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Investigate the Effect of the Metal Chain Insertion into the Heat Exchanger Tube on the Thermal Performance Factor

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Abstract: Increasing interest in the heat transfer enhancement but of its great importance in many different industrial applications. So, a CFD Model was used to simulate the heat transfer enhancement process in the circular tube with and without a metal chain insert turbulent flow conditions. And in this research, ANSYS Fluent Version 18.2 was used to demonstrate the effect of a metal chain turbulator on heat transfer and the properties of fluid friction in the heat exchanger pipe. The simulation was performed by inserting different metal chains into the tube. The metal chains used differ only in the length of the ring and five lengths of the ring were used P = 20, 40, 60, 80 and 100 mm. During the CFD simulation, the HFO was passed at 30°C during the controlled test tube under a constant temperature of the uniform wall. The Reynolds number was changed to five number from 2500-12,500. According to the results, the thermal enhancement factor (η) tends to lower with the increasing of Reynolds number for all cases depending on the Reynolds number Re and p-values. While the maximum η is about 2.4 is achieved with a metal chain at length of ring P = 60 mm compared to a plain tube and which is higher than other metal chains by 1.7-8.2%. In addition, the results also show that P = 20 mm give the highest rate of heat transfer accompanied by the highest pressure.

Key words: Insertion, thermal performance, heat exchanger, CFD Model, enhancement, industrial applications

INTRODUCTION

The improvement of thermal performance of lots heat exchanger system applied in many the industrial and engineering works is necessary to save the energy and decrease of operations cost. The methods of heat transfer augmentation usually applied in the heat exchanger system that increasing thermal performance. Generally, the turbulent or the "Turbulator" is one of the passive methods which are widely used to heat transfer improvement in form of swirl/vortex flow devices such as the fin, propeller, winglet, tribe, baffle and groove roughened surfaces (Yongsiri *et al*., 2014; Thianpong *et al*., 2009; Promvonge *et al*., 2011, 2012a, b; Skullong *et al*., 2014, 2016; Eiamsa-Ard *et al*., 2009). Many types of turbulator inserted in flow tube provides interruption of development the thermal boundary layer and increasing the heat transfer surfaces area with heat transfer enhancement through increase turbulence intensity or by quick fluid mixing. Therefore, more compact and economic, heat exchanger systems can be obtained with fewer operating costs. There are lots efforts have been made to test an application of different turbulators in order to improve the heat transfer in a heated tube in heat exchangers such as twisted tapes, corrugated, wire coils, grooved tubes, dimpled and compound turbulators (Promvonge, 2008a, b; Naphon, 2006; Bhuiya *et al*., 2013; Eiamsa-Ard *et al*., 2014; Wang *et al*., 2010; Garcia *et al*., 2012; Eiamsa-Ard and Promvonge, 2010).

In the tube inserts, Eiamsa-Ard *et al*. (2010) used twisted tape with coiled wire inserted together, the results showed that the combination of coiled wire and twisted tape gives larger heat transfer rate from a single use the coiled wire or twisted tape alone. Eiamsa-Ard and Promvonge (2010) and Plessis and Kroger (1987) studied the compained effects of conical-ring with that of twisted tape in circular tube for heat transfer enhancement. As I mentioned, use of the twisted tape with conical ring together provides average heat transfer rate of 10% higher than that of the conical ring only. Ozceyhan *et al*. (2008) studied the enhance the Nusselt number of pipe with a

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circular ring, they showed that maximum enhance was nearly 18% Which was obtained when Re = 600. Promvonge *et al*. (2015) studied the method of tends horseshoe baffles to increase the heat transfer in the circular tube, results showed was obtained the maximum thermal improvement factor of about 1.92 for horseshoe baffles at BR = 0.1 and PR= 0.5. While Herrmann *et al*. (2004) experimental study of a circular tube insert a twisted tape under the turbulent flow condition and isothermal wall. They conducted experiments on both water and ethylene glycol, also, use twisted tapes with ratios of 3, 4.5 and 6. They also improve generalized relationships to the Nusselt number and friction factor for conditions of transition and turbulent flow.

When taking into considering what has been discussed in the field of turbulator, it is possible to see a lot of studies for in order to investigate the effect of various types of turbulators at heat transfer of heat exchanger systems. This types of turbulators enhance heat transfer in the heat exchanger by creating swirl flows, also increasing the turbulence flow and distributing boundary layers. This study we aimed to present thermal performance enhancement in a heat exchanger by using new type from turbulators, they are the metal chains. So, different types of metal chain turbulators are used inside the heat exchanger pipe with the aim of enhancement of heat transfer in heat exchangers. Also, evaluate the quality of improvement concept of this method as thermal performance enhancement can be computed for various cases and compared with each other.

MATERIALS AND METHODS

Numerical modeling

Physical model: In this research, Numerical simulations were performed by using CFD Software package of ANSYS Fluent 18.2 which used finite volume method in order to solve governing equations in 3 dimensional. Single phase conversion heat transfer model was established and investigated from the tube of heat exchanger equipped by as shown in Fig. 1. The length of heat exchanger pipe is equal 2000 mm. The inner diameter of 22 mm and the outer diameter of 26 mm. The Heavy Fuel Oil (HFO) flows in the inner tube. Different metallic chains are inserted into the inner tube to study their effect on heat transfer. We will use five shapes of the metal chain, different in the length of the rings is P = 20, 40, 60, 80 and 100 mm, the outer diameter of the metal chain is W = 20 mm, t = 4 mm and the total length is L = 2000 mm. as shown the diagram shape with metal chain in Fig. 2.

Boundary conditions: The boundary conditions to the problem for pipe fitted with a metal chain. Pipe wall is subjected to constant temperature value 150°C, the sides of the pipe are also exposed to velocity inlet and the other side subjected to pressure outlet. The Reynolds numbers used was changed to five numbers from (2500-12,500), on the thermal and flow fields. Also, the outlet relative pressure in the tube was set equal to zero. At all the solid surfaces, the non-slip condition was decreed. Figure 3 showed boundary conditions for a geometric shape.

Governing equations: In relation to the derivation of the governing equations such as continuity, momentum and energy, the HFO did supposed to be a Newtonian and incompressible fluid. While an effect of gravity negligible. Those Eq. 1-3 can formulate as follows (Mashoofi *et al*., 2017): The continuity equation:

$$\frac{\partial}{\partial x_j}(\rho u_i) = 0 \tag{1}$$

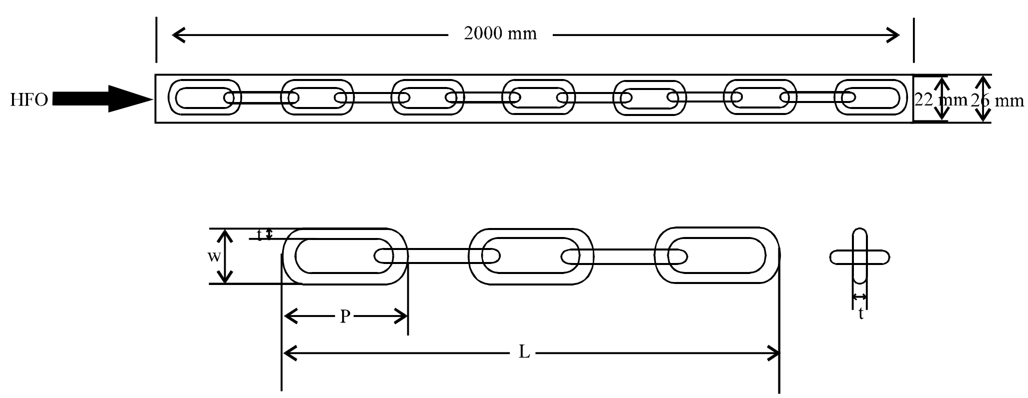

Fig. 1: Schematic diagram of a pipe fitted witha metal chain

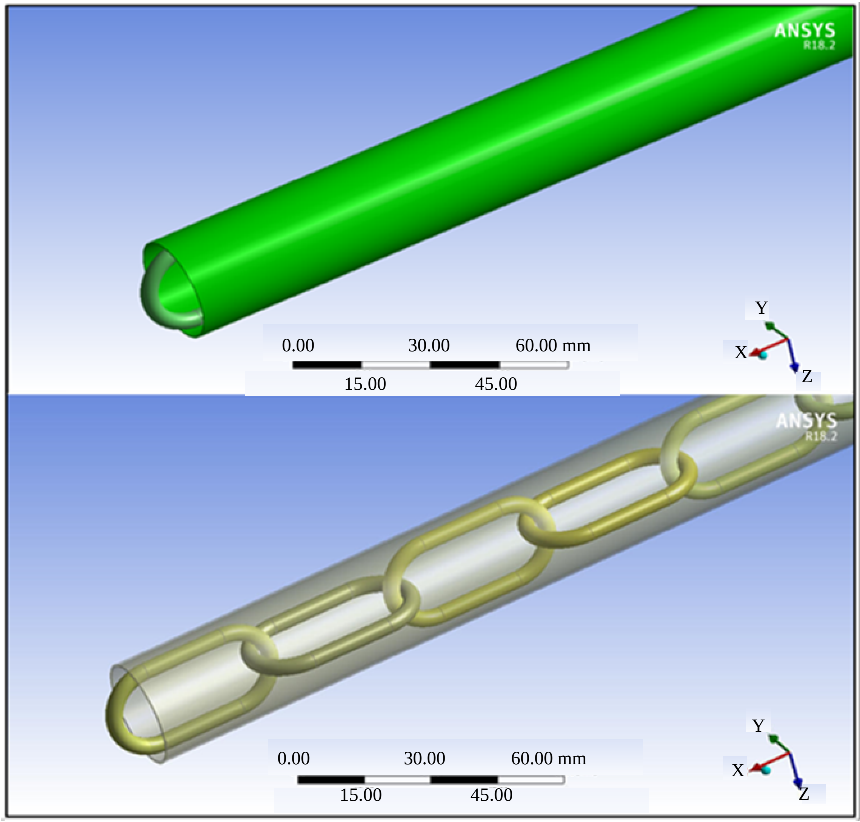

Fig. 2: The geometry shape with metal chain and without metal chain

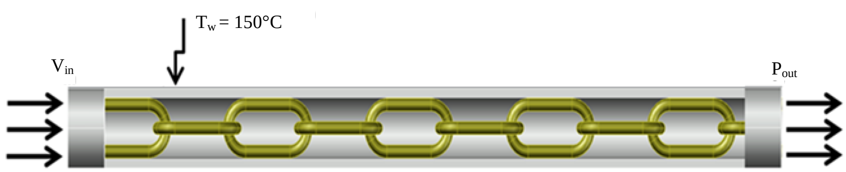

Fig. 3: The boundary conditions for geometric shape

The momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_j} = \frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] - \frac{2}{3}\mu\frac{\partial u_k}{\partial x_k}\delta_{ij} \quad (2)$$

The energy equation:

$$\frac{\partial}{\partial x_i}\left(\rho u_j C_p T - k\frac{\partial T}{\partial x_j}\right) = u_j\frac{\partial \rho}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] - \frac{2}{3}\mu\frac{\partial u_k}{\partial x_k}\delta_{ij} \quad (3)$$

Where:

k = Kinetic energy
μ = Viscosity
C_p = Specific heat on constant pressure

Renormalizing (RNG) k-ε turbulence was used in order to model a turbulence flow system with improvement wall functions were used as the wall treatment. Those Eq. 4 and 5 can formulate as follows (Yang *et al*., 2016; Ghadirijafarbeigloo *et al*., 2014):

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[(\alpha_k \mu_{eff})\frac{\partial k}{\partial x_j}\right] + G_k - \rho\varepsilon \quad (4)$$

$$\frac{\partial}{(\partial x_i)(\rho \varepsilon u_i)} = \frac{\partial}{\partial x_j}\left[(\alpha_s \mu_{eff})\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1s}\frac{\varepsilon}{k}G_k C_{2s}\rho\frac{\varepsilon^2}{k} \quad (5)$$

Where:

ε = The rate of turbulent dissipation
μ_{eff} = The effective
μ_t = The turbulent viscosity

Which can expressed as Eq. 6 while the constants at model are $C_{1\varepsilon} = 1.42, C_{2\varepsilon} = 1.68$ and $\alpha_k = \alpha_\varepsilon = 1.393$. when the Gk describes the turbulent kinetic energy generated that is consequent of mean velocity gradient.

$$\mu_{eff} = \mu_i + \mu_x \mu_i = \rho C_\mu \frac{k^2}{\varepsilon} \quad (6)$$

Finite volume procedure was used in order to numerical solving of governing equation above. The simple algorithm did adopt to handle a relation between pressure and velocity with momentum, turbulence and energy parameters did resolve by applying second-order.

Data processing: The purpose of the current search is to enhance heat transfer rate in a tube fitted with a metal chain. Parameters of interest are the Reynolds number (Re), friction factor (f) and thermal performance enhancement factor (η), it can be obtained from following Eq. 7-12 (Arsha *et al.*, 2013). Heat flux is given by the equation:

$$q = \frac{Q}{A} \quad (7)$$

where, getting the area A by:

$$A = \pi D_h L \quad (8)$$

where, that hydraulic diameter D_h = D. Getting the convective heat transfer coefficient by:

$$h = \frac{Q}{A(T_w - T_b)} \quad (9)$$

where, T_w average temperature for pipe wall and T_b bulk temperature:

$$T_b = \frac{T_i + T_o}{2} \quad (10)$$

Nusselts number can be obtained by:

$$N_U = \frac{hD}{K} \quad (11)$$

Friction factor can compute by the equation as follow:

$$f = \frac{\Delta P}{2(\frac{L}{D})\rho v^2)} \quad (12)$$

The objective of this research is to present thermal performance enhancement factor (η) in heat exchanger by using new type of turbulator as metal chain. So, to evaluate an improvement quality theory, thermal performance can be computed in various cases by various metal chain then compared with each other. It is written as follows (Pourahma and Pesteei, 2016):

$$\eta = \frac{\left(\frac{Nu}{Nu_0}\right)}{\left(\frac{f}{f_0}\right)^{\frac{1}{3}}} \quad (13)$$

RESULTS AND DISCUSSION

Validation and independence of grid density: In order that check an independence numerical results of the density of the grid, four groups of the grid numbers have been verified. And which contain 2-5 million cells. Results revealed that the cell of 4 million has 1.2% error with 5 million cell. So, to maintain the balanced between the time of solve and results accuracy, a grid number used on computational domain was chosen 4 million. Figure 4 showed a mesh in the geometry shape. The results the Nusselt number and friction factor obtained from the experimental data reported by Choudhari and Taji (2013) is verified present plain tube compared with numerical simulation with same parameters and those from the proposed correlation by Dittus-Boelter for a Nusselt number and proposed correlation by Blausius for friction factor:

$$Nu = 0.023\, Re^{0.8}\, Pr^{0.4} \quad (14)$$

Figure 5 and 6 showed the comparison the Nusselt number Nu and friction factor f to the plain tube resulting of this research with the of proposed correlation. Results obtained from plain tube experiments are acceptable with the results of the proposed correlation with variance ±3.2% and ±4.5% the Nusselt number and friction factor, respectively.

Effect of inserting the metal chain on heat transfer: Figure 7 showed the difference of Nusselt number with Reynolds number of a tube fitted with a metal chain in different shapes at P = 20, 40, 60, 80 and 100 mm. From the figure, it can see that the Nusselt number for a pipe

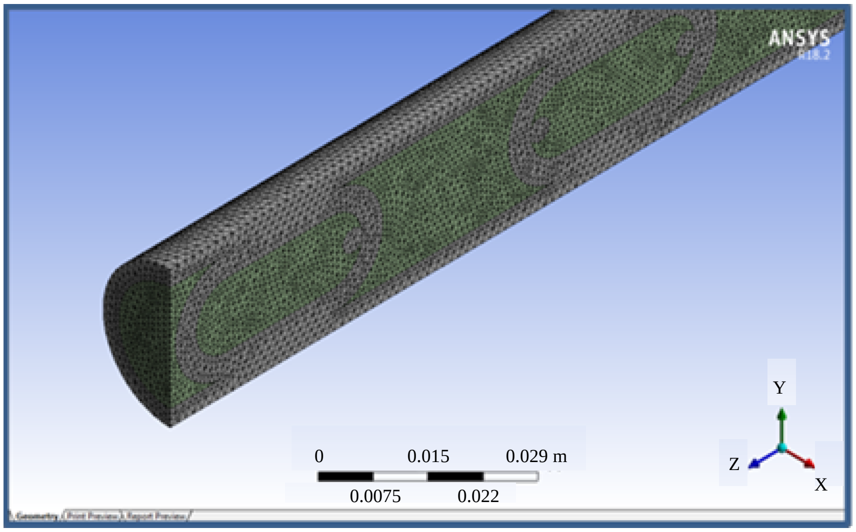

Fig. 4: The mesh in the geometry shape

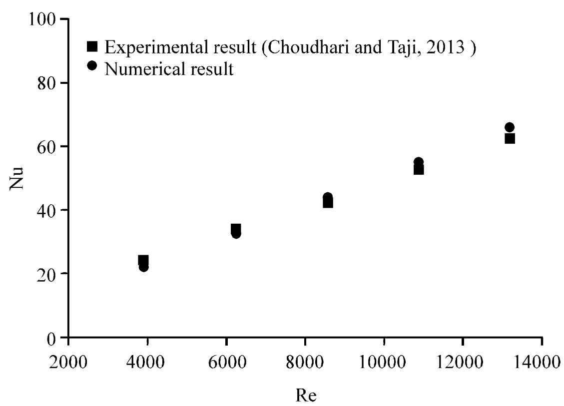

Fig. 5: Compared Nusselt number with a plain tube

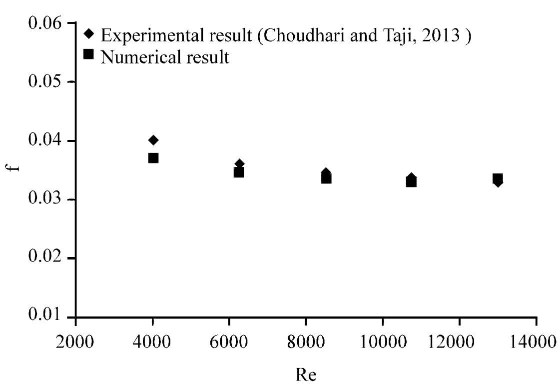

Fig. 6: Compared friction factor with a plain tube

with metal chain is higher than the pipe without metal chain, this because metal chain insert interrupt the development of the boundary layer of the fluid flow near a shell the test section, so, it augment fluid temperature

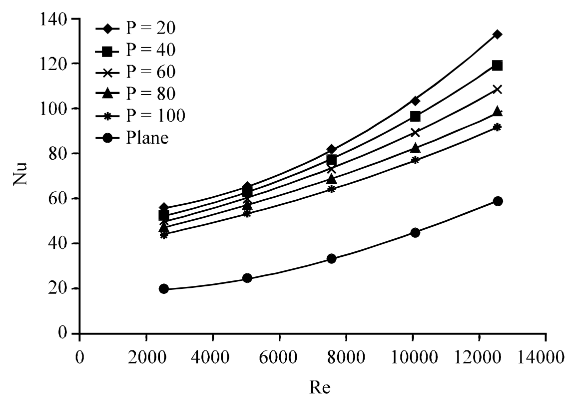

Fig.7: Comparison of Nu with Re with various metal chain inserts

and heat transfer rate in radial directions because of larger contact surface area. Too, it creates turbulence with swirl motion from HFO when it's flowing in a test section. The circulation creates the flow of high turbulent which leading the enhanced heat transfer convection.

When Reynolds number increases with metal chain inserts, the Nusselt number is also increasing, these results indicate an improvement in heat transfer. The results also showed that the Nusselt number the highest level at P = 20 mm compared to the other values, P = (40, 60, 80, 100 mm. While the metal chain at P = 20 mm causes the heat transfer to be further improved by 1.78 whereas in P = 40, 60, 80 and 100 mm, the heat transfer rate is improved to 1.62, 1.54,1.41 and 1.35%, respectively.

Effect of inserting the metal chain on heat transfer ratio: Heat transfer ratio (Nu_a/Nu_o) is the ratio of the Nusselt

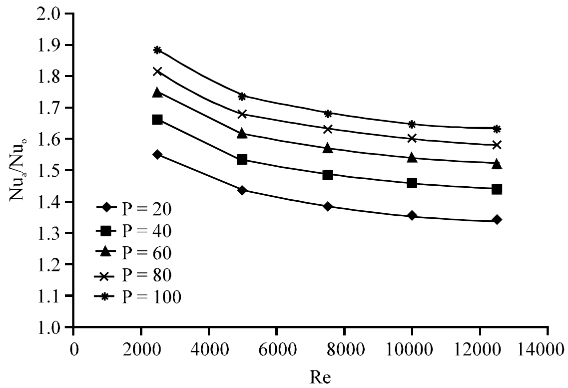

Fig. 8: Comparison of Nu_a/Nu_0 with Re with various metal chain inserts

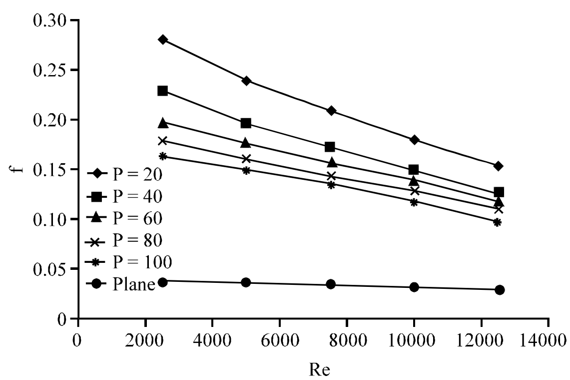

Fig. 9: Comparison of fwith Re with various metal chain inserts

number obtained from the tube with the insertion of metal chains to the plain tube. Figure 8 showed heat transfer ratio. In order to achieve energy gain from using the metal chain and to transfer the heat better, the heat transfer ratio should be greater than one. It can be observed from the figure that the increase of heat transfer when using metal chains is great and superbly. The value of Nusselt number ratio tends for decrease by increasing the Reynolds number of 2,500-12,500 for all cases. The highest heat transfer ratio at type P = 20 mm is higher than the rest of the species P = (40, 60, 80, 100) mm. The P = 20 mm in the metal chain has (Nu_a/Nu_0) ratio of 2.53-3.68, P = 40 mm has 2.35-3.53, P = 60 mm has 2.2-3.36, P = 80 mm has 2.0-3.1 and P = 100 mm has 1.95-2.83.

Effect of inserting the metal chain on friction factor: In general, the friction factor of the fluid decreases by increasing the Reynolds number and for all types of metal chains. It can see from Fig. 9, the friction factor of the tube fitted with the metal chain is above than the plane tube for same Reynolds number. The result indicates that the

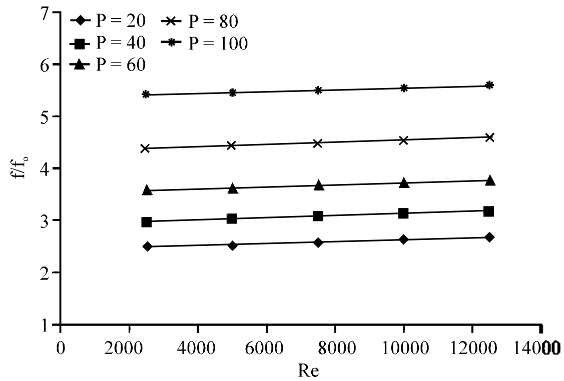

Fig. 10: Comparison of f/f_0 with Re with various metal chain insert

friction factor increases with decreasing the length of a ring (P) because of the swirl flow generated of metal chain insertions which is up a maximum at P = 20 mm. While it is clear from a figure the friction factor to a length of a ring P = 100 mm is less as compared to a length of the ring P = 20 mm. This is because to the lower contact surface from the turbulator where there is more area in HFO for flow in a test section. A friction factor obtained from the metal chain at the length of the ring P = 20 mm has increased 7.3 times from plane tube. And at P = 40 mm the friction factor has increased 6.2 times to plane tube, also P = 60 mm the friction factor has increased 5.4 times plane tube where P = 80 mm the friction factor has increased 4.2 times to the plane tube, P = 100 mm the friction factor has increased 3.8 times of plane tube.

Effect of inserting the metal chain on friction factor ratio: It is clear in Fig. 10 that the f/f_0 friction ratio of the tube inserted in a metal chain tends to increase significantly while reducing the value of P and Re. Where that highest f/f_0 friction ratio for the tube inserted in a metal chain at P = 20 mm compared to the other shapes. This is because the type of metal chain P = 20 mm leads to increased flow resistance where the larger surface is caused by the stronger vortex flow, resulting in a significant increase in pressure drop.

Effect of inserting the metal chain on thermal performance: Depicts Fig. 11 the thermal enhancement factor (η) with Re for the metal chain with varying the length of the ring P. In the figure, the Nusselt number ratio and friction factor ratio values for a tube inserted metal chain and plain tube are compared at the same Reynolds number. It could be seen the thermal enhancement factor (η) tends to lower with the increasing of Reynolds number for all cases is about 1.6-2.4 depending on the Reynolds

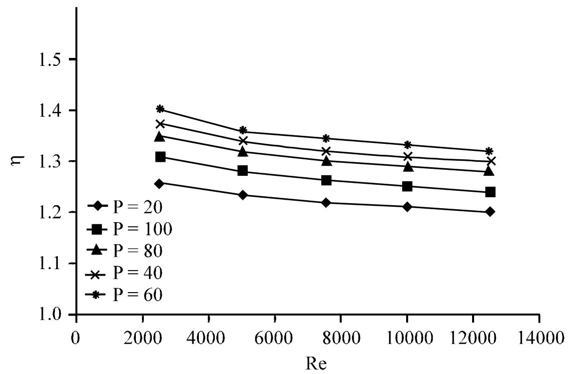

Fig. 11: Comparison of η with reformetal chain

number Re and P values. While the maximum η is about 2.4 is achieved with a metal chain at length of ring P = 60 mm which is higher than other metal chains by 1.7-8.2%.

CONCLUSION

Numerical studies of the thermal enhancement factor (η) characteristics of a heat exchanger pipe fitted with metal chain of different five shapes where that the difference shapes in the length of the ring for the chain which that P = 20, 40, 60, 80 and 100 mm. The Reynolds number was used in the investigation ranging from 2,500-12,500 and the conclusions were as follows:

The numerical data were compared with the experimental data obtained from Ozceyhan *et al.* (2008) on the plane tube. And the data obtained were in good accordance with numerical correlation with some discrepancy ±3.2 and ±4.5% for the Nusselt number and friction factor, respectively.

The results Indicate that P = 20mm gave a higher the Nusselt number compared with other shapes at P = 40, 60, 80 and 100 mm. Whereas heat transfer enhancement up to 1.78, 1.62, 1.54,1.41 and 1.35%, respectively when compared to a plane tube.

The friction factor increases when the length of the ring to the chain is less. Where the highest type P = 20 mm compared to P = 40, 60, 80, 100 mm.

Also, the results above indicate that the length of the ring at metal chain P = 60 mm gave the best results in heat transfer enhancement compared to other types and so can be used in the manufacture of metal chain used to optimize the heat exchangers.

This research also indicates that the metal chain inserts in heat exchanger pipe give good enhance for heat transfer with pressure drop.

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