NUMERICAL ANALYSIS OF HEAT TRANSFER AUGMENTATION BY ALMOND DIMPLES ON A FLAT PLATE

[1]Nikita Agarwal, [2]D. G. Kumbhar, [3]Kailasnath B. Sutar

[1]Researcher, [2,3]Associate Professor
Department of Mechanical Engineering
Bharati Vidyapeeth (Deemed to be University), College of Engineering, Pune, India

Abstract: **In this paper the numerical analysis study of the effect of almond shaped dimple at four angles on a flat plate is carried out. The heat transfer augmentation is studied by the changes in Nusselt number and friction factor. The numerical analysis is done in ANSYS Fluent. The turbulence model for CFD analysis is chosen after performing validation by the experimental and theoretical results for heat transfer augmentation in flat plate. The experiment is done to study heat transfer enhancement on a plat plate with dimples in a rectangular duct. The heater is provided below the test plate to provide constant heat to the plate. The heat flow characteristics of air after heating in the duct are studied for the enhancement of heat transfer. Because of the vortex generation and flow separation inside the dimples the heat transfer is increased. The analysis is done on dimples at four angles (0°, 90°, 180°, 270°). The maximum heat transfer enhancement is found in 270° dimpled plate. The least heat transfer enhancement is found in 180° dimpled plate. The different heat flow characteristics namely Nusselt number and friction factor are evaluated at different Reynolds number. The numerical results are compared with the experimental results obtained.**

Keywords **- Dimples, Heat transfer augmentation, Vortex, Nusselt Number**

I. INTRODUCTION

There has been extensive effort in research on reducing the consumption of nonrenewable energy. The improvement of efficiency in the process of heat exchange is one such area which has a lot of scope. There are variety of practical applications where enhancement in the efficiency of heat transfer is useful such as electronic cooling, heat exchangers both macro and micro scale, gas turbine internal airfoil cooling, combustion chamber liners, fuel elements of nuclear power plants, powerful semiconductor devices, biomedical devices, etc. Over the recent years making compact heat exchangers and internal airfoil cooling in gas turbine are two applications which for a number of researchers are taking interest to study.

A special method for the heat transfer augmentation is introducing dimpled surface which without much pressure drop improves the heat transfer rate. Generally, the vortex flow is generated within the dimple to obtain the enhancement of heat transfer. Due to the introduction of dimples on the surface there is increase in the heat transfer with very small pressure. So, arrangements of many dimples on the surface are used for a wide range of practical applications, such as heat exchangers, bio-medical devices, cooling of electronics, internal cooling of turbine blades, and liners of combustion chamber.

Turnow et.al. [1] studied heat transfer enhancement in a turbulent flow over a staggered array of dimples in a narrow channel. S. A. Isaev et. al. [2] studied computational study of heat transfer augmentation on a spherical dimple placed in a narrow channel. Yu Chen et. al. [3] studied heat transfer in turbulent flow over spherical dimpled surface. Two types of dimples were studied symmetric and asymmetric. The conclusion of the study was that the asymmetric dimples are more effective for heat transfer augmentation than the symmetric dimples. Nopparat Katkhaw et. al. [4] studied heat transfer on a flat plate with 450 ellipsoidal dimples. In this study there were 10 types of arrangements of dimples. Hence it is concluded that the inline arrangement of dimples is more effective than the staggered arrangement. M. Siddique et. al. [5] studied review of recent advancements in the heat transfer augmentation techniques. M. A. Dafedar et. al. [6] studied that the dimpled geometry has high heat transfer rate than plain plates. The triangular shaped dimple has the highest heat transfer rate and the lowest heat transfer rate is in the square shaped dimple. E. F. Alwanet. al. [7] studied that the space between the dimples is decreased which leads to increase in the heat transfer rate. This is because as there is increase in the no. of vortices in the dimples.

The present study of numerical analysis is based on heat transfer augmentation on a flat plate with almond shaped dimples at four different angles. The numerical simulations are done at Reynolds number calculated at hydraulic diameter is ranging from 6706 to 11602. The turbulence model SST K-ω was chosen after the validation. The results are recorded in terms of Nusselt number, friction factor and temperature contours.

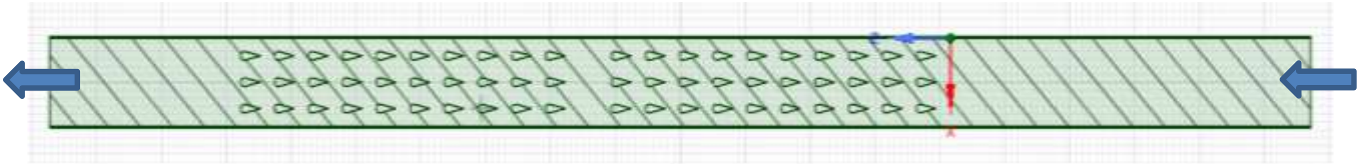
II. NUMERICAL MODEL

The geometry and mesh used for numerical analysis is shown in Figure 1 and Figure 2. The test section is an assembly of air duct and the test plate. The duct is 1000 mm in length and has a cross section of 100 mm x 50 mm. The test plate is of the same length as the air duct and the cross section is of 100 mm x 5 mm. Beneath the test plate a heater is provided to supply uniform heat to the test plate.

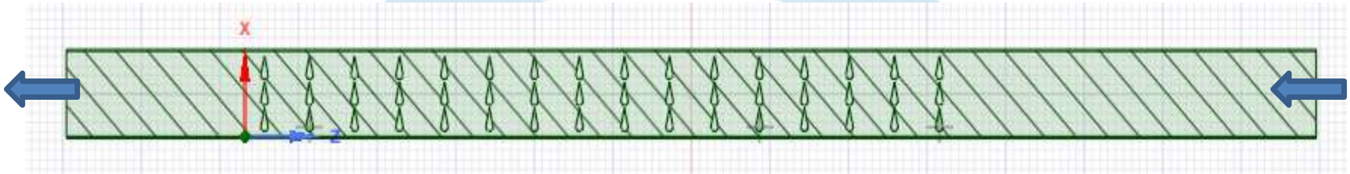
The meshing or the grid generation is the most important part of the flow analysis through computational technique. The accuracy and convergence of the solution process mainly depends upon the type, quality and the number of nodes and elements in the generated mesh. Furthermore, for the complicated geometry of the flow domain like one we choose in our study, the meshing should be done utilizing proper shapes, sizes and number of the nodes and element such a way that it can capture all the physical phenomena that may be involved in the flow domain.

The hydraulic diameter of the duct is 0.066 m. A 500 mm inlet channel is positioned upstream of the test channel and 250 mm outlet channel is positioned downstream of the test channel.

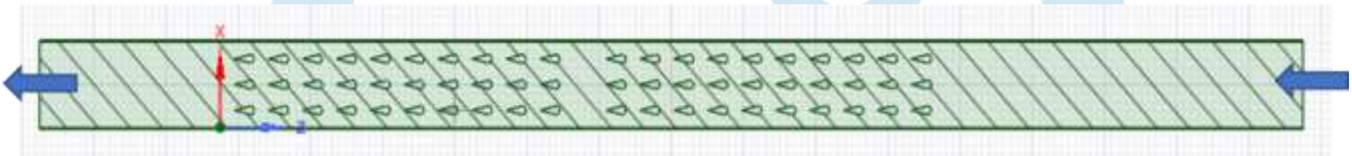
Air is used as a working fluid therefore the boundary conditions are set by providing the inlet velocity, inlet temperature and outlet pressure, outlet temperature and the wall temperature.



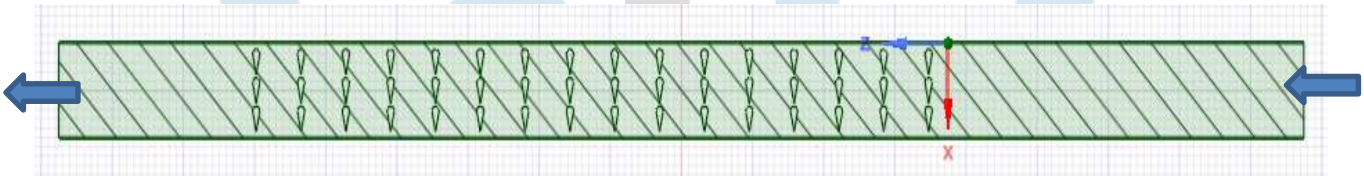
(a) Almond dimple plate at 0-degree orientation



(b) Almond dimple plate at 90-degree orientation



(c) Almond dimple plate at 180-degree orientation



(d) Almond dimple plate at 270-degree orientation

Figure 1: Geometry of almond dimple plate at different orientations

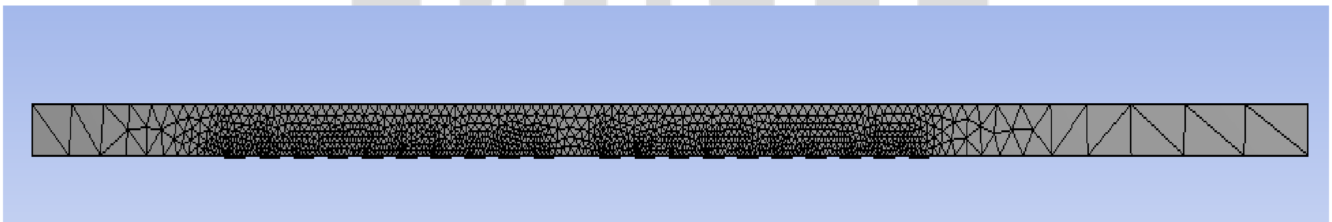


Figure 2: Mesh used for numerical analysis

Air is flowing from the inlet whose mass flow rate varies from 0.0095 to 0.0164. Hence the inlet velocity varies from 1.63 m/s to 2.82 m/s. The outlet pressure selected is an atmospheric pressure hence a zero-gauge pressure. The wall temperature is taken as a constant wall temperature of 35°C. Turbulent Intensity and Hydraulic diameter are also specified for an initial guess. Hydraulic diameter is 66 mm and the turbulent intensity is 5%. The wall of the tube was considered to have a zero roughness with no slip condition

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III. RESULTS AND DISCUSSION

For the validation performed for plain plate it is found that the values of Nusselt number of SST k-ω model are closest to the theoretical values of the Nusselt Number for plain plate. The percentage difference between theoretical and SST K-ω values for plain plate is ranging from 13% to 19%. Hence SST k-ω model method is used to carry out further simulations for dimpled plate. The variation of Nusselt number for SST k-ω model and Standard Wall Function k-Ɛ Model and theoretical is shown in Figure 3.

3.1 Effect of dimples on Nusselt Number

The Nusselt number increases with a significant amount for the plate with dimples than compared to the heat transfer in plain plate. The Nusselt number increases as there is increase in the Reynolds number. It is found that there is highest increase in Nusselt number for the 270° dimpled plate. The heat transfer is increased in the grooves because of the vortex generated in the dimples. The comparison of Nusselt number for dimples at four angles with the plain plate is shown in Figure 4.

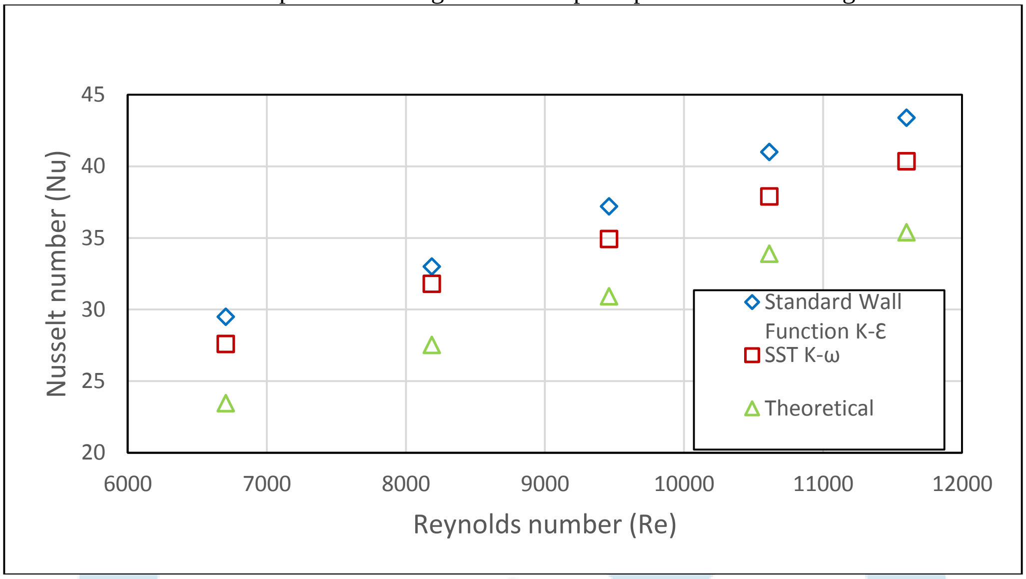


Figure 3: Variation of Nusselt number for plain plate

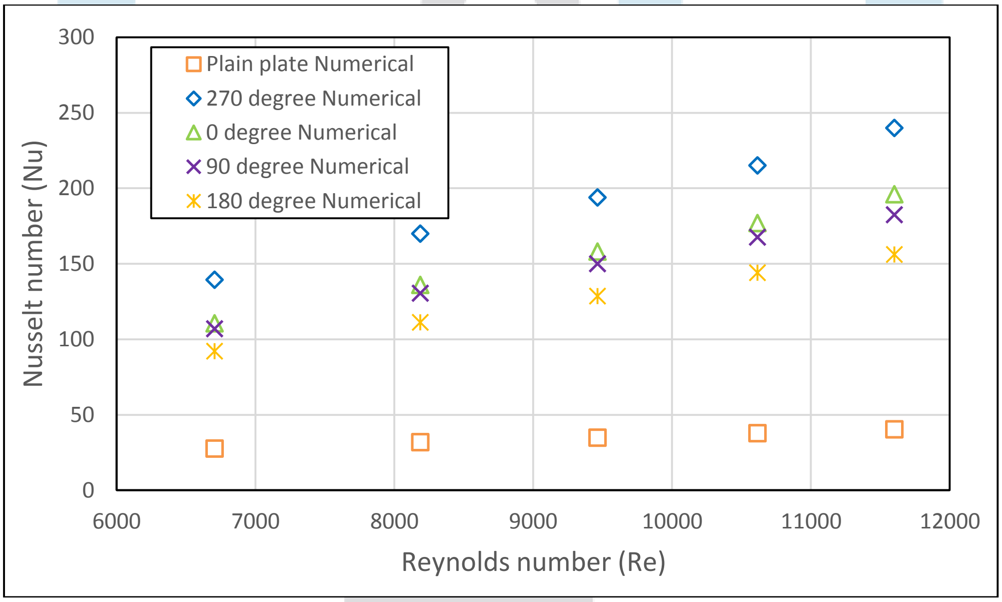


Figure 4: Variation of Nusselt number for dimples at different angles compared to the plain plate

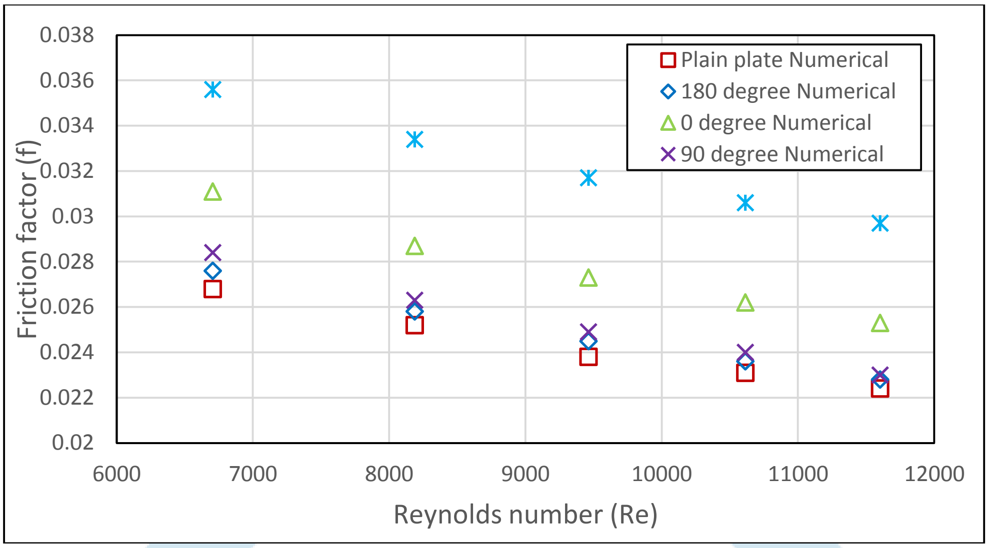


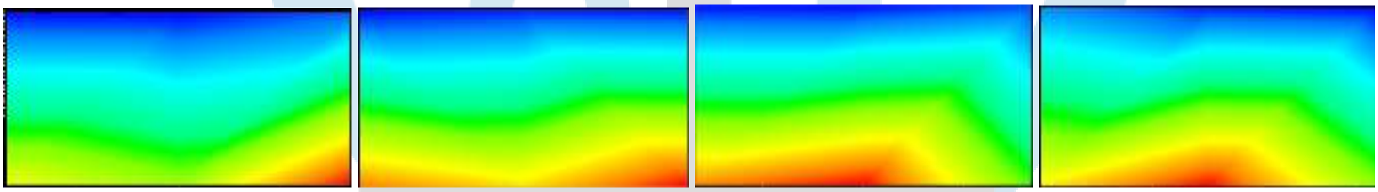
Figure 5: Variation of Friction factor for dimples at different angles compared to the plain plate

3.2 Effect of dimples on Friction Factor

The Friction factor decreases as there is increase in the Reynolds number. It is found that there is highest increase in Friction factor for the 270° dimpled plate. The comparison of Friction factor for dimples at four angles with the plain plate is shown in Figure 5.

3.3 Distribution of temperature on the cross section of the duct

The temperature increases as the flow develops towards the outlet. The temperature is high due to the recirculation of the air in the dimple. The temperature distribution is shown at inlet, middle section and outlet. It is seen that the temperature is lower initially, then increases gradually at the middle section and increases up to the outlet. The temperature contours for dimple plate with dimple at four angles at outlet section are shown in Figure 6.



(a) 0° dimple (b) 90° dimple (c) 180°dimple (d) 270° dimple

Figure 6: Temperature contours at outlet location

IV. CONCLUSIONS

Numerical analysis of flat plate with almond dimples was carried out on ANSYS Fluent with dimples at four different angles (0°, 90°, 180°, 270°). The Reynolds number is ranging from 6706 to 11602 using the SST k- ω (2 equation) turbulence model. It was found that the highest increase in heat transfer was in the 270° dimpled plate. The heat transfer enhancement was read by the change in Nusselt number and Friction factor. It was found that there is significant amount of heat transfer enhancement using plate with almond dimples compared to the plain plate.

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