IJERMS

International Journal of Engineering Researches and Management Studies

A NUMERICAL INVESTIGATION ON THE EFFECT OF SCILLATING PIPE ON NANOPARTICLE SUSPENSIONS BEHAVIOUR: THERMAL AND FLOW

Layth Al-Gebory*
* Materials Engineering Department, University of Technology, Baghdad-Iraq. Ph.D. Student, Ozyegin University, Istanbul-Turkey, Email: layth.ismael@ozu.edu.tr

ABSTRACT

In this study, numerical investigation is carried out on the laminar convective heat transfer for water based TiO_2 nanoparticle suspensions flow through an oscillating pipe subjected to constant heat flux. The numerical model is carried out by applying the two-phase (Eulerian-Lagrangian discrete phase) flow model which is one of the accurate methods for the observation of the interaction between the dispersed nanoparticles and the base fluid. The Reynolds number and nanoparticles volume fraction are in the ranges of (Re= 500-2000) and (Ø=0.1-0.5 vol. %). Friction factor and pressure drop along the oscillating pipe are investigated. Also, the thermal performance is examined in the terms of average Nusselt number and average heat transfer coefficient. The results show the effect of oscillating pipe on the flow parameters and thermal performance. Also, it can be observed that there is a significant effect of the nanoparticles on the heat transfer enhancement, taking into the consideration the required pumping power. The obtained Average nusselt number results are compared with others from litreture.

Keywords:- *Nanoparticle suspensions, oscillating pipe, constant heat flux.*

1. INTRODUCTION

Heating and cooling of fluid flow inside pipes and channels play an important role in a wide range of industrial processes. Actually, forced convection is the most effective and widely used in different heat transfer applications include heating and cooling units and heat exchangers under the concept of flow-induced heat transfer **[1]**. Indeed, heat transfer is directly related to fluids thermophysical properties; then, the possibilities of increasing the thermal conductivity and enhancing other properties are quit important. In the past years, researchers used suspended particles in the micron size after that the advances of manufacturing technologies made the production of nanometer scale particles possible. Therefore, researchers and engineers used suspended nanoparticles in the base fluids which are named nanoparticle suspensions or so called nanofluids. Nowadays, nanofluids take a high level of interest in the thermal applications because conventional coolants such as water and oils typically have a weak heat transfer performance. Therefore, using the suspended of nanoparticles in the base fluid as a heat transfer medium are very promising **[2,3]**. Basically, high performance coolants and size efficient thermal systems are the main objectives, where the benefits of using lighter/smaller thermal systems are reducing the emissions, reduction in coolant supplies, etc. Therefore, it is hopeful that the suspended nanoparticles in the base fluid as mixtures and flow passages design will offer a great opportunities for development of innovative thermal systems. Also, the enhancement of thermal conductivity and other thermophysical properties like viscosity and specific heat is very important, taking into the consideration the flow parameters such as particle migration, clustering and nanoparticle stability **[4-6]**.

The significant enhancement of forced convective heat transfer by using nanofluids has been extensively examined in water based CuO nanofluids **[7,8]**, water based Cu nanofluids **[9-12]**, water based TiO_2 nanofluids **[7,11]**, and water based Al_2O_3 nanofluids **[13,14]**. Many experimental and numerical studies in the previous time have been carried out to investigate thermal performance in different shape flow passages using conventional fluids. O'Brien and Sparrow **[15]** investigated experimentally the convective heat transfer performance in a triangular-corrugated duct, they were found an enhancement in the heat transfer but with a greater pumping power needed. Ahmed et al. studied numerically the nanofluid flow and heat transfer in a wavy square cross sectional channel, the results show the effect of the wavy wall channel on the flow behaviour and heat transfer **[16]**. Fabbri **[17]** studied numerical the laminar heat transfer of fluid flow inside composed and corrugated

International Journal of Engineering Researches and Management Studies

channel using finite element scheme, the results showed that the enhancement in heat transfer increases as Prandtl and Reynolds numbers increases.

In the present study, a numerical investigation is completed on the flow behaviour and convective heat transfer properties of nanoparticle suspensions flow inside an oscillating pipe by using Eulerian-Lagrangian discrete phase model are considered as shown in fig. (1). the pipe ($D_h = 0.04\ m\ and\ L = 1\ m$) is in the case of constant heat flux and working fluid is water-based TiO_2 nanofluid, the nanoparticles have a diameter of 50 nm. At the inlet the temperature of the nanofluid assumed (294 K), the slip velocity (the interaction between the nanoparticles and the base fluid molecules) is considered by applying the two-phase flow model. Different volume fraction of the nanoparticles in the base fluid is taken ($\emptyset = 0.1 - 0.5\ vol.\%$), in order to observe the influence of those parameters on the flow behaviour and thermal performance.

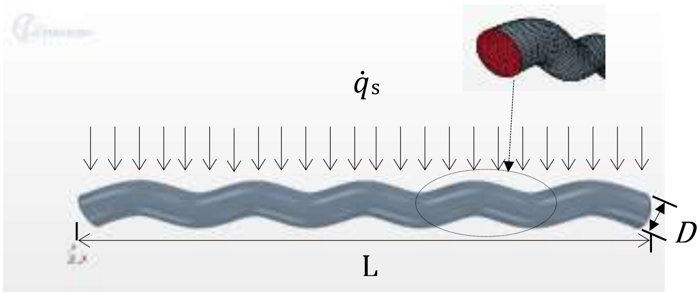

Figure 1. Schematic diagram of the geometrical configuration

2. MATHEMATICAL MODELING

The governing equations for the Eulerian-Lagrangian discrete phase (two-phase) model are considered. The flow assumed incompressible and Newtonian, no chemical reactions, negligible external forces and viscous dissipation. The governing equations are expressed as follows **[18-20]**:

$$\nabla.(\rho\vec{V}) = 0 \qquad (1)$$

$$\nabla.\left(\rho\vec{V}\vec{V}\right) = -\nabla P + \nabla.\left(\mu\nabla\vec{V}\right) + S_m \qquad (2)$$

$$\nabla.\left(\rho\vec{V}C_pT\right) = \nabla.(k\nabla T) + S_e \qquad (3)$$

$$m_p\frac{d\vec{V}_p}{dt} = F_D \qquad (4)$$

$$\rho C_{p_p}\frac{dT_p}{dt} = \frac{6h_p}{d_p}\left(T - T_p\right) \qquad (5)$$

Where: (T) is the fluid temperature, (V) is the fluid velocity, (V_p) is the particle velocity, (T_p) is the particle temperature, (h_P) is the fluid-particles interaction heat transfer coefficient and (d_P) is the nanoparticle diameter.

Because of the thermophysical properties of the nanofluid strongly depend on the ($\emptyset$), The effective density (ρ_{nf}), the effective specific heat at constant pressure ($C_{p_{nf}}$), the effective thermal conductivity (k_{nf}) and the effective dynamic viscosity (μ_{nf}) of the nanofluids can be defined as following **[21-23]**:

International Journal of Engineering Researches and Management Studies

$$\rho_{nf} = (1-\emptyset)\rho_f + \emptyset\rho_p \quad (6)$$

$$C_{p_{nf}} = \frac{(1-\emptyset)(\rho C_p)_f + \emptyset(\rho C_p)_p}{(1-\emptyset)\rho_f + \emptyset\rho_p} \quad (7)$$

$$\mathrm{k_{nf}} = \left(\frac{\mathrm{k_p} + (\mathrm{n}-1)\mathrm{k_b} - (\mathrm{n}-1)(\mathrm{k_b}-\mathrm{k_p})\Phi}{\mathrm{k_p} - (\mathrm{n}-1)\mathrm{k_b} + (\mathrm{k_b}-\mathrm{k_p})\Phi}\right) k_f \quad (8)$$

$$\mu_{\mathrm{nf}} = (1-\Phi)^{2.5}\mu_f \quad (9)$$

The source terms (S_m *and* S_e) in the equations (2 and 3) represent the momentum and energy transfer between the fluid and particles respectively **[24,25]**:

Momentum source term, S_m, can be calculated from momentum exchange between the phases as particles are moving through an element of the Eulerian phase of the base fluid with volume of δV. The Eulerian cell should be larger than the particles which in the case of nano particles there is no concern about this **[26]**:

$$S_m = \sum_{np} \frac{m_p}{\delta V}\frac{d\vec{V}_p}{dt} \quad (10)$$

The $\vec{F}$ in Eq. (4) is comprised of body forces and various hydrodynamic forces, which includes the effects of gravity, drag force, Saffman's lift force, thermophoretic force and Brownian force **[27]**.

$$\vec{F} = \vec{F}_G + \vec{F}_D + \vec{F}_L + \vec{F}_T + \vec{F}_B = m_p\frac{d\vec{V}_p}{dt} \quad (11)$$

Where: ($\vec{V}_p = dX_p/dt$) and (X_p) are the velocity and location of the particle respectively.

In this study, the Nano-particulate suspension was forced inside the channel of a volumetric reciever then the drag force considered only, The drag force on the particle (F_D) *is* **[28]**:

$$F_D = \frac{18\mu}{\rho_p d_p^2 C_c}(\vec{V} - \vec{V}_p) \quad (12)$$

Where (C_c) is the Cunningham correction factor, which is used for non continuum effects when calculating the drag on small particles. The deviation of Stocks law (It is used to calculate the drag force on small particles and it assumes no-slip condition) which is no longer correct at high Knudson number (the ratio of the molecular mean free path length to a representative physical length scale this could be for example the radius of a body in fluid). The Cunningham correction factor can be written as following **[29]**:

$$C_c = 1 + \frac{2\gamma_{mp}}{d_p}\left(1.257 + 0.4e^{-(1.1d_p/2\gamma_{mp})}\right) \quad (13)$$

Where (γ_{mp}) is the molecular mean free path:

$$\gamma_{mp} = \frac{k_b T}{\sqrt{2}\pi\sigma^2 P} \quad (14)$$

IJERMS
International Journal of Engineering Researches and Management Studies

In the definition of molecular mean free path, k_b , σ and P are Boltzmann Constant ($k_b = 1.38066 \times 10^{-23}\, J/K$), collision diameter of the molecules and fluid pressure. The collision diameter of the molecules can be written as:

$$\sigma = \pi d_f^2 \tag{15}$$

Where (d_f) is the base fluid molecule equivalent diameter, can be written as following:

$$d_f = 0.1(6M/N_A \pi \rho_{fT_0})^{1/3} \tag{16}$$

Where (M) is the molar mass, (N_A) is the Avogadro number= 6.022×10^{23}, and (ρ_{fT_0}) is the fluid density at reference temperature ($T_0 = 293\, K$).

The energy source term (S_e) would be the heat transfer between the phases **[26]**:

$$S_e = \sum_{np} \frac{m_p}{\delta V} C_{p_p} \frac{dT_p}{dt} \tag{17}$$

Where:

$$m_p C_{p_p} \frac{dT_p}{dt} = Nu_p\, \pi\, d_p\, k_f \left(T - T_p\right) \tag{18}$$

Where (Nu_p) is the particle-fluid interaction Nusselt number and be calculated using the correlation of **[29]**:

$$Nu_p = \frac{h_p d_p}{k_f} = 2 + 0.6 Re_p^{0.5}\, Pr_f^{0.3} \tag{19}$$

Where (Pr_f) is the base fluid prandtl number ($Pr_f = C_{p_f} \mu_f / k_f$) and ($Re_P$) is the nanoparticle Reynolds number, (Re_p) is given by **[30,31]**:

$$Re_p = \frac{2\rho_f k_b T}{\pi \mu_f^2 d_p} \tag{20}$$

In order to investigate the nanofluid flow behaviour, the flow parameters such as friction factor (Darcy friction factor) and pressure drop can be obtained by using the following equations.

$$f = \frac{8\tau_w}{\rho_{nf} u_m^2} \tag{21}$$

$$\Delta p = f \frac{L}{D_h} \frac{\rho_{nf} u_m^2}{2} \tag{22}$$

Where: (τ_w) is the wall shear stress, (u_m) the nanofluid mean velocity at the inlet, (L and D) are the pipe length and diameter respectfully.

In the term of the thermal performance, the average heat transfer coefficient and average Nusselt number can be estimated by using the following equations **[32]**:

IJERMS
International Journal of Engineering Researches and Management Studies

$$\bar{h}_{nf} = \frac{C_{p_{nf}} \rho_{nf} u_m^2 A (T_{b,0} - T_{b,i})}{\pi D_h L (T_w - T_b)_M} \quad (23)$$

$$\overline{Nu}_{nf} = \frac{\bar{h}_{nf} D_h}{k_{nf}} \quad (24)$$

Where: ($\bar{h}_{nf}$) is the average heat transfer coefficient, ($\overline{Nu}_{nf}$) is the average Nusselt number of the nanofluid, ($T_{b,0} - T_{b,i}$) is the temperature difference between the nanofluid at the inlet and the outlet of the oscillating pipe, and $(T_w - T_b)_M$ is the mean temperature difference between the wall temperature and the nanofluid mean temperature.

Th pumping power which is one of the important parameters in the area of pipes flow can be calculated as following **[33]**:

$$PP = \dot{V}\, \Delta p_t = \frac{\dot{m}\, \Delta p_t}{\rho_{nf}} \quad (25)$$

Where (Δp_t) is the total pressure difference between the inlet and outlet of the pipe, ($\dot{V}$) is the volumetric flow rate and ($\dot{m}$) is the mass flow rate.

3. RESULTS AND DISCUSSION

The Numerical simulation is carried out by using two-phase (Eulerian-Lagrangian discrete phase) model for TiO_2-Water nanofluid flow inside a constant heat flux (20 kW/m^2) oscillating pipe. Fig. (2) shows the velocity magnitude along the flow field inside the pipe, and Fig. (3) shows the velocity vectors along the flow field. These figures show the effect of the oscillation on the nanofluid velocity magnitudes and vectors, the nanofluid initial velocity was assumed (0.03 m/sec).

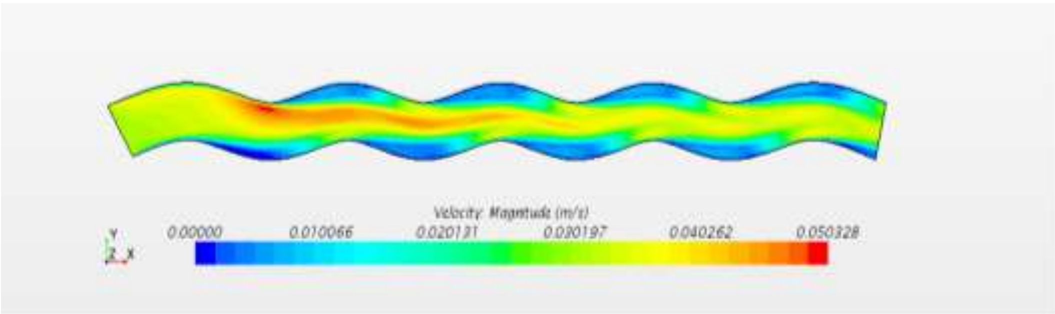

Figure 2. Velocity magnitude distribution along the oscillating pipe (Ø=0.1 vol. %) and (Re=1030)

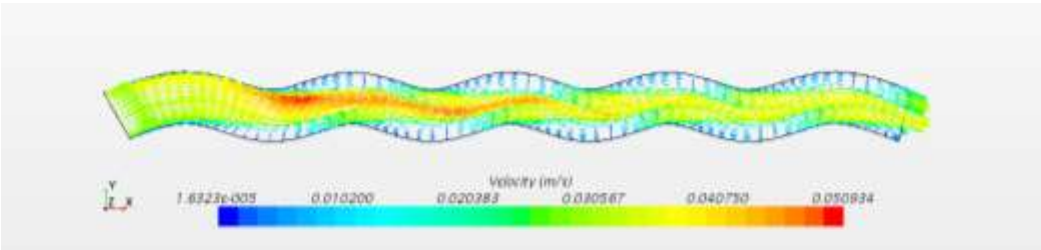

Figure 3. Velocity magnitude distribution along the oscillating pipe (Ø=0.1vol. %) and (Re=1030)

ISSN: 2394-7659
IMPACT FACTOR- 2.785

IJERMS
International Journal of Engineering Researches and Management Studies

Fig. (4) shows the nanoparticles motion inside the pipe, the dispersed nanoparticles in the base fluid could be shown be using the discrete phase (two-phase) model which offers the possibility of investigated the motion and the behaviour of the suspended nanoparticles in the base fluid rather than the single phase model.

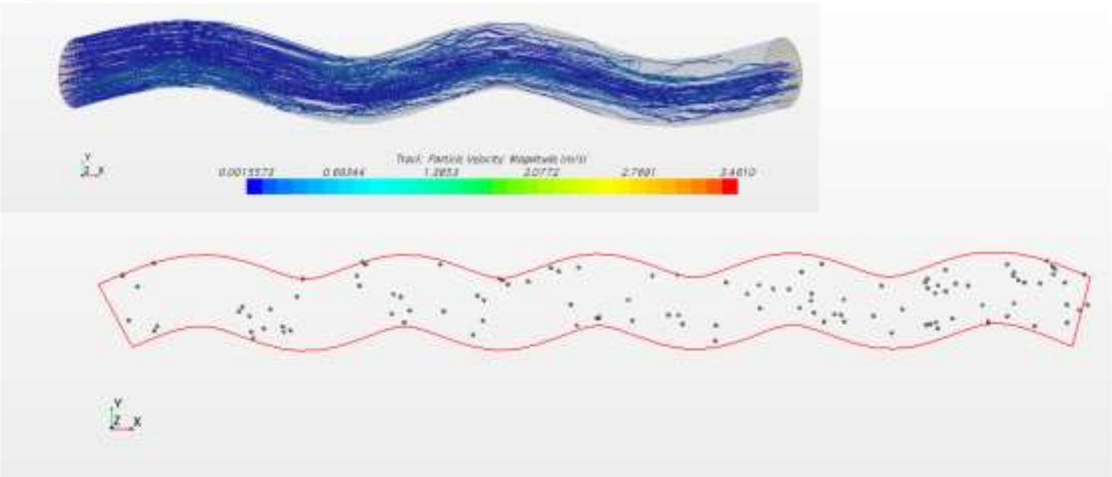

Figure 4. Motion of dispersed nanoprticles in the base fluid inside the oscillating pipe (Ø=0.1vol. %) and (Re=1030)

Fig. (5) shows the temperature distribution of the nanofluid along the pipe, the temperature of the nanofluid at the inlet was assumed (294 K). This figure represent the effect of the oscillating model on the temperature profile.

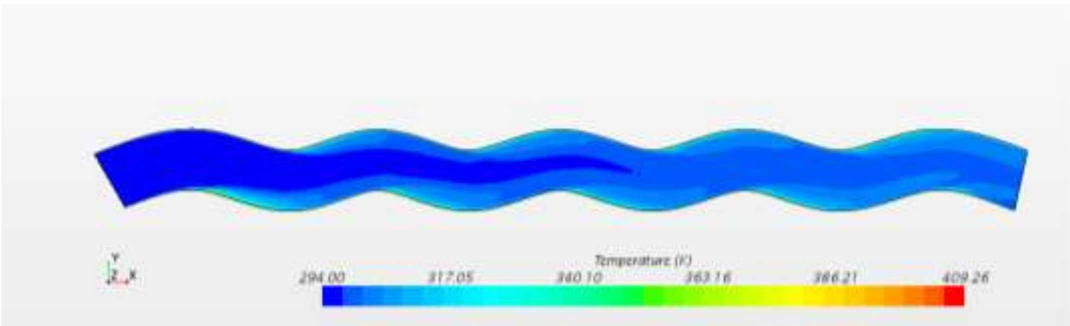

Figure 5. Temperature distribution along the oscillating pipe (Ø=0.1 vol. %) and (Re=1030)

Fig. (6) shows the temperature gain by the nanofluid inside the pipe which is the difference between the temperature in the outlet and the inlet faces. The results are taken for different nanoparticles volume fraction in addition to the pure water for different flow rates of the nanofluid. It represents the effect of increasing the nanoparticles concentration on the temperature gain which is reach the maximum value in the (Ø=0.5 vol.%) at lowest flow rate value. Fig. (7) shows the effect of increasing the nanofluid Reynolds number on the friction factor for different nanoparticles volume fraction in addition to the pure water. It is clear that the friction factor reach its minimum value in the case of pure water and high Reynolds number which is approximately equal to (0.121)

IJERMS
International Journal of Engineering Researches and Management Studies

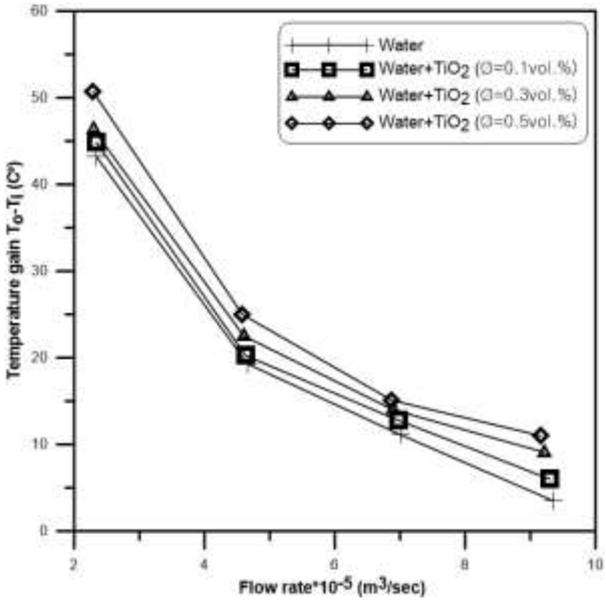

Figure 6. Temperature gain by the nanofluid versus nanofluid flow rate values

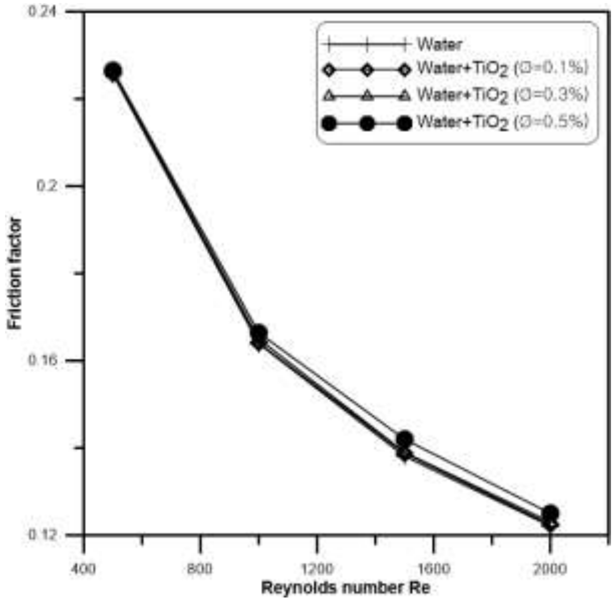

Figure 7. Friction factor versus nanofluid Reynolds number

Fig. (8) shows the relation between the pressure drop and the Reynolds number for different volume fraction and pure water. The pressure drop reaches the maximum value in the case of volume fraction (Ø=0.5 vol.%) and in the Reynolds number equal to (2000) which is about (1.9 Pa). Fig. (9) shows the effect of the nanofluid Reynolds number (up to 2000) on the average Nusselt number $\overline{Nu}$ for different nanoparticle concentration and for pure water. It can observed from the reslts the effect of increasing both Reynolds number and volume fraction on the average Nusselt number. The results are compared with others from Yang et al. research **[34]**, they investigated the thermal behavior of the nanofluid inside a oscillating square cross sectional channel with different oscillating channel amplitude (Amp.), Those results were taken for Al_2O_3/water and (Ø=0.3 vol.%).

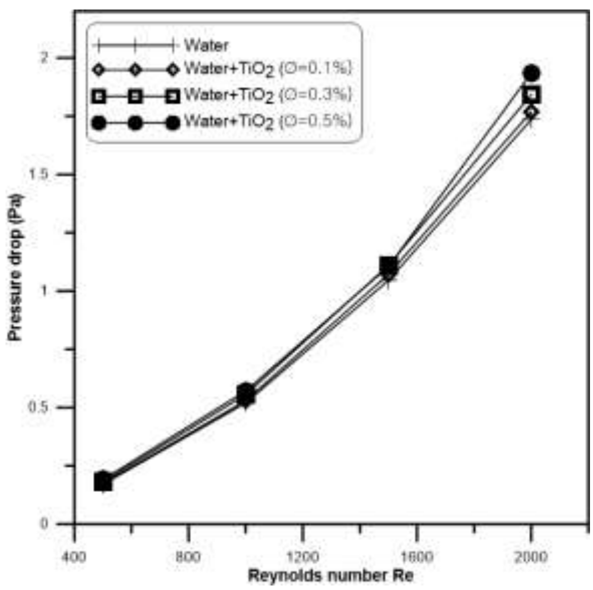

Figure 8. Pressure drop versus nanofluid Reynolds number

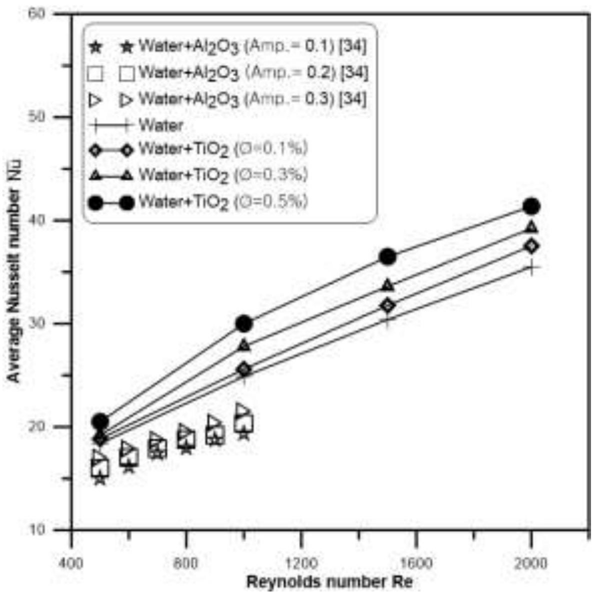

Figure 9. Average Nusselt number versus Reynolds number

IJERMS
International Journal of Engineering Researches and Management Studies

Fig. (10) shows the relation between the average heat transfer coefficient ($\bar{h}$) and the Reynolds number for different nanoparticles volume fraction.

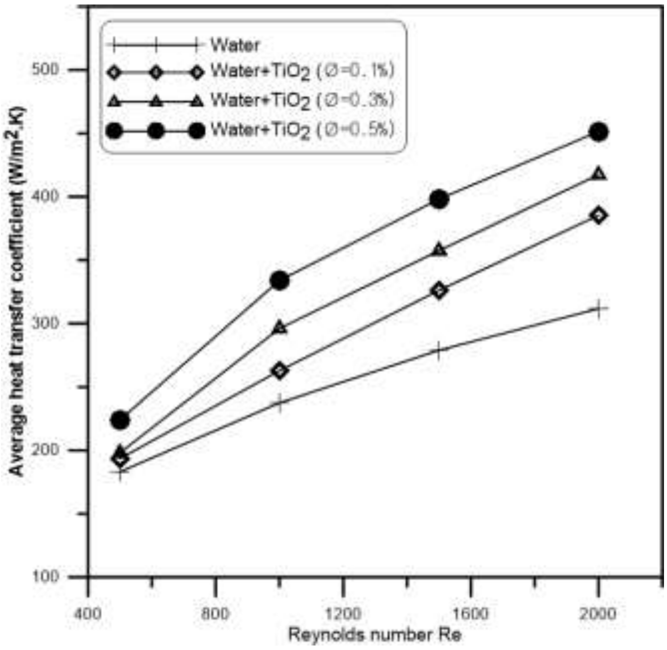

Figure 10. Average heat transfer coefficient versus Reynolds number

Fig. (11 and 12) show the thermal performance enhancement. Fig. (11) shows the average heat transfer coefficient ratio which is defined as the ratio of the nanofluid to base fluid average heat transfer coefficient, it represents that the maximum value of this ratio is about (1.45) in the Reynolds value (2000) and nanoparticles loading (Ø=0.5 vol.%). Fig. (12) shows the average Nusselt number ratio which is the ratio of the nanofluid to base fluid average Nusselt number, the results show that this ratio reaches it maximum value (about 1.35) in the Reynolds value (2000) and nanoparticles loading (Ø= Ø=0.5 vol.%). The presented work nusselt number enhancement results were compared with others from Ahmed et al. paper **[35]**, these results were taken for numerical investigation for laminar copper–water nanofluid flow and heat transfer in a two-dimensional oscillating channel. The Reynolds number and nanoparticle volume fraction considered are in the ranges of 100–800 and (0.1–0.5 vol.%) respectively as shown in fig. (12). The results show the different between nusselt number enhancement values between the oscillating channel and oscillating pipe.

IJERMS
International Journal of Engineering Researches and Management Studies

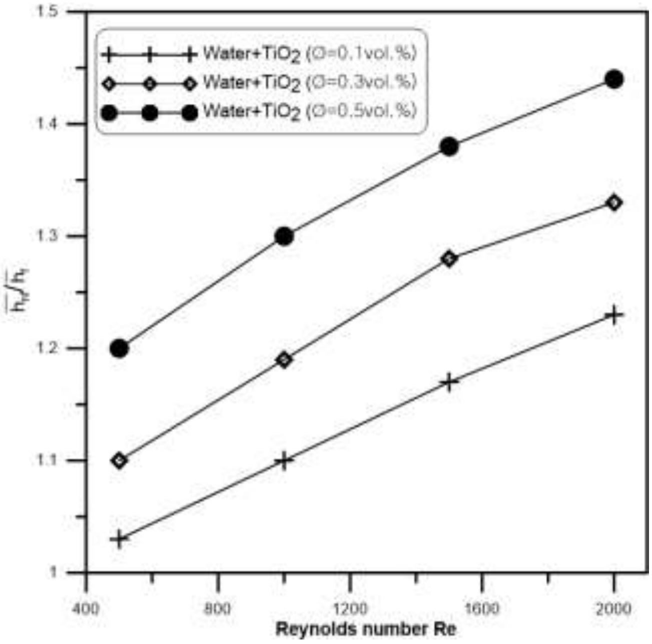

Figure 11. Average heat ransfer ratio versus Reynolds number

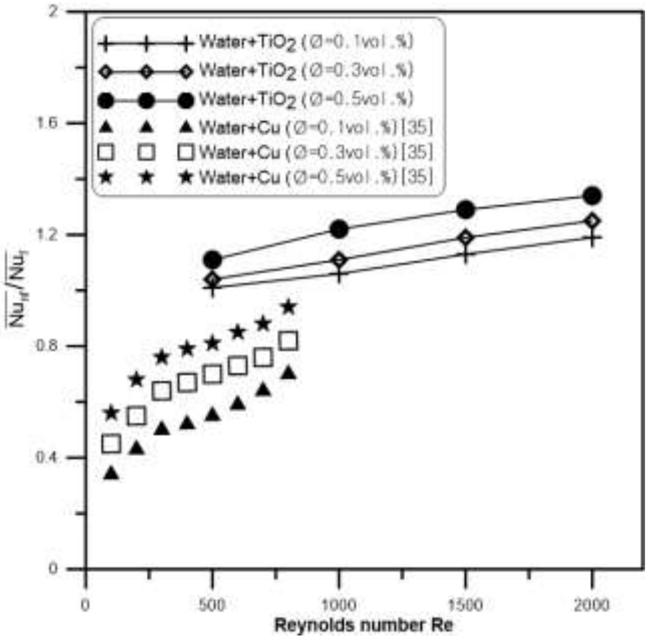

Figure 12. Average Nusselt number ratio versus Reynolds number

Fig. (13) represents the relation between the pumping power and the Reynolds number for different nanoparticles concentration (Ø=0.1-0.5 vol.%) in addition to the pure water.

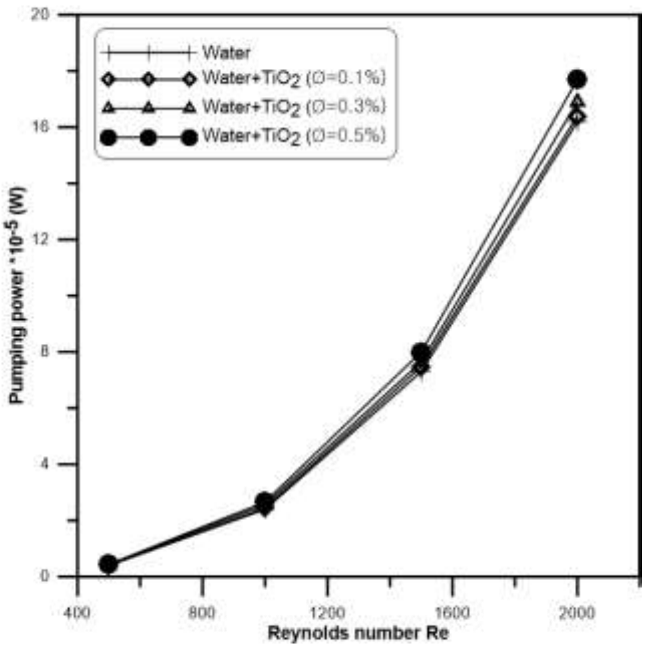

Figure 13. Pumping power versus nanofluid Reynolds number

IJERMS
International Journal of Engineering Researches and Management Studies

4. CONCLUSION

In this study, the laminar convective heat transfer and flow behaviour of TiO_2 nanofluid inside a ocillating pipe subjected to constant heat flux is numerically investigated. the two-phase model was applied to taking into the consideration the interaction between the dispersed nanoparticles and base fluid molecules. Using oscillating pipe to thermal performance enhancement methode is an inexpensive and suitable way. Ocillating pipe prevent the development of flow inside it by disturbing the flow field and boundary layer, also it improves the mixing of higher and lower temperature flows which leads to enhance the heat transfer.

The contribution of dispersed nanoparticles in the base fluid on the thermal performance enhancement is carried out for different nanoparticles loading. The better thermal performance may be cased by the chaotic movement of the nanoparticles in the base fluid. The results show the average Nusselt number an heat transfer coefficient enhancement as a result of nanoparticles loading, but tacking into the consideration the required pumping power. Also, it is found that the nanoparticles in a low volume fraction has no significant effect on the friction coefficient.

REFERENCES

1) Kreith, F., and M. S. Bohn," Principles of Heat Transfer", 5th ed. Boston, MA: PWS Publishing Company, 1997.

2) Brian J. Kirby," Micro- and Nanoscale Fluid Mechanics (Transport in Microfluid Devices)", Cambridge University Press, UK, 2010.

3) Oronzio Manca, Yogesh Jaluria and Dimos Poulikakos," Heat Transfer in Nanofluids", Hindawi Publishing Corporation, 2010.

4) Zhuomin M. Zhang ," Nano and Microscale Heat Transfer", The McGraw-Hill Companies, 2007.

5) Nanofluids (Science and Technology)-[Sarit K. Das, Stephen U.S.Choi, Wenhua Yu and T. Pradeep] 2008

6)Nanofluidics (Thermodynamic and Transport Properties- [Efstathios E. (Stathis) Michaelides] 2014.

7 Akbar, N.S.; Raza, M.; Ellahi, R. Influence of heat generation and heat flux on peristaltic flow with interacting nanoparticles. Eur. Phys. J. Plus 2014, 129.

8) Sheikholeslami, M.; Bandpy, M.G.; Ellahi, R.; Zeeshan, A. Simulation of MHD CuO-water nanofluid flow and convective heat transfer considering Lorentz forces. J. Magn. Magn. Mater. 2014, 369, 69–80.

9) Ellahi, R.; Hassan, M.; Zeeshan, A. Shape effects of nanosize particles in Cu-H2O nanofluid on entropy generation. Int. J. Heat Mass Transf. 2015, 81, 449–456.

10) Sheikholeslami, M.; Ellahi, R.; Hassan, M.; Soleimani, S. A study of natural convection heat transfer in a nanofluid filled enclosure with elliptic inner cylinder. Int. J. Numer. Methods Heat Fluid Flow 2014, 24, 1906–1927.

11) Sheikholeslami, M.; Ellahi, R.; Ashorynejad, H.R.; Domairry, G.; Hayat, T. Effects of heat transfer in flow of nanofluids over a permeable stretching wall in a porous medium. J. Comput. Theor. Nanosci. 2014, 11, 486–496.

12) Akbar, N.S.; Raza, M.; Ellahi, R. Interaction of nano particles for the peristaltic flow in an asymmetric channel with the induced magnetic field. Eur. Phys. J. Plus 2014, 129, 155–167.

13) Bianco, V.; Manca, O.; Nardini, S. Second law analysis of Al2O3-water nanofluid turbulent forced convection in a circular cross section tube with constant wall temperature. Adv. Mech. Eng. 2013, 2013, 1–12.

14) Bianco, V.; Manca, O.; Nardini, S. Performance analysis of turbulent convection heat transfer of Al2O3 water-nanofluid in circular tubes at constant wall temperature. Energy 2014, 77, 403–413.

15) O'Brien, J.E., Sparrow, E.M.: Corrugated duct heat transfer, pressure drop, and flow visualization. ASME J. Heat Transf. 104, 410–416 (1982)

16) M.A. Ahmed, M.Z. Yusoff and N.H. Shuaib, Numerical Investigation on the Nanofluid Flow and Heat Transfer in a Wavy Channel, Engineering Applications of Computational Fluid Dynamics, Volume 44 of the series Advanced Structured Materials pp 145-167, 2015.

17) Fabbri, G.: Heat transfer optimization in corrugated wall channels. Int. J. Heat Mass Transf. 43, 4299–4310 (2000).

18) M Shams and S Tolou," Heat transfer enhancement of a horizontal microchannel using ferro-nanoparticles injection, Journal of Physics: ConferenceSeries 362 (2012) 012010.

International Journal of Engineering Researches and Management Studies

19) *Angela Diggs and S. Balachandara," Evaluation of methods for calculating volume fraction in Eulerian–Lagrangian multiphase flow simulations", Journal of Computational Physics, 2016, Pages 775–798.*

20) *Vincenzo Bianco, Oronzio Manca, Sergio Nardini and Kambiz Vafai, "Heat Transfer Enhancement with Nanofluids", CRC press, New York, 2015.*

21) *Jang, S. P., and S. U. S. Choi. 2007. "Effects of various parameters on nanofluid thermal conductivity." Journal of Heat Transfer no. 129 (5):617–623.*

22) *Xuan, Y. M., and W. Roetzel. 2000. "Conceptions for heat transfer correlation of nanofluids."International Journal of Heat and Mass Transfer no. 43 (19):3701–3707.*

23) *Wang, X.-Q., and A. S. Mujumdar. 2008a. "A review on nanofluids—Part I: Theoretical and numerical investigations." Brazilian Journal of Chemical Engineering no. 25 (4):613–630.*

24) *Beñat Oliveiraa, Juan Carlos Afonsoa and Sergio Zlotnik," A Lagrangian–Eulerian finite element algorithm for advection–diffusion–reaction problems with phase change", Computer Methods in Applied Mechanics and Engineering, 2016, Pages 375–401.*

25) *Goutam Saha and Manosh C. Paul," Discrete Phase Approach for Nanofluids Flow in Pipe", Second International Conference on Advances In Civil, Structural and Mechanical Engineering- CSM 2014, 16-17 Nov 2014, Birmingham, UK.*

26) *Pak BC, Cho YI (1998) Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Exp Heat Transf 11:151–170*

27) *Efstathios E. (Stathis) Michaelides," Heat and Mass Transfer in Particulate Suspensions", Springer, New York, 2013.*

28) *H. Ounis, G. Ahmadi, J.B. McLaughlin, Brownian diffusion of sub micrometer particles in the viscous sublayer, J. Colloid Interface Sci. 143 (1991) 266–277.*

29) *Ranz and Marshall, "Correlation limits on heat flow between a sphere and its surrounding gas at high temperature", thermal science, 2015, Vol. 19, No. 5, pp. 1521-1528.*

30) *Corcione, M. 2011b. "Rayleigh-Benard convection heat transfer in nanoparticle suspensions."International Journal of Heat and Fluid Flow no. 32 (1):65–77.*

31) *Corcione, M. 2011a."Empirical correlating equations for predicting the effective thermal conductivity and dynamic viscosity of nanofluids." Energy Conversion and Management no. 52:789–793.*

32) *Hsien-Hung Ting and Shuhn-Shyurng Hou,"Investigation of Laminar Convective Heat Transfer for Al2O3-Water Nanofluids Flowing through a Square Cross-Section Duct with a Constant Heat Flux", Materials 2015, 8, 5321-5335.*

33) *Agrawal, K. N., and H. K. Varma. 1991. "Experimental-study of heat-transfer augmentation versus pumping power in a horizontal R12 evaporator.", International Journal of Refrigeration—Revue Internationale Du Froid no. 14 (5):273–281.*

34) *Yue-Tzu Yang, Yi-Hsien Wang , Po-Kai Tseng, Numerical optimization of heat transfer enhancement in a wavy channel using nanofluids International Communications in Heat and Mass Transfer 51 (2014) 9–17.*

35) *M.A. Ahmed, N.H. Shuaib, M.Z. Yusoff," Numerical investigations on the heat transfer enhancement in a wavy channel using nanofluid", International Journal of heat and mass transfer 55 (2012) 5891-5898.*