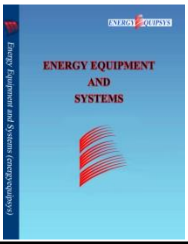
Energy Equip. Sys. / Vol. 8/No. 3/Sep. 2020/ 203-215

Energy Equipment and Systems

http://energyequipsys.ut.ac.ir
www.energyequipsys.com



Investigation of convective heat transfer, pressure drop and efficiency of ZnO/water nanofluid in alternating elliptical axis tubes

Authors

Ahmadreza Sajadi [a*]
Sasan Talebi [a]

[a] Faculty of Engineering, Shahrekord University, Shahrekord, Iran

ABSTRACT

In this study, for the first time, the heat transfer and the pressure drop of zinc oxide nanoparticles in alternating elliptical axis (AEA) tube have been investigated experimentally. The zinc oxide nanoparticles were at volumetric concentrations 1% and 2%. The base fluid was heat transfer oil and the experiments were conducted at constant wall temperature. Also, the study was done in Reynolds number range of 400- 1900. The experimental results show that the heat transfer, pressure drop and, the efficiency of AEA tubes are higher than the circular tube. The heat transfer rate and pressure drop increase by flattening the tube and adding nanoparticles. To compare the heat transfer and pressure drop simultaneously, an efficiency parameter is defined. This parameter shows how much increase in heat transfer can be obtained for the pressure drop of a circular tube with the same hydraulic diameter as the AEA tube. Using AEA tube with nanoparticles increases heat transfers by up to threefold, and pressure drop by up to twofold, resulting in an overall twofold increase in the efficiency.

Article history:

Received : 4 May 2020
Accepted : 3 June 2020

Keywords: Alternating Elliptical Axis Tube, Nanofluid, Heat Transfer, Pressure Drop, Efficiency.

1. Introduction

Recently, there has been a rising interest in increasing the heat transfer rate of heat exchangers and decreasing their size without creating significant flow resistance. To achieve this purpose, several methods have been proposed. Methods for increasing heat transfer rate are divided into two categories, namely, active and passive methods [1]. Active methods use an external force such as a magnetic field, surface vibration, or blowing fluid into the boundary layer. Setareh M. et al. [2] studied heat transfer enhancement of a double-pipe heat exchanger in the presence of ultrasonic vibrations experimentally and numerically. The use of ultrasonic vibration was optimal at low fluid flow rates. Their results showed that the cross-stream flows are the most effective reason for heat transfer enhancement.

Passive methods are the methods that do not depend on an external energy sources for increasing heat transfer rate. These methods are divided into two sub-categories. The First sub-category is improving the base fluid properties. While adding nanoparticles improves the thermal conductivity of the base flow, the random motions of particles in the flow boost convective heat transfer rate. Chowdhury Z. et al. [3] synthesized ZnO Nanoparticles by the sonochemical method. the Water-based nanofluid with 0.025% to

* Corresponding author: Ahmadreza Sajadi
Faculty of Engineering, Shahrekord University, Shahrekord, Iran
Email: ar.sajadi@sku.ac.ir

0.1% wt. concentrations were prepared. Their tube was circular and at the constant wall temperature. Results showed about fifty percent heat transfer enhancement for the based fluid with 0.1% wt. ZnO nanoparticles. For all other concentrations, heat transfer enhancement compared to base fluid.

Ahmed M. et al. [4] in the presence of nanoparticles, studied the fluid behavior and heat transfer in a tube with constant wall temperature numerically. Al_2O_3, TiO_2, and Cuwere studied with concentrations from 0 to 10% wt. at Reynolds numbers ranging from 500 to 2000. Their results showed the maximum enhancement in Nusselt number was for Cu nanoparticles, with a maximum increase 20.5% at Re = 1000. For further studies on adding nanoparticles, please refer to references 5 to 9. The second sub-category within passive methods is changing the structure of the tubes that include either changing the geometry or adding extra parts to the tubes to create secondary flows and increase flow turbulence.

Zheng L. and young H. [10] examined heat transfer and pressure drop in dimpled helically coiled mini-tubes numerically. The effects of Reynolds number, the ratio of the tube to coil diameter, dimple density and dimple size were studied. The results showed higher Nusselt number in the dimple case compared to the smooth case. The Nusselt number's ratio of the dimpled tube to the circular one varied from 1.788 to 2.281. Larger Nusselt number ratio was gotten when a lower tube to coil diameter was used.

Cattani L. et al. [11] numerically investigated the thermal performance at constant pumping power in ellipse and super ellipse-based double corrugated tubes. An ellipse and a super ellipse-based tubes were modeled at laminar, fully developed and incompressible flow. The efficiency increased up to 14% for the double corrugated tubes with an ellipse-base and up to 11% for the tubes with super ellipse-base. Najafi H. and Nazif R. [12] studied the turbulent flow and the heat transfer of water fluid flow in the alternating elliptical axis tube under four alternative angles. The aim of their study was to increase the heat transfer by generating multi-longitudinal vortices along with the tube flow. Their results showed that an improvement in the mean Nusselt number of alternating elliptical axis tube with rotation angles of 40°, 60°, 80°, and 90° compared to the circular tube are 7.77%, 14.6%, 16.93%, and 24.42%, respectively.

Zho T. et al. [13] numerically investigated the elliptical tube with the granular flow. According to the results elliptical tubes with axis ratio from 1.2 to 2.0 have more limited area of heat transfer deterioration in granular flow and as a resulthigher heat transfer coefficient compare to the circular tube (axis ratio =1.0) with the same axis length. For further study on adding nanoparticles, please refer to references 5 to 10. For further study on changing tube geometry, please refer to references 14 to 19.

In order to achieve a higher heat transfer rate, some studies have combined active and passive methods. Hatami M. et al [20] used finite element method to investigate the effect of a variable magnetic field on convection heat transfer of Fe_3O_4-water nanofluid in a half-annulus cavity. The effects of Hartmann Number (the ratio of electromagnetic force to the viscous force), nanoparticles volume fraction and Rayleigh number on the local and average Nusselt numbers of inner wall were investigated. The results show that in lower Eckert numbers, increment the Hartmann number make a reduction on the Nusselt number owning to Lorentz force resulting from the existence of stronger magnetic field.

Paisarn N. and SongkranW. [21] merged micro-fins, nanofluids, pulsating flow and magnetic field to investigate the heat transfer and flow characteristics . They compared the results obtained from the micro-fins tube with magnetic field with the results without the magnetic field and those obtained from the smooth tube with and without magnetic fields. According to the results a merged heat transfer enhancement techniques are a good potential to improve the thermal performance. For further study on the combination of active and passive methods, please refer to references 22 to 25. Other studies have tried combining two or three passive methods. Ningbo et al. [26] showed that adding aluminum oxide nanoparticles to water increase the heat transfer rate and pressure drop in flattened tubes. The study was carried out for laminar flow with constant heat flux boundary condition. Saravanan et al. [27] investigated heat transfer enhancement using nanoparticles and twisted tape inserts. They used titanium dioxide, beryllium oxide, zinc oxide and Copper oxide nanoparticles with the base fluid of water. The numerical study investigated the thermal for laminar and turbulent flows with different nanofluids in the heat exchanger tube with inserts of twisted tape with a rectangular cut on its rib. Their results showed the copper oxide had the highest heat transfer increment and using of nanoparticles is more effective at low Reynolds numbers. Zheng H. et al. [28] examined heat transfer and flow in circular tubes fitted with dimpled twisted tape inserts, and Al2O3 nanoparticles with the base fluid of water. According to the results usage of dimples led to a 25.53% increase in the convective heat transfer coefficient for most of the smooth tapes. The most increase in convective heat transfer coefficient was 58.96% achieved by using only the base fluid, while the increase in friction factor was only 5.05%.

Karami et al. [29] investigated the effect of adding carbon nanotubes (CNT) to base oil in corrugated tube experimentally. They showed that CNTs increase the heat transfer rate in Reynolds number range of 1000-3000. However, the combination of using CNTs and tube deformation increased both heat transfer and pressure drop simultaneously. Gnanavel et al. [30] numerically investigated the effect of nanofluids and spiral spring on heat transfer and pressure drop in a double tube heat exchanger. In addition, they compared the effect of different nanoparticles such as titanium dioxide, Beryllium oxide, zinc oxide and, copper oxide. The results showed that using nanofluid and spiral spring increases the heat transfer and pressure drop simultaneously. Anbu et al. [31] investigated the heat transfer rate and pressure drop of corrugated tubes with different heights and pitches of corrugation with spiraled rod inserts. Pure water and nanofluids with volumetric concentrations of 0.25% and 0.5% titanium oxide were examined in the Reynolds number range of 4800 to 8900. The results showed that adding nanoparticles enhance the heat transfer rate and pressure drop. In addition, the use of inserts and corrugation in tubes increase the heat transfer rate further. They determined the optimal geometry and nanoparticles' concentration to achieve the maximum thermal performance factor.

Sajadi et al. [32] investigated heat transfer and pressure drop of AEA tube. They used heat transfer oil as a working fluid in the Reynolds range of 400 to 1800. They indicated that the heat transfer rate and pressure drop in AEA tubes are higher than those of circular tubes. However, the use of AEA tube is more economical than a circular tube as AEA tubes have a higher heat transfer rate for the same pressure drop as that of a circular tube. As shown in the previous studies, changing the structure of the tubes or adding extra parts to the tube increases heat transfer by creating secondary flows and increasing flow turbulence. Furthermore, adding nanoparticles increase the heat transfer properties of the base fluid. In this study, for the first time, the effect of combining change of tube geometry to AEA tube and adding nanoparticles are investigated.

2. Methodology

2.1. Experimental Setup

The oil is discharged from the tank to the test tube by a gear pump. The inlet and outlet temperatures and the pressure drop of the fluid are measured by accuracy of .1˚C and 1 Pa respectively.

The test tube is passed through a saturated vapor tank to keep the surface temperature of the tube constant. To ensure the constant temperature condition, the surface temperature of the tube is measured at four points with equal distances. All the thermocouples are K-type. The fluid rate is measured by a one-liter balloon and a stopwatch with an accuracy of .01 of a second.

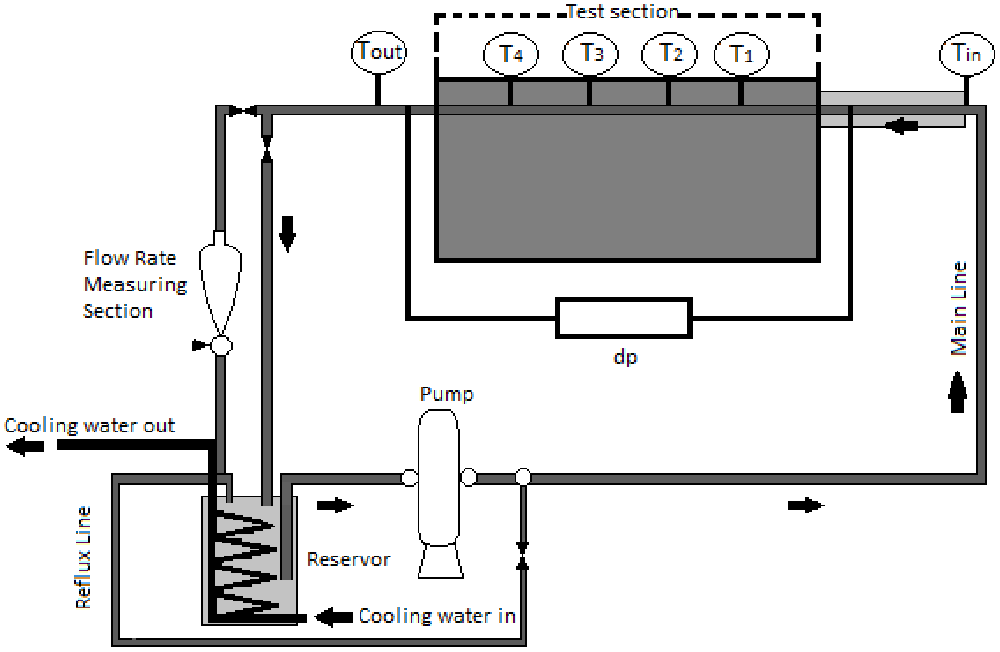


Fig. 1. Schematic of the test apparatus

According to the basic laws of heat transfer, the mean convective heat transfer coefficient equals to

$$\bar{h} = \frac{\dot{m}C_p(T_{out} - T_{in})}{A_s \Delta T_m} \quad (1)$$

where $\dot{m}$ is the mass rate, C_p is the specific heat capacity of the fluid, $T_{out} - T_{in}$ is the difference between inlet and outlet fluid temperature, A_s is the lateral area of the tested tube, and ΔT_m is the logarithmic mean temperature that is obtained from Eq. (2).

$$\Delta T_m = \frac{\Delta T_{out} - \Delta T_{in}}{\ln \frac{\Delta T_{out}}{\Delta T_{in}}} \quad (2)$$

ΔT_{out} and ΔT_{in} are the difference between the tube wall temperature and the fluid's outlet and inlet temperature, respectively.

Mean Nusselt number of the flow is obtained from Eq. (3).

$$\overline{Nu} = D_h \bar{h}/k \quad (3)$$

Friction coefficient inside the test tube is calculated according to the Eq. (4).

$$f = \frac{2D_h \Delta P}{\rho L u^2} \quad (4)$$

where D_h is hydraulic diameter, ΔP is pressure drop at the tube, ρ is the density of the fluid, L is tube length and u is the flow velocity.

In order to check the reliability of the test apparatus, first, the results of heat transfer and pressure drop of the circular tube with the well-known Hausen and Darcy relations have been investigated. Equation 5 describes Hausen equation for the tube input in laminar flows.

$$\overline{Nu} = 3.66 + \frac{.0668Gz_D}{1 + .04Gz_D^{\frac{2}{3}}} \quad (5)$$

where Gz_D is Grates number.

$$Gz_D = \left(\frac{D_h}{X}\right) RePr \quad (6)$$

where D_h is the hydraulic diameter of the tube and X is the axial distance from the beginning of the tube.

Darcy relation to calculate the friction coefficient of laminar flow is shown in Eq. (7).

$$f = \frac{64}{Re} \quad (7)$$

Figures 2 and 3, compare the results of the test apparatus with Hausen and Darcy equations, respectively.

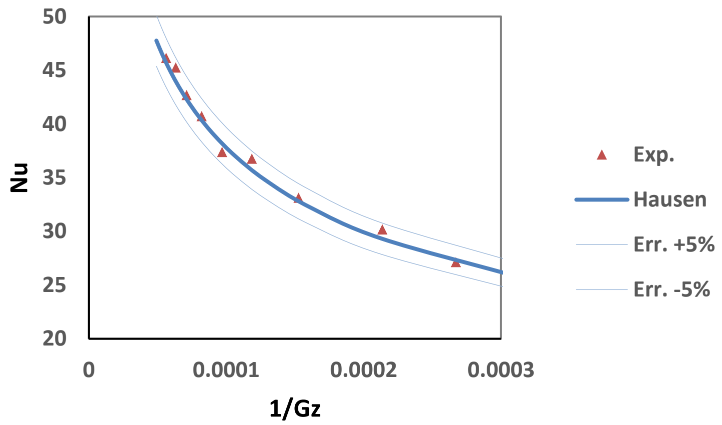


Fig.2. Comparison of the heat transfer results of the test apparatus with the Hausen equation

The maximum errors of the convective heat transfer coefficient and friction factor coefficient were 5% and 3%, respectively.

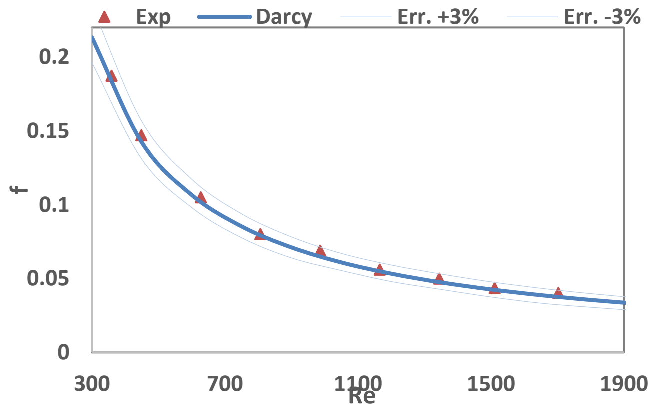


Fig.3. Comparison of the pressure drop results from the test apparatus with the Darcy equation.

2.2. Test tube

AEA tube included transition parts and segments. The cross-section of each segment is elliptical (flattened), and each segment rotates 90 degrees relative to the previous segment. Two consecutive segments are connected by a transition part. Figure 4 shows the geometry of AEA tube.

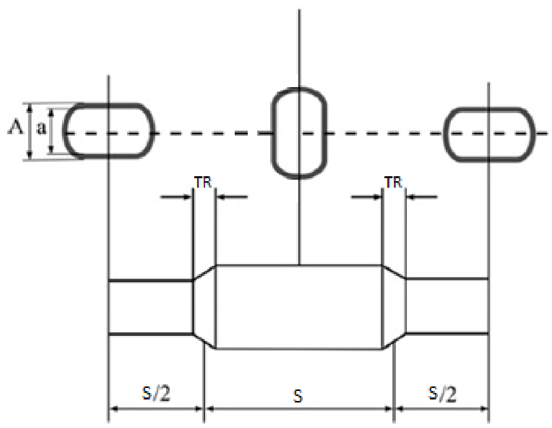


Fig. 4. Schematic of alternatively elliptical tubes.

Flattening the tube increases the presence possibility of fluid particles near the tube wall, and passing the fluid through the transition part destroys the thermal boundary layers. These factors increase the heat transfer rate. Table 1 represents the geometric properties of the investigated tubes.

3. Results and discussion

Figure 5 shows the heat transfer coefficient in A to D tubes. The results show that the heat transfer rate of AEA tubes is higher than the circular tube. In addition, by increasing the tube flattening, the heat transfer rate increase. Increase the flattening of the tube leads to an increase in the possibility of the presence of fluid particles near the tube's wall. Also, when the fluid passes from one segment to another segment heat transfer boundary layers are destroyed. As the Reynolds number increases, the ratio of the heat transfer coefficient of the AEA tubes to the circular tube increases. For B, C and D tubes in Reynolds 400 these ratios are 1.1, 1.43 and 1.55, respectively, and in Reynolds 1800 are 1.75, 2.7 and 3, respectively. Figure 6 represents the pressure drop in A to D tubes. The results show the pressure drop of AEA tubes is greater than the circular tube and enhance by increasing the amount of tube flattening.

Flattening of the tubes increases the flow velocity, and according to relation 4 the pressure drop is directly related to the second power of the speed. In addition, passing the flow from one segment to another segment makes local pressure drop. In Reynolds number 400, the ratio of pressure drop in tubes B, C and, D to the circular tube are 1.05, 1.2 and 1.75, respectively. These ratios in Reynolds 1800 are 1.15, 1.4 and 1.8, respectively.

Table 1. Geometric Properties of Test Tubes

Tube	A (mm)	a (mm)	TR(mm)	S(mm)
A	15.88	14.62	-	-
B	14	12.74	50	165
C	12	10.74	50	165
D	10	8.74	50	165

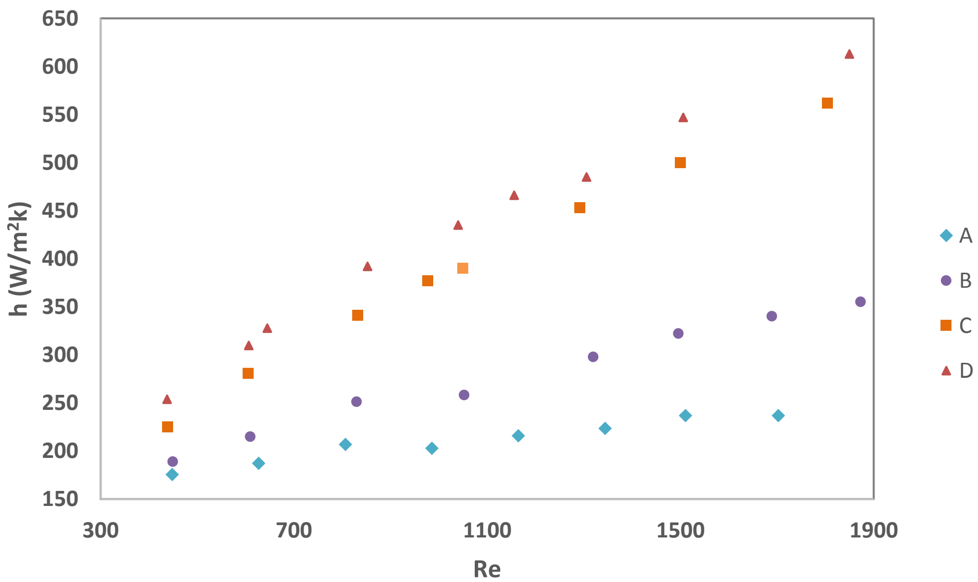


Fig. 5. Heat transfer of base oil in tubes

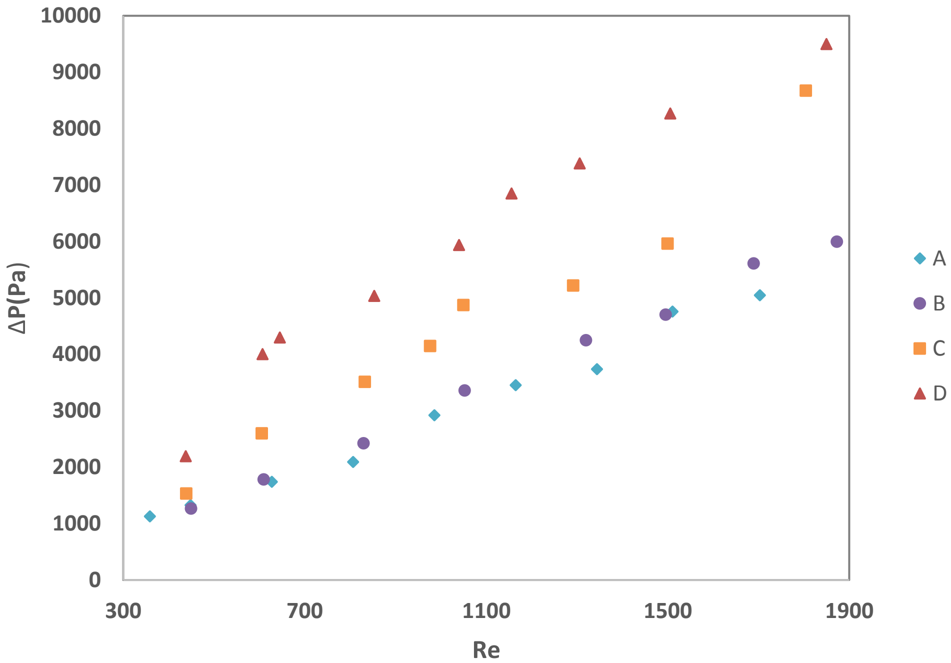


Fig.6. pressure drop of the Base oil in tubes

Figures 7 and 8 show that the heat transfer coefficient of tubes in concentrations 1% and 2% of nanoparticles, respectively.

The results show that in all tubes, the heat transfer increases by increasing the concentration of nanoparticles. Nanoparticles improve the thermal conductivity of the base fluid, and Brownian motion of particles facilitates convective heat transfer. The presence effect of nanoparticles on enhancing heat transfer decreases with increasing Reynolds number. For example, in a circular tube and a concentration of 2% nanoparticles in Reynolds 400 and 1800, the rate of heat transfer was 25% and 17% higher than that of the base fluid, respectively.

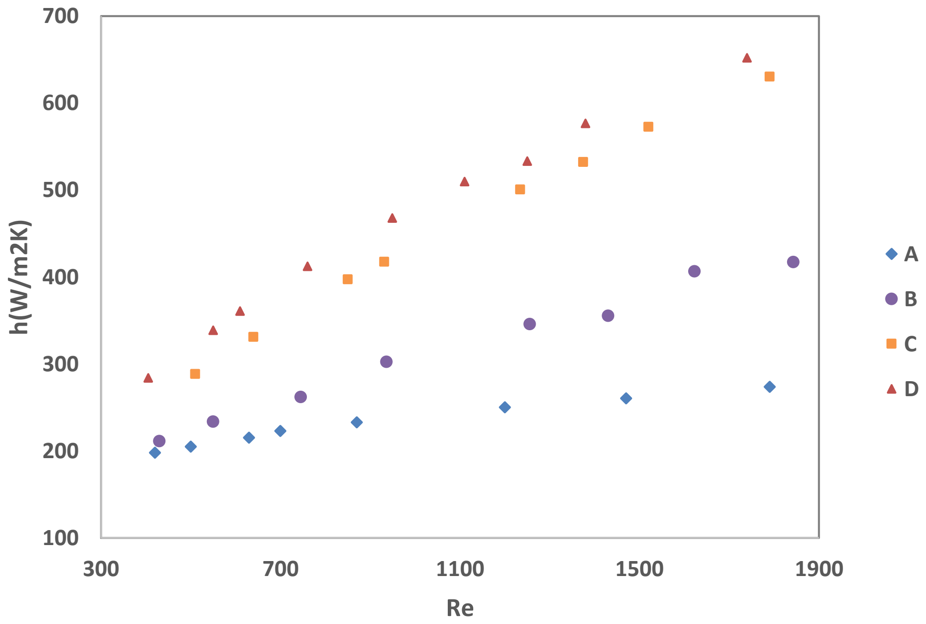


Fig.7. The heat transfer of nanofluid 1% in tubes

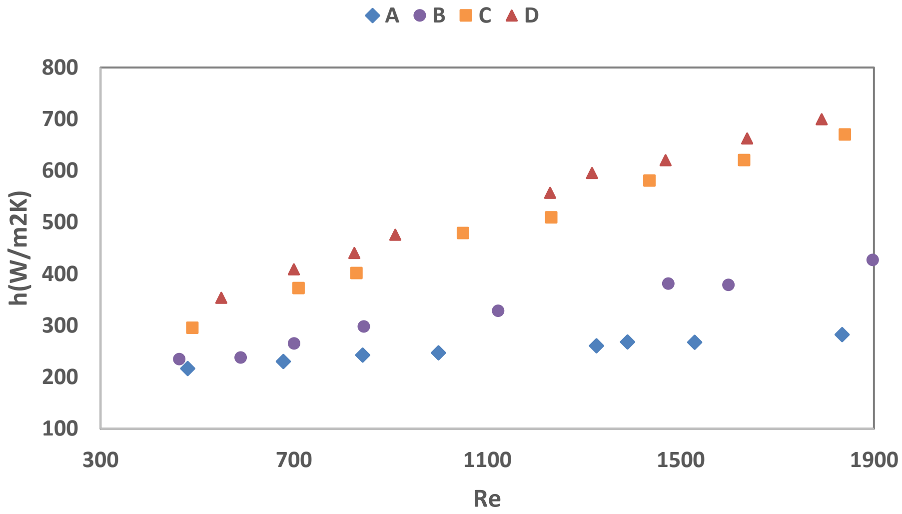


Fig.8. heat transfer of nanofluid 2% in tubes

The heat transfer rate in tube D and concentration of 2% nanoparticles at Reynolds numbers 400 and 1800, increased 20% and 16% respectively compared to the base oil. As the Reynolds number increases, the velocity and turbulence of the base fluid increase, thus the role of random motions of nanoparticles on heat transfer rate will decrease. Figures 9 and 10 show the pressure drop in all tubes with nanoparticles concentration of 1% and 2%.

The results show that the pressure drop increases with increasing concentration of nanoparticles. The increase in pressure drop at concentrations of 1% and 2% was 6% and 14% of the base fluid, respectively. These results for all investigated tubes are the same.

Adding nanoparticles to the base oil and flattening the tube increases both heat transfer rate and pressure drop. Increasing the heat transfer rate is a desirable factor and increasing the pressure drop is an undesirable factor. Therefore, it is essential to investigate their effect simultaneously.

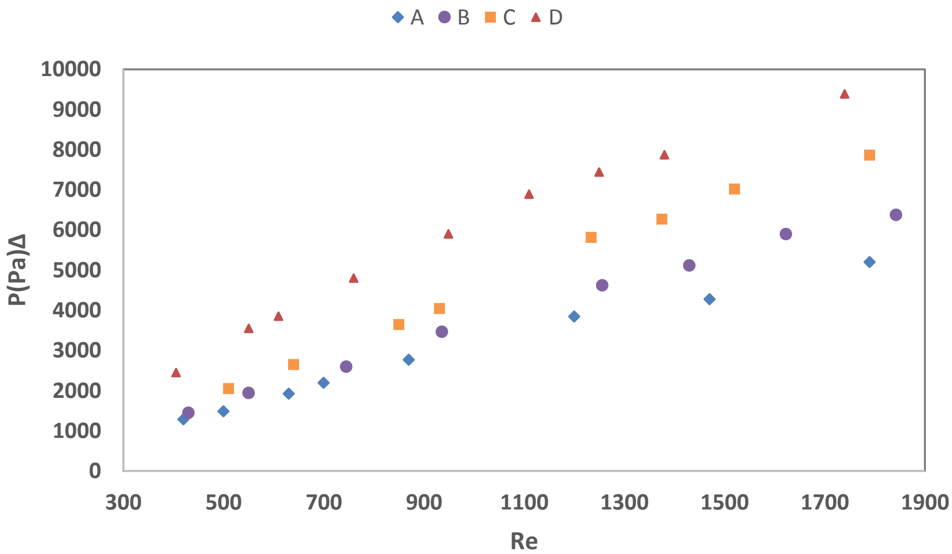


Fig.9. Pressure drop of nanofluid 1% in tubes

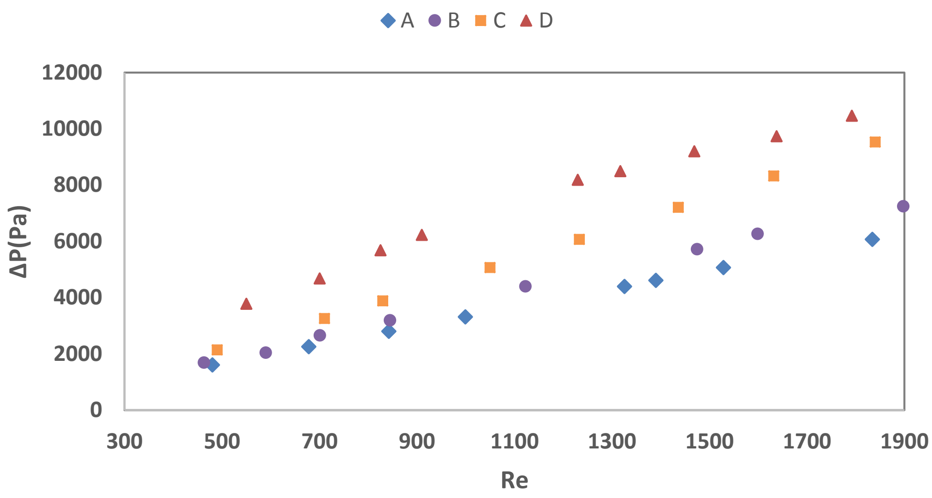


Fig.10. Pressure drop of nanofluid 2% in tubes.

Parameters that compare the performance of two tubes in terms of heat transfer and pressure drop is the effective performance ratio (PER). (Eq. 8)

$$\eta = \frac{\left(\frac{Nu_a}{Nu_b}\right)}{\left(\frac{f_a}{f_b}\right)^{(1/3)}} \tag{8}$$

According to Eq. (9), when PER is greater than 1, it means that the efficiency of tube A is greater than tube B and vice versa. Figure 11 compares the PER of AEA tubes with circular tubes.

The results show that in Reynolds number range of this study, the PER of the AEA tubes is higher than the circular tube. In addition, tube C, which was flattened more than tube B and less than tube D, had the highest efficiency among the test tubes in the wide range of Reynolds numbers. The increase in the flatness of the tube D caused an excessive increase in the pressure drop so decrease its efficiency compared to the tube C. The lower flatness of the tube B cannot increase the turbulence of the flow thus it has lower the heat transfer rate and efficiency compared to the tube C. Figure 12 shows the presence effect of nanoparticles on the efficiency of the circular tube. Increasing the nanoparticle concentration enhances the efficiency of the circular tube.

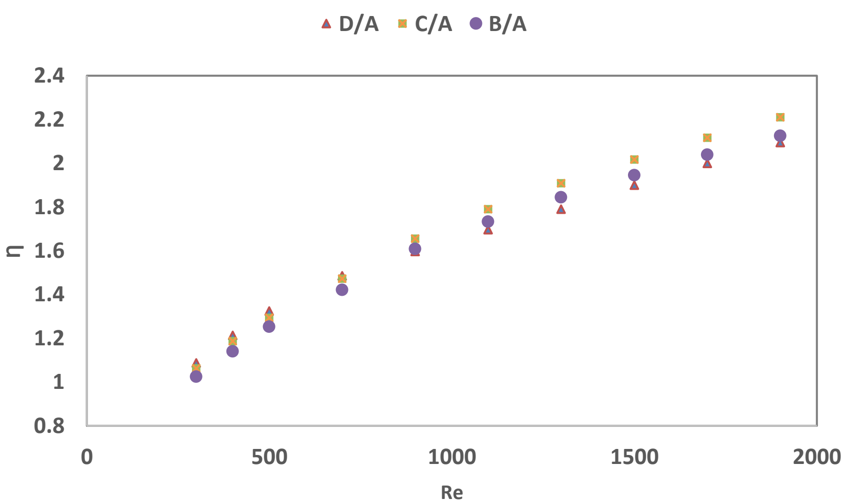


Fig. 11. Comparison of the Efficiency of AEA tubes with Circular Tube

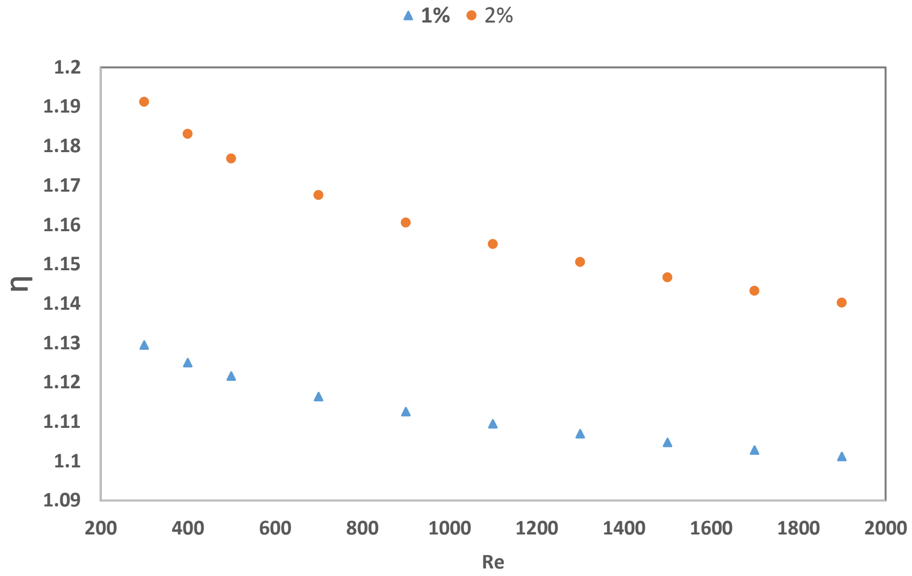


Fig. 12. Comparison of nanofluid efficiency with a base oil in tube A

Figure 13 shows the presence effect of nanoparticles on the efficiency of the tube B. Increase the nanoparticles concentration enhances the efficiency of the tube B.

The results of Figs. 11 and 12 show that by increasing the concentration of nanoparticles the efficiency of both circular and AEA tubes increase. Also, efficiency decrease by increasing Reynolds number, because by increasing the Reynolds number, the effect of nanoparticles' Brownian (random) motion decreases.

4. Conclusion

This study is the first investigation of heat transfer and pressure drop of zinc oxide nanofluid in alternating elliptical axis tubes. The tube consists of consecutive flattened sections that rotate 90 degrees relative to the previous section and are connected to each other by a transition section. The flatness of the tube and the concentration of nanoparticles have been studied as changing

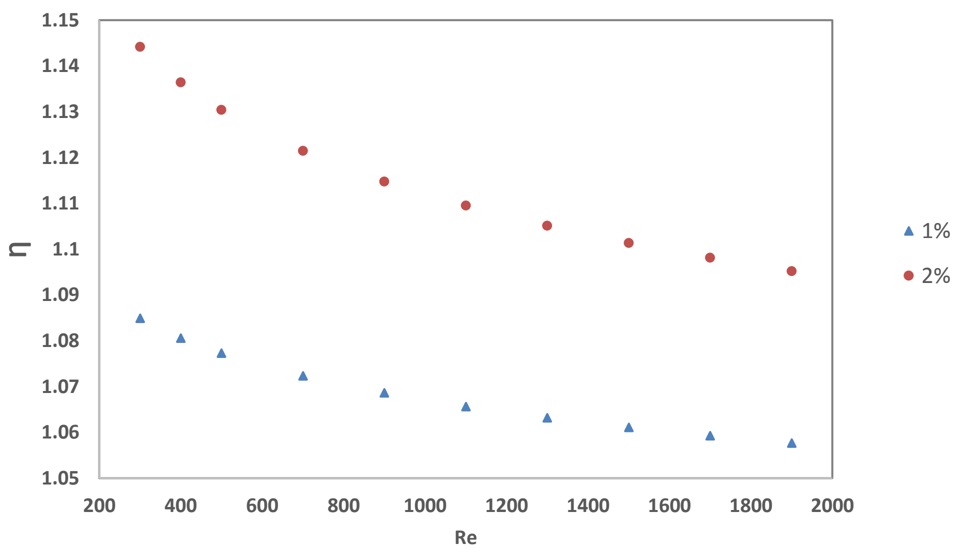


Fig. 13. Comparison of nanofluid efficiency with Base Oil in tube D

variables. An experimental set up is designed and made that keeps the wall temperature of the tube constant by placing the test tube in a steam bath. The fluid temperature is measured at the inlet and outlet of the tube as well as the wall temperature of the tube. Fluid pressure drop is also measured along the test tube. The results showed that increasing the tube flattening enhanced the heat transfer rate such that the heat transfer rate in AEA tube is three times higher than that circular tube remarkably. Furthermore, adding nanoparticles to the base fluid enhanced the heat transfer rate in all tubes. The heat transfer rate was further increased by increasing the concentration of nanoparticles. The pressure drop of AEA tube is greater than the circular tube and increased by increasing the amount of tube flattening. Adding nanoparticles to the base fluid increased the pressure drop and in all tubes the pressure drop increase by increasing the concentration of nanoparticles. In the Reynolds number range of this study, the efficiency of the AEA tubes was higher than the circular tube. In addition, the tube with medium flatting had the highest efficiency among the test tubes in the wide range of Reynolds numbers. Increasing the concentration of nanoparticles increased the efficiency of both circular and AEA tubes. Also, efficiency decreased by increasing Reynolds number. The efficiency does not have a clear relationship with the flattening of the tube so it is possible to obtain the best geometry. The main limitation of this study is to keep the test tube wall temperature constant at higher Reynolds numbers. As mass flow rate rises, the heat transfer rate increases and more steam is needed. For future work, the heat transfer rate and pressure drop in AEA tube can be investigated for a wider range of mass flow rates and the effect of the length of flattened segments can be studied.

References

[1] Bergles A. and Web R., Augmentation of convective heat and mass transfer, ASME, New York, 1970.

[2] Setareh M. et al. Experimental and numerical study on heat transfer enhancement using ultrasonic vibration in a double-pipe heat exchanger, Applied Thermal Engineering, 2019 (159): 113867.

[3] Chowdhury Z. et al., Effect of ZnO-water based nanofluids from sonochemical synthesis method on heat transfer in a circular flow passage, International Communications in Heat and Mass Transfer, 2020 (114): 104591

[4] Ahmed M. et al., Influence of nano-particles addition on hydrodynamics and heat transfer in laminar flow entrance region inside tube, Alexandria Engineering Journal, 2018 (57): 4091-4102

[5] Tehmina A. and Kim H., Heat transfer and pressure drop correlations of nanofluids, Renewable and Sustainable Energy Reviews, 2018 (91): 564-583

[6] Chiam H. et al., Numerical study of nanofluid heat transfer for different tube geometries – A comprehensive review on performance, International Communications in Heat and Mass Transfer, 2017 (86): 60-70

[7] Orlando A. et al., Experimental analysis of the thermal-hydraulic performance of water based silver and SWCNT nanofluids in single-phase flow, Applied Thermal Engineering, 2017 (124): 1176-1188.

[8] Samina J. et al., Internal convective heat transfer of nanofluids in different flow regimes: A comprehensive review, Statistical Mechanics and its Applications, 2020 (538): 122783

[9] Sajadi A. and Kazemi M., Investigation of turbulent convective heat transfer and pressure drop of TiO2/water nanofluid in circular tube, International Communications in Heat and Mass Transfer, 2011(38): 1474-1478

[10] Zheng L. and young H., Numerical investigation on heat transfer and flow characteristics in helically coiled mini-tubes equipped with dimples, International Journal of Heat and Mass Transfer, 2018(126): 544-570

[11] Cattani L. et al., Elliptical double corrugated tubes for enhanced heat transfer, International Journal of Heat and Mass Transfer, 2019 (128): 363-377

[12] Najafi H. and Nazif R, The effect of multi-longitudinal vortex generation on turbulent convective heat transfer within alternating elliptical axis tubes with various alternative angles, Case Studies in Thermal Engineering, 2018 (12) 237-247

[13] Zho T. et al., Numerical investigation of heat transfer for elliptical tube in granular flow using DEM, Energy Procedia, 2019 (158) 5504-5509

[14] Cheng J. et al., Analysis of heat transfer and flow resistance of twisted oval tube in low Reynolds number flow, international journal of heat and mass transfer, (2017) (109) 761-777

[15] Peng L. et al., Heat transfer enhancement for laminar flow in a tube using bidirectional conical strip inserts, International Journal of Heat and Mass Transfer, 2018 (127) 1064-1076.

[16] Najafi N. et al., The effect of multi-longitudinal vortex generation on turbulent convective heat transfer within alternating elliptical axis tubes with various alternative angles, Case Studies in Thermal Engineering, 2018 (12) 237-247

[17] Hong Y. et al., Thermal-hydraulic performances in multiple twisted tapes inserted sinusoidal rib tube heat exchangers for exhaust gas heat recovery applications, Energy Conversion and Management, 2019 (185), 271-290

[18] Juan D. et al., Laminar thermal and fluid flow characteristics in tubes with sinusoidal ribs, International Journal of Heat and Mass Transfer, 2018 (120) 635-651

[19] Sajadi A. et al., Experimental and numerical study on heat transfer, flow resistance, and compactness of alternating flattened tubes, Applied Thermal Engineering, 2016 (108) 740-750

[20] Feng X. et al., Study of heat transfer in oscillatory flow for a Sterling engine heating tube inserted with spiral spring, Applied Thermal Engineering, 2018 (143) 182-192

[21] Paisarn N. and SongkranW., Experimental study on laminar pulsating flow and heat transfer of nanofluids in micro-fins tube with magnetic fields, International Journal of Heat and Mass Transfer 2018 (118): 297-303

[22] Feng X. et al., Numerical study on flow characteristics and heat transfer enhancement of oscillatory flow in a spirally corrugated tube, International Journal of Heat and Mass Transfer, 2018 (127): 402-413

[23] Hatami M. et al., Variable magnetic field (VMF) effect on the heat transfer of a half-annulus cavity filled by Fe_3O_4-water nanofluid under constant heat flux, Journal of Magnetism and Magnetic Materials, 2018 (451): 173-182

[24] ShaoW. et al., Experimental test and empirical correlation development for heat transfer enhancement under ultrasonic vibration, Applied Thermal Engineering 2018 (143): 639-649

[25] Goharkhah M. et al., Convective heat transfer characteristics of magnetite nanofluid under the influence of constant and alternating magnetic field, Powder Technol, 2015 (274): 258-268

[26] Ningbo et al., Numerical investigations of laminar heat transfer and flow performance of Al2O3–water nanofluids in a flat tube, International Journal of Heat and Mass Transfer 2016 (92): 268-282

[27] Saravanan R. et al., Heat transfer enhancement through nano-fluids and twisted tape insert with rectangular cut on its rib in a double pipe heat exchanger, materials today proceedings, 2020 (21): 865-869

[28] Zheng H. et al., Numerical investigation on heat transfer performance and flow characteristics in circular tubes with dimpled twisted tapes using Al_2O_3-water nanofluid, International Journal of Heat and Mass Transfer, 2017 (111): 962-981

[29] Karami M.et al., Heat Transfer and Pressure Drop Characteristics of Nanofluid Flows Inside Corrugated Tubes, Heat Transfer Engineering, 2015 (0): 1-9

[30] Gnanavel C. et al, Heat transfer augmentation by nano-fluids and Spiral Spring insert in Double Tube Heat Exchanger – A numerical exploration, materials today proceedings, 2020 (21): 857-861

[31] Anbu S. et al., Convective heat transfer studies on helically corrugated tubes with spiraled rod inserts using TiO_2/DI water nanofluids, Journal of Thermal Analysis and Calorimetry, 2019 (137): 849-864

[32] Sajadi A. et al., Experimental and numerical study on heat transfer and flow resistance of oil flow in alternating elliptical axis tubes, International Journal of Heat and Mass Transfer, 2014 (77): 124-130

[33] Incropera F.P., David P, introduction to heat transfer, (2002) 1-506, ISBN 978-600-5107-50-0