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Convective Heat Transfer from a Circular Tube with Variable Dimple Dimension

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ABSTRACT: This paper provides an experimental study of forced convection heat transfer from water flow in a pipe that has a hemispherical dimple where the dimple is towards the inside of the pipe. The heat provided by the heating wire wrapped around the pipe is conducted by a constant flux of electric current. The heat from the pipe wall is received by the water flow in the pipe. On the circumference of the pipe, three rows of dimples are made along the length of the pipe and the variations in diameter dimple dimension are d^* = 0.21, 0,42 and 0,63. Variations in flow discharge expressed in the Reynolds number produce laminar and turbulent flow. The results show that there is an increase in temperature along the length of the pipe, the convection coefficient increases with increasing Reynolds number and heat transfer increases with increasing Reynolds number.

KEYWORDS: tube, dimple, heat transfer, spherical, convection

1. INTRODUCTION

Hot fluid channels in the heat mass transfer field are developing overtime, in which many type of the geometry and configuration of the channel have been studied by many researchers. Besides that, the fluid type is also developing, like the nanofluid type. All of this development is intended to increase heat transfer rates. In industrial applications, circular tubes are the most common use for flowing the pressurized fluid to transfer the heat, but the other types of pipe with various cross sections may be used in mass heat transfer field since the other type may have a higher heat transfer rate. The elliptical cross- section gives a higher heat transfer performance compared to other cross sections [1].

The study of convective heat transfer in tubes with dimples shows that the heat transfer performance increases significantly, as shown by Albanesi et al. [2]. In the simulation, they studied convective heat transfer in laminar flow from a circular tube with diameter 11 mm and a semicircular dimple with a depth of 2 mm. That results in a ratio of the dimple diameter and the tube is 0.18. The results give an increase of 10% in heat transfer performance. Abdul Wahid et al. [3] conducted an experiment with nanofluid flowing in tube of 25 mm in diameter and depth of dimples of 1.3 mm which are arranged inline in the direction of the tube length.

The results show that the heat transfer rate of a tube with dimples has higher heat transfer than that of the tube without dimples. The inline arrangement of dimples has higher heat transfer than the staggered dimples arrangement and the dimpled tube of spherical form has higher performance than the tube with rectangular dimples as shown by Hossen et al. [4]. The influence of the presence of the elliptical dimples on the divergent channel wall increases the heat transfer rate.[5].

The thermal performance factor of the dimple twisted tape and plain twisted tape tube is higher than that of the plain tube. There is an intensification of heat transfer obtained through a circular duct with dimple twisted tape insert than that of plain twisted tape and plain pipe [6]. The numerical simulations are conducted in heat-transfer enhanced tubes with internally roughened dimples. The effect of dimple size on heat transfer is very significant. The ratio of dimple diameter to the tube diameter seems to be about 0.18, which is an optimum dimple size that was investigated by Li et al. [7]. In the regime of transition flow, Qu et al. [8] give the study of the effect of the dimple size.

For micro-channel heat sinks with four different dimple shapes, viz. circular, square, almond and elliptical are considered and studied experimentally by Jagadale et al. [9]. The results show that elliptical dimples perform better than other dimple shapes. The constrained convection heat transfer in a trapezium channel with elliptical dimpled wall is explored by Pohare et al.[10].

The influence of the external dimple dimension on hydrodynamic performance is significant. For small dimples, the flow does not enter into the dimple to form a coherent recirculation zone. On the contrary, as the dimple diameter increases, a recirculation zone forms and moves in the downstream direction to increase dimple size [11]. Heat transfer of a fin bank with dimples creates vorticity and vorticity generated within the dimple cavity and at the dimple rim contributes substantially to heat transfer augmentation on the dimple side [12].

Vicente et al. [13] used helically dimpled tubes in the experiment to study in order to obtain their heat transfer performance. Dimensionless dimple heights ranging from 0.08 to 0.12 are observed and there is a significant increase in heat transfer rate. Kore et al. [14] used a rectangular channel with small variable ratios of dimple depth to dimple diameter in the experiment. There is an increase in thermal performance. Ying et al. [15] explored the effect of the depth of the dimple in a hemispherical channel. They show that the hemispherical dimpled channel presents better overall thermal performance due to the strength and extent of the recirculation flow reduction. For a constant depth ratio, the influence of the pith of the dimples on the plate surface shows that there is a certain limit to obtaining a better heat transfer [16]. Singh and Kumar [17] studied numerically to find the optimum diameter of the dimple on twisted tape which is inserted into a double pipe heat exchanger. The diameter of 5 mm leads to better performance in heat transfer. The dimples of the triangular shape can enhance the thermal performance in divergent ducts, as shown experimentally by More et al. [18]. The effects of the spherical dimple tube increase the heat transfer rate for different flow rates [19]. The elliptical dimple shape is used in the cooling channel and studies show the enhancement of the heat transfer [20].

Based on literature surveys, a tube with spherical dimples of variable diameter of which variable depth in all regimes of the flow, is presented in this paper. The dimples are arranged in an inline position along the tube and a constant heat flux is applied to the flow of water.

2. EXPERIMENTAL SET-UP

. The chosen tube diameter in such away in order the water flow inside the tube varies from laminar to turbulent. Therefore, the internal tube diameter and thickness are 8.7 mm and 0.8 mm respectively. The length of the copper tube is 65 cm. The tube is dimpled into a spherical shape with diameters of d = 2 mm, 4 mm and 6 mm. In the dimensionless expression d* = d/D = 0.21; 0.42 and 0.63. The dimple depth is kept constant at 2 mm and dimples are arranged inline with a distance of 25 mm. Three rows are chosen in the direction of the circumference of the circle (Fig.1).

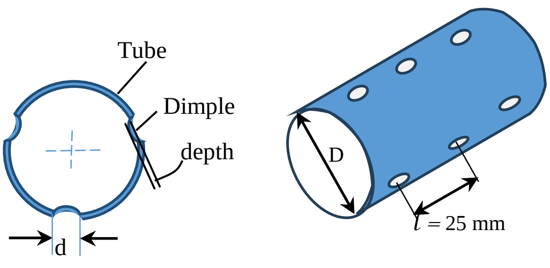

Figure 1. Spherical dimpled tube

The outer surface of the pipe is wrapped with a heating wire made of nickel wire of diameter 0.4 mm. The tube is insulated with asbestos tape. The two ends of the heating wire are connected to electric current. The outer surface of the tube is affixed to five temperature sensors at a distance of each other of 12 cm to measure the surface temperature. Two thermocouples are installed on the inlet and outlet sides of the flow in the pipe to measure the temperature of the water entering and leaving the pipe.

The photo of the test equipment is shown in Figure 2. The test pipe (1) is installed horizontally between the flowmeter (2) and the cooling tower (3). The flowmeter is a float type with a capacity of 160 l/h installed vertically and connected by hoses to both the test pipe and the pump. The pump used is a DC variable speed submersible pump with a maximum discharge of 1000 l/h. This pump is immersed in the water tank (4). Water is pumped from the tank into the flowmeter and then into the test pipe where it receives heat from the surrounding pipe and the heat is released into the cooling tower (3). During system operation, the temperature of the incoming and outgoing water and the temperature on the pipe wall and the flow rate for a certain flow rate are measured. The electric current entering the pipe is also measured. Then the flow rate is changed, and all variables are remeasured as above.

Figure 2. Experimental apparatus

3. DATA CALCULATION

The Reynolds number is calculated from the velocity obtained from the flow rate and is calculated by the following expression:

$$Re = \frac{\rho u D}{\mu} \tag{1}$$

The electric heating power is calculated from the measured current and voltage as follows.

$$Qe = IV \tag{2}$$

The heat received by water is calculated using the following formula:

$$Q_f = mc_p(T_o - T_i) \tag{3}$$

The average temperature of the water flow is calculated by

$$T = \frac{T_i + T_o}{2} \tag{4}$$

where T_i and T_o are inlet and outlet temperature of water, respectively.

The average temperature of the outer surface of the pipe is calculated by

$$T_{so} = \left(\sum_{i=1}^{n} T_{is} \right) / n \tag{5}$$

Where T_{so} is the measured temperatures at the outer surface and n is number of measurement point.

The temperature of the inner wall of the pipe is calculated by

$$T_{si} = T_{so} - \frac{Q_f \ln(r_o / r_i)}{2\pi k_c L} \tag{6}$$

where r_o and r_i are outside and inside diameter of the tube respectively.

Convection coefficient is calculated by

$$h = \frac{Q_f}{\pi D\ L(T_{si} - T\ )} \tag{7}$$

Nusselt number is calculated as foolows

$$Nu = \frac{hD}{k} \tag{8}$$

4. RESULTS AND DISCUSSION

The measurement of each dimension of the dimple has the same length of heating wire since tube diameters are constant and power supplied is constant at 421 Watt. Fig.3 presents the temperature difference of the water between the outlet and inlet sections of the tube. It is clear that the flow varies from laminator to turbulent flow with Re ≈ 1200 to 9300. All of the curves seem to decrease rather linearly with Reynolds' number. The temperature differences decrease with the increase of the flow rate from constant heat flux from the surface. At low flow rate, the water receives more heat from the internal surface. The temperature difference increases with increase in dimple dimension from d*= 0.21 to 0.42, but it seems that the temperature difference decreases to d*= 0.63 for lower low Reynolds numbers.

The temperature difference of dimpled tube is much higher than that of a tube without dimple (d^* = 0). The temperature difference increases as the dimple increases in size due to the increase in the contact surface area between the liquid and dimple surface. For d^* = 0.21, which d = 2 mm, it means that the dimple has an area of a semi-spherical shape and for d^* = 0.42, it is twice, so the area is much larger, therefore the contact area is larger.

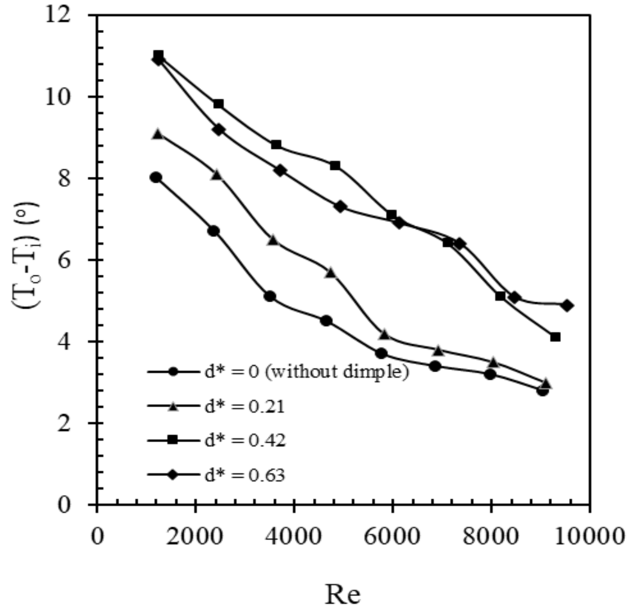

Figure 3. Temperature difference between the inlet and outlet sides

Fig.4 presents the profile of average temperature on the inner surface of the tube. The maximum temperatures are observed at the low Reynolds number or in laminar flow and the temperatures decrease linearly with the increase of the Reynolds number for all dimple sizes. A significant difference between the dimensionless dimple size. The maximum temperature is observed for d* = 0.63, and it decreases rapidly with increase Reynolds number and the profile intersects the curve of d* = 0.42 at Re ≈ 4000, which is the starting point of the turbulent flow. It indicates that a lot of heat is absorbed by the water so that the temperature drops. It can be observed further that at the same Reynolds at Laminar flow, the temperature increases with the increase of the d*, but it seems for the turbulent flow, the temperatures increase until d* = 0.42, and it decreases to d* = 0.63. The increased temperatures on the wall of the tube with the presence of the dimples may indicate a better enhancement of thermal performance.

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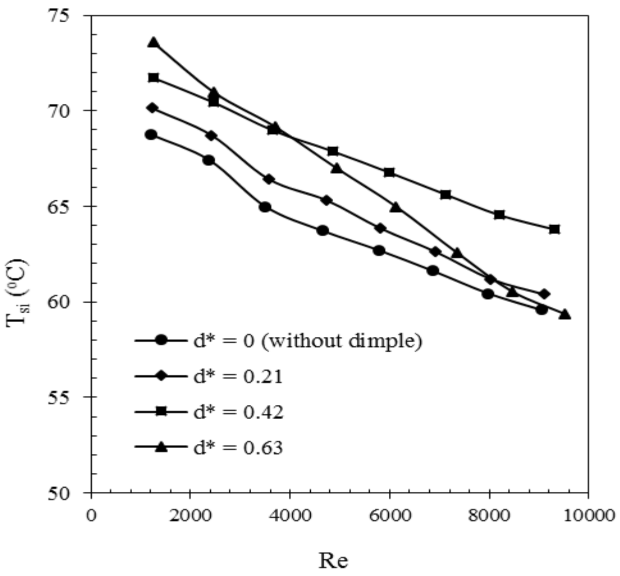

Figure 4. Average temperature on the inner wall of the tube

Fig. 5 displays the wall temperature field of a tube without dimples (d* = 0) with varying flow capacity. We present only the temperature profile only for tubes without dimples, since for other profiles, the profiles seem to be similar. It can be stated that for all capacities, the temperature profile increases linearly with the increase in length of the tube. Constant heat flux along the tube leads to a low temperature near the entrance since the water temperature is lower than the surface temperature and a lot of heat is absorbed by the water. Near the outlet tube, the water temperature increase leads to lower heat transfer. Thus, the wall temperature is higher than the entrance tube. So, at constant heat flux, the wall temperature may vary along the pipe.

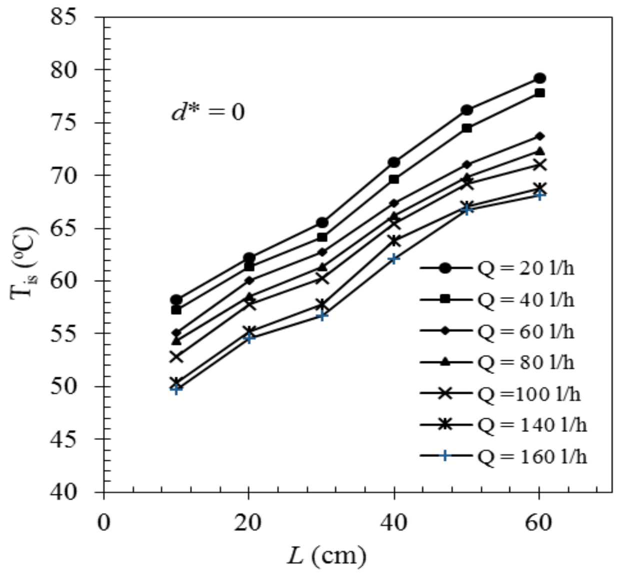

Figure 5. Inner wall temperature of tube

. Fig. 6 shows the relationship between Nusselt and Reynolds numbers for different sizes of dimples. It is clear that the tube with a spherical dimple with constant depth has better thermal performance. The curves show a significant enhancement in heat transfer performance. The different profiles between tubes without dimples and tubes with various dimples, ranging from d* = 0.21 to 0.63, are significant for high Reynolds numbers.

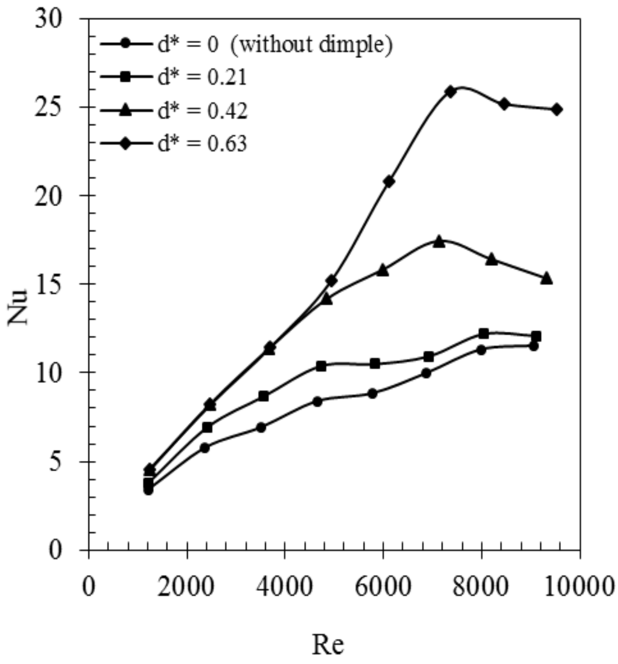

Figure 6. Nusselt number for different d^*

5. CONCLUSION

The experimental study of the convective heat transfer performance of a dimpled tube with variation in dimple size and constant depth of dimples has been explored. The presence of the dimples in the inner tube wall increases significantly the heat transfer performance. As the dimple size increases, the thermal performance increases and when the Reynolds number increases, the thermal performance increases.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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