THERMAL PERFORMANCE OF SHELL AND TUBE HEAT EXCHANGER USING NANOFLUIDS

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Abstract—
In this paper, an attempt is made to experimentally investigate the thermal performance of a shell and tube heat exchanger using nanofluids. The cold water based nanofluids flow in tube side and water as hot fluid flows on shell side. Use of nanoparticles in water based nanofluid as coolant in shell and tube heat exchanger improves the effectiveness by a considerable amount, while the convective and overall heat transfer coefficient increases even further with the addition of 3% Al_2O_3 nanoparticles in water based fluid.

Keywords: Shell and tube heat exchanger, Nanofluid, Heat transfer, Performance

I. INTRODUCTION

Heat exchangers play an increasingly important role in the field of energy conservation. The need for better efficient heat exchanging system is required for new technological and industrial development. Therefore, the scientific attention is concentrating both on improving the equipment design and on enhancing the thermal potential of the working fluid. A substantial reduction in energy consumption could be made possible by improving the performance of heat exchanger systems. Due to inadequacy of conventional fuel, optimizations in energy consumption in various industrial processes become very important. Heat transfer rate in a heat exchanger are dependent on the thermo physical properties of the fluids participating in the heat exchanger, the material of the heat exchanger and also the areas of the surfaces participating in the process [1].Numerous investigations have been made for decades to enhance heat transfer [2-6], minimize heat exchanger size and increase efficiency of fuel and energy.

Nanofluids are the new generation heat transfer fluids for various industrial and automotive applications because of their excellent thermal performance and the word was which was coined at Argonne National Laboratory of USA by Choi in 1995 [7], which showed that the conventional liquid thermal performance could be remarkably improved using nanoparticles. Nanofluids can be used for a wide variety of engineering applications like transportation, electronics, medical, food, defense, nuclear, space, and manufacturing of many types [8]. Magnetic nanoparticles in bio-fluids can be used for medical applications as drug delivery vehicles, providing new cancer treatment technique. Using nanofluids in heat transfer applications will provide a number of potential advantages, such as better long-term stability, miniaturized heat exchangers, improved heat transfer, reduced heat transfer fluid inventory, little penalty in pressure drop, and can have significantly greater thermal conductivity. As a result, these offer an opportunity for engineers to develop highly compact and effective heat transfer equipments

Very limited information is available on shell and tube heat exchanger using Al_2O_3/water which motivated this investigation. The major goal of the present study, performance analysis of shell and tube heat exchanger with Al_2O_3/water nanofluid has been predicted. The effect of using Al_2O_3 nanofluid with different particle volume concentrations (0.5-3%) are investigated in this study.

II. THERMAL MODELING AND SIMULATION

The Al_2O_3 nanofluid based shell and tube heat exchanger considered in present study..The heat exchanger is counter-flow single pass type, where the cold Al2O3 nanofluid flows through the tubes and the hot water flows through the shell. As the effect of using Al2O3 nanofluid as a cooling medium in shell and tube heat exchanger on the performance improvement is the main aim of the present study. The following assumptions have been made in the analysis:

(1) The heat exchanger is thermally insulated which ensures no heat loss to the surrounding.

(2) Only single-phase heat transfer occurs for nanofluid.

(3) Longitudinal heat conduction is negligible.

(4) The changes in kinetic and potential energies of fluids are negligible.

The energy balance equation of heat exchanger for both the fluid is written as:w

$$Q = \left(\dot{m}c_p\right)_{nf}\left(T_{nf,out} - T_{nf,in}\right) = \left(\dot{m}c_p\right)_s\left(T_{s,in} - T_{s,out}\right) \tag{1}$$

where, Q is the heat transfer rate, cp is the specific heat of fluid at constant pressure, T represent the temperature, the subscripts nf and s refer to the nanofluid and shell side fluid, respectively, the subscripts in and out refer to the inlet and outlet of heat exchanger, respectively.

Considering the cross flow between adjacent baffle, the logarithmic mean temperature difference (LMTD) is determined by:

$$LMTD = \frac{\left(T_{s,in} - T_{nf,out}\right) - \left(T_{s,out} - T_{nf,in}\right)}{\ln\left(\left(T_{s,in} - T_{nf,out}\right)/\left(T_{s,out} - T_{nf,in}\right)\right)} \tag{2}$$

The heat transferred with the overall heat transfer coefficient, the total heat transfer area and LMTD, are determined by the following equation:

$$Q = UA_t(LMTD)F \tag{3}$$

where, the correction factor F for the flow configuration involved is found as function of temperature effectiveness, the heat capacity rate ratio and the flow arrangement, defined as:

$$F = \frac{\sqrt{R^2+1}\,\ln\frac{(1-P)}{(1-PR)}}{(R-1)\ln\left[\frac{2-P\left(R+1-\sqrt{R^2+1}\right)}{2-P\left(R+1+\sqrt{R^2+1}\right)}\right]} \tag{4}$$

where, R is the correction coefficient given by:

$$R = \frac{\left(T_{s,in} - T_{s,out}\right)}{\left(T_{nf,out} - T_{nf,in}\right)} \tag{5}$$

P is given by:

$$p = \frac{\left(T_{nf,out} - T_{nf,in}\right)}{\left(T_{s,in} - T_{nf,in}\right)} \tag{6}$$

The value of F for shell and tube heat exchanger is taken as 0.9 [9].

The total heat transfer areas are determined by following equation:

$$A_t = \pi d_o N_T L \tag{7}$$

The overall heat transfer coefficient U depends on the nanofluid side and shell side heat transfer coefficient can be estimated from the following equation [10]:

$$\frac{N_T}{UA_t} = \frac{1}{h_{nf} A_i} + \frac{\ln \frac{d_o}{d_i}}{2\pi k_t L} + \frac{1}{h_o A_o} \tag{8}$$

Yu and Choi [11] proposed a modified Maxwell model for the effective thermal conductivity of solid/ liquid to include the effect of a liquid nanolayer on the surface of the nanoparticle, given by ($\phi \leq 5\%$) :

$$k_{nf} = \left[\frac{k_p + 2k_w + 2(k_p - k_w)(1+n)^3 \phi}{k_p + 2k_w - (k_p - k_w)(1+n)^3 \phi}\right] k_w \tag{12}$$

where, n =h/r is the ratio of the nanolayer thickness to the original particle radius and was set at 0.1 in this study.The properties are taken by

To evaluate the heat transfer coefficient of nanofluid Pak and Choi [12] correlation has been used, which is given by

$$\frac{h_{nf} d_i}{k_{nf}} = 0.021 \, \mathrm{Re}_{nf}^{0.8} \mathrm{Pr}_{nf}^{0.5} \tag{14}$$

Reynolds number nanofluid is defined as:

$$Re_{nf} = \frac{u_m \rho_{nf} d_i}{\mu_{nf}} = \frac{4\dot{m}_{nf}}{\pi d_i \mu_{nf} N_T} \tag{15}$$

Where d_i is the inner diameter of the tube , N_T is the number of tubes, is the viscosity of nanofluid and the mean velocity in tubes which is given by:

$$u_m = \frac{\dot{m}_{nf}}{\frac{\pi}{4} d_i^2 \rho_{nf} N_T} \tag{16}$$

Prandtl number of nanofluid is defined as:

$$Pr_{nf} = \mu_{nf} \frac{c_{pnf}}{k_{nf}} \tag{17}$$

An important parameter in the application of nanofluid in heat exchanging equipment is the pressure drop developed through the shell and tube heat exchanger. By neglecting the pressure loss in bend for the single tube pass, the total tube side pressure drop may be expressed as the sum of the distributed pressure drop along the tube length and concentrated pressure losses in elbows and in the inlet and outlet nozzles [13, 14].

III. RESULTS AND DISCUSSIONS

For the segmentally baffled shell and tube heat exchanger, the Bell-Delaware method is usually used for shell side film coefficient and pressure drop evaluation. In this method, the shell side heat transfer coefficient is determined by correcting the ideal heat transfer coefficient for pure cross flow in an ideal tube bank, which is given by as follows [14]:

The performance of shell and tube heat exchanger is presented for Al_2O_3 nanoparticle. Nanoparticle volume fraction was augmented from 0.5% to 3% for water based Al_2O_3 nanofluid. The inlet temperature of nanofluid and water has been taken as 27^0C and 90^0 C respectively. The flow rates of both water and nanofluid were kept constant at 0.36 and 0.18 kg/s, respectively. The diameter of nanoparticle is taken as 44 nm. Nanofluid Reynolds number, Prandtl number, effectiveness, pressure drop and pumping power were then determined. The heat exchanger effectiveness are plotted to illustrate the various performance trends.

Results show that the heat transfer inside the tubes in shell and tube heat exchanger increases by using Al_2O_3/water nanofluid due to increase in heat transfer properties and hence the effectiveness of heat exchanger also increases. It may be noted that the, thermal conductivity, viscosity and density increases and specific heat capacity decreases by using nanoparticle, and hence both Reynolds number and Prandtl number decreases for same operating mass flow rate as shown in Fig. 1. However, the heat transfer coefficient increases compared to base fluids due to increase in transport properties (viscosity and thermal conductivity) of nanofluids. Higher thermal conductivity of nanofluid probably is the main reason contributing to heat transfer enhancement. More heat can be absorbed and transferred with the application of nanofluid The heat transfer enhancement using nanofluids may be affected by several parameters such as Brownian motion, sedimentation, dispersion of the suspended particles, thermophoresis, diffusiophoresis, layering at the solid/liquid interface, ballistic phonon transport

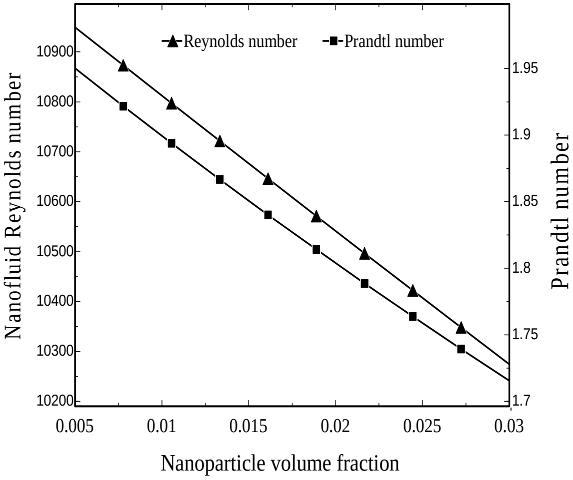

Fig. 1.Variation of nanofluid Reynolds number and Prandtl number with particle volume fraction

The pressure drop increases and volumetric flow rate decreases with increase in the volume concentration of the nanoparticles as shown in Fig. 2, and hence the pump work slightly decreases. Therefore, lower pumping power is needed when Al_2O_3/water nanofluids is used in the shell and tube heat exchanger due to increase in density. Pressure drops by using Al_2O_3/water nanofluid are similar to that of water as a coolant in shell and tube heat exchanger and found very good matching with the experimental data [15].

The NTU increases with the increase in the volume concentration of nanoparticle. At constant mass flow rate NTU increases by around 9% but there is drop in specific heat capacity of around 10.4%.This causes a decrease in the heat capacity, and hence the ratio between the minimum and maximum heat capacities of the fluid also decreases 10%. Therefore, the result is an ultimate increase in the effectiveness of the heat exchanger. The effectiveness of heat exchanger increases by almost 6.2% due to increase in percentage volume concentration from 0.5% to 3%

At constant particle volume fraction Reynold’s number is linearly depends on the mass flow rate. With the increase of nanofluid Reynolds number, Nusselt number is increased and hence the convective heat transfer of nanofluid is higher than base fluid. The same happened with the oveall heat transfer coefficient Heat transfer rate is proportional to nanofluid mass flow rate as shown in shown in Fig. 3.

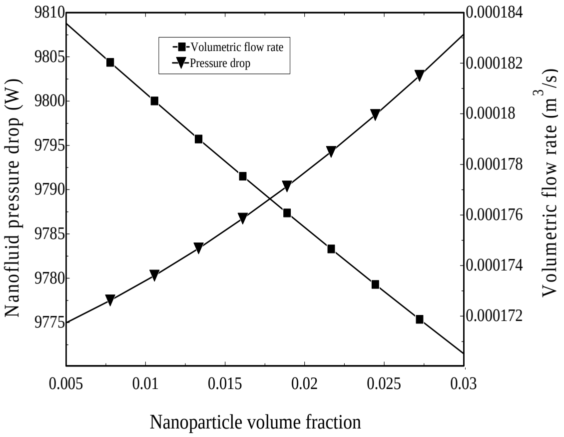

Fig. 2.Variation of nanofluid pressure drop with particle volume fraction

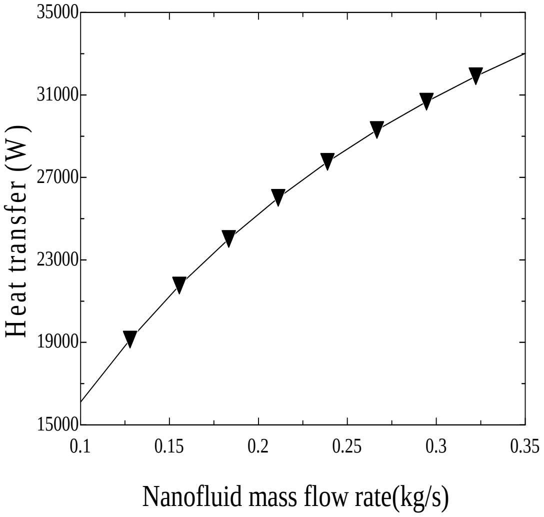

Fig. 3. Variation of nanofluid mass flow rate with heat transfer

Due to application of nanoparticle enriched coolant, it causes increase of thrust force in thermal conductivity and viscosity [16-19] during experimentation

IV Conclusions

An investigation was carried out to study the performance analysis of shell and tube heat exchanger using Al_2O_3/water nanofluid mathematically. Nanofluid convective heat transfer coefficient and overall heat transfer coefficient are higher than base fluid. From the results of the present study, it was found out that the effectiveness increases by 6.2% due to increase in volume concentration from 0.5% to 3%. Less coolant pumping power is needed for heat exchanger operated with Al_2O_3/water nanofluid compared to base fluid. Thus, there is an overall improvement in the performance of the shell and tube heat exchanger due to the use of Al_2O_3/water nanofluid. Thus, use of Al_2O_3/water nanofluid is favorable in case of shell and tube heat exchanger.

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