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Heat transfer enhancement of flat plate with staggered dimples

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Abstract

Increase of heat transfer over surface arises from depression forming recesses rather than projections. Such elements are commonly known as dimples and can be formed in several variation of geometries that results in friction and characteristics of heat transfer. This idea of enhancement of heat transfer with the help of dimples are basically depends on principle of scrubbing action of cooling fluid that take place inside the dimple and event of identifying the delay of flow separation over the surface. The significance of heat transfer enhancement has gained a more influence in terms heat exchangers like macro and micro, Gas Turbine, microelectronic cooling etc. Dimples 0.65 cm in diameter and 0.31 cm deep on the flat surfaces. The Nusselt numbers for a dimple surface with inline and staggered arrangement and a Flat surface are about the equal. The investigated parameters were Reynolds number ranged from 1100 to 1800.
Outcome shows that the existence of dimples on the purpose surface, in staggered arrangement as compare to inline and flat surface produce a higher heat transfer coefficient. This is mainly because of an increase in area of surface when compared with a smooth surface. Nusselt number are also high in staggered arrangement than inline and flat plat.

Keywords: Dimples, Enhancement, Staggered and Inline arrangement, Augmentation technique

1. Introduction

In design of another engineering parts, air side heat transfer augmentation in the science and engineering plays an important role. Surfaces engrave with dimples or cupped recognition have been studied massively recently. Micro and macro scale of heat exchanger, biomedical devices, electronic cooling, gas turbine etc. has numerous of actual applications in enhancing the efficiency of heat transfer. Two to three claims that are within the subject of learning for of several investigators over the current years are compact warmth exchangers and vapor turbine inner air foil cooling.
Recently the surface heat transfer enhancement using dimples got an interest due to its low-pressure loss characteristics with the comparison of others. Microelectronic cooling, particularly in central process units, gas turbine internal air foil cooling, fuel components of atomic energy plants, macro and small-scale heat exchangers, and bio medical devices, all these devices have a greater significance of heat transfer. And the average heat transfer coefficient was obtained with the help of various experiments. Drop in pressure, thermal performance, coefficient of Heat transfer and flow characteristics were reproduced numerically. Number of values were selected in search of what will be the effect of dimples for example: Reynolds number, relative channel height, relative dimple depth.
Nowadays the most common approach for heat transfer enhancement involves the use of rough surface. A surface can be made rough in number of ways like by using pins, inserting ribs or making dimples on the surface. Ribbed or a pinned surface under an impinging jet are mainly used because of their roughened surface that helped to enhance heat transfer coefficient. A dimpled surface may behave completely differently than the other two surfaces under an impinging jet. Because of these ups and downs of the flow field they can produce different heat transfer coefficients in dimple surface that may agitate the cross flow.
Merely thirty heat transfer enhancement methods are in use now, however, because of the design and technology restrictions, designers still apply very few of these techniques. The type of heat transfer technique is chosen by considering various factors like enhancement level, available pressure ratio, cost, and complexity. Extreme loss in pressure will manufacture a

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supplementary complex air supply arrangement and with an improved value, or its application may be all prohibited. Due to low pressure-loss feature, surface heat transfer enhancement using dimples has gained interest.
The important objective of this experiment is to find out the rate of heat transfer and air flow distribution on triangle and circular dimples with straggled and inline arrangements, and obtained results are compared with flat surface.
Usually, heat transfer augmentation methods are spread in active, passive and compound technique. Following are the few experimental studies from various papers.

Nomenclature

R_e	=	Reynold Number
Nu	=	Nusselt Number
Pr	=	Prandtl Number
T_s	=	Surface Temperature in °c
T_{bm}	=	Bulk Mean Temperature in °c
C_d	=	Coefficient of Discharge
d_0	=	Diameter of orifice in mm
d_p	=	Diameter of pipe in mm
h	=	Convective Heat Transfer Coefficient in w/m^2k
ρ_a	=	Density of Air in kg/m^3
Q	=	Volume flow Rate in m^3/sec
$\dot{m}$	=	Mass Flow Rate in kg/s
D_h	=	Hydraulic Diameter in mm
V	=	Velocity in m/s
ΔP	=	Pressure Drop
L	=	Length of Test Plate in mm
F	=	Friction Factor
H	=	Manometric Head
K	=	Thermal Conductivity of Material

2. Literature Review

Many researchers published in the past on this topic are discussed in brief in this chapter. The work is divided in two main parts, the analytical work and analysis.
Kuethe [1] was the one who suggest the use of surface dimples for heat transfer enhancement. As surface dimples behaves like a vortex generator it is generally expected to enhance the heat transfer and turbulent mixing in the flow.
Sandeep S. Kore et al. [2] investigated that at all Reynolds range as deepness will rise approx. about 0.25 to 0.35, the normalized Nusselt range and thermal performance will rise and then after when deepness rises from 0.35 to 0.45 normalized Nusselt range and thermal performance reductions.
Faheem Akthar et al. [3] studied and find out that heat transfer over circular dimpled surfaces is done for natural convection. From the obtained outcome, we can say that large amount of heat transfer enhancement takes place for the dimpled surfaces. For circular dimples the main outcome of the work is Nusselt number 'Nu' which increases with heat input for all the cases taken & Heat transfer co-efficient 'h' increases with heat input.
H.K.Mo on et al. [4] inspected the friction losses and heat transfer test on a four-sided dimpled channel with staggered dimples on one wall with effect of channel height on heat transfer performance. The geometry that was used is Re = 12k to 60k and H/D = 0.35, 0.75, 1.15, 1.50. The heat transfer development magnitude relation was invariant with Reynolds range. The friction factors (f) totally established area were methodically calculated to be about 0.0415. Neither the heat transfer constant distribution nor the friction factor exhibited a detectable impact of the channel height inside the relative height range.
Mahmood et. al. [5] studied the heat transfer and flow characteristics over staggered arrays of dimples with $\delta/D=0.2$. Nusselt number were small changes with changes in Reynolds number. Ligrani et. al. studied the effect of dimpled protrusions on the reverse wall of the dimpled surface. Thermal performance factors are generally lower than compared to a dimpled bottom surface and smooth top surface.
Pooja Patil et al. [6] presents on heat transfer constants were calculated in a round tube with mark surface. The almond kind dimples were fabricated, D 20mm and dimple deepness 3-millimetre fraction was kept uniform, while keeping diameter 12mm of hollow is wanted length 22mm owing to the elongated profile.
Raju R. Yenare et al. [7] offers an examination was showed to work out whether or not dimples on a heat sink fin will rise heat transfer for laminar airflows. This was get done by activity investigational revisions exploitation 2 differing kinds of dimples: round (spherical) dimples, and elliptical dimples.
Pavan Jadhao et al. [8] presents the The Nusselt number ratio for the cases in which compound dimples and ribs are incorporated was higher than in rib only or dimples only case. The Nusselt number ratio is found higher for plate with 650 ribs and dimples than other cases. This is probably because of the additional appropriate rib arrangement for the previous instead of the concluding cases. Hasibur Rahman Sardar et al. [9] studied that the Dimples show a really vital role in heat transfer improvement of electronic device, heat exchangers etc. This effort principally tackles with the trial examination of forced convection heat transfer over round formed dimples of various diameters on a smooth copper plate underneath external laminar flow state. Investigational trials on heat transfer features of air (with varied inlet flow rates) on a smooth plate with dimples were showed. From the gained outcomes, it had been determined that the coefficient of heat transfer and Nusselt No. Neha G. Katarwar et al. [10] presents a Dimples show important part in heat transfer improvement of electronic portions methods. Heat transfer explains the exchange of thermodynamically energy, among genuine procedures contingent on the temperature and pressure, by dissipating heat. The essential manners of heat transfer are conduction, convection and radiation.

3. Experiment Investigation

3.1 Layout of Test setup

Figure 1 represents the schematic drawing of the trial setup. In this experiment, the laminar and steady-state air flow was obtained. The air stream produced by a centrifugal air blower was flowed over the heated plate with dimples.

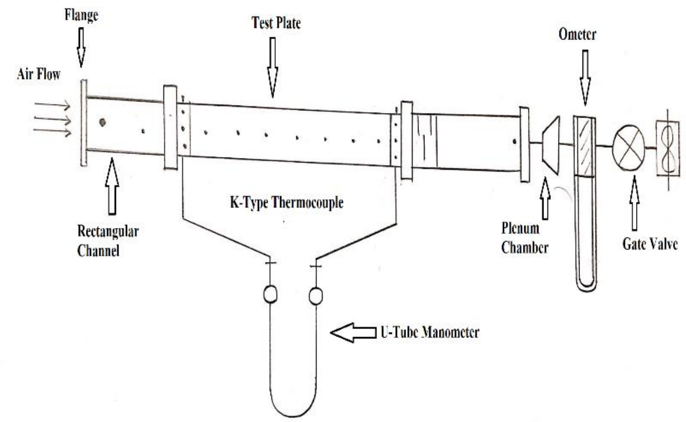

Figure 1: Layout of Test setup

3.2 Experiment setup

Setup that was made for experiment involves a blower, test plate, gate valve, U-tube manometer, MS Plate etc. Also, it includes arrangement of thermocouples (K-type), heater is needed. In this experiment also used a butterfly Valve for vary the manometer readings.
An experimental set up shown in Fig.3 is used for finding the required data for obtaining Nusselt number. The average coefficient of heat transfer on the plate surface will be measured at different manometer readings through the rectangular channel.

3.2.1 Blower

By operating pneumatic valve Reynolds number & mass flow rate requirement is achieved. Blower specification as follows: MOTOR RATING: 0.24 HP, single Phase

3.2.2 Heater

Heater is attached at side of rectangular channel and having thickness of 5mm. Heater is having a capacity of 500 watt and power supply of 230 V AC. Its length is having a 500mm and width of 80 mm with 2-meter cable.


Figure 2: Heater

3.2.3 Thermocouple

Type K thermocouples contains an Alumel leg and a Chromel. These are basically efficient for temperatures from -454 to 2300˚F (-270 to 1260˚C) and have an accuracy of temperature ±2.2˚C or ±0.75%. So, we required 6 nos. thermocouple for this experiment.


Figure 3: Experiment setup

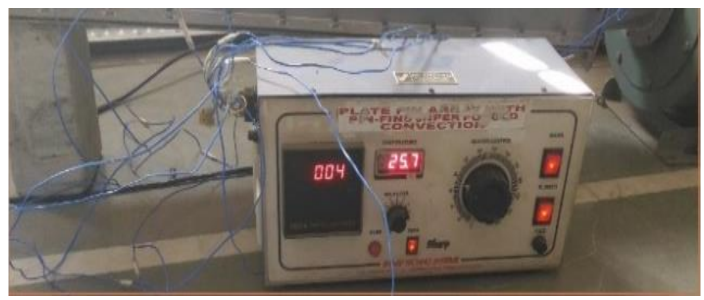
Figure 4: K - Data Recorder

3.3 Details of Test Section

Taste Pate of MS sheet of thickness 2.5 mm and dimension of 1000mm*210mm has been used. With 0.65 cm diameter and 0.31 cm depth dimples were produced on the test plate.

3.3.1 Case of staggered arrangement

The tringle dimple plate with 3 by 13. For the triangular dimples with a relative depth δ/D=0.70 cm the dimples were placed on both sides of the test plate. The flat projected area is used in order to calculate a heat transfer coefficient and Nusselt number. The total surface area for each plate will be constant.

3.3.2 Case of Inline arrangement

In this arrangement first row we will have a 3 nos. of dimple and in the 2nd row we have 2 nos. of dimples that leads us to total 13 nos. of rows. In this particular dimple will have a diameter of 0.70cm and depth of 0.35 cm.

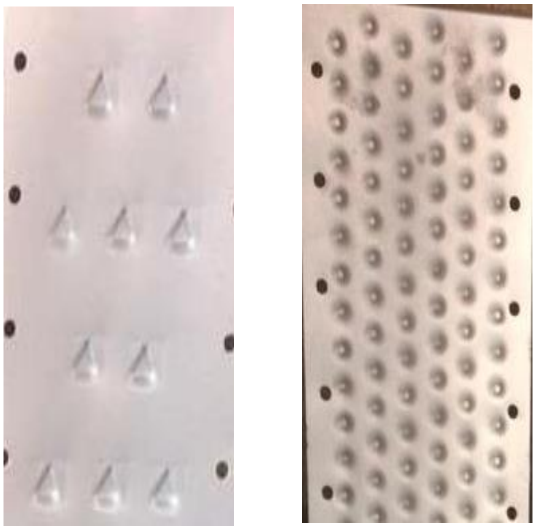

Figure 5: Staggered Arrangement

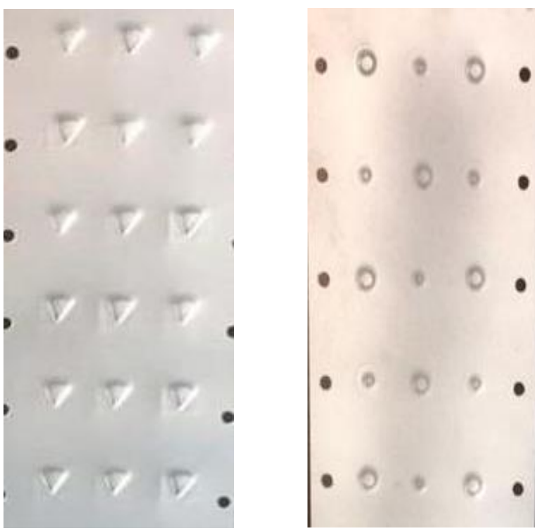

Figure 6: Inline Arrangement

Dimension of set up

Circular Flange OD	175 mm
Inside Diameter	130 mm
PCD of circular flange	160 mm
Length of Rectangular channel	1000 mm
Square Flange length	100 mm
Square Flange Width	210 mm
4 Nos of Dimples plate and 1 Flat Plate (*lxb*)	1000x210mm

3.4 Experimental Procedure

- Switch on electrical values supply to heater and allow rise in temperature of plate.
- Now start the blower and adjust the air flow with valve.
- Adjust height level difference in U-tube manometer.
- Measure Temperature at thermocouple at 8 different places in plates.

For the first time we need to set the manometer to approximately at 0.015 cm so that the heater heated a test plate then we need to note down the temperature of inlet, outlet and test plate of temperature.

4. Data Reduction

The data reduction of the found outcomes is brief in the next steps:
The average heat transfer coefficient is computed from the net heat transfer per unit area, the average temperature of the plate, and the bulk mean air temperature. Following expression can be used in order to find the average heat transfer coefficient.

$$h=Q/As\,(T_s-T_{bm})\ (W/m^2\ °C) \tag{1}$$

where, $Ts= T_1+T_2+T_3+T_4/4$

$T_{bm}= T_i+T_o$

Volume flow rate of air has been determined from pressure drop across the orifice meter:

$$Q=C_d(\pi/4)\, dp^2 * d_0^2\sqrt{2*g*H}/\sqrt{dp^4-d0^4}\ \ (m^3/sec) \tag{2}$$

The heat supplied by air by convection:

$$q=\dot{m}\, cp\, (T_0-T_i)\ (watt) \tag{3}$$

Nusselt number can determined by following expression:

$$Nu=h*D_h/k \tag{4}$$

Reynold number were $Re= V*D_h / k$ (5)

Friction factor can be determined by:

$$f = (\Delta p) * D_h / 2\rho_{air} * L * V^2_{air} \tag{6}$$

Nusselt number for a smooth rectangular duct is given by modified Dittus-Boelter equation is:

$$Nu= 0.64\, Re^{0.5}\, Pr^{0.33} \tag{7}$$

Friction factor for a flat four-sided duct is given by changed Blasius equation is:

$$F_0=0.0084\, Re^{-0.025} \tag{8}$$

5. Results and Discussions

In this unit experimentally concluded Nusselt number values for smooth plate without dimple are compared with analytical equation of Nusselt number. Nusselt number for different manometric head are discussed in the following subsections. Using the data calculated from the experiments i.e. rate of heat transfer, its coefficient, Nusselt number, and ratio of Nusselt number to base line are compared

5.1 Effect of different shape of dimples

Fig. 6, shows Nusselt number ratios for different dimple arrangements. Dimple with staggered arrangement has highest Nusselt number ratios and flat plat without dimple has lowest Nusselt number than other two arrangement. The Nu/Nu_0 ratio is greater for staggered and inline arrangement because of creation of stronger vortices, with additional pronounced shear layer reattachment.

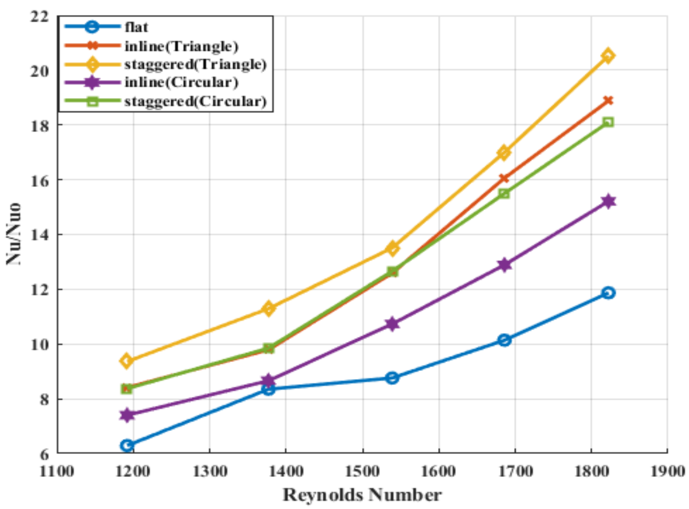

Figure 7: Normalized Nusselt number ratio vs Reynolds number for different dimple Shape.

5.2 Effect of dimple shape and reynolds number on thermal performance

Both cases showed that the thermal performance factor increases with increasing mass flow rate. The thermal performance factor for the Circular dimpled plate increased from 0.69 to 1.87. The thermal performance factor for the Triangle dimpled plate with staggered arrangement increased from 0.88 to 2.12. The factor for the Triangle type dimpled plate was larger than that of the circular dimpled plate for all cases.

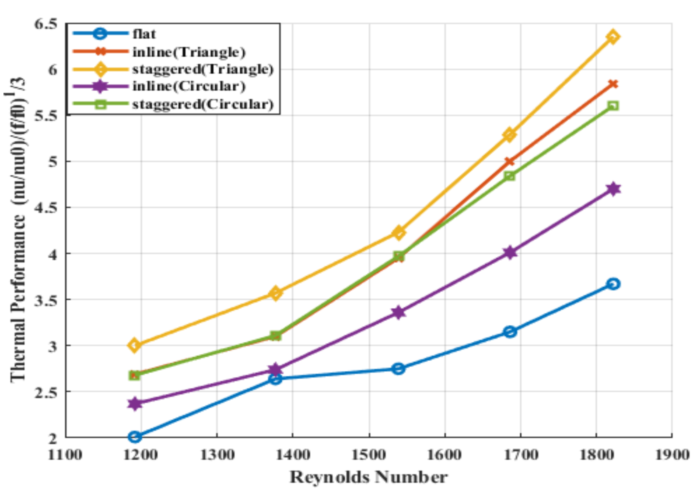

Figure 8: Thermal performance vs Reynolds number for different Shape

5.3 Effect of Convective Heat Transfer Coefficient with different shape of Reynolds Number

The heat transfer coefficients for Five different MS plates based on the flat projected is shown in figure.8. The heat transfer coefficients increased with increasing airflow rate. The results presented that the heat transfer coefficients for the circular and Triangle dimpled plates were higher than that of the flat plate for all airflow conditions. For Reynolds number 1200 the increase in heat transfer coefficient is from 7.79 for the plain plate to 11.6 for Triangle plate. While at higher Reynolds number 1800 the heat transfer coefficient is 20.63 for plain plate which increase to 35.68 for the triangle plate.

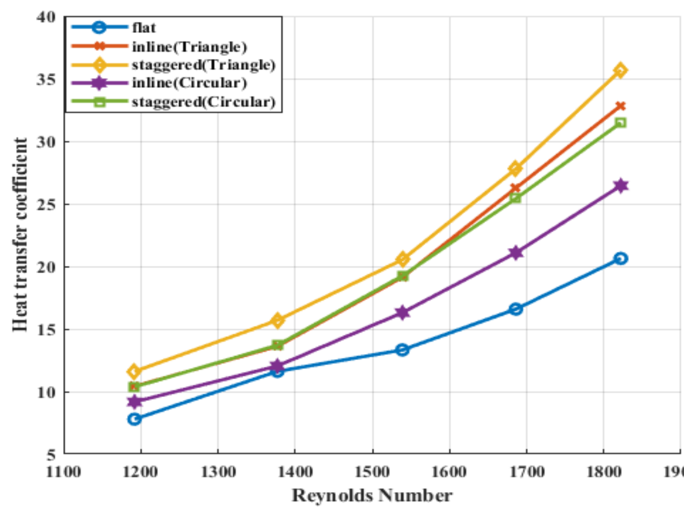

Figure 9 Heat transfer coefficient with different shape of Reynolds number

5.4 Effect of Reynolds Number

In this experiment see that Reynolds number increases with increase in Nusselt number. And mass flow rate increase with increase in Nusselt number.

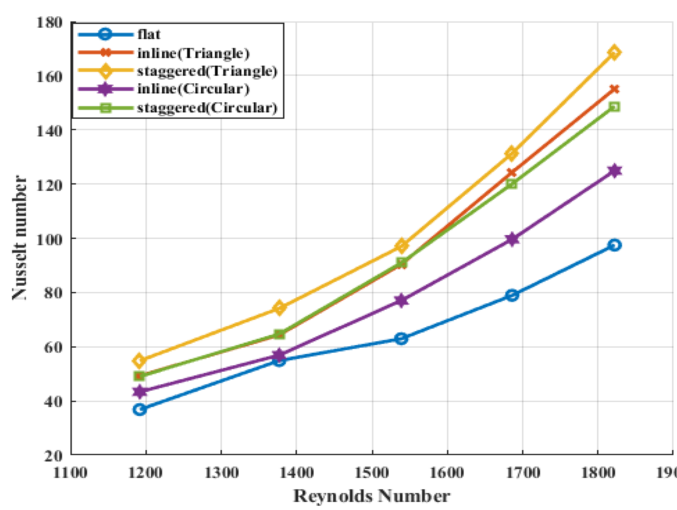

Figure 10 Nusselt number variation with different Dimple Shape

Fig. 10 shows that Nusselt number is highest for triangle dimple with staggered arrangement & less in a Flat plate without dimple surface.

6. Conclusions

After the experimental investigations of heat transfer, Nusselt number of a plain plate with Tringle plate are described and the conclusions can be drawn as follows:

- The rate of heat transfer for dimple surface with staggered arrangement seems to have maximum value than the smooth and inline plat.
- The heat transfer coefficient for dimpled surface with staggered arrangement is more when we compare it to inline and flat, due to the vortex inside the dimple that causes scrubbing action of flowing fluid inside the dimple.
- Nusselt number ratio lies in between 1.86 to 6.05. Nusselt number ratio remains nearly same for all three plates. So, we can say that Nusselt number ratio has higher value for dimple with staggered arrangement than flat plat and inline arrangement.
- Dimple with staggered arrangement has highest Nusselt number ratios and flat plat without dimple has lowest Nusselt number than other two arrangement. The Nu/Nu_0 ratio is higher for staggered and inline because of formation of stronger vortices, with more pronounced shear layer reattachment.
- The thermal performance factor for the Circular dimpled plate increased from 0.69 to 1.87. The thermal performance factor for the Triangle dimpled plate with staggered arrangement increased from 0.88 to 2.12.

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