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Performance Study of Fins and Tube Heat Exchanger with Different Fin Geometry

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Abstract

In various engineering devices, a considerable amount of thermal energy has to be dissipated through a small area using extended surfaces referred to as fins. The insufficient rate of thermal energy dissipation in heat exchangers has created a high demand for more powerful engines in smaller hood spaces. For this reason, a two-phased study was carried out to examine the relationship between varying fin shapes and their heat transfer performance, considering three selected geometric shapes namely, rectangular, triangular, and trapezoidal. The first phase (experimental) was used to analyze the performance of rectangular fins and Tube Heat Exchanger (HE) using car radiator while the second phase (numerical) was used to investigate all the selected fin geometries while an experimental test rig was developed with commercially available car radiator. A 1.5kW electrical heater was used to heat the water and circulated using 0.5 HP centrifugal pumps and gate valve with varying coolant of 0.1-0.3 Kg/s flow rate was used. The result indicates that experimental and numerical heat loss across the various fin geometries decreases as the mass flow rate decreases. Performance analysis of the fins and tube heat exchanger has shown that heat loss for trapezoidal fins and tube heat exchangers are higher when compared with the other fins geometry.

Keywords: Fins, Tube, Heat Exchanger, Thermal Energy, Computational Fluid Dynamics (CFD)

1. Introduction

1.1 Study Background

Devices that allow heat flow from one fluid medium to another fluid medium without both fluids having to mix or come directly in contact is known as the heat exchanger. The fluids may also be in direct contact in some peculiar cases. But the essential principle of a heat exchanger is that it transfers the heat without necessarily transferring the fluid that carries the heat [1]. In some instances, the fluids may also be in direct contact with heat transferred. Thus, the basic concept of a heat exchanger is its ability to transfer heat from one medium to another without necessarily transferring the fluid that carries the heat [2]. Thermal energy transfer generally occurs due to temperature at different modes of heat transfer (i.e. conduction, convection, and radiation) [3]. Fins are appendages or components of thin material attached to a larger structure. Based on the cross-sectional area type, straight fins are of different types such as rectangular fin, triangular fin, trapezoidal fin parabolic fin, or cylindrical fin. Fin performance can be measured by using the effectiveness of fin, thermal resistance, and efficiency [4].

1.2 Analysis of Heat Transfer

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The accurate analysis of heat transfer in the extended surface has become crucial with the growing demand for high performance considering smaller weights, volumes, the initial and running cost of the system [5]. Over the years contrasting fin profiles have been transformed upon the application and geometry of the primary surface. It has been identified that there are three main fin geometries [6]. These are longitudinal fins, radial or circumferential fins, and pin fins or spines. Numerous investigations have proposed high-performance heat removal characteristics. Among that numerical optimization was used to estimate the shape of pin-fins for a heat sink to improve the cooling efficiency [7]. Therefore, the constructive heat exchanger design algorithm enhances the efficiency of heat exchangers and reduces the duration along with the cost of the design process [8]. Fins are surfaces that extend from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Increasing the temperature gradient between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer [9]. Sometimes it is not feasible or economical to change the first two options. Thus, adding a fin to an object increases the surface area and can sometimes be an economical solution to the heat transfer problem [10].

In many engineering applications, a large amount of heat has to be dissipated through small areas. The above purpose is to be met by making use of extended surfaces referred to as fins [11]. In a practical application in engineering, different fin geometries are considered. They may be of a uniform cross-sectional area or variable cross-sections. The concept of this present work is to investigate whether the parameters of heat transfer of fins are affected by varying its shapes. The geometric shapes chosen for this project were rectangular, triangular, and trapezoidal fins but are of the same surface area.

1.3 Concept of Heat Exchangers

Heat transfer is thermal energy, which occurs in transits due to temperature difference. The modes of heat transfer are conduction, convection, and radiation**.** Heat transfer is thermal energy, which occurs in transits due to temperature difference. The modes of heat transfer are conduction, convection, and radiation. A heat exchanger is a device whose primary responsibility is the transfer (exchange) of heat, typically from one fluid to another [12]. However, they are not only used in heating applications, such as space heaters but are also used in cooling applications, such as refrigerators and air conditioners [13]. Many types of heat exchangers can be distinguished from one another based on the direction the liquids flow, in such applications, the heat exchangers can be parallel-flow, cross-flow, or countercurrent heat exchangers, the fluid paths flow in opposite directions, with each exiting where the other enters. Countercurrent heat exchangers tend to be more effective than other types of exchangers [14].

Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi-component fluid streams. In other applications, the objective may be to recover or reject heat or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact [15]. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally, they do not mix or leak. Such exchanges are referred to as direct transfer type, or simply recuperators. Also, thermal energy storage in a heat exchanger for cold and fluids where the heat transfer occurs within the exchanger matric are referred to as simply regeneration [16].

Stirred tank reactor and agitated vessels are typical examples of mechanical devices used in some exchangers where heat energy is transferred within the separating walls of the recuperators by conduction [17-18]. However, a heat exchanger in heat pipes can be facilitated by various mode of heat transfer mechanism irrespective of the kind of working fluid within the pipe On a general note, for immiscible fluids, where the heat transfer surface are replaced by the fluid interface, then separating wall can be eliminated [19--20].

1.4 Classifications of Heat Exchangers

Heat exchangers are classified according to transfer processes into indirect- and direct contact types. In an indirect-contact heat exchanger [21], the fluid streams remain separate and the heat transfers continuously through an impervious dividing wall or into and out of a wall in a transient manner [22].

Thus, ideally, there is no direct contact between thermally interacting fluids [23]. This type of heat exchanger also referred to as a surface heat exchanger, can be further classified into direct-transfer type, storage type, and fluidized-bed exchangers [24].
For a direct-contact exchanger, two fluid streams come into direct contact, exchange heat, and are then separated. Common applications of a direct-contact exchanger involve a mass transfer in addition to heat transfer, such as in evaporative cooling and rectification; applications involving only sensible heat transfer are rare [25]. Comparing the indirect contact recuperators and regenerators, in direct-contact heat exchangers, there is very high heat transfer rates are achievable, the exchanger construction is relatively inexpensive, and the fouling problem is generally nonexistent, due to the absence of a heat transfer surface (wall) between the two fluids [26].

1.5 Extended Surface – Fins

The special case of heat transfer by conduction is a term that can be attributed to extended surfaces for thermal exchange within solid and by convection/radiation with its borders. Surface extensions are attributed to fins by which heat transfer rate can be increased by convection [27]. The addition of fins to a heat transfer surface does enhance the surface area of the heat exchanger which in-turn brings an economic solution to heat transfer-related problems [28]. Examples of surfaces where fins are used are Air-cooled ICE, Refrigeration condenser tubes, Reciprocating air compressors, Semiconductor devices, Automobile radiators, etc. The different classifications of fins are depicted in Fig. 1 below.

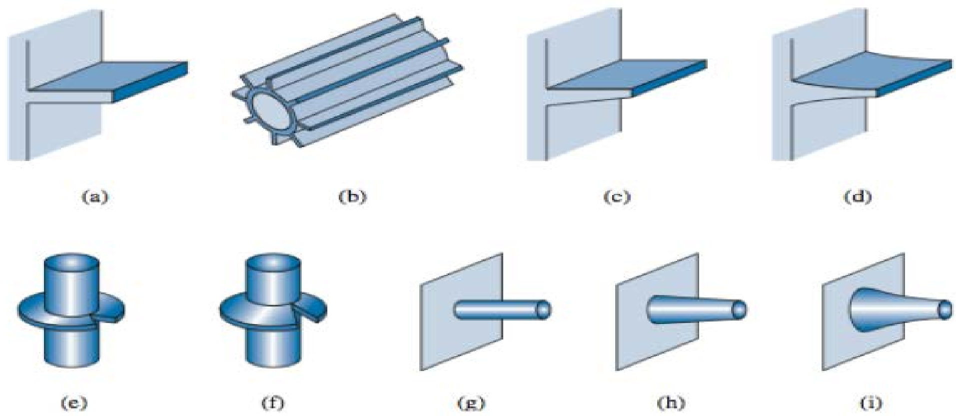

Figure 1: Classifications of Fins; **(a)** Longitudinal - Rectangular profile **(b)** Longitudinal - Circular Profile **(c)** Longitudinal - Trapezoidal profile **(d)** Longitudinal - Concave parabolic **(e)** Radial – Rectangular profile **(f)** Triangular profile **(g)** Pin - Cylindrical **(h)** Pin - Tapered profile Pin **(i)** Pin -Concave Parabolic [30]

1.6 Previous Studies on Heat Exchangers Fins

Various works have been done by researchers on heat exchangers ranging from heat transfer enhancement of nano-particles in fluid base with various configurations. It has also been established that the optimization of heat exchangers sizes under a condition of thermal comfort cause a huge pressure drop within the heat transfer fluids of vortex generator. Guo- yan *et al.* [7] do establish that Heat Transfer Research Incorporations (HTRI) method for temperature prediction in heat exchanger do give a better accuracy but this model approach is limited to straight and U-tube heat exchangers.
Eiamsa-ard, *et al.* [6] established that several factors can be responsible for the optimum performance of heat exchangers such as friction, heat transfer rate, thermal conductivity, etc. In contrast, the efficiency of various fins geometry was not considered like circular fins, triangular fins, and trapezoidal fins. Thus, heat recovery system efficiency does increases with the fin numbers and the recovery models model length as asserted by Hitami, *et al.* [8]. Srinivasan, *et al.* [22] have established that the Divine Measure Analysis Improve Control can be used to ascertain the shell effectiveness and performance of tube heat exchanger while Tawat, *et al.* [24] asserted that the efficiency of oscillating

pipe fins is 5% more efficient than that the conventional fins. Nopparat, *et al.* [13] revealed that staggered dimple arrangement of about 21.7% can provide optimum performance resistance better than the flat plates even as Patil, *et al* [28] as already postulated that that natural convection heat transfer increase with fin height and fin length even when the effect of forced convection on heat transfer of different fins geometry are not considered. Weikla, *et al.* [29] also attests to the fact that coil-wound heat exchangers have advantages over shell and tube heat exchangers without considering other types of heat exchangers (i.e. Tubes and Fins). Manglik, *et al*. [10], provide a first-hand analysis of fin optimization and its effect in heat exchangers. It was found out that the flow mal-distribution due to design limitation may result in a reverse flow of fluids [27]. Limited only to microchannel heat exchangers, microchannel because heat exchangers have a characteristic of higher heat transfer rate, compact size, and low cost [30]. Thus, having considered previous works on heat exchangers, they failed to investigate the other fin geometry (i.e. circular, triangular, and trapezoidal) efficiency was not considered. Therefore, this present work entails the determination of the performance of fins and tube heat exchangers with different fin geometries and tube heat exchangers. This was carried out through experimental and computational analysis on the performance of fins and heat exchangers the determination on heat transfer parameters such as pressure loss, heat transfer rate, maximum operating temperature, and efficiency of rectangular, triangular, and trapezoidal fins. Comparing fin effectiveness and determination of fin geometry that produces maximum heat transfer will also be ascertained.

2.0 EXPERIMENTAL PROCEDURE

2.1 Materials and Methods

This is a two-phase study, where the experimental method was used in the first phase to analyze the performance of a tube and rectangular fins heat exchanger using a car radiator. In the second phase, numerical simulation was carried out and used to investigate all selected fins geometry which is rectangular, triangular, and trapezoidal. The experiment rig consists of the car radiator with known material specification (Size: 740 × 460 × 16mm; fin-copper, Tube-brass, 200 tubes and 0.34mm^2) serpentine area with electric pump, thermocouples, pressure gauge, gate valve, water reservoir, flow meter as the components of the experimental rig set-up and schematic are shown in Fig. 2 below.

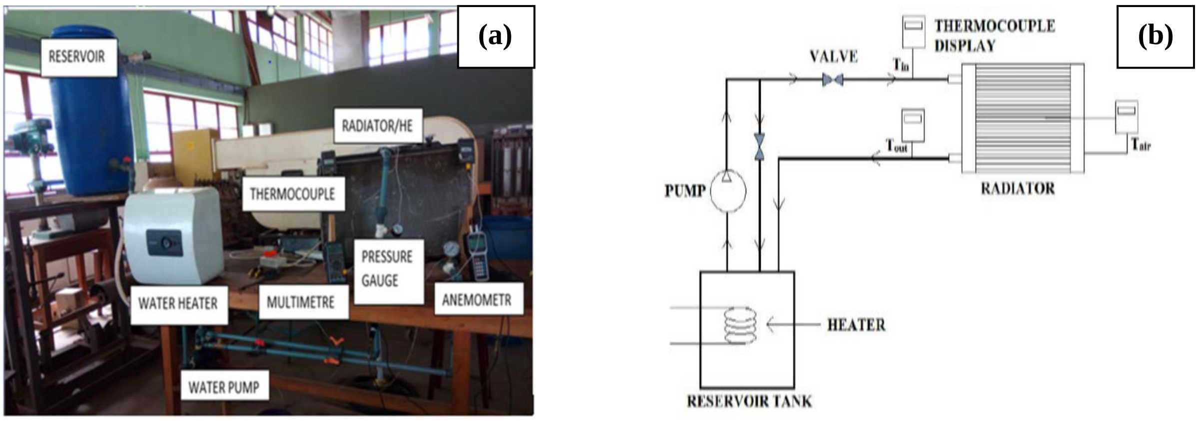

Figure 2: Experimental Rig Set-up **(a)** Full View **(b)** Schematic View

2.2 Experimental Procedure

The water flows from the reservoir into the heater by gravity. The water after heated to the desired temperature was circulated through the radiator by a pump. The water temperature at the inlet of the radiator was kept constant under a nominal operating temperature of 850^{0}C (1123K) and the mass flow rate was varied between 0.1 to 0.3 kg/s through a pipe of an inner diameter of 0.75 inches (19.05mm). The fan is switched on to blow away the heat from the hot fluid from the radiator to the environment.

The temperatures are recorded at the radiator inlet and outlet as the air velocity was kept constant at an average value of 4m/s. The K-type thermocouple was used to record the water outlet temperature and the air temperature within the walls of the radiator. The boundary conditions used are shown in Tables 2 and 3 below.

2.2.1 Radiator Performance

The characteristics of heat transfer of any given exchanger surface geometry can be carried out based on the Log Mean Temperature Difference (LMTD) and ε-NTU approach [31]. Two common methods exist for expressing the heat transfer characteristics of a given heat exchanger surface geometry. The exchanged heat amount is governed by the driving force of the LMTD approach which is quite simplistic and straight forward [32]. Thus, the approach is quite unsustainable in heat exchanger cases where phase changer does occur. Also, the LMTD approach cannot be used for cases of fluids exhibiting specific heat changes. In this case, there is no change of state therefore the LMTD approach is used to analyses experimental results. The heat loss or gain within the working fluids of the heat exchanger's cab serves as a deterministic factor in the analysis of its effectiveness and performance [33]. The fin efficiency at water end based on heat lost can be expressed as:

Heat Loss with fins: $$Q_h = m_h C_{ph}(T_{hi} - T_{ho}) \quad (1)$$

Heat Loss without fins: $$Q_c = m_c C_{pc}(T_{ci} - T_{co}) \quad (2)$$

The efficiency of Fins: $$\eta_{eff} = \frac{hA_s(T_s - T_\infty)}{hA_b(T_b - T_\infty)} \quad (3)$$

The efficiency of Fins: $$\frac{heat\ loss\ with\ fins}{heat\ loss\ without\ fins} = \eta_{eff} = \frac{hA_s}{hA_b} \quad (4)$$

2.3 Computational Fluid Dynamics in Heat Exchangers

Computational fluid dynamics (CFD) is an aspect of fluid mechanics that deals with time development and reliability increase of engineering designs using Navier stoke equations. The modeling of the radiator was done using Solidworks flow simulation software to analyze and solve CFD related problems using a numerical method and mathematical algorithms. CFD analyses reduce development time and increase the reliability of the design. Naiver stoke equation is the basis of all CFD problems [34]. CFD provides the ability to simulate any physical condition. Simulation of a model can be executed within a period with the help of high-speed computers [35]. The analysis was carried out on Heat Exchanger without fins, with rectangular fins, triangular fins, and trapezoidal fins using CFD analysis. Thus, in this present work, the software generated equations for each node using the governing equation and solves the resulting equation iteratively. The temperature distribution and the pressure distribution were displayed by the software and the outlet temperatures and pressures of the water were recorded. The water temperature at the outlet was used to actualize the rate of heat transfer in the water and effectiveness. The pressure drop was also calculated. The pressure drops, heat transfer rate effectiveness of fins geometry were compared to establish which fin gives the most optimum effectiveness based on performance. The experimental results, the Computational Fluid Dynamics (CFD) results of the rectangular fins were validated. The inlet temperature of the water was kept constant while the temperature of the air was varied and readings were recorded. The temperature of the coolant was also recorded from the contour plot.

2.3.1 Geometry Modeling

The part modeling of the tube was drawn in Solidworks (CAD 2016). To reduce complexity, four (4) tube sets were drawn completely instead of modeling the radiator core. Pattern command was used to model the fins. To increase the accuracy of the result, the serpentine type of fins was used to reduce the normal computational time and to cater for the unavailability of a high-speed computer where the analysis does cater for single tube fins. Consideration of the tube symmetry over its length was done for further implication. Result obtained in this section is replicated for the whole model of the radiator core. It was ensured that the three geometries have the same surface area as $8mm^2$. The model analysis that has been used is depicted in Fig. 3 and 4 below. Shown in Fig. 4 and Tables 1 and 2 below are the sectional views of the geometry model and material specification for the rectangular, triangular, and trapezoidal fins.

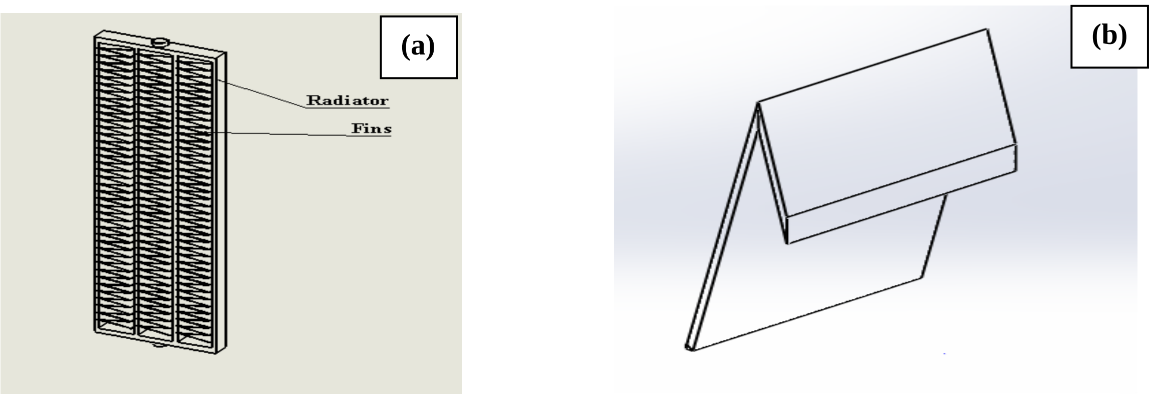

Figure 3: (a) Radiator with Fins **(b)** Sectional View of Rectangular Fins Geometry

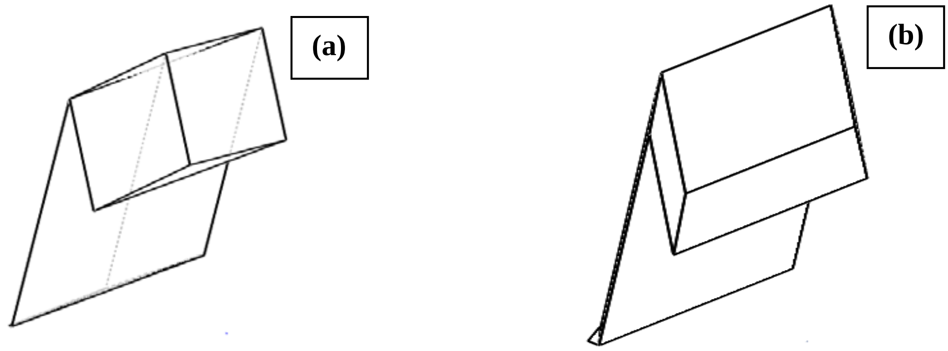

Figure 4: Sectional View of Fin Geometry **(a)** Triangular **(b)** Trapezoidal

Table 1: Material Properties of Fin-Copper and Tube Brass

Material Properties	Fin – Copper	Tube-Brass
Thermal conductivity	394 W/Mk	110 W/mK
Density	8.94 g/m^3	8.75 g/m^3
Specific heat	394 J/kgK	380 J/kgK

Table 2: Dimension of Radiator Used for the analysis

S/No	Parameters	Specification
1	Dimensions of inlet and outlet tanks (mm)	1.2 X 1.1 X 0.5 cm
2	Shape of tube	Rectangular
3	Length of tube	4.60 cm
4	The thickness of the fin tube	0.05 cm
5	Number of tubes	32
6	The breadth of the tube	1.6 cm
7	The thickness of the tube	0.05 cm
8	Distance between two fins	0.285 cm
9	Rectangular Fin	1.6 X 0.05 X 3.0 cm

10	Triangular Fin	1.6 X 0.1 X 3.0 cm
11	Trapezoidal Fins	1.6 X 0.05 X 3.0 cm

2.3.2 Meshing

The discretization of the tube heat exchanger assembly into its elemental component using the finite element method in respect of its original body in terms of the original is called meshing. During meshing, the division of the software model was done into many small components, to increase the accuracy of results. Every small component was analyzed to obtain the desired result. Thus, a reduction of computational time for meshing on the tube and fin surface was done to ascertain the result accuracy as shown in Fig. 4 below.

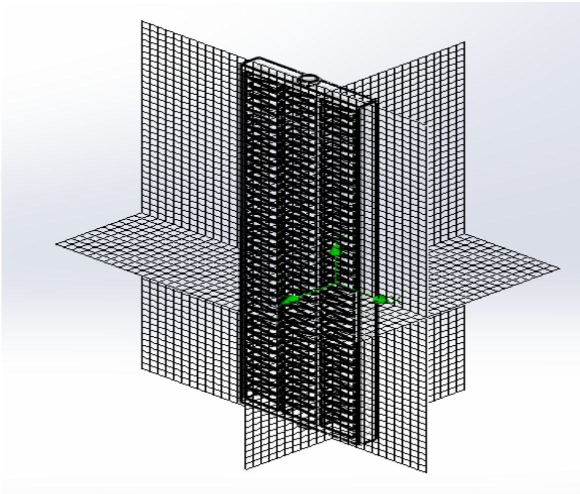

Figure 5: Meshing of the Geometry

2.3.3 Boundary Conditions

This study required the use of boundary conditions of fluid entrance and exits of the model at specific fluid flow properties. (i.e.fluid velocity, pressure drop, mass and volume flow rate). The following boundary conditions are specified for the analysis as shown in Table 4 below

Table 4: Experimental and Numerical Boundary Conditions

S/N	Boundary Conditions	Value
1.	The velocity of Air at the Radiator Surface	4.3 m/s
2.	Mass Flow rate of Water Range	0.10 - 0.30 kg/s
3.	Pressure Condition of Water	0.25 bar
4.	Inlet Temperature of Water:	358K
5.	The inlet temperature of Air	20 - 40^{0}C

3.0 RESULTS AND DISCUSSION

The experimental results of the effect of mass flow rate and pressure drop based on heat loss were first presented. Then results relating to those of numerical investigations of a radiator with triangular, rectangular, and trapezoidal fins were then presented. The results for experimental and numerical were also discussed accordingly.

3.1 Comparison of Numerical and Experimental Data for Rectangular Fins

Results of both the numerical and experimental analysis for rectangular fin geometry are comparatively discussed. The plots of numerical and experimental values of the mass flow rate against the heat loss for rectangular fins geometry are indicated in Fig. 6 below. Apparently from the Figures, the mass flow rate for both the numerical and experimental analyses increases with a decrease in heat loss. The correlation coefficient between the numerical data and experimental data is 0.9678 which implies that the numerical results are not significantly different from the experimental results.

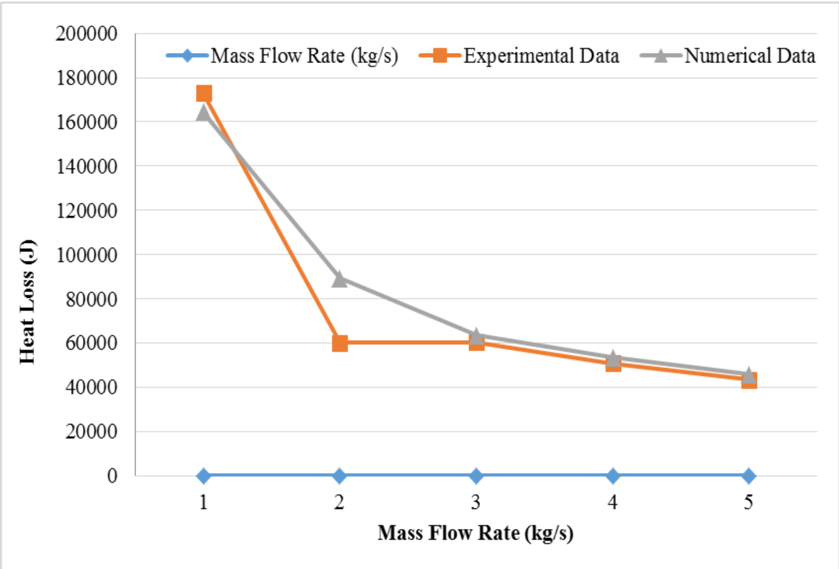

Figure 6: Plots of Numerical and Experimental Values of the Mass Flow Rate against the Heat Loss for Rectangular Fins Geometry

3.2 Effect of Temperature and Pressure Distribution in Tube and Fins

The mass flow rate and air inlet temperature effect on heat exchanger performance with different fin geometries (Triangular, Trapezoidal and Rectangular Fins) as the contour plots for the temperature and pressure distribution in the rectangular, trapezoidal, and triangular fins geometry of the heat exchanger based on numerical analysis are shown in Fig. 7 to Fig. 9 below.

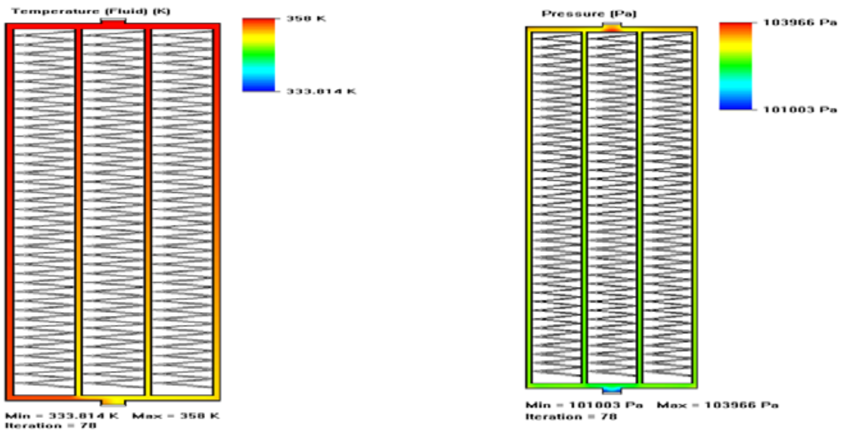

Figure 7: The Temperature and Pressure Distribution for Trapezoidal Fin Geometry

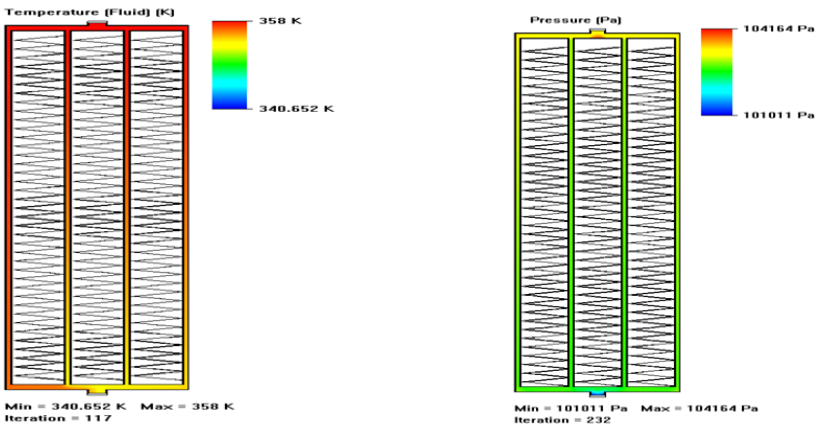

Figure 8: The Temperature and Pressure Distribution for Triangular Fin Geometry

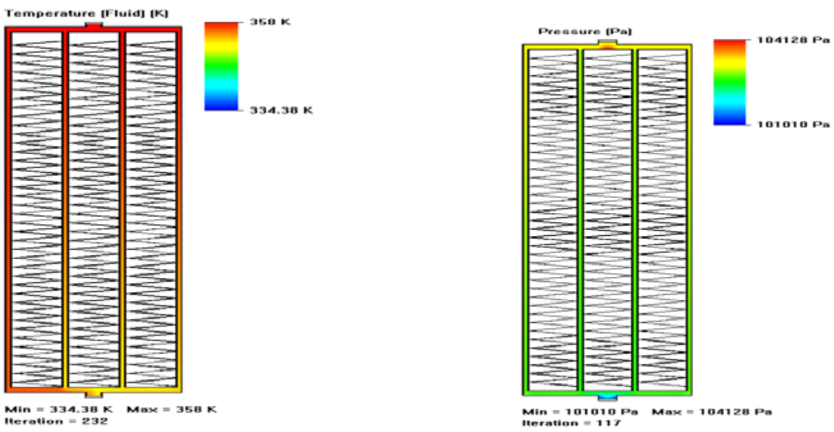

Figure 9: The Temperature and Pressure Distribution for Rectangular Fin Geometry

3.3 Variation of Mass Flow Rate with Pressure Drop, Heat Loss, and Effectiveness of Different Fins

The graph plots showing the mass flow rate effect on the triangular, rectangular, and trapezoidal fins geometry against the pressure drop and heat loss are as shown in Fig. 10. It can be observed that as the pressure drop decrease as the water mass flow rate increases across the rectangular, triangular, and trapezoidal fin geometry while the heat loss by the fin increases.

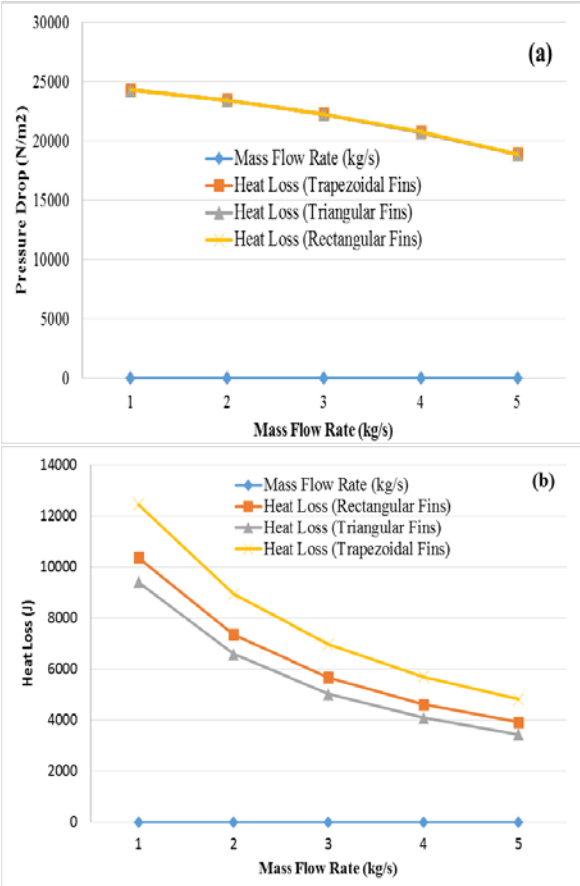

Figure 10: Effect of Mass Flow Rate in Different Fins Geometry **(a)** Pressure drop **(b)** Heat Loss

3.4 The Variation of Inlet Air Temperature with Pressure Drop and Heat Loss for Triangular Fins

Here, the result was discussed sequentially according to the parameters being varied to ensure clarity in understanding of presentations. Thus, the effect of variation of air inlet temperature on the flow pressure drop and heat loss is depicted in Fig. 11.

The graph plots showing the effect of Inlet air temperature on the triangular, rectangular and trapezoidal fins geometry against the pressure drop and heat loss are as shown in Fig. 11 below. It can be observed that pressure drop decreases as air temperature at the inlet and heat loss increase.

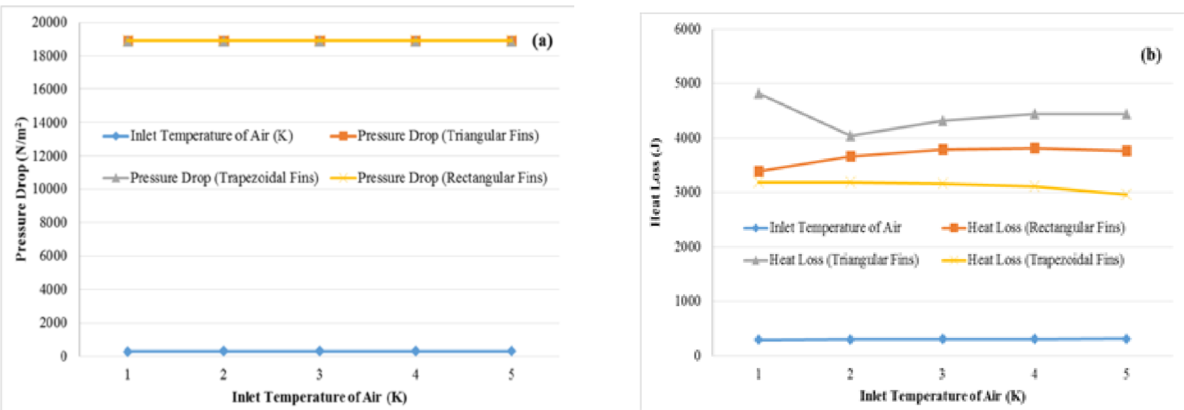

Figure 11: Effect of air temperature at the inlet for Different Fin Geometry based on **(a)** Pressure drop **(b)** Heat Loss

4.3 Comparison of the Performance of Different Fin Geometry

The comparison of the effectiveness of the fin geometry been considered is based on the fins ability to lose heat effectively. From the plot as depicted in Fig. 12 below, the heat loss by trapezoidal fin geometry is higher than that of triangular and rectangular while that of rectangular is higher than that of triangular. Therefore, Trapezoidal Fin geometry is the most effective among the three fin geometry considered in this research work, followed by the rectangular fin and the least remains the triangular fin geometry in terms of ability to easily eradicate heat from the system under consideration at a constant flow rate.

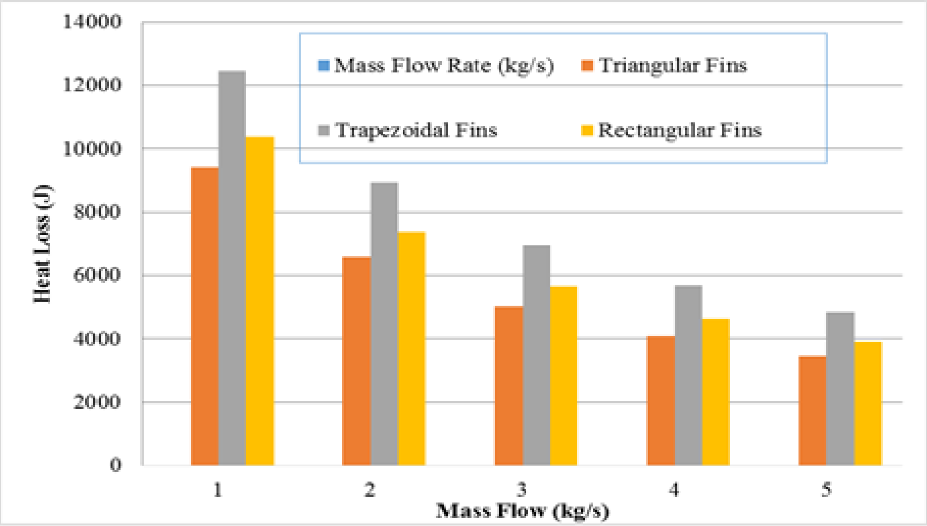

Figure 12: Comparison Chart for the Different Fin Effectiveness

4.0 CONCLUSION

This present study gives a clear cut analysis of the performances of three fin geometry, namely triangular, rectangular, and trapezoidal. Two approaches were adopted (Experimental and Numerical) to investigate the performances of these fins in heat exchangers. Experimental analysis was carried out on only the rectangular fins while numerical analysis was carried out on all the three fins geometry namely (Rectangular, Trapezoidal and triangular). The numerical analysis was validated with the experimental analysis. The effects of mass flow rate on the heat exchanger performance with triangular, trapezoidal as well as rectangular fins were examined. The air inlet temperature also affects the performance of the heat exchanger was also observed. Based on all these considerations, the following were deduced:

- A decrease in pressure drop and heat loss occurs as a result of an increase in coolant mass flow rate
- Ambient temperature increase within the environment of tube and fin heat exchangers gives a decrease in heat loss as well. The optimum operating temperature is 358K and 293K for the inlet temperature of water and air respectively.
- The heat loss for trapezoidal fins and tube heat exchanger is higher compare with rectangular and triangular fin geometry.
- Solid works Computational fluid dynamics software provides an accurate solution to the analysis of fin and tube heat exchanger.

Conflict of Interest

The authors declared they have no conflict of interest relevant to this article

5.0 REFERENCES

1. Ali N. A.; Sopian, K..; Mohammed, H.A.; Mohd H. R. and Azher, M.A. (2014): Enhancement Heat Transfer Characteristics in the Channel With Trapezoidal Rib–Groove Using Nanofluids", Case Studies in Thermal Engineering, Vol. 5, No. 5, pp. 48–58.
2. Azher, M.; Abed, K. Sopian, H.A; Mohammed, M.A.; Alghoul, M.H; Sohif, M; and Ali, N.A (2015): Enhance Heat Transfer In The Channel with V-Shaped Wavy Lower Plate Using Liquid Nanofluids, Case Studies in Thermal Engineering, Vol. 5, No. 2, pp. 13–23.
3. Chandraprabu, V.; Sankaranarayanan, G.; Iniyan, S.; and Suresh, S. (2014): "Heat Transfer Enhancement Characteristics of Al_2O_3/Water and CuO/Water Nanofluids in a Tube in Tube Condenser Fitted with an Air Conditioning System—An Experimental Comparison", Journal of Thermal Science and Engineering Applications, Vol. 6, No. 1, pp. 1-5.
4. Christopher Ian Wright (2014): Effective Management Of Heat Transfer Fluid Flash Point Temperatures Using a Light-Ends Removal Kit (LERK), Case Studies in Thermal Engineering, Vol. 4, No. 2, pp. 9 – 14.
5. Dustin R.; Ray and Debendra K. D. (2014): Superior Performance of Nanofluids in an Automotive Radiator, Journal of Thermal Science and Engineering Applications, Vol. 6, No. 1, pp. 1-16.
6. Eiamsa-ard, P.; Piriyarungroj, N.; Thianpong, C. and Eiamsa-ard, S. (2014): A Case Study On Thermal Performance Assessment of a Heat Exchanger Tube Equipped with Regularly-Spaced Twisted Tapes as Swirl Generators, Case Studies in Thermal Engineering, Vol. 3, No. 9, pp. 86–102.
7. Guo-yan Zhou, Ling-Yun Zhu, Hui Zhu, Shan-tung Tu and Jun-jie, L. (2014): Prediction of Temperature Distribution in Shell and Tube Heat Exchangers, Energy Procedia, Vol. 61, pp. 799 – 802.
8. Hatami, M.; Ganji, D.D. and Gorji-Bandpy, M. (2014): Numerical Study of Finned Type Heat Exchangers for Ices Exhaust Waste Heat Recovery, Case Studies in Thermal Engineering, Vol. 4, pp. 53–64.
9. Jiin-Yuh, J.; Ling-Fang, H. and Jin-Sheng, L., (2013): Optimization of the Span Angle and Location of Vortex Generators in A Plate-Fin and Tube Heat Exchanger, International Journal of Heat and Mass Transfer, Vol. 67, pp. 432–444.
10. Manglik, R. M.; Huzayyin, O. A. and Jog, M. A. (2011): Fin Effects in Flow Channels of Plate-Fin Compact Heat Exchanger Cores, Journal of Thermal Science and Engineering Applications, Vol. 3, No. 1, pp. 1-9.
11. Mushtaq, I. H.; Hayder, M. H; .and Adnan, G. A.; (2014): Study of the Axial Heat Conduction in Parallel Flow Micro-channel Heat Exchanger, Journal of King Sa'ad University – Engineering Sciences, Vol. 26, pp. 122–131.
12. Neda, G. and Amin, H. P. (2014): Heat Exchanger Design of Direct Evaporative Cooler Based on Outdoor and Indoor Environmental Conditions, Journal of Thermal Science and Engineering Applications, Vol. 6, No. 1, pp. 1-9.
13. Nopparat, K.; Nat, V.; Tanongkiat, K.; Yottana, K.; Damorn, B. and Atipoang, N. (2014): Heat Transfer Behavior Of Flat Plate Having 45° Ellipsoidal Dimpled Surfaces, Case Studies in Thermal Engineering, Vol. 2, No. 8, pp. 67–74.
14. Pardeep, S.; Harvinder, L.; Baljit, S. U. (2014): Design and Analysis for Heat Transfer through Fin with Extensions, International Journal of Innovative Research In Science, Engineering and Technology.
15. Rangadinesh, S.; Rajasekar, M.; Arunkumar, S. and Venkatesan, M. (2014): Experimental and Numerical Analysis on Heat Transfer Characteristics of Shoe Brush-Shaped Fins", School of Mechanical Engineering, Sastra University, Tirumalaisamudram, Thanjavur, Vol. 613, No. 401.
16. Ren-Tsung, H.; Wen-Junn, S. (2008): Orientation Effect On Natural Convective Performance Of Square Pin Fin Heat Sinks", International Journal of Heat And Mass Transfer Vol. 51, No. 1, pp. 2368–2376.
17. Sachindra K. R.; Dipti P.; Dhirendra N .T.; and Asit K.(2012.): Numerical Analysis Of mixed Convection Through An Internally Finned Tube", Hindawi Publishing Corporation Advances In Mechanical Engineering Volume.
18. Saneipoor, P, Naterer, G. F. and Dincer, I. (2014): Transient Temperature Response of Variable Flow Heat Exchangers in a Marnoch Heat Engine, Journal of Heat Transfer, Vol. 136, No. 3, pp. 1-8.
19. Sheng-Chung, T. and Tzer-Ming, J. (2013): Experimental Analysis of Mixed Convection Heat Transfer on Heat Sink of Led Lamp, Transactions of the Canadian Society for Mechanical Engineering, Vol. 37, No. 3. pp. 9-16.
20. Shengqiang, B.; Hongliang Lu, T.; XianglinYin, X and Lidong, C. (2014): Numerical and experimental analysis for exhaust heat exchangers in automobile thermoelectric generators, Case Studies in Thermal Engineering, Vol. 4, pp. 99–112.

21. Shrikant V. B.; Sanjay, K. (2014): Investigation of Optimum Porous Pin Fin Parameter for Forced Convective Heat Transfer Through Rectangular Channel Part-I", International Journal of Emerging Technology and Advanced Engineering Issn 2250-2459, Iso 9001:2008 Certified Journal, Vol. 4, No. 8, pp. 1-12
22. Srinivasan, K.; Muthu, S.; Devadasan, S.R.; and Sugumaran, C. (2014): Enhancing effectiveness of Shell and Tube Heat Exchanger through Six Sigma DMAIC phases, Procedia Engineering, Vol. 97, pp. 2064 – 2071.
23. Sunil, C. (2015): A Taguchi Approach for Optimization of Flow And Geometrical Parameters In A Rectangular Channel Roughened with V-Down Perforated Baffles, Case Studies in Thermal Engineering, Vol. 5, pp. 59–69.
24. Tawat S.; Tanongkiat K.; and Atipoang N.; (2014): Enhancement of Fin Efficiency of A Solid Wire Fin by Oscillating Heat Pipe under Forced Convection, Case Studies in Thermal Engineering, Vol. 2, pp. 36–41.
25. Tonio Sant and Robert, N.F. (2015): Modeling the Energy Yield Enhancement from a Wind Turbine at a Deep Offshore Low Wind Site through Combined Power and Thermocline Energy Production, Journal of Solar Energy Engineering, Vol. 137, No. 11, pp. 1-8.
26. Vahabzadeh, A.; Ganji, D.D.; and Abbasi, M. (2015): Analytical investigation of porous pin fins with variable section in fully-wet conditions", Case Studies in Thermal Engineering, Vol. 5, pp. 1–12.
27. Valery, P.; Yitung, C.; James, C.; Merrill, W.; and Anthony, E. H. (2008): Calculation of Fluid Flow Distribution Inside a Compact Ceramic High-Temperature Heat Exchanger and Chemical Decomposer, Journal of Fluids Engineering, Vol. 130, No. 1, pp. 1-8.
28. Patil, S.; Chopade, D, and Pande, M. (2017): Experimental Analysis of Natural Convection of Heat Transfer of Different Types of Notches in Fins: A Review, International Journal for Scientific Research and Development, Vol. 5, No.1, pp. 781-785.
29. Weikla, M. C, Braunb, K. and Weiss, J. (2014): Coil Wound Heat Exchangers for Molten Salt Applications, Energy Procedia, Vol. 49, No. 4, pp. 1054 – 1060,
30. Yanhui, H.; Yan, L.; Ming, L.; and Jin H.; (2012): A Review of Development of Micro-Channel Heat Exchanger Applied in Air-Conditioning System", Energy Procedia, Vol. 14, No. 1, pp. 148 – 153.
31. Mansour, J. and Omid, D. (2020). Heat Transfer Correlation for Two-Phase Flow in a Mixing Tank, Journal of Heat and Mass Transfer Research, Vol. 7, No. 1, pp. 1-10. DOI: 10.22075/jhmtr.2020.17712.1232
32. Soheil, N.S. and Rahim, H. (2020). Heat Transfer Enhancement in a Spiral Plate Heat Exchanger Model Using Continuous Rods, Journal of Heat and Mass Transfer Research, Vol. 7, No. 1, pp. 39-53. DOI: 10.22075/JHMTR.2020.18783.1251
33. Narender, G.., Govardhan, V. and Sarma, S.G. (2019). Heat and Mass Transfer of Nanofluid Over a Linear Stretching Surface with Viscous Dissipation Effect, Journal of Heat and Mass Transfer Research, Vol. 6, No. 2, pp. 117-124. DOI: 10.22075/jhmtr.2019.15419.1214
34. Ananda, S., Sureshb, S. and Santhosh, K.D. (2019). Heat Transfer Studies of Supercritical Water Flows in an Upward Vertical Tube, Journal of Heat and Mass Transfer Research, Vol. 6, No. 2, pp. 155-167. DOI: 10.22075/jhmtr.2019.17488.1229
35. Rahmati, A. R. and Gheibi, A. Performance Investigation of Two Two-Stage Trans-Critical Carbon Dioxide Refrigeration Cycles Ejector and Internal Heat Exchanger, Journal of Heat and Mass Transfer Research, Vol. 6, No. 1, pp. 75-84. DOI: 10.22075/jhmtr.2018.1707.1152