An Experimental Study on Heat Transfer & Fluid Flow Characteristics of Copper Pin Fin on Changing Heat Sink & Its Orientation

Prof. Abhishek Kumar[1] Raushan Kumar Mandal[2]
[1]Assistant Professor [2]Scholar
[1,2]Department of Mechanical Engineering
[1,2]Kailash Narayan Patidar College of Science and Technology, Bhopal (M.P.), India

Abstract— Many of the researchers are trying to improve the effectiveness of fin by changing its material, shape, surface finish and orientation. In this context, an experimental work has been conducted to investigate the effect of pin fin heat sink on the heat transfer performance characteristics under forced flow conditions with two different orientations. In this project, pin fins made up of Copper C106having different dimensions and pattern were used and experimental data pertaining to pin fin heat sink have been collected under fully turbulent condition and results are then plotted for different orientations, comparison with that of plate fin under similar operating conditions were carried out. Our objective was to study the effect of heat transfer with different orientation of fin heat transfer characteristics. Many experiments have been done to get the optimum heat transfer through can be achieved. It was observed that Irrespective of the type of orientation, considerable enhancement in Nusselt Number is registered at all Reynolds number as compared to the fin without perforations and highest Nusselt number 767.41 is registered for vertical orientation at Re = 10751.22 as compared to inverted and heat sink with no fins. It is also observed that vertical orientation of heat sink outperforms other two in terms of heat transfer rates however heat transfer rates from inverted heat sink is registered lower than that of smooth plate. As a result of this experiment it is concluded that as far as Nusselt number enhancement ratio is concerned heat sink with vertical orientation creates high degree of turbulence and outperforms the inverted orientation and smooth plate.

Keywords: Fin, Pin Fin, Orientation, Surface Finish, Forced Flow, Heat Transfer, Nusselt Number, Reynolds Number, Prandtl Number, Effectiveness, Efficiency

I. INTRODUCTION

Transformation of energy from one system to another system will only be possible when there is an energy gradient. Heat is one of the forms of energy which transmits from one body to another body or system as a result of temperature difference between the bodies or system. This temperature difference is called gradient. Heat transfer is the transfer of heat energy between the two systems. The transmission of heat energy is accomplished by conduction, convection or radiation or by combination of these three. Heat transfer is thus transmission of heat energy from high temperature body to low temperature body by any one of the three modes or by their combination. Each mode of heat transfer has different governing law according to which heat transfer takes place.

A. Heat Transfer through Dimpled Surface

Numerous investigations are available both in the form of experimental results and numerical approach to predict the thermal performance of heat sink by the application of some geometrical modifications on the heat transfer surface. It has been reported that application of extended surface(s) increases the surface area available for heat transfer and intensify the heat extraction rate from the primary surface. Pisal and Ranaware [1] conducted an experimental and numerical investigation on dimpled surface. In their investigation, they tested the heat transfer characteristics of the heated surface with circular and oval shaped dimples under the forced flow condition and for Re = 600 to 2000. Heat transfer data of dimpled surface were observed and recorded. To know benefit of proposed geometry they compared the heat transfer results of dimpled fins with that of fin without dimples. Irrespective of the shape of dimple and for all selected range of Reynolds number, heat transfer coefficient was found higher as compared to smooth surface. Katkhaw et al. [2] investigated the ellipsoidal dimples experimentally. In their study, ellipsoidal dimples with the angle of 45^0 were placed on the flat surface and compared the heat transfer data with that of plain fin. They also studied the effect of dimple arrangements and dimple intervals. They have taken the range of air stream velocity as 1 to 5 m/s. They observed the higher heat transfer rates with dimpled fin as compared to solid fin. Burgess et al. [3] numerically investigated the effect of dimple depth on heat transfer augmentation. They noticed that the heat transfer rate is directly affected by the depth of dimple as the Nusselt number values increases with the increase in dimple depth, however friction factor also increases with the increase in dimple depth. Yenare and Mali [4] conducted an experimental investigation on two types of dimple configurations- circular and oval. Experiments were performed under the flow Reynolds number Re = 600- 2000. They reported that heat transfer coefficient increases in both the cases, however, it was found higher in case of oval shape dimpled plate. It was thought that an oval shaped dimple generates more swirl flow and due to which higher values of heat transfer coefficient are achieved. Another experimental investigation was performed by Giram and Patil [5]. They analyzed the effect of dimple density and dimple arrangements on the heat transfer surface under the forced flow conditions. They found that with the increase in dimple density, Nusselt number values also increased. As far as dimple arrangement is concerned, highest values of Nusselt number was recorded corresponding to staggered arrangement.

B. Heat Transfer through Ribbed Surface

Use of ribbed surface is another passive way to enhance the heat transfer rates. Tariq et al. [6] investigated the effect of ribbed surface in a rectangular channel. In their experiments, solid ribs were placed on the base wall of the test section and experiments were performed under the range of

Reynolds number Re = 12,800 – 29,400 which was based on hydraulic diameter of the duct. To compute the response of their proposed configurations, they calculated the values of different performance parameters and presented the results in terms of skin friction coefficient and Nusselt numbers. Temperature profiles at different flow Reynolds number were also presented in terms of plots. They used crystal thermo-graphy for flow visualization. Higher values of Nusselt numbers they reported in case of ribbed surface as compared to plain surface for similar operating conditions. However skin friction coefficient was found not much significant as compared to increase in Nusselt number values which shows good sign as far as effectiveness is concerned. Effects of repeated ribs on the heat transfer surface were experimentally investigated by Tanda and Caballero [7]. They used liquid crystal thermography technique to visualize the flow patterns. They also studied the effect of broken ribs on the heat transfer characteristics. A numerical sensitivity analysis was conducted by Amir Keshmiri [8], in that he focused on the heat transfer and fluid flow characteristics in three as well as two dimensional rectangular duct. Another investigation in this regard was performed by Taslim et al. [9]. They demonstrated experimentally the effect of geometrical parameters on the effectiveness of the fin subjected to rib configurations. Highest thermal performance was registered corresponding to rib angle of 45° as compared to that of 90°.

C. Heat Transfer through Slotted Surface

Heat transfer and pressure drop characteristics of different types of slotted surface were numerically investigated with 3-D steady laminar model by Cheng et al. [10]. They kept the Reynolds number range as $Re = 2.1 \times 10^3$ to $Re = 1.3 \times 10^4$ and high thermal performance was reported in case of slotted surface as compared to plain surface. In continuation to this another numerical investigation was conducted by Torii and Yang [11]. They created the turbulence by placing the slots and perforations combined on the heat transfer surface. Lot of other investigations were also reported which give the clear indication that use of slotted surface promotes the turbulence and improved the thermal performance.

D. Heat Transfer through Grooved Surface

Dixit and Patil [12] investigated the heat transfer characteristics of different types of grooved surfaces. They augmented the rate of heat transfer with the surface weight reduction and material removal in the form of grooves on the heat transfer surface. They investigated the various configurations like transverse grooves, inclined grooves, V-grooves and multi V-grooves. The range of Reynolds number for their experiment was 1500 to 5000. Heat transfer data pertaining to grooved fins was then compared with that of plain fin. They found the highest range of Nusselt number corresponding to inclined grooves, however, highest value of the effectiveness of grooved fin is obtained for the multi grooved and V- grooved fins. Kaji et al. [13] investigated about the effects of inner grooved surface on the heat transfer performance of air – cooled heat exchanger. Babenko et al.[14] analyzed numerically and studied on condensation heat transfer and fluid flow for condensation on trapezoid grooved surfaces, he coupled the nonlinear equations for the mass transfer of the flow of fluid, thermal conduction were developed. He discussed the groove length and basic angle. He showed the calculation results so that the heat flux decreased. The heat flux through groove with $\alpha = 75^0$ at the top of the groove surface. The conclusion was obtained at the low parts and studied the distributions of wall temperature and heat flux on the trapezoid groove systematically and the maximum wall temperature and the heat flux both were obtained. The thermal resistance of groove with $\alpha = 60^0$ was found lower but the liquid discharge ability was better than that of groove with $\alpha = 75^0$ with a maximum deviation of 15%. Jung et al. [15] investigated heat transfer on the high density grooved surface and used water source heat pump with poly ethylene tube.

II. METHODOLOGY & EXPERIMENTAL SET UP

In order to examine the heat transfer characteristics of perforated fins test facilities have been developed in the laboratory on ASHRAE standards. The components of the experiment set up and their details are given in this chapter. Current investigation will explore the heat transfer characteristics of pin fin heat sink. An array of circular fins of diameter 10mm has been placed on the heat transfer surface. Length of fins has also been changed in an alternate manner. Constant heat flux has been provided at the base of the test heat sink. The test facility has been designed and installed as per the guidelines suggested in ASHRAE standard. The schematic of the experimental setup is shown in the figure. The experimental set-up comprises of rectangular duct, plenum, circular pipe, orifice meter, flow control valve and centrifugal blower, details of which are given the following section. The air is sucked by means of a centrifugal blower (2 HP.1440 rpm) through a rectangular wooden duct (12 mm oak plywood) and exhausts to the atmosphere. The entire length of the duct is 1220 mm. and it is divided into three lengths- entry length 635 mm, test section 135 mm and exit length 450 mm. The exit section of the rectangular duct is connected to the flow settlement chamber (500 mm x500 mm). A circular pipe of 75 mm. external diameter is used to connect the flow settlement chamber (plenum) and centrifugal blower. An orifice meter is mounted on the circular pipe to measure the flow rate. A flow control valve is used to regulate the flow and installed on the circular pipe after the orifice meter. An Inclined U-tube manometer is used to measure the pressure drop across the orifice meter. Test heat sink 13.5mm size made up of copper (cu C106) is appropriately placed inside the test section. Total 09 k- type thermocouple is used to measure the fin surface temperature and one k- type thermocouple is provided at the inlet of the duct to measure the inlet temperature, however 3 k- type thermocouples are placed at the exit. Before the commencement of each run of experiment, visual inspection has been performed to check for leakage at the joints, electric connections, air bubble in the U-tube manometer and safety measures After inserting the test heat sink into the test section a controlled power supply is being provided by the auto transformer at the base of the fin through an electric heater which is sandwiched between the mica sheet and is attached to the base of the test fin and insulated with glass wool. Now at the fully opened position of the flow control valve centrifugal blower is then switched on and the temperature of the inlet air, exit air and test heat sink is recorded by the digital temperature display device after steady state condition reached by the system. The experimental procedure is repeated for different flow rates and for all the three test configurations heat sink with vertical orientation, Inverted heat sink and heat sink without fins i.e. smooth plate. Heat transfer data pertaining to test fin has been processed and compared with the smooth plate under similar operating conditions.

III. Results & Discussion

An experimental work has been carried out to predict the effect of pin fin heat sink and its orientation on the heat transfer and fluid flow characteristics. An array of circular pin fins of diameter 10 mm were placed on the heat transfer surface. Heat transfer data pertaining to Pin fin Heat Sink as well as smooth plate was collected and processed with the standard correlations. To explore the effect of pin fin heat sink and its orientation heat transfer data pertaining to pin fins for both the orientations were compared with that of plain fin and presented in terms of plots and tables. Figure3.(a) shows the variation of Nusselt number with the flow Reynolds number.

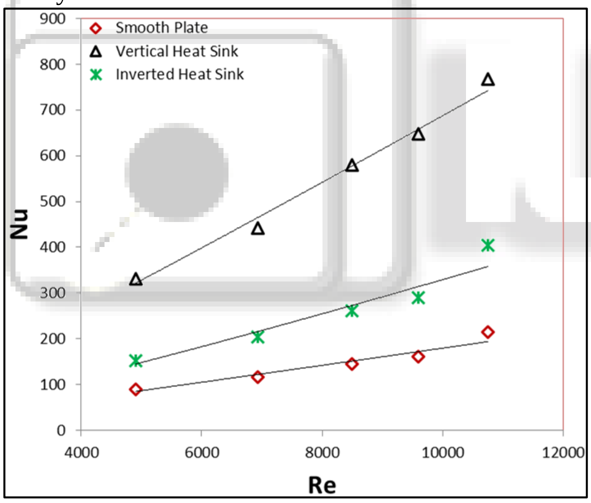

Fig. 3(a): Variation of Nusselt Number with Flow Reynolds Number

It has been observed that irrespective of the type of orientation, Nusselt number values increases at all Reynolds number. Highest value of Nusselt number is observed as 767.41 corresponding to vertical heat sink at Reynolds number Re = 10751.22. In case of inverted heat sink, plot reveals that the highest Nusselt number is 403.94 at the same Reynolds number as that of vertical heat sink. It is thought that array of circular pin fins arranged in vertical manner creates high degree of turbulence and induces secondary flow and also larger surface area is available for the fluid as compared to smooth plate. It is also observed that at Reynolds number Re= 4902, Nusselt number values are close to each other for smooth plate and inverted heat sink.

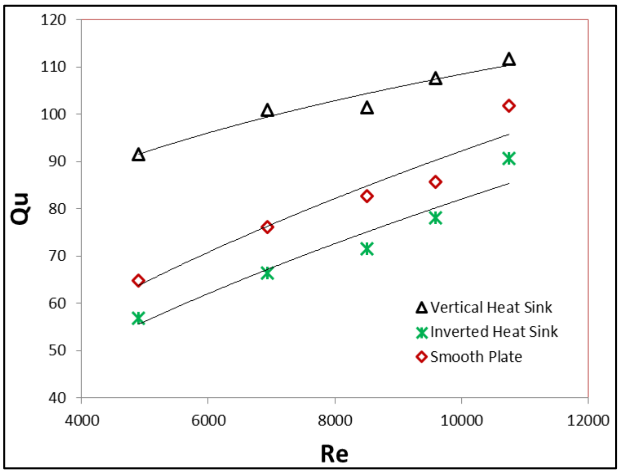

Fig. 3(b): Variation of Heat Transfer rate with Flow Reynolds Number

Figure 3.(b) depicts the variation of heat transfer rate with flow Reynolds number. Heat sink with vertical orientation outperforms the other configuration including smooth plate. Heat transfer rate is found higher (111 J/S) for vertical orientation corresponding to the Reynolds number Re = 10751. At Reynolds number Re= 4902 the lowest heat transfer rate (56 J/S) was registered corresponding to inverted orientation.

IV. Conclusion

The experimental investigations have been performed on the pin fin heat sink at various fluid flow rates. Experiments were performed under the forced flow conditions and at Reynolds number Re = 4902 to 10751. Two types of heat sink orientations- vertical and inverted in were tested. In order to quantify the enhancement heat transfer data pertaining to pin fin heat sink for both the orientations has been collected and processed and compared with that of smooth plate under similar operating conditions. It has been concluded that:

- Irrespective of the type of orientation, considerable enhancement in Nusselt Number is registered at all Reynolds number as compared to the fin without perforations.
- Highest Nusselt number 767.41 is registered for vertical orientation at Re = 10751.22 as compared to inverted and heat sink with no fins.
- It is also observed that vertical orientation of heat sink outperforms other two in terms of heat transfer rates however heat transfer rates from inverted heat sink is registered lower than that of smooth plate.
- Highest Nusselt number enhancement ratio (4.02) is achieved at Reynolds number 9521
- As a result of this experiment it is concluded that as far as Nusselt number enhancement ratio is concerned heat sink with vertical orientation creates high degree of turbulence and outperforms the inverted orientation and smooth plate.

References

[1] Hemant C. Pisal and Avinash A. Ranaware, “Heat Transfer Enhancement by Using Dimpled Surface”,

IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), ISSN: 2278-1684, p.p.07-15
[2] Katkhaw et al., "Heat transfer behavior of flat plate having 45° ellipsoidal dimpled surfaces", Case Studies in Thermal Engineering, vol. 2 (2014) p.p.67-74
[3] Burgess et al., "Effects of Dimple Depth on Channel Nusselt Numbers and Friction Factors", Journal of Heat Transfer, vol. 127 (2004) p.p. 839-847.
[4] Yenare et al, "Experimental Study for Heat Transfer Enhancement due to Surface Roughness at Laminar Flow", International Journal of Engineering Research and Applications, vol. 4 (2014) p.p. 239-243
[5] Giram and Patil, "Experimental &Theoretical Analysis of Heat Transfer Augmentation from Dimpled Surface" International journal of Engineering Research and Applications, vol. 3 (2013) p.p. 19-23
[6] Tariq et al. "An Experimental Study of Convective Heat Transfer from Flat and Ribbed Surfaces" Indian Journal of Engineering and Material Sciences, vol. 9 (2002) p.p. 464-471
[7] Tanda et al., **"**Review on Triangular Perforated Fins in Staggered Arrangement'', International Symposium on Flow Visualization, Vol.2 (2002), p.p.24-38
[8] Keshmiri et al., **"**Refined Eddy Viscosity Schemes and Large Eddy Simulations for Ascending Mixed Convection Flows'' International Journal of Aerospace and Civil Engineering, Manchester, Vol.46,(2011) p.p. 1632-1649
[9] M.E. Taslim, "Rib fin effects on the overall equivalent heat transfer coefficient in a rib-roughened cooling channel", International Journal of Heat Exchanger, vol.6 (2005) p.p. 25-41
[10] Cheng et al., "Numerical Design of Efficient Slotted Fin Surface based on the Field Synergy Principle", Numerical Heat Transfer, vol. 45 (2004) p.p. 517-538.
[11] Torii et al. "Thermal Fluid Flow Transport Phenomenon over Slot Perforated Flat Plates placed in Narrow Channel", Journal of Thermo-Physics & Heat Transfer, vol. 21 (2007) p.p. 346-357
[12] Dixit & Patil, "Heat Transfer Characteristics of Grooved Fin under Forced Convection", Heat Transfer Engineering, vol. 36 (2015) p.p. 1409-1416
[13] Kaji et al, "Heat Transfer Enhancement due to Electrically Induced Resonant Oscillation of Drop", Journal of Heat Transfer, vol. 107 (2009) p.p. 224-232
[14] Babenko et al., "Heat Transfer in condensation on a grooved surface", Journal of engineering physics, vol. 40 (1981) p.p. 615-619.
[15] Jung et al. "Heat Transfer of Refrigeration Mixture", International Refrigeration and Air Conditioning Conference, vol. 34 (1992) p.p. 150-164.

