Numerical Analysis of Heat Transfer for various shapes of dimple surfaces

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Abstract- Dimples play a very important role in improving the heat transfer in our day to day life. Dimples on the surfaces refer to recessions or notches formed on the surface. Dimples are used for increasing the surface area available for heat transfer as a result of which there is enhancement in heat transfer. Some typical examples of using dimples to enhance heat transfer are turbine blade cooling, tubular heat exchangers in chemical and textile industries, automotive radiators etc. In the present study, a numerical analysis is carried out to analyse the characteristics of heat transfer and flui d flow for various dimple shapes.Three shapes of dimples selected are elliptical, semi-circular and circular. Heat transfer rate is found to be maximum in case of circular dimples.

Keywords- **Dimple Surfaces; Heat transfer rate; Heat transfer coefficient; Forced Convection; Heat Transfer Augmentation**

I. INTRODUCTION

Removing excess heat from system components is essential to avoid the damaging effects of overheating or burning. The improvement of heat transfer is an important part of the discipline of thermal engineering. In general, by increasing the area of heat transfer from the surface, the heat transfer coefficient between the surface and its surroundings can be increased. Normally, the heat transfer area increases when using an extended fin- shaped surface attached to the plate base. Fins as devices to improve heat transfer have become very common. Due to continued development in extended surface technology various new concepts have come into existence which includes fins made using different materials.Optimization of fin sizes is extremely important because of heavy demand of compact, lightweight and economical fins.Therefore, the heat sink must be designed to achieve maximum heat dissipation, taking into account the minimum consumption of material due to which it becomes easy to manufacture the shape of the heat sink. A lot of research has been done on the optimization of the fin shape. Varieties of different techniques are used for improving the rate of heat transfer for the plate surface. It can be a passive or active technique. The significant drag of the pressure is produced by the protrusion of the fin or fin in the flow. The heat transfer within the flow passages can be improved by the use of passive modifications of the surface, such as ribs, dimples and pin fins. Some of the techniques to improve heat transfer are found in electronic cooling devices, combustion chamber liners, biomedical devices, aerodynamic turbines and heat exchangers. Heat transfer can be enhanced by below mentioned techniques. They are classified widely into three different categories:

a) Passive
b) Active &
c) Compound

II. LITERATURE REVIEW

Turnow et al. [1] investigated vortex structures and the mechanism for improving heat transfer in a turbulent flow over a set of staggered dimples in a narrow channel. The flow and temperature fields are captured by Large Eddy Simulation (LES) through a mixed dynamic model applied both by speed and temperature. The simulations were validated in comparison to the experimental data obtained for both smooth and dimpled channels. The experiments and LES show that fields averaged over time are symmetric in the width direction for each dimple. The flow onto the dimple surface is chaotic and consists of small eddies with a wide range of scales where the coherent structures are difficult to detect.For both Reynolds numbers, it was found that the dimple package with the ratio of depth t to diameter D of t / D = 0.26 provides the highest heat transfer and thermos-hydraulic performance.

Pisal et al. [2] investigated to determine if dimples in a heat sink fin can increase heat transfer for laminar air flows. This was achieved by carrying out an experimental and numerical investigation with two different types of dimples:1) circular dimples and 2) oval dimples. In the case of the circular and oval dimple surfaces, improvements were observed in heat transfer (relative to a flat plate) for the Reynolds number range from 600 to 2000.Numerical simulations of pressure drop, thermal performance and flow characteristics were carried out. **Jadhao et al. [3]** performed an experiment to measure the change in heat transfer coefficient in a channel having inclined ribs and dimples. The heat transfer coefficient of the dimple plate and the grooved plate is used. The dimples created between the ribs increased the heat coefficient and the pressure drop increases significantly. The cooling technique consists of ribbed sand pits whose angle is considered to be one of the solutions to improve the heat transfer performance of gas turbine blade cooling technology.

Akhtar et al. [4] conducted an experimental investigation of heat transfer by natural convection on circular dimple surfaces. The various heat transfer parameters considered for the study are the Nusselt number, heat transfer coefficient and the heat transfer rate. From the results, he concluded that a large amount of heat transfer improvement takes place on dimpled surfaces.

Ranaware et al. [5] conducted an experimental investigation of heat transfer by forced convection on the surface with V-shaped dimples. The experiments were performed on a 150 mm × 150 mm × 15 mm aluminum plate with dimples in the form of V with a pitch 3.2D, where D = diameter of the dimple. The dimples in V shape are investigated with δ / D = 0.2, 0.3, 0.5, where δ = depth of the dimple. The maximum improvement is observed at δ = 0.3D in the in-line pattern. The dimpled surface with δ = 0.5D shows a minimal improvement. The maximum friction losses are observed in dimple surface with depth of 0.5D and minimum in dimple surface with depth of 0.2D.

Alfarawi et al. [6] experimented with heat transfer and flow friction measurements for a fully developed turbulent flow. Its lower wall was ribbed with three different rib geometries like semi-circular, rectangular and hybrid ribs. The hybrid ribs provided mostly high values for the efficiency indices compared to the cases of rectangular and semi-circular ribs.

Huang et al. [7] investigated the heat transfer characteristics in several walls with protrusion/protrusion patterns as well as straight and rectangular test channels. In each test box, the dimples/protrusions are placed on one side of the wall (simple) or on both sides of the wall (double).For a wall on only one side, several secondary flows created by the dimples/protrusions coexist. The vortices from the upstream strongly influence the downstream mode. For wall housing with a double-sided pattern, eddy current interactions affected by opposing walls greatly improve heat transfer. The increase in heat transfer at a lower Reynolds number is greater due to the effective vortex interaction. Therefore, an improved performance factor in consideration of heat transfer and pressure loss increases as the Reynolds number decreases.

Iftikar Ahemad and Borse [8] studied the improvement of heat transfer on the surface of the depression. The main purpose of his experiments was to find the heat transfer and airflow distribution in the surface of the recess and compare the results obtained with the results of the flat surface. It is noted that the thermal performance increases as the Reynolds number increases. However, the thermal performance of the recessed arrangement is poor compared to a plate having a staggered dimple arrangement.

Jung Shin Park [9] experimentally showed that with the increase of Reynolds number, the Nusselt number relationship decreases, and the friction factor ratio increases with the increase of Reynolds number. The heat transfer coefficient and pressure loss are greatly affected by the number and configuration of the jets. The case with the sidewalls of the dimples shows a large increase in heat transfer compared to the case of smooth sidewalls, while the pressure loss is slightly increased.

Shiva Vyas et al. [10] investigated that the heat loss is lower in the case of dimple tubes, compared to normal tubes. This is because there is a more turbulent mix due to the vortices formed by the secondary flows of the almond dimple tubes, which improves the heat transfer coefficient.

Ambesange et al. [11] provided an experimental setup to improve heat transfer by forced convection over the dimpled surface and without the dimpled surface. The heat transfer coefficient, the Reynolds number, the Nusselt number, the efficiency of the fin on the dimpled surfaces were all factors that were discovered and all the results obtained were compared with those without a dimpled surface of the same surface of the material.

III. NUMERICAL ANALYSIS OF DIMPLE PLATES

3.1 Selection of material for plate

Aluminum has a high thermal conductivity and therefore provides the best heat transfer rate. Aluminum conducts more heat than cast iron. Based on thermal conductivity, aluminum also transfers heat better than stainless steel. The quality of aluminum, such as flexibility and strength, makes it an ideal choice for other applications. Aluminum is 70% lighter than copper with better thermal conductivity. This is why we chose aluminum as a material for the plate on which dimples will be produced.

3.2 Geometrical model of dimple surfaces

The designing of dimple plates was done in ANSYS Design Moduler. ANSYS Fluent 18.1 was used as CFD solver in present study. There are total 18 number of dimples on each of the three dimple plates.Following figures show the circular, elliptical and semi-circular dimples formed on a rectangular plate.

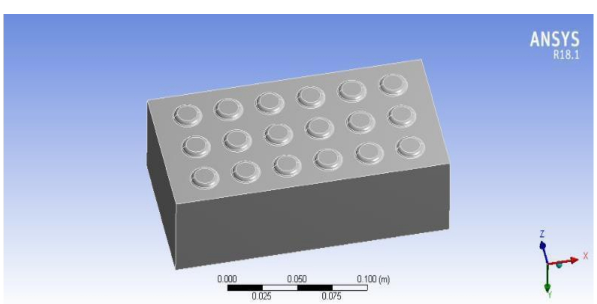


Fig 3.1 Circular dimples

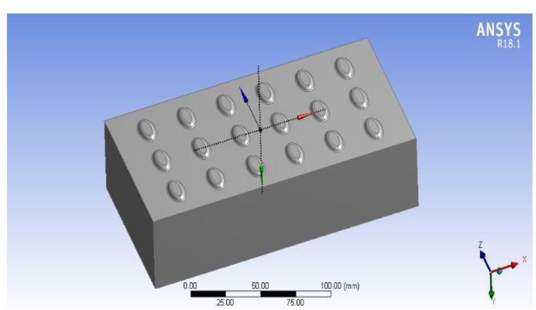


Fig 3.2 Elliptical dimples

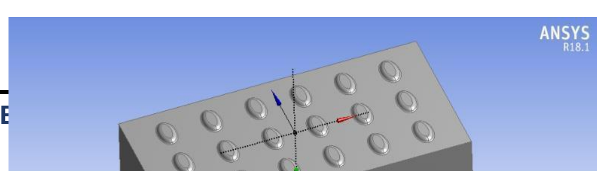


Fig 3.3 Semi-circular dimples

Dimension of the dimple plate is taken as 100 mm*50 mm. The other dimensions of the dimple surfaces are listed in the table 3.1 given below.

Table 3.1 Dimensions of dimple surfaces

	Depth	Diameter	Axis	
Circular Dimple	5 mm	10 mm	-	
Elliptical Dimple	5 mm	-	**Major**	**Minor**
			7.15 mm	3.5 mm
Semi-circular Dimple	5 mm	14.15 mm	-	

3.3 Meshing of dimple plates

Table 3.2 Details of meshing

	Circular	Elliptical	Semi-circular
Nodes	2,51,286	2,71,715	2,54,875
Elements	50,065	42,900	2,22,900

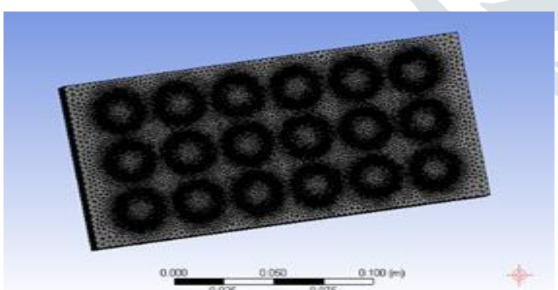


Fig 3.4 Circular dimples meshing

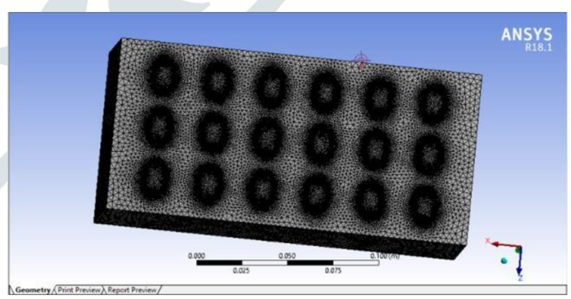


Fig 3.5 Elliptical dimples meshing

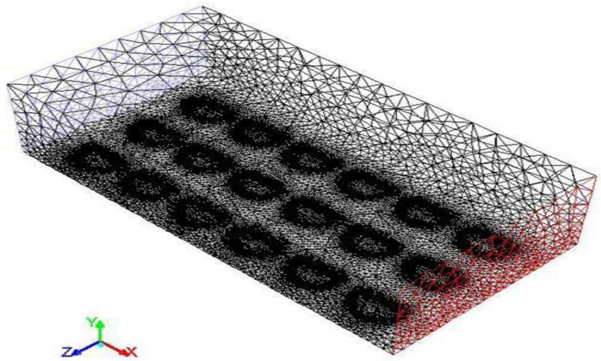


Fig 3.6 Semi-circular dimples meshing

The meshing of dimple plates is carried out in ANSYS 18.1 meshing modular.

3.4 Boundary conditions:-

Following boundary conditions are used during the analysis.

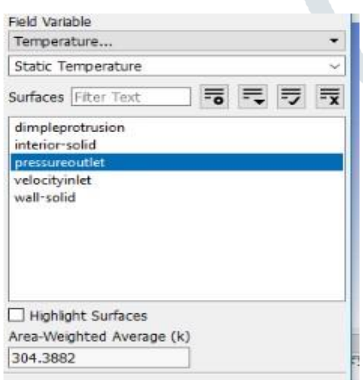
Table 3.3 Boundary Conditions

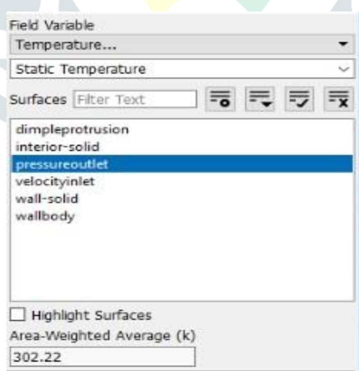
Sr. No.	Face	Type of boundary condition	Velocity/Heat Flux	Temperature (k)
1	Inlet	Air inlet	5 m/s	300 K
2	Heating Plate	Convection	2000 W/m^2	-

3.5 Solution Method and Solver Settings

Since it is a stable state analysis, the configuration of the solver is set as the default. For the pressure coupling the SIMPLE scheme was used because the flow was not complex to model. A scheme of discretization of second order against the wind was used to obtain the solution of the equations of Continuity, Momentum and Energy. There was no defined convergence criterion since a predetermined criterion was used. All governing equations were solved using the control volume approach using commercial software ANSYS Fluent 18.1. The double-precision option was adopted for all calculations, since it will include all significant 6-digit values in the response. Re-Normalized k-ε model was used.

IV.RESULTS AND DISCUSSION





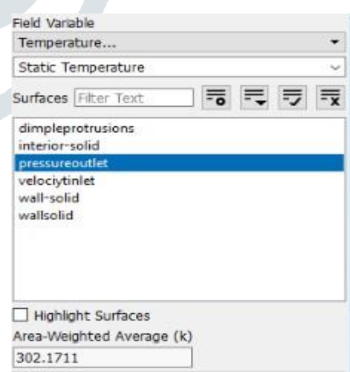


Fig 4.1 Circular outlet temp. Fig 4.2 Elliptical outlet temp. Fig 4.3 Semi-circular outlet temp. The outlet temperature for circular dimple surface [4.1] is 304.38 which is higher than that of the elliptical and semi-circular surfaces.

Convective heat transfer coefficient of air flow is given by,

$h_c = 10.45 - V + 10\,V^{1/2} = 27.811$ (V= 5 m/s)

Also, $Q = h.A.\Delta T$

ΔT is the difference between outlet temperature and the inlet temperature. Inlet temperature is considered as atmospheric temperature.

Total heat transfer rate	Circular	Semi-circular	Elliptical
Q (w)	0.610	0.302	0.313

Thus, we observe that circular dimple surfaces provide much more heat transfer enhancement when compared with elliptical and semi-circular dimple surfaces.

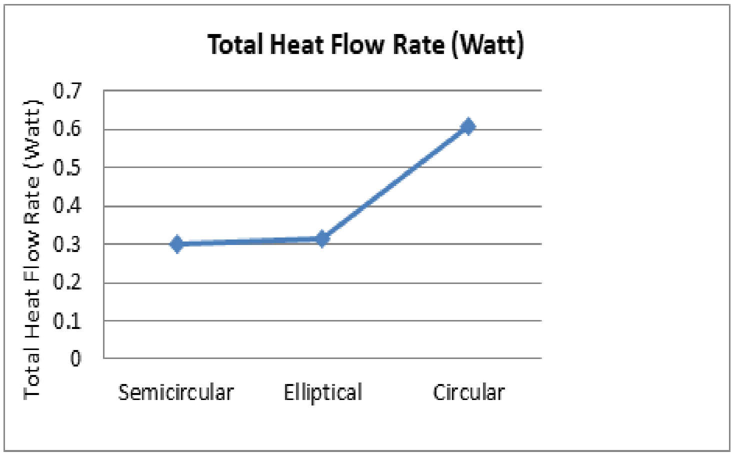


Fig 4.4 Heat flow rate for various shapes

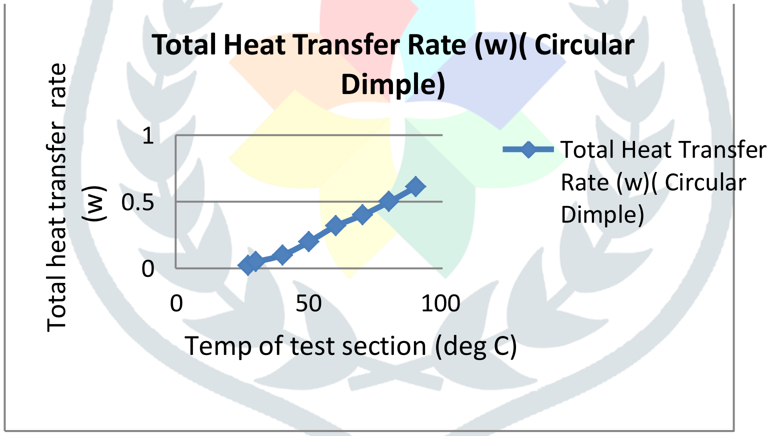


Fig 4.5 Heat transfer rate for circular dimple surface

From the above figures [4.4 and 4.5], we can conclude that maximum heat transfer rate is observed in case of circular dimples.

V. CONCLUSION

Numerical investigation of various shapes of dimples on an aluminium plate is carried out and heat transfer characteristics were studied for circular, semi-circular and elliptical case with different variable parameters with respect to boundary conditions. From numerical work it is found that circular dimples give higher thermal performance i.e. heat transfer rate as compared to elliptical and semi-circular dimple arrangements. Thus the primary advantage offered by the circular dimples is that there is increase in heat transfer enhancement.

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