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Heat Swapping Analysis for a Finned Heat Pipe Using CFD

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ABSTRACT
The present study is carried out on a concentric heat pipe by intriguing the geometries of the pipe considered. The fin configurations are placed about the circumference of the tube in 2D manner. The numerical and simulation analysis are evaluated for the geometry using the computational dynamics tool. The main grail of the work is to increase the heat swapping behavior by modifying the geometry thereby increasing the effectiveness of the pipe. The geometries are evaluated in terms of velocity, pressure and temperature lineation in order to calculate for the heat swapping behavior. The results depicted that the maximum amount of heat swapping can be observed in model – M3. The outlet values with regard to the temperature lineation are found to be in considerable correlation with the regression data generated.

Keywords: *Fins, Heat pipe, Lineation, Heat Swapping, Fin extensions*

INTRODUCTION
Heat exchangers are the equipment used to transport the fluid from high temperature to lower temperature without direct contact. They are found in every industry as the key component for the transportation of the fluid without loss in terms of the volume thereby increasing the heat transfer rate between the considered geometry and the fluid. The operational principle for the conception and evaluation of the geometry is to determine the sensitivity of the heat swapping behavior and between the considered fluid and the surface of the pipe.

Stephenraj. V et al.[1] have studied the flow in plain tube, angular tube, stepped tube & combined angular and stepped tube. Among the combined angular and stepped tube has shown the maximum temperature difference between inlet and outlet. Heidar Sadeghzadeh et al.[2] have studied the heat transfer rate in a finned shell and tube type heat exchanger and concluded that the fins on the walls of the tube increases the heat transfer rate. L. Prabhu et al.[3] designed and analyzed the heat transfer through Straight fin with uniform cross sections, Straight fin with non-uniform cross sections, Annular fin and Pin fin with non-uniform cross section. Among, the heat transfer from a rectangular configuration fin is higher when compared to other configurations. Pardeep Singh et al.[4] designed and analyzed the heat transfer through fins with rectangular, trapezium, circular and triangular extensions. The fins with extensions enhances the heat transfer by 5% to 13% when compared to the plain fins. Among the extensions , Rectangular extensions gives highest heat transfer rate. Chirag Maradiya et al.[5] conducted experimental investigation on conical tube heat exchanger. The heat transfer rate and overall heat transfer increases with decrease in diameter ratio of a conical tube. Mehran Ahmadi et al.[6] studied the flow in heat sinks with interruptions. The rectangular extensions increase the heat transfer rate by interrupting the thermal and hydrodynamic boundary layers. Hamed Sadighi Dizaji et al.[7] have studied the heat transfer from a corrugated tube. The convex corrugation tube has given the best results compared to concave corrugated tube.

Heat swapping plays a major role in terms of the transportation of the required fluid medium wherever needed. So, the heat exchangers themselves are applied as a key component in every industry. The grail of the discussed work is to conceptualize and evaluate an appropriate model which contribute to the maximum amount of heat between the two models.

PROCEDURE :
A 2 – Dimensional conception of the assumed pipe geometry is designed in a cross sectional view. The total length of the pipe is 600mm with deviations for the stepped nature as 140mm, 140mm and 120mm; with a step length of 100mm twice. The diameter is a reducing instinct from 40mm at the starting to 28mm at the end of the pipe. The different models considered are indicated in the table – 1.

Table. 1 : Description for the models considered

Model Name	Description
M2	Heat pipe with plain geometry
M2	Heat pipe with single finned geometry
M3	Heat pipe with double finned geometry

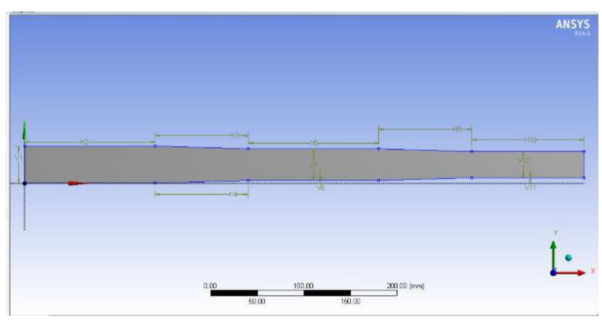

Fig 1 : 2D geometry of the plain heat pipe

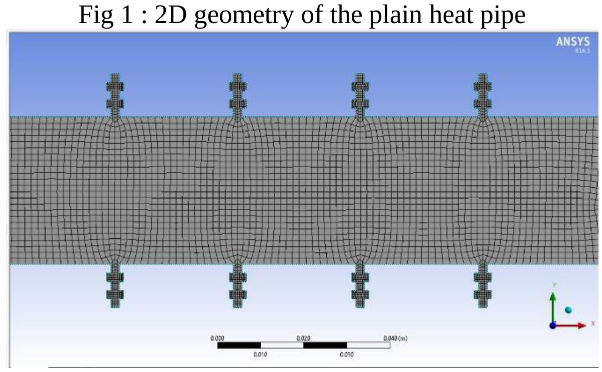

Fig 2 : Meshed geometry of the model – M3

STRATEGIES AND CONDITIONS :

The geometries are applied with principles such as the continuity principle, Bernoulli's principle and equations such as energy equation, kappa – epsilon equation. The calculation and evaluation are termed as follows:

- Continuity Equation

The constitute of the fluid entering the intended profile must be same as the constitute of the fluid leaving the profile.

$m_1 = m_2$ (1)

$\frac{dm1}{dt} = \frac{dm2}{dt}$ (2)

$\rho_1 A_1 U_1 = \rho_2 A_2 U_2$ (3)

$A_1 V_1 = A_2 V_2$ (4)

- Momentum Equation

The rate at which the momentum of a fluid particle changes, must be equal to the forces acting along the flow stream

F = mass × acceleration

Now,

Consider a functional sample from the depicted fluid flow

Let,

dA = cross sectional area of considered functional fluid sample

dL = length of the functional fluid element

dW = weight of the functional fluid element u = velocity of the functional fluid element

p = pressure of the functional fluid element

Assume that the fluid is steady, non-viscous, and incompressible so that the frictional losses are zero and the density of the fluid is constant.

The different forces acting on the fluid are,

a. Pressure force acting in the direction of the flow (PdA)

b. Pressure force acting in the opposite direction of the flow [(P+dP)dA]

c. Gravity force acting in the opposite direction of the force (dWsin θ).

Therefore,

Total force = gravity force + pressure force

The pressure force is considered in the direction of low

$F_p = P\,dA - (P + dP)dA$ (5)

The gravity force considered in the direction of flow

$F_g = -dw\,sin\theta$ (6)

$[W = mg = \rho\,dA\,dL\,g]$

$= -\rho g\,dA\,dL\,sin\theta$ (7)

$sin\theta = \frac{dZ}{dL}$

$= -\rho g\,dA\,dZ$ (8)

The net force is considered in the direction of flow

$F = m\,a$

$m = \rho\,dA\,dL = \rho\,dA\,dL\,a$ (9)

We have

$\rho\,dA\,dU = -dP\,dA - \rho\,g\,dA\,dZ$ (10)

{÷ ρ dA }

$\frac{dP}{\rho} + u\,dU + dZ\,g = 0$ (11)

(Euler's equation of motion)

On integrating the Euler's equation, we get the Bernoulli's equation

$\int \frac{dP}{\rho} + \int U\,dU + \int dZ\,g = constant$ (12)

$\frac{P}{\rho} + \frac{U_2}{2} + Zg = constant$ (13)

$\frac{\Delta P}{\rho} + \frac{\Delta U_2}{2} + \Delta Z\,g = 0$ (14)

(Bernoulli's equation)

(a) Kappa – epsilon model: the k-epsilon model of the energy equation is generally used to analyze the turbulent flow. The final equations for the turbulent flow analysis are

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial t}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + p_k + p_b\,\rho\epsilon\,\gamma_k + s_k$$

$$\frac{\partial}{\partial t}(\rho \epsilon) + \frac{\partial(2)}{\partial t}(\rho \epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_1\frac{\epsilon}{k}(p_k + C_3\,p_b) - C_2\rho\frac{\epsilon^2}{k} + s_k$$

RESULTS

The intended grail of the work is to obtain effective heat swapping values for the considered models by intriguing and altering the geometry of the plain heat pipe. The concepted models are analyzed for the temperature lineation using the ANSYS – FLUENT software. The energy equation and the Bernoulli's equation are applied to the concepted models. The inlet is provided with a mass flow rate of 0.142Kg/Sec and an inlet temperature of 30oC. The outlet is evaluated to be in terms of outflow with regard to the temperature lineation.

The fins when attached to the geometry of the heat pipe, contributes for the accumulation of the fluid at the corners. The addition of the fins along the circumference of the pipe provides an increase in the threshold of the fluid thereby contributing for the increase in the heat swapping behavior of the heat pipe considered.

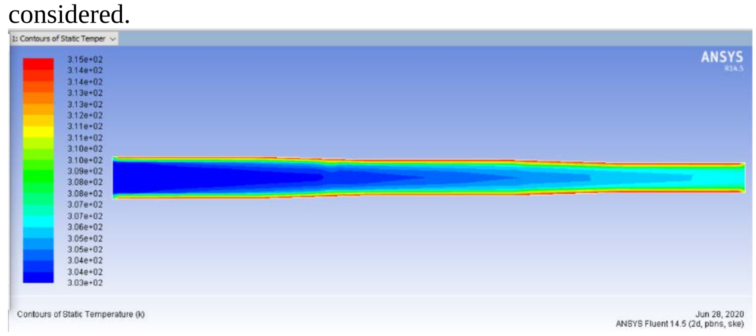

Fig 3 : Temperature lineation for model – M1

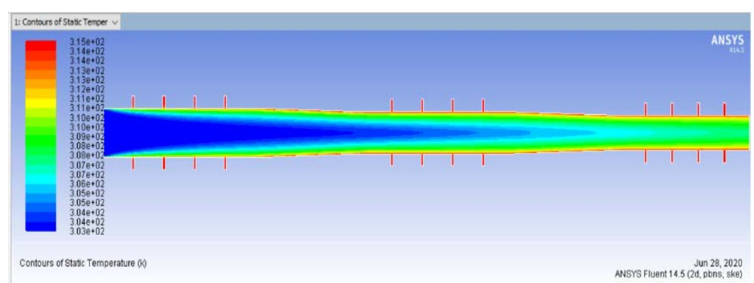

Fig 4 : Temperature lineation for the model – M2

The models considered when attached with the fins depicted the lineation as displayed in the figures fig.3 – fig.7. On considering the applied principles and generated results, the model – M3 has been found to be the best model with an increase in the heat swapping behaviour. The model – M3 was observed to reach optimum values by transferring maximum amount of heat of 1.84% between the fluid and the surface of the considered geometry of the pipe.

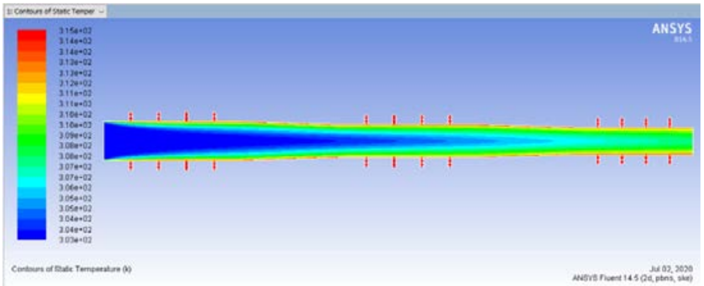

Fig 5 : Temperature lineation for the model – M3

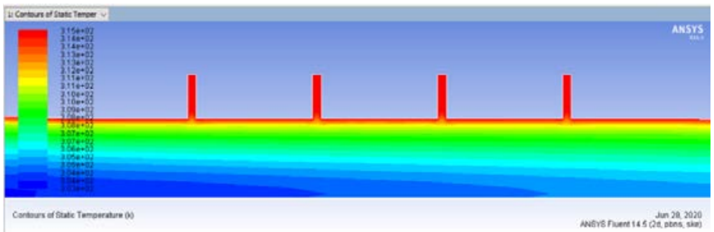

Fig 6 : Heat swapping at the fins for model – M2

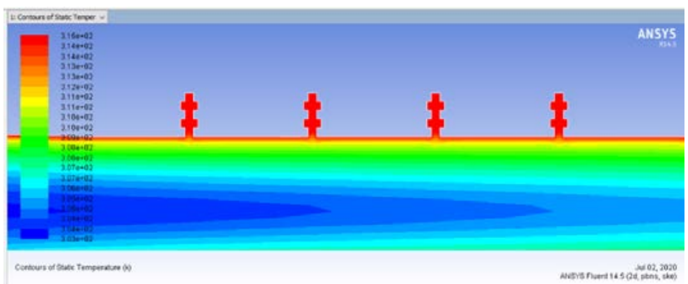

Fig 7 : Heat swapping at the fins for model – M3

Table 2 : Temperature lineation values of the considered models

Model	Outlet Temperature	
	Min Outlet Temp	Max Outlet Temp
M1	303	314.9851
M2	302.999	314.982
M3	302.999	315.0011

Table 3 : Comparison between the software and regression data

Model	Outlet Temperature	
	Software Data	Regression Data
M1	314.9851	314.9851
M2	314.982	314.9814
M3	315.0011	315.0011

Table 4: R Square details

S	0.0556612
R - Sq	98.9%
R – Sq (adj)	98.5%

The figures fig 3 – fig 5 display the heat swapping of the considered models accordingly. The figures fig 6 & fig 7 displays the heat swapping at the fins attached along the circumference of the heat pipe. As the fins are modified with two layers for each fin, the accumulation of the fluid along the corners contributed to the heat swapping. The maximum heat swapping values was found to be 12.0011K for the model – M3 with an increase of 1.84%. The values of the heat swapping lineation with regard to the outlet temperature are mentioned in the table 2. The results depicted optimum values and are in considerable correlation with the regression data generated [8 – 9].

CONCLUSION

The computational fluid dynamics were analyzed to the considered geometries which are modified by attaching various fins along the circumference of the heat pipe. The conception and evaluation of the pipe are commuted using the ANSYS – FLUENT software. The analysis is carried out to depict the optimum values of the temperature lineation. The fins arranged along the circumference of the pipe contributed to the enhancement of the heat swapping behaviour for the heat pipe. The maximum value of the heat swapping was depicted for the model – M3 with the fins arranged twice i.e. double finned geometry as it's having a larger area when compared to the other two models. The value of the heat swapping has been enhanced up to 1.84% . The final data simulated from the software found to be in good correlation with the regression data when compared.

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