CFD Analysis of Cross Flow Heat Exchanger with Different Fin Thickness

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Abstract- **The world today is striding towards the ways and means of conserving energy. In recent years it has become increasingly important to develop methods for the efficient transport of thermal energy form one location to another or from one medium to another, i.e. where the processes of heating and cooling occur, is known as heat exchanger. Therefore there is an urgent need for developing more and more efficient and reliable heat exchanger. Cross flow heat exchanger are found in different industrial sectors, such as steam generation in a boiler or air cooling in the coil of an air conditioner, where heat has transferred between different media. Heat transfer is usually better when a flow moves across tubes than along their length. Hence, cross-flow is often the preferred flow direction, and tends to be better than parallel flow or counter flow configurations.**

Fins are commonly used in extended surface exchangers. Conventional fin-tube exchangers often characterize the considerable difference between liquids' heat transfer coefficients. In a gas-to-liquid exchanger, the heat transfer coefficient on the liquid side is generally one order of magnitude higher than that on the gas side. To minimize the size of heat exchangers, fins are used on the gas side to increase the surface area and the heat transfer rate between the heat exchanger surface and the surroundings.

In present study, heat transfer and temperature gradient in a cross flow heat exchanger using different fin thickness have been investigated. The governing equations have been solved using CFD simulation, based on finite volume method The velocity of the inlet air is limited with a values of (1, 2, 3, and 4) m/s, while the volume flow rate of tube side liquid is limited with a values of (2, 3, 4, 5 and 6) L/min and the temperature of inlet air is the room temperature, while the temperature of tube side liquid is limited with a values of (50, 60, 70 and 80) °C. Based on the results obtained by the CFD and mathematical calculations it is found that Heat Transfer rate increased by 15% by using 3mm fin instead of 1.5 mm fin.

Index terms- Cross Flow, Heat Exchanger, Temperature distribution, Fin, Thickness, Heat transfer, ANSYS

I. INTRODUCTION

The process of heat exchange between two fluids at different temperatures and separated by a solid wall is found in many engineering applications. The equipment used to implement such heat exchange process is termed as a heat exchanger. A heat exchanger is a device in which two fluid streams, one hot and one cold, are brought into thermal contact with each other in order to transfer heat from the hot fluid stream to the cold one. It provides a relatively large surface area of heat transfer for given volume of the equipment. The specific applications of heat exchangers are most frequently found in chemical process industries as well as power production, waste heat recovery, cryogenic, air conditioning, petrochemical industries, etc.

Due to the large number of heat exchanger configurations, a classification system was devised based upon the basic operation, construction, heat transfer, and flow arrangements. The following classification as outlined by Kakac and Liu (1998) will be discussed:

- Recuperators and regenerators
- Transfer processes: direct contact or indirect contact
- Geometry of construction: tubes, plates, and extended surfaces
- Heat transfer mechanisms: single phase or two phase flow
- Flow Arrangement: parallel flow, counter flow, or cross flow

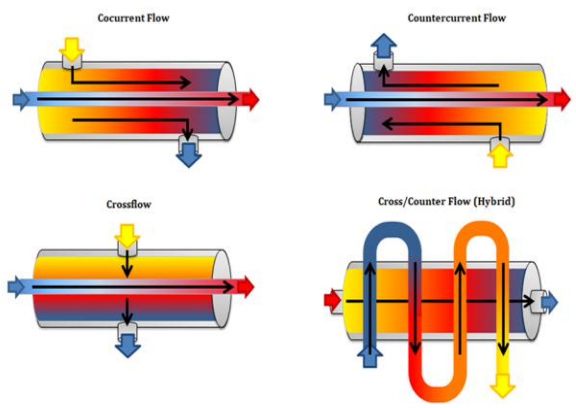

Figure 1 Heat Exchanger Flow Configurations

Cross flow heat exchanger are found in different industrial sectors, such as steam generation in a boiler or air cooling in the coil of an air conditioner, where heat has transferred between different media. Heat transfer is usually better when a flow moves across tubes than along their length. Hence, cross-flow is often the preferred flow direction, and tends to be better than parallel flow or counter flow configurations.

As a result of the global energy crisis, which is one of the most crucial problems due to the large and continuous increase in the consumption and the increment shortage of energy resources as well as the high cost, many researchers have performed to increase the efficiency of thermal systems and reduction of the size and thus energy consumption rates.

Heat transfer enhancement is a process of increasing the heat transfer rate and thermo hydraulic performance of a system using various methods. The methods of heat transfer enhancement are employed for developing the heat transfer without affecting the overall realization of the systems significantly, and it covers a wide range of areas where heat exchangers are used for such functions as air-conditioning, refrigeration, central heating systems, cooling automotive components, and many uses in the chemical industry. Heat transfer enhancement techniques generally reduce the thermal resistance either by increasing the effective heat transfer surface area or by generating turbulence. Heat transfer enhancement techniques are classified as the - Passive Methods, Active Methods, and Compound Methods. In the passive techniques, any external power is not required; rather, geometry or surface of the flow channel is modified to increase the thermo hydraulic performance of the systems. The inserts, ribs, and rough surfaces are utilized to promote fluid mixing and the turbulence in the flow, which results in an increment of the overall heat transfer rate. Passive techniques have also some advantages in relation to the other heat transfer enhancement techniques such as low cost, easy production, and installation.

Saving material and energy are common objectives for optimization. One of the important issues that should be defined during the design work, taking in consideration the cost of material, is the optimization of the heat efficiency. The optimization function can consider minimum weight for a specified heat flow, placement of individual fins to form channels or fin profile based on a set of specified conditions (for instance the dissipation from the fin faces, minimum mass, minimum pressure drop etc.). In order to intensify the heat transfer from the heat exchanger surface to fluid, it is possible to increase convection coefficient (by growing the fluid velocity), widen temperature difference between surface and fluid or increase the surface area across which convection occurs. Extended surfaces, in the form of longitudinal or radial fins are common in applications where the need to enhance the heat transfer between a surface and an adjacent fluid exists.

Efficiency of heat exchanger and its dimensions are ones of the most important parameters to consider in engineering design activity. The size of heat exchanger can be more compact by introducing the fins to increase the heat transfer rate between the heat exchanger surface and the surroundings. The analysis of heat transfer from finned surfaces involves solving second-order differential equations and is often a subject of researches including also the variable heat transfer coefficient as a function of temperature or the fin geometrical dimensions. In general, the study of the extended surface heat transfer compromises the movement of the heat within the fin by conduction and the process of the heat exchange between the fin and the surroundings by convection

II. LITERATURE REVIEW

Jang et al. [1996] study numerically and experimentally fluid flow and heat transfer over a multi-row (1-6 rows) plate-fin and tube heat exchanger. The effects of different geometrical parameters such as tube arrangement, tube row numbers and fin pitch are investigated in detail for different Reynolds number. They find that an average Nusselt number is decreased as the number of tune row is increased from 1 to 6. The number of tube row has a small effect on average heat transfer coefficient as the row numbers became greater than 4.

Athene et. al. [2012] In this study, an experimental study of heat transfer and air flow over in-line flat tube bundle. They found the average Nusselt number of air flow increases with the increase of Reynolds number. In present study effect of v-grove in 1 mm depth which made on the surface tube bank with different number grove (14, 29, and 59), tube bank are arranged in staggered, in this study heat transfer and pressure drop are investigated .Idea of small grooved on surface of tube bank is simulation to finite ribs on the skin of fish and dolphin which reduce friction with water.

Sundus H. Abd [2013] Experimental study was made on free and forced heat transfer from three cylinders of different cross-sections circular, triangular and square in cross flow of air. The three cylinders were manufactured from copper for its high conductivity. The three cylinders were made to have equal surface area to compare the effect of their shape on heat transfer coefficient. It was found that in the case of forced convection, the heat transfer of the triangular cylinder is better than that of the square and circular cylinder and several empirical relationships were obtained for the case of forced convection.

Numerical studies of heat transfer are used by Wais [2014]. Analyses are carried out to examine finned tube heat exchanger and to determine the performance of the radiator, when the tube-fin heat exchanger geometry is modified.

Mallikarjuna, et al [2014] performed a numerical three dimensional simulation of turbulent flow for flat and round tube fin heat exchangers having two rows of staggered arrangement to study heat transfer and fluid flow using ANSYS Fluent software, for different Reynolds number of fin side in turbulent regime to detect the effect of various parameters (tube pitch fin pitch, and fin temperature on Friction factor f and Colburn j factor for both flat and round tubes). The performance of flat tubes is compared with that of round tubes with same geometrical parameters and flow area. For both flat and round tube domains with all the geometrical configurations simulated in the study Colburn j factor varies inversely with the inlet air velocity. More heat transfer with the higher fin spacing for both flat and round tubes following the above side trend.

Piyush and Kumbharb [2014] performed CFD to predict the heat transfer and flow of air over the dimpled fins due to forced convection. Dimpled fins are made and modeled using variation in parametric dimensional. Three parameters were considered [depth, diameter and pitch] of dimples. For analysis purpose, three different Reynolds number [6500, 8000 and 10000] is done. The increase of Heat transfer coefficient for the diameter is higher when compared with the depth and pitch, but the increase of heat transfer coefficient is very low for pitch variation, thus combination with the depth and maximum diameter, shows the best convective heat transfer coefficient. For dimpled configurations there is a substantial increase in the Nusselt number value with respect to plain fins. As the Reynolds number increase the friction factor decreases.

Hsieh [2015] presented a simple and a systematic procedure to determine the effectiveness and exit temperatures of complex assemblies of identical heat exchangers. Three different assemblies were considered for overall parallel flow and overall counter flow configurations.

Zena K. Kadhim et al. [2016] CFD investigations have been carried out in this paper to study the temperature difference for cross flow heat exchanger with smooth tube and low integral finned tube. The study includes geometry creation with dimensions (250×500×1200) mm width, height and length, respectively. Has a single copper tube with eight passes.. The low integral finned tube with (19 mm) inner diameter, (21 mm) root diameter and (24 mm) outer diameter. The fin height is (1.5 mm). Air is assumed as a cooling fluid passing across the test tube with a range of velocities (1, 2, 3 and 4) m/sec. The inner side flow rates with a range of (2, 3, 4, 5 and 6) L/min. for water. The water temperatures at the inlet of test tube were (50, 60, 70, 80) °C. The results show that the temperature difference and heat transfer coefficient for heat exchanger with finned tube is higher than with smooth tube.

From the above literature review introduction of fin of different thickness might be one of the promising techniques to increase the turbulence in the flow.

This also increases the turbulence and thus enhances the different parameters such as heat transfer rate, efficiency etc. Studies have been done on different fin thickness conditions and results show a considerable enhancement in the different parameters such as heat transfer performance, turbulence etc.

Based on above mentioned research gaps, It can be observed that the problem describes on the previous chapter can be dissolving by the improvement in the cross flow heat exchanger by applying passive techniques which causes the result in the enhancement of heat transfer rate in the heat exchanger. The effort make to enhancement of heat transfer in heat exchanger are as fallows

- The research objectives of the present study are CFD analysis of cross flow heat exchanger in a tube section and make a proper validation with previous work.
- The main aim of the study is to increase the temperature gradient in the cross flow heat exchanger in a tube section.
- To study the heat transfer rate in the cross flow heat exchanger and show the temperature and velocity distribution over the tube in cross flow heat exchanger.
- Increase the overall heat transfer coefficient in the Heat Exchanger.
- Decrease the pressure drop in the heat transfer system.

III. METHODOLOGY

The geometry created in the present work consists of single tube eight passes having one inlet and one outlet portion for hot water and Nano fluid the air duct has inlet and outlet portion, software program design modular is used to draw the geometry in 3D form. The study includes geometry creation with dimensions (250×500×1200) mm width, height and length, respectively, has a single copper tube with eight passes. The low integral finned tube with (19 mm) inner diameter, (21 mm) root diameter and (24 mm) outer diameter. The fin height is (1.5 mm and 3 mm).

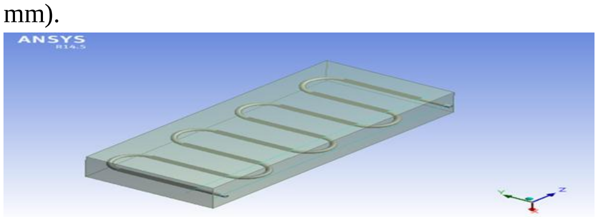

Figure 2 Geometry of test section

By, default, a coarse mesh is generated by ANSYS software. Mesh contains mixed cells per unit area (ICEM Tetrahedral cells) having triangular faces at the boundaries. The meshing that has used in this transient thermal analysis is none mesh metric with medium smooth curvature. The mesh type generated tetrahedral meshing as shown in figure.

Table 1 Meshing detail of models

S.No.	Parameters	Validation	Work
1	Curvature	On	On
2	Smooth	Fine	Fine
3	Number of nodes	202355	436892
4	Number of elements	717487	2089250
5	Mesh metric	None	None
6	Meshing type	Tetrahedral	Tetrahedral

A different part of the cross flow heat exchanger with fin is selected and the names are given to them so that boundary conditions can be applied.

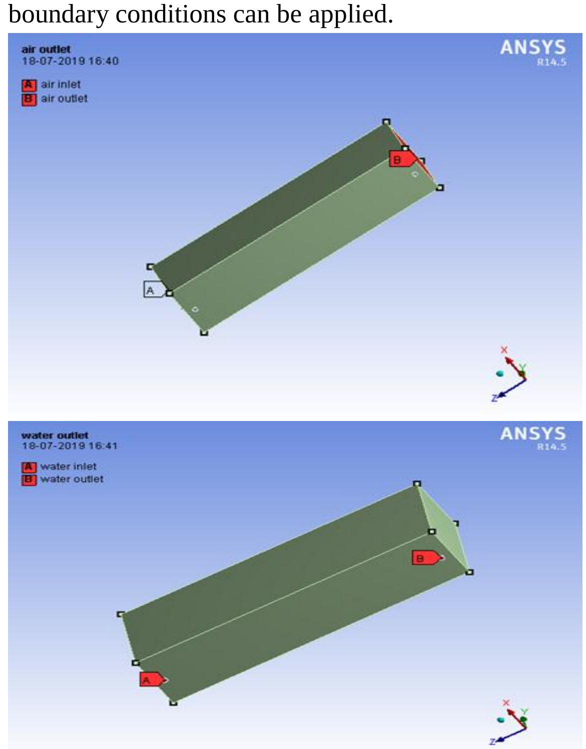

Fig 3 Boundary condition of cross flow heat exchanger

Inlet Boundary Conditions: The velocity of the inlet air is limited with a values of (1, 2, 3, and 4) m/s, while the volume flow rate of tube side liquid is limited with a values of (2, 3, 4, 5 and 6) L/min and the temperature of inlet air is the room temperature, while the temperature of tube side liquid is limited with a values of (50, 60, 70 and 80) °C.

Outlet Boundary Conditions: The outlet for air side and tube side fluid is specified as pressure outlet and it's represented by the atmospheric pressure.

The numerical simulation is done by ANSYS FLUENT 14.5. Software to show both the flow field and heat transfer of the present models. Many cases are studied. Three cases are discussed in the following sections. Same boundary conditions are used in the three cases, which are (air velocity of 1 m/s, water inlet temperature and flow rate of (80 °C) and (2 L/min) respectively).

The computational domain of the present work is represented by the inlet and outlet for hot water and nanofluid for eight passes single cupper tube (without and with low integral fin). The inlet and out for cooling air which flows inside rectangular cross sectional duct. The flow of cooling air is normal to the tube (cross flow heat exchanger).

The following assumptions are adopted to simplify numerical simulation:

1. Steady state and turbulent flow for water and air side.
2. No phase change for all the flowing fluids.
3. Radiation effects are negligible.
4. No heat generation.
5. Constant physical properties for the cooling air, hot water and nanofluid.
6. Three dimensional fluid flows.

Material Property

Table 2 Material properties which are used in analysis.

Parameter	Air	Water
Density (Kg/m^3)	1.225	998.2
Thermal Conductivity (W/m-k)	0.0242	0.6
Specific heat (J/kg-k)	1006.43	4182
Viscosity (kg/m-s)	$1.789*10^{-5}$	0.001003

IV. RESULTS AND DISCISSIONS

After applying all boundary condition we have obtained the fallowing results which are shown in figure:

4.1 Contours for 1.5mm fins at 1 m/s air inlet and water inlet temperature and flow rate of 80°C and 2 L/min respectively.

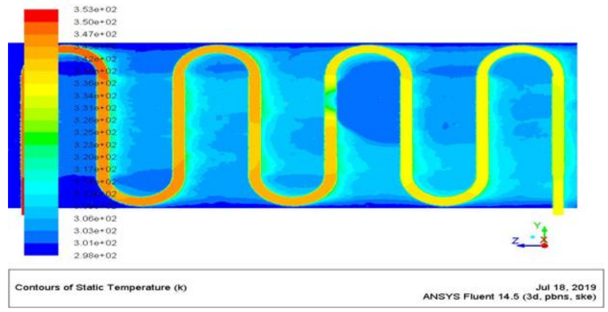

Figure 4 Temperature contour of cross flow heat exchanger for validation.

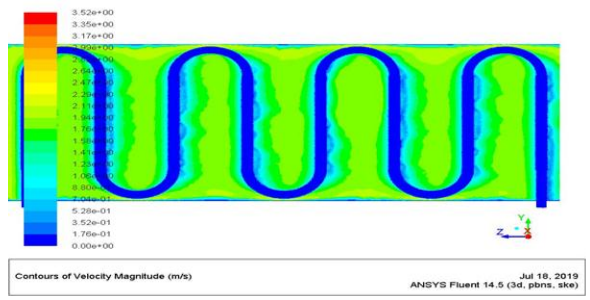

Figure 5 Velocity contour of cross flow heat exchanger for validation.

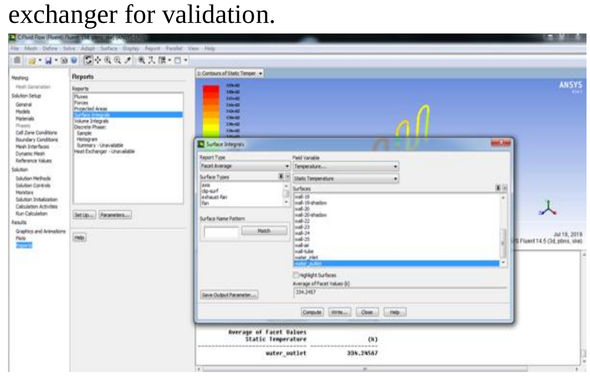

Figure 6 Temperature distribution of cross flow heat exchanger for validation.

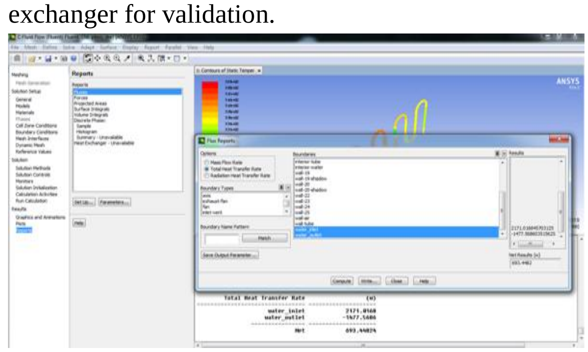

Figure 7 Heat transfer rate of cross flow heat exchanger for validation.

4.2 Contours for 3 mm fins at 1 m/s air inlet and water inlet temperature and flow rate of 50°C and 2 L/min respectively.

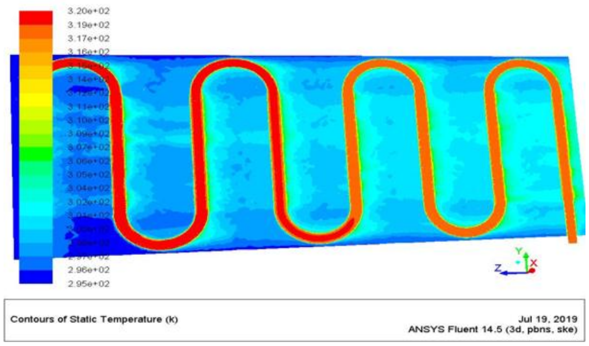

Figure 8 Temperature contour of cross flow heat exchanger at 50°C and 2 L/min.

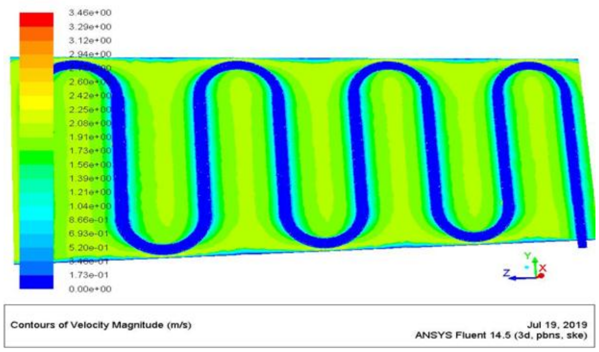

Figure 9 Velocity contour of cross flow heat exchanger at 50°C and 2 L/min.

4.3 Contours for 3 mm fins at 1 m/s air inlet and water inlet temperature and flow rate of 50°C and 4 L/min respectively.

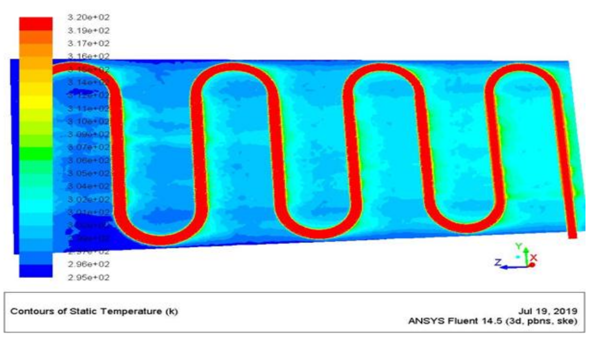

Figure 10 Temperature contour of cross flow heat exchanger at 50°C and 4 L/min.

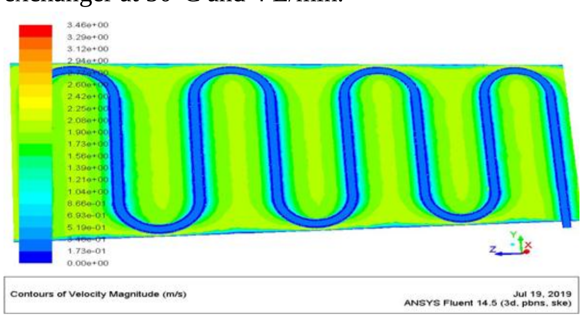

Figure 11 Velocity contour of cross flow heat exchanger at 50°C and 4 L/min.

4.4 Contours for 3 mm fins at 1 m/s air inlet and water inlet temperature and flow rate of 50°C and 6 L/min respectively.

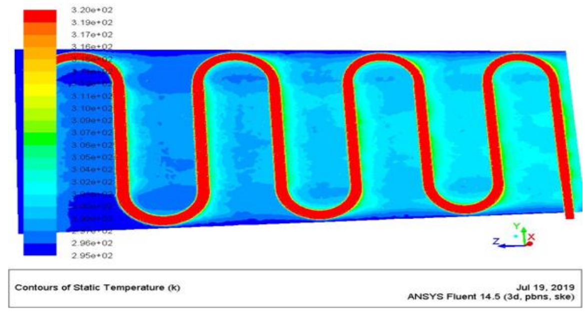

Figure 12 Temperature contour of cross flow heat exchanger at 50°C and 6 L/min.

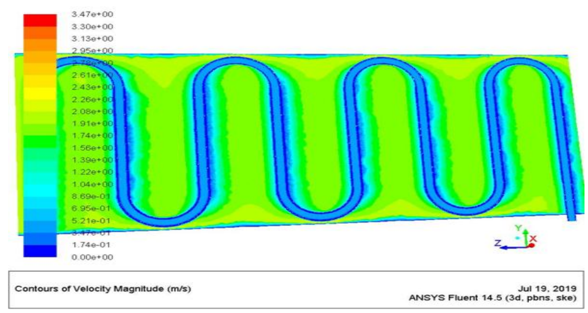

Figure 13 Velocity contour of cross flow heat exchanger at 50°C and 6 L/min.

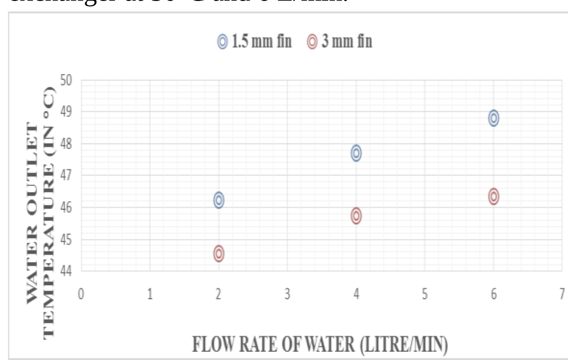

Figure 14 Water outlet temperature (in °C) with 1.5 mm fin and 3mm fin

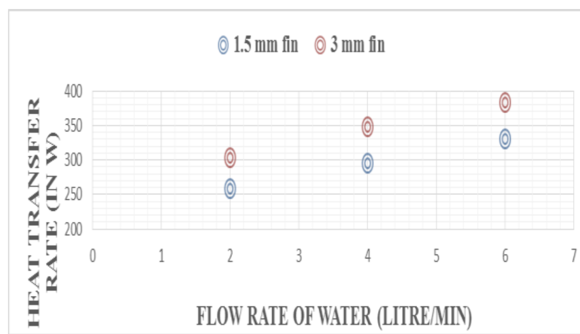

Figure 15 Heat transfer rate (in Watt) with 1.5 mm fin and 3mm fin

V.CONCLUSIONS

In this analysis, the effect of varying thickness of fin in cross flow heat exchanger has been investigated using CFD analysis. Based on the results obtained by the CFD and mathematical calculations it is found that:

- The study provides a CFD analysis for cross flow heat exchanger with smooth tube and low integral finned tube.
- From the above results this can be observed that by changing the dimension of the fin heat transfer would be increase and the temperature of water outlet decrease more.
- A gradient of temperature distribution along with test tube and the temperature difference are clearly appearing in all cases.
- The temperature difference increase with increasing the cooling air velocity and increase with decreasing the hot water velocity inside the tube.
- Temperature gradient of 3 mm finned tube is higher than that of 1.5 mm finned tube and smooth tube.
- Ansys Fluent is good CFD program to simulate the heat transfer cases.
- Good agreement is attain between the experimental and numerical results
- Heat Transfer rate increased by 15% by using 3mm fin instead of 1.5 mm fin.

REFERENCES

[1] Zena K. Kadhim* , Muna S. Kassim**, Adel Y. Abdul Hassan, CFD study for cross flow heat exchanger with integral finned tubes" International Journal of Scientific and Research Publications, Vol. 6 , Issue 6, 2016.

[2] Mallikarjuna, V. Seshadri and V. Raghu B. , "Numerical Analysis of Fin Side Turbulent Flow for Round and Flat Tube Heat Exchangers" , International Journal of Modern Engineering Research (IJMER), Vol. 4 , Issue 7, 2014.

[3] Piyush .V. Patil and D. G. Kumbharb, "CFD Investigation on Dimpled Fins With Parameter Variation for Heat Transfer Augmentation", International Journal of Engineering Research & Technology (IJERT), Vol. 3 Issue 6, 2014.

[4] Ahmed F. Khudheyer and Mahmoud Sh. Mahmoud, "numerical analysis of fin-tube plate heat exchanger by using CFD technique", ARPN Journal of Engineering and Applied Sciences, VOL. 6, NO. 7, JULY 2011.

[5] Firas Abd Ali Abbas, "Augmentation of Heat Transfer by Using Nanotechnology", M.Sc. Thesis, University of Al – Mustansiriya, 2014.

[6] Sinan Abdul Ghafar Ali, "Study the Effect of Upstream Riblet on Wing-Wall junction", M.Sc. Thesis, University of Tecnology, 2011.

[7] "Ansys Fluent User's Guide", Ansys Inc., South pointe 275 Technology Drive Canonsburg, 2011.

[8] P. Wais, One row fin heat exchanger numerical optimization, Proceedings of International Congress on Thermodynamics, 4-7 Sept Poznan, (2011) 709-716.

[9] R. K. Shah, D. P. Sekulic, Fundamentals of Heat Exchanger Design, Wiley, 2003.

[10] P. Wais, Extended Surfaces (Fins and Pins), in: R.B. Hetnarski, Encyclopedia of Thermal Stresses, Vol 3, Springer, Dordrecht, 2014, 1536- 1550.

[11] J. Y. Jang, M. C Wu., W. J. Chan, Numerical and experimental studies of three dimensional plate-fin and tube heat exchangers. International Journal of Heat and Mass Transfer 14, (1996) 3057-3066.

[12] P. Wais, J. Taler, Fin shape optimization in tube heat exchangers by means of CFD program, 2nd International Conference on Engineering Optimization, Sept. 6 - 9, Lisbon, Portugal, (2010) 1-10.

[13] P. Wais, Fluid flow consideration in fin-tube heat exchanger optimization, Archives of Thermodynamics, 31, (2010) 87-104.

[14] W. M. Yan, P. J. Sheen, Heat transfer and friction characteristics of fin-and-tube heat exchangers, International Journal of Heat and Mass Transfer 43, (2000) 1651-1659.

[15] M. S. Mon, U. Gross, Numerical study of fin-spacing effects in annular-finned tube

heat exchangers. International Journal of Heat and Mass Transfer 47, (2004) 1953–1964.

[16] R. Romero-Mendez, M. Sen, K. T. Yang, R. McClain, Effect of fin spacing on convection in a plate fin and tube heat exchanger, International Journal of Heat and Mass Transfer 43, (2000) 39-51.

[17] P. Wais, Fin-tube heat exchanger performance for different louver angles, Zeszyty Naukowe Politechniki Rzeszowskiej Mechanika 86, (2014) 115-122.

[18] P. Wais, Influence of fin thickness and winglet orientation on mass and thermal efficiency of cross-flow heat exchanger, Applied Thermal Engineering 102, (2016) 184-195.

[19] S. Y. Yoo, H. K. Kwonb, J. H. Kima, A study on heat transfer characteristics for staggered tube banks in cross-flow. Journal of Mechanical Science and Technology 21, (2007) 505-512.

[20] D. Taler, Methods for obtaining heat transfer correlations for plate finned heat exchangers using experimental and CFD simulated data, Archives of Thermodynamics 25, (2004) 31-54.

[21] D. Taler, P. Ocłoń, Determination of heat transfer formulas for gas flow in fin-and-tube heat exchanger with oval tubes using CFD simulations, Chemical Engineering and Processing 83, (2014) 1–11.

[22] D. Taler, P. Ocłoń, Thermal contact resistance in plate fin-and-tube heat exchangers, determined by experimental data and CFD simulations, International Journal of Thermal Sciences 84, (2014) 309–322.

[23] P. Ocłoń, S. Łopata, M. Nowak, A. C. Benim, Numerical study on the effect of inner tube fouling on the thermal performance of hightemperature fin-and-tube heat exchanger, Progress in Computational Fluid Dynamics, An International Journal, 5, (2015) 290–306.

[24] P. Wais, Fin-tube heat exchanger optimization, in: J. Mitrovic, Heat Exchangers – Basics design applications, In-Tech Rijeka, (2012) 343- 366.

[25] F. C. McQuiston, D. R. Tree, Optimum space envelopes of the finned tube heat transfer surface, ASHRAE Transactions, Vol. 78, Part 2, (1972) 144-152.

[26] G. H. Hewitt, G. L. Shires, T. R. Bott, Process Heat Transfer, CRC Press, 1994.

[27] R. W. Serth, Process heat transfer: principles and applications, Elsevier USA, 2007.

[28] T. Kuppan, Heat exchanger design handbook, Marcel Dekker USA, 2000.

[29] O. James, J. O. Maloney, Perry’s chemical engineers’ handbook. Mc Graw-Hill, USA, 2008