International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
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Research Article

A Review on Experimental and Numerical Investigation of Heat Transfer Augmentation using Dimpled Geometries

Yogesh P Bhatt[†*] and D. B. Hulwan[‡]

[†]Department of Mechanical Engineering, Savitribai Phule Pune University, Vishwakarma Institute of Technology, Bibwewadi, Pune, India

Accepted 12 June 2016, Available online 17 June 2016, **Vol.6, No.3 (June 2016)**

Abstract

The development of high performance thermal systems has stimulated interest in methods to increase heat transfer using different enhancement techniques. Improvements in the performance of thermal systems can lead to substantial cost, space and material savings. Roughness enhancement method is one of the most effective ways to improve the heat transfer performance with small increase of pressure drop. Compared to other passive enhancement geometric forms, three-dimensional roughness method holds more potential because of the high levels of enhancement and energy efficiency. One innovative technique, which is the subject of a number of recent investigations, involves the use of dimples on tubes, plates, surfaces of channels etc. as they are competitive in comparison to performance and cost of other enhancement techniques. This paper makes an attempt to review the experimental and numerical investigations carried out using dimples as passive enhancement technique.

Keywords: *Heat transfer enhancement, Dimples, Reynolds Number, Nusselt Number, Heat transfer coefficient*

1. Introduction

Thermal systems especially heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include steam generation & condensation in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings has led to development & use of many techniques termed as Heat transfer augmentation. These techniques are also referred as heat transfer enhancement or intensification. Enhancement techniques can be broadly classified into three different categories: 1) Active Techniques 2) Passive Techniques 3) Compound Techniques.

Active Techniques: These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. Some examples are surface vibration, mechanical aids, electrostatic fields, fluid vibration.

*Corresponding author: **Yogesh P Bhatt**

Passive Techniques: These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. Passive techniques hold the advantage over the active techniques as they do not require any direct input of external power. Heat transfer augmentation by these techniques can be achieved by using rough surfaces, extended surfaces, swirl flow devices, displaced enhancement devices, coiled tubes and additive for fluids.

Compound Techniques: A compound augmentation technique is the one where more than one of the above mentioned techniques are used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger. These methods are complex in the design and implementation.

Dimples are arrays of indentations along surfaces. These are often spherical in shape, although a variety of other shapes have also been employed, ranging from triangular to tear drop. These are an attractive method for heat transfer because they produce multiple eddies and vortex pairs as they advect downstream. They are notable for the high heat transfer coefficients and low-pressure drop penalties that they produce, which is because they do not protrude into the flow to produce significant amounts of form drag. Dimpled surfaces can create one or more combinations of the following conditions that are favorable for increasing the heat transfer coefficient with a consequent increase in the friction factor:

1) Interruption of development of boundary layer and increase of degree of turbulence,

2) Effective heat transfer area increase

3) Generation of rotating and secondary flows or vortices.

2. Literature Review

Pedro G Vicente *et al* studied three dimensional helically dimpled tubes using water and ethylene glycol as test fluids for 10 tubes of different geometric forms and one smooth tube for the purpose of comparison. Two non-dimensional parameters have been defined for tube roughness: reduced height and dimple density. The experimental study was conducted for turbulent flow in the dimpled tubes between Reynolds number (Re) 2000< Re < 100,000 (2000-10,000 for ethylene glycol and 8000-100,000 for water) and Prandtl numbers (Pr) 2.5 < Pr < 100(35-100 for ethylene glycol and 2.9-4.5 for water).Reduced height showed higher influence on performance characteristics as compared to dimple density. It was observed that friction factor increased from 150 % to 300 %, Nusselt number increased up to 250 %. Under the same flow conditions all dimpled tubes showed higher pressure drop and better heat transfer than smooth tubes. The performance study demonstrated that dimpled tubes are suitable for use between 2000<Re<40000. Total area under heat transfer can be reduced from 80% to 20% if dimpled tubes replace smooth tubes in a heat exchanger design.

Alberto Garcia *et al* investigated three dimensional helically dimpled tubes using water and ethylene glycol as test fluids for 10 tubes of different geometric forms and one smooth tube for the purpose of comparison. Effect of roughness techniques on pressure drop and heat transfer rate for laminar and transition flows has been studied. Three dimensional helically dimpled tubes have been studied using water and ethylene glycol as test fluids for Reynolds number (Re) 100< Re < 100,000 Prandtl numbers (Pr) 2.5< Pr <100 Reduced length (x^*) 10^{-5}< x^* <10^{-2} Rayleighs number (Ra) 10^6 < Ra < 10^8 . Heat transfer augmentation produced by dimpled tubes versus Ra in fully developed region is higher and varies from 0.9-1.3 .It was observed that at low Re ; Nu in dimpled tubes shows constant value depending on Ra and at critical Re it suddenly rises due to viscosity reduction in boundary layer and is independent of Ra. In turbulent region Nu rises by 4 to 5 times providing high heat transfer rate as compared to smooth tube value. Pressure drop in dimpled tubes was slightly higher than smooth tubes. Friction factor augmentation was between 1.1-1.3 for laminar flows and 2-4 for turbulent flows.

Juin Chen *et al* investigated heat transfer enhancement in a coaxial-pipe heat exchanger using dimples as the heat transfer modification on the inner tube. Tube-side Reynolds numbers (Re) were in the range of 7.5 *10^3 <Re< 5.2 * 10^4 for water flow. A constant annular mass flow rate was chosen to obtain the highest possible Reynolds number of 1.1 *10^4. Typically, the heating water inlet temperature was 68.1 ±0.1°C. All six variants with inward-facing, raised dimples on the inner tube increased the values of heat transfer coefficient significantly above those for the smooth tube. Heat transfer enhancement ranged from 25% to 137% at constant Reynolds number, and from 15% to 84% at constant pumping power.

Pooja Patil *et al* conducted an experimental study for the staggered configuration of dimpled tube and compared with the base line results of plain tube. In addition to this numerical investigation was carried out which showed that staggered array of dimple in circular tube has 66% greater thermal performance factor than aligned dimple configuration.

Yogesh Banekar *et al* studied the heat transfer through plain and dimpled tube or channels Reynolds no for fluid flow ranges from 2900-6000. Nusselt no for dimpled tube is 30-40% higher than that for plain tube considering both parallel and counter fluid flow as the Reynolds no increases gradually. Also, convective heat transfer coefficient is slightly increased for dimple tube as compared to plain tube.

Vilas Apet *et al* performed experimental investigation of forced convection heat transfer from dimpled tube with varying diameter and depth of dimples. Experimental tests were carried out with heating air on the entry side with a constant flow rate. For circular dimples, heat transfer enhancements were observed for Reynolds number range from 5000 to 12000.

Yu Wang *et al* performed heat transfer and hydrodynamics analysis of a new enhanced heat transfer tube with ellipsoidal and spherical dimples. Experimental tests were carried out with heating water on the shell side with a constant flow rate, and cold air in the tube side with flow rates range from 1 to 55 m^3/h. The heat transfer and pressure drop of the new dimpled tube were investigated and compared with the results of a dimpled tube with spherical dimples and a conventional smooth tube. The results indicated that the Nusselt number for ellipsoidal dimpled tube and spherical dimpled tube are 38.6–175.1% and 34.1–158% higher than that for the smooth tube respectively. The friction factors of dimpled tube increase by 26.9–75% and 32.9–92% for ellipsoidal and spherical dimples compared with the smooth tube respectively.

Somin Shin *et al* measured the heat transfer coefficient in a channel with one side dimpled surface. The sphere type dimples were fabricated, and the diameter (D) and the depth of dimple were 16 mm and 4 mm, respectively. Two channel heights of about 0.6D and 1.2D, two dimple configurations were tested. The Reynolds number based on the channel hydraulic diameter was varied from 30000 to 50000. Results showed that the heat transfer coefficient upstream side of the dimple was low because of flow recirculation. Similarly, a high heat transfer region was found downstream of the dimple due to flow reattachment. 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 became smaller, the overall heat transfer coefficient and the thermal performance factors increased.

Nopparat Katkhaw *et al* investigated the heat transfer behaviour of a flat surface with ellipsoidal dimple for external flow. Ten different types of arrangements, five each for inline and staggered configuration have been studied by varying streamwise and spanwise pitch. For the staggered arrangement, the heat transfer coefficient increased by 15.8% and for the inline arrangement by 21.7% as compared to smooth surface.

Iftikarahamad H. Patel *et al* performed experimental investigation of the forced convection heat transfer over the dimpled surface. The objective of the experiment was 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 varying parameters were i) Dimple arrangement on the plate i.e. staggered and inline arrangement and ii) Heat input iii)Dimple density on the plate. The study concludes to more heat transfer enhancement on dimpled surfaces with lesser pressure drop penalty. Heat transfer rate from the test surface increases with increase in Reynolds number of flowing fluid and heat input. The value of maximum Nusselt number obtained for staggered arrangement of dimples is greater than that for inline arrangement, keeping all other parameters constant. It shows that for heat transfer enhancement staggered arrangement is more effective than the inline arrangement. Antonio Viedma *et al* studied the thermal-hydraulic behaviour of three types of enhancement technique based on artificial roughness: corrugated tubes, dimpled tubes and wire coils were analyzed. Heat transfer and pressure drop experimental data in laminar, transition and turbulent regimes are used in this investigation. The study concludes that for Reynolds numbers lower than 200; the use of smooth tubes is recommended. For Reynolds numbers between 200 and 2000, the employment of wire coils is more advantageous, while for Reynolds numbers higher than 2000, the use of corrugated and dimpled tubes is favored over the wire coils because of the lower pressure drop encountered for similar heat transfer coefficient levels.

3. Summary

Experimental research carried out using dimple shaped geometries on tubes, plates, surfaces concludes to more heat transfer enhancement with lesser pressure drop penalty. Hence dimpled tubes present a feasible solution for heat transfer augmentation as compared to other techniques and can be employed in practical applications efficiently in nearby future

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