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Numerical investigation of heat transfer enhancement in a pipe heat exchanger by adding nano particle and twisted tape

Ali Marzban[1,2], Ghanbar Ali Sheikhzadeh[2], Hamid Hasanzadeh[3] and Ahmad Ali Rabienataj[4]

1,* - Department of Mechanical Engineering, Islamic Azad University Aligudarz Branch, Aligudarz, Islamic Republic of Iran.
2- Department of Mechanical Engineering, University of Kashan, Kashan, Iran
3- Department of Mechanical Engineering, Babol University of Technology, Babol, Islamic Republic of Iran
4- Department of Mechanical Engineering, University of Mazandaran, Babolsar, Islamic Republic of Iran

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ABSTRACT

In present study, the effect of adding twisted tape and Nano particles are investigated in a pipe heat exchanger. The Reynolds number, Nano particle volume fraction and tape width ratio changes between 500 to 1700, 0.01 to 0.03 and 0.5 to 0.8 respectively. The present results show good agreement with a published results. Results show that heat transfer increases by width ratio and Nano particle concentration. The increment ratio is approximately constant for each Reynolds number but the ratio raises by increasing the width ratio.
KEYWORDS: Heat Transfer, Nusselt Number, Nano-Fluid, Twisted Tape, Heat Exchanger,

1. INTRODUCTION

Twisted tapes, as one of the passive heat transfer enhancement technology, have been extensively studied due to their advantages of steady performance, simple configuration and ease of installation. By generating swirls which enhance the fluid mixing of the near-wall and central regions, the heat transfer in tubes with twisted tapes could be enhanced [1-3]. Moreover, the twisted tape can partition and block the flow, reduce the hydraulic diameter, elongate the twisted flow path and generate afin effect[1,2]. All these lead to additional heat transfer improvements. However, the thermal improvements are accompanied by increased pressure drop.

How to optimize the thermo hydraulic performance of tubes fitted with twisted tapes has gained increasing attention [4-21]. For instance, Saha et al.[4] experimentally studied the heat transfer and pressure drop characteristics of laminar flow in a circular tube fitted with regularly spaced twisted tape elements connected with rod. The results showed that the pressure drop of the tube fitted with the segmented twisted tape elements is 40% smaller than that of the tube fitted with a continuous twisted tape, and the former has a better thermo hydraulic performance. Eiamsa-ard et al. [5] experimentally investigated the convective heat transfer behaviors in a circular tube fitted with regularly spaced twisted tape elements in laminar and turbulent flows, and they found that the heat transfer coefficient and friction factor were both significantly reduced as compared with those of the tube fitted with a continuous twisted tape. Later, Saha et al.[6] further investigated the effects of the width of tape elements and the diameter of connecting rod on heat transfer and pressure drop characteristics. This work indicated that a narrower width of tape elements led to a worse thermohydraulic performance, while a thinner connecting rod resulted in a better one. Therefore, he proposed to abolish the connecting rod and 'pinch' the tube to fix the segmented twisted tape elements. Jaisankar et al. [7] studied the heat transfer and friction factor characteristics of thermo syphon solar water heater system using full-length twisted tape, and short-length twisted tapes with and without connecting rod. In their experiment the segmented twisted tape elements with several twist cycles were used, while in Saha and Eiamsa-ard's investigations the segmented twisted tape elements only have half twist cycle. Jaisankar et al. found that whether it is fitted with rod or not, the heat transfer coefficient and friction factor for the segmented twisted tape elements were both much smaller than those for the full-length twisted tape. Moreover, the overall performance for the segmented twisted tape elements connected with rod was better than that for the elements without rod. Other researchers investigated the convective heat transfer behaviors in tubes fitted with short-width twisted tapes. In these cases, there is a gap between the twisted tape edge and tube wall, which might lead to a reduction in the flow resistance. For example, Ayub and Al-Fahed [8] experimentally investigated the effect of gap width on the pressure drop in turbulent flow. The results showed that increasing the gap width could effectively reduce the friction factor. Eiamsa-ard et al. [9] numerically studied the swirling flow and convective heat transfer in a circular tube fitted with loose-fit twisted tapes. They found that it was beneficial to reduce the pressure drop by reducing the width of twisted tape. However, the heat transfer coefficient and overall performance were also weakened. Later, Liu et al. [10] conducted a numerical investigation on heat transfer behaviors of laminar and turbulent flows in a circular tube fitted with short-width twisted tapes. Their results of laminar flow also showed a worse overall performance of this method. Recently, some new types of twisted tapes were developed by some investigators[11-16]. Chang et al. [11] designed a serrated twisted tape

Corresponding author: Ali Marzban, Department of Mechanical Engineering, Islamic Azad University Aligudarz Branch, Aligudarz, Islamic Republic of Iran. E-mail: Marzban.eng@gmail.com

with square-sectioned serrations on each side. Their investigation showed that the heat transfer enhancement attributed to the serrated twisted tape is about 1.25e1.67 times that of the tube fitted with smooth twisted tape in a Re range of 5000-25,000. Different from Chang et al.'s work [11], Eiamsa-ard and Promvonge [12] developed a twisted tape with serrated edges. Their experiment demonstrated that the heat transfer rate and thermal performance factor in the tube with this type of twisted tape insert were about 1.04-1.27 and 1.02-1.12 times those in the tube with smooth twisted tape insert, respectively. Later, Rahimia et al.[13] studied the heat transfer and friction factor characteristics of the tube fitted with perforated, notched and jagged twisted tapes. The results revealed that only the jagged insert was better than the conventional twisted tape in the heat transfer coefficient and thermal performance factor. More recently, Chang et al.[14] invented a broken twisted tape insert which can induce a better fluid mixing. They reported that, as compared with those of the tube fitted with smooth twisted tape, the heat transfer coefficient, mean Fanning friction factor and thermal performance factor of the tube fitted with broken twisted tape were augmented up to 1.28-2.4, 2.0-4.7and 0.99-1.8 times, respectively, in a Re range of 1000-40000. Sivashan mugam and Suresh [15,16] proposed a helical screw tape which made the swirl flow rotate in only a single way smooth direction. Their experimental results indicated that the helical screw tape had better thermo hydraulic performances as compared with the conventional twisted tape for both laminar and turbulent flows. The compound heat transfer enhancement technologies have broadened the ability of twisted tapes[17-22]. Ray and Date [17-18] numerically investigated the convective heat transfer behaviors in square duct with twisted tape insert. In square ducts, the twisted tape contacts with and away from the wall periodically. This structure creates periodical bursting swirls in the gaps which alter the fluid structure near the wall. Therefore, it ensures the effectiveness of the twisted tape under larger Re conditions as compared with circular tubes. Zimparov [19, 20] experimentally studied the heat transfer and friction factor characteristics of the three-start and single-start spirally corrugated tubes with twisted tape insert. He found that these methods could achieve higher heat transfer coefficient and thermo hydraulic performance than the smooth tubes with twisted tape insert. Promvonge and Eiamsa-ard [21] investigated the heat transfer behaviors in a tube with combined conical-ring and twisted tape inserts. Their work verified that this compound technique had better performance than using conical-ring only. Liao et al.[22] studied the heat transfer and friction factor characteristics in tubes with three-dimensional internal extended surfaces and twisted tape inserts. The experimental results showed that this method was of particular advantage to enhance the convective heat transfer for laminar tube side flow of highly viscous fluid.

In the present study the effect of tape width and nano particle concentration are investigated on the heat transfer characteristics in a pipe heat exchanger.

2. physical model and mesh structure

The geometries of a twisted tape in a tube are depicted in Fig. 1.

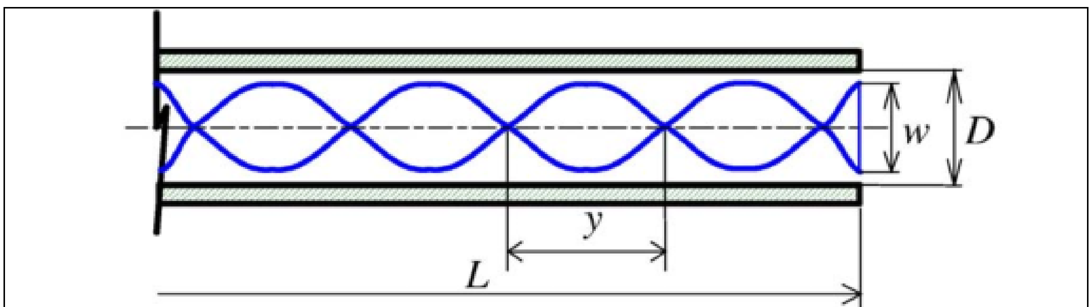

Fig 1. The enhanced tube fitted with twisted tapes.

Twisted tapes with thickness (d) of 0.002 m are fitted in the full length of all tubes. The diameter (D) and length (L) of the tube are 0.02 m and 0.5 m, respectively. The 180 deg twist pitch (H) is 0.05 m and thus the relative twisted ratio (H/D) is 2.5. The effects of the tape width ratio (W/D) and nanofluid on the heat transfer characteristics will be investigated. The Reynolds number (Re), Nusselt number (Nu) are defined as follows:

$$Re = \frac{\rho u D}{\mu} \quad (1)$$

$$Nu = \frac{hD}{k} \quad (2)$$

2.1. Assumption

The nano fluid is a homogenous material and is in thermo dynamic equilibrium. The geometry is 3D and the constant heat flux is used as thermal boundary condition at tube surface. The flow is assumed to be laminar in the studied range. The velocity inlet and pressure outlet are used as boundary condition for inlet and outlet boundary respectively. No slip boundary condition is assumed for both of the tube and twist walls. The governing equation is conventional navier-stokes equation which is not presented here.

2.2. Thermo phsical properties of nano fluid

In the present study, the Alumina is used to enhance the thermal conductivity of water. The conventional relation for density and specific heat are as follow:

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np} \quad (3)$$

$$\left(c_p\right)_{nf} = (1-\varphi)\left(c_p\right)_{nf} + \varphi.\left(c_p\right)_{nf} \quad (4)$$

In recent two equations, Cp stands for specific heat, φ stands for nano particle volume fraction and the indices of p and f stand for particle and base fluid respectively.

The effective viscosity and thermal conductivity are presented as follow respectively [22]:

$$\mu_{nf} = \mu_f / (1-\varphi)^{2.5} \quad (5)$$

$$\frac{k_{eff}}{k_f} = \frac{k_p + 2k_f + 2\varphi(k_p - k_f)}{k_p + 2k_f - \varphi(k_p - k_f)} \quad (6)$$

2.3. Geometry and mesh production

The geometry and correspond mesh are produced in Gambit V.2.4.6 as a preprocessing software for Fluent 6.3.26. the tetrahedral structure is used for meshing the volume. As indicated in fig. 2, the mesh has higher concentration near tube and tape walls.

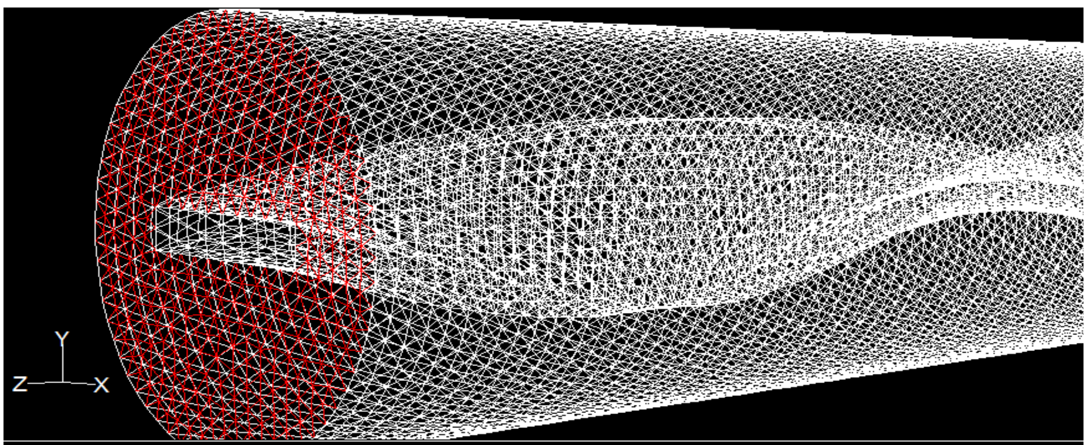

Fig. 2. The produce mesh for near the inlet section of tube

The Fluent V.6.3.26 is used to solve the governing PDE equations set. The standard scheme is used for pressure discretization and other equation is discretized by second order upwind scheme.

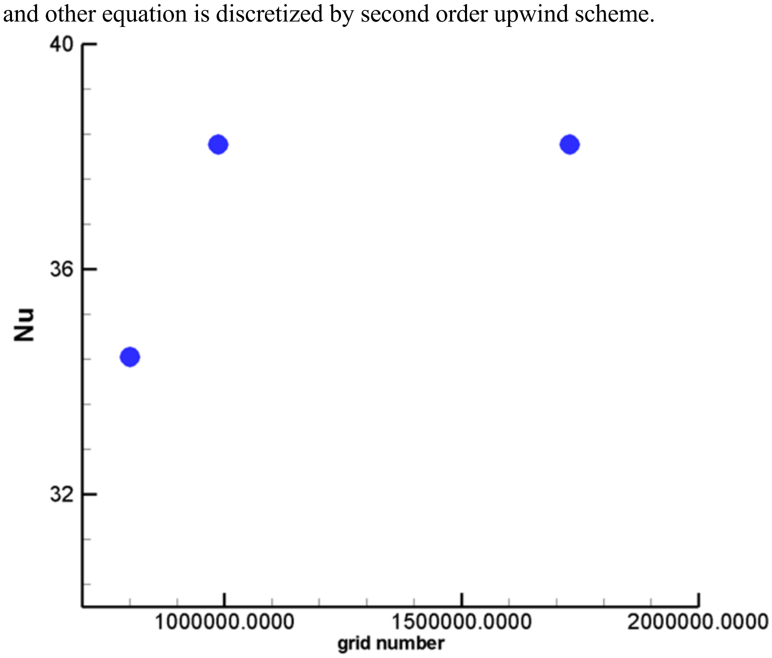

Fig. 3. Mesh study for the case with width ratio of 0.75 and Reynolds number of 1400.

3. mesh study and validation

The case with width ratio of 0.75 and Reynolds number of 1400 is selected to test the mesh independency. The Nusselt number does not significant change when the grid number increment from 977000 to 1720000. The results of Guo et al [23] are selected for validation in the case with pure water. Fig. 4 shows that present study is in good agreement with the selected ref [23].

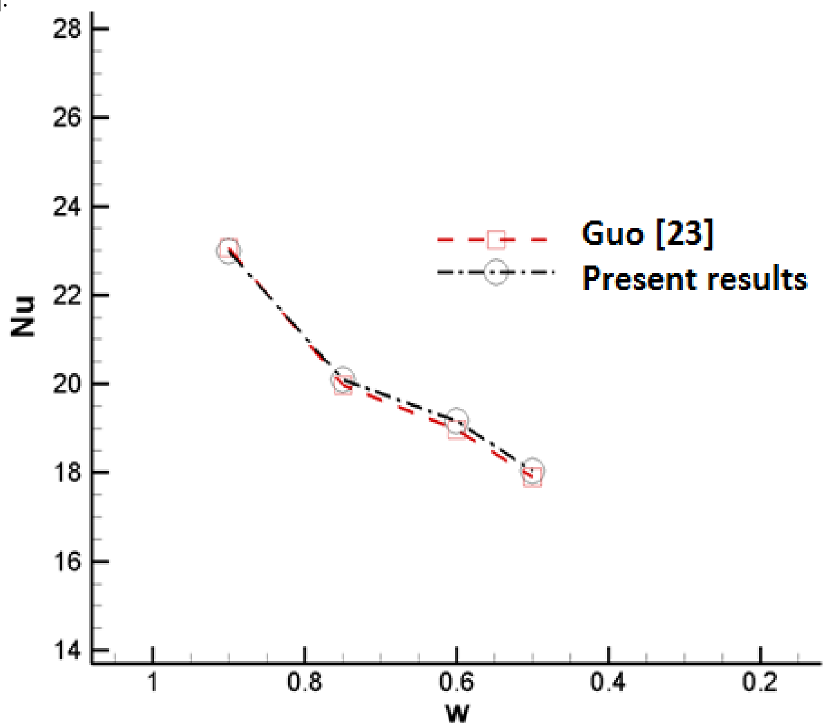

Fig. 4. Validation of Nusselt number with result of the Guo et al [23]

4. Results and discussion

Fig. 5 and Fig. 6 show the temperature contours in various section in the tube for width ratio of 0.5 and Reynolds number of 500. Heat transfer to the layers with smaller radius are observed clearly.

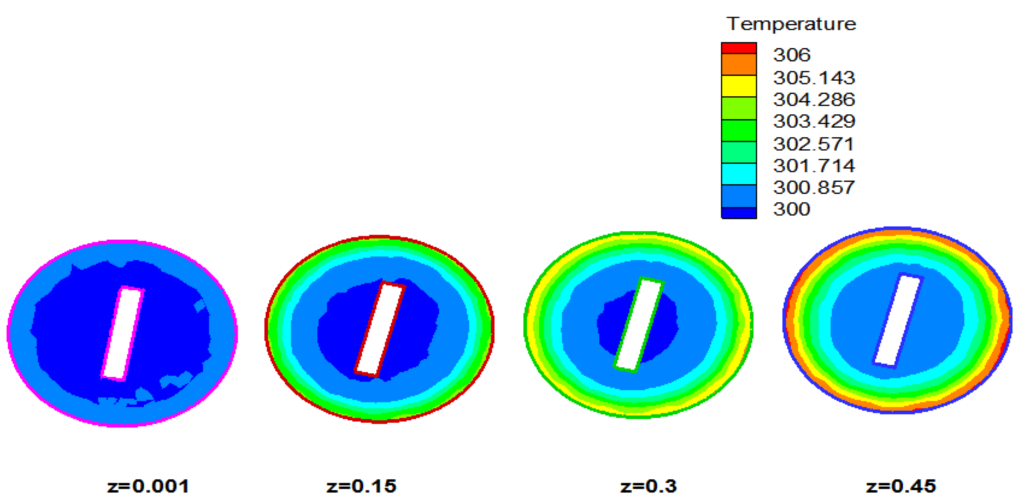

Fig 5. Temperature contours for Re=500 and width ratio of 0.5 in different section of tube

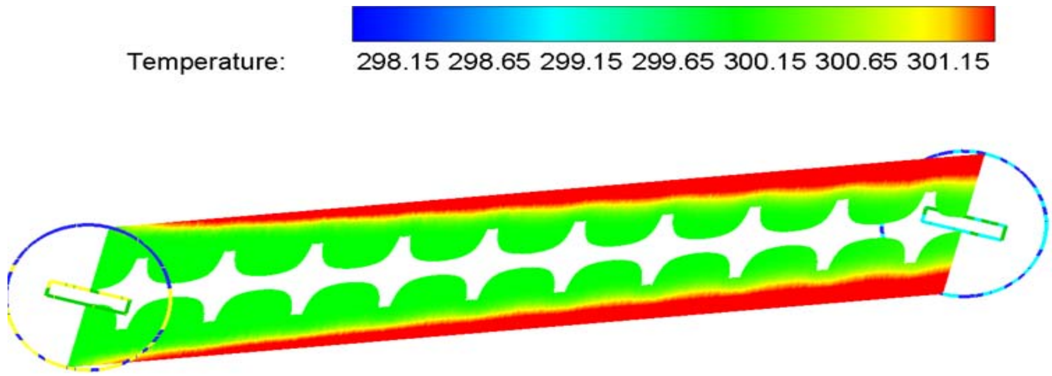

Fig. 6. The temperature contour in a longitudinal section in the tube for Re=500 and width ratio of 0.5

Figure 7 shows the effect of width ratio on the temperature distribution in a cross section which is in the middle section of tube at Reynolds number of 500. It is clear from figure 6 that the increment of width ratio from 0.75 to 0.9 has a great effect on the temperature distribution. As it is predictable this should be yields to higher nusselt number in this range of width ratio.

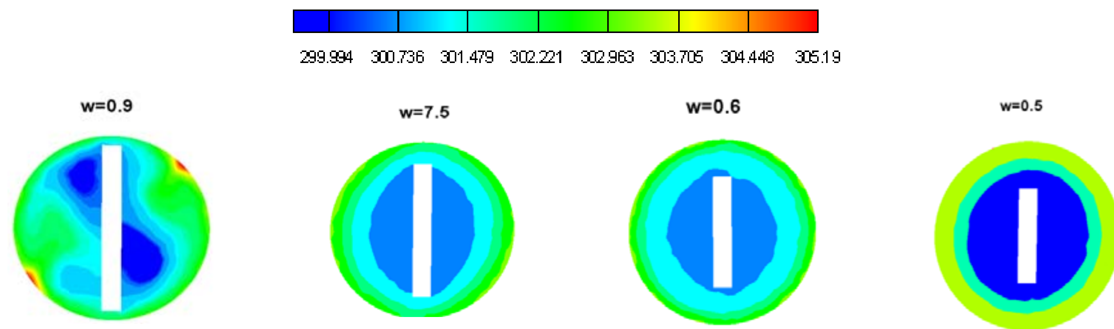

Fig. 7. Temperature contour in the middle cross section of tube at Re=500.

Figure 8 shows the effect of width ratio on nusselt number at different Reynolds number. It is clearly observable that more nusselt numbers are achieved for higher Reynolds number at constant width ration. The nusselt number in addition experiences more value for higher width ratio at constant Reynolds number. Finally it should be indicated that the rate of nusselt increment augments by width ratio. The nusselt number increases specifically when width ratio changes from 0.75 to 0.9. it is due to the effect of tape and tube proximity.

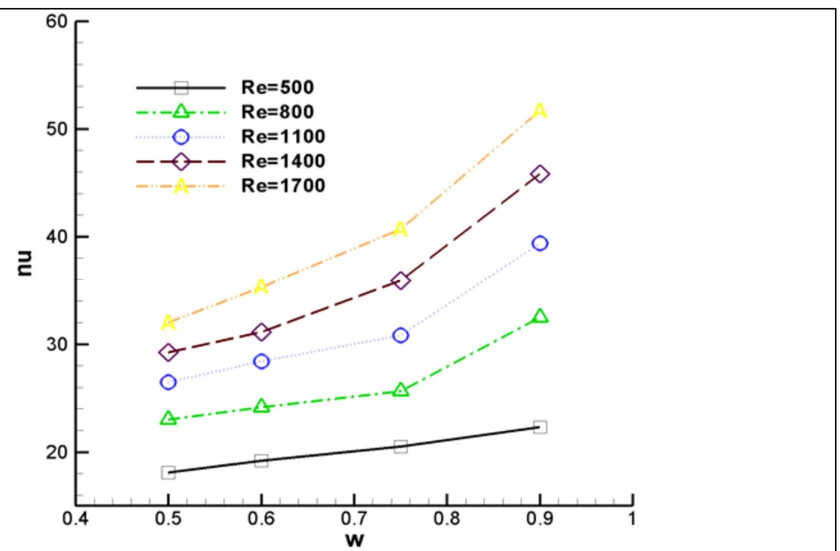

Fig. 8. Nusselt number versus width ratio at different Reynolds number.

Table 1 shows the Nusselt numbers from different Reynolds number and width ratio. The maximum and minimum nusselt numbers occur at Re=1700 and width ratio 0.9 and Re=500 and width ratio of 0.5.

Table 1. Nusselt numbers from different Reynolds number and width ratio

	Re=500	Re=800	Re=1100	Re=1400	Re=1700
W=0.5	18.09	22.99	26.49	29.22	31.99
W=0.6	19.17	24.13	28.4	31.13	35.31
W=0.75	20.49	25.66	30.83	35.92	40.68
W=0.9	22.31	32.49	39.37	45.83	51.69

The effect of adding Alumina nano-particles are investigated as presented in continue. Fig. 9 shows the effect of Alumina concentration on the nusselt number for different Reynolds number at constant width ratio of 0.6. it should be said that nusselt number increases by nano particle concentration for all Reynolds numbers. However the rate of increment is higher for greater Reynolds number. The same trend is observe for other width ratio.

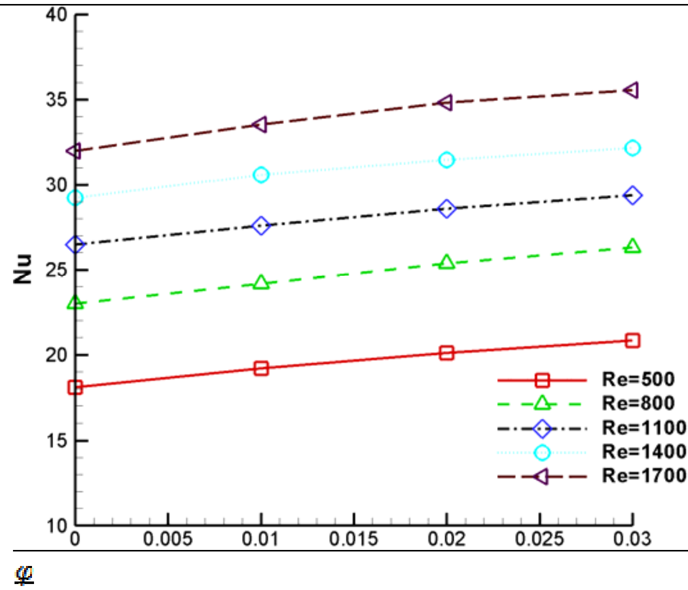

Fig. 9. Nusselt numbers versus nano particle concentration for different Reynolds numbers at width ratio of 0.5

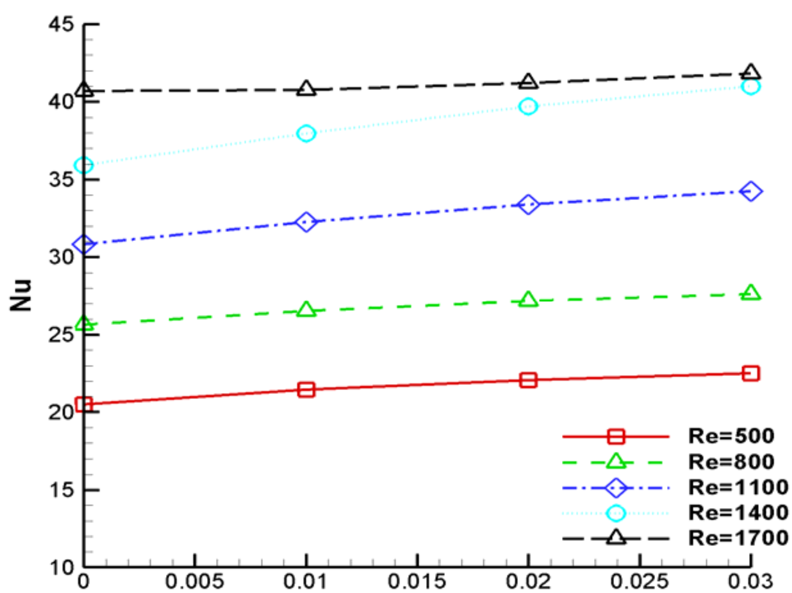

Fig. 10. Nusselt numbers versus nano particle concentration for different Reynolds numbers at width ratio of 0.75

5. Conclusion

The simultaneous effect of inserting twisted tape and adding Alumina nano particles are investigated numerically on the heat transfer characteristics in a pipe heat exchanger. The flow was assumed to be 3D and laminar and set of PDE governing equation is solve by Fluent V.6.3.26. the numerical simulation was well validated by comparison with published numerical data. Results showed that generally nusselt number increases with increment of tape width ratio and nano particles concentration. The maximum nusselt number was reache at Re=1700 and width ratio of 0.9. the effect of nano particles in heat transfer enhancement reduces slightly by augmentation of nano particles concentration.

REFERENCES

1. Manglik, R.M. and A.E. Bergles, Heat transfer and pressure drop correlations for twisted tape inserts in isothermal tubes: part Ielaminar flows, ASME J. Heat Transfer 115 (1993) 881-889.
2. Manglik, R.M. and A.E. Bergles, Heat transfer and pressure drop correlations for twisted tape inserts in isothermal tubes: part II etransition and turbulent flows, ASME J. Heat Transfer 115 (1993) 890-896.
3. Martemianov, S. and V.L. Okulov, On heat transfer enhancement in swirl pipe flows, Int. J. Heat Mass Transfer 47 (2004) 2379-2393.
4. Saha, S.K. and U.N. Gaitonde, A.W. Date, Heat transfer and pressure drop characteristics of laminarflow in a circular tubefitted with regularly spaced twisted tape elements, Exp. Therm. Fluid Sci. 2 (1989) 310-322.
5. Eiamsa-ard, S. and C. Thianpong, P. Promvonge, Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements, Int. Commun. Heat Mass Transfer 33 (2006) 1225-1233.
6. Saha, S.K. and A. Dutta, S.K. Dhal, Friction and heat transfer characteristics of laminar swirlflow through a circular tubefitted with regularly spaced twisted tape elements, Int. J. Heat Mass Transfer 44 (2001) 4211-4223.
7. Jaisankar, S. and T.K. Radhakrishnan, K.N. Sheeba, Experimental studies on heat transfer and friction factor characteristics of thermosyphon solar water heater systemfitted with spacer at the trailing edge of twisted tapes, J. Appl. Therm. Eng. 29 (2009) 1224-1231.
8. Ayub, Z.H. and S.F. Al-Fahed, The effect of gap width between horizontal tube and twisted tape on the pressure drop in turbulent water flow, Int. J. Heat Fluid Flow 14 (1993) 64-67.
9. Eiamsa-ard, S. K. Wongcharee, and S. Sripattanapipat, 3-D Numerical simulation of swirlingflow and convective heat transfer in a circular tube induced by means of loose-fit twisted tapes, Int. Commun. Heat Mass Transfer 36 (2009) 947-955.
10. Liu, W. K. Yang, Z.C. Liu, T.Z. Ming, A.W. and Fan, C. Yang, Mechanism of heat transfer enhancement in the coreflow of a tube and its numerical simulation, Open Transport Phenomena J. 2 (2010) 9-15.
11. Chang, S.W. Y.J. Jan, and J.S. Liou, Turbulent heat transfer and pressure drop in tube fitted with serrated twisted tape, Int. J. Therm. Sci. 46 (2007) 506-518.
12. Eiamsa-ard, S. and P. Promvonge, Thermal characteristics in round tubefitted with serrated twisted tape, J. Appl. Therm. Eng. (2010).
13. Rahimia, M. S.R. Shabaniana, and A.A. Alsairafib, Experimental and CFD studies on heat transfer and friction factor characteristics of a tube equipped with modified twisted tape inserts, Chem. Eng. Process 48 (2009) 762-770.
14. Chang, S.W. T.L. Yang, and J.S. Liou, Heat transfer and pressure drop in tube with broken twisted tape insert, Exp. Therm. Fluid Sci. 32 (2007) 489-501.
15. Sivashanmugam, P. and S. Suresh, Experimental studies on heat transfer and friction factor characteristics in laminar flow through a circular tubefitted with helical screw-tape inserts, J. Appl. Therm. Eng. 26 (2006) 1990-1997.
16. Sivashanmugam, P. and S. Suresh, Experimental studies on heat transfer and friction factor characteristics of turbulent flow through a circular tube fitted with helical screw-tape inserts, Chem. Eng. Process 46 (2007) 1292-1298.
17. Ray, S. and A.W. Date, Laminar flow and heat transfer through square duct with twisted tape insert, Int. J. Heat Fluid Flow 22 (2001) 460-472.
18. Ray, S. and A.W. Date, Friction and heat transfer characteristics of flow through square duct with twisted tape insert, Int. J. Heat Mass Transfer 46 (2003) 889-902.
19. Zimparov, V. Enhancement of heat transfer by a combination of three-start spirally corrugated tubes with a twisted tape, Int. J. Heat Mass Transfer 44 (2001) 551e574.
20. Zimparov, V. Enhancement of heat transfer by a combination of a single-start spirally corrugated tubes with a twisted tape, Exp. Therm. Fluid Sci. 25 (2002) 535-546.
21. Promvonge, P. and S. Eiamsa-ard, Heat transfer behaviors in a tube with combined conical-ring and twisted-tape insert, Int. Commun. Heat Mass Transfer 34 (2007) 849-859.
22. Broto, M. Synthesis of nickel nanoparticles: influence of aggregatio induced by modification of poly(vinylpyrrolidone) chain length on their magnetic properties.
23. Guo, J. Aiwu Fan, Xiaoyu Zhang,and Wei Liu, A numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with center-cleared twisted tape, International Journal of Thermal Sciences50 (2011) 1263-1270