Flow and Heat transfer Experimental Investigation of Nanofluid in a Double pipe Heat Exchanger

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Abstract. This paper presents an experimental study on heat transfer characteristics in a double-pipe heat exchanger using different types of fluid. The nanofluid consists of zirconia was added to the base fluid (deionized water and Ethylene Glycol). The concentration of nanofluid was varied with a range of 0.2, 0.7 and 1.2 % and the flow rates of the base and nanofluid were varied with a range of 1.5, 1.8 and 2.1 L/min. The results indicated that the Ethylene Glycol has the highest Nusselt number (40.70) at inlet temperature (70 °C) and flow rate (2.1 L/min) among the other working fluids. The mixture of ethylene glycol and water has Nusselt number lower than that for number at (φ =1.2 %, temperature=70 °C and flow rate 2.1 L/min) and Reynolds number is (the Ethylene Glycol alone. From the experimental result it is clear that the Nusselt number of nanofluid increases with an increase in the concentration and flow rate. It was found that (24.2) of Nusselt 3679). The maximum heat transfer enhancement is (1.5077) for ethylene glycol at inlet temperature (70 °C) and the minimum enhancement is (0.16844) for ethylene glycol at temperature (40 °C).

1. Introduction

Heat exchanger is a device which is used to transfer the heat from one fluid to another fluid. It is widely used in several industries such as power plants, air conditioning equipments, Automobile, chemical processing plants etc. The conventional heat transfer fluids such as Ethylene Glycol, water, mineral oil, Propylene Glycol, etc. are used widely as a heat transfer medium in all the heat exchangers [1, 2].

Nano fluids are used to investigate the behaviour of fluids, which are limited to Nano sized of particles. Nano fluids play crucial role in the applications of heat transfer. Transfer of heat applications have been used in various industrial processes. cooling or Heating in an industrial application could reducing time, produce reserves heat energy, and increasing life of working tools such as boilers, heat exchangers, and radiators, etc. [3]. According to the results of the research, thermal properties of nanofluids are very different from thermal properties of conventional heat transfer fluids such as ethylene glycol or water. In addition, thermal conductivity of nanofluids is changed with the size, shape, and type of materials of nanoparticles that distributed in the base fluid. Heat transfer overall performance is increased by the increasing of the thermal conductivity. In fact, heat transfer could be improved due to existence of the nanoparticles which cause the reduction of thickness of the thermal boundary layer, and the random motion within the base fluid as well [2]. From the literature of nanofluids heat transfer, higher thermal conductivities than conventional fluids, have a strongly non-linear temperature dependency on the effective thermal conductivity, reduce or enhance heat transfer in single-phase flow, nanofluids result in enhancement or reduction nucleate pool boiling heat transfer, and they yield higher critical heat fluxes when using pool boiling conditions. One of the simplest types of heat exchangers is the double-pipe heat exchangers. In a double-pipe heat exchanger, the flow can be counter-current or co-current [4].
In the literature there are many researches have studied the nature of heat transfer and heat transfer characteristics experimentally for numerous nanofluids with different flow rates and particle concentration. They reported that increasing in the Reynolds number and concentration of nanofluid lead to increase in the heat transfer rate. Selvakumar and Suresh [5] investigated experimentally that there is important improvement in heat transfer using Copper Oxide/water nanofluid as the working fluid in a copper heat sink. They performed experiments for 0.1% and 0.2% of nanofluid concentrations. They reported about 29.63% increase in heat transfer coefficient using 0.2% nanofluid compared to the deionized water. Ho and Chen [6] performed an experiment on a rectangular minichannel heat sink using alumina/water nanofluid flow and heat transfer. They got a very high improvement in heat transfer coefficient using nanofluid compared to the pure water. Byrne et al. [7] were focused on the effect of surfactants and nanoparticle concentration on the heat transfer performance of nanofluids flow in a parallel microchannel configuration. Their experimental work revealed the significance of using surfactants of nanoparticles in the base fluid to have good suspension.

Williams and Buongiorno [8] studied experimentally the turbulent convective heat transfer behavior of Al$_2$O$_3$ of size 46nm and ZrO$_2$ of size 60 nm nanoparticle dispersions in water in a horizontal tube. The concentration tested was up to 3.6% for Alumina and up to 0.9% for Zirconia. They found that no significant improvement in heat transfer and concluded that any traditional correlation can predict convective heat transfer coefficient. They did not present a Nusselt number correlation. Rea et al [9] conducted experiment using 50nm Al$_2$O$_3$ and ZrO$_2$ nanoparticles in water to show an increase of 27% compared to water. The zirconia–water nanofluid heat transfer coefficient increases by approximately 2% in the entrance region and 3% in the fully developed region at 1.32 volume %. Abdulhassan A. Karamallah [4] noted that addition of small amounts of Al$_2$O$_3$ nanoparticles to the distilled water increased heat transfer significantly as the concentration of nanofluid increases the Nusselt number increases.

Recent material technology provides opportunities to produce reduced nanometer sized particles, which are quite different from the parent material in mechanical, thermal, electrical, and optical properties. A very small amount of guest nanoparticles, when dispersed uniformly and suspended stably in host fluids, can provide dramatic improvements in the thermal properties of host fluids. The significant of using nanofluids particles is to achieve the highest possible thermal properties at the smallest this goal it is vital to understand how nanoparticles enhance energy transport in liquids [4]. In this work the experiments are performed in different volume concentrations of metal oxide nanofluid type ZrO$_2$ at concentrations of $\phi = 0.2, 0.7, 1.2$ % by volume. Since this behaviour has not been already determined, experiments with distilled water, 100 % Ethylene glycol (EG), distilled water 50 % + Ethylene glycol 50 % and ZrO$_2$ with distilled water in a double-pipe heat exchanger counter flow are planned to see the behaviour of Zirconium oxide nanofluid and provide an experimental data to demonstrate the hypothesis that the nanofluids can be treated as homogeneous mixtures, as such the heat transfer coefficient enhancement is not abnormal, but due to the different mixture properties of the nanofluids. Therefore, the objective of this work is to investigate heat transfer characteristic for ZrO$_2$/water nanofluid in double pipe heat exchanger.

2. Data Reduction

The heat is transferred from the hot fluid is equal to cold fluid can be expressed as [10]:

\[ Q_c = (\rho C_p) c u_c A_{cc}(T_{co} - T_{ci}) \]  

\[ Q_h = (\rho C_p) h u_h A_{ch}(T_{ho} - T_{hi}) \]  

Where the specific heat of a fluid stream denotes the rate of heat transfer required to alter the temperature of the fluid stream by 1°C as it flows inside the heat exchanger or:

\[ Q = C_c(T_{co} - T_{ci}) \quad \text{and} \quad Q = C_h(T_{ho} - T_{hi}) \]

Where

\[ C_c = m_c C_p c \quad \text{and} \quad C_h = m_h C_p h \]

The total heat transfer coefficient is calculated as below:

\[ Q = U A \Delta T_{lm} \]  


Where \((U)\) is the overall heat transfer coefficient (W/m\(^2\).K), \((A)\) is the heat transfer area (m\(^2\)), and \((\Delta T_{lm})\) is logarithmic mean temperature difference between cold and hot fluids inlet and outlet temperatures in (K), which is \([11]\):

\[
\Delta T = \frac{\Delta T_2 - \Delta T_1}{\ln(\frac{\Delta T_1}{\Delta T_2})} = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})}
\]

Where for counter flow:

\[
\Delta T_1 = T_{hi} - T_{co} \Delta T_2 = T_{ho} - T_{ci}
\]

2.1. The Overall Heat Transfer Coefficient (U):

The heat transfer coefficient of the fluid can be defined as follows:

\[
Q = \Delta T_{lm} = U A \Delta T_{lm} = U_o A_{os} \Delta T_{lm} = U_o A_{os} \Delta T_{lm}
\]

Where \(A_0\), \(A_{os}\) are inner and outer surface of tube, \((R)\) is a single resistance which is combine all the thermal resistance in the test section of heat flow from the hot fluid to the cold fluid, the total thermal resistance is given by:

\[
\Sigma R = R_{total} = R_i + R_{wall} + R_o = \frac{1}{h_i A_{is}} + \frac{\ln(\frac{r_o}{r_i})}{2 \pi k_i L} + \frac{1}{h_o A_{os}}
\]

\(R_{wall}\) is he thermal resistance of the tube wall can be determined as follows:

\[
R_{wall} = \frac{\ln(\frac{r_o}{r_i})}{2 \pi k_i L}
\]

Where \((k_i, L)\) are the thermal conductivity of the tube wall material and length respectively.

After omitting \((\Delta T_{lm})\), equation (6) become as follows:

\[
\frac{1}{UA} = \frac{1}{UA_{is}} = \frac{1}{UA_{os}} = \Sigma R = \frac{1}{h_i A_{is}} + R_{wall} + \frac{1}{h_o A_{os}}
\]

Substitute equation (8) in equation (9) gives:

\[
U_o = \frac{1}{A_{os}} A_{os} \ln(\frac{d_0}{d_i}) \frac{1}{h_0}
\]

\[
U_o = \frac{1}{d_0} \ln(\frac{d_0}{d_i}) + \frac{1}{h_o}
\]

2.2. Water Side Heat Transfer Coefficient Calculations:

The Monrad and Pelton’s equation for turbulent flow inside shell can be used to yield the value of \((h_o)\) \([10]\):

\[
\frac{h_o d_o}{k_o} = Nu_o = 0.02 Re^{0.8} Pr^{\frac{1}{3}} \left(\frac{r_a}{r_i} \right)
\]

Where \(D_e\) is the equivalent shell diameter, given by

\[
D_e = \frac{d_i^2 - d_o^2}{d_o}
\]

And the dimensionless numbers are

\[
Pr = \frac{\mu C_P}{k}, \quad Nu = \frac{h_d}{k}, \quad Re = \frac{\rho u D_e}{\mu}
\]
The enhancement in heat transfer using different working fluids is calculated by:

\[
E_{\text{EG}} = \frac{\text{Nu}_{\text{av,EG}} - \text{Nu}_{\text{av,water}}}{\text{Nu}_{\text{av,water}}} \\
E_{\text{EG+W}} = \frac{\text{Nu}_{\text{av,EG+W}} - \text{Nu}_{\text{av,water}}}{\text{Nu}_{\text{av,water}}} \\
E_{\text{nano}} = \frac{\text{Nu}_{\text{av,nano}} - \text{Nu}_{\text{av,W}}}{\text{Nu}_{\text{av,W}}}
\]

(15)  
(16)  
(17)

3. Experimental Apparatus and Procedure

3.1. Experimental Apparatus:

The schematics diagram of the experimental apparatus is shown in figure (1) the experimental rig consist of pump for cold and hot fluids, heater and hot fluid tank, electronic flow meter for hot fluid, control valves and piping system, Digital flow rate recorder, cooling unit and concentric tubes as test section. The temperature was measured by 6 K-type thermocouples and digital temperature. The uncertainty in temperature measurement was ±0.1 °C. The test section was isolated thermally from surrounding with a good multilayer insulator to minimize the heat loss resulting. It is necessary to measure the temperature at five stations altogether of the test section to find the average Nusselt number.

Double pipe heat exchanger is constructed from concentric tubes. The length of test section was 80 cm copper tube with \( D_o = 12.7 \) mm was selected as inner tube and a polyvinyl chloride tube with \( D_o = 50.8 \) mm was chosen as outer tube. In this exchanger, the hot fluid flows into the pipe while the cooling fluid in the annular space of the pipe. The inlet temperature is (40, 50, 60 and 70 °C) used for hot fluid and the flow rates of the fluid was conducted at (1.5, 1.8 and 2.1) L/min. while the temperature of fluid in annulus is the atmospheric temperature (23-33 °C) with flow rate (10.75 L/min). Four types of working fluid are tested distilled water, 100 % ethylene glycol, distilled water 50 % + ethylene glycol 50 % and metal oxide nanofluid type ZrO₂ with distilled water. Three volume concentrations are used of \( \varphi = 0.2, 0.7, 1.2 \% \).

3.2. Nanofluids Preparations:

The nanofluid used in the experiment was 99.0 % pure Zirconia with an average particle size of 30 nm predisposed in distilled water. Various effective thermophysical properties of ZrO₂ nanoparticles like the density, the viscosity, the thermal conductivity and the specific heat are computed using the equations available in the literature [9]. Preparation of nanofluid with low agglomeration of particles is the first key step in experimental work in order to get stable, durable suspension and no chemical reaction of fluid. The electric mixer is used for mixing the nanoparticles and the distilled water directly. The nanoparticles are weighted using a sensitive balance for each concentration by dispersing pre-weighted quantities of nanoparticles type ZrO₂ in 3 liters of distilled water.

3.3. Uncertainty Analysis:

Because of errors in the measurement, the quantities which used to estimate the Nusselt number are subjected to certain uncertainties. One of these individual uncertainties is obtained in table 1. The analysis is carried out on the basis of the suggestion made by Robert J. Moffat:

\[
\frac{S_R}{R} = \left[ \left( \frac{\partial R}{\partial X_1} S_{X_1} \right)^2 + \left( \frac{\partial R}{\partial X_2} S_{X_2} \right)^2 + \cdots \left( \frac{\partial R}{\partial X_t} S_{X_t} \right)^2 \right]^{\frac{1}{2}}
\]

4. Results and Discussion

Local temperatures along the inner pipe using distilled water with different inlet temperature and flow rate are shown in the figures 2 and 3. From these figures, it is observed that the temperature difference between inlet and outlet of the working fluid in the inner pipe is higher in case of higher inlet temperature. Temperature are recorded (57-59) °C in the inner pipe for the case of inlet temperature of 70 °C while (27-29) °C for inlet temperature at 40 °C. This is due to high heat which is transferred between the two fluids and the effect of increasing volume flow rate of water as a working fluid from...
1.5 to 2.1 L/min. Figures 4 and 5 represent the same relation where using ethylene glycol which give low temperature difference (53-56 °C) for inlet temperature (70 °C) and (25-27 °C) for inlet temperature of (40) °C. Low temperature difference is caused by higher viscosity and density of ethylene glycol compared with water. Figures 6 and 7 present the same relation of water as working fluid but for using 50 % ethylene glycol + 50 % distilled water which give less temperature difference, where for inlet temperature 70 °C (54 - 57) °C and (25.5 - 28) °C for inlet temperature of 40 °C. Also, less temperature difference is caused by high density and viscosity of ethylene glycol with distilled water compared with water. The temperature difference is less as volume flow rate increases. Figures 8 and 9 give the relation but for using nanofluid ZrO₂ in distilled water with volume concentration 0.2 % which give temperature difference between inlet and outlet of the working fluid (52-53) °C for inlet temperature (70 °C) and (24-25) °C for inlet temperature of (40 °C). Figure 10 shows the local temperature along the inner pipe for nanofluid but for concentration 0.7 % which give temperature difference (48-50) °C for inlet temperature (70 °C) and (21-22.7) °C for inlet temperature of (40) °C. Also, figure 11 presents the relation for nanofluid with concentration 2.1 % which give higher temperature difference (41-41.8) °C for inlet temperature (70) °C and (17-17.5) °C for inlet temperature of (40) °C. The temperature difference variation is caused by the change of physical properties of nanofluid with concentration such as increasing thermal conductivity and Brownian motion of nano particle which causes to increase the heat extraction from fluid.

The values of Nusselt number increases with increasing Reynolds number and inlet temperature as shown in figures 12 to 16 for all fluid cases. The increases in flow rate maintain a high temperature gradient close to the tube wall and in turn increase the enhancement in heat transfer. Also the change in fluid properties increases the values of Nusselt number as shown in the same figures .The ethylene glycol gives the highest Nusselt number among the other working fluids due to the high Prandt number (high density and viscosity). The mixture of ethylene glycol and water has Nusselt number lower than that for the ethylene glycol alone. For nanofluid, the Nusselt number increases with increasing concentration (∅=0.2, 0.7 and 1.2) % because the effective thermal conductivity of nanofluid increases with increasing volume fraction of the nanoparticles, which is explained by Brownian motion of the nanoparticles, molecular–level layering of the liquid at liquid/particle interface (wettability).

Enhanced thermal conductivity reduces the resistance to thermal diffusion in the laminar sub layer of the boundary layer figure 17 shows the enhancement as a function of inlet temperature for three types of fluids used and the maximum enhancement is (1.50766) established for ethylene glycol at inlet temperature (70) °C and the minimum enhancement is (0.16844) established for the mixture of ethylene glycol and water at inlet temperature 40 °C. It is showed that nanofluid ZrO₂ with ∅=1.2 % is the best for heat transfer applications. In spite of that the ethylene glycol gave higher values of enhancement but, due to its physical properties (viscosity and density), it is considered as impractical for various applications of heat transfer.
Figure 1. Schematic diagram of the experimental set-up.

Table 1. Uncertainty analysis for nanofluid $\phi = 0.2\%$.

| Working fluid | Flow rate (L/min) | Uncertainty of flow rate | Temperature ($^\circ$C) | Uncertainty of Temperature |
|---------------|-------------------|--------------------------|-------------------------|----------------------------|
| ZrO$_2$ Nanofluid $\phi = 0.2\%$ in Water | 1.5 | 0.03955 | 40 | 0.06328 |
| | | | 50 | 0.03828 |
| | | | 60 | 0.17578 |
| | | | 70 | 0.03828 |
| | 1.8 | 0.01732 | 40 | 0.13203 |
| | | | 50 | 0.00078 |
| | | | 60 | 0.09453 |
| | | | 70 | 0.00703 |
| | 2.1 | 0.02786 | 40 | 0.22578 |
| | | | 50 | 0.06328 |
| | | | 60 | 0.03828 |
| | | | 70 | 0.00078 |
**Figure 2:** Temperature along the inner pipe for water at flow rate (1.5 L/min).

![Graph showing temperature along the inner pipe for water at 1.5 L/min with temperatures 40°C, 50°C, 60°C, and 70°C.](image)

**Figure 3:** Temperature along the inner pipe for water at flow rate (2.1 L/min).

![Graph showing temperature along the inner pipe for water at 2.1 L/min with temperatures 40°C, 50°C, 60°C, and 70°C.](image)

**Figure 4:** Temperature along the inner pipe for Ethylene Glycol at flow rate (1.5 L/min).

![Graph showing temperature along the inner pipe for Ethylene Glycol at 1.5 L/min with temperatures 40°C, 50°C, 60°C, and 70°C.](image)

**Figure 5:** Temperature along the inner pipe for Ethylene Glycol at flow rate (2.1 L/min).

![Graph showing temperature along the inner pipe for Ethylene Glycol at 2.1 L/min with temperatures 40°C, 50°C, 60°C, and 70°C.](image)

**Figure 6:** Temperature along the inner pipe for 50% water+50%Ethylene Glycol at flow rate (1.5 L/min).

![Graph showing temperature along the inner pipe for 50% water+50%Ethylene Glycol at 1.5 L/min with temperatures 40°C, 50°C, 60°C, and 70°C.](image)

**Figure 7:** Temperature along the inner pipe for 50% water+50%Ethylene Glycol at flow rate (2.1 L/min).

![Graph showing temperature along the inner pipe for 50% water+50%Ethylene Glycol at 2.1 L/min with temperatures 40°C, 50°C, 60°C, and 70°C.](image)
Figure 8: Temperature along the inner pipe for ZrO$_2$ nano fluid at flow rate (1.5 L/min) and $\phi=0.2\%$.

Figure 9: Temperature along the inner pipe for ZrO$_2$ nano fluid at flow rate (2.1 L/min) and $\phi=0.2\%$.

Figure 10: Temperature along the inner pipe for ZrO$_2$ nano fluid at flow rate (2.1 L/min) and $\phi=0.7\%$.

Figure 11: Temperature along the inner pipe for ZrO$_2$ nano fluid at flow rate (2.1 L/min) and $\phi=1.2\%$.

Figure 12: Nusselt number for water at $T_{in}=40$, 50, 60 and 70 $^\circ$C at flow rate 1.5, 1.8, and 2.1 L/min.

Figure 13: Nusselt number for Ethylene glycol at $T_{in}=40$, 50, 60 and 70 $^\circ$C at flow rate 1.5, 1.8, and 2.1 L/min.
5. Conclusion

The convective heat transfer performance and the flow characteristics of ZrO$_2$ nanofluid flowing in the heat exchangers have been experimentally investigated. The flow behaviour of water, ethylene glycol and ZrO$_2$ nanofluid have been compared. It is concluded that the temperature difference between inlet and outlet of the working fluid in the inner pipe decreases as moving from the water to ethylene glycol + water, ethylene glycol and to nanofluid. Ethylene glycol gave highest Nusselt number due to the high Prandtl number. The mixture of ethylene glycol and water has Nusselt number lower than that for the ethylene glycol alone. As Reynold number increases, the Nusselt number increases for all cases and the Nusselt number increases with increasing concentration. The best working fluid for practical applications is the ZrO$_2$ for ($\phi$ = 1.2 %) which enhances heat transfer and improves the heat exchanger performance. Experiments are needed for wide range of Reynolds number, heat flux or temperature and the doublepipe heat exchanger configurations, U-bend double pipe or internally/externally finned tube. Work needs for the use of multi-type twisted tapes aiming to achieve good thermohydraulic performance for laminar and turbulent fully developed flow in inclined pipes.
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