DESIGN ANALYSIS AND STUDY OF HEAT TRANSFER FOR DIFFERENT FINNED QUAD TUBED HEAT EXCHANGER

Akshath K R¹, Chaitanyaa K K², Basavaraj Devakki³
1,2,3 Department of Mechanical Engineering, presidency University, Bangalore, India
E-mail: akshathkr3@gmail.com

Abstract: - The finned quad tubed heat exchanger has been modelled, and analyzed numerically. On the surface of each inner tube, the different shapes of fins have been modelled i.e., square, triangular and Y shape throughout the entire length. The analysis has been carried for Reynolds's number 8748, 10935 and 13123 and cold fluid temperature kept constant at 25 °C and hot fluid in annulus shape varied at 40 °C, 50 °C and 60 °C as inlet temperatures. It was found that triangular and Y shaped fins show higher heat transfer enhancement as compared to square fins. An increase of 152% and 145% in heat transfer found for Y and triangular shaped fins respectively as compared to square fin for same inlet conditions. It is the reason being the surface area for triangular and Y shapes fins is much higher. Hence the Y shaped fins can be used in most of the applications which involves combination of conduction and convection heat transfer i.e., in evaporator, condensers, radiators tubes etc. which results in higher heat transfer and increases the efficiency.

Keywords: Quad tubed heat exchanger; Y- shape fins; heat transfer enhancement; triangular fins;

1. Introduction
Double Pipe Heat Exchanger (DPHE) is commonly used in oil, petrochemical, nutrition industries and heat pumps. Double pipe heat exchangers are simple in geometry and construction, it can be used in high pressure and temperature environments. DPHE can also be used in harsh conditions since it can be easily cleaned and good parallel or counterflow combinations can be achieved. Thermal engineers in the HVAC industry are using DPHE to save energy consumption as they are commonly used in condensers, evaporators or in air conditioning systems. Small scale industries prefer DPHE because of its low cost in design and maintenance. The literature contains many efforts to increase the performance of DPHE. The transfer of heat between two or more fluids in a constrained chamber is known as heat exchanger. At present scenario, it plays a very important role in industrial applications in transferring heat in between fluids, here Quad Tubed Heat Exchanger is one of the basic formats of heat exchanger that transfers heat from hot fluid to cold fluid through a cylindrical wall that separates both hot and cold fluid. Its efficiency can be increased by increasing the performance of heat exchanger this can be done by increasing the contact area of hot fluid with cold fluid, the efficient configuration of the heat exchanger in turn results with decreased overall size of the heat exchanger, decreased manufacturing cost of the heat exchanger etc. So, this phenomenon encourages even small-scale industries to use heat exchangers. In heat exchangers initial heat transfer occurs between liquid to solid which known as Convection and then from one side of the wall to other side of the wall i.e. from solid to solid known as Conduction and then again from solid to liquid that is convection.
In this paper, heat transfer analysis has been performed numerically for Quad Tubed Heat Exchanger in ANSYS Fluent software under steady state heat transfer condition. The K-epsilon method on various fins i.e. inner tube - without fins, with triangular fins, with squared fins and with Y- shaped fins used. Parallel flow type heat exchanger is considered and finally its heat transfer rate and Reynolds number are determined, and graphs plotted. For every model totally 9 trials are done by assuming the cold-water temperature at 25 °C and by varying hot water temperature at 40 °C, 50 °C, and 60 °C. The study is carried out assuming that cold water is made to flow through inner tubes and...
hot water is made to flow through annulus space. And it is observed that efficiency is increased for Y shaped Quad Tubed Heat Exchanger.

2. Literature review
Dynamic characteristics of DPHE can be predicted with numerical and experimental methods. Experiment on the SCO2 water heat transfer was conducted on the DPHE and correlation between the experimental data and the genetic algorithm is obtained. Numerical studies on DPHE with longitudinal fins of triangular and rectangular cross-sections with variable thickness of the tip is conducted [2], [5] and [7]. By up to 178% increase in the Nusselt number (Nu) relative to the rectangular cross-sections has been obtained. Numerical analysis of DPHE was made with twisted pipe cross-section. It was observed that an increase in the pressure drop increases the heat transfer rate, which was considered as a friction coefficient. The experimental study was made by using MgO nanofluid in a DPHE. 27% increase in heat transfer was achieved for 0.3 wt% as compared with the base fluid [9]. It has been done an experimental study on the DPHE with helical wire in the inner pipe. An increase of up to 2.64 times in Nusselt number (Nu) was observed in comparison to empty pipe [10]. The numerical studies of heat transfer in the DPHE with exponential fins are conducted. With the increase in the thermal conductivity the Nusselt number (Nu) increased significantly. The performance of the exponential fins was better than the triangular fins by 0.02%–15.09% [11]. The viscosity of the fluid had a little effect on the Nu number and significant effect on the Newtonian fluids [12], [8]. The optimal design for the DPHE has been performed [13]. The solution gives the optimum values for the inner and outer diameter of the DPHE. Many engineering techniques have been performed to increase the efficiency of the DPHE, one such effective method is to impart the helical fins around the pipe to allow the helical flow of the fluid. The numerical analysis of thermal performance of the DPHE with helical fins on the annulus will increase as the increase in the baffle spacing and Re number. The thermal and fluid flow properties of the helically twisted DPHE were studied [17]. It was observed 3 times enhancement in the heat transfer in compare to smooth double pipe and a factor of 2–4 increase in the corresponding pressure drop. The experimental study of air bubbles injection in the fluid has shown an overall increase in heat transfer by 10.3% [20].

3. Modelling and Meshing
The complete geometries of the Quad tubed Heat exchanger of all the models are constructed using SolidWorks and then it is imported to ANSYS to study the heat transfers of different constructed models. Geometry of different Quad tubed Heat Exchanger with dimensions of its fins are shown in Table.1. The parallel flow typed Quad Tubed Heat Exchanger with different models are shown with the dimensions of the fins. The dimensions of the complete model such as length and diameter of the tubes in the heat exchanger are kept constant for all the models and the same is shown below.

![Figure 01. Modelled heat exchanger](image-url)
Table 1. Details of heat exchanger

| Particulars                        | Dimensions (mm) |
|-----------------------------------|-----------------|
| Length of the tube                | 600             |
| Inner diameter of the inner tube  | 12.5            |
| Inner diameter of the outer tube  | 53              |
| Thickness of the inner tube       | 2.5             |
| Thickness of the outer tube       | 3               |

3.1 Model 1 - Quad Tubed Heat Exchanger without fins

| Nos. of Elements | 244648 |
| Nos. of Nodes   | 346280 |
| Avg. Skewness   | 0.14306 |

3.2 Model 2 - Quad Tubed Heat Exchanger with Triangular fins

| Nos. of Elements | 233269 |
| Nos. of Nodes   | 301408 |
| Avg. Skewness   | 0.2407 |

3.3 Model 3 - Quad Tubed Heat Exchanger with Square fins

| Nos. of Elements | 219921 |
| Nos. of Nodes   | 288126 |
| Avg. Skewness   | 0.2457 |

3.4 Model 4 - Model 3 - Quad Tubed Heat Exchanger Y-shaped fins

| Nos. of Elements | 249961 |
| Nos. of Nodes   | 341691 |
| Avg. Skewness   | 0.2929 |

4. Simulation

As discussed in the previous sections, totally of 9 trials have been analyzed by K-epsilon method with standard wall function and considering parallel flow of water with constant cold-water inlet temperature at 25 °C and hot water inlet temperatures at 40 °C, 50 °C, 60 °C. The cold water is made to flow in the inner tubes at velocity of 0.1060895 m/s and the hot fluid water is made to flow in the annulus space at different velocities i.e., 0.0303113 m/s, 0.0252594 m/s, and 0.0202075 m/s and the Reynolds number equal to 13123, 10935 and 8748 respectively corresponding to these velocities. The pressure outlet boundary is enforced for all the trials. To plot graphs to compare heat transfer of various models, the dimensionless Reynolds number is being calculated using

\[
Re = \frac{\rho v d}{\mu}
\]
5. Governing Equations
- Fourier law of conduction

\[ Q = -k \cdot A \cdot \frac{dT}{dx} \]

Where, \( k \) = Thermal conductivity of the metal
\( A \) = Area of cross-section
\( \frac{dT}{dx} \) = Temperature gradient

- Newton law of cooling

\[ Q = h \cdot A \cdot \Delta T \]

Where, \( h \) = Heat transfer coefficient
\( A \) = Area of the object in contact with the medium
\( \Delta T \) = Change in temperature

6. Data Reduction

\[ T_{LMTD} = \frac{(T_{hi} - T_{ci}) - (T_{ho} - T_{co})}{\ln \left( \frac{T_{hi} - T_{ci}}{T_{ho} - T_{co}} \right)} \]

Heat transfer rate is computed using Equations

\[ Q_{\text{avg}} = \frac{Q_h + Q_c}{2} \]

\[ Q_h = m_h \times C_{ph} \times (T_{hi} - T_{ho}) \]

\[ Q_c = m_c \times C_{pc} \times (T_{co} - T_{ci}) \]

Where, \( T_{hi} \) is the inlet temperature of hot fluid, \( T_{ho} \) is the outlet temperature of hot fluid, \( T_{ci} \) is the inlet temperature of cold fluid, \( T_{co} \) is the outlet temperature of cold fluid, \( Q_{\text{avg}} \) is the total heat transfer, \( Q_h \) is the heat transfer by hot fluid, \( Q_c \) is the heat gained by cold fluid, \( m_h \) is the mass flow rate of hot fluid, \( m_c \) is the flow rate of cold fluid, \( C_{ph} \) and \( C_{pc} \) is the specific heat of hot and cold fluid respectively.

7. Results and Discussion

7.1 without fins

| Velocity of cold fluid (m/s) | Velocity of hot fluid (m/s) | Cold fluid inlet (°C) | Cold fluid outlet (°C) | Hot fluid inlet (°C) | Hot fluid outlet (°C) | NET. (°C) |
|-----------------------------|-----------------------------|-----------------------|-----------------------|----------------------|----------------------|----------|
| 0.1060895                   | 0.0303113                   | 25                    | 27.861101             | 40                   | 37.617976            | 31.892284 |
| 0.1060895                   | 0.0303113                   | 25                    | 29.768502             | 50                   | 46.029965            | 36.487141 |
| 0.1060895                   | 0.0303113                   | 25                    | 31.675903             | 60                   | 54.441944            | 41.081997 |
| 0.1060895                   | 0.0252594                   | 25                    | 27.79738              | 40                   | 37.23134             | 31.78918  |
| 0.1060895                   | 0.0252594                   | 25                    | 29.662301             | 50                   | 45.38556             | 36.315307 |
| 0.1060895                   | 0.0252594                   | 25                    | 31.52722              | 60                   | 53.59379             | 40.84143  |
| 0.1060895                   | 0.0202075                   | 25                    | 27.50883              | 40                   | 36.68869             | 31.64473  |
| 0.1060895                   | 0.0202075                   | 25                    | 29.51472              | 50                   | 44.48115             | 36.07455  |
| 0.1060895                   | 0.0202075                   | 25                    | 31.320619             | 60                   | 52.27362             | 40.50437  |
### 7.2 Triangular fins

| velocity of cold fluid (m/s) | velocity of hot fluid (m/s) | cold fluid inlet (°C) | cold fluid outlet (°C) | hot fluid inlet (°C) | hot fluid outlet (°C) | NET. (°C) |
|-----------------------------|----------------------------|-----------------------|-----------------------|---------------------|----------------------|----------|
| 0.1060895                  | 0.0303113                  | 25                    | 33.825984             | 40                  | 33.860891            | 32.913582 |
| 0.1060895                  | 0.0303113                  | 25                    | 39.709974             | 50                  | 39.768151            | 39.189303 |
| 0.1060895                  | 0.0303113                  | 25                    | 45.59396              | 60                  | 45.675412            | 43.465024 |
| 0.1060895                  | 0.0252594                  | 25                    | 38.794167             | 50                  | 38.850471            | 37.730963 |
| 0.1060895                  | 0.0252594                  | 25                    | 44.311834             | 60                  | 44.390659            | 42.823349 |
| 0.1060895                  | 0.0202075                  | 25                    | 32.630053             | 40                  | 32.662337            | 32.315006 |
| 0.1060895                  | 0.0202075                  | 25                    | 37.716755             | 50                  | 37.770562            | 37.770562 |
| 0.1060895                  | 0.0202075                  | 25                    | 42.803475             | 60                  | 42.87878             | 42.06834  |

### 7.3 Square fins

| velocity of cold fluid (m/s) | velocity of hot fluid (m/s) | cold fluid inlet (°C) | cold fluid outlet (°C) | hot fluid inlet (°C) | hot fluid outlet (°C) | NET. (°C) |
|-----------------------------|----------------------------|-----------------------|-----------------------|---------------------|----------------------|----------|
| 0.1060895                  | 0.0303113                  | 25                    | 28.045295             | 40                  | 37.242228            | 31.642071 |
| 0.1060895                  | 0.0303113                  | 25                    | 30.075491             | 50                  | 45.403713            | 36.403713 |
| 0.1060895                  | 0.0303113                  | 25                    | 32.105687             | 60                  | 53.565198            | 40.498165 |
| 0.1060895                  | 0.0252594                  | 25                    | 27.968769             | 40                  | 36.801412            | 31.526734 |
| 0.1060895                  | 0.0252594                  | 25                    | 29.947949             | 50                  | 44.66902             | 35.87789  |
| 0.1060895                  | 0.0252594                  | 25                    | 31.927158             | 60                  | 52.536628            | 40.229046 |
| 0.1060895                  | 0.0202075                  | 25                    | 27.862313             | 40                  | 36.185578            | 31.365735 |
| 0.1060895                  | 0.0202075                  | 25                    | 29.770521             | 50                  | 43.64263             | 35.609558 |
| 0.1060895                  | 0.0202075                  | 25                    | 31.67873              | 60                  | 51.099682            | 39.853382 |

### 7.4 Y-shape fins

| velocity of cold fluid (m/s) | velocity of hot fluid (m/s) | cold fluid inlet (°C) | cold fluid outlet (°C) | hot fluid inlet (°C) | hot fluid outlet (°C) | NET. (°C) |
|-----------------------------|----------------------------|-----------------------|-----------------------|---------------------|----------------------|----------|
| 0.1060895                  | 0.0303113                  | 25                    | 33.679626             | 40                  | 33.697857            | 32.976632 |
| 0.1060895                  | 0.0303113                  | 25                    | 39.466043             | 50                  | 39.496429            | 38.294387 |
| 0.1060895                  | 0.0303113                  | 25                    | 45.25246              | 60                  | 45.295              | 43.612141 |
| 0.1060895                  | 0.0252594                  | 25                    | 33.157123             | 40                  | 33.174679            | 32.715217 |
| 0.1060895                  | 0.0252594                  | 25                    | 38.595205             | 50                  | 38.624465            | 37.858695 |
| 0.1060895                  | 0.0252594                  | 25                    | 44.033287             | 60                  | 44.074251            | 43.002173 |
| 0.1060895                  | 0.0202075                  | 25                    | 32.550295             | 40                  | 32.567              | 32.411597 |
| 0.1060895                  | 0.0202075                  | 25                    | 37.583825             | 50                  | 37.611666            | 37.352661 |
| 0.1060895                  | 0.0202075                  | 25                    | 42.617354             | 60                  | 42.656333            | 42.293726 |

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**Figure 2.** Contour of model 1  
**Figure 3.** Contour of model 2
The performance of heat exchanger with fins and without fins are compared. And the rate of heat transfer vs Reynolds number graphs is plotted for every model. The efficiency of heat exchanger and the amount of heat transfer between cold water and hot water depends upon the design and exact configuration of the heat exchanger. And this heat transfer happens due to difference in temperature between hot and cold fluid. From the below graphs i.e. between heat transfer rate(Q) and Reynolds number (Re) it is understood that heat transfer rate increases as the Reynolds number increases, this applies only for model 2, model 3, and model 4 whereas in case of model 1 slight change is observed i.e. heat transfer rate slightly decreased with increase in Reynolds number. It is clearly understood that the Quad tubed Heat Exchanger of triangular finned hold the maximum heat transfer. And also, it is clearly indicated that heat transfer rate increases as increase in Reynolds number of 40°C of hot water at outer tube and 25 °C of cold water at inner tube. From Figure.2, it can be seen that as the inlet temperature is increased from 40 °C to 60 °C for triangular fins, 80% increase in heat transfer was observed. From Figure.3, for 50 °C as inlet temperature of hot water at outer tube and 25 °C of cold water at inner tube, the maximum heat transfer occurs in both Y shaped and triangular fins with slight changes between them and also it can be observed that in the graph the line of triangular fin intersected the line of Y-shaped fin. The optimum heat transfer can be seen at Re=11000 for both Triangular and Y-shaped fins.

From Figure.4, by considering the 60 °C of hot water as inlet temperature at outer tube and 25 °C of cold water at inner tube it is clearly understood that the maximum heat transfer occurred at Y shaped fin quad tube heat exchanger. This is due the reason that surface area for Y-shape fin is much higher as compared to that of other fins considered in this work. Since the convection heat transfer directly proportional to surface area, higher the surface area higher will be the heat transfer. This results in higher heat transfer by Y-shape fins.

As we discussed, from above figures it is clearly understood that at low temperature triangular finned Quad Tubed Heat Exchanger holds the maximum efficiency and at slightly higher temperature Y-shaped fin Quad Tube Heat Exchanger showed the maximum efficiency. Also, the contours of every model are compared to understand the maximum heat transfer between the fluids. The above shown contours also indicate that maximum heat transfer efficiency occurred at quad tubed heat exchanger with triangular and Y shaped fins.
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triangular fins with slight changes between them and also it can be observed that in the graph the line of triangular fin intersected the line of Y-shaped fin. The optimum heat transfer can be seen at Re=11000 for both Triangular and Y-shaped fins.

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The above shown contours also indicate that maximum heat transfer efficiency occurred at quad tubed heat exchanger with triangular and Y shaped fins.

8. Conclusion

The heat transfer study was done on different types of fins of Quad Tubed Heat Exchanger by considering parallel flow with K-epsilon method where hot water flowing in outer tube and cold water was flowing in inner tubes. It is well known that high heat transfer occurs when the inner tube with cold water had more contact area with hot water at outer tube. From the results it can be concluded that an increase of 152% and 145% in heat transfer found for Y and triangular shaped fins respectively as compared to square fin for same inlet conditions. It is the reason being the surface area for triangular and Y shapes fins is much higher. Therefore, increasing the use of Y-shaped fin in industries and other applications can save time and money with its effective efficiency.

9. References

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