



A Review on Heat Transfer Augmentation for Various Dimpled Geometries

¹Saurabh R Verma, ²P. M. Khanwalkar, ³V. N. Kapatkar

^{1,2,3}Department of Mechanical Engineering, SCOE, Pune 411041, India

Email: ¹saurabhverma312@outlook.com, ²pmkhanwalkar.scoe@sinhgad.edu, ³vnkapatkar.scoe@sinhgad.edu

Abstract: — Heat transfer enhancement over surface results from the depression forming recesses rather than projections. Such features are known as dimples, and may be formed in an infinite variation of geometries which results in various heats transfer and friction characteristics. Heat Transfer enhancement using dimples are based on the principle of 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

Index Terms—Dimple shaped Geometry, Heat Transfer Enhancement, Flow Separation, Heat Exchanger

I. INTRODUCTION

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 (i.e. air-cooled condensers, nuclear fuel rods). These applications, as well as numerous others, have led to the development of various enhanced heat transfer surfaces.

In general, enhanced heat transfer surfaces can be used for three purposes: (1) to make heat exchangers more compact in order to reduce their overall volume, and possibly their cost, (2) to reduce the pumping power required for a given heat transfer process, or (3) to increase the overall UA value of the heat exchanger. A

higher UA value can be exploited in either of two ways: (1) to obtain an increased heat exchange rate for fixed fluid inlet temperatures, or (2) to reduce the mean temperature difference for the heat exchange; this increases the thermodynamic process efficiency, which can result in a saving of operating costs. Enhancement techniques can be separated into two categories: active and passive.

A. Active Method

This method involves some external power input for the enhancement of heat transfer. Some examples of active methods include mechanical aids, surface vibration, fluid vibration, electro-static fields, suction or injection and jet impingement requires an external activator/power supply to bring about the enhancement

B. Passive Method

This method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. For example, inserts extra component, swirl flow devices, treated surface, rough surfaces, extended surfaces, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids

C. Compound Method

If two or more techniques can be utilised simultaneously to produce an enhancement larger than that produced by only one Technique than it can be said as Compound Method. A compound method is a hybrid method in which both active and passive methods are used in combination. The compound method involves complex design and hence has limited applications.

This paper mainly focuses on review on various dimple geometries which help in increasing the heat transfer rate. Dimples on surface can significantly increase the heat transfer rate. The vortices formed inside the dimples results in reducing and disturbing the thermal boundary layer formed over the surface during coolant flow and serve ultimately to bring about enhancement of heat transfer between the fluid and its neighbouring surface at the price of less increase in pressure drop. A variety of experimental, analytical and computational

research works has been carried out on enhancement of heat transfer.

Dafedar et al. [1] 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 and also the heat transfer rate was found to be maximum for triangular shape dimple when the apex of triangle was faced towards inlet of air flow.

Katkhaw et al. [2] has investigated the flat surface with ellipsoidal dimple of external flow with 10 types of different dimple arrangement and intervals. Heat transfer was determined and compared with smooth surface. Results showed that for staggered arrangement the heat transfer coefficients were 15.8% more than smooth surface and 21.7% more for inline arrangement.

Pisal and Ranaware [3] 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 (spherical) and oval (elliptical). These dimples were placed on both sides of copper plate with a relative pitch of $S/D=1.20$ and relative depth of $\delta/D=0.2$ and for these configurations Nusselt number and overall heat transfer coefficient were determined. Heat transfer enhancements were observed between the range of 600 and 2000.

Patil and Deshmukh[4] have investigated the staggered arrangement of almond shape dimples. The results integrated that staggered array of dimple in circular tube has 66% greater thermal performance factor than inline arrangement. The overall heat transfer coefficients were also increased.

Patel and Borse [5] have experimentally investigated the forced convection heat transfer over the dimpled surface. The objective of the experiment is 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. The results showed that use of dimples on the surface results in heat transfer augmentation in forced convection heat transfer with lesser pressure drop penalty and the value of maximum Nusselt number obtained for staggered arrangement of dimples is greater than that for inline arrangement, keeping all other parameters constant.

Kanokjaruvijit and Martinez-botas [6] has investigated an eight-by-eight jet array impinging onto a staggered array of dimples at Reynolds number 11,500 by the transient wide band liquid crystal method. Two dimple geometries of hemispherical and cusped elliptical shapes were examined. The investigation on the effect of dimple geometry showed that hemispherical and a cusped elliptical dimple did not perform immensely

differently. However, comparing in terms of economy, manufacturing and pressure loss, the hemispherical shape should be a better choice.

Kueth [7] was the first to 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.

Shin et al. [8] has measured the heat transfer coefficient in a channel with one side dimple surface. The sphere type dimples were fabricated, and the diameter (D) and the depth of dimple were 16 mm and 4 mm, respectively. The Reynolds number based on the channel hydraulic diameter was varied from 30000 to 50000. As the Reynolds increased, the overall heat transfer coefficients also increased with the same dimple arrangement, the heat transfer coefficients and the thermal performance factors were higher for the lower channel height. As the distance between the dimples was reduced the overall heat transfer coefficient and the thermal performance factors increased.

Gaikwad et al. [9] has done a computational investigation of convective heat transfer in turbulised flow past a dimpled surface and 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. 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 results showed that more heat transfer was occurred downstream of the dimples due to flow reattachment.

Giram and Patil [10] have studied the heat transfer characteristics and the pressure drop of the forced convection apparatus of six dimpled plates. Six test plates with varying dimple densities were taken and by varying the input voltage Nusselt Number variation was recorded. It was found that Nusselt Number increases as the dimple density increases and also the heat transfer rate from the test surface increases with increase in mass flow rate of flowing fluid and heat input.

II. VORTEX HEAT TRANSFER TECHNIQUE

Each dimple acts as a "Vortex Generator" which provides an intensive and stable heat and mass transfer between the dimpled surface and gaseous heating/cooling media. Taking advantages of vortex heat transfer enhancement (VHTE), as

- a) Higher heat transfer coefficient
- b) Negligible pressure drop penalty
- c) Potential for fouling rate reduction
- d) Simplicity in design and fabrication
- e) Compactness and/or lower cost

This method is potentially used in heat transfer enhancement in convective passages for industrial

boilers, process heaters, furnaces, heat exchangers and variety for other industries like automotive (radiators, oil coolers etc.), heat treating (recuperator), aerospace, military, food processors etc.

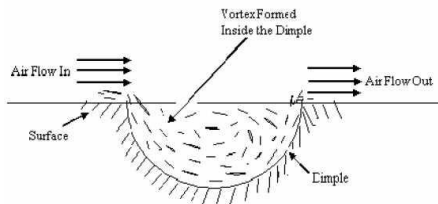


Figure 1: VHTE Mechanism [9]

III. DIFFERENT DIMPLE GEOMETRIES

A. Inline arrangement of various dimple shapes (triangular, circular, square)

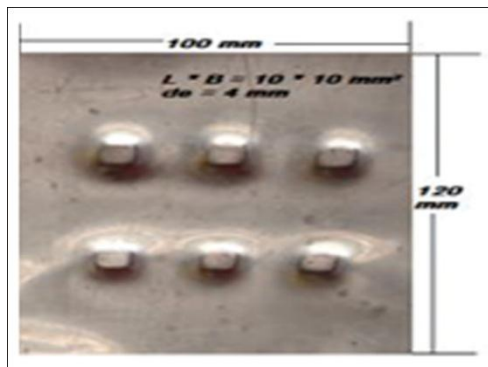


Figure 2: Square dimple [1]

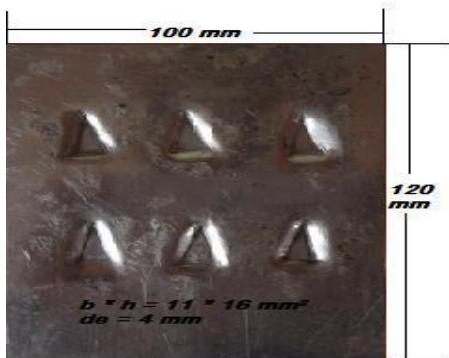


Figure 3: Triangular dimple [1]

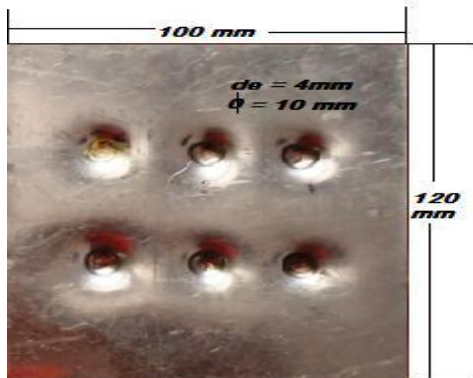


Figure 4: Circular dimple [1]

Dafedar et al. [1] studied the behaviour of heat transfer coefficients by varying different parameters and also using different material plate under natural convection.

The heat transfer rate increases for various dimpled surfaces as compared to plane surface. The depth of all the dimples is kept constant and six dimples on each plate with inline arrangement are used. Figure (2,3,4) shows different dimple geometries on rectangular plate of size 100mm x120mm. The size of square dimple is 10mm x10mm, triangular dimple is 11mm x 16mm, circular dimple of diameter 10mm were used.

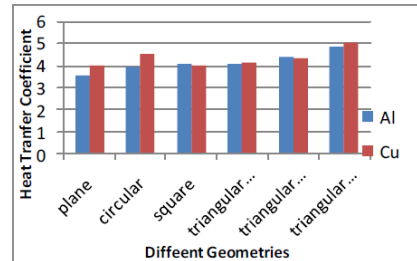


Figure 5: Variation of heat transfer coefficient with different geometries [1]

From figure 5, it has been found that heat transfer coefficient for plane surface is more in copper plate as compared to aluminium plate for same surface area. And it is also found that the heat transfer coefficient is high for triangular dimpled surface facing apex towards flow in copper plate compared to aluminium plate. But for square and triangular (base facing towards flow) dimpled surface the heat transfer coefficient is more in aluminium plate compared to copper plate.

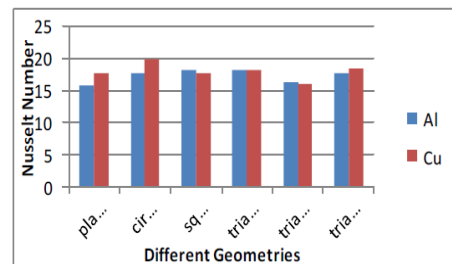


Figure 6: Variation of heat Nusselt Number with different geometries [1]

From figure 6, it is found that the Nusselt number for copper plate with plane surface, circular and triangular (apex facing towards flow) dimpled surface is found to be more as compared to aluminium plate. It is also found that the Nusselt number for aluminium plate with square and triangular (base and hypotenuse facing towards flow) dimpled surface is more compared to copper plate.

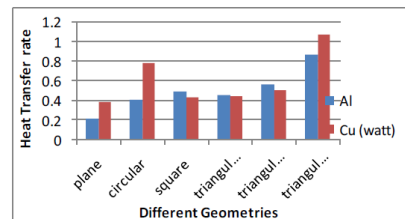


Figure 7: Variation of heat transfer rate with different geometries [1]

From figure 7, it is found that the heat transfer rate for copper plate with plane surface, circular and triangular

(apex facing towards flow) dimpled surface is found to be more compare to aluminium plate. It is also found that the heat transfer rate for aluminium plate with square and triangular (base and -hypotenuse facing towards flow) dimpled surface is more compared to copper plate

B. Inline and Staggered arrangement of Ellipsoidal dimples

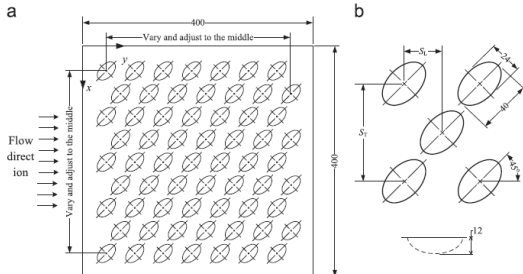


Figure 8: Details of (a) dimpled-tested surface for staggered arrangement and (b) individual dimple geometry [2]

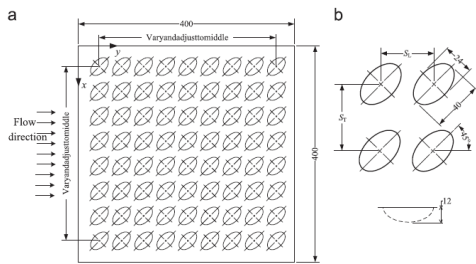


Figure 9: Details of (a) dimpled-tested surface for inline arrangement and (b) individual dimple geometry [2]

Katkhaw et al. [2] investigated the heat transfer on flat surface with ellipsoidal dimples. The dimples were placed at an angle of 45° with different arrangements and the result was found that for staggered arrangement there was an increase in value of heat transfer coefficient by 15.8% and for inline arrangement there was an increase of 21% than smooth surface.

C. Staggered Arrangement of circular and oval shape dimple

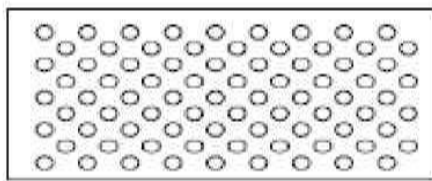


Figure 10: Staggered arrangement of circular dimple [3]

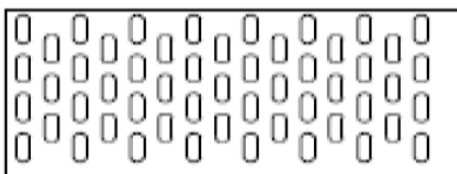


Figure 11: Staggered arrangement of oval dimple [3]

Pisal and Ranaware [3] studied the average heat transfer coefficient and Nusselt number ratio. The dimples in shape of circular and oval were placed in staggered arrangement under forced convection as shown in figure 9, 10. Heat transfer enhancements (relative to a flat plate) were observed for Reynolds number range from 600 to 2000 for above arrangement. For low flow velocity the heat transfer enhancement ratio was less than 1.02 for both circular and oval shaped dimples and for high flow it was found to be 1.11 regardless of Reynolds number.

D. Staggered arrangement of almond shaped dimple



Figure 12: Almond shaped dimple [4]

Patil and Deshmukh [4] have investigated the staggered arrangement of almond shape dimples. The results integrated that staggered array of dimple in circular tube has 66% greater thermal performance factor than inline arrangement. The overall heat transfer coefficients were also increased

E. Inline and Staggered arrangement of Circular dimple

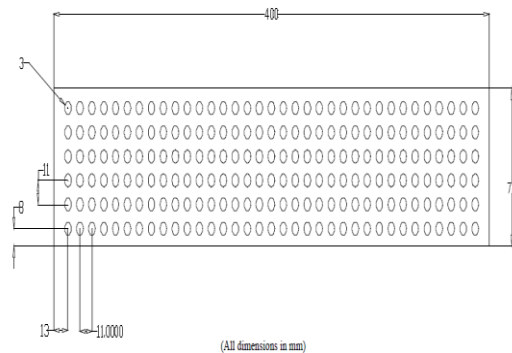


Figure 13: Inline arrangement of Circular dimples [5]

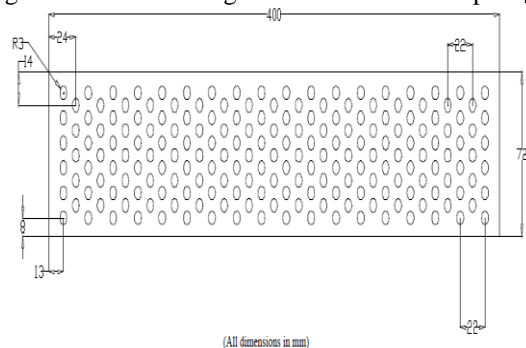


Figure 14: Staggered arrangement of circular dimple [5]

Patel and Borse [5] studied aluminium plates of dimensions $400 \times 72 \times 6 \text{ mm}^3$ were used as test surfaces and it was found that dimple density and dimple

arrangement have significant effect on heat transfer enhancement

F. Staggered arrangement of cusped elliptical shape

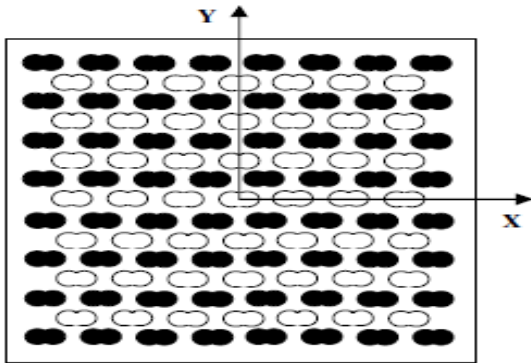


Figure 15: Cusped shape dimple [6]

Kanokjaruvijit and Martinez-botas[6] has studied two dimpled plates with the same wetted area for each dimple were tested. Both were manufactured in staggered pattern on a square Acrylic plate of the size 320 x 320 x25.4mm. The investigation on the effect of dimple geometry showed that hemispherical and a cusped elliptical dimple did not perform immensely differently. Comparing in terms of economy, manufacturing and pressure loss, the hemispherical shape should be a better choice.

Table 1: Different Dimple geometries

S. No	Author	Dimple Shape	Arrangement	Conclusion
1	Dafedar et al.	Triangular, Square, Circular	Inline	Heat transfer enhancement was found most in triangular
2	Katkhaw et al.	Ellipsoidal	Inline and Staggered	Heat transfer coefficient was increased by 15.8% for staggered and 21% for inline
3	Pisal and Ranaware	Circular and Oval	Staggered	Heat Transfer coefficient increased
4	Patil and Deshmukh	Almond	Staggered	Thermal performance factor by 66%
5	Patel and Borse	Circular	Inline and Staggered	Importance of dimple density and arrangement
6	Kanokjaruvijit and Martinez-botas	Cusped	Staggered	Shows same results as hemispherical but economically is not preferred
7	Somin Shin, Ki Seon Lee, Seoung Duck Park and Jae Su Kwak	Spherical	Staggered	Dimple and Channel Height ha effect on thermal performance factor

IV SUMMARY

Lot of research work has been done for the heat transfer augmentation out of which the procurement of dimple shape geometries have been found to be very effective. 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.

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