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Experimental Study of Convective Heat Transfer by Using Aluminum Pin-Fin with Metal Matrix Composites

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Abstract:- Augmentati0n of heat transfer is a crucial aspect in various engineering applicati0ns, and pin fins have proven to be effective heat transfer enhancement devices. This study focuses on investigating the augmentation of heat transfer for different materials of pin fins. The main aim of project is to analyze the steady state thermal performance of straight fin made with four different composite materials namely AA6061 MMC, AA6061+6%Al_2O_3, AA6061+6%BN, AA6061+6%SiC, as fin material and geometry plays an important role in heat dissipation. An experimental investigation has considered to evaluate the heat transfer performance of pin fins made from different materials. The results demonstrate that the ch0ice of material significantly influences the heat transfer characteristics of pin fins. Materials with high thermal conductivity and low surface roughness exhibit enhanced heat transfer rates. For heat dissipation, parameters like density, thermal conductivity and heat transfer coefficients are taken into c0nsideration and surface area is kept same. This study provides valuable insights into the augmentation of heat transfer for different materials of pin fins. The findings aid in material selection and 0ptimization of pin fins for various engineering applications, including heat exchangers, electronics cooling, and gas turbines, where efficient heat dissipation is crucial.

Keywords:- *Heat Transfer Rate: Nusselt's Number: Heat Transfer Coefficient.*

I. INTRODUCTION

A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium (air or liquid), where it will be exhausted away from the device. The basic purpose of a heat sink is to maintain the sink temperature below the maximum allowable temperature specified by the device. Heat sinks offer a low cost, convenient method for lowering the film resistance and, in turn, maintaining junction operating temperatures at a safe level for long time, reliable operation. In computers, heat sinks are used to cool central processing units. They also used with high-power semiconductor devices such as power transistors and optoelectronics such as lasers and light emitting diodes, where the heat dissipation ability of the component itself is insufficient. There has been continuous research on improving heat transfer rate of pin fin with multimode heat transfer. Early analysis had done by Rajput et al. [1] performed experimental, numerical and analytical studies with the purpose of optimization of geometrical fin parameters for heat sink of North Bridge based on natural convective heat transfer. In this Heat sink of the Northbridge used in IBM mother board has been optimized for more heat transfer and less weight using finite element analysis. Krug et al. [2] performed numerical analysis on optimization of the vertical heat sink. The fins are oriented in a way to permit a natural convection air draft to flow upward through rectangular U-channels, or ducts, formed by the fins. It is concluded that Heat sink optimization helps us to determine the dimensions, weight, and thermal performance in order to meet design requirements. Also, it became clear that when the number of fins was increased past an optimal value, the thermal performance of the sink would worsen, leading to choked flow inside the U-channels and, eventually, electronic box failure. Kulkarni et al. [3] performed numerical simulation on CFD and conjugate heat transfer analysis which carried out for various fin geometries with Zigzag, Fluted, Slanted mirror, Custom pin fin and staggered array configurations for low thermal resistance and minimum pressure drop and Numerical simulations are carried out. It is observed that slanted mirror fin array gives the almost constant heat transfer a coefficient value that is highest among all other fin configurations. Thermal resistance is minimum for custom pin fins but gives higher pressure drop. In the other hand zigzag fin configuration gives lowest pressure drop. Pawar et al. [4] performed experimental analysis for high heat flux condition. The heat sink mounted on the hot component for cooling the component under forced convection. The CFD simulations are performed for optimization of heat sink parameters with objective of maximization of heat transfer coefficient. It is concluded that better configuration of a heat sink which can work smoothly even after the temperature inside the component exceeds the IGBT permissible temperature is found i.e., best optimised configuration of heat sink is found. Terrestrial [5] developed analytical models for the average heat transfer rate in forced convection-cooled, slotted fin heat sinks. Experimental measurements are performed for a variety of slot configurations over a range of Reynolds numbers. An approximate model for predicting the performance of slotted fin heat sinks based on an arithmetic mean of the bounds has been proposed, with an RMS percent difference from the model of 12%. Mathew et al. [6] has conducted experimentation on heat transfer by Aluminum and brass PIN

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FIN. Work is concerned with experimental set up for enhancement of the forced convection heat transfer over the dimpled surface and flow structure analysis within a dimple. In the present work aluminum & brass plate were used as a test surface. Variation of Nusselt Number with Reynolds Number is investigated, with various parameter combinations. The experimental results give heat transfer coefficient & efficiency of aluminum fin is greater than brass fin.

II. DESCRIPTION OF PROBLEM

Improvement of heat transfer rate is very important in the radiators and heat sinks. Materials for heat sink and radiators are blasted because of poor materials. In this project there are four materials were considered like AA6061 reinforced with Sic, Al_2O_3, & Boron Nitride. The objective of this study is to found the thermal conductivity and heat transfer rate by conducting an experimental work using pin fin apparatus.

Fig. 1: Casting process of pin fins

Fig. 2: Pin-fin apparatus

Fig. 3: Aluminum fin with metal matrix

This setup is designed to study the heat transfer in a pin fin. It consists of cylindrical fin fitted to the base in rectangular duct. A blower is provided on one side of duct to conduct experiments under free and forced convection heat transfer mode. Seven thermocouples are embedded along the axis of the cylindrical fin at different locations and one thermocouple placed in the air stream at the exit of the test section to measure the outlet air temperature. Digital Temperature Indicator is provided to read temperatures distribution along the fin. Test pipe is connected to the delivery side of the blower along with the Orifice to measure flow of air through the pipe. A heater heats one end of fin and heat flows to another end. Heat input to the heater is given through varia.

A. Specifications of pin fin

Duct width, b = 150 mm
Duct height, w = 100 mm
Orifice diameter, $d_o = 20\ mm$
Orifice coefficient, $c_d = 0.6$
Fin length, L = 14.5 cm
Fin diameter, D_f = 12 mm

B. Equations

Surface Temperature, $T_s = \frac{T_1+T_2+T_3+T_4+T_5+T_6+T_7}{7}$

Reynold's number = $\frac{\rho_a \times V_a \times d}{\mu_a}$

Nusselt number = $0.681(Re)^{0.466}$

$Nu = \frac{hl}{k_a}$

$$Q_{fin} = \sqrt{hpKA} \times (T_s - T_8)$$

III. RESULTS AND DISCUSSIONS

The present experimental work is compared with experimental analysis of et al. [6] for heat transfer coefficient by using pin fin apparatus. The above validation is conducted for Brass, Aluminium and Aluminium+6% BN for 100V of fixed heat input. The results are plotted in the above figure 4.1. The results show a decent agreement with experimental work for Aluminium+6% BN and maximum deviation observed is 10.7%. The deviation is due to increase in thermal conductivity of material in forced convection regime.

A. Validation

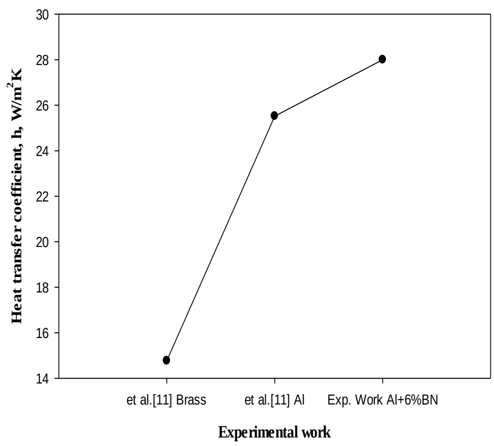

Fig.4 : Validation of present work with experimental work of et al

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B. Consolidated performance of fin

Table 1 Free Convection

Type of fin material	Voltage (V)	Convection Type	Nusselt No. (Nu)	Heat transfer coefficient (h) W/m^2K	Heat transfer rate (Q) W
Aluminum 6061 T6	80	Free	3.85	8.98	1.46
Aluminum 6061 T6	100	Free	3.89	9.07	1.55
Aluminum 6061 T6+6%SiC	80	Free	4.09	9.54	1.6
Aluminum 6061 T6+6%SiC	100	Free	4.25	9.91	1.67
Aluminum 6061 T6+6%Al_2O_3	80	Free	4.4	10.26	1.69
Aluminum 6061 T6+6%Al_2O_3	100	Free	4.95	11.55	1.75
Aluminum 6061 T6+6%BN	80	Free	5.2	12.13	2.18
Aluminum 6061 T6+6%BN	100	Free	5.45	12.71	2.3

Table 2 Forced Convection

Type of fin material	Voltage	Convection Type	Nusselt No.	Heat transfer coefficient (h) W/m^2K	Heat transfer rate (Q) W
Aluminum 6061T6	80	Forced	10.56	24.65	2.7
Aluminum 6061 T6	100	Forced	10.68	24.93	2.76
Aluminum 6061 T6+6%SiC	80	Forced	10.79	25.2	2.8
Aluminum 6061 T6+6%SIC	100	Forced	10.96	25.57	2.9
Aluminum 6061 T6+6%AL_2O_3	80	Forced	11.23	26.21	3
Aluminum 6061 T6+6%AL_2O_3	100	Forced	11.47	26.76	3.12
Aluminum 6061 T6+6%BN	80	Forced	11.73	27.37	3.4
Aluminum 6061 T6+6%BN	100	Forced	12	28	3.83

C. Free Convction

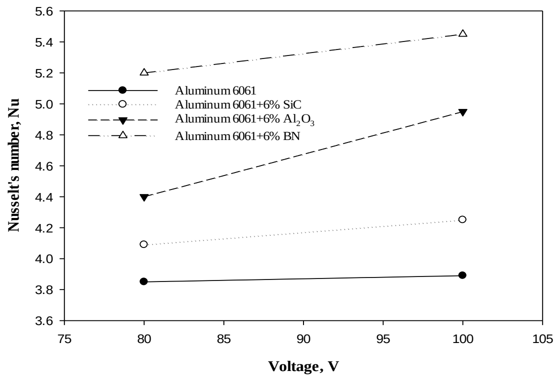

Fig.5 : Variation of Nusselt's number for different materials in free convection

The above graph is plotted for the voltage and nusselt number for four materials in free convection. The nusselt's number obtained high for Aluminium 6061+6% BN fin due to high thermal conductivity. High nusselt's number value causes higher thermal dissipation, which occurs more in pin fins.

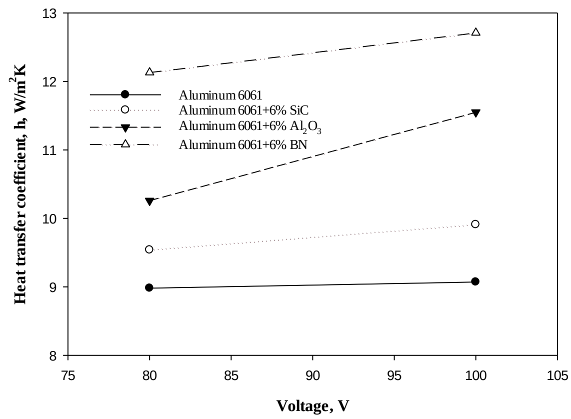

Fig. 6: Variation of heat transfer coefficient for different materials in free convection

The above graph is plotted for the variation of voltage and heat transfer coefficient for four different materials in free convection. In natural convection the fluid motion occurs by natural means such as buoyancy, since the fluid velocity associated with natural convection is relatively low, the heat transfer coefficient encountered in natural convection Is also low. Here if we compared with aluminium with metal matrix composites fins, the heat transfer coefficient obtained high for aluminium 6061+6% BN due to high thermal conductivity.

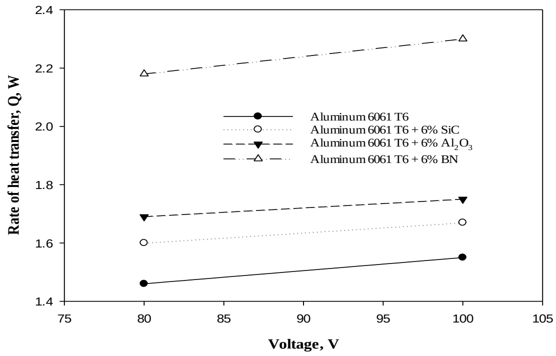

Fig. 7: Variation of heat transfer rate of fin for different materials in free convection

The above figure depicts the variation of voltage and heat transfer for aluminium and metal matrix composites fins in free convection. Here the heat transfer rate obtained high for Aluminium 6061 T6+6%BN fin with fre convection. In free convection, heat transfer occurs due to the natural movement of fluid caused by buoyancy forces. These buoyancy forces arise from temperature differences within the fluid, leading to density variations and subsequent fluid motion.Thermal conductivity is a property that quantifies a material's ability to conduct heat. It represents how quickly heat can be transferred through a substance by conduction. When the thermal conductivity of a fluid or a solid surface increase, it means that the material is more effective at conducting heat.

D. Forced Convection

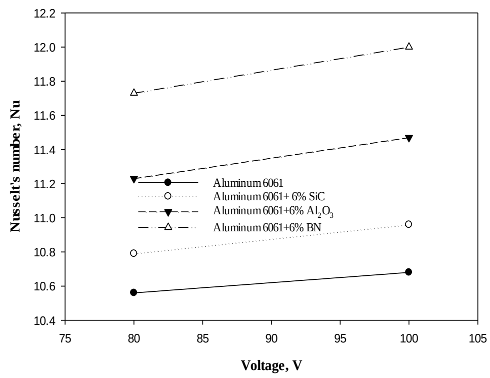

Fig. 8: Variation of nusselt's number for different materials in forced convection

The above graph is plotted for the voltage and nusselt number for four materials in forced convection. The nusselt's number obtained high for Aluminium 6061+6% BN fin due to higher value of Reylond's number. In forced convection, to increase the reylond's number, which affect to obtain higher nusselt number.

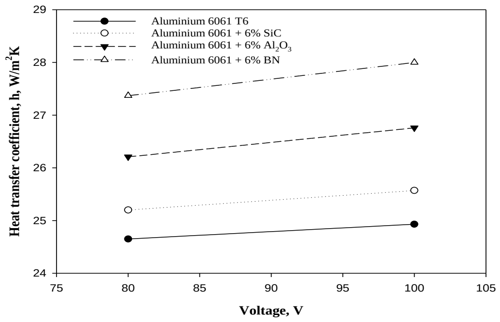

Fig. 9: Variation of heat transfer coefficient for different materials in forced convection

The above figure depicts the variation of voltage and heat transfer for aluminium and metal matrix composites fins in forced convection. In forced convection, the fluid is forced to flow over a surface or in a tube by external means such as a pump or fan.,the convective heat transfer coefficient will usually be higher in forced convection since heat transfer coefficient depends on fluid velocity and forced convection involves higher fluid velocity. Here if we compared with aluminium and metal matrix composites fins, the heat transfer coefficient obtained high for Aluminium 6061 T6+6% BN due to high thermal conductivity.

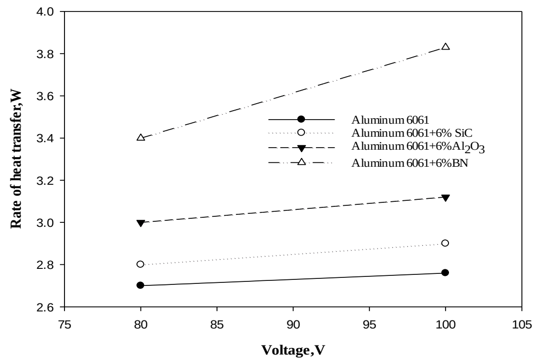

Fig. 10: Variation of heat transfer rate of fin for different materials in forced convection

The above figure depicts the variation of voltage and heat transfer for aluminium and metal matrix composites fins in forced convection. Here the heat transfer rate obtained high for Aluminium 6061 T6+6%BN fin with forced convection due to higher heat transfer coefficient, it is clear that the material and regime of convection place a major role in heat transfer. In forced convection, heat transfer occurs when a fluid is forced to flow over a surface due to an external means such as a pump or a fan. The fluid flow enhances the heat transfer process by increasing the convective heat transfer coefficient.The convective heat transfer coefficient represents the effectiveness of heat transfer between a solid surface and a fluid in forced convection. It depends on various factors, including the fluid properties, flow conditions, and the thermal conductivity of the fluid. When the thermal conductivity of the fluid increases in forced convection, it means that the fluid becomes more efficient at conducting heat. This increased thermal conductivity facilitates a faster conduction of heat from the solid surface to the fluid. Consequently, the temperature gradient between the solid surface and the fluid becomes larger.

IV. CONCLUSIONS

The investigation into the augmentation of heat transfer for different materials of pin fins has provided valuable insights and findings. Based on the comprehensive analysis and experimental investigations, the following conclusions can be drawn:

- An experimental investigation has been performed for different regime of convection for four different aluminium with composites. It is observed that fin temperatures have been decreased by increasing thermal conductivity of a material .
- The effect of material with higher thermal conductivity materials facilitates more efficient conduction of heat from the solid to the fluid, resulting in improved heat transfer rates. Copper, with its excellent thermal conductivity, proves to be a favorable material for achieving enhanced heat transfer in pin fins.
- According to experimental analysis it shows that heat transfer coefficient of fin is more for forced convection due to the presence of fluid motion and enhanced mixing in the flow. Forced convection involves the use of an external force, such as a pump or a fan, to drive the fluid flow over a surface. This forced flow creates several mechanisms that contribute to higher heat transfer coefficients
- So finally heat transfer enhancement has been obtained by increased heat transfer rate. AA6061 T6+6% BN achieved high heat transfer rate while considering forced convection. Heat transfer coefficient plays an important role in achieving high heat transfer rate.

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