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# Experimental Heat transfer enhancement in Oval dimpled Tube

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ABSTRACT: Heat transfer magnification attracted more attention recently to support industry by solving a chronic issue represented by saving energy, cost and time. The current study adopted oval cross-section tube having oval dimpled surface. Water was used as working fluid and non-Newtonian fluid was assumed with constant heat flux condition. Such arrangement exhibits good results and holds promises in the field of heat transfer enhancement. Where it was found that the maximum Nusselt number of 39.8 at w/l of 0.133 and minimum Nusselt number was found to be 12.8 at w/l ratio of 0.15. Moreover, the overall maximum enhancement was found to be 19.048 at x/y=1.2 and the minimum enhancement was 9.731 at x/y=1.

KEYWORDS: Heat transfer, oval tube, oval dimple, Nusselt number

## INTRODUCTION

In general, energy is the engine of life and many efforts were made in order to maintain it. Without energy, no work done at all, that is why it is a crucial element in human life. Unfortunately the energy is depleting at tremendous rate, especially nowadays due the growth of life.

Finding out an efficient, low cost and suitable heat recovery technique is the challenge that irks the specialists and researchers so far. Many heat transfer techniques are innovated and emerged due to consistent Researches and efforts. These techniques contributes in heat transfer enhancement in different way, some of them increase the heat transfer tremendously with vast increase in pressure drop, while the other with reasonable pressure drop [1]

Yet, there are three types of heat transfer enhancement techniques, such as active, passive and compound techniques [2]. Each one has merits and defaults. Based on the reported outcomes [3], the surface modification has a superior performance in magnification heat transfer with less pressure drop. That is the reason behind using such technique in much application especially in modern industrial technology.

Surface modification or surface manipulation has an impact role in passive heat transfer enhancement; it helps to increase the wet perimeter without acting as obstacle. These merits motivate many authors to investigate dimple surface, corrugated surface and other surface modification types.

The most recent related studies dealt with dimple tube was conducted by Patil and Deshmukh [4]. A turbulent flow past almond dimpled surface was tested to reveal the extra gain in thermal performance of such technique by using air as working fluid. The reported results showed that the reattachment of the flow helps to carry more heat when a dimple length to width of 4.3 is used. Yenare and Mali [5] conducted a series of experimental tests on oval and circular dimpled fins to show their potential on heat transfer enhancement. The used fins have length to width ratio of 18/8 and the Reynold number range was 600-2000. It was reported that the Nusselt number increase more than the increase in case of circular dimple.

Zhao et al. [6] numerically investigated an oval dimpled tube with heat transfer enhancement structure to improve the heat transfer performance of H-type finned oval tube. The study indicated that the major advantage of such oval dimple with longitudinal vortex generator has better thermal performance than others. Banekar et al. [7] investigated an almond shape dimpled tube at Reynold number range of 3000 to 6000 with dimple length to width ratio of 16/6. The major conclusion was that the employed dimpled tube showed better performance in term of heat transfer enhancement by 21%. Apet and Borse [8] conducted a series of test using four types of dimpled tubes with various arrangements. The experiments focused on the effect of both dimple diameter and depth. The reported results showed that the heat transfer coefficient increase with the decrease of both dimple depth and diameter at constant flow rate of air.

Li et al. [9] conducted a comprehensive numerical tests and simulation on both water and water/glycol solution under laminar-to-turbulent flow conditions. The study aimed to reveal the thermal-hydraulic characteristics of dimpled tubes. The reported results indicated that the dimple helps to mix the secondary flow and break both the thermal and hydraulic boundary layer. Albanesi et al. [10] carried out a series of tests on four tubes with various dimensions and arrangements to clarify and quantify the effect of dimpling tube on the performance of heat exchanger. The experiments data showed that both the heat transfer and pressure increase as the dimple depth increase.

Dagdevir et al. [11] tested a trapezoidal dimpled tube having dimple diameter of 5, 6 and 7 mm, the dimple orientation$\alpha$ = 30°, 45° and 60°, and pitch of 10, 20, 30, 40 and 50 mm to reveal the thermal and hydraulic performance of such arrangement. The study conducted at Reynold number range of $3000 \leq Re \leq 8000$.the reported outcomes refer to the maximum gain in Nusselt number of 2.1 compared to plain tube. Liu et al. studied a multi inlet tube with dimpled surface to clarify its effect on both heat transfer and pressure drop. The tube to diameter ration is 20 and Reynold number range was 10000-40000. It was found that the dimples surfaces offered an increase of 7.2% in heat transfer rate.

Reddy found out the dimples pitch and dimensions have a direct effect on the thermal performance of the solar air channel, when such arrangement was studied experimentally at Reynolds 2000-13500. Moreover the outcomes were statically correlated, whereas the maximum enhancement in Nusselt number is 3.94 compared to the plane channel.

Based on the mentioned literature, the optimal solution did not achieve yet and would never attained due to the encounter difficulties and grown demands on energy resources. This is the motivation behind conducting the current study, which is to fill the gap in heat magnification field by embracing the oval dimple along with oval cross-section tube having staggered arrangement. Such combination believes to exhibits good outcomes and presents something new.

EXPERIMENTAL SET UP

In the current study, an oval tube having oval dimpled surface was embraced to conduct a series of experimental test upon which to reveal the thermal and hydraulic performance induced by this kind of dimpled tubes. The tubes having the following specifications as shown in figure 1 and table 1.

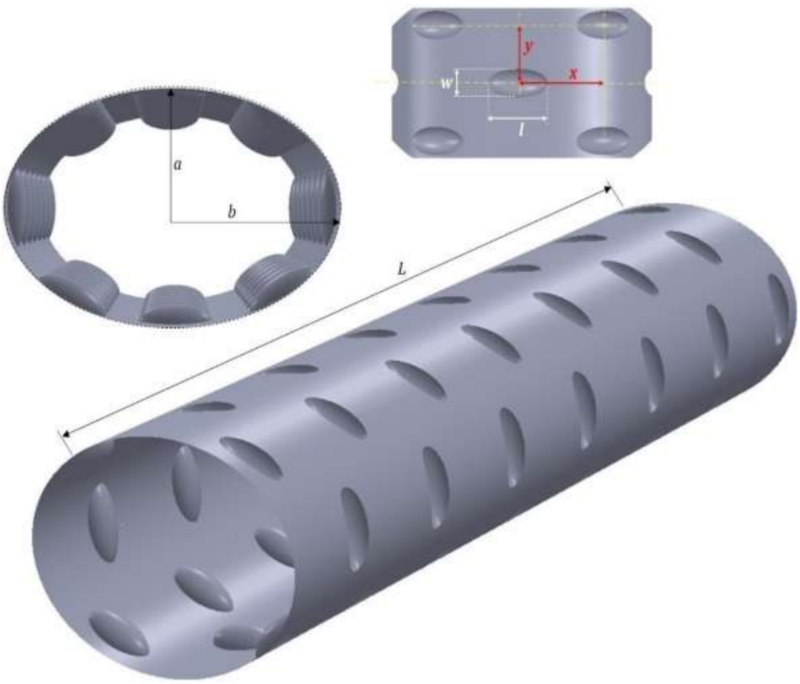


**Figure 1.** Tube configuration.

**Table 1.** Tubes Specifications

| Tube No. | a (mm) | b (mm) | w (mm) | l (mm) | a/b ( - ) | w/l ( - ) |
|---|---|---|---|---|---|---|
| **1** | 12 | 16 | 3 | 20 | 0.75 | 0.150 |
| **2** | 12 | 16 | 3.2 | 22 | 0.75 | 0.145 |
| **3** | 12 | 16 | 3.4 | 24 | 0.75 | 0.141 |
| **4** | 12 | 16 | 3.6 | 26 | 0.75 | 0.138 |
| **5** | 12 | 16 | 3.8 | 28 | 0.75 | 0.135 |
| **6** | 12 | 16 | 4.0 | 30 | 0.75 | 0.133 |

A closed piping system were built to conduct the tests on five tubes, the tubes have a fixed inner diameters a and b as shown in the previous figure 1. The working fluid (plain water) is pushed by the gear pump of type (ONDINA 100 M, 1 Hp, Ravel Hiteks Pvt. Ltd., India) to initiate the flow circulation as shown in figure 2. [14-18].

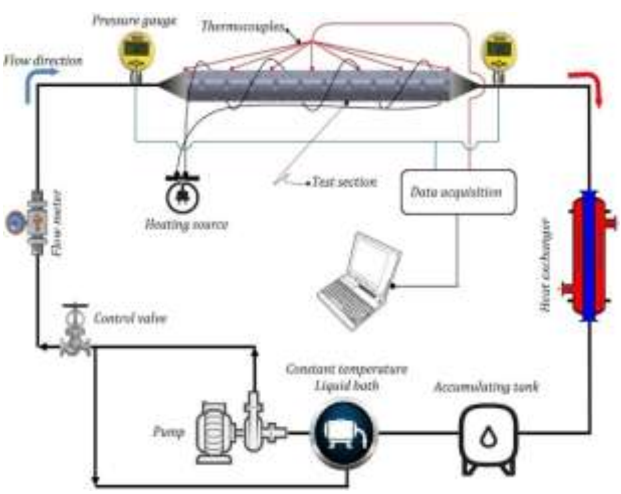


**Figure 2.** Experimental setup scheme.

The flow should remain in laminar conditions throughout the whole tests. A control valve was used to ensure the required amount flow rate which achieved the desired Reynold number according to the flow meter reading. The operating values of Reynold number were 200, 400. 600, 800, 1000. After each test, the valve is adjusted to a specific position in order to supply the exact flow rate which read by the flow meter (MT3809 Flow Meter, Brooks Instrument, USA). A one meter entrance extension was made to allow the fully development flow condition. Two gages (PX409-WWDIFF, Norwalk, Omega, USA ) were amounted on both tube entrance and exit to read the pressure difference. Ten J-type thermocouples were mounted on the test section of tube to read the temperature gradient along the flow direction. A constant heat flux was supplied by a standard wire gage SWG, which controllable by voltage regulator to deliver the required voltage. In order to minimize the heat loss, a ceramic fiber layer was wounded around the test section and this layer was fixed by an asbestos rope. Thereafter the working fluid endured heat removal process by heat exchanger and then accumulated in an accumulation tank. Eventually, the fluid settles in the constant temperature water bath.

DATA REDUCTION

The experiments are run at fixed Reynold number values; it could be calculated as follows.

$$Re_{nf} = \rho_{nf} u D / \mu_{nf} \quad (1)$$

Where, D represents the hydraulic diameter, and the cross-section area of the tube is calculated by the following formula.

$$A=\pi ab \quad (2)$$

The electric energy which heated the tube should be equal to the heat removed from the tube by the working fluid if the energy loss is negligible. Accordingly, the conductive energy must equal to convective energy as follows

$m\ C_p(T_o-T_i)=hA(T_{lw}-T_b)$ (3)

The character A holds for the surface area of tube. The inlet and outlet temperature of the fluid are $T_i$, and $T_o$. The character $T_b$ represents the bulk temperature of the tube at a certain axial location, While $T_{lw}$ holds for lower surface temperature of the tube. As it known, the upper surface temperature of tube $T_{up}$ is measured by thermocouple, while the lower tube surface temperature $T_{ls}$ is calculated by one direction conduction equation

$q=-k(T_{up}-T_{ls})$ (4)

The electrical power supplied is q, and calculated by the q=IV. Where, I and V hold for electrical current and voltage respectively. Nusselt number can be calculated as follow

$Nu = hD/k$ (5)

UNCERTAINTY

There is no experiment without errors whatever the taken precaution or the counter measure is because even if the process has zero errors, the inherent apparatus errors would be remains. That is why the effort is made not to get rid of errors, it made to reduce it as possible. A confidence level of 95% [19] is considered in the current study to calculate the important dependent variables as shown in the following equations.

$$\left(\frac{\delta h}{h}\right)=\sqrt{\left[\left(\frac{\delta U}{U}\right)^2+\left(\frac{\delta D}{D}\right)^2+\left(\frac{\delta T}{T}\right)^2\right]}=4.01\% \quad (6)$$

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$$\left(\frac{\delta Re}{Re}\right)=\sqrt{\left[\left(\frac{\delta U}{U}\right)^2+\left(\frac{\delta D}{D}\right)^2+\left(\frac{\delta \rho}{\rho}\right)^2+\left(\frac{\delta \mu}{\mu}\right)^2\right]}=3.84\% \quad (8)$$

The current experiments are conducted with a thorough procedure and a logical algorithm was followed, the apparatus and measuring devices uncertainties are listed in Table 2.

VALIDATION

Validation is the step which precedes all other procedures in the experimental work to ensure the correctness of the followed approaches and algorithms. It should be conducted prior to experience the core experimental process. Since the heat transfer is usually interprets by Nusselt number, hence the validation was conducted in term of Nusselt number for bot smooth and dimpled tubes as shown if figure 3.

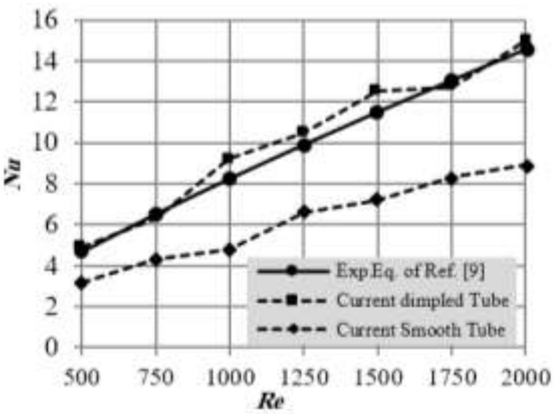


**Figure 3.** Validation of Nusselt number Nu of eq. (9) with the current dimpled and smooth tubes

The validation is done according the equation proposed by Li et al. [9] regarding almond dimpled tube as follows.

$Nu=0.033Re^{0.82}\ Pr^{0.4}$ (9)

Which is valid for $5.2 \le Pr \le 30.7$ and $500 \le Re \le 8000$

Where the Reynold number was set to be 500 to 200 according to the operational range of the comparable equation, and the heat flux was 8000 w/m2 to ensure an optimum match with the condition stated in reference (9). Moreover, the thermo physical properties were set to a specific values in order to get a constant Pr which had a value of 7. The above validation's deviation between equation (9) which correlated for almond shape dimple tube and current oval tube having oval dimple primarily came from the difference in tube and dimple shapes. Anyway, the maximum deviation between them is strictly fall within the range of ±5%, which is relatively satisfied.

RESULT

The experimental test carried out on six dimpled tubes having staggered arrangement, they have dimple width to length ratio w/l of 0.150, 0.145, 0.141, 0.138, 0.135 and 0.133 respectively. The cross-section dimensions of the tubes were held to be constant at a=12 mm and b=16 mm, while the staggered arrangement dimensions ratio x/y varied to fall in the range of 1, 1.1, 1.2, 1.3, 1.4 and 1.5. The boundary conditions of Reynold number 200, 400. 600, 800, 1000 and constant heat flux of 10000 w/m2 were applied. This study is strictly limited to heat transfer investigation without experiencing of pressure drop, and the outcomes are shown in figures below.

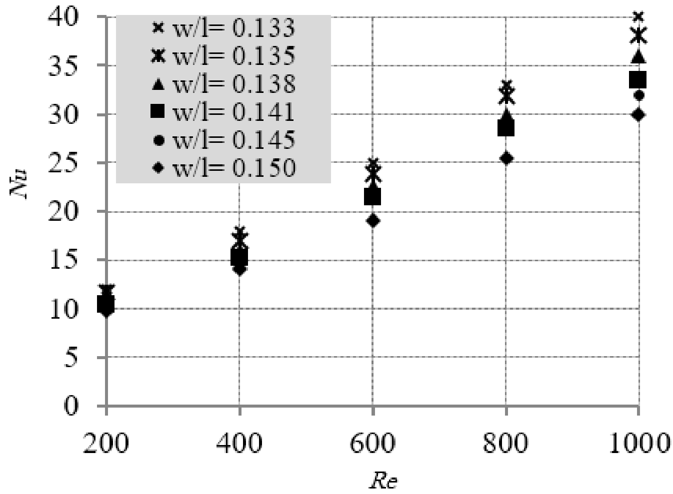


**Figure 4.** Nusselt number vs. Reynold number for various w/l ratios and at x/y=1

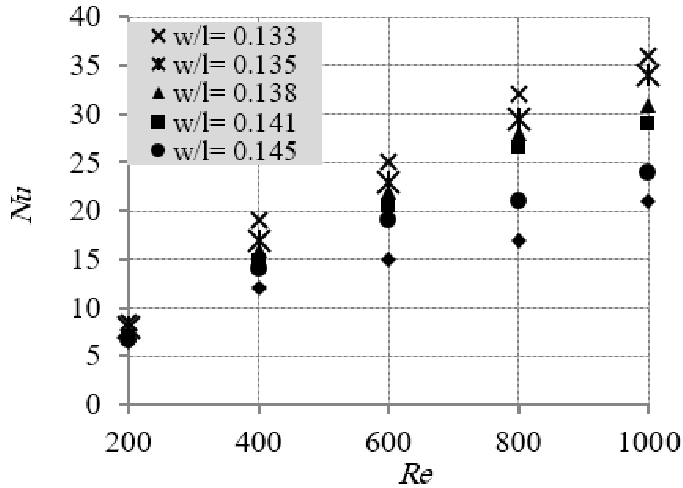


**Figure 5.** Nusselt number vs. Reynold number for various w/l ratios and at x/y=1.1

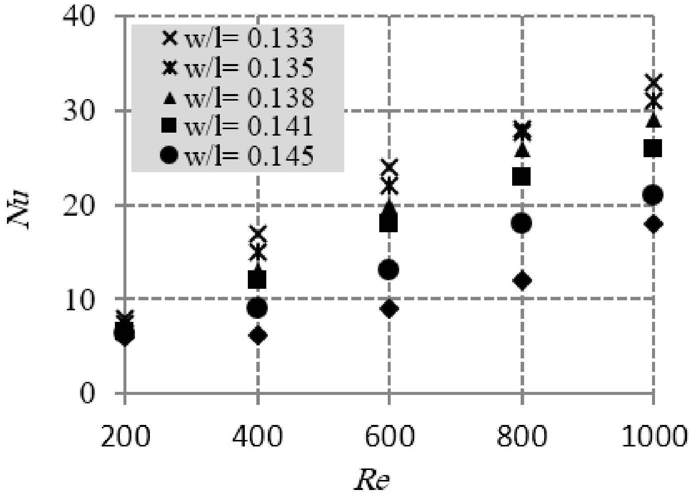


**Figure 6.** Nusselt number vs. Reynold number for various w/l ratios and at x/y=1.2

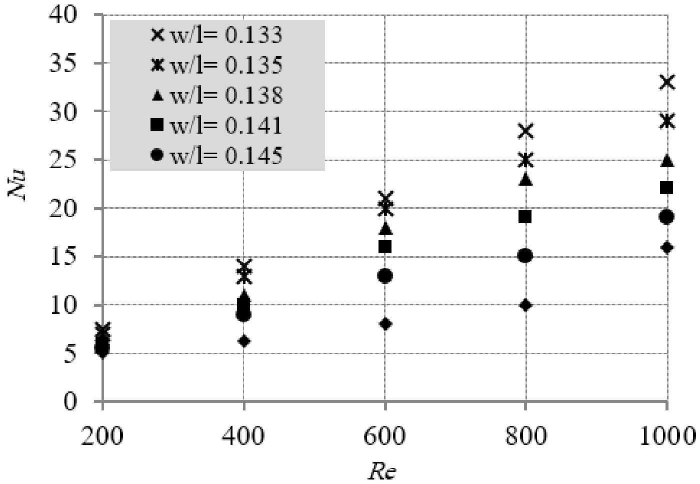


**Figure 7.** Nusselt number vs. Reynold number for various w/l ratios and at x/y=1.3

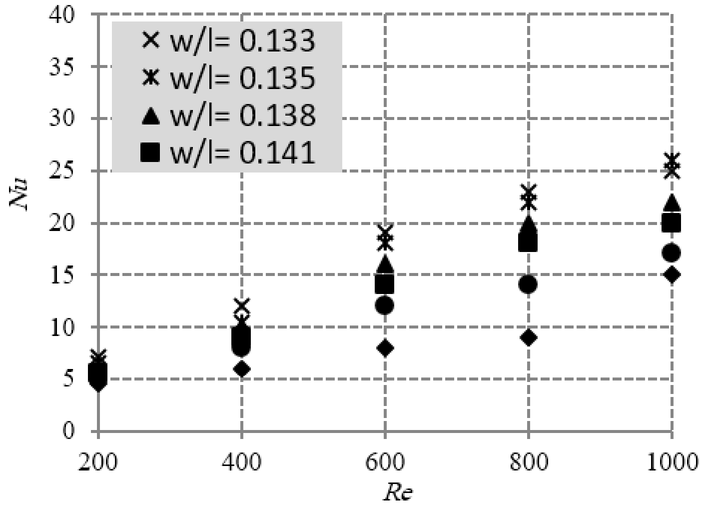


**Figure 8.** Nusselt number vs. Reynold number for various w/l ratios and at x/y=1.4

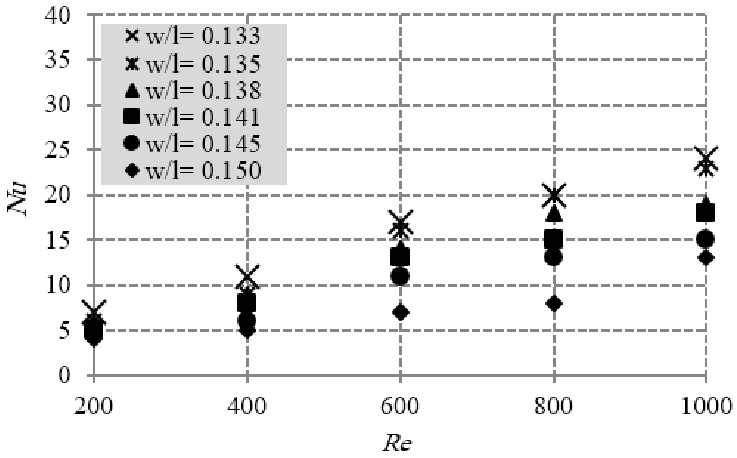


**Figure 9.** Nusselt number vs. Reynold number for various w/l ratios and at x/y=1.5

Figures 4-9 show the Nu relation with Re for dimple size ratio w/l (0.133, 0.135, 0.138, 0.141, 0.145 and 0.15) at x/y (1-1.5). These figures strongly indicates that the heat transfer is increase with both Reynold number increase and dimple width to length ratio w/l decrease. The interpretation of this behavior is that when w/l decrease the Nu increase due to the increase of the surface area of the wet perimeter. On the other hand, The Nusselt number decrease as the x/y ratio increase as a result of the decrease in dimple number due to the decrease in the overall wet surface area that marched by the working fluid. In general, any increase in the wet perimeter causes increase in the heat exchange rate, the major cause of using dimpled surface is to increase the wet surface area, and also the dimples act like a vortices promoter in the secondary flow region, the combined synergy between the extra wet surface area and vortices in the secondary flow region would definitely exhibit an enhancement in the heat exchange rate. The resulted outcomes confirmed this hypothesis. The above figures show a maximum Nusselt number of 39.8 at w/l of 0.133 and minimum Nusselt number was found to be 12.8 at w/l ratio of 0.15 To clarify how far this combination of oval tube with oval dimple is useful in heat transfer enhancement, a Nusselt number enhancement ratio is embraced as an index for this purpose, it could be computed as in the following equation.

$$Nu_d/Nu_s \quad (10)$$

Where $Nu_d$ represents Nusselt number of dimpled tube (in the presence of one or more enhancement technique) and $Nu_s$ represents plain tube (without presence of any enhancement technique). Figure 10 shows the effect of the current dimpled tube in heat transfer magnification in term of Nusselt number ratio.

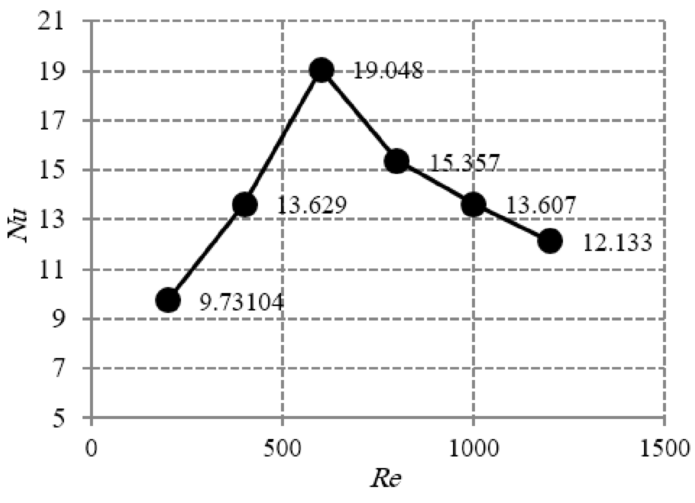


**Figure 10.** Nusselt enhancement ratio vs. Reynold number

The Nusselt number ratio increase with the increase of Reynold number until a certain value of x/y which is 1.2. Then the increase in Reynold number is no longer affect in Nusselt number enhancement due to the fact that the The Nusselt number ratio increase with the increase of Reynold number until a certain value of x/y which is 1.2. Then the increase in Reynold number is no longer affect in Nusselt number enhancement due to the fact that the increase of the surface area are desired but to a certain limit where the domination of wet perimeter would reverse the heat exchange process and the working fluid is already saturated with the gained heat.

In general, the overall maximum enhancement was found to be 19.048 at x/y=1.2 and the minimum enhancement was 9.731 at x/y=1.

## CONCLUSIONS

The current study conducted to reveal the effect of innovative passive heat transfer technique represented by an oval cross-section tube having oval dimpled surface with staggered arrangement. The experimental tests were set to be laminar flow at constant heat flux and the study limited to heat transfer

A validation was conducted prior to commence the tests. When the validation showed an acceptable deviation compared to analogous study, the experimental test were conducted. This new technique showed a good outcome in term of Nusselt number enhancement. Where it was found that the maximum Nusselt number of 39.8 at w/l of 0.133 and minimum Nusselt number was found to be 12.8 at w/l ratio of 0.15. Moreover, the overall maximum enhancement was found to be 19.048 at x/y=1.2 and the minimum enhancement was 9.731 at x/y=1.

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