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Analysis of Heat Transfer Enhancement of Heat Exchanger using Nanofluid

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Abstract - *Now days to achieve high heat transfer rate, different techniques have been used. One of the advanced techniques among them is suspension of nanoparticle in the base fluids as water, ethylene glycol, oil. In the present work Al_2O_3 nanoparticle of diameter size 50 nm is suspended in water. The present work has been carried out on double pipe heat exchanger for water to water and nanofluid to water heat transfer investigation with counter flow arrangement under turbulent flow condition. The computational fluid dynamic code is used to simulated different concentrations of nanofluid (0.01% to 0.19%) in ANSYS FLUENT 14 software. The overall heat transfer coefficients for all concentrations are measured as a function of hot and cold streams mass flow rates. Considering friction factor, one appropriate concentration (0.1%) is taken into account experimentally. The thermal performance parameter overall heat transfer coefficient is compared for nanofluids with water. The study is done at different mass flow rates and inlet fluid temperatures. It is observed that for high Reynolds number low concentration of nanofluid is useful. The work concludes that there is promising enhancement in heat transfer rate using nanofluid*.

Key Words: *Nanofluid, overall heat transfer coefficient, mass flow rate, LMTD, CFD.*

1. INTRODUCTION

In last few years so many research have been done for enhancing the heat transfer rate like inserting baffles, twisted tapes, brushes, etc. This leads to increase in weight of heat exchangers and also cost of manufacturing. The world wide researchers are making hard efforts to find out suitable alternatives for heat exchangers with different geometry and varying parameters which effects on performance of heat exchanger. Now days nanofluid has became blessings for researchers. Nanofluid increases the heat transfer rate when suspended in base fluids water, ethylene glycol. With the fast track development of nanotechnology, particles of nanometer size are used for enhancing heat transfer rate are called nanofluids.

At present condition many scientists have focused on Alumina (Al_2O_3) due to ease of preparation, availability, and manufacturing. Table below compares the thermal properties of water and Alumina. From literature survey it is observed that higher concentration leads to increase in the viscosity of the nanofluid leading to increase in friction factor. This thesis is focused on study of heat transfer rate enhancement at low concentration.

1.1 Materials selection

Many different particle materials are used for nanofluid preparation. Al_2O_3, CuO, SiO_2, ZnO nanoparticles are frequently used in nanofluid research. Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications such as, water, ethylene glycol and engine oil. From available materials we have selected water as base fluid and Al_2O_3 as nanoparticles because of availability and safe to use.

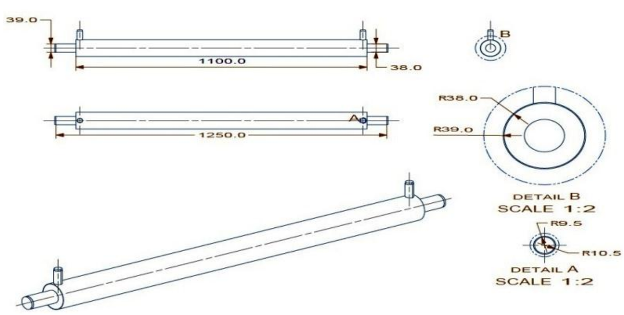
Table-1: Thermal Properties of water and Alumina. [10]

Sr.no.	Property	Water	(Al_2O_3)
1	C, J/kg K	4179	765
2	ρ, kg/m^3	997.1	3970
3	k, W/m K	0.65	40
4	α, m^2/s	$1.45*10^{-7}$	$1.31*10^{-5}$

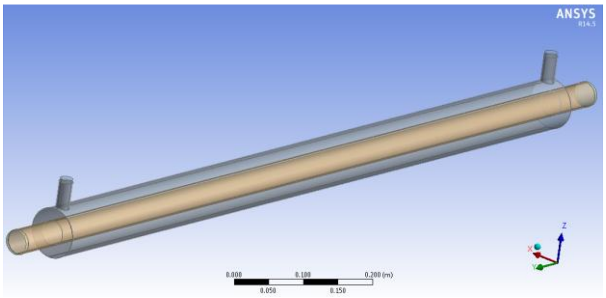
2. Computational fluid dynamic procedure

2.1 Geometry and computational fluid domain

The schematic diagram of computational fluid domain is as shown in fig.1.



(a)



(b)

Fig-1: Geometry and computational fluid domain

2.2 Grid Generation

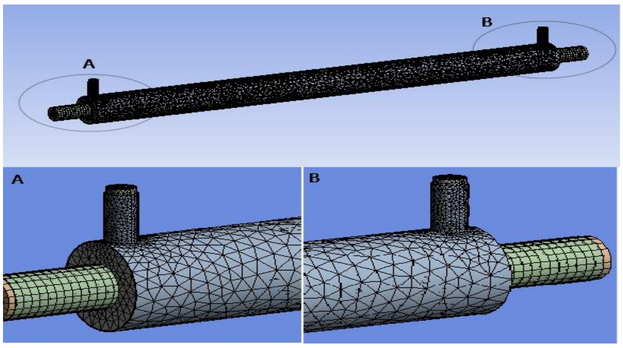


Fig-2: Discretized computational domain

2.3 Setting of boundary condition and solving

Table-2: Boundary Conditions

Quantities	Boundary Conditions	
Working fluid	Water	Nanofluid
Inner pipe (hot fluid)	Hot inlet (Nanofluid)	
	Velocity	Temperature
	0.1472 m/s	42°C
Outer pipe (cold fluid)	Cold inlet (Water)	
	Velocity	Temperature
	0.05859 m/s to 0.5859 m/s	25°C

2.4 Post processing

The variables such as temperature, velocity, with water and with nanofluid are represented in the form of vectors, contours which are extracted from post processing tool.

3. Experimental set up

3.1 Fabrication

The experimental set up fabricated as per design of heat exchanger. Four temperature indicators are used to measure inlet and outlet temperatures. Two pumps with two flow controlling valves each and a flow meter, two tanks to store the water and nanofluid, a heating arrangement is fitted for heating nanofluid as well as water. The system line diagram is shown in fig.3

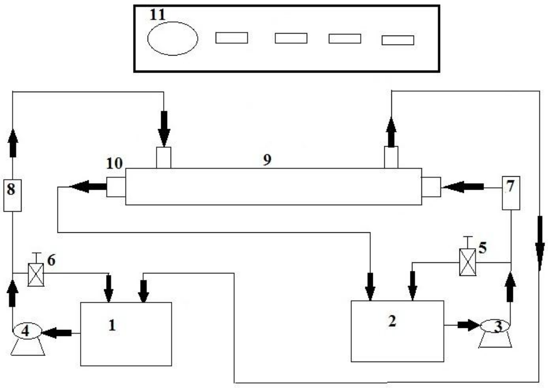


Fig. 3 Line diagram of set up

3.2 Nanofluid preparation

Preparation of nanofluid is the most important step. Nanoparticles Al_2O_3 of particles diameter size 50 nm were purchased from Sigma-Aldrich Company. Nanofluid is prepared with the help of mechanical stirrer [13] with electrical motor of 3000 rpm. This method is based on Das et al. (2008), Mahendran et al., 2012, Han and Rhi (2011) and Lee et al. (1999). It was found that the nanofluid prepared with this method can be stable for one day, after that sedimentation occurs.

Fig-4: Nanoparticles

Fig-5: Preparation of nanofluid

3.2 Actual set up photo

4. Data processing

4.1 Thermophysical properties of nanofluid

The effective properties of nanofluids like density, specific heat, thermal conductivity, and viscosity are to be calculated according to the mixing theory [3].

1. The density of nanofluid is calculated using Pak and Cho correlations [7].

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \rho_p$$

Where, ρ_{nf} is the density of nanofluid, ρ_{bf} is the density of base fluid (water), ρ_p is the density nanoparticles (Al_2O_3).

2. The specific heat of nanofluid is calculated from Xuan and Roetzel correlation [7].

$$\rho_{nf}\, Cp_{nf} = (1-\varphi)\, \rho_{bf}\, Cp_{bf} + \varphi\, (Cp)_p\, \rho_p$$

Where, Cp_{nf} is the specific heat of nanofluid, Cp_{bf} is the specific heat of base fluid (water), Cp_p is the specific heat of nanoparticles (Al_2O_3).

3. The thermal conductivity of nanofluid is calculated from Yu and Choi formula [7]

$$K_{nf} = K_{bf}\, \frac{Kp+2Kbf-2\varphi(Kbf-Kp)}{Kp+2Kbf+\varphi(Kbf+Kp)}$$

Where, K_{nf} is the thermal conductivity of nanofluid, K_{bf} is the thermal conductivity of base fluid (water), K_p is the thermal conductivity of nanoparticles (Al_2O_3).

4. The viscosity of nanofluids less than 5% concentration [7] is calculated using Drew and Passman correlation.

$$\mu_{nf} = (1+ 2.5\,\varphi)\, \mu_w$$

Where, μ_{nf} is the viscosity of nanofluid, μ_w is the viscosity of water.

5. Friction factor of nanofluid is given by,

$$f = 0.961Re^{-0.375}\varphi^{0.052}$$

All above properties of nanofluid are to be calculated considering water and Alumina at room temperature.

4.2 Analysis of heat exchanger

1. According to first law of thermodynamics,

i) Hot fluid heat transfer rate $Q_h= m_h*C_{ph}*(Th_i-Th_o)$
ii) Cold fluid heat transfer rate $Q_c= m_c*C_{pc}*(Tc_o-Tc_i)$

Where, m_h and m_c are the mass flow rates of hot and cold fluid respectively, C_{ph} and C_{pc} are the specific heats of hot and cold fluid respectively, Th_i and Tc_i are hot and cold inlet temperatures, Th_o and Tc_o are hot and cold outlet temperatures.

$$Q_{avg} = (Q_h + Q_c)/2$$

2. Logarithmic mean temperature difference (LMTD) is calculated by using formula,

$$LMTD\ (\Delta T_{lm}) = \frac{(Thi - Tco)-(Tho - Tci)}{ln(Thi - Tco)/(Tho - Tci)}$$

3. The surface area is calculated as

$$A_s= \Pi*Do*L$$

The overall heat transfer coefficient is calculated by using formula, $Q_{avg}= U*A_s*\Delta T_{lm}$

5. Results and Discussion

In order to study the effect of nanofluid it is essential to focus on thermo physical properties of nanofluid at different concentrations. It was found that as the concentration increases there is improvement in thermal conductivity with viscosity and density. From CFD analysis of nanofluid concentrations (0.01% to 0.19%) it is found that increase in nanofluid concentration increases the overall heat transfer coefficient. Also, the mass flow rate increases the values of U. The graph shows the effect of mass flow rate on overall heat transfer coefficient for four concentrations and remaining are in between them.

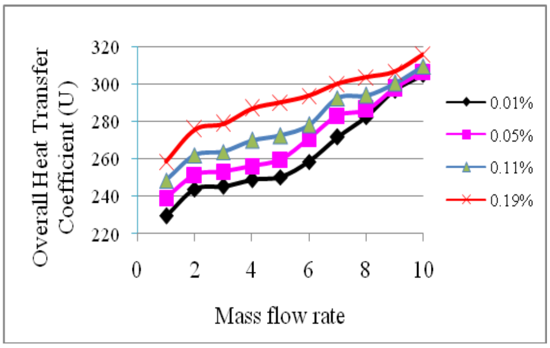
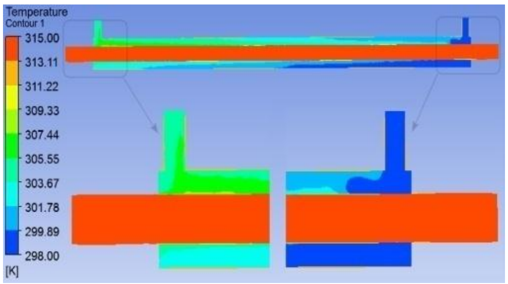
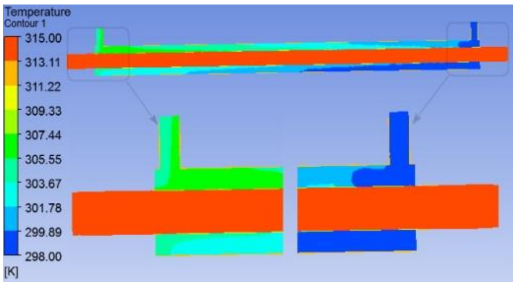


Fig.-6: Mass flow rate Vs Overall Heat Transfer Coefficient

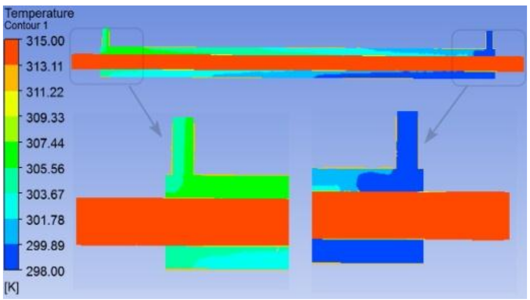
The figure 7 shows the temperature distribution diagrams for four concentrations explained in above graph (0.01%, 0.05%, 0.11%, and 0.19%). Diagrams are for the first reading of each concentration. As hot flow rate is constant throughout and cold flow rate is varied from 1 LPM to 10 LPM so, hot outlet is not showing variation.



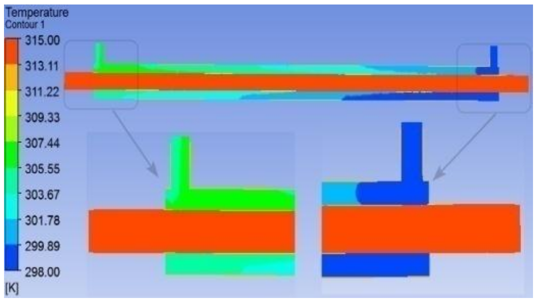
(a) 0.01%



(b) 0.05%



(c) 0.11%



(d) 0.19%

Fig-7: Temperature distribution diagrams

While selecting the concentration of nanofluid friction factor plays an important role. The graph below shows calculated friction factors with respective Reynolds numbers. It shows that if the concentration increases friction factor also increases due to increases in viscosity. The friction factor decreases with increase in Reynolds number. So, low concentration of nanofluid with high Reynolds number is preferred for heat exchanger.

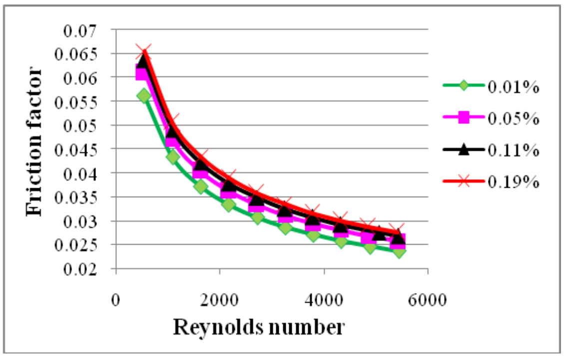


Fig-8: Reynolds number (Re) Vs Friction factor

Figure 9 shows experimental results of water to water and 0.1% nanofluid to water. It is observed that increase in mass flow rate increases the heat transfer rate as compared to base fluid upto the flow rate of 6 LPM and after that value of overall heat transfer coefficient is same for both fluids.

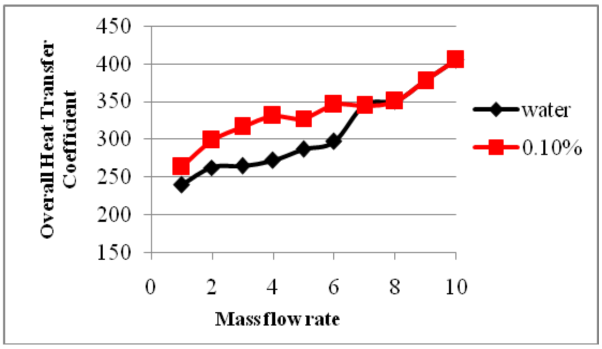


Fig-9: Mass flow rate Vs Overall heat transfer coefficient

Figure 10 shows CFD analysis for overall heat transfer coefficient of water to water and 0.1% nanofluid to water. The graph follows same trend for values of overall heat transfer coefficient as experimental values. Maximum heat transfer enhancement is observed for flow rates 4LPM, 5LPM and 6LPM.

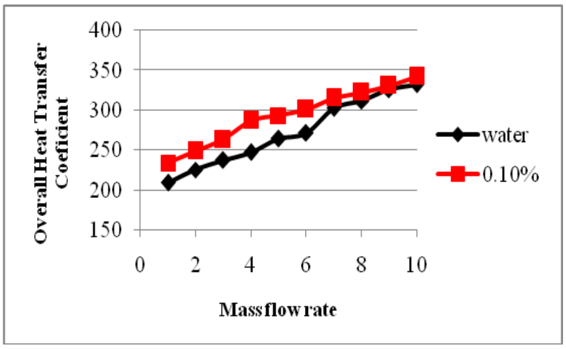


Fig-10: Mass flow rate Vs Overall heat transfer coefficient

6. Conclusions

Analysis of different concentrations of Al_2O_3 for double pipe heat exchanger with the help of ANSYS FLUENT 14 is studied. From those concentrations experimental study on one concentration (0.1%) is performed. The thermal performance parameter overall heat transfer coefficient has been determined. Also, the effect of friction factor on heat transfer rate is determined. Some of main conclusions are noted below.

1. Dispersion of nanoparticle into the water increases the thermal conductivity (from 0.65 W/m °C to 0.6511 W/m °C) and viscosity (from 0.001030 Ns/m^2 to 0.001035 Ns/m^2).
2. From CFD analysis it is observed that increase in nanofluid concentration gives promising enhancement in heat transfer rate.
3. Experimentally overall heat transfer coefficient increases with mass flow rate upto 6 LPM then it shows same value for water and nanofluid.
4. From CFD analysis of 0.1% concentration found that 11.5% (from 209.07 W/m^2°C to 234.02 W/m^2°C) enhancement in heat transfer rate.
5. Experimentally 9.5% enhancement (from 239.41 W/m^2°C to 262.63 W/m^2°C) in heat transfer rate is observed.

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