CFD Analysis for Different Types of Fins to Enhancement the Heat Transfer Rate Through A Cross Flow Heat Exchanger

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Abstract. The main target of this study is to find and compare the effect of fins design, surface area and air distribution on the heat transfer of the Cross-flow heat exchanger. This study includes Six different models designed using Solid work 2017 program and numerically analyzed using ANSYS 16.1. All finned tubes share similar dimensions with (24, 19 and 21) mm of outer, inner and root diameters respectively. The study clarified non-linear relationship between the increase in surface area, the rate of the heat transfer, the coefficient of the heat transfer and enhancement ratio, taking into consideration the effect of the external shape of the fin and the method of air distribution on the surface of the tubes. Circular fins with a rectangular section showed the best heat transfer rate among all others models, although the increase in surface area of circular fins was not optimal among the other fins.

Keywords: Cross-flow heat exchanger, types of fins, rate of the heat transfer, coefficient of the heat transfer, enhancement ratio.

1. Introduction
The cross-flow heat exchanger is a special type of heat exchanger where two fluids flowing in a perpendicular direction. The heat exchanger often comprises of number of tubes carrying hot medium along with the colder medium usually flowing over the tubes [1].

Optimizing heat transfer for heat exchangers is always the main target of developers in this field, in order to reduce manufacturing cost and minimizing the size of the parts. Thus, the present work aims to serve this approach; as it is well-known that the heat flows from hot temperature side to cold temperature side by mean of various mechanism such as thermal conduction, thermal convection, thermal radiation [2].

Many techniques were used to increase the heat exchangers thermal performance including passive, active and compound techniques. Passive technique does not require external power includes rough surfaces, extended surfaces, treated surfaces, displaced enhancement devices etc. In another hand, active technique requires external power and includes surface vibration, fluid vibration, mechanical aids etc. Compound methods include two or more techniques (active and passive) for enhancing heat
transfer [3]. In the absence of moving parts, passive methods are cost-effective and more efficient than active method [4].

The heat exchanger is very important in many industrial engineering applications. Has sparked the researchers interest in investigating ways to improve the heat transfer coefficient. Taher (2019) [5] carried out cross-flow heat exchanger 8 passes (smooth and finned tubes) using air as outside tubes and the water inside. Practical results showed that the external heat transfer coefficient of finned tubes is higher than smooth tubes and high finned tube has transferred heat more than the others fins. Srivastava et. al. (2015) [6] Study three types of fins formed on the outer side of the inner tube (rectangle, triangle and parabolic) was used at a different height with parallel flow double-tube heat exchanger. The water as a working fluid. By performing numerical simulations between the smooth tube and fins using the ANSYS software, the results showed that the tube provided with fins enhancement the heat transfer compared with the smooth and the best heat transfer fins were 6.1% respectively. Fins to choose the best geometrical shape of fins that work to improve heat transfer between two fluids with different temperatures.

However, another important factors directly impact heat transfer enhancement the heat transfer compared with the smooth tube and fins share similar dimensions with (24, 19 and 21) mm of outer, inner and root diameters respectively. Water was used as the hot medium which flowing inside the tube, and air as cold medium with temperatures of the inlet water are (50, 60, 70, 80 °C). The low integral finned tube is higher than smooth tubes and high finned tube has transferred heat more than the others fins. Srivastava et. al. (2015) [6] Study three types of fins formed on the outer side of the inner tube (rectangle, triangle and parabolic) was used at a different height with parallel flow double-tube heat exchanger. The water as a working fluid. By performing numerical simulations between the smooth tube and fins using the ANSYS software, the results showed that the tube provided with fins enhancement the heat transfer compared with the smooth and the best heat transfer fins were 6.1% respectively. Fins to choose the best geometrical shape of fins that work to improve heat transfer between two fluids with different temperatures.

As it is known adding fins to smooth tubes increases the heat transfer coefficient in heat exchangers. Thus obtaining the best heat exchange between two fluids with different temperatures. However, another important factors directly impact on the heat transfer coefficient and have to be taken in account. Those factors are the difference in the shape of the fins and methods of air distribution on the surface of the finned tube. In the current study, all the above stated factors have studied using six different types of fins that designed in the Solid work 2017 program and analyzed numerically in the Ansys 16.1 program.

The main aim of this study is enhancing the coefficient of heat transfer by using different shapes of fins to choose the best geometric shape of fins that work to improve the heat transfer between them by using passive technique.

2. Numerical model

This study includes smooth and six different finned tubes which designed via Solid work 2017 program and numerically analyzed using ANSYS 16.1 for cross-flow heat exchanger. In order to speed up the simulation, and to obtain an accurate mesh, a portion of the heat exchanger has been analyzed instead of full geometry; one tube instead of eight tubes see Farah Abdul Zahra Taher [5] for more details. Tubes made from copper with length 250 mm, the dimensions of controlled volume surrounding the tube (250×110×400 mm) as width, height and length, respectively, as shown in figure 1. Finned tubes share similar dimensions with (24, 19 and 21) mm of outer, inner and root diameters respectively. Water was used as the hot medium which flowing inside the tube, and air as cold medium.
flowing outside crossing the finned tubes. For the sake of the comparison, the boundary conditions of this study are similar to that in [5]. Briefly, the air velocity is (1 m/s), inlet air temperature is (22°C), volumetric flow of water (6 L/m), and the inlet water temperature is (50°C).

***Figure 1.*** Geometry of the smooth tube with dimension.

Six different types of fins were analyzed in this study named; Rectangular fins (10 fins) with angle 20 degrees from the original point, whose shape extracted from Srivastava al.et. [6], Circular with a rectangular section (16 fins) using pitches to height ratios (P/H) =10, the height is 1.5 mm, whose shape extracted from the Al-Kayiem al.et. [10].

In order to make the study more comprehensive, four shapes of fins designed specifically for this study as irregular rectangular fins were made on a tube (9 fins) with large angle 40 degrees and the small angle is 20 degrees from the original point, longitudinal triangle (18 fins) with 20 degrees arch length from the original point, circular with a triangular section (19 fins) the base length is 4.74 mm and the p (space between triangle head to other triangle head) are 12.5 mm. According to the ratio of the distance between the p to the outer diameter (P/D = 0.5), circular with a triangular section (same as 19 fins) but the ratio of P/D =0.25 and the number of fins is 38. Figure 2 shows the types of the fins and table 1 shows the different case study with specifications.

To solve the flow and heat transfer equations (continuity, momentum and energy equations) some assumptions should be made to fit the case under consideration. These assumptions are [Three-dimensional analysis, incompressible fluid, steady state, turbulent flow, physical properties of fluids are constant with temperature, adiabatic walls of tubes, negligible heat generation, heat radiation and heat dissipation (\(\Phi=0\)].

The rate of heat transfer is [11]:

\[
Q = UA\Delta T_{\text{LMT}}
\]  

(1)

The flow is counter, logarithmic mean temperature difference (LMTD) [12]:

\[
\Delta T_{\text{LMT}} = \frac{\Delta T_2 - \Delta T_1}{\ln \left(\frac{\Delta T_2}{\Delta T_1}\right)}
\]  

(2)

The overall heat transfer [11]:

\[
U_o = \frac{1}{\frac{h_s}{A_{s}} + \frac{\ln(h_0/A_{s})}{2\pi k_4l} + \frac{1}{h_0}}
\]  

(3)
Figure 2. Types of the finned tube with cross-section area. (a) Longitudinal Rectangular finned tube. (b) Longitudinal Triangular finned tube. (c) Circular finned tube with a triangular section (19 fins). (d) Circular finned tube with a triangular section (38 fins). (e) Circular finned tube with a rectangular section. (f) Rectangular finned tube.
Table 1. The different cases of the fins.

| No | Type of fins                                    | No. of Fins | Specifications                                                                 |
|----|------------------------------------------------|------------|-------------------------------------------------------------------------------|
| a  | Longitudinal Rectangular fin                   | 9          | large angle 40 degree and the small angle is 20 degree from the original point |
| b  | Longitudinal Triangular fin                    | 18         | with 20-degree arch length                                                    |
| c  | Circular with a triangular section             | 19         | base length is 4.74 mm and the p are 12.5 mm, the ratio of the distance between the p to the outer diameter, P/D =0.5 |
| d  | Circular with a triangular section             | 38         | With the ratio is P/D =0.25                                                   |
| e  | Circular with a rectangular section            | 16         | The pitches to height ratios (P/H) =10, the height is 1.5 mm                  |
| f  | Regular Rectangular fin                        | 10         | The angle 20 degree from the original point                                   |

Nusselt number of the water side [13]

\[
\text{Nu} = 0 \cdot 023 \text{Re}^{0.8} \text{Pr}^n \tag{4}
\]

\[
\text{Pr} = \frac{\mu C_p}{k} \tag{5}
\]

\[
N_u = \frac{h d}{k} \tag{6}
\]

\[
h_i = 0 \cdot 023 \text{Re}_w^{0.8} \text{Pr}_n^{0.2} \frac{k_w}{d_i} \tag{7}
\]

\[
\text{Re}_w = \frac{\rho_w u_o d_i}{\mu_w} \tag{8}
\]

The air side heat transfer coefficient of smooth and finned tube [11][13].

\[
h_o = \frac{1}{u_o} \frac{1}{\frac{d_o}{d_i} \ln \left( \frac{d_o}{d_i} \right)} \frac{d_o}{h_0 d_i} \tag{9}
\]

\[
h_o = \frac{1}{u_o} \frac{1}{\frac{d_o}{d_i} \ln \left( \frac{d_o}{d_i} \right)} \frac{d_o}{h_i d_i} \tag{10}
\]

The effectiveness for \( C_{max} \) mixed, \( C_{min} \) unmixed, the equation is [13]

\[
\varepsilon = \frac{1}{C_r} \left( 1 - \exp \left[ -C_r \left( 1 - e^{-NTU} \right) \right] \right) \tag{11}
\]

For \( C_{max} \) unmixed, \( C_{min} \) mixed, the equation is:

\[
\varepsilon = \left( 1 - \exp \left[ -\frac{1}{C_r} \left( 1 - e^{-NTU} \right) \right] \right) \tag{12}
\]

The heat capacity ratio is,

\[
C_r = \frac{C_{min}}{C_{max}} \tag{13}
\]

\[
\text{NTU} = \frac{U_o A_{os}}{C_{min}} \tag{14}
\]
The enhancement ratio (ER)

\[ ER = \left( \frac{h_{of} - h_{os}}{h_{os}} \right) \times 100 \hspace{1cm} (15) \]

To ensure that the results are accurate and the solution is true, grid independency test was implemented. Different element sizes were analyzed in simulation. As shown in figure 3 outlet water temperature stabilized at (5, 4.5 and 2). Therefore, the size of the element was chosen as 2 mm to increase simulation accuracy at the expense of the time taken for the solution. This can be considered as the better mesh for the calculation. Table 2 shows the element size, number of elements, number of nodes and outlet water temperature.

![Figure 3. The test of grid independence between number of element and outlet water temperature.](image)

| Element size | Number of elements | Number of Nodes | water outlet temperature |
|--------------|--------------------|-----------------|--------------------------|
| 7            | 497335             | 95558           | 323.1111                 |
| 5            | 949438             | 174667          | 323.1106                 |
| 4.5          | 1218636            | 221463          | 323.1103                 |
| 2.5          | 1575313            | 280545          | 323.1116                 |
| 2            | 1644522            | 295047          | 323.11014                |
| 1.5          | 1742932            | 314455          | 323.1089                 |
| 1            | 2127266            | 384941          | 323.1115                 |

The reliability of the numerical model including experimental and numerical study for integral finned tube heat exchanger has been previously studied [5]. A comparison was made between the heat transfer rate results of the current study and the results of [5] using air velocities (1, 1.7 and 2.3 m/s). The results are almost identical to the previous study. The error in the rate of heat transfer is 0.0771%. Figure 4 shows the comparison between the present work and [5]. In figure 4a due to the low error rate, the two lines are identical in the drawing however, it is illustrated in figure 4b.
Figure 4. The comparison between the comparative research and the present work, (a) the rate of heat transfer and air velocity, and (b) 3-D area chart.

3. Results and discussion

Table 3 show the types of fins, the rate of the heat transfer, the enhancement surface area, the coefficient of heat transfer and the enhancement ratio, as well as, the discussion involve the effect of the shape on heat transfer. The results show that the circular fins are the best fins. Circular fins with a rectangular section showed the best heat transfer rate among all others models, due to discontinuous thermal boundary layer, although the increase in surface area of circular fins with a rectangular section were not optimal among the other fins. This behavior can be explained as a result of the uniform distribution of air on the surface of the tube, in additional vortexes formed behind the tube penetrate the boundary layer and this reduce thermal resistance and increase heat transfer [14]. Figures (5) shows the contour of the fin’s types. The surface area of the longitudinal rectangular, longitudinal triangular and regular rectangular fins is higher than the circular fins with a rectangular section but the enhancement ratio is less because the shape of the other fins works as buffers to prevented air from flowing smoothly and whenever the vertical distance behind the tube increase, the amount of heat transfer decrease (the circular fins with a rectangular section distance behind the tube is shorter than the others fins; therefore it is the best) also, the reverse vortexes reduce heat transfer because one of them reduces the energy of the other as shown in the figure 6. Figure 7a shows that when the rates of heat transfer increase, the coefficient of the heat transfer increases. Figure 7b shows that the increase in heat transfer causes increasing in the enhancement.
Table 3. Types of fins with different parameters.

| Types                                               | Q(w)       | Enhancement surface area | ho (w/m²s) | ER=(ho−ho)/ho * 100 |
|-----------------------------------------------------|------------|--------------------------|------------|----------------------|
| Smooth tube                                         | 12.059693  | ---                      | 6.611781   | ---                  |
| Longitudinal Rectangular fin                        | 14.813638  | 13.2%                    | 8.181655   | 23.74%               |
| Longitudinal Triangular fin                         | 14.473861  | 18.3%                    | 7.973859   | 20.6%                |
| Circular with a triangular section (19 fins)        | 14.007162  | 5%                       | 7.621287   | 15.26%               |
| Circular with a triangular section (38 fins)        | 15.79796   | 10%                      | 8.707008   | 31.68%               |
| Circular with a rectangular section                 | 15.852697  | 11.2%                    | 8.792783   | 32.98%               |
| Rectangular fin                                     | 14.66896   | 27.8%                    | 8.091946   | 22.38%               |

Figure 5. Temperature contour of all types of the fins, (a) smooth tube. (b) Longitudinal Rectangular finned tube. (c) Longitudinal Triangular finned tube. (d) Circular finned tube with a triangular section (19 fins). (e) Circular finned tube with a triangular section (38 fins). (f) Circular finned tube with rectangular section. (g) Rectangular finned tube.
Figure 6. the temperature vector of the air part of (a) Longitudinal Rectangular finned tube. (b) Longitudinal Triangular finned tube. (c) Circular finned tube. (d) Regular rectangular finned tube.

Figure 7. (a) the relationship between the rate of the heat transfer and heat transfer coefficient. (b) the relationship between the heat transfer coefficient and ER.
4. Conclusions
The present numerical study investigated six types of fins to get the best one that can transfer more
heat. This study shows that an increase in the heat transfer coefficient for all its the shapes select,
respected to smooth tube, but this increase will be different according to the geometric shapes of the
fin, as follows:
1- The circular fins with a rectangular section are the best one.
2- The shape of the fin effects on the heat transfer.
3- Vortexes formed behind the tubes penetrate the boundary layer and these reduce thermal
resistance and increase heat transfer.
4- Due to the effect of the fins shape on the tube, the rate of the heat transfer does not always
increase when the surface area increases.
5- The increasing of the rate of heat transfer leads to increase in the heat transfer coefficient (ho)
and enhancement ratio (ER).

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