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Estimation of Steady State Heat Transfer in Hollow Sectioned Curved Pipe

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Abstract: Present work determines the rate of heat flow from a cylindrical member which is curved. Following element is modelled and analyzed using computational analysis software ANSYS CFX and the results are compared with the conventional equations. A study is conducted by considering various materials to obtain optimum material selection to enhance the better flow of heat from the system.

Keywords: ANSYS CFX, DOT NET, heat transfer, steady state, thermal analysis.

Introduction

Overhead pipelines are widely used in industries as well as household purposes. Pipelines systems are complex in nature because of the variability of the outside temperature and the determination of the thermal and heat transfer is a tedious task. Design of the pipe may be of utmost challenge because of the non-linearity. The amount of the mass flow rate inside the pipe influence the convective heat transfer and the material which is selected cause the conduction heat transfer. The surrounding temperature around the pipe leads to convection. Conduction heat transfer takes place within the material and the convective heat transfer is from one medium to the other. Therefore selection of the conduction and convection equations is important for deducing the overall heat transfer [3].

Present Paper is based on the heat transfer theory which considers theoretical model which is programmed in DOT NET software, and the solution which is obtained is validated using finite element analysis software [3]. The entire element is modeled and the overall heat transfer is determined. The software which is used can assess the heat loss with acceptable accuracy and improve the computing efficiency significantly. It is thus a useful tool for engineers and pipe network designers

In the present case mild steel is selected as a material which transmits the heat. A curved member with circular cross section is considered and the fluid flowing inside the tube is steam with its known film coefficient. The amount of heat transfer takes place is based on the second law of thermodynamics which says the heat always flow from the higher to the lower potential. Similarly, the steam which is flowing inside the tube will be of higher temperature is a high temperature reservoir, and heat flows from pipe by convection or outside temperature is a low temperature reservoir. The heat flows within the material is conduction and finally heat transfer from the material to the surroundings is the convection.

Boundary conditions are specified when the various modes of heat transfer is considered. Low carbon steel with a thermal conductivity 50 W/mk is taken. The steam which is flowing inside the cylindrical element has a heat transfer coefficient of 14.2 W/m^{2}k and the element which is exposed to the air has a film coefficient of 7.9 W/m^{2}k. The magnitude and the direction of the heat transfer are deduced with the simulation and numerical approach. Inside temperature of the pipe in which the fluid is flowing is at a temperature on 120^{0}C and the ambient temperature is 30^{0}C.

The following element is modelled, meshed and analyzed in software ANSYS CFX and the results and compared [1, 8]. Finite element approach provides the solution at every node of consideration. The present problem was structured as a sequence of fundamental problems built on simple models that determine structural property of the element under study. The models proceed from the simple toward the complex [7]. The objective is to uncover the most fundamental optimization principles (or design trade-offs) that can be put to practical use in real applications. The method of analysis and optimization is the combination of Thermal analysis & structures which is used subsequently in many engineering applications [3].

Literature Review

Xiaowei Zhu, Hui Tang et.al [1] In this paper, analysis is conducted in both theoretical and numerical aspects on the heat transfer in a pipeline system using MATLAB-based software for the evaluation of heat loss within the pipeline system and Validation of the software via three-dimensional computational fluid dynamics (CFD) simulations using ANSYS FLUENT. Sampath S S et.al [3] investigated the various stresses in a spherical pressure vessel which are subjected to pressure. Thermal analysis is carried out to determine the deformations at various points. An improvement in the performance is achieved by using the computational analysis software ANSYS CFX and the comparative tool DOT NET software. Rarularasan et.al [4] carried out a thermal analysis inside a engine cylinder, he determined the temperature distribution and suggested the method to improve the heat transfer. G. Babu et.al [5] analyzed the thermal properties by varying geometry, material and thickness of cylinder fins. Parametric models of cylinder with fins have been developed and predicted the transient thermal behavior. The models are created by varying the geometry, rectangular, circular and curved shaped fins and also by varying thickness of the fins. The 3D modeling software used is Pro/Engineer. The analysis is done using ANSYS. Mishra A.K et.al [6] investigated a finned metal cylinder using CFD and is validated against the experiments. A transient numerical analysis is carried out with wall cylinder temperature of 423 K initially and the heat release from the cylinder is analyzed for zero wind velocity. The heat release from the cylinder which is calculated numerically is validated with the experimental results.

Methodology

Since the heat transfer takes from different modes that are conduction and convection, governing equations of heat transfer between the elements are applied. Below equation (1) represents the heat transfer which takes place during conduction derived by the Fourier, and equation (2) represents the heat transfer during conduction which is by Newton's law of cooling [2,3]. The heat transmitted from inside the cylinder to the outside is given by the equation (3), it considers both the modes of heat transfer.

Fourier's Law of conduction

$Q = - K A_c dt/dx$............ (1)

Newton's Law of cooling

$Q = h A_s (t_s - t_a)$........... (2)

Heat transfer rates based on different modes

$$Q = \frac{2\pi(t_i - t_a)}{\left[\frac{1}{h_i r_1} + \frac{\ln(\frac{r2}{r1})}{k} + \frac{1}{h_o r_2}\right]} \qquad \text{............ (3)}$$

Modelling and Analysis

It involves in the modelling of the curved hollow cylindrical member and the corresponding simulation is carried out using analysis software [1]. The convection and the conduction parameters are considered and thermal analysis is achieved. The heat flows from inside surface to the outside which approves the second law of thermodynamics. The temperature distribution will be observed over the element due to the different modes of heat transfer. Different material can be chosen accordingly by changing the thermal conductivity of the material. The meshed model of the element is shown in figure 1.

Fig1: Meshing of the element

Following element is modelled and it is meshed using ANSYS software [1, 3]. Meshing is discretizing of an element into finite number of parts and each element is considered and solved separately. Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric domain. The term "grid generation" is often used interchangeably. Typical uses are for rendering to a computer screen or for physical simulation such as finite element analysis or computational fluid dynamics [4]. After this step a thermal steady state simulation is performed. By using ANSYS numerical simulation tool, whole analysis of entire assembly is performed. Present simulations adopt realistic boundary conditions by considering various different materials with different thermal conductivities [3].

As an important boundary condition is the radiation property of the mild steel. But due to the high film coefficient, the part of the heat flow caused by radiation is neglected in this work. Modelling and Meshing is done using finite element analysis (FEA) and the simulation is performed. By means of the numerical solution, a steady state analysis of the entire heating element is achieved. Validation of the results obtained in the FEA is carried out using dot net frame work software [3].

DOT NET provides user interface, data access, database connectivity, cryptography, web application development, numeric algorithms, and network communications. Governing equations are fed and the results are obtained. Classical equations parameters are varied accordingly and the output relating to this are compared with the numerical method [3].

Results and Discussion

Analysis is carried out with the application of boundary conditions by defining the thermal parameters. Coefficient of convection and the thermal conductivity is defined at appropriate points of the element. Figure 2 shows the model with the application of conduction and convection parameters.

Fig 2: Application of Boundary conditions (Conduction and Convection)

Figure 3 shows the analysis of curved element after the application of the conditions. It is clear that the temperature drops from the inside of the pipe to the outside, since it is exposed to the ambient temperature.

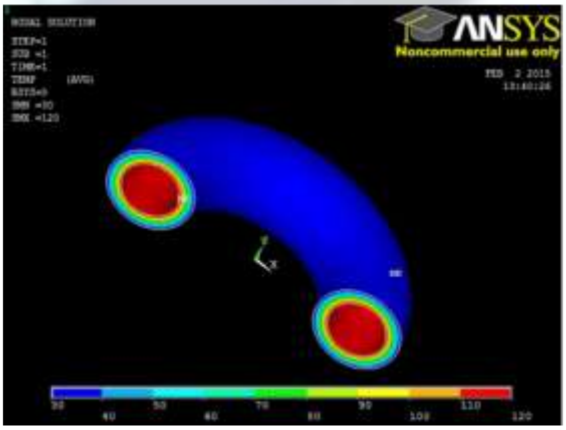

Fig 3: Temperature distribution from inside to outside of pipe

Figure 4 represents the thermal flux along the x direction, Heat flux or thermal flux is the rate of heat energy transfer through a given surface, per unit surface.

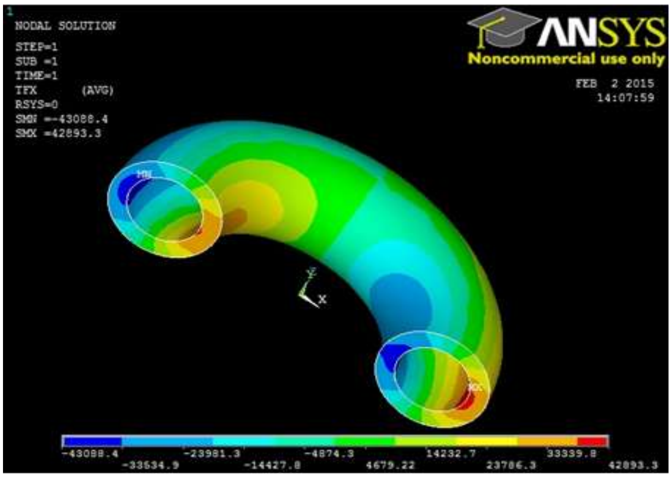

Fig 4: Thermal flux along X direction

Table 1: Temperature variation with the wall thickness using classical and FEA approaches

Thickness (m)	Temperature distribution using classical method (^{0}C)	Temperature distribution using FEA (^{0}C)
0.25	120.00	120.00
0.26	118.94	119.01
0.28	105.77	108.64
0.30	90.54	94.92
0.32	85.38	86.43
0.32	70.64	71.03
0.34	50.45	52.41
0.36	44.38	45.76
0.375	30.00	30.00

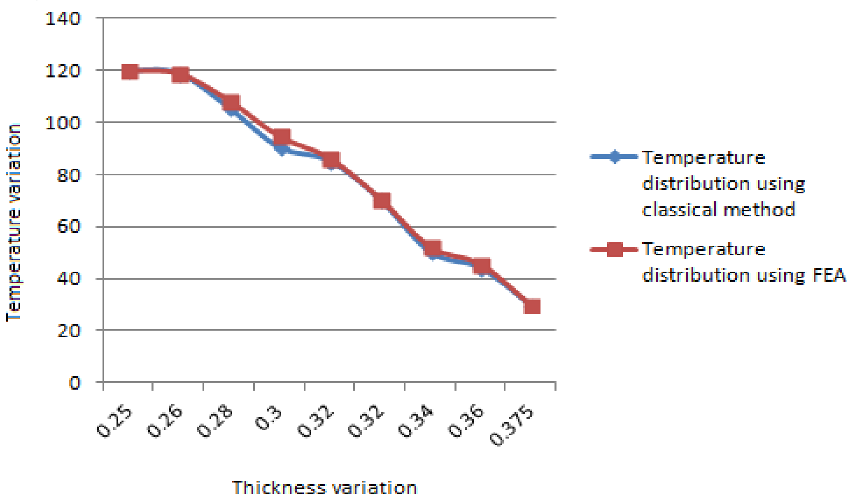

Fig 5: Variation of temperature with the wall thickness

Table 1 and figure 5 infer that the temperature go on decreasing from the inner to the outer surface. It is due to the various thermal parameters which is defined. Heat thus flows from inside to the outside satisfying the law of thermodynamics. It is also observed that the temperature variation in both classical and FEA technique is almost similar. Overall heat transfer from the hollow sectioned curved member is 914.8 W.

Table 2: Variation of thermal conductivity with heat transfer rate

Conductivity (W/m^0C)	Heat transfer rate (W)
10	869.30
20	897.23
30	906.94
40	911.88
50	914.80
60	916.87
70	918.30
80	919.38
90	920.22
100	920.90

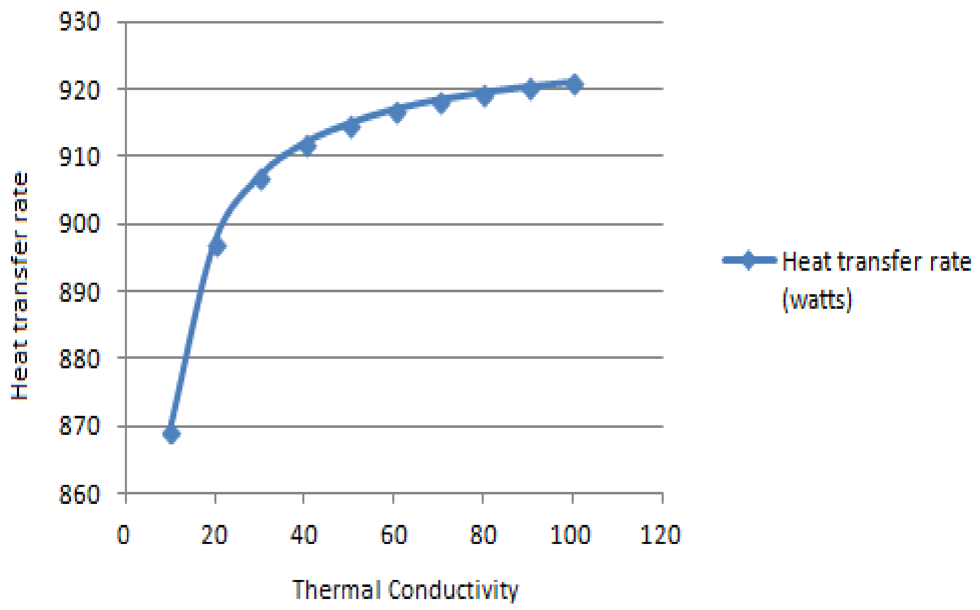

Fig 6: Change in heat transfer rate with the change in thermal conductivity

Table 2 shows the change in heat transfer with the change in thermal conductivity. Figure 6 shows that there is a increase in heat dissipation with the rise in the thermal conductivity. Change in the thermal conductivity is the indication of change in the material which enhances better heat transfer with the existing film coefficients [3].

Table 3: Variation of external temperature with heat transfer rate

External Temperature (^0C)	Heat transfer rate (W)
10	1111
15	1060.5
20	1010
25	959.5
30	909
35	858.5
40	808
45	757.5
50	707
55	656.5

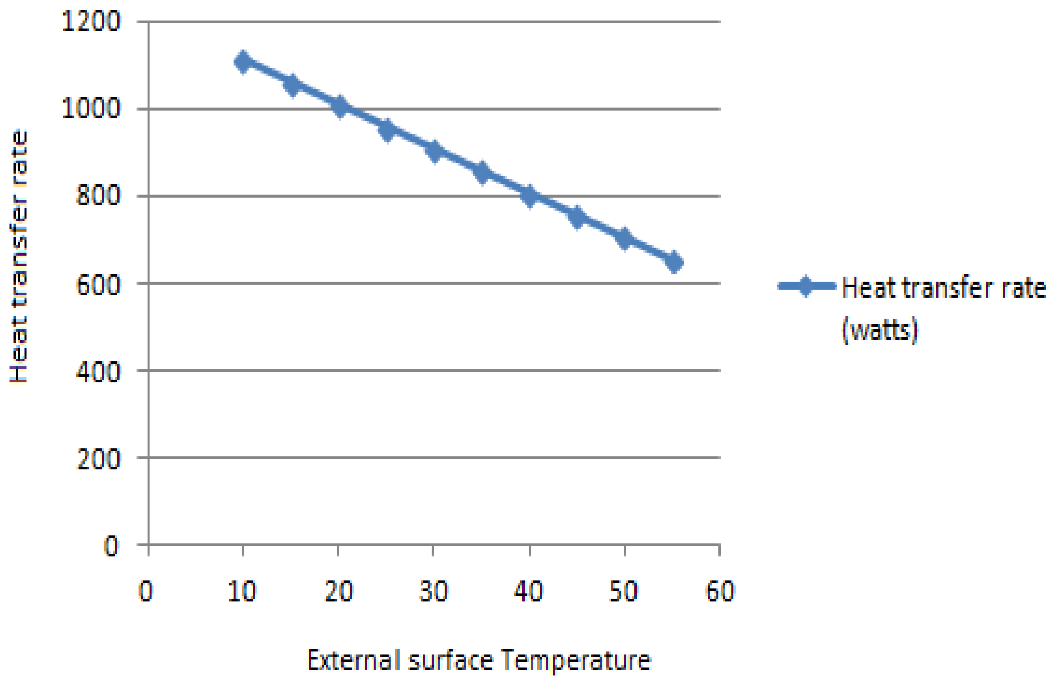

Fig 7: Change in the heat transfer rate with the change in external temperature

Figure 7 shows the variation of heat transfer rate with the change in the external temperature. Graph which is shown varies linearly from the minimum to the maximum temperature taken into account.

Table 4: Variation of heat transfer rate when the pipe is in contact with different fluids

External Convective coefficient ($W/m^{20}C$)	Heat transfer rate (W)
2	348.75
4	592.27
6	771.93
7	845.19
10	1019.31
12	1108.08
14	1181.58
16	1243.45
18	1296.23
20	1341.80

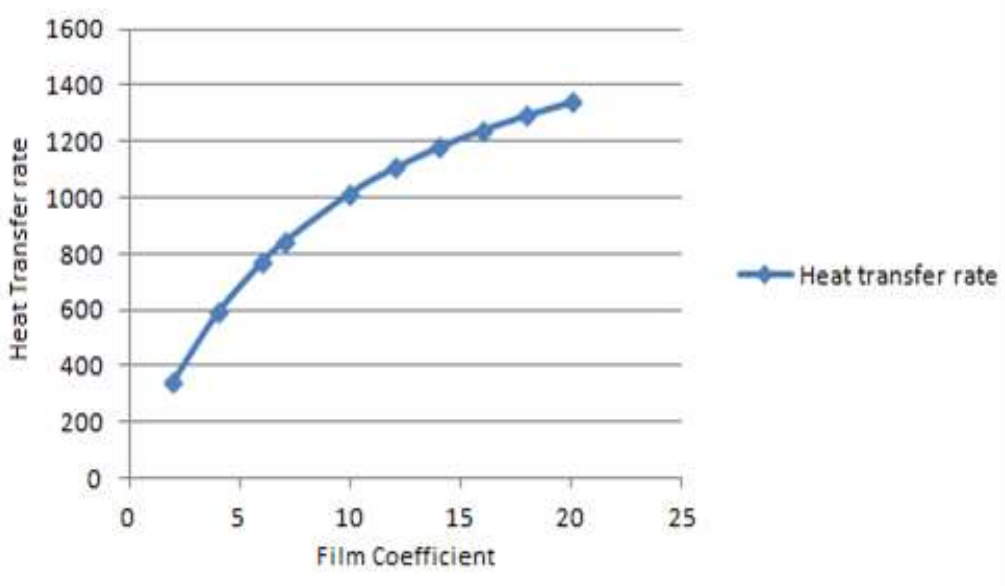

Fig 8: Change in the heat transfer rate with the change in external convective coefficient

Table 4 and figure 8 infer that as there is rise in the heat transfer coefficient there is an increase in heat transfer rate. In other words, when the element is exposed to different fluids there will be a definite change in the heat transfer rate [3]. Results obtained in the figure 6, 7 and 8 are similar to the results obtained in [3]. Hence results are validated.

Conclusions

In the present analysis, a hollow section acted with conduction and convection parameters is studied and the temperature at various points is investigated which enhances better heat transfer from the system . The hollow curved pipe which circulates steam within when it is comes in contact with the external fluid will transfer or receive energy. The transfer of energy will also depend on the type of material used. An attempt is made to demonstrate the improvements to enhance the maximum heat dissipation from the system using FEA technique and the validation of this is carried out by using computer software Dot Net. By increasing the value of thermal conductivity and film coefficient it is possible to increase the heat dissipation rate. Also it is clear from the graph that with the rise in external temperature there will be a drop in heat transfer rate. Fins can be provided which may enhance the heat transfer rate also with the consideration of dimensionless numbers heat transfer calculations can be carried out. Transient analysis can be done for the same case.

Nomenclature

Q= Heat Transfer rate, W
A_c= Cross-Sectional Area, m^2
k= Thermal Conductivity of the material, W/m^0C
h= Heat transfer coefficient, $W/m^{20}C$
t= Temperature, ^0C
A_s= Surface Area, m2
t_s= Surface Temperature, ^0C
t_i= Internal Temperature, ^0C
t_a= Ambient Temperature, ^0C
L=Length of the element, m
dt/dx= Temperature gradient, $^0C/m$
r_1=inner radius of pipe, m
r_2=outer radius of pipe, m

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