Experimental Investigation of Natural Convection Heat Transfer in Inline & Staggered Dimpled Plates

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Abstract— Convection is usually the dominant form of heat transfer in liquids and gases. Although sometimes discussed as a third method of heat transfer, convection is usually used to describe the combined effects of heat conduction within the fluid (diffusion) and heat transference by bulk fluid flow streaming. Convective heat transfer is the transfer of heat from one place to another by the movement of fluids, a process that is essentially the transfer of heat via mass transfer. Bulk motion of fluid enhances heat transfer in many physical situations, such as between a solid surface and the fluid. This paper refers to the convective heat transfer from a V-Fin Array whose surface is made black and the fins are sticked to it to form horizontal fin array and in form of V-Fins to form V-Fin array.

Key words: Heat Transfer, Natural Convection, Dimpled Plates, Heat Transfer Coefficient

I. Introduction

Free, or natural, convection occurs when bulk fluid motions (streams and currents) are caused by buoyancy forces that result from density variations due to variations of temperature in the fluid. Forced convection is a term used when the streams and currents in the fluid are induced by external means—such as fans, stirrers, and pumps—creating an artificially induced convection current.

Natural or free convection is observed as a result of the motion of the fluid due to density changes arising from the heating and cooling process. Natural convection represents an inherently reliable cooling process. Further, this mode of heat transfer is often designed as a backup in the event of the failure of forced convection due to fan break down.

Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Fins 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. Other applications include Internal Combustion engine cooling, such as fins in a car radiator. Feasible and practical means to improve natural convection heat transfer is by the use of finned surfaces.

II. Literature review

Many studies have focused on cooling through natural convective heat transfer in many books and many previous researchers investigated natural convection from the extended surfaces. These studies are motivated by the fact that the heat transfer rate from the extended surfaces differs greatly that from the base surfaces. Relevant literature pertaining to enhancement of heat transfer by introducing protrusions mounted on the heat transfer surfaces, reviewed from different points. A number of heat transfer studies from Russia utilize dimples. A variety of experimental, analytical and computational research works has been carried out on enhancement of heart transfer.

Kuethe et al.[1] was the first suggest the use of dimple surface for heat transfer enhancement. Surface dimples are expected to promote turbulent mixing in the flow and enhance the heat transfer, as they behave as a vortex generator.

M.A.Dafedar et.al.[2] studied experimentally the heat transfer augmentation through various geometries of dimpled surfaces in longitudinal and lateral directions. In his paper horizontal rectangular plates of copper and aluminum with different dimpled geometries (like square, circular and triangular) for in-line arrangements were studied in natural convection with steady laminar external flow condition. The various parameters considered for study are Nusselt number, heat transfer coefficient and heat transfer rate for a constant Prandtl number (0.7) and Grashof number (104 -107).It has been found that the heat transfer coefficient and heat transfer rate increases for various dimpled surfaces as compared to plane surface. It has been also found that the heat transfer coefficient and heat transfer rate increases along longitudinal direction as compared to lateral direction. And it is seen that heat transfer rate is maximum for triangular shape dimple when the apex of triangle is faced towards inlet of air flow finally it is concluded that heat transfer enhancement takes place along the dimpled surface.

Iftikarahamad H. Patel et.al.[3] presented the computational investigation of convective heat transfer in turbulised flow past a dimpled surface. A parametric study is performed with k-ε turbulence model to determine the effects of Reynolds number, dimple depth and Nusselt number on heat transfer enhancement. In this paper we have computed heat transfer coefficients in a channel with one side dimpled surface. The sphere type dimple geometry was considered with diameter (D) 10 mm and the depth (δ) 4 mm, to obtain δ/D ratio as 0.4 and it was increased later to 5 mm to increase δ/D ratio to 0.5. The Reynolds number based on the channel hydraulic diameter was varied from 200000 to 360000.The results showed that more heat transfer was occurred downstream of the dimples due to flow reattachment. Due to the flow recirculation on the upstream side in the dimple, the heat transfer coefficient was very low. As the Reynolds number increased, the overall heat transfer coefficient was also increased.

Faheem Akthar et.al.[4] experimental investigated the natural convection heat transfer over circular dimpled surfaces is carried out. The various heat transfer parameters considered for study are Nusselt number, heat transfer coefficient and heat transfer rate. From the obtained results, it can be concluded that large amount of heat transfer enhancement does takes place for the dimpled surfaces.

Saurabh R Verma et.al [5] studied Heat Transfer enhancement using dimples are based on the principle scrubbing action of cooling fluid taking place inside the dimple and phenomenon of intensifying the delay of flow separation over the surface. Spherical indentations or dimples have shown good heat transfer characteristics when used as surface roughness. The technology using dimples recently attracted interest due to the substantial heat transfer augmentations it induces, with pressure drop penalties smaller than with other types of heat augmentation. From all the research work studied the researchers have used various dimple shaped geometries such as triangular, ellipsoidal, circular, square out of which ellipsoidal shape gives better results due to prior vortex formation then other shapes

Amjad Khan et.al.[6] studied the fluid flow and heat transfer characteristics of spherical dimples at different angle of orientation from the centre with apex facing the inlet were investigated. The experiment was carried out for laminar Natural convection conditions with air as a working fluid. The overall Nusselt numbers and heat transfer coefficient at different orientation angle of dimples were obtained. From the obtained results, it was observed that the Nusselt numbers and heat transfer coefficient increases with decrease in the orientation angle of dimples.

Burgess et al.[7] experimentally analyzed the effect of dimple depth on the surface within a channel with the ratio of dimple depth to dimple printed diameter, equal to δ/D, 0.1, 0.2, and 0.3. The data showed that the local Nusselt number increased as the dimple depth increased due to an increased strength and intensity of vortices and three dimensional (3D) turbulent productions.

Ligrani et al.[8]experimentally showed the influence of dimple aspect ratio, temperature ratio, Reynolds number and flow structures in a dimpled channel at Re = 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 indicated that the vortex pairs which are periodically shed from the dimples become stronger and local Nusselt number increase as channel height decreases. As the temperature ratio Toi/Tw decreases, the local Nusselt number also increased.

Mahmood et al.[9] studied the flow and heat transfer characteristics over staggered arrays of dimples with δ/D=0.2. For the globally average Nusselt number, there were small changes with Reynolds number. He studied the effect of dimpled protrusions (bumps) on the opposite wall of the dimpled surface.

S. D. Hwang et al.[10] in present study, heat transfer and thermal performance of a periodically dimple protrusion patterned surface have been investigated to enhance energy-efficiency in compact heat exchangers. The local heat transfer coefficients on the dimple/protrusion walls are derived using a transient TLC (Thermo chromic Liquid Crystal) technique at low Reynolds number. The periodically patterned surface is applied to the bottom wall only or both the bottom and top walls in the test duct. On the single-side patterned walls, various secondary flows generated from the dimple/protrusion coexist. The vortices induced from the upstream affect strongly on the downstream pattern. For the double-side patterned wall case, vortex interaction affected by the opposite wall enhances highly the heat transfer. The heat transfer augmentation is higher in the lower Reynolds number due to the effective vortex interactions. Therefore, the performance factor considering both heat transfer enhancement and pressure loss increases with decreasing the Reynolds number.

Moon et al.[11] shows that heat transfer is enhanced and pressure loss is reduced for dimpled surfaces. Some practical applications dimpled surfaces in internal passages include macro-and micro-scale heat exchangers, electronics cooling, combustion chamber liners, passages for internal cooling of turbine blades in gas turbine engines, biomedical devices, etc.

Sane et al.[12] was carried out experiment to study heat transfer and friction coefficient by dimpled surface with the aspect ratio of rectangular channel is kept 4:1 and Reynolds number based on hydraulic diameter is varied from 10000 to 40000. They were observed that at all Reynolds number as depth increases from0.2 to 0.3, the number and thermal performance increases and then after when depth increase from 0.3 to 0.4 normalized Nusselt number and thermal performance decreases.

III. DIFFERENT ARRANGEMENTS

A. Inline circular dimples of diameter 6mm

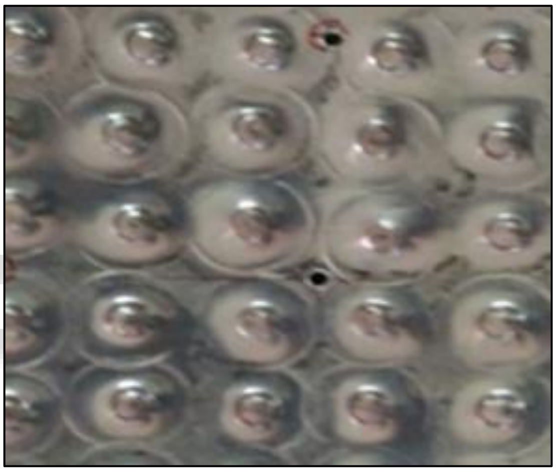

Fig. 3.1

B. Inline circular dimples of diameter 10mm

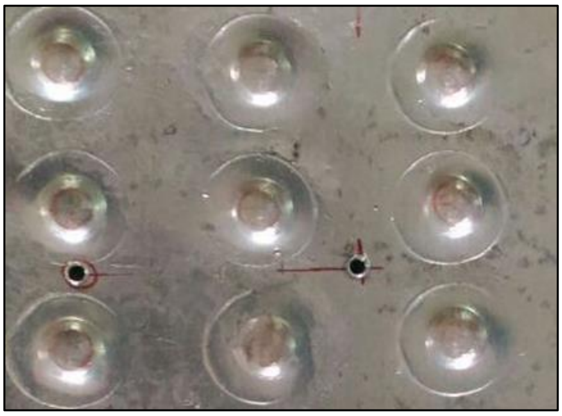

Fig. 3.2

C. Staggered circular dimples of diameter 6mm

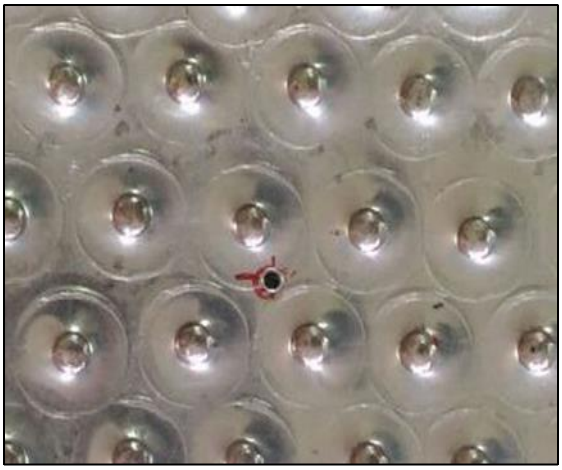

Fig. 3.3

D. Staggered circular dimples of diameter 10mm

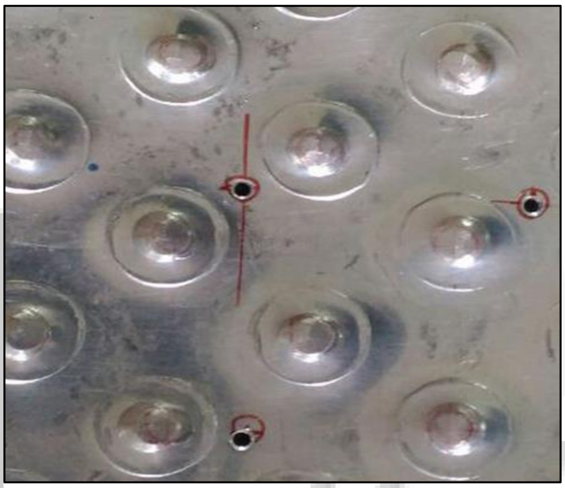

Fig. 3.4

E. Inline Triangular dimples

Fig. 3.5

F. Staggered Triangular dimples

Fig. 3.6

IV. Experimental Set Up

The below images show the various photos of experimental setup. The power system contains the wattmeter, dimmerstat for heat supply and temperature indicator with selectors. Besides the power box, the duct or enclosure is provided for natural convection purpose. The overall dimensions of the duct or enclosure are 1m x 1m x 1m. A gap of 70mm is kept open at the bottom side for air intake. The heater plate will be sandwiched between the vertical plates and will be attached to the hook provided at the top end of the enclosure. One end of enclosure side is covered with a transparent acrylic sheet, in order to visualize the total system while the other three ends are covered with white acrylic sheet

Fig. 4.1

Fig. 4.2

V. EXPERIMENTAL PROCEDURE

The experimental work conducted is given in the following procedure:

1) Initially, the enclosure is opened from two sides. This is in order to hook the test plate to the enclosure from inside end. After that, the sides of the enclosure are closed by acrylic sheets.
2) The connections of the thermocouples were made at required positions.
3) The remaining electrical connections are checked i.e. connections of heater, wattmeter and dimmerstat etc.
4) After checking all the connections, the switch of temperature indicators and dimmerstat is turned ON.
5) The temperatures at different points were read by the digital temperature indicator and were recorded at a time interval of 30 minutes.
6) The final reading was recorded when steady state is reached.

This procedure was repeated for all type of arrangements

VI. PARAMETERS & CACULATIONS

Experimentation was carried on the plane and six configuration of vertical dimple aluminum plate as mentioned above.

Parameters	Descriptions
Heat Load (W)	10W,20W,30W,40W,50W
Time	Until Steady State

All the essential components were assembled and experimental set was developed. The necessary instruments were attached at correct composition and the setup is ready for the experimentation

VII. FORMULAE USED

GrashofNumber

$$Gr = \frac{g \times \beta \times \Delta T \times L^3}{\nu^2}$$

Nusselt Number (Nu) = hL/k
Relays Number (Ra) = Gr×Pr
Heat Transfer coefficient (h) = (Nu)/kL

VIII. RESULT & DISCUSSION

It has been observed that increase in heater input heat transfer coefficient is increases. As well heat transfer coefficient is high for staggered triangular Aluminum plate as compared to other geometries. The reference fig. is as below.

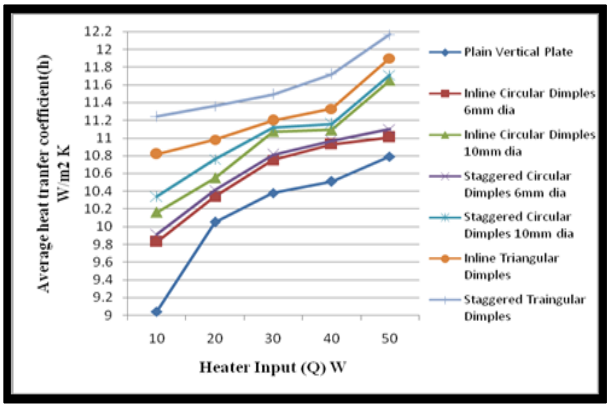

Fig. 8.1

It has been observed that increase in heater input Nussalt Number is increases. As well Nussalt Number is high for staggered triangular Aluminum plate as compared to other geometries. The reference fig. is as below

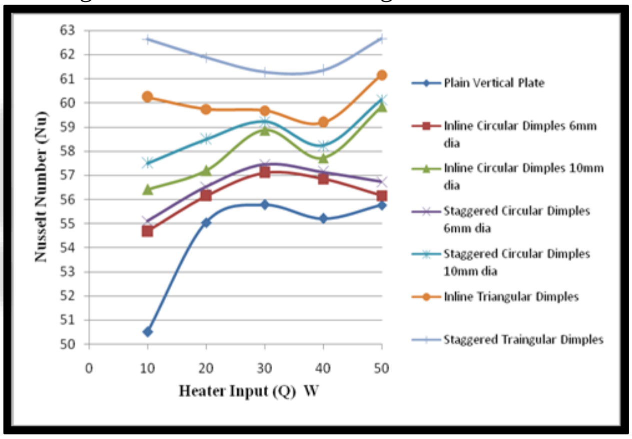

Fig. 8.2

It has been observed that increase in heater input temperature difference increases. As well the temperature difference is low for staggered triangular Aluminum plate as compared to other geometries. The reference fig. is as below

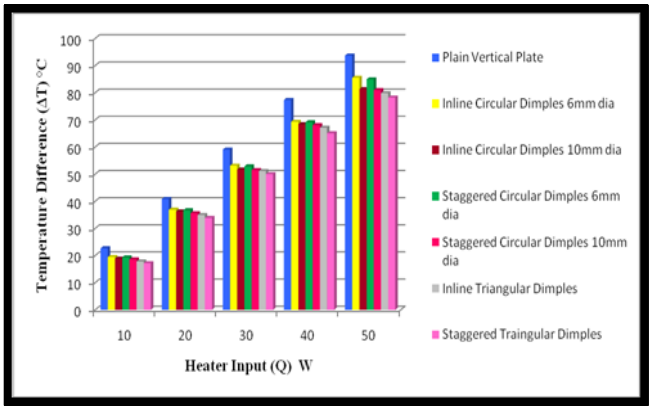

Fig. 8.3

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