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Analysis of enhancement of heat transfer in water heater with fins using CFD technique

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Abstract

In present day most of the industries and power plant preferred for fire tube boiler. From that most of the case, fire tube boiler without fins are used. So, few of them needs optimization of finparameter. In this paper, we studied, attempts were made to investigate the flow and heat transfer characteristics of finned tube by experimental and numerical simulation. The test fined tube was installed in a single smooth tube and formed a shell and tube heat exchanger. The experiment was conducted in heat transfer test system with hot electrical heater inside a tube and water in the shell side. The three dimensional computation was performed to predict the flow and heat transfer performance in a finned tube. After using numerical simulation, we have used CFD technique, optimization of finned geometry can be performed.

Keyword—*Fins, heat exchangers and passive techniques.*

1. Introduction

In recent years, the high cost of energy and material results an increased effort for producing efficient water heaters. The improvement of design techniques is relevant and important for better performance over several engineering applications. Although a number of research works have been performed to investigate the heat transfer and performance of fins, no publications relating to water heating boiler. The rate of heat transfer to water around a pipe can be greatly enhanced by the use of extended fins. The main objective in improving the performance of thermal system is to enhance heat transfer. To expand warm execution of water warming kettle, it is important and viable to utilize augmented surface, alluded to as balances, on the focal pipe, to make up for the low warmth exchange coefficient. The model finned tube comprises of equispaced balances mounted on the external surface of tube, with a specific end goal to locally expand warm exchange between the blade base territory and the encompassing liquid. Since warmth directed through blades is extremely proficient for metals, it brings about high balance surface temperature and an expansion of aggregate dynamic range.

Proper design of water heater will increase the rate of heat transfer so that the water will heat in less time with less energy consumption is the main purpose behind the design of water heater. Keeping in mind the end goal to expand the warmth exchange rate and proficiency of the water radiator, the finned tube water warmer is the one of the most ideal route rather than water warmer without balances. The glow trade coefficient is the most essential parameter for compelling blueprint. Examination and exhibiting of tube with and without equalizations is basic.

2. Objective

1. To determine optimum design specifications for water heater by means of CFD.
2. Analysis of water heater with and without fins.
3. To investigating the shape, size, introduction and dispersing of blades for ideal outline determinations of water warmer by methods for
4. To study the fluid flow characteristics of vertical positioned water heater (smooth and finned) by means of CFD.
5. To determine the heat transfer coefficient in vertical water heater (smooth and finned) by means of CFD.
6. Comparison between the Computational Fluid Dynamics (CFD) results and experimentation results.

3. Literature review

The shear-peel bond strengths and the fluoride release of four orthodontie adhesives. The adhesive groups included a composite resin control, a resin-modified glass ionomer cernent, and two polyacid-modified composite resins (Assure and Experimental). Metal sections were clung to the buccal surfaces of 240 (six gatherings of n = 40) human premolars. The fortified teeth were put away in deionizer water at 37°C for 30 days and thermo cycled for 24 hours preceding debonding.Sample disks, 10 mm diameter by 2 mm thick, were made

from each adhesive and stored in deionizer water [1].

In order to intensify the heat transfer from the heat exchanger surface to fluid, it is possible to increase convection coefficient (by growing the fluid velocity), large temperature difference between surface and fluid or intensify the surface area across which convection occurs. Extended surfaces, in the form of longitudinal or radial fins are common in applications where the need to enhance the heat transfer between a surface and an adjacent fluid exists [2].

The removal of excessive heat from system components is essential to avoid the damaging effects of burning or overheating. In this way, the upgrade of warmth exchange is a vital subject of warm designing. The warmth exchange from surfaces may when all is said in done be improved by expanding the warmth exchange coefficient between a surface and its environment, by expanding the warmth exchange zone of the surface, or by both. As a rule, the zone of heat exchange is expanded by using augmented surfaces as balances connected to dividers and surfaces. Amplified surfaces (balances) are consistently utilized as a part of warmth trading gadgets with the end goal of expanding the warmth trade between essential surface and the encompassing liquid [3].

The blade dividing, warmer information and rate of region expelled as upset score are the parameters. For few dividing, it is checked by Computational Fluid Dynamics examination and the outcomes are well coordinating.It is found that the average heat transfer coefficient for INFAs is nearly 30– 40% higher as compared with normal array [4].

The present street numbers electronic chips cooling with constrained convection of water in silicon based single small scale channel warm sinks by the assistance of a business CFD programming FLUENT. The computational space is discretized with non-uniform lattices on the stream confront however uniform matrix along the stream [5].

NTU method was applied to estimate the heat exchanger pressure drop and effectiveness. Balance pitch, balance tallness, blade balance length, cool stream length, no-stream length and hot stream length were considered as six outline parameters [6].

TheHeat exchanger design involves complex processes, including selection of geometrical parameters and operating parameters. The traditionally designed shell and- tube heat exchangers involves rating a large number of various exchanger geometries to identify those that satisfy a given heat duty and a set of geometric and operational constraints. However, this approach is time-consuming and does not assure an optimal solution. Hence the present study explores the use of a non-conventional optimization technique; called particle swarm optimization (PSO), for design streamlining of shell-and-tube heat exchangers from economic view point. Minimization of total annual cost is considered as an objective function [7].

4Theory of Heat Transfer

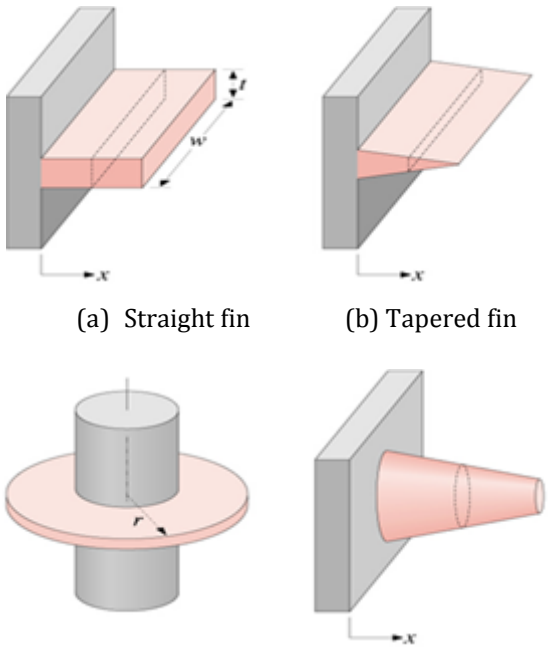
4.1 Heat transfer

Heat transfer deals with the study of different ways and estimation of the rates of energy in transit. Naturally energy always flows from a higher temperature region to a lower temperature region. There are three modes of heat transfer namely Conduction, Convection and Radiation.

4.2 Extended Surfaces (fins)

Blades or stretched out surfaces are broadly used to expand the rate of warmth exchange from the essential surface to the surrounding medium in an extensive assortment of warm gear. A precise investigation of warmth move in blades has turned out to be urgent with the developing interest of superior of warmth exchange surfaces with dynamically littler weights, volumes, introductory and running expense of the framework. Throughout the years diverse balance shapes have been advanced relying on the application and the geometry of the essential surface

Types of extended surfaces (fins):



(a) Straight fin (b) Tapered fin

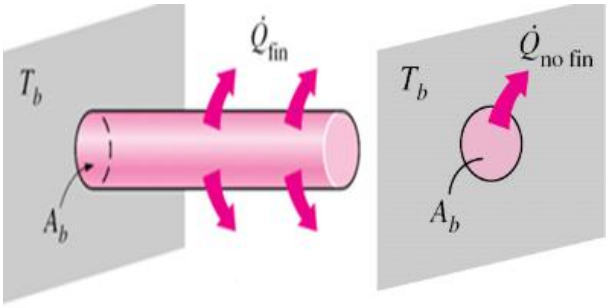
(c) Circular fin (d) Pin fin

Fig 3.1 Types of Extended Surfaces

4.3 Fin effectiveness (ε_{fin})

The effectiveness of fins is the ratio of the fin heat transfer rate to the heat transfer rate that would exist without a fin. $\boldsymbol{\varepsilon}_{fin}=(Q_{fin}/Q)$

$$\varepsilon fin = (Q\ fin / (h\ Ac\ (Tb - T0))$$



(a) Heat transfer from Fin from base area (b) Heat transfer

Fig 3.2 Heat transfer rate from fin and from base area

5 Software Simulation

5.1 Computational Domain

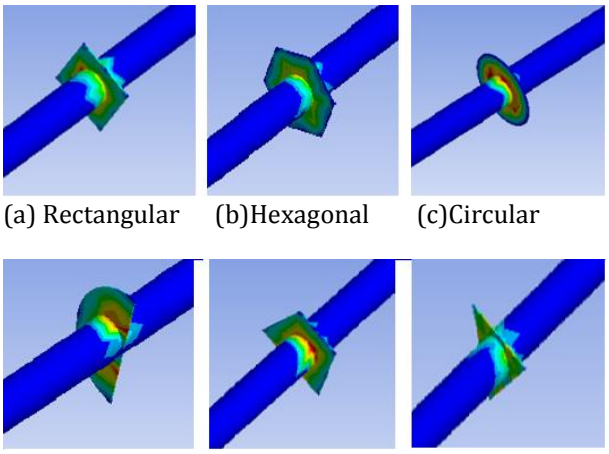
The business CFD code FLUENT is utilized to examine the model stream qualities of tube with and without blades. Displaying and work era are however performed in Gambit condition. Water will be taken as the liquid medium. Figure 5.1 demonstrates the 2-D model of water warmer with balances and without balances that involves 65mm external shell, 15mm inward radiator tube. Table 5.1 demonstrates the parameter utilized as a part of investigation of water radiator show for CFD works think about.

TABLE 5.1 Parameters for Analysis Without Fins

Tube material	Inner diameter of inner tube(mm)	Outer diameter of Inner tube(mm)
Mild Steel	30	32

5.2 Optimization of Fin Shapes

By analysing different types of fins shapes,we found that the circular fins are the most effective as compare to other shapes of the fins, thats why we select the circular fin for further analysis.



(a) Rectangular (b) Hexagonal (c) Circular

(d) Semi-circular (e) Trapezoidal (f) Traingular

Fig 5.1 Different Shapes of Fins

5.3 Geometry Creation

As mention above, in CFD generally 3D,2D analysis is carried out. If geometry is axis symmetric then in that case the geometry is smiplified into simple geometry. In our case the geometry is also axis symmetric hence conversion of geometry into simple geometry means smplification of the analysis.

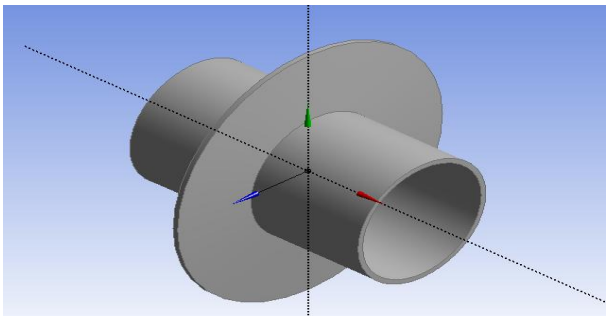


Fig 5.2 3D Diagram of Tube With Fin

For converting the geometry into two dimensional, the geometry must have symmetric about the any plane in which geometry is located. Our model geometry is satisfied this condition, which is symmetric about the X-axis as well as Y-axis also. Hence we can convert the geomerty into both axis plane, but conversion along the Y-axis is not useful in our case as our aim is to analyse the heat transfer through the fins which is mounted along the circumference of the tube, so we must have to convert the geometry into two dimensional geometry along the X-axis only. The following figure shows the extrcation of the symmetric plane along the X-axis.

5.4 Steps Used in Analysis

Before going to the meshing, one of the important step is name selection. Naming is important in the point of view giving the boundary condition in next step which is setup. In naming we assigne the sutaible name to the required location where we will going to assigne the boundary condition.

Considering the simplicity, we have given name to the different location. The name it self indicate the meaning of the location as like the tubeid means the location of internal surface of the tube,etc. After the name selection, next step is the actual meshing of the object. When we talking about the meshing, we must think about the element type, element quality and aspect ratio. For better and accurate analysis the element type must be the quard, element quality must be nearer to the zero and the aspect ratio is must be less than 18. Another one term consider in meshing which is the grid independency. The grid independency is nothig but the such a smaller element size on which further result of the analysis is dosenot depend upon the element size. In our case such element size is the 1mm. Figure 5.8 shows the mesh model of analysis setup.

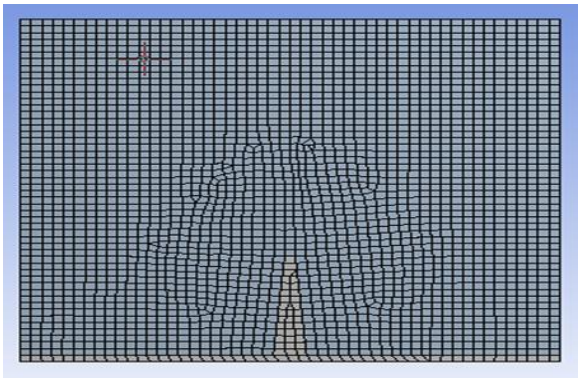


Fig 4.3 Mesh Model

6Mathematical Calculation

6.1 Statement of problem

A cylindrical heater of radius 13 mm gives constant heat is having 4 mm thickness which is surrounded by shell of radius 65 mm and 50 mm length containing water.

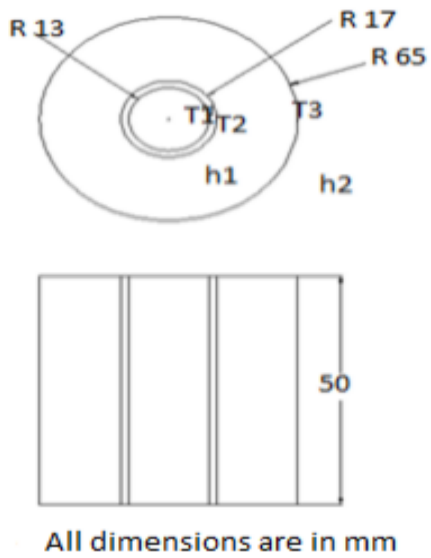


Fig 6.1 Schematic Diagram of Water Heater

6.2 Equivalent electrical circuit

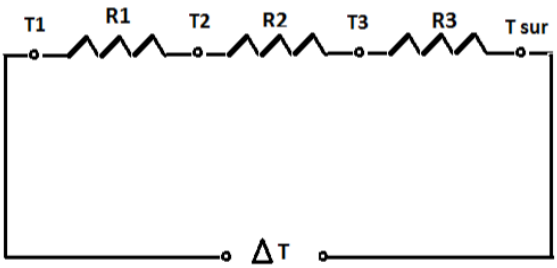


Fig 6.2 Electrical Analogy of System

6.3 Mathematical Equation

According to heat balance,

Heat input = heat output.

$$Q = \frac{\Delta T}{\sum R} = \frac{T1-T4}{\sum R} = \frac{T3-T4}{R3} = \frac{T2-T3}{R2} = \frac{T1-T2}{R1} \quad (1)$$

Where,

$$\sum R = R_1 + R_2 + R_3$$

$$\sum R = \frac{\log\left(\frac{R1}{R2}\right)}{2\pi Lka} + \frac{1}{2\pi R2Lh1} + \frac{1}{2\pi R3Lh2} \&$$

$$\sum R = \frac{\log\left(\frac{0.017}{0.013}\right)}{(2\pi*0.05*202.4)} + \frac{1}{(2\pi*0.017*0.05)h1} + \frac{1}{(2\pi*0.065*0.05*19.5)}$$

$$\sum R = 4.2189e\text{-}3 + \frac{1}{(2\pi*0.017*0.05)h1} + 2.5112 \quad \&$$

$$\sum R = 4.2189e\text{-}3 + \frac{187.2411}{h1} + 2.5112$$

By using equation (1) In steady state condition heat transfer to surrounding is remains constant.

$$Q = \frac{T3-T4}{R3} = \frac{T3-288}{2.5112} \quad (2)$$

From above equation we get the values of temperature at outer casing of water (T_3) for different constant amount of heat supplied (Q) in watt.

The convective coefficient of water can be found out by using natural convection as follows:

$$Gr = \frac{\beta*g*\Delta T1*L*L*L}{v*v}$$

Where:

Gr- Grashof number.

$\Delta T1$ - Temperature difference between T_2& T_3.

We have, kinematic viscosity (v),

$$v = \frac{\mu}{\rho} = \frac{0.001003}{1000} = 1.003e\text{-}6 \quad (m^2/sec)$$

$$Gr = \frac{4*e-6*\Delta T1*9.81*0.05*0.05*0.05}{1.003e-6*1.003e-6}$$

$$Gr = 4875.7019*\Delta T1$$

$$Pr = \frac{\mu*Cp}{k}$$

Where,Pr - Prandtl number

$$Pr = \frac{0.001003*4182}{0.6}$$

$$= 6.9909$$

Therefore,

$$(Gr*Pr) = (4875.7019*\Delta T1*6.9909)$$

$$(Gr*Pr) = (34085.6*\Delta T1)$$

The flow is laminar due to (Gr*Pr) is lies between ($10^4 < Gr*Pr > 10^9$) and maximum temperature difference is up to 60°C.

Correlations for Nusselt number for laminar flow by R. K. Rajput book (pg.no-501)

$$Nu = 0.13(Gr*Pr)^{(1/3)}$$

$$Nu = 0.13(34085.6*\Delta T1)^{(1/3)}$$

But;

$$Nu = \frac{hL}{K} = \frac{h1*0.05}{0.6}$$

Therefore, equation reduces to,

$$\frac{h1*0.05}{0.6} = 0.13(34085.6*\Delta T1)^{(1/3)}$$

$$h_1 = 1.56*(34085.6*\Delta T1)^{(1/3)}$$

$$h_1 = 50.58*(\Delta T_1)^{(1/3)}$$

$$h_1 = 50.58*(T_2-T_3)^{(1/3)} \quad (3)$$

This is the equation gives the relationship between convective heat transfer coefficient of water and temperature near water surface.

The heat transferred from water cylinder is given by,

$$Q = \frac{T2-T3}{R2} = \frac{T2-T3}{\frac{187.2411}{h1}} = \frac{h1(T2-T3)}{187.2411}$$

$$Q = \frac{50.58*(T2-T3)^{(1/3)}*(T2-T3)}{187.2411}$$

$$Q = \frac{50.58*(T2-T3)^{(4/3)}}{187.2411} (4)$$

From above equation we get value of temperature (T_2) at outer surface of aluminum cylinder. Then substitute the value of temperature (T_2) in equation (3), and find out the value of convective heat transfer coefficient of water. The temperature of outer heater surface can be obtained by equation,

$$Q = \frac{T1-T2}{R1} = \frac{T1-T2}{4.2189e-3} (5)$$

6.4 Sample calculation

Let Q = 11watt

From equation (2)

$$11 = \frac{T3-288}{2.5112}$$

$$T3 = 315.6232 \text{ K}$$

By substituting this value in equation (4)

$$Q = \frac{50.58*(T2-T3)^{(4/3)}}{187.2411}$$

$$11 = \frac{50.58*(T2-315.6232)^{(4/3)}}{187.2411}$$

$$2059.6521 = 50.58*(T_2 - 315.6232)^{(4/3)}$$

$$T2 = 331.46 \text{ K}$$

This is the temperature of outer aluminum cylinder. To find inner side temperature

$$Q = \frac{T1-T2}{4.2189e-3}$$

$$11 = \frac{T1-331.46}{4.2189e-3}$$

$$T_1 = 331.71 \text{ K}$$

The convective heat transfer coefficient of water can be found by equation (3)

$$h_1 = 50.58*(T2 - T3)^{(1/3)}$$

$$h_1 = 50.58*(331.46 - 315.6232)^{(1/3)}$$

$$h_1 = 128.45 W/m^2K$$

7 Results and Discussion

7.1 Calculation for Effectiveness of Fins

The following data available for the rectangular fins:

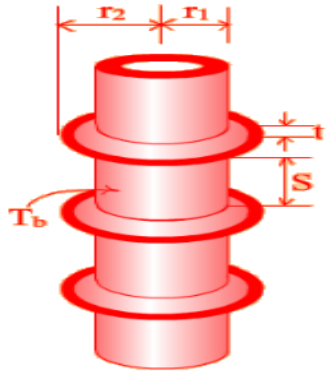


Fig 7.1 Circular Fins Mounted on Aluminum Cylinder

In the case of no fins, heat transfer from the tube per unit length is determined from Newton's law of cooling,

$$A_{no\ fin} = \pi D_2 L = \pi (0.034)*(0.05) = 0.00534 \text{ m}^2$$

$$Q_{no\ fin} = h A_{no\ fin} (T_2-T_3)$$

$$Q_{no\ fin} = 128.45*0.00534 (331.743-315.32)$$

$$= 11.26 \text{ W}$$

The efficiency of the circular fins attached to a circular tube is plotted in following graph

In this case we have,

$$L_1 = ½(D_3 - D_2) = ½ (0.064 - 0.034) = 0.015 \text{ m}$$

$$\frac{r_3+\frac{t}{2}}{r_2} = \frac{0.032+\frac{0.003}{2}}{0.017} = 1.97$$

$$(L_1 + \frac{t}{2})\sqrt{\frac{h}{kt}} = (0.015+\frac{0.003}{2})\sqrt{\frac{123.52}{202.4*0.003}} = 0.2354$$

In this case we know $\eta_{fin} = 0.93$

$A_{fin} = 3*2\pi(r_2^2 - r_1^2) + 3*2\pi r_2 t$

$A_{fin} = 3*2\pi(0.032^2 - 0.017^2) + 3*(2\pi 0.032* 0.003)$

$A_{fin} = 0.01566\ m^2$

$Q_{fin} = \eta_{fin} Q_{fin\ max} = \eta_{fin}\ hA_{fin}(T_2-T_3)$

$= 0.93*128.45*0.01566*(331.743 - 315.32)$

$= 30.73$ W

The space (S) between the two fins is 12.5 mm,

Heat transfer from the unfinned portion of the tube is,

$A_{unfin} = \pi D_2 *2*(S+ S_1) = \pi (0.032) *2* (0.0125+0.008) = 0.0041217\ m^2$

$Q_{unfin} = h A_{unfin}(T_2-T_3) = 128.45*0.0041217*(331.743 - 315.32)$

$Q_{unfin} = 8.695$ W

There are 3 fins in 50 mm length of the tube, the total heat transfer from the finned tube becomes,

$Q_{total\ fin} = (Q_{fin} + Q_{unfin}) = (30.73+ 8.695) = 37.227$ W

Therefore, the effectiveness (ε) of fins,

$$\varepsilon = \frac{Q_{total\ fin}}{Q_{no\ fin}} = \frac{39.425}{11.26}$$

$$\varepsilon = 3.501$$

When,

1. $\varepsilon < 1$, no need of fins.
2. $\varepsilon = 1$, no change in heat transfer rate if fins are mounted.
3. $\varepsilon > 1$, need of fins. But in practically it should be greater than 2.

7.2 Results from CFD

In result we can find different types of contours, velocity diagram and plot of various graphs of different properties etc.

Analysis of the tube without fins:

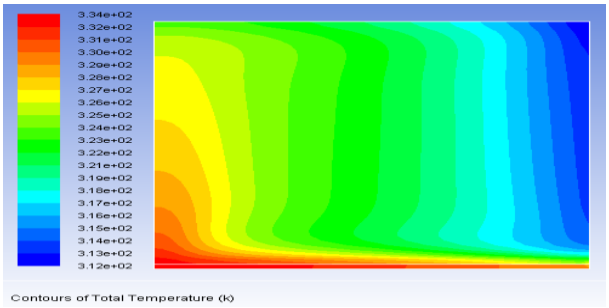


Fig 7.2 Contours of Total Temperature For Tube Without Fins

The investigation of tube without balances is done by giving the limit conditions as said above, we get the examination consequence of tube without blades. Figure 5.1 demonstrates that the temperature profile and figure 5.2 demonstrates the speed vectors which demonstrates that without blade, water moves along the surface as it were.Middle portion of the water remains at the same temperature. Water which is in contact with tube, get heated. That indicates the heat is not uniformly distributed in the water-liquid zone. Whenever we mount the fins on the tube, it create the pocket for the heat transfer and more water will come in contact with the tube surface, as increase in surface area will cause the increase in the heat transfer rate. Hence mounting of fins is necessery for increasing heat transfer rate.

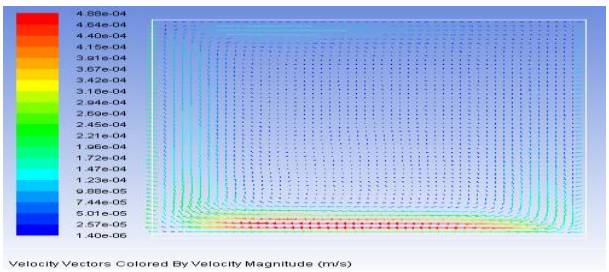


Fig 7.3 Velocity Vectors For Tube Without Fins

7.3 Optimization parameters of fins

Shape of fin:

As specified in the supposition, we just consider blades which are cicumferentially mounted. When we consider the state of the blades then by and large three kind of balances which are triangular, rectangular and trapezoidal balances. The accompanying figures demonstrate the investigation of the these three balances.

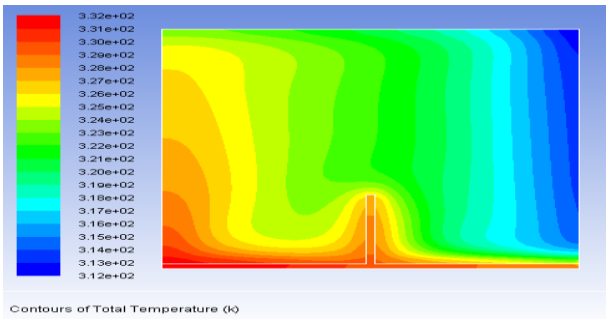


Fig 7.4 Contours of Total Temperature For Tube With Single Rectagular Fin

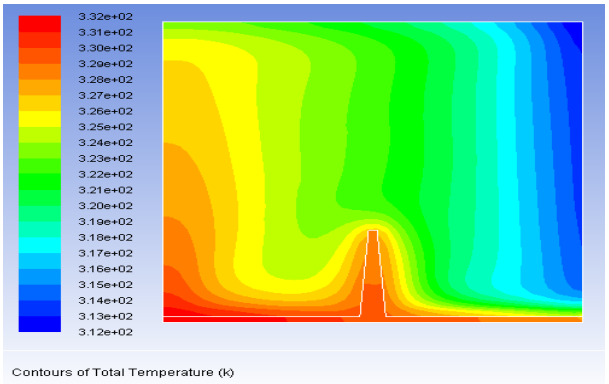


Fig 7.5 Contours of Total Temperature For Tube With Single Trapezoidal Fin

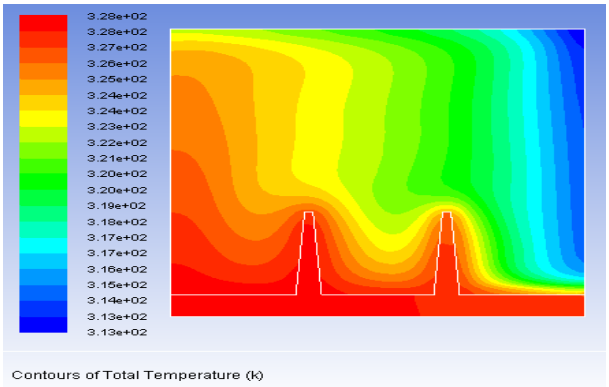


Fig 7.6 Contours of Total Temperature for Tube With Two Trapezoidal Fins

Comparision of the result obtained:

TABLE 7.1 Comparision of Rectangular and Trapezoidal Fins

Sr.No.	Shape of fin	Temperature (K)		Total heat transfer rate (w)	Surface heat transfer coefficient (w/ m^{2}K)
		Max.	Min.		
1	Rectangular fin	331.93	312.11	11.04	108.26
2	Trapezoidal fin	331.67	312.12	11.04	106.0231

Optimization of fins spacing:

TABLE 7.2 Optimization of Fin Spacing

Sr. No.	Number of fins	Total heat transfer rate (w)	Surface heat transfer coefficient (w/ m^{2}K)	Temperature (K)	
				Max.	Min.
1	1	11.04	108.26	331.69	312.11
2	2	11.04	97.9233	330.46	312.25
3	3	11.04	84.3455	330.00	312.31
4	4	11.04	83.1045	329.63	312.32

The following figures show the temperature and velocity vector profile of the analysis.

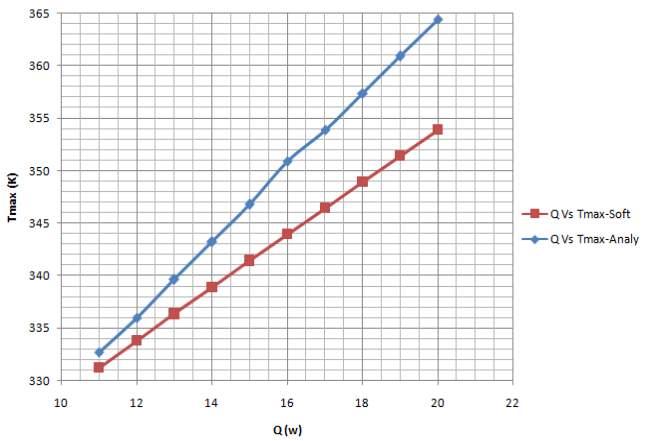
7.4 Comparision of Results

TABLE 7.3 Results obtain by analytical calculations for tube without fins

Total heat transfer rate (W)	Temperature at tubeid (K)	Temperature at shell (K)	Surface heat transfer coefficient (W/m^{2}K)
11	331.71	315.32	128.45
12	336.01	318.12	130.41
13	339.6	320.65	133.22
14	343.19	323.16	135.72
15	346.77	325.67	138.07
16	350.94	328.18	140.32
17	353.88	330.69	142.48
18	357.4	333.2	144.53
19	360.92	335.71	146.48
20	364.43	338.22	148.37

TABLE 7.4 Results obtain by software analysis for tube without fins

Total heat transfer rate (W)	Temperature at tubeid (K)	Temperature at shell (K)	Surface heat transfer coefficient (W/m^{2}K)
11	331.20	312.31	117.27
12	333.78	313.48	121.79
13	336.34	314.65	125.97
14	338.89	315.82	129.85
15	341.42	317.00	133.46
16	343.94	318.18	135.57
17	346.45	319.36	137.67
18	348.94	320.55	139.73
19	351.42	321.74	141.74
20	353.89	322.93	143.40

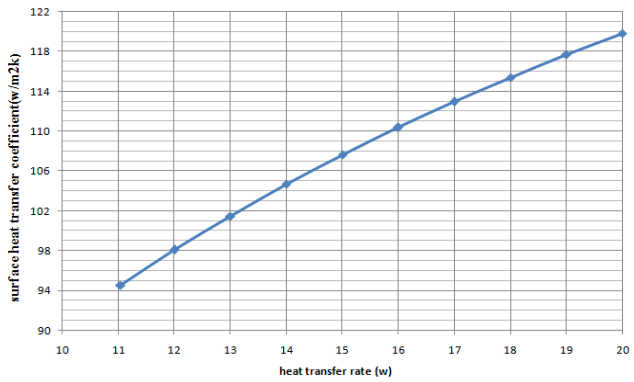


Graph No.1 Maximum temperature (K) Vs Heat transfer rate (W) for tube without fins.

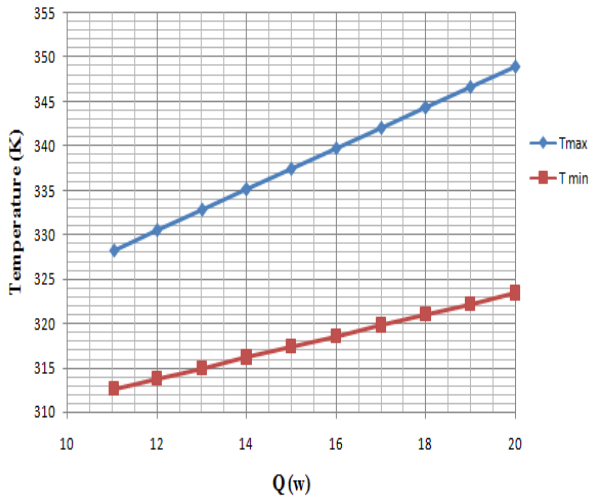
The change in heat transfer rate causes change in surface heat transfer cofficient as well as change in temperature. From software analysis the obtained results are tabulated as follows

TABLE 7.4 Results for Aluminium Fins

Sr. No.	Total heat transfer rate (W)	Surface heat transfer coefficient (W/ m^2K)	Maximum Temperature (K)	Minimum Temperature (K)
1	11.04	94.56	328.30	312.63
2	12	98.09	330.55	313.77
3	13	101.49	332.88	314.97
4	14	104.65	335.21	316.17
5	15	107.63	337.52	317.37
6	16	110.38	339.83	318.57
7	17	112.96	342.12	319.77
8	18	115.39	344.41	320.99
9	19	117.69	346.69	322.20
10	20	119.86	348.96	323.42



Graph No 2 Surface Heat Transfer Coefficient (h) Vs Heat Transfer Rate (Q) for two fins.



Graph No 3 Temperature (T) Vs Heat Transfer (Q) for two fins.

Conclusion

For littler dispersing, augmentation in h is little because of the stream choking impact. The estimation of h increments with separating giving an ideal incentive at about S= 16.67 mm for 50 mm length pipe. This is in understanding in different agents. Single fireplace stream example is held in INFAs likewise with a more extensive stack zone, which is the conceivable purpose behind warmth exchange improvement. At the point when single stack stream example is available, in midchannel stale base bit ends up noticeably ineffectual. The changed cluster is outlined in reversed indented frame and that has turned out to be fruitful holding single fireplace together with the expulsion of ineffectual blade level bit. This is the principle commitment of present paper. Constrained CFD arrangements got are in great concurrence with exploratory work. Radiation contribution is also important and needs further investigation.

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