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Experimental Investigation of Convective Heat Transfer by Permeable Fins at Different Angles of Inclination and Reynolds Numbers in Forced Convection

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Abstract – Heat dissipation management is significant job in industries, where temperature conditions play vital role. For proper heat dissipation fins are extensively used. In this study heat transfer coefficients of solid fins and permeable (porous) fins are compared for same heat input and surrounding temperature under forced convection conditions. Also affect of Reynolds no (Re) and angle of inclination (θ) is analysed. Permeable fins are made by drilling holes on plane surface of solid fins. Experimentation has been carried out for 3 holes, 5 holes 6 holes and 8 holes. It has been found that heat transfer coefficient increases with increase in no. of holes. But increase in angle of inclination decreases heat transfer coefficient i.e. maximum heat transfer coefficient is observed when angle is 0°with constant surface area in forced convection. And as Re increases heat transfer coefficient also increases. For 8 holes fin with flow of Re = 20000 and 20 W of heat input, 37.9 % increase in heat transfer coefficient is achieved over solid fins.

Keywords— Permeable Fins, Forced Convection, Heat Transfer Coefficient, Angle of Inclination, Base Temperature.

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INTRODUCTION

A Heat removal from system components is essential to avoid damaging effects due to overheating. Therefore the enhancement of heat transfer is an important subject of thermal engineering. Heat transfer rate may be increased by increasing the heat transfer coefficient between a surface and its surroundings, or by increasing the heat transfer area of the surface. In most cases, the area of heat transfer is increased by extending surfaces which are called as fins. They are used to enhance convective heat transfer in a wide range of engineering applications and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. They are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Other applications include internal combustion engine cooling, condensers in refrigeration and air conditioning. The different materials like Mild Steel, Stainless Steel, Aluminium, Silver and Copper are used for making fins. In order to get lightweight, compact, and economical fins, the optimization of fin size is of great importance. Therefore, fins must be designed to achieve maximum heat removal with minimum material expenditure taking into account the ease of fin manufacturing. In forced convection the rate of heat removal depends on maximum contact between air and fin surface. Using permeable fins flow of air can be increased with equal surface area.

By making fins permeable, reduction in weight can be achieved. In forced convection creating perforations on fin formulates eddies in flow of air over fins which eventually increase amount of air in contact.

LITERATURE SURVEY

Ashok Tukaram Pise and Umesh Vandeorao Awasarmol [1] used the original engine block for experimentation work. They modified the solid rectangular fins into permeable fins by drilling three inline holes on them. They monitored heat transfer rates, heat transfer coefficients and percentage saving of material. The experiment showed that the heat transfer rate improves with the use of permeable fins. The base temperatures and tip temperatures profiles of solid fins were more elevated as compared to permeable fins. From this it can be concluded that for the same heat input the cylinder with permeable fins runs cool. Bassam and Abu [2] numerically analysed heat transfer through the permeable fins. They concluded that under no condition increase in number of permeable fins result in decrease in Nusselt number as opposite to solid fins. This indicates that the permeable fins increase surface area without penalty of reducing the convection, unlike in the case of solid fins. Umesh Vandeorao Awasarmol and Ashok Tukaram Pise [3] calculated heat transfer rates, average heat transfer coefficients and percentage saving of material for solid and permeable fins at different angles of inclinations. They found that natural convection heat transfer rate improves with the use of permeable fins oriented at an angle of 90° (vertical).A.V. Zoman and D. D. Palande [4] found , Nusselt number increases with increasing number of perforations on rectangular fin array. Heat transfer enhancement depends on number of perforation, size and shape of perforation, thickness of perforated fin and thermal conductivity of fin material. Al-Essa and Al-Widyan [5] studied the natural convection heat transfer augmentation from horizontal rectangular finembedded with triangular perforations. Al-Essa and Al-Hussien [6] numerically investigated natural convection heat transfer from a horizontal rectangular fin with square perforation with two orientations.

Jaber Al Hossain*etal* [7] has conducted experimental and numerical analysis on a solid annular fin which was mounted on a cylinder. S. G. Khomane*et al.* [8] observed that fins with longitudinal cut, show remarkable heat transfer enhancement in addition to the considerable reduction in weight by comparison with solid fins. Ashiqur Rahman *et al.* [9] studied heat transfer from a flat plate by solid and drilled fins under different relative humidity condition.

After the literature review one can conclude that the permeable fins show increase in heat transfer rate as compared to solid fins. In this study, efforts have been taken to compare heat transfer coefficients and base temperatures at different *Re* and at different angles of inclinations under forced convection conditions.

A. Optimal Area Condition

Alike previous researchers who made perforations of random sizes without any significant proof regarding convective area, a mathematical relation between thickness of fins and diameter of hole is developed. And due to this one can compare the performance of solid and permeable fins

∴Area of solid fin removed = Area added due to perforations

$$\therefore \quad 2\pi r^2 = \pi d t$$

$$\therefore \quad r = t$$

(d = diameter of hole drilled = 2r, t = thickness of fin)

Using above mathematical relation perforation size can be justified from fin thickness. If the hole radius exceeds value of thickness then it will reduce the total convective area. Using hole diameter twice of the thickness, the area will remain constant irrespective of no. of holes drilled. And the size of hole will be big enough to allow flow of air through it. Hence this condition can be treated as *"optimal area condition"* while making perforations.

Data Reduction

The models used for study were taken with finite length and the convection takes place along the surfaces as well as at the end. Hence relation for heat transfer by fins with convection off the end was used.

$$Q_{fin} = \sqrt{hpkAc}(t_0 - t_a)\frac{\tan h(ml) + \frac{h}{km}}{1 + \frac{h}{km}\tan h(ml)}$$

Where, $m = \sqrt{\frac{hp}{kAc}}$ .... [10]

h = coefficient of convective heat transfer (w/m^2K)

k = thermal conductivity of material (w/mK)

A_c = c/s area of fin

p = perimeter of fin

t_o= base temperature

t_a= ambient temperature

Experimental setup and procedure

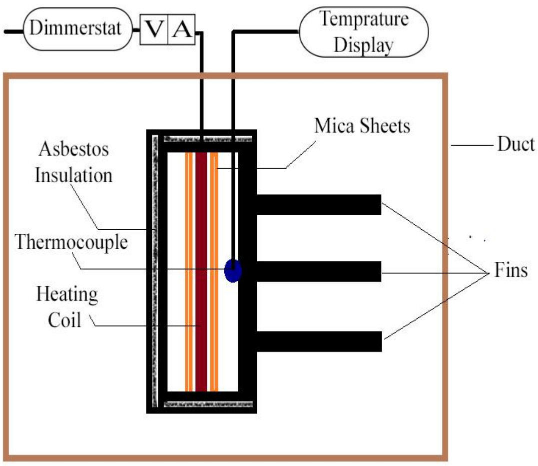

Fig.11Schematic of Experimental Setup

Setup consisted of arrangement for holding model, heating coil, voltmeter, ammeter, dimmer stat and temperature display.Each model had three fins and it was geometrically balanced. Permeable fins had four different geometrical arrangements i.e. Fins with 3 inline holes, 5 inline holes, 6 inline holes and 8 inline holes.Each hole drilled of 4 mm diameter. Heating coil (450 W) was inserted at the base of models to supply heat. An enclosed box was constructed with asbestos, mica and plywood to make unidirectional heat flow towards base without loss of heat. Electric supply was given to the coils through a dimmer stat so as to vary the input power. To calculate actual heat supplied, ammeter and voltmeter were connected at output of the dimmer stat. Base temperature of each fin was measured by k-type thermocouple. Tests were carried out by varying the input supplied to the heating coils. Different heat inputs given heat were 10 W, 15 W and 20W respectively. A duct was constructed to obtain steady flow of air at particular Reynolds no. A blower was used to obtain air flow in duct and orifice was used to determine Reynolds no. of flow. To analyse the heat transfer coefficient at different inclination, inclined geometries were constructed at 0° ,30°, 45°, 60° and 90°.

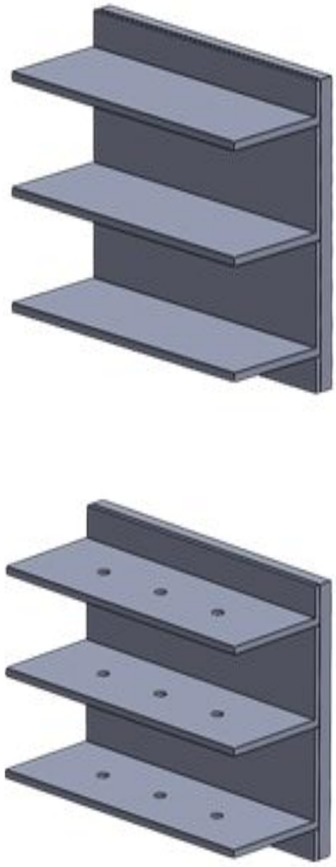

Fig. 2 Models of Solid and Permeable Fins

RESULT AND DISCUSSION

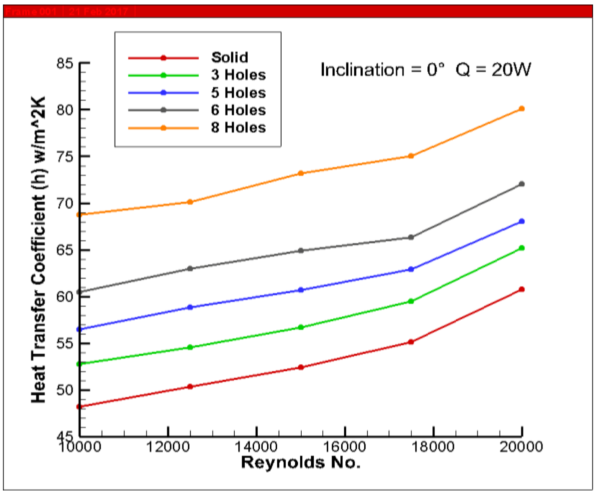

Fig. 3 Variation in Convective Heat Transfer Coefficient with *Re*

Fig. 3 shows the variation in convective heat transfer coefficient with increase in Reynolds no. The trend is gradually increasing and maximum heat transfer occurs at fins with maximum no. of holes and at maximum Reynolds no. It clearly indicates that in permeable fins amount of air which comes in contact with fins increases. Also thermal boundary layer formation is not significant in permeable fins under forced convection. Percentage increment in average heat transfer coefficient for permeable fins over solid fins with *Re* = 20000 at 20W of heat supplied is 8.3% 15.2% , 22.7% and 37.9% for 3 holes, 5 holes, 6 holes and 8 holes fins respectively.

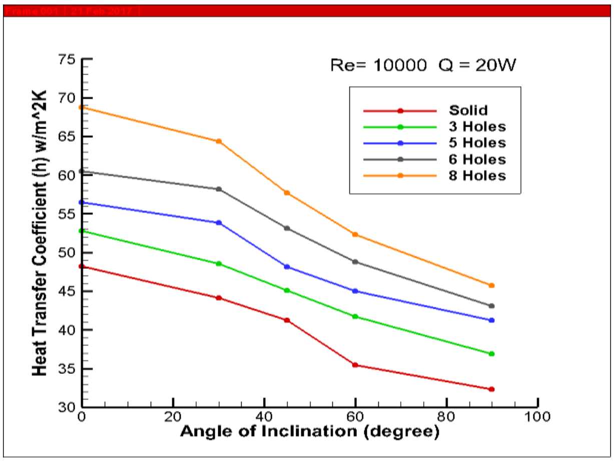

Fig 4 Variation in Convective Heat Transfer Coefficient with *θ*

From Fig.4 it can be clearly seen that with increase in angle of inclination the heat transfer coefficient decreases. From trend of graph it can be concluded that for horizontal position maximum heat transfer is possible and it decreases gradually as the fins are given inclination. This happens due to blockage of air flow. When fins are inclined at certain angle and air flows over them, one face acts as leading face and other is trailing. Since maximum flow of air is possible at leading edge the heat transfer occurs mostly from one surface while the trailing face doesn't receive enough amount of air. Still we can see increment in heat transfer coefficient is possible due to air passing through holes drilled over fin surface. Hence permeable fins are most beneficial over solid fins at horizontal position.

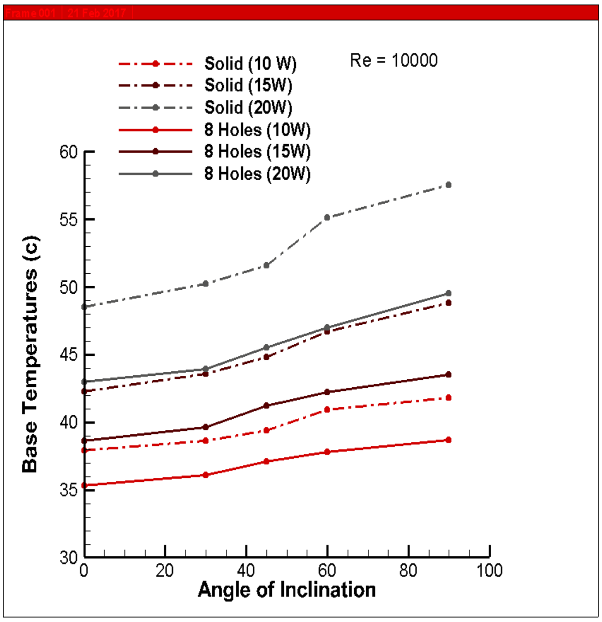

Fig 5. Comparison of base temperatures of solid and permeable fins

From Fig. 5 it can be seen that base temperatures of solid fins are higher than that of permeable fins at different heat inputs. But with increase in angle of inclinations, base temperatures also increase hence it can be concluded that lower base temperatures are possible in permeable fins in horizontal position which eventually reduce the thermal stresses over the assembly.

CONCLUSIONS

Experiments were conducted and analysed for the values of heat transfer coefficients and base temperatures at different *Re* and at different angles of inclination (*θ*). Percentage increment in average heat transfer coefficient for permeable fins over solid fins with Re = 20000 at 20W of heat supplied is 8.3%, 15.2% , 22.7% and 37.9% for 3 holes, 5 holes, 6 holes and 8 holes fins respectively. Following conclusions can be drawn:

1. Heat transfer coefficient increases with increasing number of perforations on solid fin.

2. Maximum heat transfer occurs at horizontal position (at 0°) in forced convection.

3. For same heat input permeable fins are cooler than solid fins hence heat transfer rate is more in permeable fins as compared to solid fins.

4. Increase in Reynolds no. also increases heat transfer coefficient.

5. Overall weight of the component is reduced by significant value of 10 -15%.

The experimentation can be further extended by varying geometry and shape of perforations.

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