Review on Experimental and Numerical Analysis of Heat Transfer and Friction Factor using Almond Dimple in Rectangular Duct

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Abstract – *A great emphasis has been given in developing an apparatus and in performing experiments to define the situations under which an effective technique will improve heat transfer. Heat transfer technology is being highly used in heat exchanging applications like refrigerators, automobiles, process industries etc. Enhanced heat transfer study is also referred to heat transfer enhancement, augmentation and intensification. Thought process of saving energy a raw material has led to efforts to build extra efficient heat exchange equipment. Standard techniques of heat transfer like active, passive and compound are also addressed in this paper. Enhancement of heat transfer is one of most important significance in almost every industry. Hence, a very effective solution of heat transfer is required for not only improving the heat transfer but also for the minimization of flow resistance as much as possible. In the past few years the idea of using dimpled surfaces over producing devices has gathered a lot of attention because of the combination of high heat transfer enhancement and low pressure loss penalty. This paper presents a review on experimental and numerical analysis of heat transfer using almond dimple on rectangular duct.*

Key Words: Reynolds's number, Heat Transfer Rate, Friction Factor, Dimpled plates, Heat Transfer Augmentation, Almond Dimple, Rectangular Duct

1. INTRODUCTION

Heat transfer enhancement leads to saving in energy and cost. Because of the rapid increase in demand of energy around the world, reducing energy lost related with ineffective use and enhancement of energy in terms of heat have become very significant for design and operation engineers. In the past few decades various researches have been performed on heat transfer enhancement. These researches focused on finding techniques which not only increases heat transfer, but also helps in achieving high efficiency. To achieve higher heat transfer rates, various heat transfer enhancement techniques are used which can result in energy saving. It also gives more compact and less expensive equipment with higher efficiency.

Heat transfers enhancement technology is widely used in heat exchanger application. Inserting different shaped elements with different geometries in channel flow is one of the widely-used heat transfer enhancement technique. Thermal power plants, process industries, heating and cooling in evaporators, air-conditioning equipment, radiators for space vehicles, automobiles, Electronic devices etc. are some areas where heat transfer enhancement techniques are widely used. The focus on using dimples on surface for increasing the heat transfer has been researched by many researchers.

1.1 Motivation

In this review paper it is proposed to carry out the experimental and numerical analysis of almond dimple considering frictional factor. The various enhancement techniques that are present for enhancing heat transfer are active, passive and compound. Among all of them active technique is used as the insert manufacturing process is simple and cheap. Also, it can be easily employed in an existing heat transfer system. An experimental system can be designed to study the effect of almond dimple in heat transfer characteristics.

1.2 Classification of Enhancement Techniques

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers. Heat transfer enhancement techniques can be broadly classified into three different categories:

1. Passive Techniques
2. Active Techniques
3. Compound Techniques

The effectiveness of these methods is purely dependent on the mode of heat transfer type of process application of the heat exchanger.

Passive Techniques

Passive techniques use certain geometrical modifications like perforation, protrusions and dimples to the flow channel by adding inserts or additional devices. They change the existing flow behavior which promotes higher heat transfer coefficients and also increase pressure drop. Such techniques do not require any direct input of external power instead it uses power from the system itself which leads to increase in fluid pressure drop. Heat transfer augmentation can be achieved by using: [3]

(i) *Treated Surfaces*: Surface having a fine scale alters their finish which can be continuous or discontinuous. These surfaces are generally used for Boiling and condensing applications.

(ii) *Rough surfaces*: Rough surface modification promotes turbulence in the flow field.

(iii) *Extended surfaces*: Extended surfaces provide effective heat transfer and they also led to improve the heat transfer coefficients by disturbing the flow field. This leads to increases the surface area.

(iv) *Displaced enhancement devices*: These are the inserts that are used in confined forced convection. These devices improve energy transport indirectly at the heat exchange surface by displacing the fluid from the heated or cooled surface of the duct with bulk fluid from the core flow.

(v) *Swirl flow devices*: They produce and superimpose swirl flow on the axial flow in a channel. For example, helical strip or cored screw type tube inserts, twisted tapes. They can be used for single phase and two-phase flows.

(vi) *Surface tension devices:* These devices consist of wicking or grooved surfaces. They direct and improve the flow of liquid from condensing surfaces and to boiling surfaces.

(vii) *Additives for liquids*: Under this technique addition of solid particles, soluble trace additives and gas bubbles in single phase flows and trace additives. This usually depress the surface tension of the liquid for boiling systems.

(viii) *Additives for gases*: It includes introduction of liquid droplets or solid particles in single- phase gas flows either as dilute phase (gas-solid suspensions) or as dense phase (fluidized beds).

Active Techniques

Active techniques are more complex from design point of view and application as this method requires some external power input to improve heat transfer rate and to cause the desired flow modification. Active techniques have limited applications, as it requires external power and it is difficult to provide external power input. Augmentation of heat transfer by this method can be achieved by [3]:

(i) *Mechanical Aids*: Fluid is stirred with the instruments by mechanical means or by rotating the surface which includes rotating tube heat exchangers and scrapped surface heat exchangers.

(ii) *Surface vibration*: Surface vibration is applied in single phase flows to obtain higher heat transfer coefficients.

(iii) *Fluid vibration*: Fluid vibration is used in single phase flows. It the most practical type of vibration enhancement technique.

(iv) *Electrostatic fields*: The form of electric or magnetic fields or a combination of the two from dc or ac sources, which can be applied in heat exchange systems involving dielectric fluids. It can also produce greater bulk mixing and induce forced convection or electromagnetic pumping to augment heat transfer.

(v) *Injection*: Injection process is generally used in single phase flow. It is the method of injecting the same or a different fluid into the main bulk fluid either through a porous heat transfer interface or upstream of the heat transfer section.

(vi) *Suction*: Suction involves vapour removal through a porous heated surface in nucleate or film boiling. In some applications fluid is withdrawal through a porous heated surface in single-phase flow.

(vii) *Jet impingement*: It involves the direction of heating or cooling fluid either perpendicularly or obliquely to the heat transfer.

Compound Techniques

A compound technique is the one in which more than one of the above mentioned passive and active techniques are used in combination for improving the hydraulic performances.

1.3 Basis of Heat Transfer

Heat transfer can be defined as the exchange of thermal energy between physical systems. The rate of heat transfer is dependent on the properties of the intervening medium and temperatures of the systems through which the heat is transferred. The three basic fundamental modes of heat transfer are conduction, convection and radiation. Heat transfer is a process by which a system changes its internal energy. Hence it plays a vital role in applications of the First Law of Thermodynamics. Conduction is also known as diffusion. The direction of heat transfer is from a region of high temperature to another region of lower temperature, and is governed by the Second Law of Thermodynamics. Heat transfer changes the internal of the systems from which and to which the energy is transferred. Heat transfer occur in a direction that increases the entropy of the collection of systems. When all involved bodies and the surroundings reach the same temperature, thermal equilibrium is achieved. Thermal expansion is the tendency of matter to change in volume in response to a change in temperature.

1. *Convection* is the transfer of heat by the actual movement of the warmed matter. It is the transfer of heat energy in a gas or liquid by the movement of currents. (It can also happen in solids, like sand.) The heat moves with the fluid. For example, heat leaves the coffee cup as the currents of steam and air rise. Consider this: convection is responsible for making macaroni rise and fall in a pot of heated water. The warmer portions of the water are less dense and hence it rises. On another part the cooler portions of the water fall because they are denser.

2. *Conduction* is the transfer of energy through matter from one particle to another particle. It is the transfer and distribution of heat energy from atom to atom within a particular substance. For example, a spoon in a cup of hot soup becomes warmer as the heat from the soup is conducted through the spoon. Conduction is most effective in solids. It can happen in fluids as well.

3. *Radiation* are electromagnetic waves that directly transport energy via space. Sunlight is one of the form of radiation that is radiated through space to earth without the aid of fluids or solids. The sun transfers heat through 93 million miles of space. As there are no solids the sun and our planet hence conduction is not responsible for bringing heat to Earth. Also, there are no fluids in space so, convection is also not responsible for transferring the heat. Thus, radiation brings heat to our planet.

2. LITERATURE SURVEY

Saurabh Verma *et. al*. [1] states that Dimple on surfaces significantly increases heat transfer rate. The vortices formed inside the dimple results in reducing and disturbing thermal boundary layer over surface during coolant flow. It brings enhancement of heat transfer between the fluid and its neighboring surface which results in less increase of pressure drop. Heat transfer coefficient is more for square and triangular dimpled shape and more in aluminum plate than copper plate.

Raju .R.Yenare *et. al.* [2] comments that Use of dimple shape increases convective heat transfer rate. Convective heat transfer rate increases with managing growth of thermal boundary layer. Thermal boundary layer can be made thinner or partially broken by flow disturbance. The heat transfer enhancement increases for an oval plate over circular plate and plain plate. This is due to increase in the turbulence of air provided by oval plate is more as compared to plain and circular dimple. Friction factor increases for an oval plate over circular and plain plate. Pressure drop of dimpled plates for laminar flow are less than flat plate with no dimples. Pressure drop of oval type is smaller than all type dimpled plates.

M.A.Dafedar *et.al.* [3] presents that heat transfer rate is more for different dimpled geometry compare to plain plates both for aluminum and copper material. Maximum heat transfer rate takes place in triangular dimple shape. Minimum heat transfer rate takes place in square dimple shape.

Hemant .C. Pisal *et.al.* [4] discussed Heat transfer coefficient for circular and oval dimple shaped were higher than that of flat plate for all airflow conditions. Test section should be insulated with fiberglass to minimize heat loss through test section.

Neha Katarwar *et. al.* [5] shows Heat transfer rate is higher as dimple of plate is increases. Heat transfer rate increases as the heat supplied to plate increases. Heat transfer coefficient obtained from the dimple surface at higher diameter is 1.66 times higher than those from the plane surfaces.

E.F.Alwan *et. al.* [6] states that Decreasing the spacing between the dimples increases the heat transfer enhancement level due to the increase in no. of vortices shedding from the dimples and the collection of vortices that yields a longer up wash region.

Carson D. *et. al.* [7] presents The doubled dimple surface feature exhibited very effective heat transfer enhancement and drastically improved the heat transferred from the channel side walls for all of the tested Reynolds numbers. In a narrow channel the effect of the channel is weighted for more heavily than in a channel with a comparatively larger aspect ratio.

Pooja Patil *et. al.* [8] (2014) performed experiments and mentioned that Nu no increases about 28% to 30% experimentally and 47% to 60% numerically. According to her research enhancement efficiency obtained by almond dimple in circular tube increased by 2% to 4%.

Johann Turnow *et al*. [9] (2012) investigated about the vortex structure and heat transfer enhancement mechanisms of turbulent flow over a staggered array of dimples in narrow channel. The vortices are created inside of concave cavities on dimpled surface preventing a blockage of the channel and keeping the additional resistance at a minimum. Its formation was in the focus of many studies, but main attention has been paid to time averaged value. On other part the flow structures within the cavities and their contribution to the heat transfer mechanism remain still unclear and are not completely understood. Especially, in the turbulent range and at large ratio of dimple depth to dimple diameter h/D the flow is complicated. Since the form of vortex has a strong impact on heat transfer. The objective of this study is to clarify the role of the vortex formation with respect to the heat transfer on staggered arrangement dimple package and measurement of pressure and velocity. It was revealed that heat transfer and friction factor increase for a decreasing channel height and rising dimple depth. Heat transfer rate can be enhanced up to 201% by using staggered arrangements of dimple having depth to diameter ratio 0.26.

Sumantha Acharya *et al*. [10] worked on experimental and computational study of heat and mass transfer and flow structure for four dimple shapes in a square internal passage. Computations are performed for the same dimple geometries, and with the same flow conditions as in the experiments. Flow patterns for the four dimples are identified and heat transfer distributions for each dimple are obtained Both the experimental and numerical results suggest that the teardrop dimple has the highest heat /mass transfer among the four dimple shapes studied.

3. METHODOLOGY

1. Determine detailed dimension of almond dimple.
2. Determine the standard arrangements of almond dimples.
3. Determine the proper orientation of the dimples.

4. During experimentation pressured difference across the orifice meter, temperature of the heated surface and temperatures of air at inlet and outlet of the test section and Pressure drop across the test section are measured. The mass flow rate of air is determined from the pressure drop across the orifice meter, the useful heat gain of the air is calculated, and the Nusselt number is calculated. The friction factor was determined from measured vales of pressure drop across the test section. Reynolds number based on hydraulic diameter is calculated.

5. Using the data obtained from experiments, the heat transfer, friction factor and the thermal performance characteristics of almond dimple at different arrangements and orientations is calculated. These calculated data are analyzed to find out increased heat transfer.

4. REVIEW OF PROPOSED WORK

Phase-I: Literature Review

Detailed information of existing techniques available for augmentation of forced convection heat transfer.

Phase-II: Study of Almond Dimple

Almond dimple can be inserted in rectangular duct for heat transfer augmentation in forced convection heat transfer according to following arrangements and orientations.

Arrangements: Arrangement of almond dimple can be done by two ways:

-Inline Arrangement

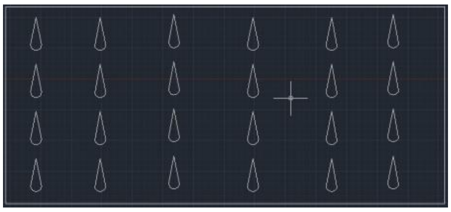

***Fig 1**: Inline arrangement*

-Staggered Arrangement

***Fig 2**: Staggered arrangement*

Orientation: Orientation of almond dimple inside the rectangular duct can be done in any of the following angles:

90^0

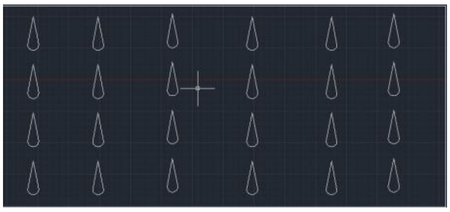

***Fig 3**:* 90^0

180^0

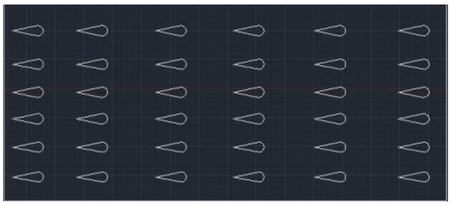

***Fig 4**:* 180^0

270^0

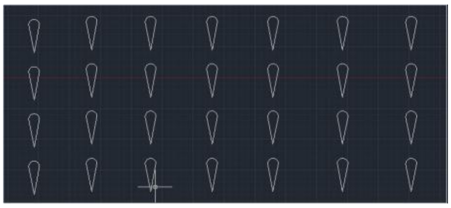

***Fig 5**:* 270^0

360^0

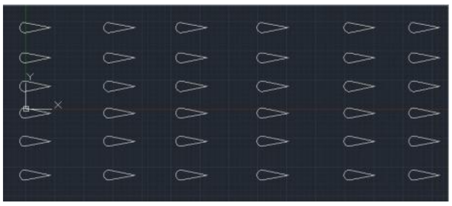

***Fig 6**:* 360^0

Phase-III: Standard Experimental Setup

Figure 7 shows a standard experimental setup for analysis of heat transfer and friction factor using almond dimple in rectangular duct. The setup mainly consists of:
- Heater with capacity of 1 KW
- Dimmer stat
- Digital temperature
- voltmeter and Ammeter
- K Type Thermocouple
- Air Control Valve
- Orifice meter
- U tube manometer
- Centrifugal suction type blower

The test plates will be placed on heater in a both side closed rectangular. Two ports namely, inlet and outlet ports are provided for inlet and outlet of air. A constant heat is supplied using dimmer stat to heater. Flow of air takes place parallel to the dimpled test surface. The heater is fixed at the bottom of the test plate, and is connected to power socket through dimmer stat. Required heat input is provided to the test plate by varying the readings of dimmer stat. Only top dimpled surface of the test plate will be exposed to the air stream. From these dimpled surface the convective heat transfer to the air stream takes place. On reaching a steady state the inlet and outlet temperature of air with surface temperature of plate and dimples can be measured using thermocouple.

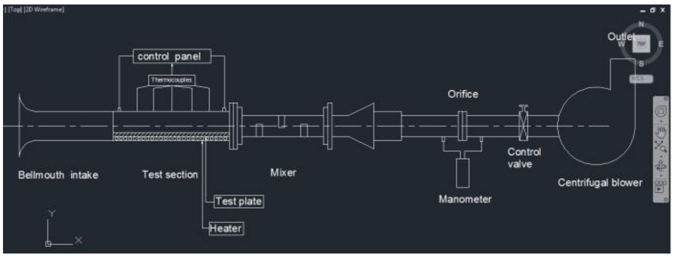

***Fig 7**: Standard Experimental Setup*

6. CONCLUSION

From the study of various research papers, it is observed that researchers have used various dimple shaped geometries such as triangular, ellipsoidal, circular and square. Out of which ellipsoidal shape gives better results due to prior vortex formation as compared to other shapes. And in the current review it is found that almond shape is extended surface of ellipsoidal shape. Also, theoretically it is proved that thermal performance factor increases with use of almond shaped dimple on rectangular duct. Using almond shaped dimples laminar flow changes to turbulence flow which causes disturbance in air flow resulting in increase in heat transfer rate.

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