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Research Article

Modeling and Simulation of Unsteady Forced Convection Heat Transfer for Water/Al_2O_3 Nanofluid in Cylindrical Duct

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Abstract

The flow field, heat transfer and forced convection heat transfer for the Al_2O_3-water nanofluid in a cylindrical Duct were numerically studied. Certain boundary conditions using a numerical method were used to solve the governing equations. The effect of different volumes of the volume fraction of nanoparticles Al_2O_3 on the flow and heat transfer of Al_2O_3-water nanofluid in a cylindrical Duct in a developed and unstable flow regime under convection heat transfer conditions with constant temperature boundary condition were numerically investigated. The resulted nanofluid was modeled using homogeneous mixture model relationships assuming the distribution of nanoparticles in water is homogeneous. The constant temperature condition and at the outlet cross-section, the velocity and temperature profile development condition was used in the Duct walls. The profile of velocity and temperature is assumed to be uniform and constant at the input stage. The present study was carried out aimed to study the variations of the parameters of flow and heat transfer of water/ aluminum oxide nanofluids due to the use of volume fraction, Reynolds Number and different inlet temperature of nanofluid. According to the results, increasing the Reynolds number of the flow and the fluid velocity and the inlet temperature of the nanofluid increases the heat transfer.

Keywords: Heat transfer; Forced convection; Nanofluid; Numerical study; Al_2O_3 nanoparticle; Single phase model.

Introduction

Nanofluids are prepared by dispersing nano-scale solid particles (less than 100 nm) in a pure fluid such as water, ethylene glycol or propylene glycol. Choi was the first person who has named these compositions with excellent thermal properties as "Nanofluid" [1]. Then, Xuan and Li [2] during a study concluded that the presence of nanoparticles with high thermal conductivity coefficient (such as copper, aluminum, silver and titanium) inside Nanofluids leads to increase the thermal conductivity coefficient of such mixtures, and in general, increase their ability for heat transfer.

Nowadays, Nanofluids as fluids that are used as a new heat transfer factor in building heating, various heat exchangers and cooling applications for automobiles, have attracted much attention of researchers due to their unique thermal performance. Some of the most important advantages of using Nanofluids include improving heat transfer, reducing the size of heat transfer systems, minimizing contamination, micro-channels cooling and minimizing systems.

There are many studies on the energy transfer and thermal properties of Nanofluids (such as effective dynamic viscosity, thermal conductivity coefficient, etc.). Lee et al. [3], Xie et al. [4], Patel et al. [5] and Chang et al. [6] have conducted relevant studies on the study of the thermal properties of Nanofluids. In addition, many studies have been carried out on the effects of the presence of nanoparticles in convection heat transfer by analytical, numerical and experimental methods [7].

The heat transfer coefficient or Nusselt number (Nu) for the Nanofluids depends on the thermo-physical properties of the base fluid and the ultra-fine particles, the flow pattern and flow structure, the volume fraction of the suspended

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particles, the dimensions and the shape of these particles. The aim of the present study is to investigate the forced convection heat transfer in a cylindrical Duct, taking into account the effects of all of the above mentioned parameters on the most widely used dimensions of the desired geometry.

Experimental

In general, calculations of heat transfer from high temperature plates lead to produce simultaneous different effects of heat transfer mechanisms on the characteristics of heat exchangers and other heat transfer equipment. On the other hand, forced convection heat transfer in heated nanofluid layers around a rotation axis is still arisen as a major issue which needs further studies. Figure 1, shows the geometry of the problem, which is a cylinder with a length/diameter ratio of L/D=30. The non-slip condition is applied in the walls and the temperature is constant and varies between 20-25°C. The nanofluid flows enters Duct in a slow-flow regime, unsteady state and uniform temperature, respectively, U_0 and T_0, and after exchanging heat with the walls, leaves the channel in full developed hydrodynamic and thermal state. It is assumed that the spherical shape nanoparticles have an average diameter of 10 nm and are in a thermodynamic equilibrium with a base fluid and non-slip in relation to its molecules.

It is obvious that, there is a need to introduce the nanofluid fluid and thermal properties to solve the equations. These characteristics include conduction coefficient, viscosity, density, thermal expansion coefficient and specific heat capacity. Most of the models presented by Kerosene are used according to the results of examination of a large number of theoretical and quasi-experimental models presented by the researchers to model the thermal conductivity coefficient and viscosity and comparing their results with each other. These models are quasi-experimental and their results are consistent with the empirical results of others [8].

Thermo-physical properties of nanofluids

The thermo-physical properties (specific heat, viscosity, thermal conductivity and density) of the nanofluid can be calculated as a function of the percentage and characteristics of the base fluid and volumetric nanoparticles of nanoparticle due to the small temperature variations. Table 1, shows the thermo-physical properties of water and nanoparticles at 310k temperature [9].

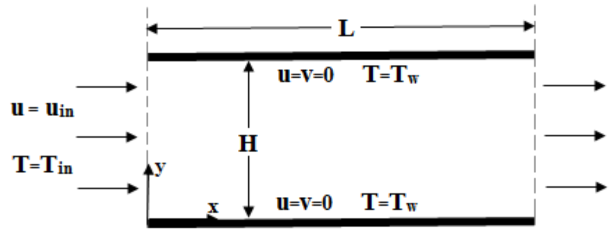

Figure 1. Flow in a cylindrical Duct with a length/diameter ratio of 30.

The density variations in the term buoyancy force, as are given in the conservation of angular momentum, follow the Boussinesq approximation. The effective density of the nanofluid, the Boussinesq coefficient and the denominator of the thermal diffusion coefficient are also calculated using the mixing rule.

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

It is assumed that the density and specific heat capacity of the base fluid, in contrast to the conduction coefficient, viscosity and thermal expansion coefficient, is variable with temperature during numerical solving, which the following correlation relations are determined for the water base fluid [10-12].

$$C_{pf} = 2\times10^{-6}T^4 - 3\times10^{-3}T^3 + 1.6T^2 - 357.7T + 342.82 \quad (2)$$

$$\rho_f = -0.0034T^2 + 1.7538T + 775.93 \quad (3)$$

Although, them above equations (2) and (3) need more time for the convergence of the problem, but gives more accurate results about modeling.

It is necessary to consider the nanofluid-related fluid and thermal properties in equations to model nanofluid. The viscosity and thermal conductivity coefficient of Al_2O_3-water are calculated based on the Maiga et al. Model. According to laboratory studies conducted by Masuda et al, Lee et al., And Choi et al., for the Al_2O_3-water Nanofluid, the viscosity and effective conductivity can be expressed as follows [13-16].

$$\mu_{nf} = (123\varphi^2 + 7.3\varphi + 1)\mu_{bf}$$

$$k_{nf} = (4.97\varphi^2 + 2.72\varphi + 1)k_{bf} \quad (4)$$

Where, p indicates nanoparticles, nf represents Nanofluid and, and bf indicates base fluid. The

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thermo-physical properties of water and nanoparticles are according to Table 1.

According to Buongiorno [17], the specific heat of the nanofluid is calculated using the following equation assuming that the base fluid with the nanoparticles is in heat balance.

$$(\rho C_p)_{nf} = \frac{(1-\emptyset)(\rho C_p)_f + \emptyset(\rho C_p)_{np}}{(1-\emptyset)(C_p)_f + \emptyset(C_p)_{np}} \quad (6)$$

The accuracy of these equations are based on the nanofluid properties which is measured by Pak and Cho [18] and Xuan and Roetzel [19], which these equations are suitable based on their experimental data.

The nanofluid velocity and temperature field is assumed to be symmetric with respect to the central line of the pipe. Conservation equations for single-phase methods are presented in Equations (7)-(9).

Table 1. Thermo-physical properties of water and Al_2O_3 nanoparticles

Material	Water	Al_2O_3 nanoparticles
Density (kg / m3)	998.2	3970
Specific heat capacity (J kg.K)	4180	765
Thermal conductivity (W / m.C)	0.6	40
Viscosity (N.s / m2)	0.001003	-

The governing equations

In order to achieve a correct numerical solution in single-phase fluid flows simulation, when no accurate information on the flow regime is available, it is necessary to use the Reynolds number range to ensure the Laminar flow and the classical equations of the Laminar flow to be used. The continuity equation in a steady-state state is expressed by the following equation.

$$\nabla.(\rho\vec{V}) = 0 \quad (7)$$

Note that the fluid density is constant and there is no mass production. The linear conservation of angular momentum equation for the incompressible fluid flow is written in form of Equation (6).

$$(\vec{V}.\vec{\nabla})\vec{V} = -\frac{\vec{\nabla}P}{\rho} + \frac{\mu\nabla^2\vec{V}}{\rho} + g \quad (8)$$

The Navier-Stokes equation is that last equation. For temperature analysis of the fluid, the energy equation in the following equation is used:

$$\rho C\vec{V}.\vec{\nabla}(T) = K_{eff}\vec{\nabla}.(\vec{\nabla}T) \quad (9)$$

The quantities C and T are the temperature and heat capacity of nanofluid, respectively. The boundary conditions used in the numerical solution are summarized as follows:

Input:

$$v_r = v_\theta = 0 \; v_z = \text{cte} \quad T_{in} = 310K \quad (10)$$

Output:

$$v_r = v_\theta = 0 \; v_z = \text{cte} \quad P = 1\,atm \quad (11)$$

Results and discussion

The number of 210 × 100 node networks along radial and axial for 200 × 100 node non-uniform networks has been used. There are more nodes near the tube wall. The conservation equations were solved for unstable conditions in a two-dimensional system using a discrete central difference method.

The model for analysis of the effect of Al_2O_3 concentration on the Reynolds number (300-1120), the inlet temperature of the nanofluid (35-20°C) was used. The nanofluid temperature field containing 5 % (v/v) of Al_2O_3 at Re =885 and the surface temperature of 80 °C in an unsteady state is shown in Figure 2.

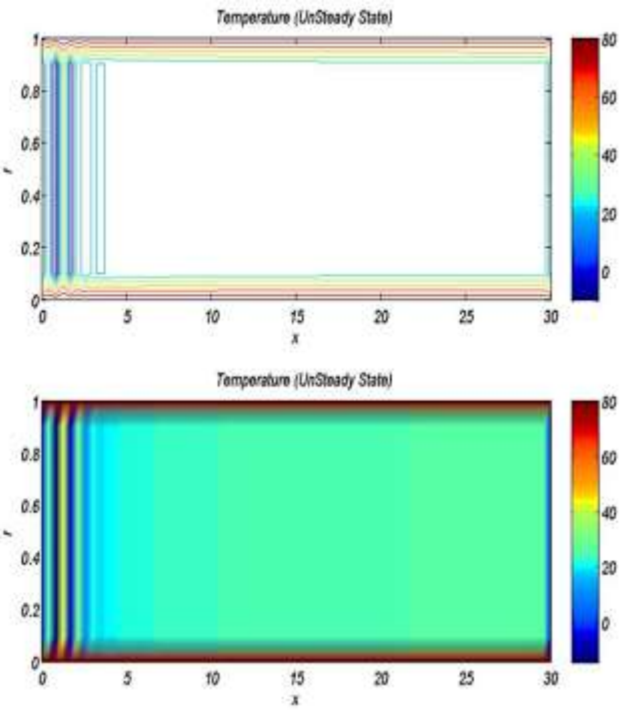

Figure 2. The nanofluid temperature field containing 5 % (v/v) of Al_2O_3 at Re =885 and the surface temperature of 80°C

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The effect of the concentration of Al_2O_3 nanoparticles

The concentration of nanoparticles was set at 1, 2, 3, 4, 6, 8, and 10% vol. The forced convection heat transfer was studied at Re = 450 and at surfaces temperature of 80 ° C. The forced convection heat transfer coefficient of nanofluid is shown in Figure 3 as a function of the amount of Al_2O_3 nanoparticles. The increase of the forced convection heat transfer coefficient of nanofluid by increasing the nanoparticles is shown in this figure. The forced convection heat transfer coefficient of nanofluid containing *5 %vol* of Al_2O_3 is 60.43% higher than the forced convection heat transfer of water.

In similar operating conditions, fluids with a higher heat transfer coefficient have a higher forced convection heat transfer coefficient. The thermal conductivity coefficient of the nanofuild is a function of both the thermal conductivity of the nanoparticles and the thermal conductivity of the base fluid. An increase in the concentration of nanoparticles increases in the conduction heat transfer coefficient and hence the convection heat transfer coefficient.

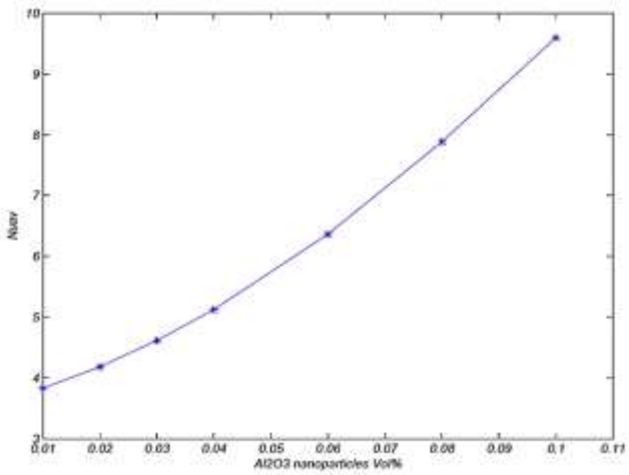

Figure 3. The effect of Al_2O_3 nanoparticle concentration on the convention heat transfer coefficient of nanofluid

Nanofluid effect of Reynolds number

Figure 4 shows the effect of Reynolds on the heat transfer coefficient. The forced convection heat transfer increases by increasing the Reynolds number of the nanofluid flow. An increase in the Reynolds number of the flow leads to increased flow turbulence. This event increases the effective thermal conductivity of the fluid and, as a result, increases the convection heat transfer [20].

Effect of the inlet temperature of the nanofluid

As shown in the figure 5, as in conventional liquids, the convection heat transfer coefficient of nanofluid increases with increasing inlet temperature. This may be due to an increase in the nanoparticle's Brownian motion. Similar results have been reported by Keblinski et al. [21].

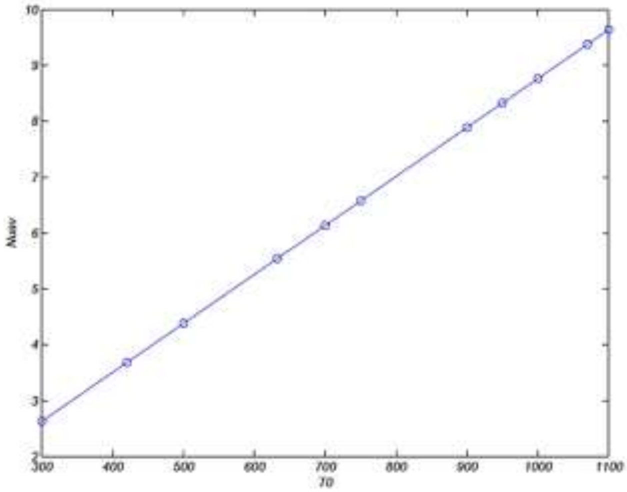

Figure 4. The effect of Reynolds on the convection transfer coefficient of the nanofluid

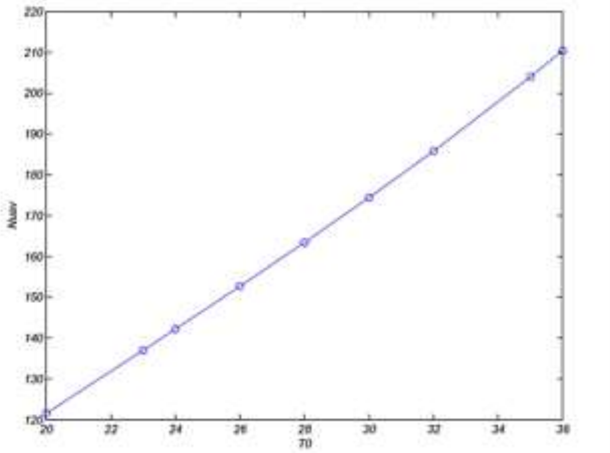

Figure 5. The effect of the fluid inlet temperature on the convection heat transfer coefficient in Re = 450, 4%vol of Al_2O_3 and the constant surface temperature of 80 °C in cylinder

Conclusions

Numerical simulation was used for the study of laminar flow. Laminar flow forced convective heat transfer fluid containing Al_2O_3 particles the size 10 nm, were studied under conditions of constant temperature level. Numerical Investigation results show that the convective heat transfer water by adding Al_2O_3 nanoparticles significantly increased. Nano convective heat transfer fluid with increasing

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nanoparticle concentration, Reynolds number and inlet temperature increases.

Conflicts of interest

Authors declare no conflict of interest.

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References

[1] Choi SUS. Enhancing thermal conductivity of fluids with nanoparticles. Proceedings of the 1995 ASME International Mechanical Engineering Congress and Exposition; 1995 Nov 12-17; San Francisco, USA, ASME, FED 231/MD 66, pp. 99-105.

[2] Xuan Y, Li Q. Investigation on convective heat transfer and flow features of nanofluids. J Heat Transfer 2003;125(1): 151-5.

[3] Lee S, Choi SUS, Li S, Eastman JA. Measuring thermal conductivity of fluids containing oxide nanoparticles. Int J Heat Mass Transfer 2001;121(2):280-9.

[4] [4] Xie HQ., Wang JC, Xi TG, Li Y, Ai F. Dependence of the thermal conductivity of nanoparticle–fluid mixture on the base fluid. J Mater Sci Lett 2002;21(19):1469-71.

[5] Patel HE, Pradeep T, Sundararajan T, Dasgupta A, Dasgupta N, Das SK. A micro convection model for thermal conductivity of nanofluid. Pramana J Phys. 2005;65(5):863-9.

[6] Chang H, Jwo CS, Lo CH, Tsung TT, Kao MJ, Lin HM. Rheology of CuO nanoparticle suspension prepared by ASNSS. Rev Adv Mat Sci 2005;10:128-32.

[7] Hadi Seyedi S, Nemati Saray B, Ramazani A. On the multiscale simulation of squeezing nanofluid flow by a high precision scheme. Powder Technol 2018;340:264-73.

[8] Tahir SH, Mital M. Numerical investigation of laminar nanofluid developing flow and heat transfer in a circular channel. Appl Therm Eng 2012;39:8-14.

[9] [9] Pathipakka G, Sivashanmugam P. Heat transfer behaviour of nanofluids in a uniformly heated circular tube fitted with helical inserts in laminar flow. Superlattices Microstruct 2010;47(2):349-60.

[10] Rabienataj Darzi AA., Farhadi M, Sedighi K. Heat transfer and flow characteristics of AL2O3– water nanofluid in a double tube heat exchanger. Int Commun Heat Mass Transfer 2013;47:105-12.

[11] Guo W, Li G, Zheng Y, Dong C. Laminar convection heat transfer and flow performance of Al2O3–water nanofluids in a multichannel-flat aluminum tube. Chem Eng Res Des 2018;133:255-63.

[12] Kordani N, Paknejad M. Numerical Investigation of the Thermal Performance Linear Parabolic Solar Collector Absorber Tubes Using Nanofluids Copper Oxide - Heating Oil. Iran J Marine Technol 2018;5(2):39-52.

[13] Pattanayak B, Mund A, Jayakumar JS, Parashar K, Parashar SKS. Synthesis, Characterisation and Heat Transfer Analysis of TiO_2-Water Nanofluid. MMSE J 2018;14:1-10.

[14] Liu L, Stetsyuk V, Kubiak KJ, Yap YF, Goharzadeh A, Chai JC. Nanoparticles for convective heat transfer enhancement: heat transfer coefficient and the effects of particle size and zeta potential. Chem Eng Commun. 2018;1-11. https://doi.org/10.1080/00986445.2018.1525364.

[15] Jayarami Reddy K, Madhusudhana Reddy NP, Konijeti RK, Dasore A. Numerical Investigation of Chemical Reaction and Heat Source on Radiating MHD Stagnation Point Flow of Carreau Nanofluid with Suction/Injection. Defect and Diffusion Forum 2018;388:171-89.

[16] Kean TH, Che Sidik NA, Asako Y, Ken TL, Aid SR. Numerical Study on Heat Transfer Performance Enhancement of Phase Change Material by Nanoparticles: A Review. J Adv Res Fluid Mech Therm Sci 2018;45(1):55-63.

[17] Buongiorno J. Convective transport in nanofluids. J Heat Transfer 2006;128(3):240-50.

[18] Pak BC, Cho YI. Hydrodynamic and heat transfer study of dispersed fluids with

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submicron metallic oxide particles. Exp Heat Transfer 1998;11(2):151-70

[19] Xuan Y, Roetzel W. Conceptions for heat transfer correlation of nanofluids. Int J Heat Mass Transfer 2000;43(19):3701-7.

[20] Ramachandrana K, Kadirgama K, Awad OI, Ramasamy D, Samykano M, Azmi WH. Comprehensive review of principle factors for thermal conductivity and dynamic viscosity enhancement in thermal transport applications: An analytical tool approach. Int Commun Heat Mass 2018;98:13-21.

[21] Keblinski P, Phillpot SR, Choi SUS, Eastman JA. Mechanism of heat flow in suspensions of nanosized particles (nanofluids). Int J Heat Mass Transfer 2002;45(4):855-63.

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