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Thermal Performance Improvement of a NFU Type Heat Exchanger Using Hybrid Nanofluids

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Abstract

Thermal performance of an NFU heat exchanger using nanofluid (Al_2O_3/water and CuO/water) and their mixture has been studied in this works. Heat transfer rate, overall heat transfer coefficient, LMTD have been evaluated to determine the thermal performance of heat exchanger. Al_2O_3, CuO and different compositions of Al_2O_3/CuO nanoparticles have been mixed with water to prepare the nanofluid. For the different components of nanoparticles, the thermal performance of the heat exchanger has been determined at different flow rates. Four thermometers have been used to measure the temperature of the fluid. A rotameter also has been used for flow regulation. The result shows that 30% Al_2O_3 and 70% CuO include a heat transfer rate of 1250 W and an overall heat transfer coefficient of 1934 W/m^{2}K. Effectiveness is also higher for this hybrid nanofluid, which is around 4.3%. Heat transfer rate as well as the overall heat transfer coefficient increase due to the increase in flow rate.

Keywords: Heat Exchanger, Nano fluids, LMTD, Heat Transfer Effectiveness.

1. Introduction

Ordinary fluids, which are used to enhance heat transfer rate, such as oil, water and ethylene glycol are hardly satisfying the necessaries of modern industry, transportation, nuclear, electronic engineering and so forth with the development of industry. The performance of the normal heat transfer fluids can be enhanced by suspending foreign materials having high thermal conductivity and solubility with the fluid. Application of nano size particles in the base fluid have emerged as an suitable and viable option as heat transfer enhancement technique. Moraveji and Razvarz [1] performed an analysis on a heat pipe's thermal efficiency using Al_2O_3 nanofluid at different weight concentration and demonstrated that, comparing to pure water, the thermal performance of the pipe was increased by using 12% for nanofluid. Reddy and Rao [2] experimentally searched on the condition of heat transfer coefficient as well as friction factor in a heat exchanger adding TiO_2 nanofluid. The base fluid was the mixture of pure water as well as ethylene glycol in this analysis. They demonstrated that the heat transfer coefficient increases due to the increment of Reynolds number as well as volume concentration of nanoparticles. Vermahmoudi et al. [3] performed an experimental investigation in a heat exchanger, which was finned in the surface, to evaluate the overall heat transfer coefficient of Fe_2O_3-water nanofluid. They demonstrated that the overall heat transfer coefficient increases due to the increase of air Reynolds number, flow rate and volume concentration of nanoparticles.

Goodarzi et al. [4] showed that heat transfer of working fluid increases due to the increase of Reynolds number or the percentage of nanoparticles performing an analysis on the thermal performance of a counter flow double pipe heat exchanger. Akhtari et al. [5] carried out an experimental as well as numerical analysis in double pipe and shell and tube exchangers to find out heat transfer of α Al_2O_3-water nanofluid. In this case, they showed that, comparing with pure water, 13.2% and 21.3% increment of heat transfer coefficients occur in double pipe and shell and tube heat exchanger respectively. Using a biological nanofluid, Sarafraz and Hormozi [6] performed an analysis on forced convective heat transfer enhancement. In the experiment, they used a double pipe heat exchanger and revealed consequences of inlet bulk temperature, flow rate and nanofluid concentration on heat transfer coefficient. Sarafraz et al. [7] carried an experimental study on the pressure drop behavior and heat transfer coefficient of COOH-CNT/water nanofluids. They performed this study in a double pipe heat exchanger and showed that for the appearance of carbon nanotube thermal conductivity enhances up to 56%.

The result of rising of friction factor with curvature ratio was showed by Aly [8] performing a numerical study on heat transfer and pressure drop behavior of Al_2O_3/water flow. The flow continued into parallel and cross flow concentric tube heat exchangers. They also demonstrated that as the nanoparticles volume concentration increased the pressure drop penalty was negligible. Sozen et al. [9] performed an experiment to examine the consequences of using nanofluid on a parallel flow performance concentric tube heat exchanger (PFCTHE) and a cross flow concentric tube heat exchanger (CFCTHE). The nanofluid was from alumina and fly ash. In this experiment, they showed that due to the presence of fly ash nanofluid that was used as working fluid increases the efficiency by 31.2% and 6.9% for PFCTHE and CFCTHE respectively. Chavda et al. [10] experimentally investigated the parallel/counter flows of a nanofluid in a double pipe heat exchanger. Hashmi and Akhavan-Behabadi [11] agreed that using helical tube insert is a more effective method without using of straight tube to enhance the convective heat transfer coefficient. They revealed that 78.4% increment in heat transfer coefficient in helical coil at 82.2% Reynolds number comparing to the straight tube. Kumar et al. [12] carried on an experiment in a shell and tube heat exchanger. The exchanger was helically coiled and the study was done under turbulent condition using Al_2O_3/water nanofluid with varying nanoparticles concentration. They revealed that the Nusselt number was increased by 56% for distilled water with 0.8 % Al_2O_3 nanoparticles.

From the above study, it is clear that alumina and copper oxide showed higher thermal performance individually. By combining of these two nanoparticles the thermal performance of heat exchanger seems to be increased. In this experimental study, the thermal performance of a NFU type heat exchanger with Al_2O_3/water, CuO/water, and combination of Al_2O_3/CuO/water have been analyzed for 1% volume concentration of the suspended nanoparticles

2. Experimental facility

2.1. Nanofluid preparation

The CuO and Al_2O_3 nanoparticles having an average size of 50 nm and 40nm respectively with density 6.3 gm/cm^3 for CuO and 3.6 gm/cm^3 for Al_2O_3 have been used in the present experimental work. CuO and Al_2O_3 nanofluid of 1% volume of fraction have been prepared for the measurement of the temperature dependent thermal conductivity. The nanoparticles accumulation takes place when nanoparticles have been suspended in the base fluid. The sample of CuO and Al_2O_3 nanofluid have been subjected to magnetic stirring process for 48 hours but no ultrasonic vibration. Thus, there were particle settlement but the fluids have been stirred adversely before use. On the other hand, to prepare a solution of 1% volume fraction the composition of Al_2O_3 and CuO nanoparticles and their corresponding weight is given in Table 1. Materials with a nominal composition of 70 wt% Al_2O_3 and 30 wt% CuO, 50 wt% Al_2O_3 and 50 wt% CuO and 30 wt% Al_2O_3 and 70 wt% CuO have been prepared by mechanical mixing. These have been mixed in a planetary ball-milling machine for 2 hours to produce a homogenous mixture.

Table 1. Different Composition of Al_2O_3 and CuO Nanoparticles and their Corresponding Weights.

Composition of Al_2O_3 and CuO nanoparticles for 1% volume concentration of hybrid nanoparticles	Weight of Al_2O_3 nanoparticles (Grams)	Weight of CuO nanoparticles (Grams)
70% Al_2O_3 and 30 % CuO	7	3
50 % Al_2O_3 and 50 % CuO	5	5
30 % Al_2O_3 and 70 % CuO	3	7

2.2. Experimental setup

In this experiment a NFU-type heat exchanger has been used as experimental test section. Four thermometers have been used that indicate the temperature at different location of the setup. A centrifugal pump has been used to flow the nanofluid through the heat exchanger. Flowmeter have been used to regulate the flow of water and to determine the rate of flowing water. An electric heater has been installed to heat the water for hot water supply through the heat exchanger. This experiment includes a heating tank, a nanofluid reservoir tank, a shell and tube heat exchanger, a nanofluid cooling system, by pass line, thermometers, pump and flow meter. In this experiment, nanofluid is subjected to flow through the tube and water have been flown through the shell of the NFU-type heat exchanger. The hot reservoir is thermally isolated and two valves is used to control flow. Four thermometers have been used in the entrance and exit pipes of the heat exchanger. Two of the thermometers are used to measure the temperature of nanofluid at the entrance and exit of tube side, and the other two has been applied to assess the temperatures of water at the entrance and exit of shell side. There are two loops (nanofluid and water flow loops) exist in the experiment. Experimental line diagram and experimental setup is shown in Figure 1 and Figure 2 respectively.

The following mathematical equations are used to determine different characteristics of the nanofluid as well as the performance of the heat exchanger. Rate of heat transfer, overall heat transfer coefficient, LMTD and effectiveness of the heat exchanger were calculated from the measured experimental data.

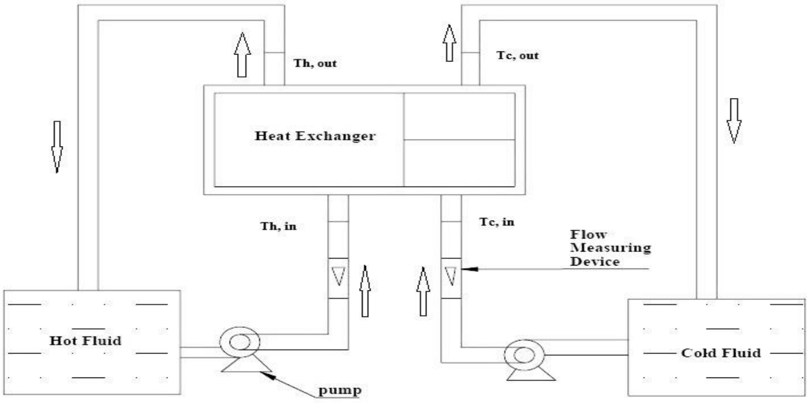

Fig 1. Experimental Line diagram

Fig 2. Experimental setup

3. Data reduction

Density of nanofluid, $\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_{bf}$ (1)

Specific heat of nanofluid, $C_{p,nf} = \frac{\varphi(\rho C_p)_p + (1-\varphi)(\rho C_p)_{bf}}{(1-\varphi)\rho_{bf} + \varphi\rho_p}$ (2)

Where φ =Volume concentration, ρ_p = Density of nanoparticles, ρ_{bf} = Density of base fluid, $C_{p,bf}$ = Specific heat of base fluid, J/KgK, $C_{p,p}$ = Specific heat of nanoparticles, J/KgK

Log mean temperature difference (LMTD), $\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\frac{\Delta T_1}{\Delta T_2}}$ (3)

Here, $\Delta T_1 = T_{h,in} - T_{c,in}$ (4)

$\Delta T_2 = T_{h,out} - T_{c,out}$ (5)

Overall heat transfer coefficient, $U = \frac{\dot{Q}}{AF\Delta T_m}$ (6)

Here, U = Overall heat transfer coefficient, W/m^{2}K, $\dot{Q}$ = Actual heat transfer rate, A = Area of the heat exchanger, m^2 ,F = Correction factor

Correction factor can be obtained from Kakac et al. [16] chart using two parameters P and R.

$P = \frac{t_2 - t_1}{T_2 - t_1}$ (7)

$R = \frac{T_1 - T_2}{t_2 - t_1}$ (8)

Effectiveness, $\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}}$ (9)

Where,

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) = \dot{m}_h C_{ph}(T_{h,out} - T_{h,in}) \quad (10)$$

$$\dot{Q}_{max} = C_{min}(T_{h,in} - T_{c,in}) \quad (11)$$

Here, $\dot{m}_c, \dot{m}_h$ = Mass flow rates, $T_{c,in}, T_{h,in}$ = Inlet Temperatures, $T_{c,out}, T_{h,out}$ = Outlet temperatures, C_{min} = The smaller of $\dot{m}_c C_{pc}, \dot{m}_h C_{ph}$

4. Results and discussion

Figure 3 and 4 shows that 30% Al_2O_3 and 70% CuO hybrid nanofluid shows better thermal performance than the other nanofluid in a constant flow rate (18 L/min).

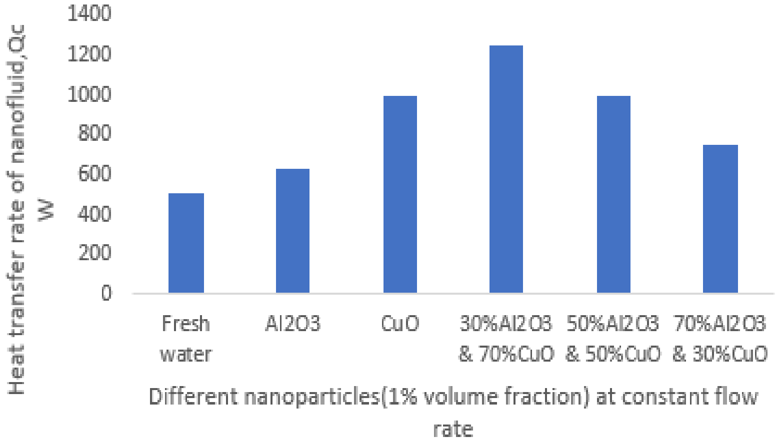

Fig 3. Heat transfer rate at constant flow rate

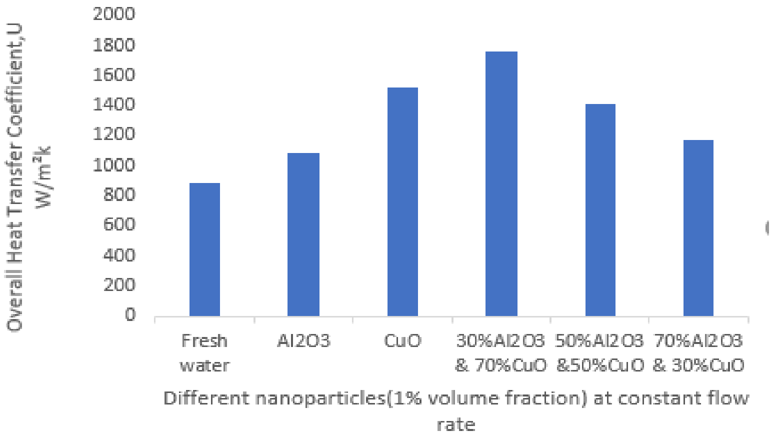

Fig 4. Overall heat transfer coefficient at constant flow rate.

The figures clearly show that utilization of nanofluid increase the heat transfer rate as well as overall heat transfer coefficient than the fresh water. Since the nanoparticle has greater thermal conductivity than the base fluid so heat transfer rate as well as overall heat transfer coefficient also increased in accordance with the conductivity of the fluid. The figures also show that in case of hybrid 30% Al_2O_3 and 70% CuO nanofluid heat transfer rate and overall heat transfer coefficient are higher, it may cause because of the following reasons:

- Between Al_2O_3 and CuO nanoparticles whose mean radius is smaller, that small sized nanoparticles may get inserted into the other particles and form a grain of larger surface area and for this increasing surface area heat transfer rate as well as overall heat transfer coefficient increase.
- If the mean radius of the particles are nearly same, then the particles get diffused which also increase the surface area as well as heat transfer rate.

Figure 5 and 6 show that heat transfer rate of nanofluid and overall heat transfer coefficient increase with the increase of LMTD for same volume concentration. Due to increasing log mean temperature difference, heat transfer rate increases and the heat transfer rate is directly proportional to overall heat transfer coefficient.

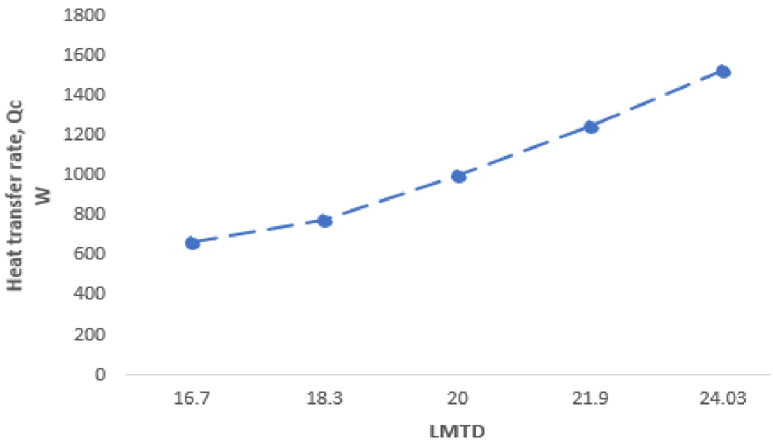

Fig 5. Variation of Heat Transfer rate with LMTD

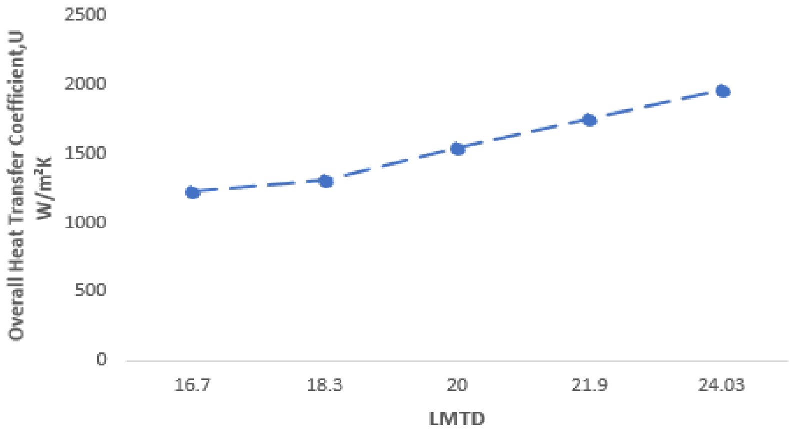

Fig 6. Variation of overall heat transfer coefficient with LMTD

In Figure 7 it is clear that using hybrid nanofluid of 30%Al_2O_3 and 70% CuO shows higher effectiveness. On the other hand using nanofluid the effectiveness increases comparing to the base fluid.

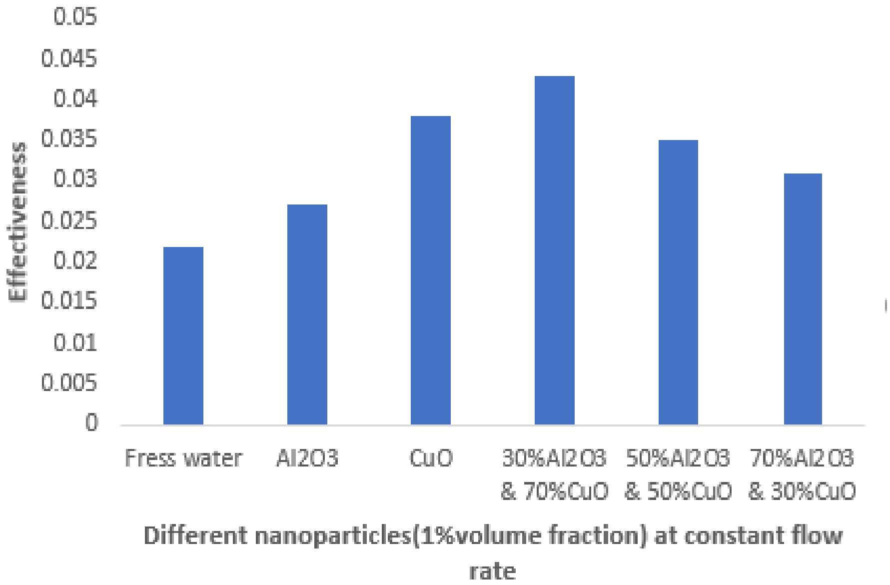

Fig 7. Variation of effectiveness

5. Conclusions

The significance of using nanotechnology to the heat transfer process can bring a new era to the world. As this technology is spreading itself to almost all engineering section, we can use it to the heat transfer devices for increasing the device's efficiency. It will ensure the longer time of these devices. As we know the application of these devices, any kind of positive and advanced modification can tremendously change the process of industry like steam power plant, thermal power plant etc. So this study would surely help us to know about the properties of nanoparticles and would show us how it is useful in heat transfer. The outcomes of this experimental analysis are

- Comparing to the conventional fluid like water nanofluid shows better heat transfer characteristic. In case of hybrid nanofluid, better heat transfer rate is shown. In this experiment, it is shown that 30% Al_2O_3 and 70% CuO have higher heat transfer rate and overall heat transfer coefficient than Al_2O_3, CuO, 70% Al_2O_3 and 30% CuO, 50% Al_2O_3 and 50% CuO water base nanofluid.
- For the same 1% volume fraction heat transfer rate increases by 49.5%, 55.2%, 55.2%, 59.6%, 63.6% and overall heat transfer coefficient increases with the increase of flow rate.
- For the same volume fraction heat transfer rate as well as overall heat transfer coefficient increase with the increase of logarithmic mean temperature difference (LMTD).

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