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Enhancement of Heat Transfer Characteristics of Plain Fin Coated With Graphene Nanoparticle

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Abstract

Improving the cooling performance of electronic devices and engines, unlike is an important area that is being investigated by several investigators. Poor performance of conventional cooling methods has necessitated enhancing heat transfer by using different fins with different configurations. Further various thin film coatings on fins using different nano-particles of silver, copper and carbon-based materials like Graphene, Multi Walled Carbon Nanotubes (MWCNTs) and their benefits in enhancing heat transfer have been reported in the literature. This work involves highlights on heat transfer characteristics of heat sinks having different shapes such as copper concave, aluminium congruent and copper flat plate. These differently shaped heat sinks were subsequently coated with graphene nanoparticles and their effect on heat transfer characteristics is studied. The outcomes obtained from the experimental forced convection are used to compare the heat transfer characteristics for different heat sinks with and without nano-coating. The experiment is conducted for varied voltage inputs and the heat dissipation is compared. Different parameters like surface temperature, Nusselt number, Reynolds number, and effectiveness are compared for different heat sinks with and without nano-coating. Experimental analysis showed that for a constant voltage input of 100V, copper concave, aluminium congruent and copper flat plate-shaped heat sinks with graphene coating showed higher heat transfer coefficients which more by 45.35%, 40.64%, and 21.43% when compared to those without the coating. Also, the Nusselt number increased by 9.9%, 13.9% and 40% accompanying a decrease in thermal resistance by 40%, 30.9% and 30.36% with respect to those without the coating. The copper concave-shaped heat sink, with graphene nano-coating exhibited a higher heat transfer coefficient, higher Nusselt number and decreased thermal resistance compared to that without coating and hence can be used in electronic elements for greater heat dissipation.

Keywords: *Fins, Fin Configuration, Graphene, Heat Sink, Heat Transfer Characteristics, Thin Film Coating*

1.0 Introduction

Heat transfer performs a significant role in the presentation of thermal systems. The need to increase heat transfer rate is gaining more prominence in electronic components and devices as the working of the components and devices at designed efficiency is very much required.

Distinct types of heat sinks are employed in many present-time electronic and electrical systems to elevate the heat transfer rate thereby avoiding overheating of such

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systems. In this regard, a lot of exploration is being made to optimize the heat transfer performance of thermal systems by adopting different fin geometries, fin material, fluid velocity and direction as well.

Non-identical types of heat sinks were investigated and are reported that the average heat transfer coefficient, and heat transfer rate increases with the reduction of weight in discrete fins and perforated fins compared to the solid fins block. Nusselt number rises with an increase in heat input for all types of testing geometries[1–7]. Elliptical fin with elliptical perforation showed maximum efficiency[8]. Circular (spherical) and oval (elliptical) dimples were investigated for heat transfer studies using numerical analysis and found that oval type plate exhibited higher thermal performance while spherical shape resulted in a smaller pressure drop[9]. Simulation using Ansys FLUENT showed better performance for staggered conic fins compared to staggered rectangular fins with regard to heat transfer, quality factor and pumping power. Heat sinks of longitudinal pin fins and radial fins with inverted trapezoidal-shaped holes were found to be better[10,11].

Thermal-hydraulic performance of different shapes like plain, rectangular and wavy fins was analyzed by varying the velocity of air and tube inclination angles. Higher heat transfer from rectangular fin and higher efficiency from plain fin with the lower pressure drop was reported by Moorthy P, *et al*[12]. Heat transfer coefficient, efficiency, and effectiveness were numerically and analytically calculated for different cavity shapes like triangle, rectangular, trapezoidal, and semicircular on rectangular extension. It is found that the fin rectangular-shaped cavity exhibited higher effectiveness with enhanced heat transfer rate[13]. Experimental investigations were done on the aluminium fin with shapes like circular, square and triangular extensions and found that the circular fin exhibited a higher heat transfer rate[14]. An experimental study on heat transfer characteristics using circular, aerofoil and square fins inside a rectangular duct was done and found that aerofoil geometry showed a higher rate of heat transfer and lesser pressure drop compared to others[15]. An increase in pumping power increases thermal resistance and a flattened cross section produces lesser thermal resistance compared to a rectangular cross section[16].

Experiments were conducted on the heat sink with pin-fin array under forced convection and found that the Nusselt number and heat transfer coefficient elevates with the rise in Reynolds number. Further with the rise in twisting angle, the pressure drop and friction factor reduce. Non-twisted fins showed lesser efficiency compared to twisted fins[17].

Fins efficiency can be upgraded by increasing its thermal conductivity using thermal coatings with surface modification. Usually, thermal coating on the material is accustomed to lessen corrosion and scaling and increase the life of the material. The use of nanomaterials for heat transfer applications is gaining prominence. Graphene is used for coating fin surfaces of different shapes like square and cylindrical shapes made from aluminium and copper materials have been investigated by Sabarish, *et al*[18]. The heat transfer rate and efficiency of fin modes under free and forced convection heat transfer are studied, and significant improvements in rates of transfer of heat have been reported. Seo, *et al.,*[19] used some blankets of deposited nanocoating which is made up of indium tin oxide (SWCNT, hybrid graphene) to rise the heat transfer coefficient and critical heat flow of nuclear coating surfaces[20]. The efficiency of heat transfer of a pin-fin heat sink made up of aluminium material was investigated under natural convection using a device. At different controlled temperatures, the dissipation of heat without and with coating was tested. The heat sink which is nanocoated evaluated that the height of the end would be reduced by 25% and that the efficiency of heat transfer would still be akin. The benefit of nano-coating also expanded the coefficient of surface heat transfer due to the increase in ruggedness. Several inspections and examinations have been carried out so far to procure the thermal efficiency to make certain that the heat pipe in heat exchangers works expertly and accurately[21–24]. Prabhu, *et al.,*[25] highlighted the significance of nano-coating on the substrate and it could become an important thing in enhancing the heat transfer of thermal systems. Higher thermal conductivity coating materials provided on the extended surfaces could increase the heat transfer significantly. Senthilkumar, *et al.,*[26] studied heat transfer characteristics of fins made up of aluminium with carbon Nano Tubes coatings (CNTs) using the PVD technique. Nanomaterial-coated aluminium fins exhibited higher fin efficiency by 5% compared with non-coated fins.

Nagarani, *et al.,*[27] conducted experiments to determine heat transfer characteristics on elliptical-shaped stainless steel coated with MWCNTs at different surface temperatures. The thermal conductivity and heat transfer coefficient of coated heat sink grew by 21.1% and 7% respectively compared with the non-coated heat sink. Further fin effectiveness was boosted by 21.8% when compared with stainless steel non-coated material.

From the exhaustive literature, a survey carried out it is found that the combined effect of heat sinks geometry and nano-coatings on the heat transfer characteristics is not investigated in depth. The present work addresses the enhanced heat transfer mechanism considering the effect of both heat sink geometries as well as nano-coatings on the enhanced heat transfer.

2.0 Methodology

The experimental set up consists of a mild steel tube table which has a top frame cover and panel which consists of a digital ammeter, voltmeter, blower, flow control valve, heater control, manometer, selector knob, and gate valve. The test duct is chosen with the dimension of 70mm*100mm*190mm. Air is the fluid used for convection and the type of flow chosen is turbulence. Further, the entrance ledge is not considered into account (Figure 1).

Figure 1. Experimental set up.

Figure 2. Copper concave.

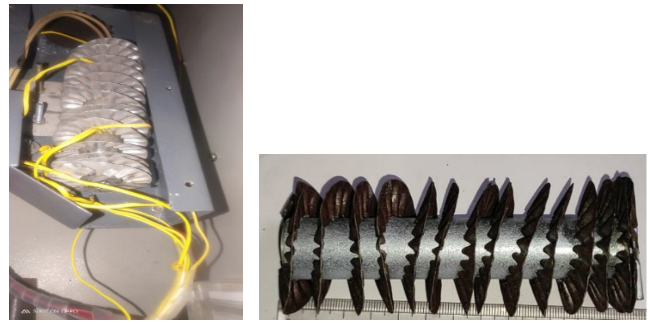

Figure 3. Aluminium congruent.

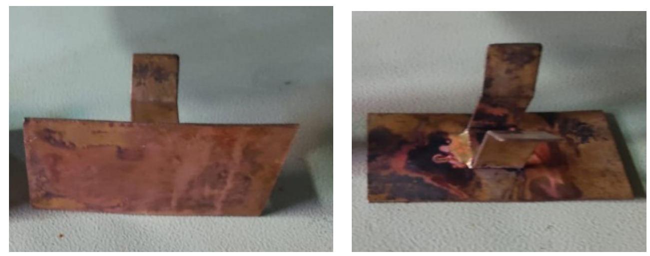

Figure 4. Copper flat plate.

2.1 Nano-coating of Heat Sinks

The coating of graphene on different heat sinks is explained in the following section.

2.1.1 Graphene Coating on Copper

The copper concave (Figure 2), copper flat plate and copper concave fins were etched with HNO_3 and HCl to remove oxide layers on the surface, and then ultrasonic cleaning was carried out in a bath containing 99% ethanol for 20 minutes. The cleaned copper fins were sandblasted for 1 minute. The cleaned copper and brass fin were loaded into a three-inch CVD quartz tube. The tube was filled with ultra-pure nitrogen gas and evacuated to 10-4 m.bar and repeated thrice to achieve a contamination-free environment during the deposition. Then the tube is heated to 900°C and maintained for one hour for stabilization. The copper fins were maintained at 900°C. Then a mixture of CH_4 (Vol.10%) and N_2(Vol. 90%) was introduced to the quartz tube at the required rate for 20 minutes. Finally, the flow of CH_4 was turned off, and the quartz tube allows to cool to room temperature at a natural cooling rate. The removed sample was performed for further analysis such as structural analysis.

2.1.2 Graphene Coating on Aluminum

The Dip coating was used to coat graphene on aluminum congruent. The aluminum congruent was cleaned by etching in 50 wt.% NaOH solution at 50°C for 30s, then immersed in a 40% nitric acid solution for the 20s, and finally ultrasonicated in the ionized water bath for 10 minutes. Then the entire aluminum congruent was immersed into the graphene oxide solution kept at 30°C and taken out at speed of 1 cm per second. Then the aluminum congruent was dried at room temperature for 3 hours. Then the prepared sample was taken for further studies such as thermal conductivity and functional characterization (Figure 3).

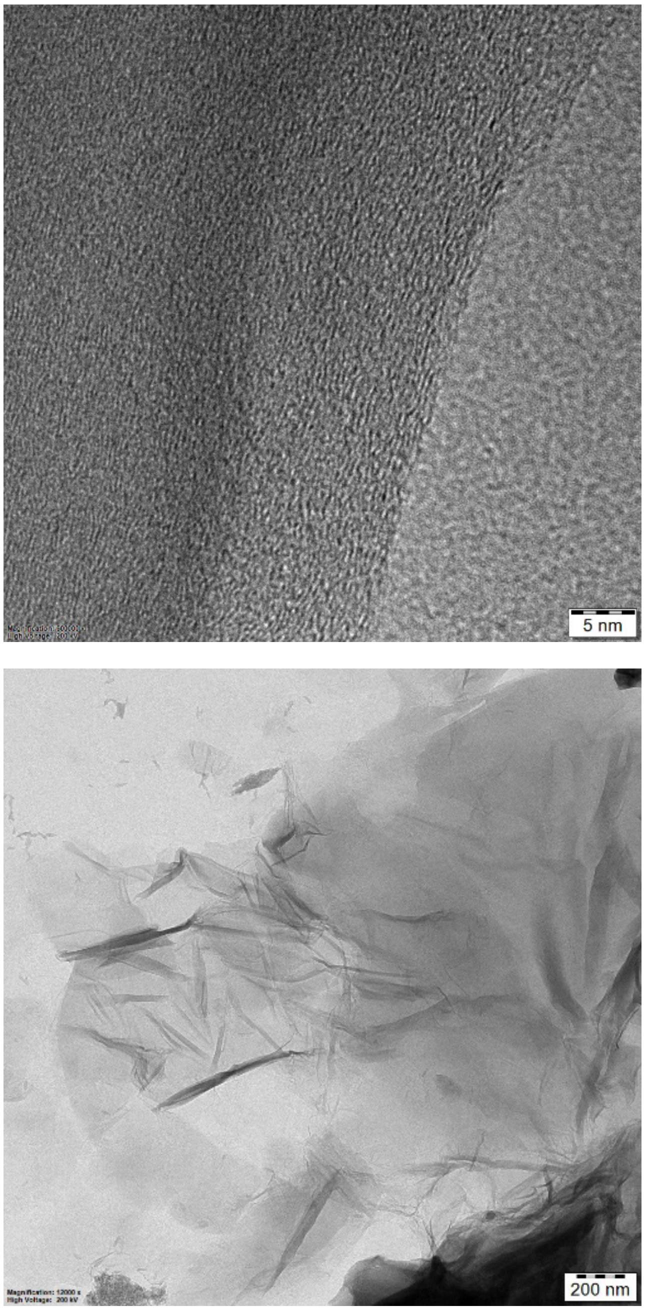

Figure 5. TEM image of the Graphene coating provided on different heat sinks.

Figure 5 shows the TEM image of the graphene coating material provided on different heat sinks of copper concave aluminium congruent and copper flat plate (Figure 4) respectively.

3.0 Experimental Procedure

Three different-shaped heat sinks made up of brass material are tested in the test rig as shown in Figure A for knowing their heat dissipation capacity. Each sample plate has dimensions of 38mm width, 68mm length and 1mm thickness. For Forced condition, the blower is kept in ON condition, set manometer by adjusting the valve slowly as the mains gets switched ON, and the heater control knob is rotated to set the required voltage, after reaching steady-state readings of voltage, current and all temperatures are noted. The experiment is repeated for different heat inputs.

4.0 Result and Discussion

The heat transfer rate Q is calculated using Newton's law of cooling i.e.

$$Q = h\ A\ \Delta T$$

Where h is the heat transfer coefficient in $W/m^2 °C$
A is the area of heat transfer surface in m^2
Q is the rate of heat transfer in W
ΔT is the temperature difference between the surface and the surroundings.
The Nusselt number is calculated using

$$Nu = C\ Re^m Pr^n \left(\frac{Pr_f}{Pr_w}\right)^{0.25}$$

Where Nu is Nusselt number
Re is Reynold's number
Pr is Prandtl's number
Pr_f is the Prandtl number at the film temperature
Pr_w is the Prandtl number at the wall temperature

4.1 Forced Convection Heat Transfer Rate

Figure 6 shows the comparison of forced convection heat transfer rate with voltage input for the different heat sinks with and without coating. Heat generation is proportional to the power dissipation, and power is defined as voltage times current. From Figure 6 it is noticed that the heat transfer increases with the increase in voltage. Among the different-shaped heat sinks copper concave-shaped heat sinks showed higher heat transfer rates compared to aluminium congruent and copper flat plates respectively (42.71% and 18.75%). Further, the nano-coated copper concave and aluminium congruent heat sinks showed higher heat transfer by 62.5% and 67.5% compared to their uncoated ones. This is attributed to the fact that for the same voltage input, the nano-coated surfaces with higher thermal conductivity exhibited higher temperature differences compared to that without coated ones. A similar behaviour is followed by the copper flat plate heat sink but the heat transfer rates were comparatively lower.

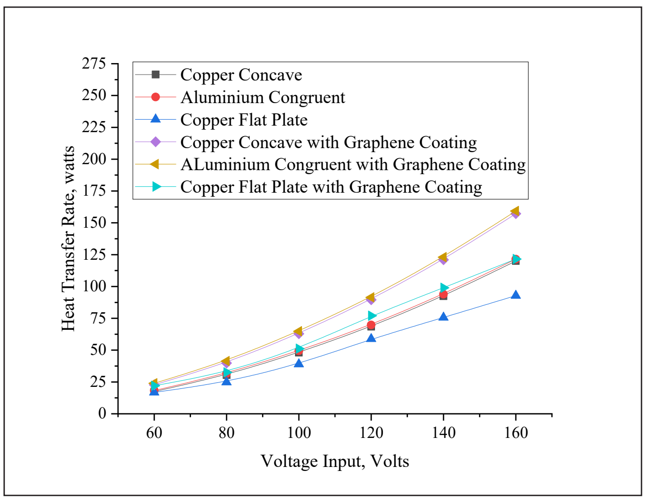

Figure 6. Variation of forced convection heat transfer rate with voltage input for heat sinks with and without coating.

Enhancement of heat transfer due to Al_2O_3 nano-coatings on copper and aluminium material were reported in the literature[29]. A measurable amount of increase in temperature difference was also observed.

4.2 Fin Surface Temperature

Figure 7 shows the comparison of forced convection average surface temperature vs. voltage input for the different heat sinks with and without coating. It is noticed that the average surface temperature increases with a rise in voltage due to an increase in the flow of current which leads to the rise in surface temperature. Among the different-shaped heat sinks copper concave and aluminium congruent-shaped heat sinks showed higher fin surface temperature compared to copper flat plate respectively (21.51% and 32.91%).

Further, the nanocoated copper concave and aluminium congruent heat sinks showed higher average surface temperatures by 25% and 20% compared to their uncoated ones. This is attributed to the fact that for the same voltage input, the nano-coated surfaces with higher heat transfer rates associated with higher thermal conductivity exhibited higher temperature differences compared to that without coating. The behavior is followed by the copper flat plate but the average surface temperatures were comparatively lower.

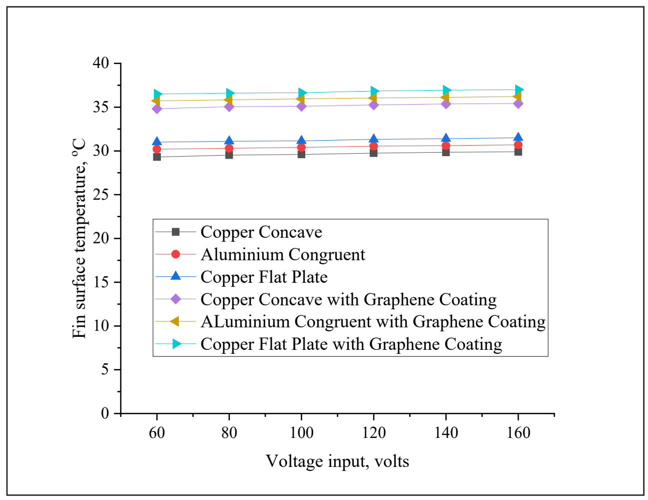

Figure 7. Variation of forced convection surface temperature with voltage input for heat sinks with and without coating.

4.3 Temperature Difference

Figure 8 shows the comparison of forced convection average temperature difference vs. voltage input for the different heat sinks with and without coating. As mentioned earlier (Figure 7) copper concave-shaped heat sinks exhibited higher temperature differences followed by other heat sinks. The coated versions of heat sinks with higher heat transfer rates showed higher temperature differences as well.

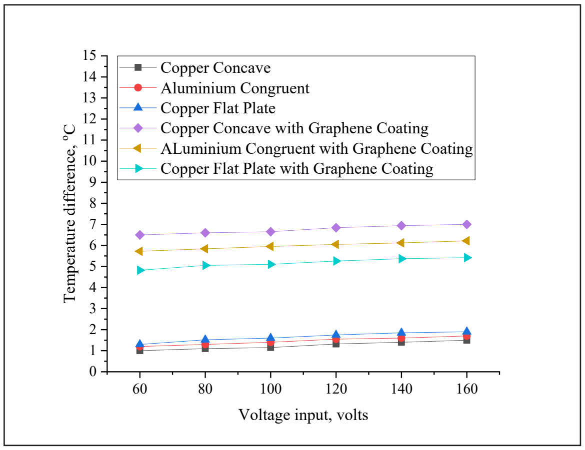

Figure 8. Variation of temperature difference with voltage input for heat sinks with and without coating.

4.4 Heat Transfer Coefficient

Figure 9 shows the variation of heat transfer coefficient (experimental) vs. voltage input in forced convection. It is noticed that the heat transfer coefficient increases with the rise in voltage due to the increase in the heat transfer rates. The copper concave-shaped heat sink has a higher heat transfer coefficient compared to the aluminium congruent and copper flat plate heat sink. It is also observed that graphene coating has increased the heat transfer coefficient of the aluminium congruent and copper concave heat sink by 40.64% and 45.35% respectively.

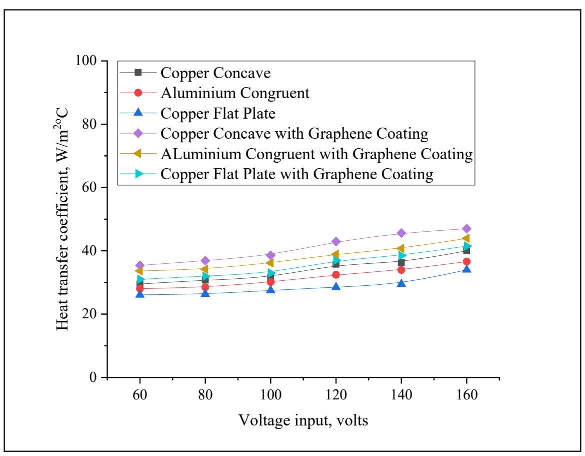

Figure 9. Variation of heat transfer coefficient with voltage input for heat sinks with and without coating.

The work from Long Chen, *et al*., shows that there is an enhancement of heat transfer and thermal conductivity due to the graphene coating. The results obtained from the work of Long Chen are in line with the current experimental works presented[28].

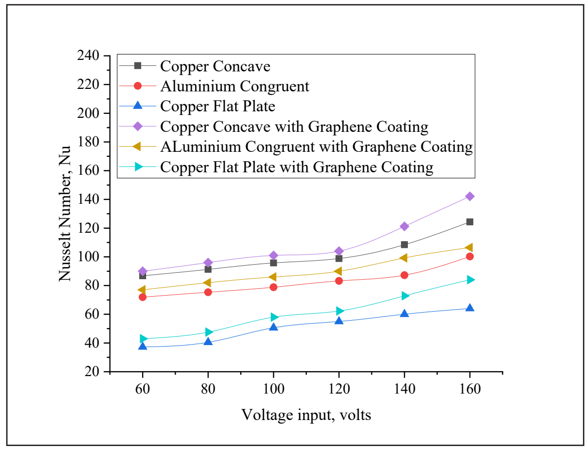

Figure 10. Variation of Nusselt Number with voltage input for heat sinks with and without coating.

4.5 Nusselt Number

Figure 10 shows the variation of Nusselt number vs. voltage input for coated and uncoated heat sinks in the forced convection mode of heat transfer. Nusselt number increases with an increase in voltage due to increased heat transfer coefficient as is evident in Figure 10. Coated heat sinks showed higher Nusselt numbers due to enhanced heat transfer rates. Among the heat sinks graphene coated copper concave showed higher Nusselt numbers followed by aluminium and copper flat plate heat sinks respectively.

4.6 Thermal Resistance

Figure 11 gives the comparison of thermal resistance vs. voltage input for coated and uncoated heat sinks in the forced convection mode of heat transfer. It is found that the thermal resistance magnifies with the increase in voltage due to more vibrations of atoms, which enhances the difficulty of the flow of electrons. The copper concave heat sink exhibited lower thermal resistance compared to aluminium congruent and copper flat plate heat sinks respectively. Further, these heat sinks when coated with graphene showed comparatively lower thermal resistance. Heat sinks being common the addition of graphene coating on them resulted in higher heat rates with reduced thermal resistance as evident from Figure 11. Graphene-coated copper concave heat sink showed the lowest thermal resistance by 40% compared to the uncoated copper concave heat sink.

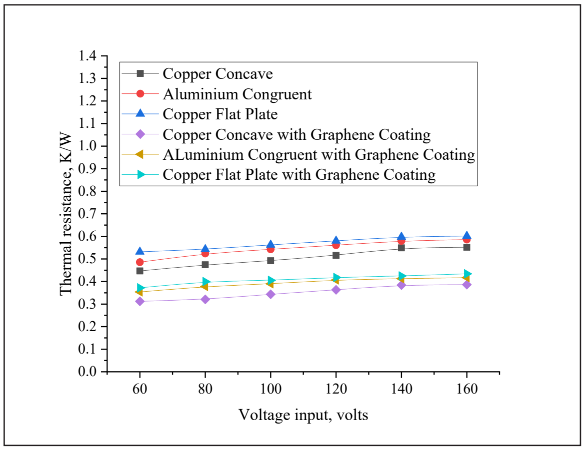

Figure 11. Variation of thermal resistance with voltage input.

4.7 Pressure Drop

Figure 12 shows the comparison of pressure drop vs. voltage input for coated and uncoated heat sinks in the forced convection mode of heat transfer. From the figure, it follows that the pressure drops increase with the increase in voltage, because of the increase in gas viscosity. Pressure drop is found more for the aluminium congruent heat sink compared to copper concave and flat-shaped heat sink. No appreciable changes in pressure drops were observed between coated and uncoated heat sinks.

The work done by Megaraj Meikandan et.al shows that the nano-coatings of MWCNT help to marginally reduce the pressure drop and increase the rates of heat transfer. The results obtained from this experiment are in line with the experimentation work of Megaraj Meikandan, *et al*[30].

4.8 Fin Effectiveness

Figure 13 shows the comparison of Effectiveness vs. voltage input for coated and uncoated heat sinks in the forced convection mode of heat transfer. From the figure, it is observed that the Effectiveness remained nearly the same with an increase in voltage. Graphene-coated heat sinks showed higher effectiveness compared to uncoated heat sinks. Among the heat sinks graphene-coated copper concave showed higher effectiveness followed by aluminium congruent and copper flat-coated heat sinks respectively.

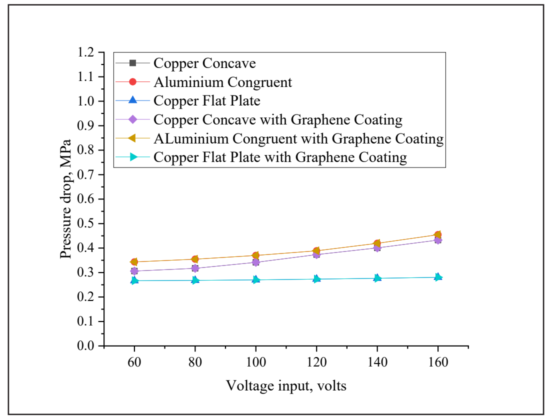

Figure 12. Variation of pressure drop with voltage input.

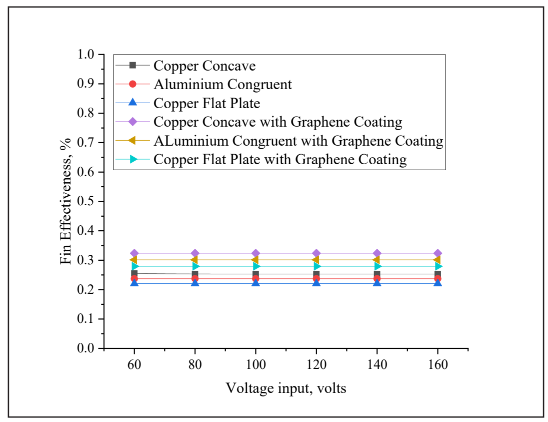

Figure 13. Variation of fin effectiveness with voltage input.

4.9 Fin Efficiency

Figure 14 shows the variation of fin efficiency with voltage input for coated and uncoated heat sinks in forced convection. Fin efficiency remains the same for all the voltage inputs applied. Compared to uncoated heat sinks the graphene-coated ones showed comparatively higher fin efficiency. Among the different heat sinks graphene-coated copper concave-shaped heat sinks showed higher followed by coated aluminium congruent and coated copper flat heat sinks respectively. The percentage increase in the fin efficiency varied from 86.96% to 73.58% between the coated and uncoated heat sinks due to the improved thermal conductivity of the material coating provided on the heat sinks. The experimental work by Sreedhar Vulloju, *et al.*,[31] shows that the coated material increases the Nusselt number, Reynolds number and also the efficiency of fin and these results are in line with the present work as the same trends were reported in this experimentation.

4.10 Reynolds Number

Figure 15 shows the variation of the Reynolds number with voltage input for coated and uncoated heat sinks in forced convection. Reynolds number decreased with a rise in voltage input. A higher Reynolds number is observed for copper concave heat sinks compared with aluminium congruent and copper flat heat sinks respectively. From the figure, it is observed that the increase in the percentage of Reynolds number for coated heat sinks varied from 8% to 27.3% when compared to uncoated ones.

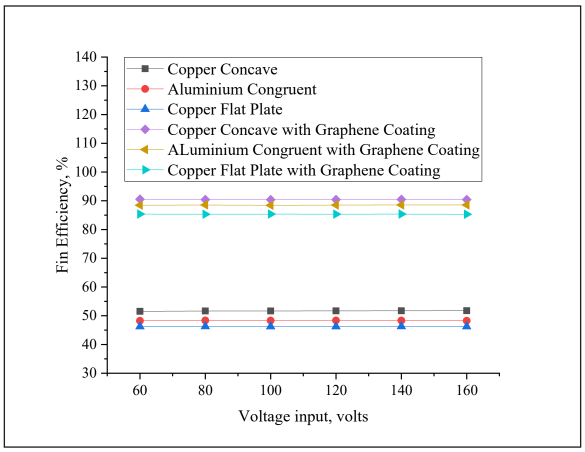

Figure 14. Variation of Fin Efficiency with voltage input.

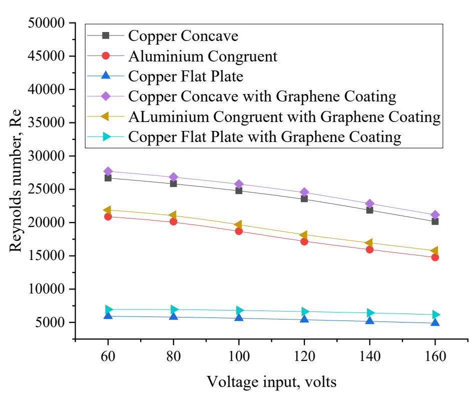

Figure 15. Variation of Reynolds number with voltage input.

5.0 Conclusion

Experimental investigations were done to assess the heat transfer characteristics of three heat sinks of different geometries viz, copper concave, aluminium congruent and copper flat plate respectively. Further, these heat sinks were coated with graphene nanoparticles using a suitable technique.

The compared heat transfer characteristics of copper concave, aluminium congruent and copper flat plate-shaped heat sinks coated with graphene showed higher heat transfer coefficients which more by 45.35%, 40.64%, and 21.43% when compared to those without the coating. Also, the Nusselt number increased by 9.9%, 13.9% and 40% along with a decrease in thermal resistance by 40%, 30.9% and 30.36% with respect to those without the coating. The surface temperature increased by 25, 20 and 15.6%, fin efficiency increased by 73.58, 85.42 and 86.96%, and fin effectiveness increased by 32%, 25% and 33.3% respectively. Nano-coated heat sinks can be effectively used to enhance heat transfer characteristics.

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