IMPROVING THERMAL PERFORMANCE USING AL_2O_3-WATER NANOFLUID IN A DOUBLE PIPE HEAT EXCHANGER FILLING WITH POROUS MEDIUM

by

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A double pipe heat exchanger is significant device for many industrial applications. In this paper, an experimental study using both porous media and nanofluid to enhance heat transfer in a double pipe heat exchanger is performed. The test rig has been fabricated with inner copper pipe of 1.10 m length, 16 mm, and 14 mm outside and inside diameter, respectively. While, the outer PVC pipe is 1 m length, 31 mm, and 27 mm outside and inside diameter, respectively. The inner pipe has been filling with 3 mm diameters of steel balls porous media. The experimental tests were performed utilizing alumina nanofluid (Al_2O_3-water) with two volume concentrations 0.5% and 1%. The volume flow-rates are in the range of (2-5) Lpm and 10 Lpm through inner and outer pipe, respectively. It was conducted with a constant 28 ^oC inlet temperature of cold fluid-flow inside the inner pipe and 50 ^oC inlet temperature of hot fluid-flow inside the outer pipe. Results indicated that the heat transfer enhanced as nanofluid volume concentrations and volume flow-rates increase. It was observed that effectiveness increases as increase of flow-rate and nanofluid concentrations.

Key words: *heat exchanger, effectiveness, NTU, nanofluid, porous media*

Introduction

There are many applications of convection heat transfer through porous media, including the machine parts of rotating as petroleum refinery, geophysical problems, nuclear reactors, chemical and biomechanics branches. Many authors were investigated the convective heat transfer in porous medium may be found in the famous science books by Vafai [1], Ingham and Pop [2].

Kim *et al.* [3] were studied a different porous medium context adopting Darcy model with nanofluids. Ingham and Pop [4] were used the mathematical formula of nanofluid that proposed by Buongiorno [5] Tiwari and Das [6]. However, a nanofluid seems very flexibility of heat transfer and future coolants, which desirable to perform investigations including nanofluids and porous media [7]. Nield and Kuznetsov [8] were investigated the boundary-layer flow embedded through porous media filling with nanofluid adopting the mathematical formula Buongiorno [5].

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The problem of stability of nanofluid was first considered by Nield and Kuznetsov [9] that faced all problems of nanofluid users. The nanofluid boundary-layer flow over a moving surface in a flowing fluid has been studied by Bachok *et al.* [10]. The applications of nanofluid were reported by number of articles [11, 12].

The hybrid nanofluid including two or more types of solid nanoparticles suspended in water has been studied experimentally by Hussein [13]. Mixed convection nanofluid boundary-layer flow through porous media has been investigated by Tham *et al.* [14] adopting the mathematical nanofluid model proposed by Tiwari and Das [6]. Nield and Kuznetsov [15] were studied the nanofluid volume fraction as a boundary condition. It was not realistic due to the difficulty of controlling the volume concentrations of nanofluid on boundaries.

Hussein *et al.* [16] prepared three types of nanofluids and measured the thermal properties experimentally. They concluded that the thermal properties enhanced as increase of nanofluid concentrations from 1% to 2.5%. Rudraiah *et al.* [17] investigated convection heat transfer in a viscoelastic fluid through saturated porous medium. The heat transfers and fluid-flows on non-Newtonian fluid through a porous media have been reported by Shenoy [18].

The convection heat transfer onset in a viscoelastic fluid in porous medium influenced by thermal non-equilibrium has been conducted Shivakumara *et al.* [19] and Malashetty *et al.* [20]. There is significant comprehensive of references on nanofluid in the recent book by Das *et al.* [21], Duangthongsuk and Wongwises [22]. Both linear and non-linear stability analyses of convection heat transfer in a horizontal layer of a fluid through a porous media heated from below were studied by Wang and Mujumdar [23], Zhang *et al.* [24], Kakac and Pramuanjaroenkij [25], Eagen *et al.* [26], and Lee *et al.* [27].

Number of review studies have been focusing of heat transfer enhancement through porous medium like Fan and Wang [28] and Nazar *et al.* [29]. Sheu [30] investigated the onset of convection through a porous media in a horizontal layer with a nanofluid flowing.

Some review papers have contained the studies of nanofluid with porous medium in the heat exchanger Agarwal *et al.* [31] and Hussein *et al.* [32]. Hussein *et al.* [33-35] have investigated numerically the heat transfer and friction characteristics by employing elliptical tube to increase the heat transfer rate with a minimum increase of pressure drop. It was concluded that the heat transfers and pressure drop increase with increasing volume concentrations but decreasing with diameters of nanoparticles.

In this study, the nanofluid is a new class of heat transfer enhancement which includes the nanoparticles suspended in a base-fluid, we study the steady forced convection flow through a horizontal double pipe heat exchanger. The inner tube is filling with saturated porous medium and the nanofluid is flowing through it. On the other hand, the hot water is flowing through the outer tube. There are limited studies that considered the nanofluid flowing in a double pipe heat exchanger filling with porous medium using Darcy model.

Methodology

Governing equations

The under taken physical model configuration shown in fig. 1, is considered that a horizontal double tube heat exchanger. The continuity, momentum, and energy equations are governing the motion:

$$\nabla \vec{V} = 0 \tag{1}$$

$$\left(1+\pi\frac{\partial}{\partial t}\right)(\nabla p - \rho g) = -\frac{\mu}{k}\left(1+\delta\frac{\partial}{\partial t}\right)\vec{V} \tag{2}$$

$$(\rho c)\frac{\partial T}{\partial t}+(\rho c)_{\rm f}(\vec{\rm V}\nabla)T=k\nabla^2 T+\varepsilon(\rho c)_{\rm p}\left[D_B\nabla\phi\nabla T+\frac{D_T}{T_o}\nabla T\nabla T\right] \tag{3}$$

$$\frac{\partial\phi}{\partial t}+\frac{1}{\varepsilon}(\vec{\rm V}\nabla)\phi=D_B\nabla^2\phi+\frac{D_T}{T_o}\nabla^2 T \tag{4}$$

where $\vec{\rm V}$ is the velocity vector, p – the pressure, ρ – the density, g – the acceleration due to gravity, μ – the viscosity, π and δ – the retardation and the relaxation time, respectively, K – the porous media permeability, T – the temperature, β – the thermal expansion coefficient, ε – the porous media porosity, D_B, D_T – the coefficient of Brownian motion and the diffusion of thermophoretic coefficient, respectively, ϕ – the volume concentrations of nanofluid.

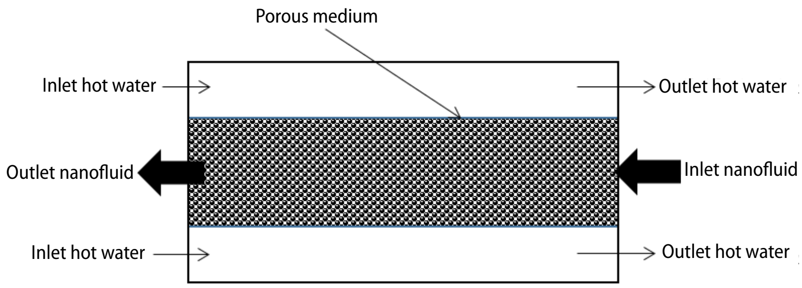

Figure 1. Physical model configuration

Experimental tests

The test section of this experimental study shown in fig. 2, is consisted of a double pipe heat exchanger that including both the outer and inner tubes. The tubes have made of aluminum and collected after fixing 14 thermocouples at the inlet and outlet and surface of tube. All thermocouples have been connected to the data logger with computer software to save all data recorded. The outer and inner tubes have length of 1 m and diameters of 21 mm with hot water and 18 mm with cold nanofluid, respectively. A digital manometer with accuracy 0.1 N/m^2 was connected to the inlet and outlet of the inner tube to read pressure difference between the inlet and outlet flow. Two flow meters with accuracy 0.2 Lpm have been provided to measure the flow of hot and cold flow. Two tanks are provided for cold and hot fluid, one of them has been filled with cold nanofluid and the other has been filled with hot water then connected to boiler to pumping hot water with an automatic sensor to control the temperature at the inlet flow. There are supplying two pumps with 1 horse power that connected with hot and cold fluid.

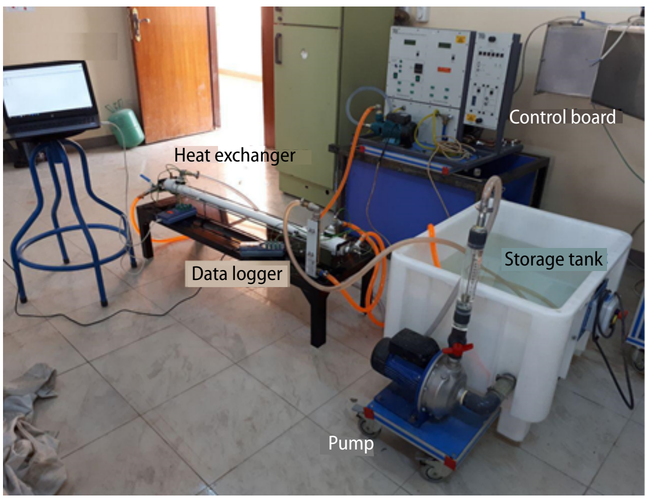

Figure 2. Picture of the experimental system

One radiator with fan has been provided to cool nanofluid after exiting and heating by convection from hot water.

Before starting the experiment tests, water/ethanol solution has been flowing through the system to remove any scales inside the pipes [35]. After filling the cold tank with nanofluid and another hot tank with water, temperature of both water and nanofluid tanks are set, then setting the flow rate of each loop. The system has given enough time to reach steady state of velocity and temperature then recording the temperatures. All experiments have been repeated five times to ensure about repeatability and reproducibility of results.

Nanofluid preparation properties

In order to estimate the nanofluid volume concentrations depending on nanoparticles volume, V_p, and basefluid volume, V_f, respectively eq. (5) below is used:

$$\phi = \frac{V_p}{V_p + V_f} \tag{5}$$

The pH test is using to test the nanofluids stability by OAKTON device for the nanofluid volume fraction. The pH value before and after tests refers to change of thermal properties and the nanofluid stability [23]. Alumina nano solid particle suspended in water as a basefluid undertaken are assumed as a Newtonian fluid, incompressible, single phase flow and an isotropic and all thermophysical properties have been taken form [23] referring to tab. 1.

Table 1. Thermosphysical properties of water and nanoparticles [13]

	Density [kgm^{-3}]	Specific heat capacity [kJkg^{-1}K^{-1}]	Thermal conductivity [Wm^{-1}K^{-1}]
Water	998	4179	0.6
Alumina	3970	765	40

In order to evaluate the nanofluid density, ρ_{nf}, and specific heat capacity, C_{nf}, can be calculated as following equations [16]:

$$\rho_{nf} = \left(\frac{\phi}{100}\right)\rho_p + \left(1 - \frac{\phi}{100}\right)\rho_f \tag{6}$$

$$C_{nf} = \frac{\frac{\phi}{100}(\rho C)_p + \left(1 - \frac{\phi}{100}\right)(\rho C)_f}{\rho_{nf}} \tag{7}$$

The nanoparticles thermal conductivity suspended in the water has been evaluated theoretically by the Maxwell model [16]:

$$k_{nf} = \frac{k_p + 2k_m - 2\varphi(k_w - k_p)}{k_p + 2k_w + \varphi(k_w - k_p)} k_w \tag{8}$$

To estimate the nanofluid viscosity, μ_{nf}, theoretically, Einstein model is adopted as [16]:

$$\mu_{nf} = (1 + 2.5\phi)\mu_f \tag{9}$$

Data collections

The mass-flow rate can be calculated:

$$\dot{m} = \rho V^{\bullet} \tag{10}$$

Reynolds number is estimated:

$$\text{Re} = \frac{\rho D u}{\mu} \tag{11}$$

The pressure drop may be calculated:

$$\Delta P = S\text{g}H \tag{12}$$

The heat inlet and outlet through the cold and hot fluid can be estimated:

$$Q_\text{c} = \dot{m}_\text{c} C_p \left(T_\text{in} - T_\text{out}\right)_\text{c} \tag{13}$$

$$Q_\text{h} = \dot{m}_\text{h} C_p \left(T_\text{in} - T_\text{out}\right)_\text{h} \tag{14}$$

And the average heat can be evaluated:

$$Q_\text{av} = \frac{Q_\text{h} + Q_\text{c}}{2} \tag{15}$$

The logarithmic average of the temperature difference will estimate:

$$\text{LMTD} = \Delta T_\text{m} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\dfrac{\Delta T_1}{\Delta T_2}\right)} \tag{16}$$

where $\Delta T_1 = T_\text{h1} - T_\text{c1}$ and $\Delta T_2 = T_\text{h2} - T_\text{c2}$.

The overall heat transfer coefficient can be evaluated:

$$\text{UA} = \frac{Q_\text{av}}{\Delta T_\text{m}} \tag{17}$$

Number of transfer units is:

$$\text{NTU} = \frac{\text{UA}}{C_\text{min}} \tag{18}$$

Effectiveness of a double pipe heat exchanger:

$$\epsilon_\text{parallel} = \frac{T_\text{h1} - T_\text{h2}}{T_\text{h1} - T_\text{c1}} \tag{19}$$

Results and discussion

In order to evaluate the experimental measurements, the accuracy system was tested with deionized water. The flow direction through the inner pipe along the tube length is illustrated in fig. 3. It should be noted that the deviations between the counter and parallel flow temperature values are approximately 3%. It can be assumed the difference between the counter and parallel flow is insignificant and the data along the tests will assume in the parallel flow di-

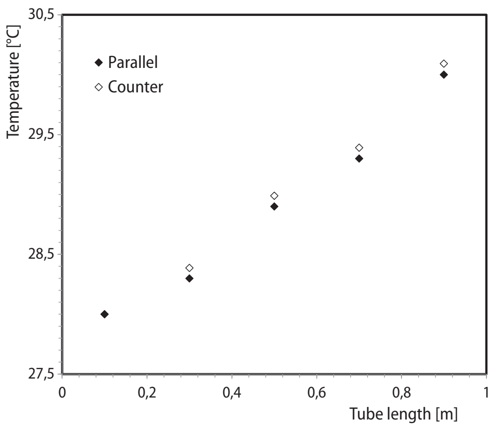

Figure 3. Direction of flow affected to temperature

rection. The temperature profile along the tube length is increasing from inlet to outlet of inner tube by 2 °C for pure water only. The inlet temperatures of inner and outer tubes are 28 °C and 50 °C, respectively.

Figures 4-8 are including six cases that pure water through inner tube, pure water through inner tube is filling porous media, 0.5% nanofluid volume fraction through inner tube, 0.5% nanofluid volume fraction through inner tube is filling porous media, 1% nanofluid volume fraction through inner tube and 1% nanofluid volume fraction through inner tube is filling porous media.

Figure 4 indicates that temperature distribution along tube length under two volume flow-rates 2 Lpm and 5 Lpm. It can be noted that the temperature increases along the tube length for all six cases. The minimum temperature values are found by using pure water in the inner tube, while the maximum temperature values are recorded under using 1% nanofluid and inner tube filling with porous media.

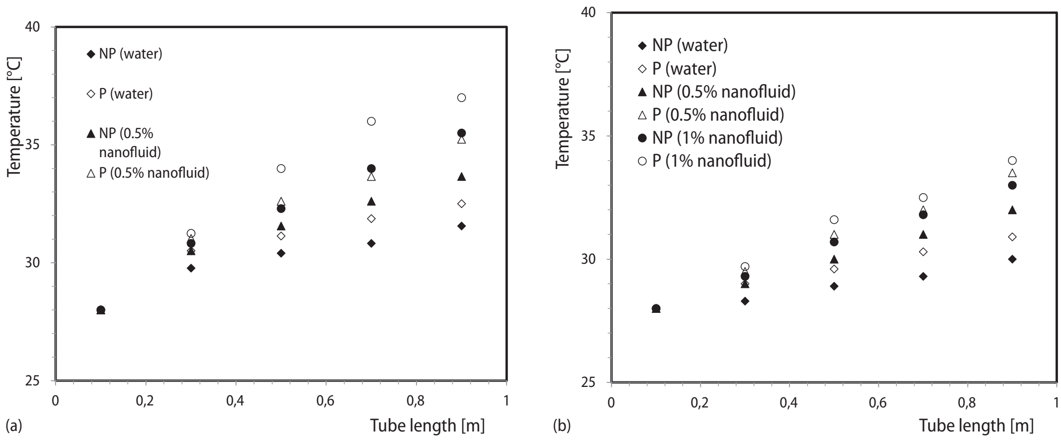

Figure 4. Temperature distribution along tube length for six cases; (a) Q = 2 Lpm and (b) Q = 5 Lpm

Similar behaviors for NTU and effectiveness are shown in figs. 5 and 6. It seems both NTU and effectiveness are increasing as increase in the volume flow-rate and the maximum deviations are 12% and 23%, respectively. Additionally, the using of 1% alumina nanofluid through inner tube filling with porous media has the highest values of NTU and effectiveness. The reason to increase of the NTU and effectiveness values is dependent them on the overall heat transfer coefficient that increasing with increase of nanofluid volume fractions [13].

Figure 7 demonstrates that overall heat transfer coefficient with different volume flow-rates and six cases of this study. It can be seen that the overall heat transfer coefficient increases as increase of volume flow-rates and the deviation between them is approximately 20%. Likewise, it is increased due to increase of porous media size and nanoparticle volume

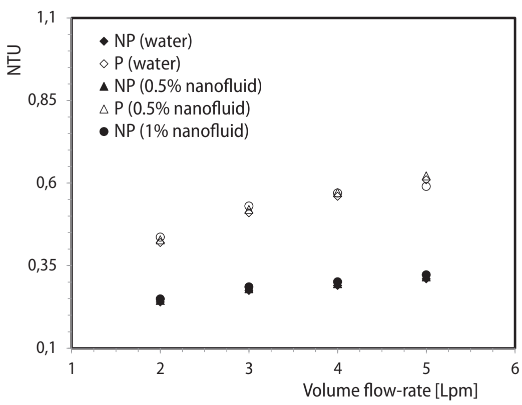

Figure 5. The NTU against volume flow-rate for six cases

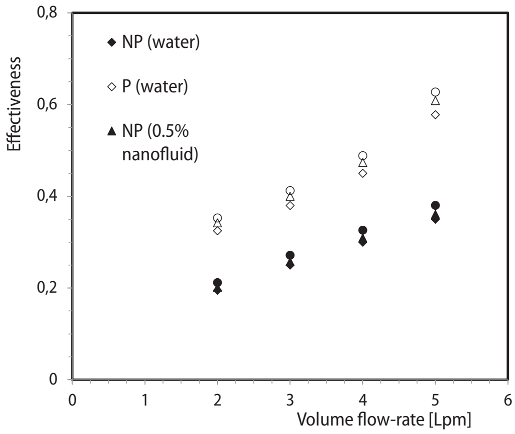

Figure 6. Effectiveness against volume flow-rate for six cases

concentrations. The reason to heat transfer enhancement may be related to the thermal conductivity enhancement of nanofluid and the reduction of boundary-layer on the tube walls by porous media [13].

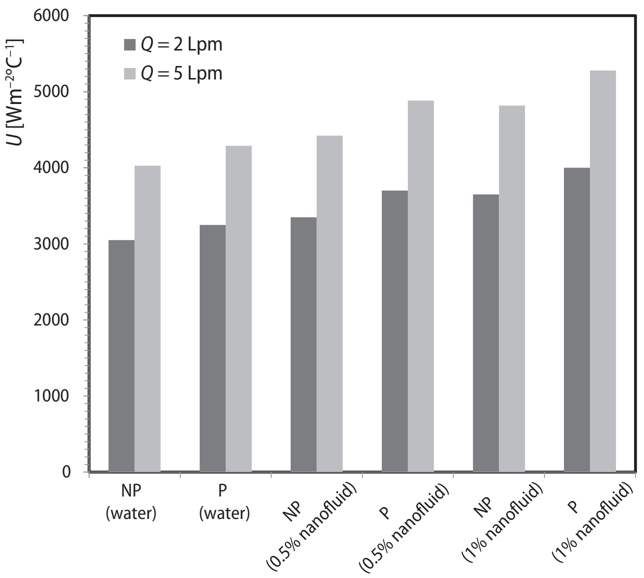

Figure 7. The overall heat transfer coefficient against volume flow-rate for six cases

Conclusions

This project presents an experimental investigation into heat transfer parameter in a double pipe heat exchanger with parallel and counter flow by adding a porous media with size of 3 mm particles and flowing alumina nanofluid with two volume fractions through the inner pipe. While the hot water with constant inlet temperature flow through the outer pipe of the heat exchanger. The experimental tests and theoretical calculations have concluding that:

- The axial temperature profile of outer surface of inner pipe increases towards the ends of heat exchanger with slightly deviation between the counter and parallel flow.

- The surface temperature of the inner pipe increases by using porous media and nanofluid as compared with the empty tube.
- The NTU and effectiveness are increasing as increase in the volume flow-rate and nanofluid fraction.

The overall heat transfer coefficient increases as increase of volume flow-rates and nanofluid fraction.

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