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Numerical Analysis of Heat Transfer Characteristics of Finned Tube Heat Exchanger Using System CFD (Flownex)

Prasanna Shankara R [1], Harikanth S[2]

[1]Dr. M. V. Shetty Institute of Technology, Moodbidri, Karnataka, India
[2]Dr. M. V. Shetty Institute of Technology, Moodbidri, Karnataka, India

Abstract: ***Finned tube heat exchanger is used in the area of heat transfer to conserve energy. The present study mainly involves heat transfer characteristics of finned tube heat exchanger. Finned tubes are used for the present study in order to increase the heat transfer characteristics of the heat exchanger. Shell and Tube Heat Exchanger design is carried out with the help of correlation between the Bell Delaware and Kern method. Bell Delaware method is accurate as compared to kern method. The numerical steady state analysis is carried out using system CFD (Flownex). Flownex is an integrated systems CFD code which is used for the design simulation and optimization of complete thermal-fluid systems. Flownex's solution is more accurate, fast and resembles that of a conventional CFD code. The present steady state numerical analysis involves the effects of pressure drop, Nusselt number, Reynolds number, friction factor and temperature rise on the rate of heat transfer at the tube side of finned tube heat exchanger. The numerical analysis also carried out with and without fins. The performance parameters of the heat exchanger also have been evaluated by using Flownex and have been compared with calculated values.***

Keywords: Finned tube heat exchanger, Pressure drop, friction factor, Temperature rise, Flownex simulation

1. Introduction

Heat exchangers are devices that facilitate heat transfer between two or more fluids at different temperature. The driving force for the operation of heat exchanger is temperature difference between fluids. Heat exchangers are one of the mostly used equipments in the process industries. Heat exchangers are used to transfer heat between two process streams. One can realize their usage that any process which involves cooling, heating, condensation, boiling or evaporation will require a heat exchanger for these purposes. Different heat-exchangers are named according to their applications. For example, heat exchangers being used to condense are known as condensers; similarly heat exchangers for boiling purposes are called boilers. Performance and efficiency of heat exchangers are measured through the amount of heat transferred using least area of heat transfer and pressure drop. A better presentation of its efficiency is done by calculating over all heat transfer coefficient. Pressure drop and area required for a certain amount of heat transfer, provides an in- sight about the capital cost and power requirements (running cost) of a heat exchanger.

There are three principles of achieving heat transfer. They are namely conduction, convection, and radiation. In a heat exchanger, heat transfer takes place by convection and conduction. Conduction occurs as the heat from the hot fluid passes through the inner pipe wall. To achieve more heat transfer, the inner pipe wall should be thin and very conductive. However, the biggest contribution to heat transfer is made through convection.

2. Problem Definition

In order to improve the performance (heat transfer rate), the area of the tube (theoretically) should be increase. But, this will increase the size of the heat exchanger. Therefore a study is needed to improve the performance (heat transfer rate) by having a compact heat exchanger.

3. Objectives

- Numerical analysis of finned shell and tube heat exchanger by varying the tube side fluid velocity and shell side fluid velocity kept constant.
- Investigating the effects of pressure drop, Reynolds number, Nusselt number, friction factor and temperature rise along the length of the finned tube heat exchanger.
- The numerical analysis is carried out by varying number of tubes.

The exhaust gas from the diesel engine is treated as the shell side fluid for the shell side analysis and water is used as a tube side fluid. System CFD (Flownex) provides the flexibility to change design parameters quickly without the expense of changes in hardware. It also reduces the design cycle time and cost effective. Hence present project work is carried out with the system CFD (Flownex.)

4. System CFD (FLOWNEX) Approach

Flownex is an integrated systems CFD code used for the simulation, design and optimization of complete thermal-fluid system. Flownex's implicit solution algorithm is fast, accurate and resembles that of a conventional CFD code. The system is discretised into a number of spatial or conceptual control volumes. Then a set of conservation equations are applied to such control volumes and then solved. Flownex uses nodes

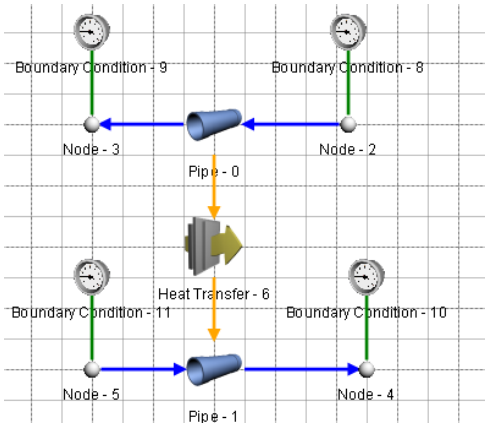
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and elements to represent a complete thermal-fluid network graphically. Elements are components such as pipes, valves, pumps, compressors or heat exchangers. The nodes are the end points of elements. Elements can be connected in any arbitrary way at common nodes to form a network. Flownex provides the ability to model the complete integrated system to engineers. Standard components with different levels of complexity are linked together in an arbitrary way to build any flow system. Flownex solves the momentum, continuity and energy equations. Momentum equation is solved in each element and the continuity and energy equation at each node. The main network with embedded sub-networks is treated as one large network in the solution algorithm

4.1 Governing Equations

- Conservation of Mass (Continuity)
- Conservation of Momentum
- Conservation of Energy

4.2 Flow Network for Simulation



5. Methodology

5.1 Steps Involved in the Numerical Simulation

- Create the flow network using elements and nodes.
- Create the operating fluid.
- Assign the operating fluid.
- Assign the properties to the shell as well as the tube.
- Assign the properties to the conductive heat transfer element.
- Assign the properties to the convective heat transfer element.
- Apply shell side inlet and outlet boundary conditions.
- Apply tube side inlet and outlet boundary conditions.
- Create layers for both upstream and downstream heat transfer element.
- Set the scheduler
- Specify the graph properties.
- Specify the graph variable.
- Plot the required graph.
- Save and run the network.
- View the graphs and results

5.2 Case Studies

The numerical analysis consists of following cases.

- Effects of pressure drop and friction factor on heat exchanger performance.
- Effects of Nusselt number on overall heat transfer coefficient.
- Numerical analysis along the tube length.
- The numerical analysis is carried out by varying number of tubes
- Tube with and without fins studied numerically.

5.3 Working Fluid Properties

Shell side fluid is exhaust gas which is coming from the exhaust of the diesel engine. The properties of exhaust gas (flue gas) at 120^0C

Table: 5.1

Density (ρ)	0.9096 kg/m^3
Viscosity (μ)	21.202*10^{-6}Ns/m^2
Prandtl number (Pr)	0.686
Thermal conductivity(k)	0.033W/mK
Specific heat (C_p)	1073.8 J/kg-K

Tube side fluid is water, which flows at a temperature of 25^0C.Therefore the properties of water at 25^0C.

Table: 5.2

Density (ρ)	997 kg/m^3
Viscosity (μ)	0.891*10^{-3} Ns/m^2
Pradllt number (Pr)	6.14
Thermal conductivity(k)	0.607 W/mK
Specific heat (C_p)	4180 J/kg-K

5.4 Boundary Conditions

Table 5.3: Boundary conditions

	Inlet	Outlet
Shell	Temperature boundary condition	Mass flow rate
	Pressure boundary condition	
Tube	Temperature boundary condition	Mass flow rate
	Pressure boundary condition	

5.5 Specification of Finned Tube Heat Exchanger [11]

Table 5.4

Shell material	Mild Steel
Shell outer diameter	323 mm
Shell thickness	6 mm
Length of the shell	500 mm
Tube material	Copper
Tube outer diameter	12.5 mm
Tube thickness	1.65 mm
Tube type	Finned tube
Type of the tube arrangement	Inline arrangement
Number of tubes inside the shell	36
Fin thickness	2 mm
Fin height	6 mm
Transverse pitch	37.5 mm
Longitudinal pitch	37.5 mm
Finned area	1.008 mm^2
Unfinned area	0.5625 mm^2
Shell side fluid (Hot)	Exhaust gas or flue gas
Tube side fluid (Cold)	Water

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6. Results and Discussion

6.1 Steady State Tube Side Numerical Analysis [With Fins]

Table 6.1: The values of Re and Nu

Sl.No	Mass flow rate (kg/s)	Reynolds number	Nusselt number
1	0.25	1086	4.364
2	0.5	2155	4.364
3	0.75	3266.7	18.4553
4	1.00	4296.5	33.962

Table 6.2: Pressure drop and friction factor

Sl.No	Mass flow rate(kg/s)	Pressure drop(kPa)	Friction factor
1	0.25	0.015655	0.0589
2	0.5	0.03255	0.0407
3	0.75	0.08727	0.0338
4	1	0.18634	0.029

Table 6.3: The heat transfer rate with and without fins

Sl.No	Mass flow rate(kg/s)	Heat transfer rate (with fin) (kW)	Heat transfer rate (without fin) (kW)
1	0.25	7.12	5.22
2	0.5	7.3	5.3
3	0.75	8.4	7.5
4	1	8.6	8.1

6.2 Graphical Representation of Obtained Results

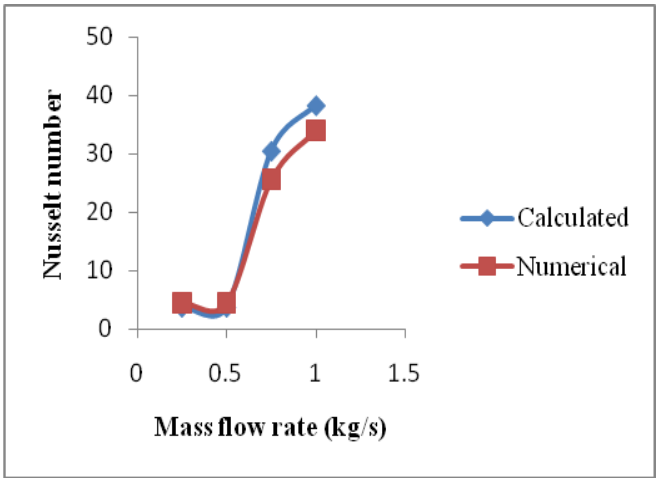


Figure 6.1: Mass flow rate vs Nusselt number

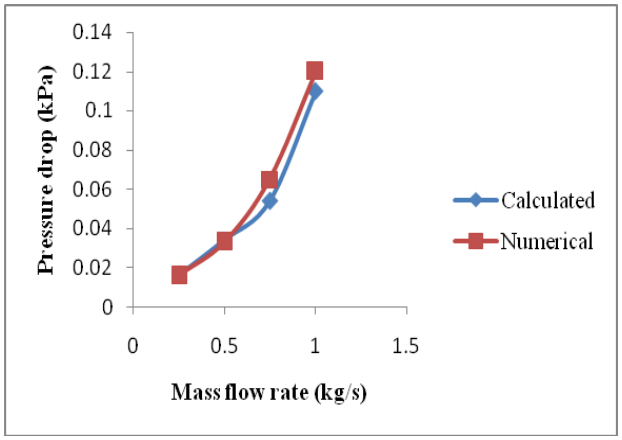


Figure 6.2: Pressure drop vs Mass flow rate

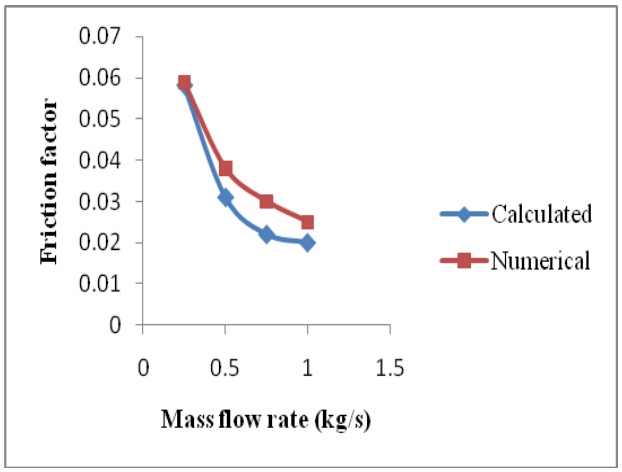


Figure 6.3: Mass flow rate vs friction factor

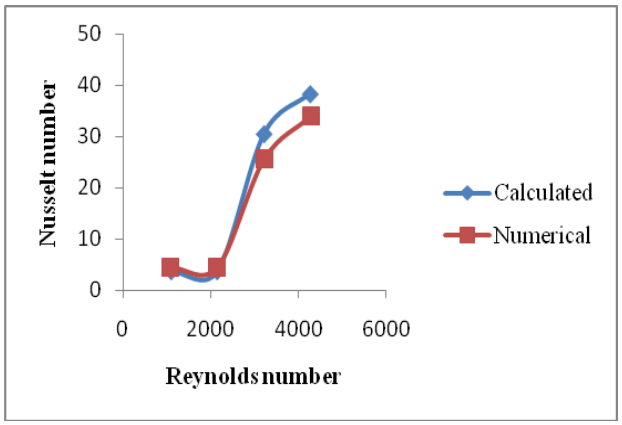


Figure 6.4: Reynolds number vs Nusselt number

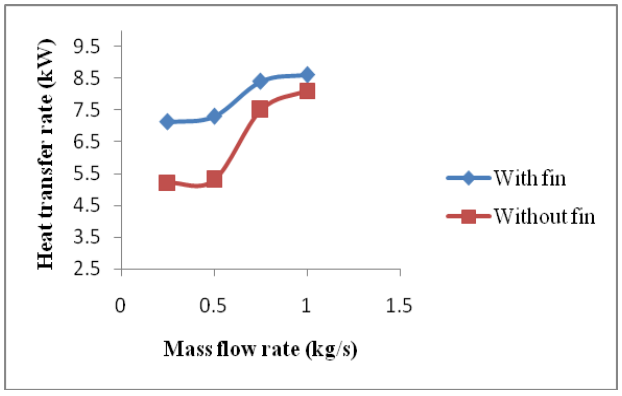


Figure 6.5: Mass flow rate vs heat transfer rate

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Figure 6.1 shows the variation of Nusselt number for the different mass flow rates. From the graph it is cleared that with increase in the mass flow rate on tube side, Nusselt number also increases. This indicates that convection is predominant; this results in the enhanced heat transfer.

Figure 6.2 shows the variation of pressure drop with different mass flow rates. From the graph it is seen that pressure drop increases with the increase in the mass flow rate. So designers have to think about optimum mass flow rate while designing the compact heat exchanger.

From figure 6.3 it is seen that with the increase in the mass flow rate at the tube side, friction factor gradually decreases. This results in the increased heat transfer rate.

Figure 6.4 shows the variation of Nusselt number with respect Reynolds number. With the increase in the Reynolds number of the tube side, Nusselt number also increases. This shows that convection is predominant. From this it is cleared that heat transfer rate can be increased by increasing Reynolds number.

Figure 6.5 shows variation of heat transfer rate with respect to varying mass flow rate at the tube side. As the mass flow rate increases at the tube side, heat transfer rate also increases. It is seen that tubes with fins gives higher heat transfer rate as compared with the tubes having no fins.

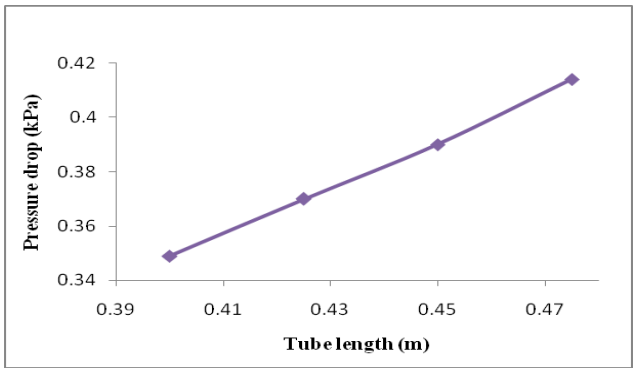


Figure 6.6: Tube length vs pressure drop

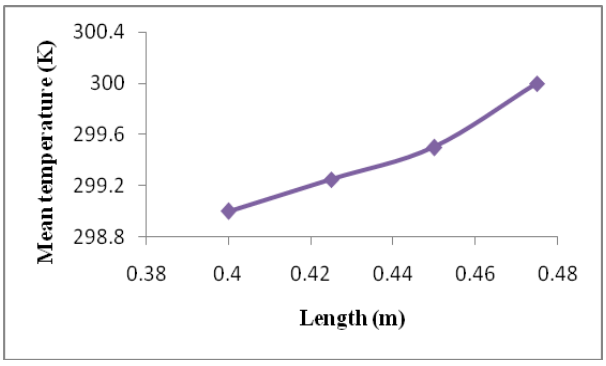


Figure 6.7: Tube length vs mean temperature

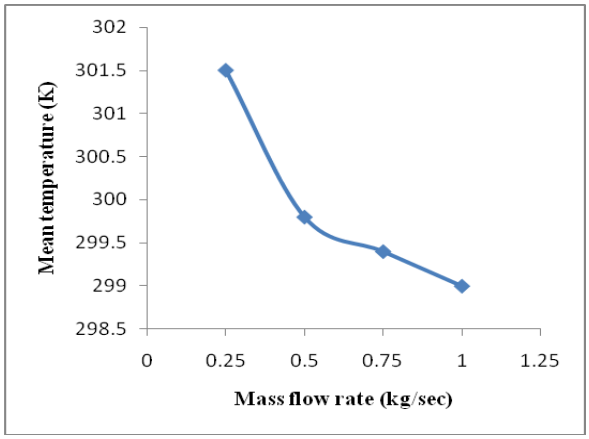


Figure 6.8: Mass flow rate vs mean temperature

Figure 6.6 shows the variation of pressure drop with respect to the tube length. From the above graph it can be noted that with the increase in tube length, pressure drop also increases. Therefore pumping power is more required.

Figure 6.7 shows the variation mean temperature with the tube length. From the above graph it can be seen that mean temperature increases gradually with the increase in tube length, as a result heat transfer rate increases. But designer should take care of pressure drop also.

Figure 6.8 shows the variation of mean temperature with the mass flow rate at the tube side. The graph shows that with increase in the mass flow rate at the tube side, the mean temperature of the fluid gradually decreases.

7. Conclusions

The present study mainly involves heat transfer characteristics of shell and finned tube heat exchanger. Finned tubes are used for the present study in order to improve the heat transfer rate of the heat exchanger.

- Reynolds number of the flow play a vital role in the heat transfer enhancement in a heat exchanger. From the numerical analysis it is concluded that with the increase in the Reynolds number, Nusselt number also increases. Hence heat transfer rate increases. The magnitude of heat transfer coefficient is proportional to the Reynolds number of the flow.
- The heat transfer coefficient for the turbulent flows (Re >2500) is more than laminar flows (Re <2500).
- The pressure drop is evaluated along the tube length. Pressure drop curve shows that pressure drop increases with increase in tube length.
- With the increase in the velocity of the tube side fluid Nusselt number increases and hence convective heat transfer coefficient increases; this enhances the rate of heat transfer.
- Steady state analysis shows that mean temperature increases gradually with the increase in tube length, as a result heat transfer rate increases.
- The numerical and analytical results are compared and they are in close agreement to each other.

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8. Scope for Further Work

i. The vortices or eddies play an important role in enhancing the heat transfer in a heat exchanger. Because the turbulent flows gives better heat transfer as compared to laminar flows. The turbulent flow is due to formation of set of vortices.
ii. At a given Reynolds number the flow can be made more turbulent by introducing artificial eddies in to the flow.

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Author Profile



Prasanna Shankara R received the B.E. (MECHANICAL) and M.TECH. degrees in Thermal Power Engineering from SIR.M.V.I.T Bangalore in 2011 and U.B.D.T.C.E Davangere in 2014, respectively. Currently working as asst. professor in Dr. M.V. Shetty Institute of Technology, Moodbidri, Karnataka, India.

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