Novelty Journals

ISSN 2394-7349

International Journal of Novel Research in Engineering and Science
Vol. 3, Issue 1, pp: (86-92), Month: March 2016 - August 2016, Available at: www.noveltyjournals.com

CFD ANALYSIS OF HEAT TRANSFER AUGMENTATION OF PLATE FIN WITH DIMPLED SURFACE

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Abstract: **Heat transfer enhancment technique have a greater importance to deal with thermal management problem associated with varies engineering applications. Active techniques and passive techniques are used for heat transfer enhancement. Among this passive techniques of heat transfer enhancement are more compactable to improve heat transfer performance than active methods due to various reasons. In this work the effect of surface modification on heat transfer performance is studied using ANSYS fluent software. A straight fin heat sink is selected and its heat transfer performance is analysed. Surface of the existing flat plate fin is modified with hemispherical grooves called dimples on both sides of the plate. Hemispherical grooves of depth half as thickness of plate is chosen. The effect of dimples on heat transfer performance is analysed. Flat plate is replaced with a tapered plate of same base width and dimples are imposed on the surface. All modifications are analysed using ANSYS fluent for various flow conditions, under various flow conditions heat transfer coefficient, Nusselt number and temperature drop of all models are analysed. Results shows that heat transfer coefficient and Nusselt number of dimpled straight fin is higher than that of straight fin and tapered fin with dimples. Heat transfer performance of all the model increases with increase in flow velocity of air Also temperature drop on fin is maximum in straight fin with dimples.This shows heat transfer performance of straight fin with dimples is higher than that of straight fin and tapered fin with dimples.**

Keywords: **Fin, heat transfer enhancement, heat transfer coefficient, Nusselt number, CFD.**

1. INTRODUCTION

Improving the efficiency of heat exchange is an area which has wide range of use in various applications and various studies are still going on in the area of heat transfer augmentation. Improving the efficiency of heat transfer is useful in a variety of practical applications such as macro and micro scale heat exchangers, gas turbine internal airfoil cooling, fuel elements of nuclear power plants, powerful semiconductor devices, electronic cooling, combustion chamber liners, biomedical devices, etc. In all these applications, enhancements in the efficiency of heat exchangers can lead to cost, space and material savings. Higher performance, higher heat transfer rate with minimum pumping power requirements are some of the main challenges of the heat exchanger design. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment Therefore; considerable research work has been done in the past to seek effective ways to increase the efficiency of heat exchangers.

Various heat transfer augmentation techniques are developed and implemented in heat exchanger applications over the past couple of years. Several attempts are concerned to reduce the size and cost of the heat exchangers. Both active and passive methods are used to improve heat exchanger performance among these the passive techniques can be considered important one because of its wide variety of applications like in electronic cooling (heat sinks), process industries, cooling and heating in evaporators, solar air heaters, turbine airfoil cooling etc [1]. One of the earliest research studies conducted by Bearn and Harvey [2], who experimentally showed that dimpled circular cylinders, can reduce drag force by affecting flow conditions around the circular cylinder similar to dimples on a golf ball. Several experimental and numerical studies exist for the use of dimples to improve surface heat transfer. Moon et al. [5] experimentally studied the effect of height of channels on heat transfer performance and losses due to friction in rectangular dimpled passage with staggered dimples on one wall. Heat transfer enhancement was found to be 2.1 times higher than the smooth channel configuration with H/D values from 0.37 to 1.49. The heat transfer augmentation was invariant with the Reynolds number and channel height. The increase in friction factor was 1.6 to 2.0 times less than the smooth channel. Mahmood et al [8] experimentally studied the influence of dimple aspect ratio, Reynolds number, temperature ratio, and flow structures in a dimpled channel at ReH = 600 to 11,000 and air inlet stagnation temperature ratio of 0.78 to 0.94 with H/D =0.20, 0.25, 0.5, 1.00. The results show that the vortex pairs which are periodically shed from the dimples become stronger and local Nusselt number increase with decrease in channel height. Burgess et al [9] experimentally analyzed effect of depth of dimple on the surface in a channel with the δ /D ratio of 0.1, 0.2, and 0.3. The results showed that the local Nusselt number increased as the dimple depth increases. Ligrani et al [10] studied the effect of turbulence level at the inlet in the heat transfer improvement in walls with dimple ratio δ/D=0.1, showing that as the turbulence level was increased, the relative Nusselt number reduced due to the increased turbulent diffusion of vorticity. Bunker et al [11] use circular pipes with in-line arrays of dimples with δ/D=0.2 and 0.4 and surface area densities ranging from 0.3 to 0.7 and heat transfer enhancement was found to be 2 times greater than the smooth circular tube. Increase of friction factor was approximately 4 to 6 times greater than the smooth circular tube. Han [12] studied the rotational effect of dimples in turbine blade cooling. In the case where a pressure drop is the main design concern, dimple cooling can be a good choice. Jet impingement over a convex dimpled surface was studied by Chang et al. [13] showing an incremental increase in the relative Nusselt number (Nu/Nu0) up to 1.5.

The above mentioned literature shows that hemispherical grooves called dimple can improve heat transfer performance. Most of the investigations are concentrated on the use of dimples and various dimple geometries in channels. The objective of this work is to analyse the effect of dimpled surface on heat transfer performance of straight plate fin. A straight fin made of aluminium attached to a base plate is considered for study, the base plate to which fin is attached is a heat source at a temperature of 400K. This arrangement is a simplification of heat sink used in electronics devices for heat removal from electronics components. Heat transfer coefficient, Nusselt number, temperature drop on fin will be find out by analyzing the straight fin, straight fin with dimples, tapered fin and tapered fin and Compare the result of this heat transfer performance parameters on different modifications.

2. GOVERNING EQUATIONS AND COMPUTATIONAL SETUP

To analyse the effect of heat transfer properties with dimples on flat surface, a heat sink was modeled using solid works software. The analysis was conducted in ANSYS workbench software version 16. The heat sink measures 300 mm long × 220 mm wide × 70 mm high. To simplify the problem and to reduce calculation load only one fin is selected. The flat plate fin is of 12 mm thickness, 58mm height, 300mm long. Fin is attached to a base plate of 12 mm thickness which is at a higher temperature. Flat plate fin is enclosed in a fluid demine of size 70 mm width 120 mm height and 600 mm length. Flat plate is modified by creating hemispherical grooves called dimples of 12 mm diameter and a depth of 6 mm. Dimples are arranged on both sides of the plate in a zigzag manner. Another surface modification imposed is, flat plate is replaced with tapered plate whose thickness is such that thickness is 12 mm at base plate and 6 mm at top. Same dimpled arrangement is done on tapered fin ad analysis is being done. Hemispherical grooves of 12mm diameter and 6mm depth are made on the surface of the straight fin on both sides. Another modification is straight fin is made tapered such that the thickness is 12mm at the base and 6mm at the tip and dimples are imposed on tapered fin. The continuity equation, energy equation and momentum equations are solved in the analysis.

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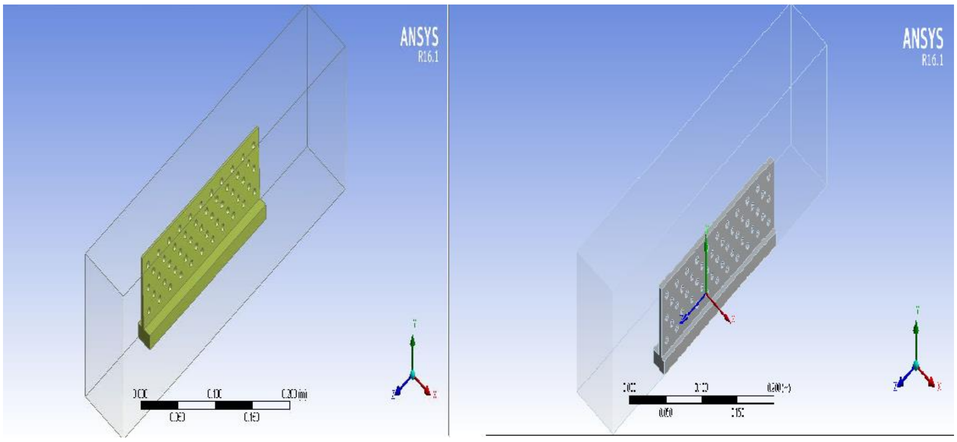

Fig. 1. Model of straight fin and tapered fin with dimples

3. VALIDATION OF SOFTWARE

The straight fin attached to the base plate is a simplified model of a heat sink using in electronic devices. Since the available date about the characteristics of straight fin for the dimension is limited. Validation is done by comparing the results obtained from the Solid Works Fluid Flow Simulation software with ANSYS FLUENT R16.1. Model of straight fin attached to a base plate is analysed on both software under same boundary conditions and compared, both software shows similar results and hence the software is validated. Figure 2 shows the temperature contour of straight fin under same boundary condition in ANSYS FLUENT and Solid Works Fluid Flow Simulation software.

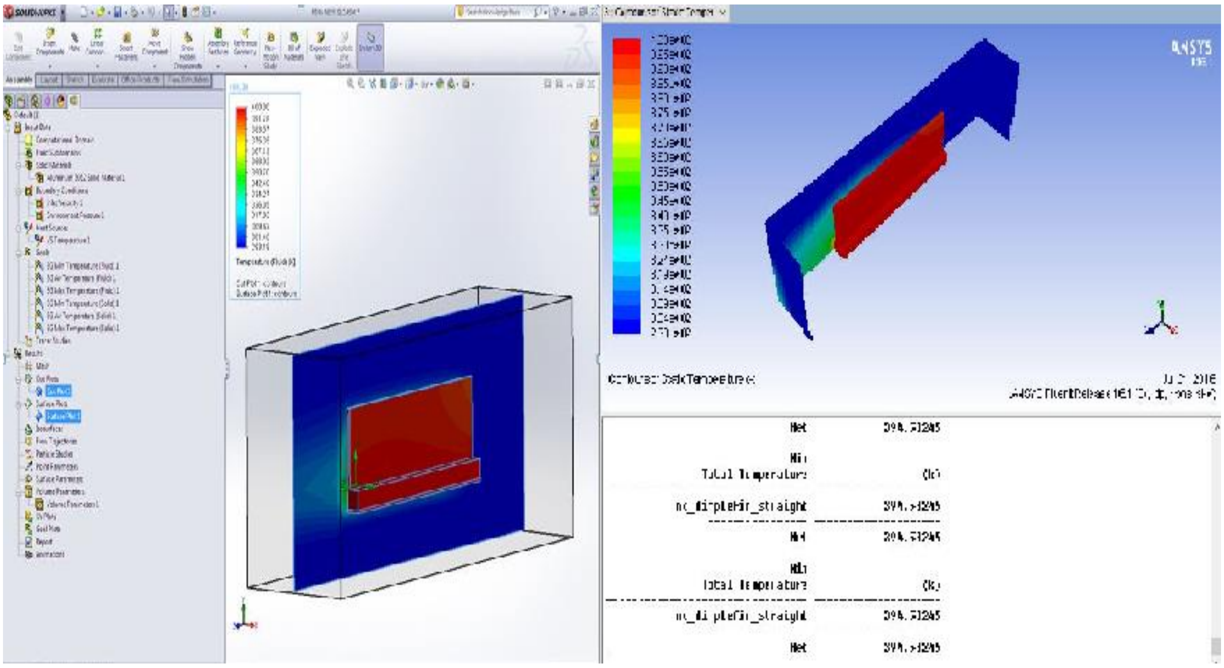

Fig. 2. Temperature contour in Solid Works Fluid Flow Simulation software and ANSYS FLUENT

4. RESULTS AND DISCUSSION

The analysis were done on straight fin, dimpled straight fin, tapered fin, tapered fin with dimples. All the mentioned analysis were done for air flow velocities of 1.5 m/s, 2 m/s,2.5 m/s, 3 m/s and 3.5 m/s. Dimpled fin is analysed for different spacing between dimples, inline array of dimples and staggered array of dimple. Results of the above analysis are discussed below.

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NUSSELT NUMBER:

Nusselt number represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across the same fluid layer. The larger the Nusselt number, the more effective the convection. Plot of Nusselt number of dimpled fin and straight fin at different velocity is shown in the figure 3. From the result it can be seen that for a velocity of 1.5 m/s the value of Nusselt number is 15.67 for fin without dimple and for dimpled fin its value is 23.45, which is 33.17 % higher than that of straight fin. When the velocity increases from 1.5 m/s to 3.5 m/s, Nusselt number of straight fin increases from 15.67 to 25.78, for dimpled fin Nusselt number increases from 23.45 to 36.01. Nusselt number comparison of straight fin, dimpled straight fin and tapered fin with dimple is plotted in the figure 4. The result shows that Nusselt number of straight fin with dimple is higher than that of other type of fin and it gives better heat transfer performance among the three models.

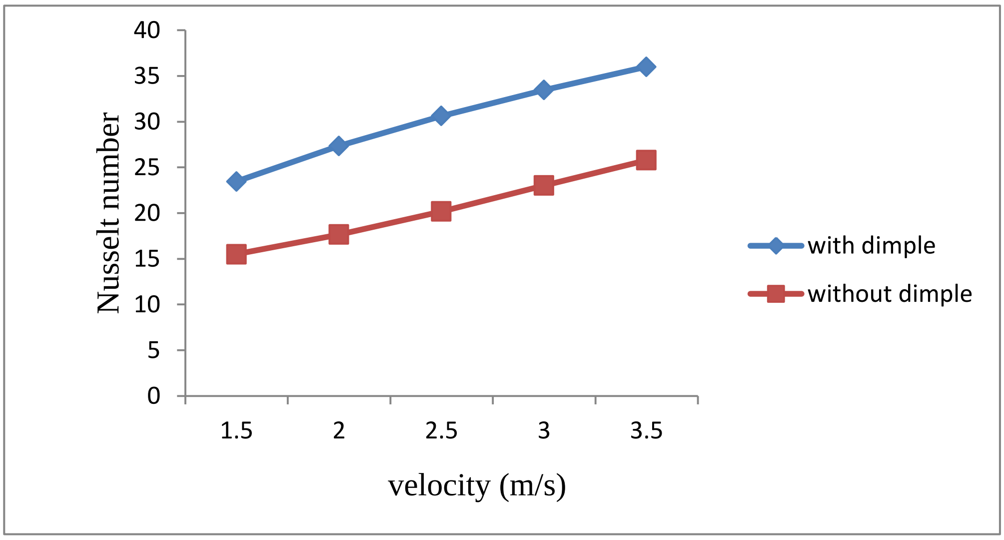


Fig. 3, Nusselt Number – Velocity Graph for Fin with and without Dimple

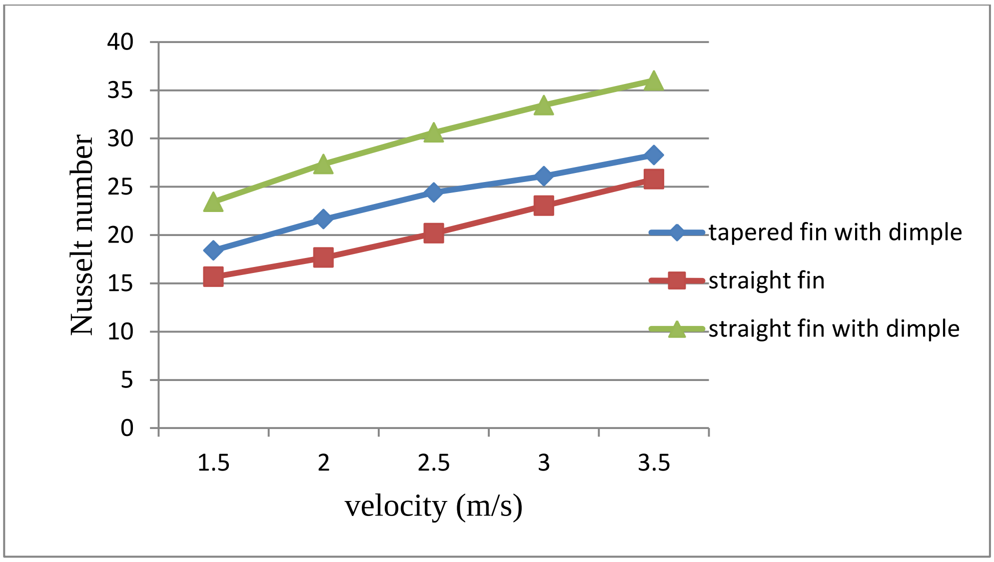
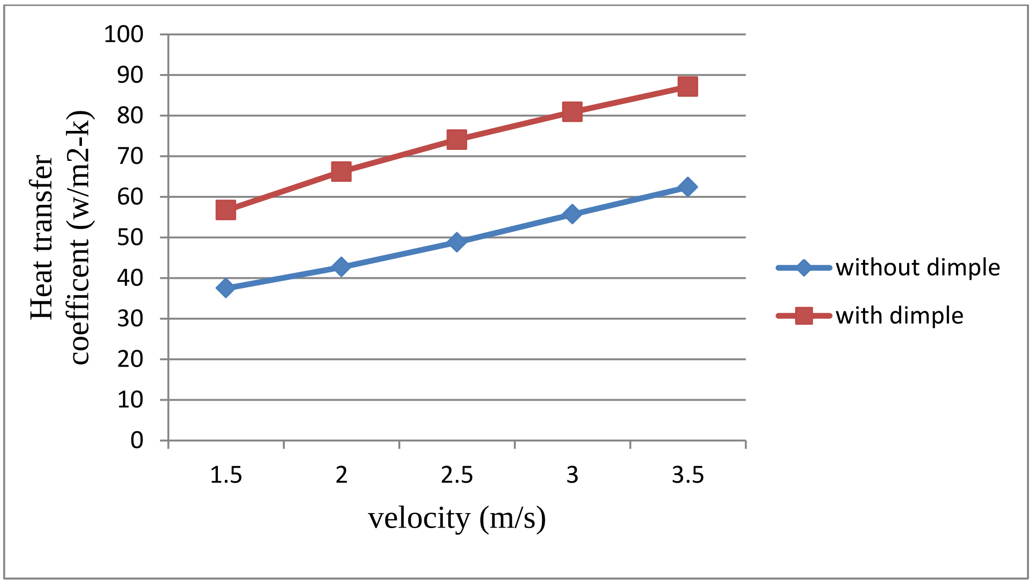


Fig. 4, Nusselt Number – Velocity Graph for straight fin, straight fin with dimple, and tapered Fin with Dimple

HEAT TRANSFER COEFFICIENT:

Heat transfer coefficient is a quantitative characteristic of convective heat transfer between a fluid medium (a fluid) and the surface (wall) flowed over by the fluid. The above results shows that for air velocity of 1.5 m/s heat transfer coefficient of straight fin is 0.375 W/m^2K and for dimpled fin value is 0.567 W/m^2K, which is 33.86 % higher than that of straight fin. Similarly, with varying velocities of 2 m/s, 2.5 m/s, 3 m/s, 3.5 m/s the percentage increase in heat transfer coefficient for dimpled fin than straight fin are 35.49 %, 34.14 %, 31.14 % and 28.35 %, respectively. When velocity increases from 1.5 m/s to 3.5 m/s heat transfer coefficient of straight fin increases from 0.375 W/m^2K to 0.624 W/m^2K and dimpled fin 0.567 W/m^2K to 0.871 W/m^2K. Plot of heat transfer coefficient of dimpled and straight fin at different velocity is shown in fig.5. Figure 6 shows the plot of heat transfer coefficient of straight fin, dimpled straight fin and tapered fin with dimple. From the figure it is clear that heat transfer coefficient of straight fin with dimple has maximum heat transfer coefficient and it is the best suited modification among the three.



Fir.5, Heat Transfer Coefficient – Velocity Graph for Fin with and without Dimple

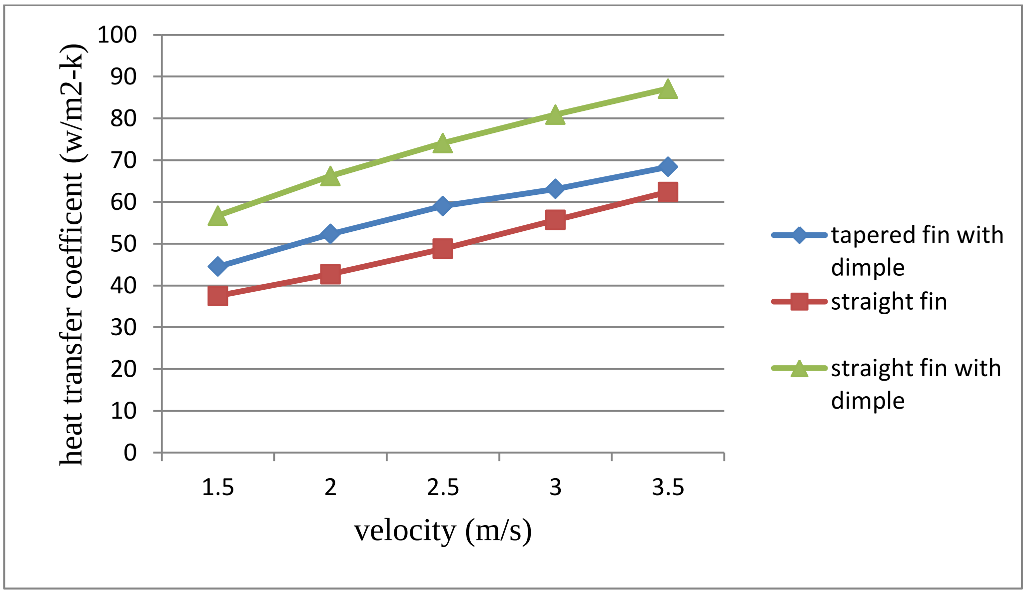


Fig.6, Heat Transfer Coefficient – Velocity Graph for tapered Fin with and without Dimple

TEMPERATURE DROP:

The improvement of heat transfer performance is reflected as drop in temperature on surface of fin. A lower heat sink temperature is an indication of enhancement in heat transfer performance. Temperature drop verses velocity plot of straight fin with and without dimple is shown in figure6. The results show that for a velocity of 1.5 m/s temperature on straight fin was 394.76 K and for dimpled fin 336.55K, which is 14.7 % less than that of straight fin. Similarly, with different velocities of 2 m/s, 2.5 m/s, 3 m/s and 3.5 m/s the percentage decrease in fin temperature of dimpled fin over

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straight fin are 16.1 %, 17.2 %, 18.9 % and 19.5 %. When velocity increases from 1.5 m/s to 3.5 m/s temperature of fin reduced from 394.76 K to 391.7 K for straight fin and 336.55 K to 315.06 K for dimpled fin. Temperature drop versus velocity plot of straight fin, straight fin with dimple and tapered fin with dimple is shown in the figure 7. The plot shows that lower fin temperature is obtained for straight fin with dimples, which means dimples on the surface of a straight fin increase convective heat transfer. Lowest temperature drop is for straight fin compared to tapered fin with dimples and straight fin with dimples.

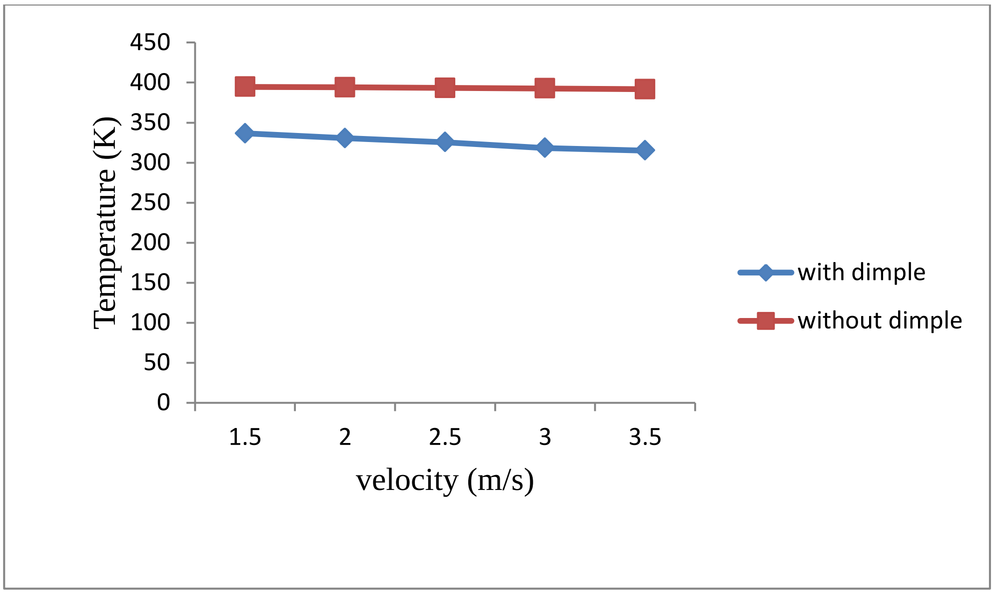

Fig.6, Temperature – Velocity Graph for Fin with and without Dimple

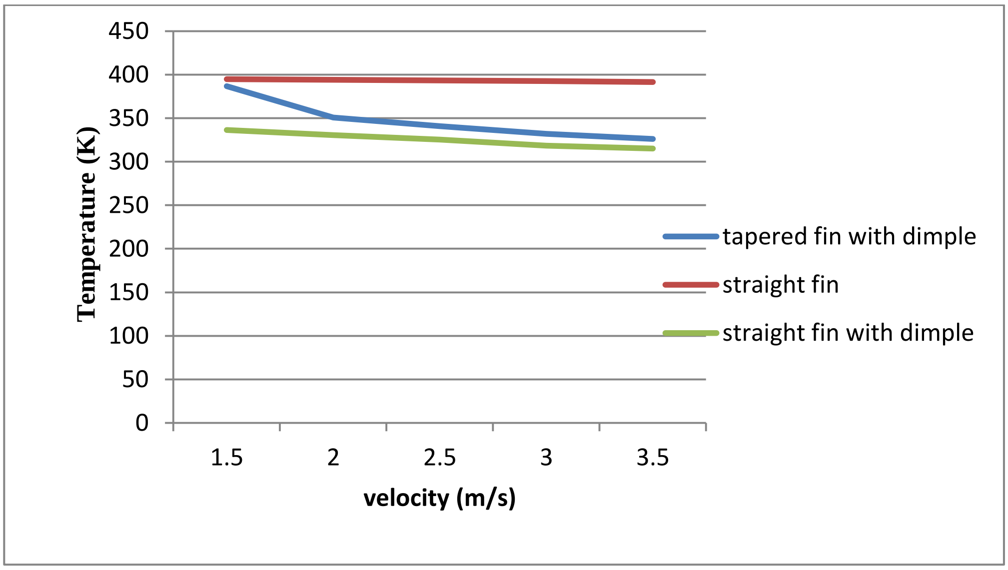

Fig. 7, Temperature – Velocity Graph for straight Fin, dimpled straight fin, dimpled tapered fin

5. CONCLUSION

The major conclusion drown from the study are summarized below. Heat transfer coefficient of straight fin with dimples found higher than that of straight fin. Dimples on the surface of straight fin increased heat transfer coefficient by 30%. As the airflow gets faster heat transfer coefficient of both straight fin with dimple and without dimple increases and the rate of increase is more for dimpled fin. Heat transfer coefficient of tapered fin with dimples is higher than that of tapered fin without dimple. But among the four types heat transfer coefficient of straight fin with dimples are higher and it gives maximum heat transfer performance. When Nusselt number of four models were compared, results shows that straight fin with dimples has maximum value and for all the models Nusselt number increases as the air flow become faster. Straight fin with dimples shows minimum fin temperature than straight fin, tapered fin and tapered fin with dimples. Tapered fin with dimples and straight fin with dimples shows better heat transfer performance than tapered and straight fin without dimple. So from the studies we can conclude that dimples on the surface improve heat transfer performance. Also results shows that heat transfer performance of straight fin with dimples is higher than that of straight fin, tapered fin and tapered fin with dimples.

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