindrical pressure tube, heated by conjugate conduction and radiation from inside of it that is cooled by natural convection and radiation from outside, are reported in this paper. Pressure tube is subjected to the higher temperature at top and lower temperature at bottom. These two extreme temperatures are input to the FDM and ANSYS software. The comparison is made with the experimental results and agreement between the mathematical model (FDM) and the ANSYS results is very good.

General Terms
Mathematical model, CAD model and result comparison with experimental setup.

Keywords
Temperature, nuclear reactor, ansys

1. INTRODUCTION
Enery and Carson [1] have compared the FDM and FEM and reported that the two methods are comparable for some constant-property steady state solutions but that the FDM is better for most other cases. It is also reported that for FDM is more suitable than FEM for thermal analysis. The two principal techniques for obtaining numerical solution to boundary value problems are the finite difference method (FDM) and the finite element method (FEM). The FEM was developed for stress analysis. In the area of conduction heat transfer the FDM is still most widely used method. S. B. Bopche and Arunkumar Sridharan [8] presented an experimental setup and investigate the decay heat removal in advanced nuclear reactors using a single heater rod test facility: Air alone in the annular gap, and identify the temperature distribution on pressure tube by experimental setup

2. EXPERIMENTAL SETUP
The detailed specifications of the experimental facility studied are presented in this chapter. The experimental results have been referred from literature [8] for validation of present FEM results.

The schematic of the experimental set up fabricated is as shown in Fig. 1. The electrical equipments are designed for the maximum power supply of 1500 W. The annular space between the pressure tube and calandria tube is specified here as an annular gap. Generally, in the reactor it is filled with an inert gas that isolates the reactor core from the moderator. Electrical power is supplied to the heater rod through two copper bus bars at its ends. Power supply is varied with the help of an autotransformer (10 A). The power supply to the heater is measured with the help of a voltmeter and a clamp-meter is used for monitoring the current.

3. GOVERNING EQUATIONS
Consider a hollow cylinder i.e. pressure tube in nuclear power plants shown in Fig. 2. The base is maintaining a constant temperature with the assumption of one directional heat conduction along the tube and steady state heat operation, an energy balance applied to a differential element yields:

$$Q_r + Q_x - Q_{z+dz} - dQ_{loss} = 0 \qquad \text{Eq. [1]}$$

Where, Q_{loss} accounts for heat transfer due to convection and radiation from the surface. With the use of standard equation of conduction convection and radiation the energy balance can be written as:

$$Q_{z+dz} + h_c dA\Delta T + h_r dA\Delta T = Q_r + Q_z \qquad \text{Eq. [2]}$$

In theory, h_c and k can vary along the length of the fin. In this study, the thermal conductivity k is assumed to be independent of the temperature and thus constant. The convection heat transfer coefficient is assumed to depend on the local surface temperature. The convective heat transfer coefficient, h_c is related to the Nusselt number, for which correlation by Churchill and Chu [9] is referred, which is as given in Eq. 5.

The correlation is presented below. For the vertical hollow cylinder the values of radiative heat transfer coefficient (hr) are obtained using the experimental analysis [8].

$$Nu_D = \frac{hD}{k_f} = \frac{\left(0.518 \times {Ra_D}^{1/4}\right)}{\left[1+(0.559/Pr)^{9/16}\right]^{4/9}}$$

$$\frac{d^2T}{dz^2} = \frac{4hD_o(T-T_{\infty o})}{k({D_o}^2-{D_i}^2)} - \frac{4h_{r_i}D_i(T_{\infty i}-T)}{k({D_o}^2-{D_i}^2)} \qquad \text{Eq. [4]}$$

Where, $T_{\infty i}$= Inside Core Temperature (800°c)

$T_{\infty o}$= Outside Core Temperature (100°c)

h_{r_i}=Inside radiation Heat Transfer Coefficient ($25W/m^2K$)

h= Total Heat Transfer Coefficient ($72W/m^2K$)

D_o = Outside diameter of pressure tube (.038M.)

D_i = Inside Diameter of Pressure Tube (.036M.)

Now applying finite difference method and equate the governing equation

$$\frac{4hD_o(T-T_{\infty o})}{k(D_o{}^2-D_i{}^2)} - \frac{4h_{r_i}D_i(T_{\infty i}-T)}{k(D_o{}^2-D_i{}^2)} = \frac{T_{m+1}+T_{m-1}-2T_m}{\Delta x^2} \quad \text{Eq. [5]}$$

The tube is divided into 9 elements. Each element is assumed at uniform temperature specified by the centre node where thermocouple is fixed. So taking 9 nodes for prediction the temperature distribution of vertical pressure tube, where the values of bottommost and topmost nodes temperatures are input to the mathematical model. The values of radiative heat transfer coefficient values, referred from [8], have been presented in Table 1.

These equations are solved using MATLAB code developed, for the pressure tube wall temperatures at seven respective nodes. The developed mathematical model using Finite Difference Method can be used for higher temperatures values that are practically not feasible (e.g. above 800°C).

The mathematical model developed has been first checked for maximum temperature of heater rod = 600˚C and the pressure tube rod = 400˚C. The FDM results are compared with the experimental results obtained [8]. The results obtained from Finite Difference analysis is presented in Table 2. The data tabulated is plotted as shown in Fig. 3.

4. GENERATION OF CAD MODEL USING ANSYS

The temperature distribution of pressure tube can be evaluated by using ANSYS for different nodes. The prediction of temperature distribution is given below:

Input Data

Step 1: Select Steady State Thermal Analysis from Analysis System tool bar.

Step 2: select Engineering Data from New toolbar A,
Insert the required Input Data:
Material: Structural Steel
Thermal Conductivity: 20.5W/mK
Press, 'Update Project' and 'return to project'

Step 3: Select geometry icon and export the geometry file from saved files.

Step 4: Select Model setup and generate meshed model
Generate Mashed Model by using Free Mashed Tool

Body Name	Nodes	Elements
Solid	6198	8832

Generic Element Type Name	Mechanical APDL Name
Quadratic Hexahedron	Mesh200

Step 5: Input Analysis Parameter and boundary parameter

Step6: Generate solution Click 'temperature'; click 'generate solution'; Click 'temperature distribution'. (See Fig.4)

The average temperature values and node numbers at that elevation of pressure tube are as shown in Table 3.

The results obtained using ANSYS is as shown in Fig. 5 and 6.

The maximum and minimum percentage deviation between the results yielded using Finite Difference Method, Finite Element Method and Experiments are ±14.4 and ±2, respectively shown in fig.7. These experimental results are for the maximum limiting temperature of heater rod as 600˚C and that of pressure tube as 400˚C.

5. EVALUATION OF DEFORMATION OF PRESSURE TUBE

The above mentioned formulation shows the temperature distribution in pressure tube rod. At the same time thermal stress induced in the pressure tube due to temperature difference.
Now same CAD Model applied for analysis of deformation using ANSYS. The effect of temperature over the pressure tube of nuclear reactor can be shown by the deformation and stresses induced on pressure tube.

Step7: Transfer solution Data into Static Structural Analysis. (See fig. 8).
Step8: Input Analysis Parameter and Boundary Condition
Apply Fixed support at both the face end (See fig.9)

Step9: generate solution
Click to deformation and solve the CAD model (See fig.10)

6. CONCLUSIONS

Finite difference method is proved to be an accurate and easy tool for analysing the actual situations of the nuclear reactor. The percentage deviation created between the experimental results and the predicted values may be due to the assumption made in the analysis and larger uncertainty in choosing values of heat transfer coefficients. The conclusions obtained from the present study are listed as follow.

1. The axial temperature distribution is observed in the pressure tube, where temperature is increasing towards the top end. This temperature distribution may be attributed to the natural convection occurring inside and outside the pressure tube. The similar temperature distribution is predicted using FDM and ANSYS analysis.
2. The mathematical model developed using FDM can be used to predict surface temperature distribution of pressure tube for higher temperature ranges also, which is experimentally not feasible.
3. ANSYS software is also a good tool, to analyse the entire situation, thereby analyzing and generating the solution at radial and azimuthal direction by generating nodes and elements. It's able to evaluate the exact solution at user defined location by refinement and sizing of meshed body, with a good accuracy.
4. The surface temperatures could be obtained only at the locations where thermocouples are fixed. ANSYS has been proven a suitable tool for predicting temperatures at all the nodes meshed in the pressure tubings. It is also seen that almost the same temperatures values have been predicted for one particular elevation which looks fundamentally correct since there is uniformity in boundary conditions of the pressure tube.

Table 1 Values of inside radiative heat transfer coefficient, h_{r_i}

Node	1	2	3	4	5	6	7	8	9
h_{r_i} **(W/m^{2}K)**	32	44.16	55.2	70.27	78.2	82.9	89.04	92.04	96.43
h **(W/m^{2}K)**	97	95	85	75	70	65	60	55	52

Table 2 Experimental values of pressure tube

Distance from bottom, z (cm)	0.0	12.5	25	37.5	50.0	62.5	75	87.5	100
PT Temperature (F. D. M.) (˚C)	150	225	245	267	278	286	296	303	400

Table 3 Arithmetic Average of Surface Temperatures at that particular elevation (Using ANSYS)

Distance from bottom, z (cm)	0.0	12.5	25	37.5	50.0	62.5	75	87.5	100
PT Temperature (F. D. M.) (˚C)	150	181.23	212.49	243.73	274.99	306.2	337.48	368.73	400

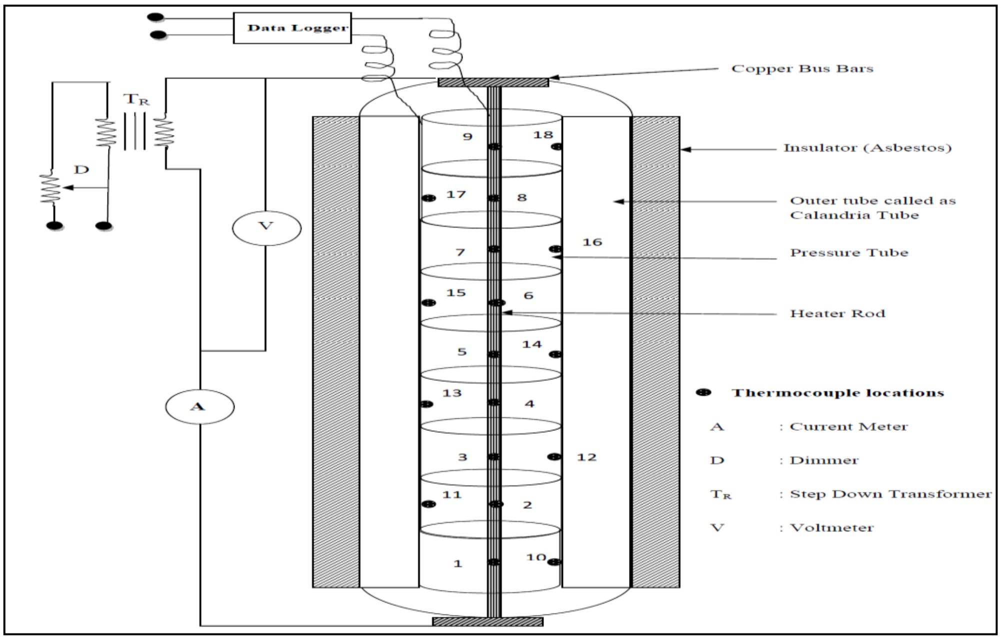

Fig. 1 Schematic diagram of single rod set up

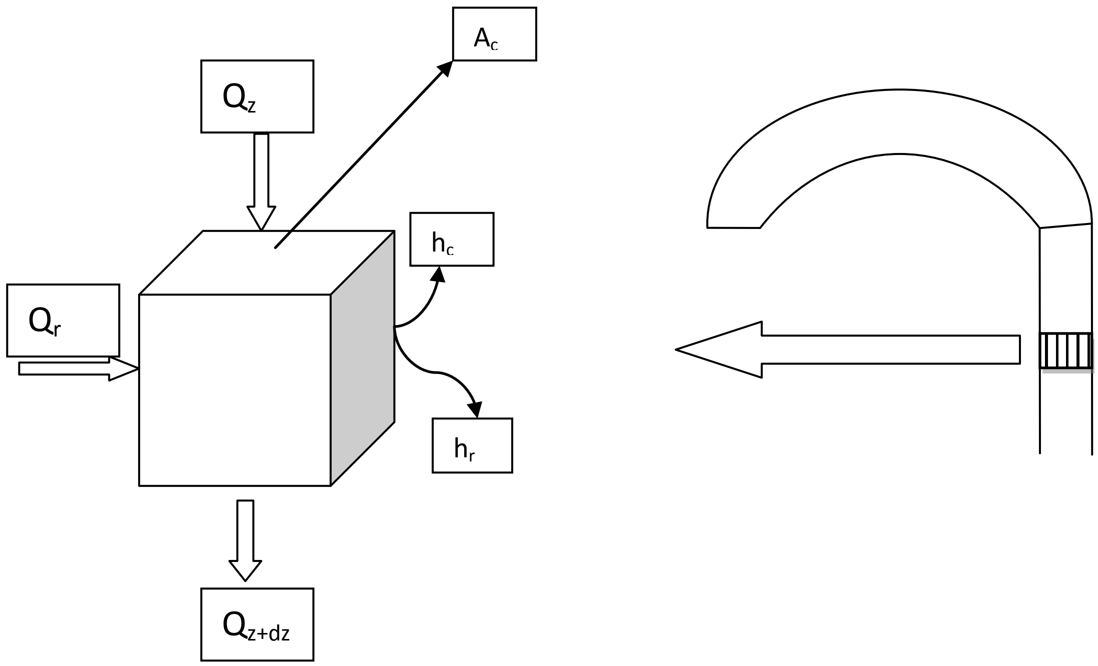

Fig. 2 Physical representation of the differential element of the pressure tube

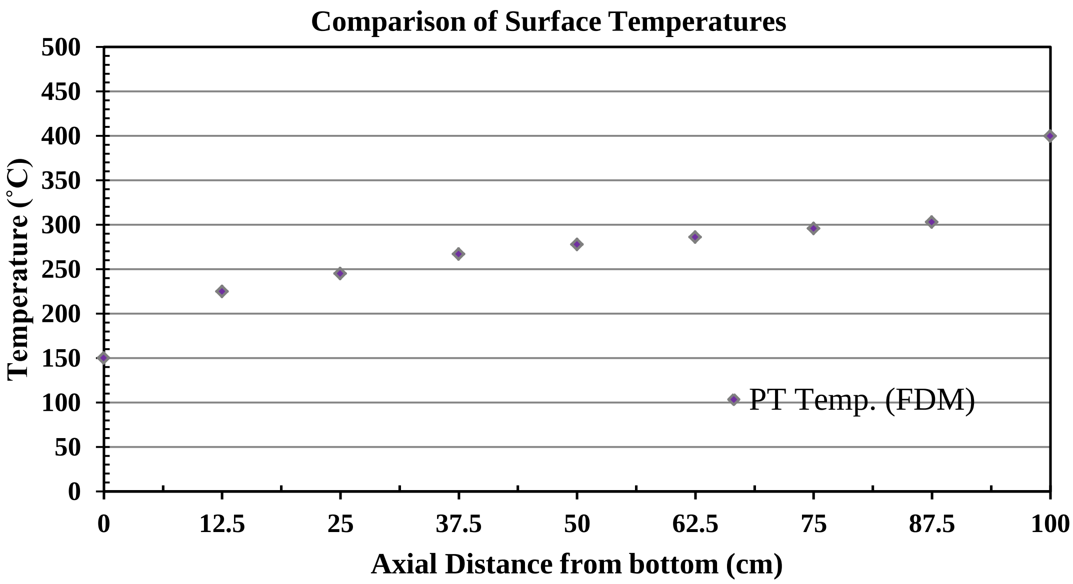

Fig. 3 Surface Temperature Distribution of pressure Tube for end temperatures; 150°C and 400°C

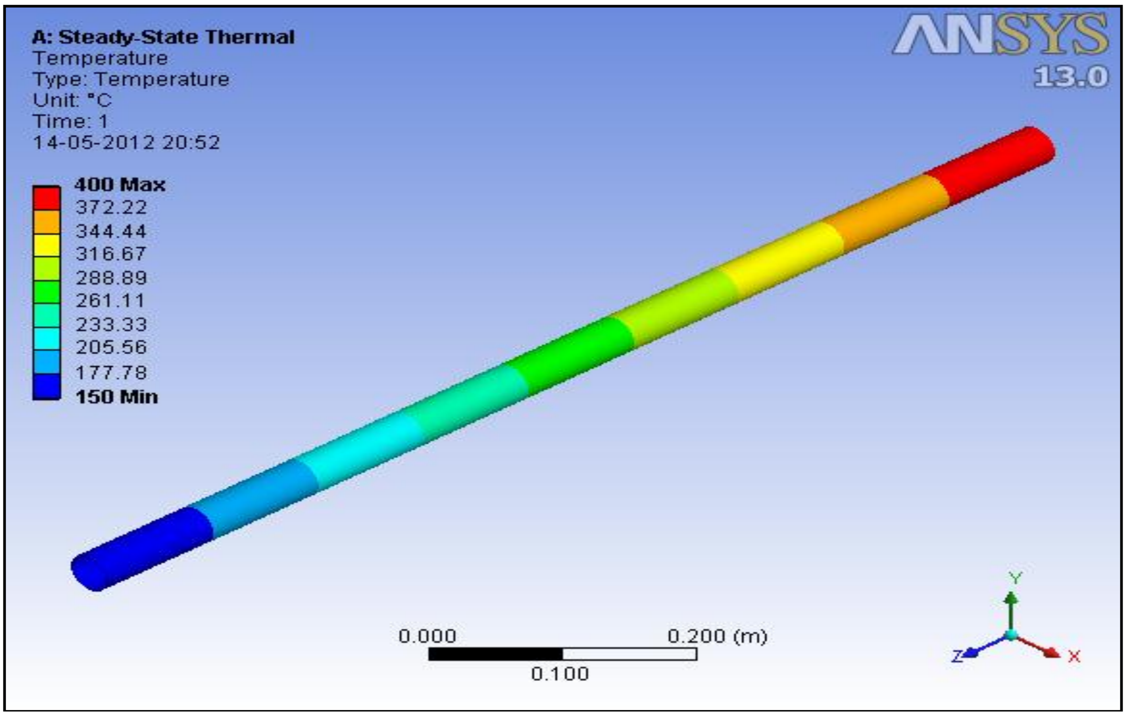

Fig. 4 Surface Temperature Distribution of pressure Tube at 400˚C Using ANSYS

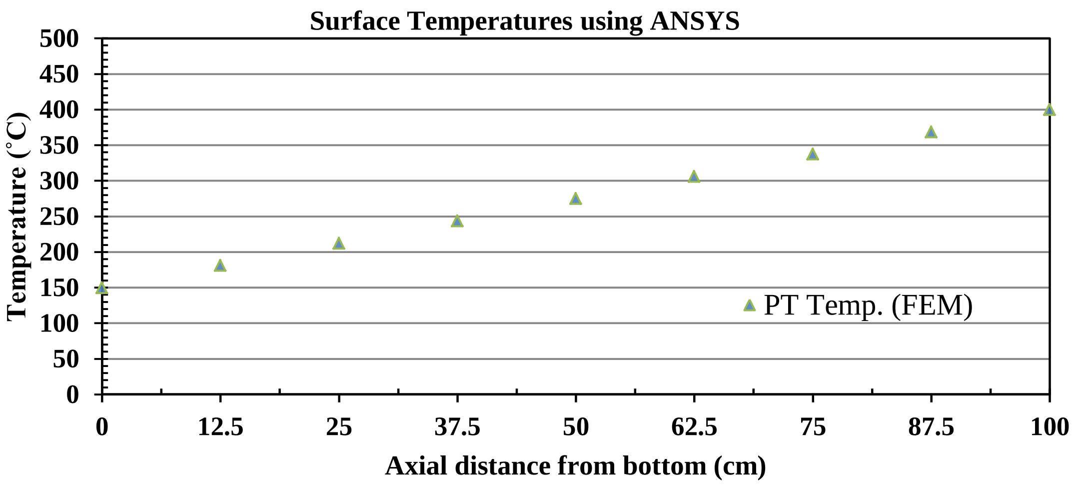

Fig.5 surface temperatures obtained using ANSYS

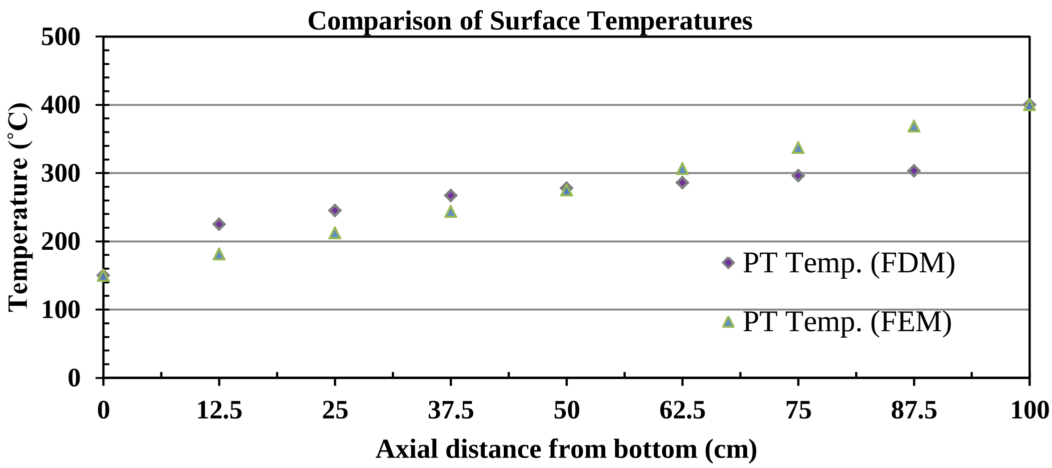

Fig.6 Comparison of surface temperatures obtained using FDM, ANSYS

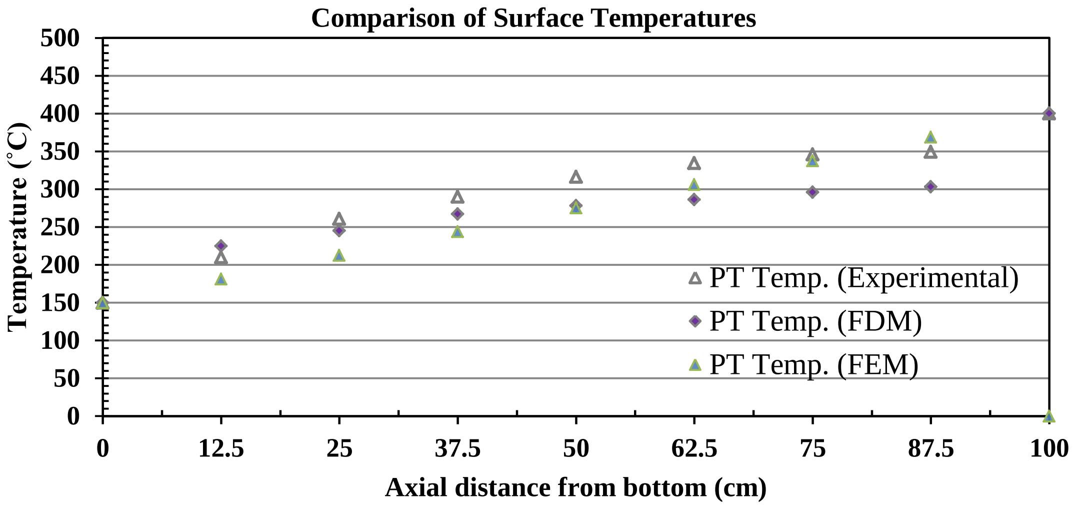

Fig. 7 Comparison of surface temperatures obtained using FDM, ANSYS and Experimental Runs [8]

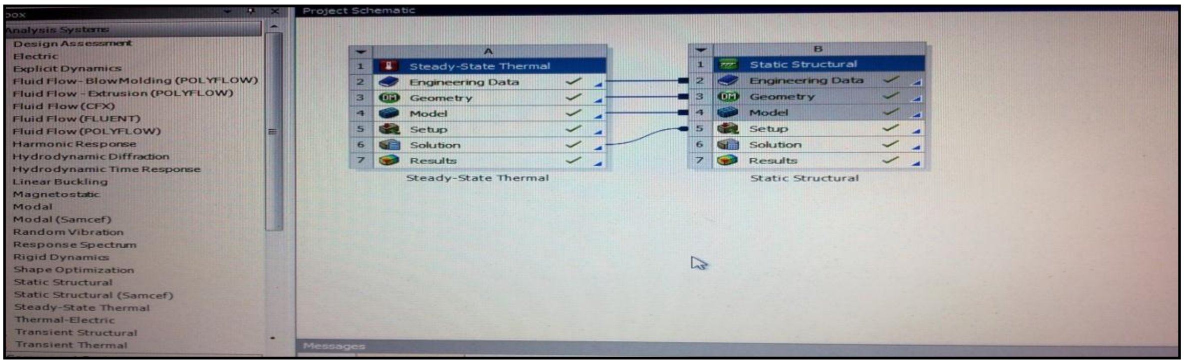

Fig.8 Formulation of static structural analysis (ANSYS)

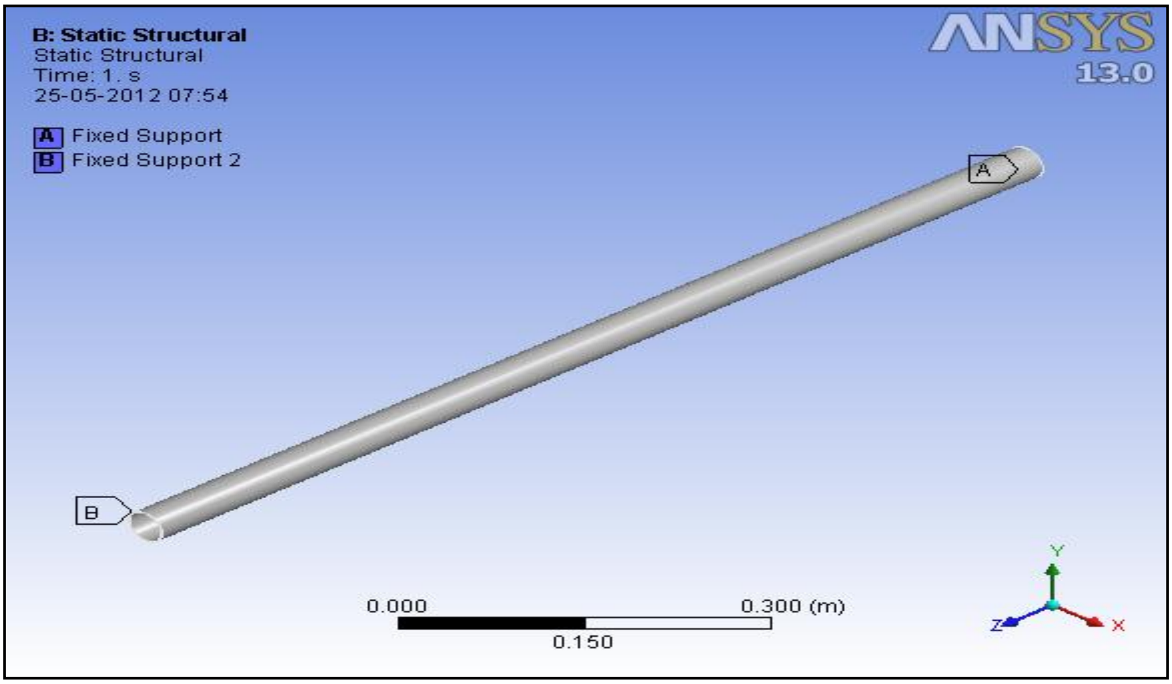

Fig. 9 Boundary condition used for pressure tube

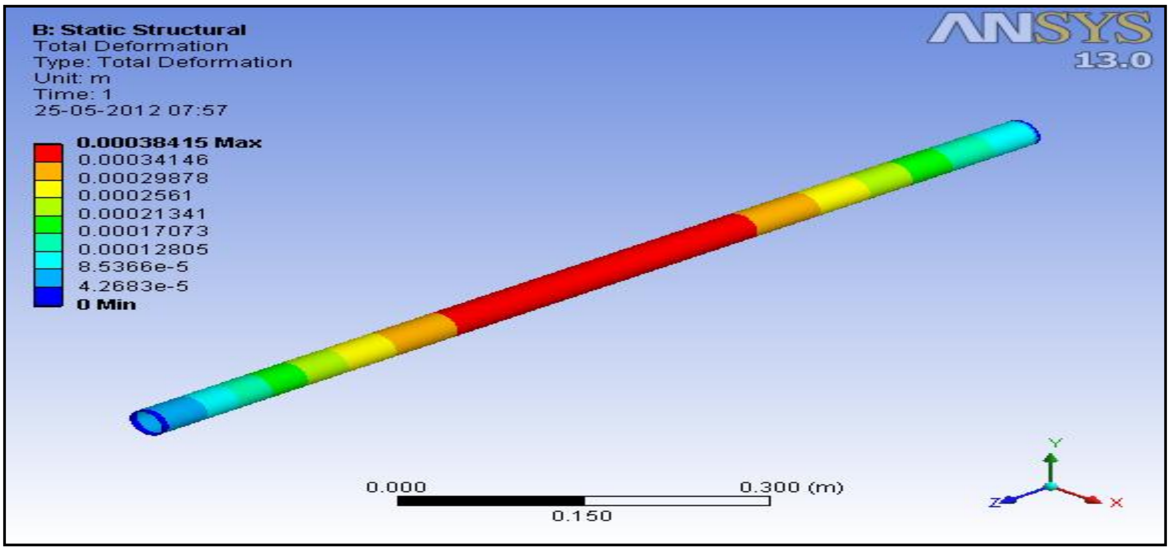

Fig. 10 Deformation of pressure tube for temperature distribution from 150˚C to 400˚C

7. ACKNOWLEDGMENTS

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