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Experimental Studyon Performance Evaluation of Pin Fin

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Abstract : *In modern engineering applications like air conditioning, cooling of nuclear reactor fuels, internal combustion engines as well as in electronic devices & solar energy applications, heat dissipation has been a major problem & a challenge to thermal engineers. In this paper, performance of pin fin of three different materials (Aluminium, Brass & stainless steel) is studied. The influence of design parameters like the pin fin length, diameter & fin material on thermal efficiency of the natural convection heat sink is evaluated using the experimental setup prepared by graphical programming language with LabVIEW (Laboratory Virtual Instruments for Engineering Workbench).The result show efficiency of Aluminium is highest followed by Brass and steel respectively.*

Keywords –*Pin fin, LabVIEW, Efficiency, Heat Transfer, Natural convection*

I. INTRODUCTION

In modern engineering applications like air conditioning, cooling of nuclear reactor fuels, internal combustion engines as well as in electronic devices & solar energy applications, heat dissipation has been a major problem & a challenge to thermal engineers. Modern portable electronics have seen component heat loads increasing, while the space available for heat dissipation has decreased. These factors have forced thermal engineers to develop and optimize devices that not only perform better, but also are at the same or lower cost than previous generations. Extended surfaces have played an important role in heat dissipation & have found themselves in most of the applications. Though extended surfaces & fins have been efficient, they remain a very good subject of research as the heat transfer rate from the fins depends on a variety of factors. The studies have shown that the convective heat transfer rate from fin arrays depends on geometric parameters, fin material, base-to-ambient temperature difference & approach velocity.

Younghwan Joo et al[1] compared the performance of plate fin heat sinks analytically in natural convection. They also proposed a new correlation for optimized pin fin heat sink. For optimizing the performance two objective functions were used: Total heat dissipation and heat dissipation per unit mass. It was observed that plate fin heat sink performs better when total heat dissipation function is used whereas pin fin performs better when heat per unit mass function is used. A Dewan et al [2] have done computational study and performance analysis through rectangular channel with circular pin fins attached to the surface. A staggered arrangement of pin fins was adopted. The results show that pin fin material has higher heat transfer rate with no increase in pressure drop. Saurabh Bahadure et al [3] has done theoretical and experimental study on thermal performance of pin fin with circular perforations. The results show that perforations increases heat transfer rate.Kai-Shing Yang [4] has done experimental study on pin fin heat sink with circular, elliptic and square cross-section. Both inline and staggered arrangement of pin fin was tested. Circular pin fin shows superior performance under inline arrangement. For staggered arrangement, elliptical pin fin performs better. Amol Dhumne et al [5] have done analysis on heat transfer enhancement by experimentation. In addition, analysis of pressure drop over a flat surface with cylindrical pin fin in rectangular channel was done. The performance parameters considered were Reynolds number and Nusselt number. The correlation equations for friction factor, heat transfer and enhancement efficiency were developed. The results shows that the cylindrical perforated pin fins have higher heat transfer rate than cylindrical fins. It was observed that efficiency of fins vary depending on the inter-fin spacing ratio and clearance ratio. A low inter-fin spacing ratio assured high heat transfer. Mehran Ahmadi et al [6] manufactured and tested two sets of continuous and interrupted rectangular fins. In addition, the experimental and numerical analysis of the effects of interruptions on rectangular heat sinks were studied. To study fin interruption effects a 2-D numerical model was developed.It was observed that adding interruptions enhances the heat transfer rate of fin considerably. In addition, there exists an optimum fin interruption length.Mukesh Kumar et al [7] developed cross cut pin fin and compared its performance with parallel plate heat sink.An effort was made in the experiment by placing the heating element asymmetrically for the study of heat transfer characteristics and the thermal performance. It was observed that the temperature variation was more for a heat sink with cuts as compared to heat sink without cut leading to higher heat transfer.Murtadha Ahmed et al [8] investigated experimentally natural heat transfer rate for square and perforated pin fins heat sink at different heat flux values. The effect oftemperature difference and geometric parameters on the heat transfer performance of fin arrays discussed. Results show that temperature difference between the fin base and fin tip becomes larger, by adding perforation.In addition,perforated fins have higher fin effectiveness than solid fin and it rises remarkably by adding more perforations.

Nomenclature

Q	Heat transfer rate
h	Convective heat transfer coefficient
P	Perimeter of fin
k	Thermal conductivity
A	Cross section area
L	Length of fin
T_s	Fin surface temperature
T_b	Fin base temperature
T_m	Mean film temperature
T_∞	Ambient temperature
β	Coefficient of thermal expansion
Gr	Grashof's number
Nu	Nusselt number
g	Gravitational acceleration
ΔT	Temperature difference between fin and ambient
ν	Kinematic viscosity
η_{fin}	Fin efficiency

The heat transfer from pin fin by convection is expressed as:

$$Q = \sqrt{hPkA} \times \left(T_b - T_\infty\right) \times \tanh\left(mL\right) \tag{1}$$

Average fin surface temperature is given by:

$$T_s = \frac{\left(T_1 + T_2 + T_3 + T_4 + T_5\right)}{5} \tag{2}$$

Mean film temperature is expressed as:

$$T_m = \frac{Ts + T_6}{2} \tag{3}$$

Coefficient of thermal expansion is given as:

$$\beta = \frac{1}{T_m + 273} \tag{4}$$

Grashof's number is expressed as :

$$Gr = \frac{g\beta\Delta TL^3}{\nu^2} \tag{5}$$

Nusselt number is given by:

$$Nu = \frac{hL}{k} \tag{6}$$

Efficiency of circular pin fin is expressed as:

$$\eta_{fin} = \tanh\left\{\frac{\left[m\left(L-x\right)\right]}{\left[mL\right]}\right\} \tag{7}$$

The average Nusselt number (Nu) for pin fins under natural convection will be correlated as function of Gr and Pr as follows:

$$Nu = 1.1\left(Gr\times Pr\right)^{\frac{1}{6}} \quad 10^{-1} < Gr\times Pr < 10^{4}$$

$$Nu = 0.53\left(Gr\times Pr\right)^{\frac{1}{4}} \quad 10^{4} < Gr\times Pr < 10^{9}$$

$$Nu = 0.13\left(Gr\times Pr\right)^{\frac{1}{3}} \quad 10^{9} < Gr\times Pr < 10^{12}$$

II. EXPERIMENTAL SETUP

The experimental setup consists of the heat sink whose performance is to be analyzed, thermocouples & an arrangement to vary the base temperature of the heat sink. This setup uses a heater to vary the base temperature of heat sink. The heat sink has to be assembled with the heater. Five thermocouples are fitted along the length of the fin. First thermocouple is fitted at 25mm from the base surface. Second thermocouple is fitted at 55mm from the base surface. Third thermocouple is fitted at 85mm from the base surface. Fourth thermocouple is fitted at 115mm from the base surface. Fifth thermocouple is fitted at 145mm from the base surface. The sixth thermocouple is fitted in the rectangular duct. All these six thermocouples are connected to a digital temperature indicator. To measure the supply to heater, a dimmer stat is provided. An ammeter and a voltmeter is also provided. For experimentation, the heater is switched on and the readings from the thermocouples are taken once the temperature is stabilized.

Fig. 1 Experimental setup of pin fin apparatus

(a) (b) (c)

Fig. 2 Different pin fin materials (a) Aluminium (b) Brass (c) Stainless Steel

III. ALGORITHM IMPLEMENTATION IN LABVIEW

The programming language used in LabVIEW, also referred to as G, is a dataflow programming language. Execution is determined by the structure of a graphical block diagram (the LabVIEW-source code) on which the programmer connects different function-nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution. Multi-processing and multi-threading hardware is automatically exploited by the built-in scheduler, which multiplexes multiple OS threads over the nodes ready for execution.With a graphical programming syntax that makes it simple to visualize, create, and code engineering systems, LabVIEW is unmatched in helping engineers translate their ideas into reality, reduce test times, and deliver business insights based on collected data. From building smart machines to ensuring the quality of connected devices, LabVIEW has been the preferred solution to create, deploy, and test the Internet of Things for decades.

LabVIEW ties the creation of user interfaces (called front panels) into the development cycle. LabVIEW programs/subroutines are called virtual instruments (VIs). Each VI has three components: a block diagram, a front panel and a connector panel. The last is used to represent the VI in the block diagrams of other, calling VIs. The front panel is built using controls and indicators. Controls are inputs – they allow a user to supply information to the VI. Indicators are outputs – they indicate, or display, the results based on the inputs given to the VI. The back panel, which is a block diagram, contains the graphical source code.

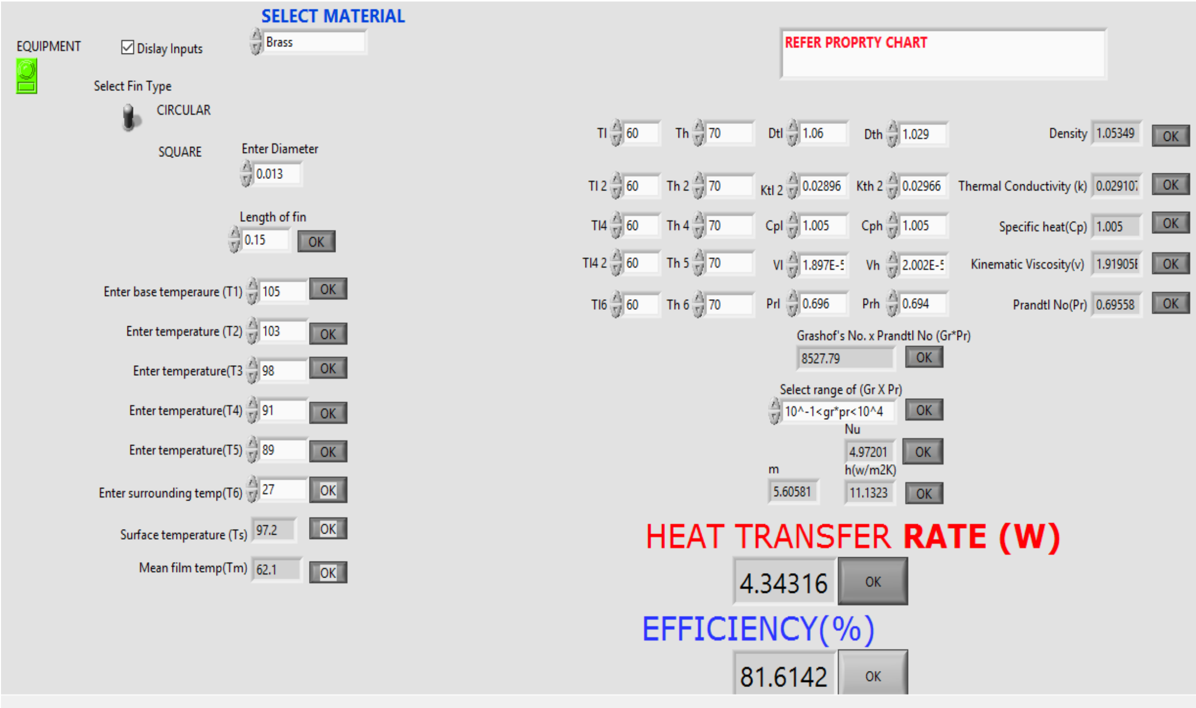

Fig. 3 LabVIEW Panel

All of the objects placed on the front panel will appear on the back panel as terminals. The back panel also contains structures and functions which perform operations on controls and supply data to indicators. The structures and functions are found on the Functions palette and can be placed on the back panel. Collectively controls, indicators, structures and functions will be referred to as nodes. Nodes are connected to one another using wires – e.g. two controls and an indicator can be wired to the addition function so that the indicator displays the sum of the two controls.Thus a virtual instrument can either be run as a program, with the front panel serving as a user interface, or, when dropped as a node onto the block diagram, the front panel defines the inputs and outputs for the node through the connector pane. This implies each VI can be easily tested before being embedded as a subroutine into a larger program.The graphical approach also allows non-programmers to build programs by dragging and dropping virtual representations of lab equipment with which they are already familiar. The LabVIEW programming environment, with the included examples and documentation, makes it simple to create small applications.The most advanced LabVIEW development systems offer the possibility of building stand-alone applications.

The equations mentioned are programmed in LabVIEW. LabVIEW not only provides a graphical interface for the simulation but also a customizable front panel as shown in Fig. 3. As shown, the front panel of LabVIEW provides a platform for the user to carry out the experimentation. The material whose performance is to be tested is selected, the fin geometry is selected & then the temperatures are entered. LabVIEW provides the calculated heat transfer rate and fin efficiency along with other parameters such as Grashof's number, Nusselt number and heat transfer coefficient. It provides a very interactive and user-friendly user interface as shown in Fig. 3.

IV. RESULTS

In this paper, the effect of different pin fin materialson fin efficiency and natural convection heat transfer rate is studied. The experimentation results show that aluminium has highest heat transfer rate and efficiency.

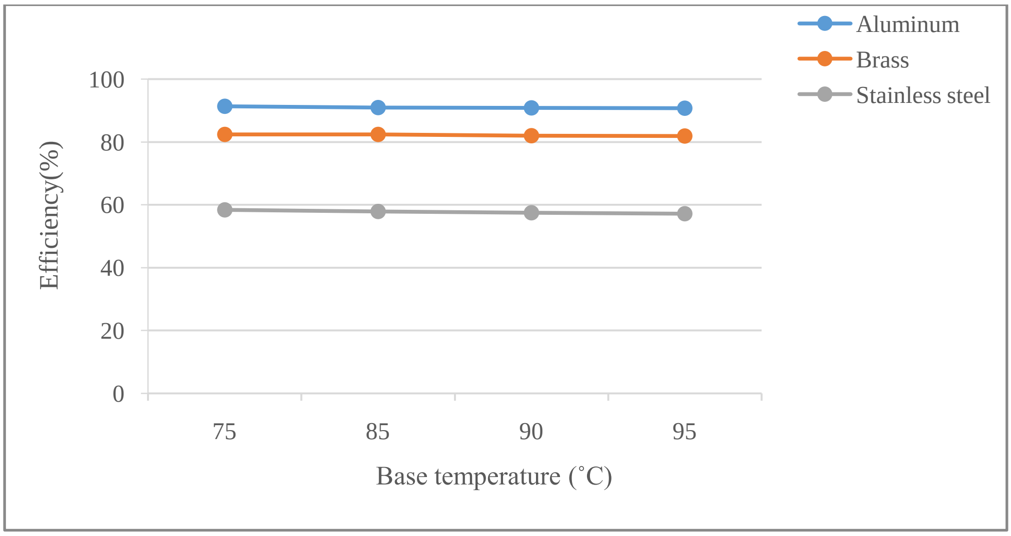

Fig. 4 Variation of fin efficiency with base temperature for different materials

Fig. 4 shows the variation of fin efficiency with the base temperature for different materials. From the Fig.4, itis seen that the efficiency of aluminium is highest followed by brass and stainless steel.In addition, it is observedthat as the base temperature increases, the efficiency decreases.

Fig. 5 shows variation of heat transfer rate with base temperature for different materials. It is observed from the graph that the heat transfer rate is highest for aluminium followed by brass and stainless steel. In addition, it can be seen that as the base temperature increases, the heat transfer rate increases as the overall temperature increases.

From the above figures, it can be inferred that aluminium is the best suitable material for pin fin heat sink due to its low weight, high thermal conductivity, good corrosion resistance and low price.

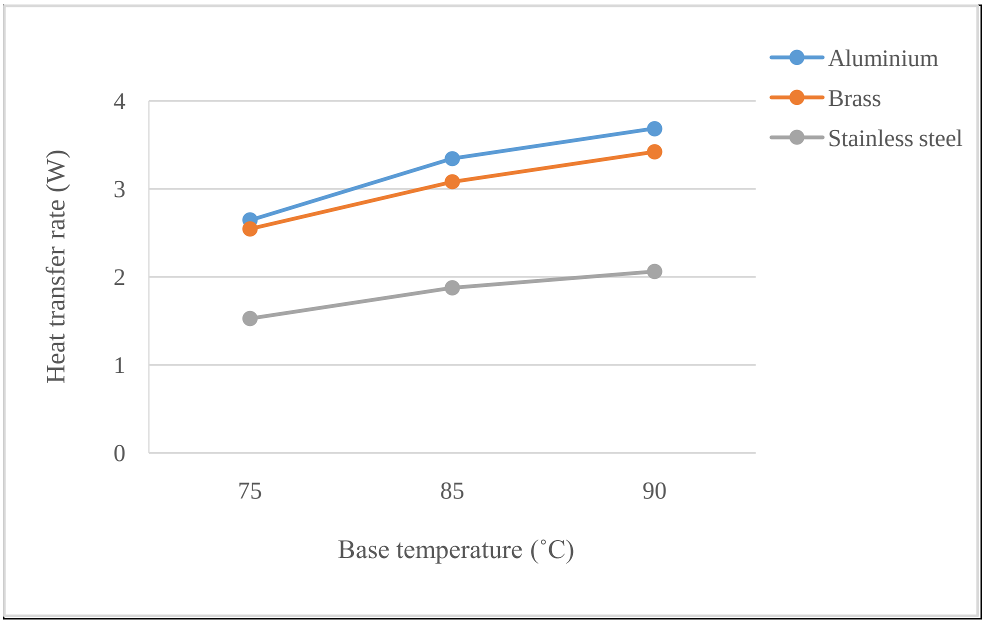

Fig 5. Variation of heat transfer rate with base temperature for different materials

V. Conclusion

The objective of this paper was to investigate the heat transfer rate and efficiency of the pin fin for different materials.Comprehensive analysis of three fin materials (Aluminium, Brass and Stainless Steel) iscompleted. Temperature distribution along the length of fin for different base temperatures is studied. An algorithm for determination of heat transfer rate and efficiency is developed using LabVIEW.A 'Virtual Lab' for heat transfer experiments can be setup for the better interaction of students.

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