Numerical Investigation of double pipe heat exchanger with different nanofluids

Bharat Naik1, Manzoore Elahi M Soudagar2, Merwyn Thomas1, Kshitij Dasurkar1, Omkar Alloli1, Fayaz Hussain3, N.A. Madlool4, and Mahalaxmi Alloli2
1Department of Mechanical Engineering, Jain College of Engineering, Belagavi, Karnataka, India
2Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
3Modeling Evolutionary Algorithms Simulation and Artificial Intelligence, Faculty of Electrical & Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
4Department of Mechanical Engineering, Faculty of Engineering, University of Kufa, 21 Kufa, Najaf, Iraq

*Corresponding author
me.soudagar@gmail.com

Abstract: The study represents an enhancement of heat transfer using different nanofluids containing nanoparticles (Al₂O₃, Cu, Ag, TiO₂, SiO₂, Fe) Volume fraction (0.02≤ϕ≤0.05). Numerical simulations are conducted using CFD (Computational Fluid Dynamics) and the model is generated using Solid works. The governing equations are solved using a SIMPLE technique and discretized using finite volume approach. The results show that the heat transfer rate increases with the increase of the flow rates, also it has been observed that heat transfer rate increases with increase of operating temperature and also by the concentration of nanoparticles.

Keywords: Computational Fluid Dynamics; Heat transfer; Nanofluids; Double Pipe Heat Exchanger; Ansys-Fluent; Solid works.

1. INTRODUCTION

The basic definition of a heat exchanger is that it is a device which is designed to perform the heat transfer action by obeying the fundamentals of thermodynamics. The applications of Heat exchangers in various sectors such as power plants, heating and air conditioning in buildings, household refrigerators, radiators. The heat exchangers are classified according to heat transferring method, design and construction, flow configuration, the number of fluids used. The examples of heat exchangers are boilers, super heaters, condensers, automobile radiators, etc. The most commonly used fluids in the heat exchangers which are being used in the current industries are less efficient. There is a demand needed in industries for fluids which are having higher heat transfer coefficient. There are various methods for enhancing the thermal properties and its performances and one of the best methods to do so is by using nanofluids [1-2]. Nano fluids are colloidal suspensions of nano sized (smaller than 100 nm) particles. Nanofluids are used for various applications and has many advantages such as better stability and rheo-logical properties, no extra pressure drop, high thermal conductivity. Masuda et al. [3] experimented thermal conduction of nanofluids using water as the base fluid which contains the particles of SiO₂, TiO₂ and Al₂O₃. T. Mateescu et al. [4] detailed an exploratory examination on constrained convective warmth move on nanofluids with 0 to .2 volume% of Al₂O₃ nanoparticles streaming in a twofold funnel heat exchanger. According to Palm et al. [5] and Liu et al. [6], introducing the nanoparticles at low concentrations (i.e. 1 to 5 %) can increase the heat transfer coefficient.

2. NUMERICAL ANALYSIS

The geometric model of the double pipe is prepared by the specification according to Table.1. Assuming there is no heat loss in the system. The heat removed $Q_h$ is hot fluid (nanofluid) which is calculated by Eq. (1). The heat absorbed $Q_c$ (water) calculated by Eq. (2),
\[ Q = Q_h = (\dot{m}C_p)_h \Delta T_h \]
\[ Q = Q_c = (\dot{m}C_p)_c \Delta T_c \]

Table 1: Geometry parameters

| Geometry      | Value  |
|---------------|--------|
| Outer tube dia| 20 mm  |
| Inner tube dia| 10 mm  |
| Thickness     | 1 mm   |
| Length        | 725 mm |

The effectiveness is calculated using the Eq.’s (3), (4) and (5),

\[ \varepsilon = \frac{Q}{Q_{\text{max}}} \]  
\[ \varepsilon = \frac{T_{hi} - T_{ho}}{(T_{hi} - T_{ci})} \quad m_hC_h < m_cC_c \]  
\[ \varepsilon = \frac{T_{ci} - T_{co}}{(T_{hi} - T_{ci})} \quad m_cC_c < m_hC_h \]

CFD method comprises of numerical arrangements of force, mass, and vitality protection with different conditions. The CFD method has been used to explore the heat exchanging process in the double-pipe exchanger. Consistent state, incompressible liquid stream without mass exchange and substance response were expected. Consequently, just the congruity, force, and vitality conditions are thought of. The overseeing conditions for laminar flow, consistent, and incompressible liquid stream are as follow.

Continuity,

\[ \text{div}(\rho \dot{V}) = 0 \]  

Momentum,

\[ \text{div}(\rho \dot{V} V) = -\text{grad}p + \nabla(\mu \dot{V} V) + S_m \]  

Energy,

\[ \text{div}(\rho \dot{V} C_p T) = \text{div}(k \text{grad}T) + S_e \]

The Drew and Passman relation is used for calculating the viscosity of nanofluid.

\[ \mu_{nf} = \mu_f (1 + 2.5\phi) \]  

By using Choi relation the density of the nanofluid is calculated.

\[ \rho_{nf} = (1 - \phi) \rho_f + \phi\rho_s \]  

The Xuan and Roetzel co-relation] is used for the calculation of the heat capacity.

\[ (C_p)_{nf} = [(1 - \phi)(\rho C_p)_f + \phi(\rho C_p)_s] / \rho \]  

Maxwell-Garnett’s approximation equation for thermal conductivity

\[ \frac{k_{\text{mixture}}}{k_f} = \frac{k_f + 2k_f - 2\phi(k_f - k_s)}{k_f + 2k_f + \phi(k_f - k_s)} \]
The Ansys–FLUENT 17.1 was utilized in the current investigation. The program utilizes a method dependent on the control volume hypothesis to change over exemplary singular stage conservation conditions to mathematical conditions. The SIMPLE semi-certain strategy for pressure connected conditions was utilized to combine the weight and speed. The conditions were characterized at the inlet boundary as mass flow inlet and pressure outlet for outlet boundary. The magnitude of the inlet velocity was specifically determined, and the velocity direction was considered to be normal to the boundary. The velocity values and the temperature values are indicated.

3. RESULTS AND DISCUSSIONS

The geometry of the domains and the meshing was done using Ansys 17.1. The cut cell method was used for meshing. The geometrical config of double pipe for CFD simulation are shown in Fig 1 (a). The model was meshed by cut cell cells which consists of 253637 elements and 324099 nodes. The flow rates applied for the hot fluid (nano fluid) are 100, 150, 200, 250 and 300(l/h) and the cold fluid was kept constant at 90(l/h). Fig 1 (b). The temperatures distributed in the double pipe is ranged from 296K to 323K which indicates the temperature contour of the nanofluid is shown in Fig 1 (b).

![Figure 1](image)

**Figure 1**: (a) Mesh Double pipe heat exchange, (b) Temperature contour and (c) Grid Independent
Figure 1. (c) indicates the relationship between the Error in average heat transfer vs number of cells in the double pipe. The comparison of mesh size was done from course to fine mesh size.

Figure 2: Effects of nanofluids on heat transfer: (a) Al₂O₃, (b) Cu, (c) Ag, (d) TiO₂, (e) SiO₂ and (f) Fe

The Fig. 2 (a),(b),(c),(d),(e) and (f) illustrates the effects of Al₂O₃, Cu, Ag, TiO₂, SiO₂ and Fe nanofluid on the heat transfer rate Q (W) vs Flow rate(l/hr) are seen. The 5% of Al₂O₃ nanofluid is 16.21% is higher than that of 2% Al₂O₃. The 5% of Cu nanofluid is 2% higher than that of 2% (Cu) nanofluid. The 5% of Ag (nanofluid) is 7.47% higher than that of 2% Ag nanofluid. The 5% of TiO₂ (nanofluid) is 25% higher than that of 2% TiO₂ nanofluid. The 5% of SiO₂ (nanofluid) is 40% is higher than that of 2% SiO₂ nanofluid. The 5% Fe (nanofluid) is 32% higher than that of 2% Fe nano fluid.
Figure 3: Effects of flow rate on the effectiveness: (a) Al₂O₃, (b) Cu, (c) Ag, and (d) TiO₂ (e) SiO₂ (f) Fe

Fig. 3 (a), (b), (c), (d), (e) and (f) illustrates the influence of Al₂O₃, Cu, Ag, TiO₂, SiO₂ and Fe nanofluid on effectiveness and flow rate (l/hr). The effectiveness of 5% Al₂O₃ nanofluid is about 22.4% higher than that of 2% Al₂O₃ nanofluid. The effectiveness of 5% Cu nanofluid is about 19% higher than that of 2% Cu nanofluid. The effectiveness of 5% Ag nanofluid is about 19% higher than that of 2% Ag nanofluid. The effectiveness of 5% TiO₂ nanofluid is about 25.7% higher than that of 2% TiO₂ nanofluid. The effectiveness of 5% SiO₂ nanofluid is about 43% higher than that of 2% SiO₂ nanofluid. The effectiveness of 5% Fe nanofluid is about 42.85% higher than that of 2% Fe nanofluid.
Figure 4. Comparison between present result and Akhtari [7] of (Al₂O₃) nanofluid

In the Fig. 4 shows the result of the present study being compared with Akhtari et al. [7] of Al₂O₃ nano fluid. After comparing the results with Akhtari et al. [7] the heat transfer rate has increased by 6.3% in the present study.

4. CONCLUSIONS

The heat transferring performances of the nanofluid streaming within the double pipe were examined. Impacts of nanofluid on temperature, the concentrations of nano particles, flow rates and heat transfer coefficients were explored. The following conclusion are obtained. The nanoparticles enhanced the rate of heat transfer and the effectiveness of the base fluid. The nanofluid temperature and flow rates of nano fluid enhance the heat transfer rate.

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