Experimental Investigation of Heat Transfer Characteristics of Cylindrical Fin with Different Grooves

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Abstract — **An experimental study was performed to provide information about the effect of pressure reduction on heat loss from cylindrical fins of three different geometries. A literature review shows that much of work on radiating fins has been carried out analytically and numerically. In this research, a solid cylindrical fin and two other cylindrical fins with circular grooves and threads on their outside surface are investigated experimentally. A test facility with a pressure reduction chamber and instrumentation is fabricated. The heat input to the fin is varied such that the base temperature is maintained constant under steady state. Based on a study of effect of pressure reduction, using available resources, the chamber is designed for a vacuum of 680 mm Hg. The experimental result shows that for cylindrical fin with circular grooves (depth 3.5mm) heat loss is a maximum. The grooved cylindrical fin loses approximately1.23 times greater heat per unit area, compared to the threaded cylindrical fin, and 2.17 times greater heat per unit area, respectively compared to the solid pin fin at a pressure lower than atmospheric pressure. As pressure decreases heat loss reduces and contribution of radiation heat transfer on total heat loss increases.**

Index Terms — **Cylindrical Fin, Grooves, Heat Transfer and Pressure reduction.**

I. INTRODUCTION

Heat is energy in transition under the motive force of a temperature difference. If a temperature difference exist between two bodies heat will transfer in the direction of lower temperature. The mechanism of heat exchange is brought about by three methods: conduction, convection and radiation.

Fins are thin strips of metal attached to the heat transfer surface in order to increase heat transfer area. Since there is a certain relation between pressure and heat transfer rate, at low density situation the rate of heat transfer does not remain same as that at atmospheric pressure. To use fins for heat rejection at low density situation it is necessary to observe the heat transfer characteristics of the fin at that situation. Moreover, to reduce high waste heat, it is necessary to increase the heat transfer area of the radiator. But a radiator is generally optimized with respect of mass, since it is difficult and costly to handle a large radiator. The use of grooved or threaded cylindrical fin can be useful in this case.

Most of the work on space radiators has been carried out analytically and numerically. Krishnaprakash presented mass optimized design of a straight rectangular plate fin array extending from a plane wall. Ramesh and Venkatesan numerically optimized the tubular finned space radiator. Krikkis and Razelos presented the correlations for optimum dimensions of longitudinal rectangular and triangular radiating fins with mutual irradiation. Chung B.T.F.; Nguyen L.D. solved the general equation for radiating spines and studied the spine dimensions and heat transfer characteristics numerically. Razini .A.; Zohoor H. studied a conducting radiating spine with an arbitrary profile to find the optimum dimensions of the spine. Black and Schoenhals, and Black studied the directional radiation properties of specially prepared V groove cavities also optimized the directional emission from V groove and rectangular cavities. Gorchakov and Panevin analyzed the effectiveness and efficiencies of radiating fins having a surface roughness in the form of V groves oriented in the direction of temperature gradient. Bhise et al. investigated a corrugated fin structure for space radiator applications and presented correlations for the optimum corrugation angle and maximum heat loss to space. Srinivasan and Katte proposed a grooved radiator with higher heat loss per nit mass compared to the flat radiator.

The review shows that there have been a very few attempts to experimentally study the effect of modification of a cylindrical fin on its heat transfer characteristics. In this study, cylindrical fins with grooves and threads on its outside surface are investigated experimentally.

II. EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup consists of a pressure reduction chamber, an air compressor for suction purpose, thermocouples, heating element, digital manometer, multimeter and control valves. The pressure reduction chamber is designed for a maximum vacuum of 680mm Hg. It consists of- a hollow cylinder and two detachable end plates. A 30cm long, 20cm diameter (inner), and 4.5mm thick GI pipe is used as the hollow cylinder. Six passages are made through the cylinder, among which three passages are provided for thermocouples, one for suction inlet of compressor, one for vacuum control valve and one for vacuum measuring instrument. Three passages provided for thermocouples are placed at equidistance. The interior side of the cylinder is painted in black. Two GI plates of thickness 6.5mm are used to enclose the hollow cylinder. The plates are clamped to the cylinder. One of the plates is provided with a passage for the cylindrical fin. The inner side of the passage is threaded so that the cylindrical fin fits perfectly.

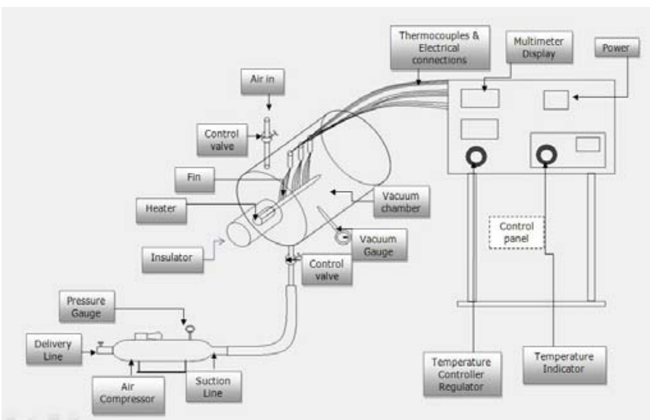

Fig. 1: Schematic Diagram of Experimental Setup

Three types of cylindrical fin model are used in present investigation- solid cylindrical fin, circular grooved cylindrical fin, threaded cylindrical fin. Aluminum is chosen as the fin material. The portion of each fin considered for the investigation has the following dimensions- length = 150mm, diameter = 20mm. Each fin is extended 55mm more. This extension is provided for heating and attachment of the fin with the end plate. Among this extension, 15mm length consist external thread which matches the internal threads provided to the passage of the detachable. Rest 40 mm length has a diameter of 32 mm to which heating element is attached. All the three cylindrical fins are painted black. Circular grooves are considered for the analysis. Four rows of grooves, consisting 9 grooves each; total 36 grooves are made through the cylindrical fin. Each groove has depth around 3.5mm. The threaded fin has a tpi of 12.

The control valves are checked and attached to the passages of the pressure reduction chamber. Before attachment the threaded portion of each valve is wrapped with thread tape. The compressor suction line is connected to the control valve provided to the passage at the bottom of the chamber. The delivery valve of the compressor is remained open so that compress air can escape and the compressor runs with no load. The digital manometer is attached to the control valve at the sidewall of the chamber. The manometer is calibrated before using for ensuring proper functioning. The fin is attached to the endplate, which is then attached to the cylinder and clamped tightly. The thermocouples are inserted to the chamber and are attached to the fin in equidistance. The soldering coil is used as heating element which is attached to the extended end of the fin. The multimeter is calibrated also before using. The outside surface of the soldering coil must be properly insulated to prevent heat loss and to maintain the root of the fin at desired temperature. Glass wool and cork sheet are used for this purpose. The temperature of the root of the fin is controlled by a temperature controller which is connected in series with the soldering coil.

Fig. 2**:** Experimental Setup

After completing the setup the heater (soldering coil) is switched on and the temperature controller is set to 50◦C. All experiments are to be carried out under steady state, for a root temperature of 50◦C. The root of fin is maintained constant at the desired temperature by adjusting the temperature controller. All the sealed passages must be checked properly before starting the compressor.

For observing the effect of vacuum on heat loss, pressure is varied by controlling the suction of air by the compressor and the corresponding variations of temperature are noted from the multimeter display. The vacuum in the chamber is controlled by adjusting the air flow into the chamber using the control valve. The procedure is continued for each three types of fin. Heat losses corresponding to different pressure are calculated from the data.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Experimental results are presented graphically with detailed explanations. For each three fins, total heat loss vs. pressure, convective heat loss vs. pressure, radiative heat loss vs. pressure and percentage of heat loss vs. pressure curves are plotted.

3.1 Solid Cylindrical Fin

Experimental data of solid fin gives the following curves shows below –

Figure 3 shows the effect of variation of absolute pressure on total heat loss by a solid cylindrical fin, which includes the effect of convective as well as radiative heat losses. The curve follows an exponential trend line. It is observed that heat loss reduces as pressure falls.

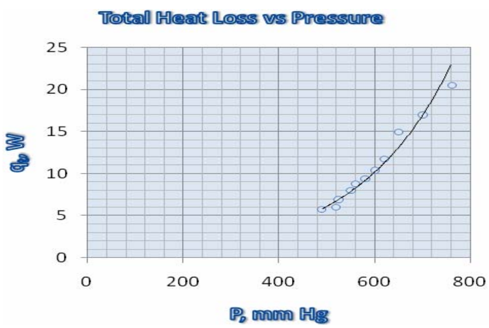

Fig. 3**:** Effect of pressure reduction on heat transfer from solid cylindrical fin

At a pressure of 490 mm Hg heat loss is only about 6.23 W which is only 29.67% of the total heat loss corresponding to the atmospheric pressure. As pressure is reduced by the suction of air, the density of air inside the pressure reduction chamber also reduces. This causes considerable reduction in the rate of convection heat transfer, as a result of which total heat loss is reduced. The curve also indicates that if pressure is further reduced, at a certain vacuum pressure, convective heat loss can reach negligible value.

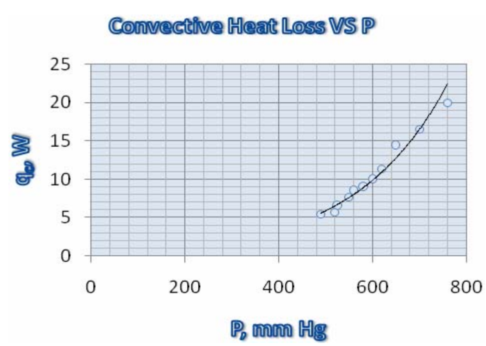

Fig. 4: Effect of reduction of pressure on convective heat loss by a solid cylindrical fin

Figure 4 shows that convective heat loss reduces sharply as pressure is decreased. It is because as the pressure inside the pressure reduction chamber is reduced, a low-density situation arises. In low-density circumstances the mean free path of the gas molecules is large enough, and as density reduces this distance increases. The larger this distance becomes, the greater the distance required to communicate the temperature of a hot surface to a as in contact with it. This means, it cannot be assumed that the layer or air in the immediate neighborhood of the surface of the fin will not have the same temperature as the heated surface. This causes a considerable reduction in convective heat transfer coefficient, h.

From Fig. 5 it is observed that heat loss due to radiation also reduces with the reduction of pressure. During investigation it is noted that, the average temperature of fin also falls with pressure and since temperature inside the pressure reduction chamber remains unchanged, the temperature difference is a little lower than that corresponding to the atmospheric pressure. This causes the reduction in radiative heat loss. It is observed that for a reduction of pressure about 270mm Hg, heat loss by radiation reduces about 46% than that corresponding to the atmospheric pressure.

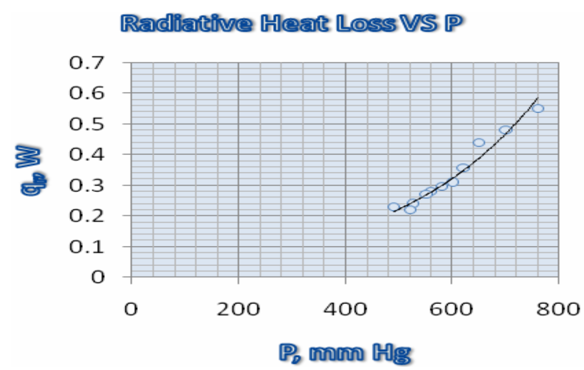

Fig. 5: Effect of pressure reduction on radiation from a solid cylindrical fin

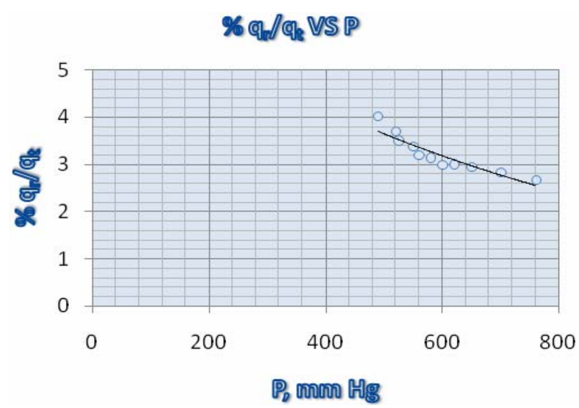

Fig. 6: Effect of pressure reduction on the percentage of radiation heat loss to total heat loss for solid cylindrical fin

Figure 6 shows that as pressure is decreased heat loss by radiation plays more vital role in total heat loss. It is observed that at atmospheric pressure heat loss by radiation is only .55 W which is only 2.68% of the total heat loss (which is 21 W). At a pressure of 490mm Hg heat loss by radiation is increased to 3.69% of the total heat loss. A further decrease in pressure will increase the percentage.

3.2 Grooved Cylindrical Fin

Grooved fin from the calculated heat loss and pressure following curves are plotted -

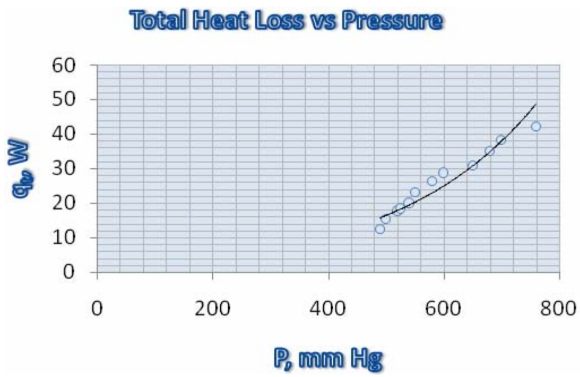

Fig. 7: Effect of pressure reduction on heat transfer through the grooved cylindrical fin

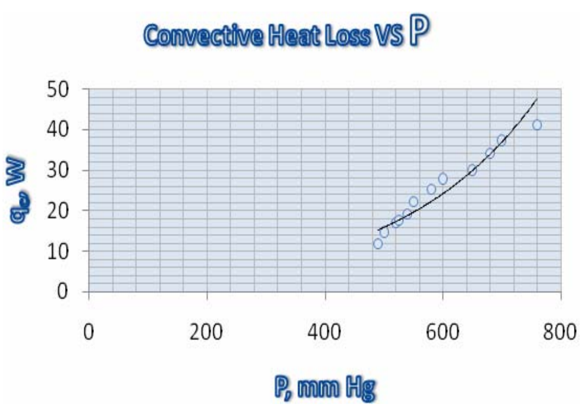

Fig. 8: Effect of reduction of pressure on convective heat loss by a grooved cylindrical fin

Figure 7 shows the effect of pressure reduction on the heat transfer through the cylindrical fin with circular grooves. From the figure it is observed that, with the increase of vacuum pressure there is a considerable reduction in heat transfer rate. At atmospheric pressure heat loss is about 42 W. For a pressure of 490mm Hg heat loss is about 12.4, which is 29.52% of the total heat loss corresponding to the atmospheric pressure. From Fig. 8 it is observed that heat loss due to convection reduces more rapidly with pressure for circular grooved cylindrical fin. The curve obtained from above figure has much higher slope than the curve obtained from fig- 29 for solid cylindrical fin. This indicates higher performance of grooved cylindrical fin than solid cylindrical fin.

Figure 9 shows that, radiation heat loss reduces with pressure. It is for the same reason as for the solid cylindrical fin which is explained before. In circular grooved fin radiation heat loss is greater than that of a solid cylindrical fin due to greater surface area. It is observed that for a reduction of pressure about 270mm Hg, heat loss by radiation reduces about 54.56% than that corresponding to the atmospheric pressure; which is 46% in case of solid cylindrical fin.

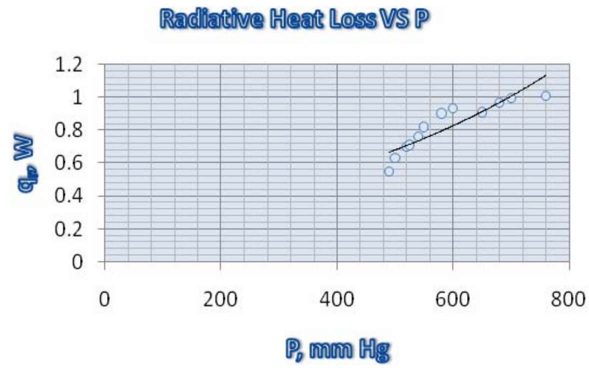

Fig. 9: Effect of pressure reduction on radiation from a grooved cylindrical fin

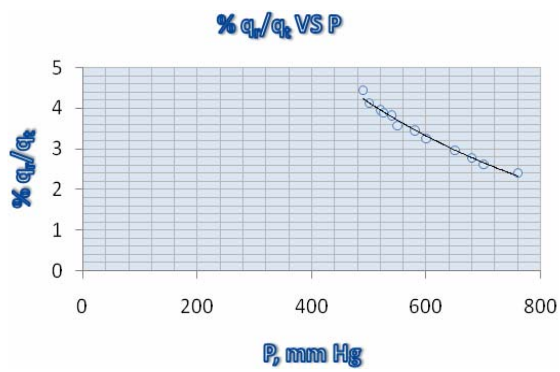

Fig. 10: Effect of pressure reduction on the percentage of radiation heat loss to total heat loss for grooved cylindrical fin

Fig. 10 shows the effect of pressure reduction on the percentage of radiation heat loss to total heat loss for grooved cylindrical fin. It may be noted that at atmospheric pressure radiative heat loss is 2.4% of total heat loss, and at 490mm Hg this value reaches 4.44% of the total value.

3.3 Threaded Cylindrical Fin

The curves obtained for threaded fin are discussed below –

The figure -11 shows the effect of variation of absolute pressure on total heat loss by a threaded cylindrical fin, which includes the effect of convective as well as radiative heat losses. From the above figure it is observed that, with the increase of vacuum pressure there is a considerable reduction in total heat transfer rate. At atmospheric pressure heat loss is about 33.9 W. For a pressure of 490mm Hg heat loss is about 10, which is 29.49% of the total heat loss corresponding to the atmospheric pressure.

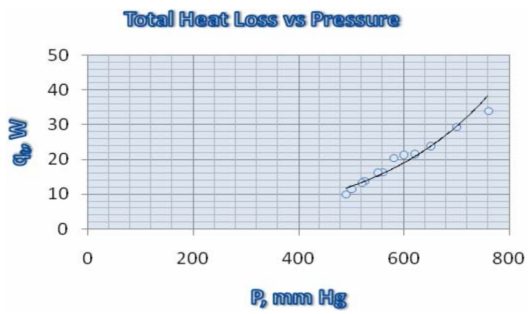

Fig. 11: Effect of pressure reduction on heat transfer through the threaded cylindrical fin

The figure -11 shows the effect of variation of absolute pressure on total heat loss by a threaded cylindrical fin, which includes the effect of convective as well as radiative heat losses. From the above figure it is observed that, with the increase of vacuum pressure there is a considerable reduction in total heat transfer rate. At atmospheric pressure heat loss is about 33.9 W. For a pressure of 490mm Hg heat loss is about 10, which is 29.49% of the total heat loss corresponding to the atmospheric pressure.

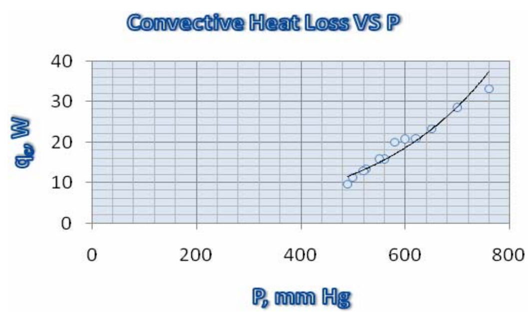

Fig. 12: Effect of reduction of pressure on convective heat loss by a threaded cylindrical fin

Figure 12 shows effect of pressure reduction on heat loss due to convection by a cylindrical fin with thread on its outer surface. The curve trend is similar to the trend obtained from fig- 3 (for solid cylindrical fin) and figure -7 (for circular grooved cylindrical fin). But there is variation in slope from both curves obtained before. This curve from fig- has a larger slope than the curve obtained for a solid cylindrical fin, and a smaller slope than the curve obtained for a circular grooved cylindrical fin. Heat loss by convection from a threaded Cylindrical fin with tpi=12 and thread depth = 1.5mm is less than a Cylindrical fin with 36 circular grooves of 3.5mm depth. At atmospheric pressure convective heat loss by this threaded cylindrical fin is 33.16 W, which is almost 78.95% of the convective heat loss by circular grooved cylindrical fin corresponding to atmospheric pressure.

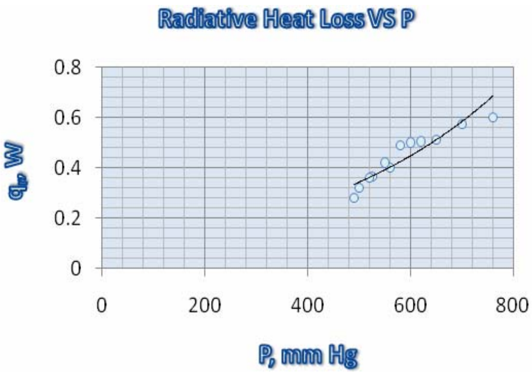

Fig. 13: Effect of pressure reduction on radiation from a threaded cylindrical fin

The curve from above Fig.13 has the same pattern as obtained for solid and grooved cylindrical fin. Heat loss due to radiation from the threaded cylindrical fin under consideration is less than that of a circular grooved cylindrical fin. At atmospheric pressure radiation heat transfer for threaded cylindrical fin is .6, which is only about 59.52% than that of a grooved fin. Even this value is less than that of a solid cylindrical fin. It is due the effect of shape factor, since the thread angle is small.

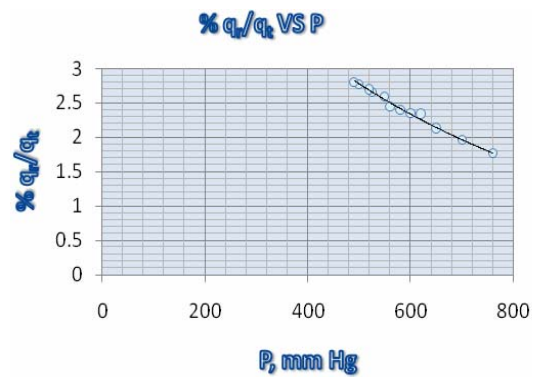

Fig. 14: Effect of pressure reduction on the percentage of radiation heat loss to total heat loss for threaded cylindrical fin.

Figure 14 shows that as pressure is decreased heat loss by radiation becomes more prominent in total heat loss. It is observed that at atmospheric pressure heat loss by radiation is only .6 W which is only 1.77% of the total heat loss (which is 33.9 W). At a pressure of 490mm Hg heat loss by radiation is increased to 2.8% of the total heat loss. A further decrease in pressure will increase the percentage.

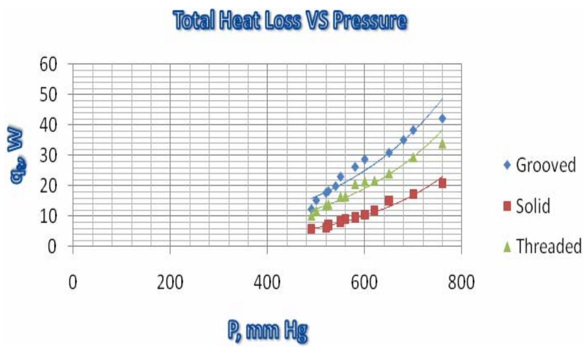

Fig. 15: Comparison of total heat loss by solid, grooved and threaded cylindrical fin at different pressure

A comparison is of total heat loss from solid, grooved and threaded cylindrical fin is made. The curves obtained from above figure have the same pattern for all fins. The figure shows that heat loss by grooved cylindrical fin is maximum, which is because heat transfer surface increases as grooves are made, which results in considerable increase in convection heat transfer rate. Moreover due to cavity effect radiation heat transfer also increases. Maximum heat loss obtained from the experiment at atmospheric pressure is 42 W, and at 490mm Hg pressure it is 12.4 W.

For the threaded Cylindrical fin heat loss is greater than solid cylindrical fin but less than grooved cylindrical fin. Heat loss, in this case is larger than solid cylindrical fin due to increased heat transfer area. But since the thread angle and depth is small rate of heat loss is less than grooved Cylindrical fin. Maximum heat loss obtained from the experiment for threaded cylindrical fin at atmospheric pressure is 33.9 W, and at 490mm Hg pressure it is 10 W. these values are close to that for grooved cylindrical fin. So maybe it is possible to increase heat loss by threaded cylindrical fin than a grooved cylindrical fin by varying thread angle and depth.

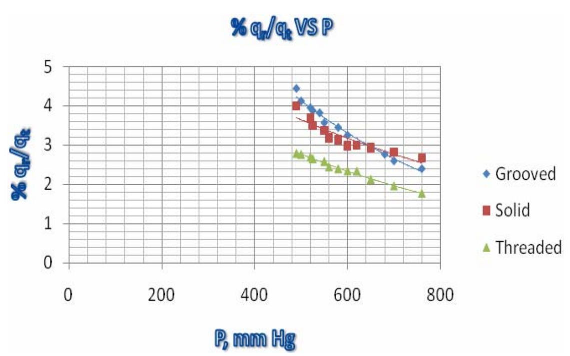

Fig. 16: Comparison of participation of radiation on total heat loss for solid, grooved and threaded Cylindrical fin with varying pressure.

Figure 16 shows the comparison of participation of radiation on total heat loss for solid, grooved and threaded Cylindrical fin with varying pressure. It may be noted that at a pressure of 490mm Hg the percentage of radiation to total heat loss is maximum for grooved cylindrical fin, due to cavity effect. But for the solid cylindrical fin it is less than threaded cylindrical fin. This is because of increased heat transfer area due to threads.

IV. CONCLUSION

From this experimental study it has been found that the grooved radiating fin loses approximately1.23 times greater heat per unit area, compared to the threaded pin fin, and 2.17 times greater heat per unit area, compared solid to the solid pin fin at a pressure lower than atmospheric pressure. As pressure decreases heat loss reduces and contribution of radiation heat transfer on total heat loss increases.

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