Effect of vibration on Heat Transfer Enhancement in dimpled Surfaces

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Abstract — Over the past couple of years the focus on using dimple surface provides enhanced heat transfer has been documented by a number of researchers. Dimples are used on the surface of flow passages because they produce substantial heat transfer. This project work is concerned with experimental investigation of the convective heat transfer over the dimpled surface. The objective of the work is to perform an experiment to find out the comparative results for heat transfer rate on dimpled surface to the vibrating dimpled surface. Also the investigation for heat transfer on dimpled surface and vibrating dimpled surface has been performed. The parameters used for the present investigations are pitch of the dimple, Air velocity and vibration. The results obtained from the experiment are compared and found the enhanced rate of heat transfer for vibrating dimpled surface by 25-27% as compared to the without vibrating surface one.

Keywords — Heat Transfer Coefficient; Dimple surfaces, vibration, Reynold Number, Nusselt number

I. INTRODUCTION

The conventional heat transfer enhancement approaches to increase either the heat transfer rate or the turbulence of fluid stream, in general, it involves the incorporation of fins, baffles, nebulizers and etc. Although, these approaches are the effective method to improve the heat transfer performance. Efforts have been made to produce more efficient heat exchangers by employing various methods of heat transfer enhancement. The study of enhanced heat transfer has gained serious momentum during recent years, however, due to increased demands by industry for heat exchange equipment that is less expensive to build and operate than standard heat exchange devices. Savings in materials and energy use also provide strong motivation for the development of improved methods of enhancement. When designing cooling systems for automobiles and spacecraft, it is imperative that the heat exchangers are especially compact and lightweight. Also, enhancement devices are necessary for the high heat duty exchangers found in power plants. These applications, as well as numerous others, have led to the development of various enhanced heat transfer surfaces. The dimpled surface is one of the effective methods to improve the heat transfer rates without the significant pressure drop.

II. LITERATURE SURVEY

In order to get the idea about area of research it is essential to discuss some of the previous studies undertaken in this field. Review of literature shows that different researcher and expert work in the field of investigation of heat transfer enhancement in plane, dimpled and vibrating surfaces. The available literature is reviewed as under Hemant et al. [1] has conducted an experiment to determine whether dimples on a heat sink fin can increase heat transfer for laminar airflows and it was done by using two different types of dimples circular and oval. These dimples were placed on both sides of copper plate with a relative pitch and relative depth and for these configurations Nusselt number and overall heat transfer coefficient were determined. Ifikarahamad et al. [2] investigated heat transfer enhancement over the dimpled surface. The main objective of his experiment ware to find out the heat transfer and air flow distribution on dimpled surfaces and all the results obtained are compared with those from a flat surface. For obtaining the results, the spherical type dimples were fabricated, and the diameter and the depth of dimple were 6 mm and 3 mm respectively. Lance et al. [3] studied effect of dimple depth on heat transfer enhancement in a rectangular channel with hemispherical dimples. They observed that same Nusselt number ratios for each Reynolds number and high heat transfer due to thermal boundary layer development at the entry of the test section. Saleh et al. [4] studied the flow and heat transfer performance of a parallel/counter flow heat exchanger, when the heat transfer surface is provided with dimples on one or both sides i.e. on the cold fluid side and hot fluid side. The experimental set up consists of two parallel identically and geometrically passages: one for the hot fluid and the other for the cold fluid. The average duct height is 10 mm and duct width is 110 mm The Results consist of flow characteristics and heat transfer characteristics (Nusselt number distributions) comparison against the non-dimpled case (smooth surface) was held. It was found that the overall heat transfer rates were 2.5 times greater for the dimpled surface compared to a smooth surface. Sandeep et al. [5] experimentally investigated that heat transfer enhancement from dimpled surface in a channel. The heat transfer improvement with dimples seems to have a maximum. An experimental investigation has been carried out to study heat transfer and friction coefficient by dimpled surface.

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Iftikarahmad et al. [6] did the Computational investigation of convective heat transfer over a dimpled surface in their work aluminum plates. Variation of Nusselt numbers with Reynolds numbers are investigated, with various parameters combinations. Effect of dimple density, dimple depth and dimple arrangement on heat transfer in terms of Nusselt number enhancement is also reported. Dafedar et al. [7] has studied experimentally the heat transfer augmentation through various geometries of dimpled surfaces. Longitudinal and lateral directions for in-line arrangements were studied in natural convection with steady laminar external flow condition. The result showed that the heat transfer coefficient and heat transfer rate increases along longitudinal direction as compared to lateral direction. Somin et al. [8] studied Measurement of the heat transfer coefficient in the dimpled channel, effects of dimple arrangement and channel height Results showed that the heat transfer coefficient upstream side of the dimple was low because of flow recirculation. Similarly, a high heat transfer region was found downstream of the dimple due to flow reattachment. The heat transfer coefficient increased as the Reynolds number increased. Saini et al. [9] experimentally investigate the heat transfer and friction factor correlations for a duct having dimple-shape artificial roughness for solar air heaters and conclude that maximum value of Nusselt number has been found corresponds to relative roughness height and relative pitch. Lau et al. [10] studied that effect of dimple geometry on flow and heat transfer in a Square channel with a dimpled wall and numerical results showed that cylindrical dimple configuration might be a better alternative than concave dimples in enhancing heat transfer. Chen et al. [11] conducted a numerical study on turbulent heat transfer in plate over dimpled surface. Different depth ratios of symmetric and asymmetric dimple were investigated. The optimum dimple configuration for maximum heat transfer was determined. This was due to the generation of secondary flow and flow vortex structures downstream of the dimple. Choi et al. [12] suggested a cooling technique consolidated of dimples in plate flow. The results showed that heat transfer coefficient was significantly enhanced compared to that for the rib. Zhou et al. [13] carried out experiments on heat transfer enhancement using different plane and curved shapes as vortex generators with and without holes. The results showed that the punched holes on the face improved the heat transfer rate due to the reduction of flow resistance. Kim et al. [14] investigated the effects of dimples on the heat transfer performance of a rotating channel using liquid crystal technique. The experimental study provided a general understanding of the heat transfer enhancement rates using roughened surfaces in rotating heat exchangers. Peng et al. [15] carried out an experimental and numerical study of heat transfer in a plate roughened with blind holes. The results revealed that circular shape blind holes enhance the heat transfer compared to the smooth duct. Zidi et al. [16] investigated that the Effect of Vertical Vibrations on Heat and Mass Transfers through natural convection in partially porous cavity and has been found that increasing vibration intensity has a decreasing effect on the average heat and mass transfer rates for various porous thicknesses. Saini et al. [17] studied that the effect of vibration on heat transfer enhancement in a rectangular channel heat exchanger and conclude that vibration increases the heat transfer rate. Use of artificial roughness of different geometries has been extensively investigated to enhance the heat transfer rate in pipes and ducts. The recent works of Ashwinkumar et al. [18-30] for three side’s artificial roughened solar air heater have been reported for such enhancement in heat transfer coefficient. And many more investigations [31-53] have been conducted to show the enhancement of heat transfer coefficient by using different methodology (Computational fluid dynamics, use of booster mirror, using transverse wires as roughness element, wire screen and reviews on methodology for such enhancement of heat transfer coefficient).

III. PROBLEM DEFINITION

The problem statement for the current project is to carry project on analyzing the effect of dimpled and vibrating dimpled surface convective heat transfer rate. To avail the platform for educational purpose, non-educational purpose and research purpose at local level to measure heat transfer rate for dimpled pitch and frequency of vibration.

A) Objective

The objectives of this work are to:

1. To find variation in convective heat transfer rate of dimpled surface.
2. To find variation in convective heat transfer rate by varying air velocity.
3. To find variation in convective heat transfer rate by providing vibration on dimpled surface.
4. To compare dimpled and vibrating dimpled surface convective heat transfer rate.

B) Scope

The scope of the current project is limited to determine the effect of vibration on plane and dimpled surface to find the convective heat transfer rate and also at different air velocity

IV. EXPERIMENTAL SETUP

The main components of the test apparatus are a copper plate, a rectangular duct, a volt meter, a ammeter, a dimmer stat, temperature indicator, a heater, axial blower and vibrator. The duct inner cross section dimensions are 14 inches wide and 6 inches high. The entrance duct is 14 inches long. Test plate size is 12 x12 inches. Flat Plate electric heaters 10 x10 inches, 230 to 440 Volts, 20 to 100 W total power, pressure sensitive adhesive on one side is used to provide a constant heat flux to the copper plate. The duct was constructed with 1 mm G.I. sheet. The copper test plate is bolted to the plywood on the table. Cylindrical dimple bored of 10 mm diameter and having depth of 1.5 mm. Total 36 dimple bored on test plate. Distance between the dimples is 4 cm along the flow and 4 cm perpendicular to the flow. Also heater is fix on plywood behind the test plate. And vibrator is fitted between the test plate and heater. The care is taken that the vibrator is not have
any physical contact with the heater and only connected to test plate. The rubber pad is used between vibrator and table plywood to absorb the vibrations. The lower surface of the heater are insulated with glass wool (k=0.0372W/mk) to minimize heat losses. The heaters allowed heat flux through the 3mm thick test plate. Power was supplied by a dimmer stat, with voltmeter and ammeter used to vary voltage and current into the heater. The blower will be turned ON and air is forced through the test setup. The duct is provide to direct the air flow only over the plate.

![Test setup](image)

Fig. 1. Test setup.


V. EXPERIMENTAL PROCEDURE

The copper plate is located in the rectangular duct. Care is taken so that the copper plate can be located in the rectangular duct in order to ensure an equal duct height conditions and airflow rate for the copper plate on the wooden floor the glasswool is placed. On that glasswool the heater is placed to minimize the heat losses from the heater to the plywood floor. The blower is turned ON and air is forced through the test setup. The air flow is directed towards the rectangular duct with the help of plenum. As time elapsed for roughly 45 minutes to 1 hour, the temperature of the copper plate reached steady state. At steady state, the temperatures of the copper plate are checked by the temperature indicator. Now turned ON the vibrator and put the plate on vibration. Take the temperature readings again with same air flow as before. The velocity of the air at inlet to the duct and leaving the duct is measured with the help of anemometer. The voltage supplied to the heater and the corresponding current is taken to calculate the heat supplied to the copper plate. The temperatures of the inlet air into the test section and leaving the test section will also check. The objective of this investigation is to study the heat transfer characteristics using vibratory test plate. An average heat transfer coefficient will be calculated from the net heat transfer per unit area, the average temperature of the plate, and the bulk mean air temperature.

A. Abbreviations

- $T_i$ - Inlet Temperature, °C
- $T_o$ - outlet Temperature, °C
- $T_{avg}$ - Average temperature °C
- $V$ - Velocity, m/s
- $A_s$ - surface area of duct, m²
- $A_c$ - cross section area of duct, m²
- $Q$ - Discharge m³/s
- $\rho$ - Density of air, kg/m³
- $m$ - Mass flow rate, kg/s
- $C_p$ = Specific heat of air
- $Q$ - Heat transfer rate, W
- $H$ - Height of test plate, m
- $h$ - Convection heat transfer coefficient, W/m²K
- $K$ - Thermal conductivity of gas, W/mK
- $l$ - Characteristics length of plate, m
- $v$ - Kinematic Viscosity at avg. temp in m²/s.
- $Re$ = Reynolds number
- $Nu$ - Nusselt number

VI. DATA REDUCTION

The study is carried out under forced convection for external laminar flow condition. Steady state value of the plate and air temperatures in the channel are used to calculate heat transfer coefficient. The mass flow rate of air through duct is given by,

$$ m = Q \times \rho \quad \text{(i)} $$

The Heat gain by the air is calculated as,

$$ q = m \times C_p \times (T_i - T_o) \quad \text{(ii)} $$

Convective heat transfer coefficient is given by,

$$ h = \frac{q}{A_s \Delta T} \quad \text{(iii)} $$

Reynolds number calculated by using,

$$ Re = \frac{\nu l}{v} \quad \text{(iv)} $$

Nusselt Number is given by,

$$ Nu = \frac{h \times l}{K} \quad \text{(v)} $$

VII. RESULT AND DISCUSSION

By using the data obtained from experiments, the heat transfer coefficient, Reynolds Number and the Nusselt Number obtained. These result are discussed as follows,
Fig. 2. Comparison between air velocity and heat transfer coefficient of dimple surface.

In fig. 2. The graph is plotted velocity of air against heat transfer coefficient of dimple surfaces and it is observed that heat transfer enhancement rate for minimum velocity is low as compare to higher velocity. As velocity of air increases heat transfer enhancement also increases.

Fig. 3. Comparison between air velocity and heat transfer coefficient of dimple vibrating surface

In fig 3. The graph is plotted velocity of air against heat transfer coefficient of dimple vibrating surfaces and it is observed that heat transfer enhancement rate for minimum velocity is low as compare to higher velocity. As velocity of air increases heat transfer enhancement also increases.

Fig. 4. Comparison between Reynolds Number and Nusselt Number of dimple vibrating surfaces

In above fig 4. Reynolds Number against Nusselt Number graph is plotted. As Reynolds Number increases Nusselt Number also get increased. This Number are higher for vibrating dimpled surface.

VIII. CONCLUSION

1. The convective heat transfer coefficient of dimple and dimpled vibrating surface calculated and there is increase in heat transfer coefficient for the dimpled vibrating surface.
2. Also heat transfer coefficient is found out for the different mass flow rate and it is observed that at higher mass flow rate heat transfer coefficient is higher.
3. The convective heat transfer coefficient of dimpled and dimpled vibrating surface calculated by providing different velocity and as compare to dimpled surface dimpled vibrating surface having more heat transfer coefficient.
4. There is increase in heat transfer rate by comparing with non-vibrated surfaces. After result it is found that Reynolds number and Nusselt number also increases with increase in mass flow rate.

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Actual Test Set up.