Comparative Study of Overall Heat Transfer Coefficient for Water and Nanofluids in Parallel Flow Configuration

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Abstract

Shell and tube heat exchangers are primarily used in power plants, chemical industry and HVAC systems owing to the effectiveness in transfer of heat between fluids. An experimental setup for shell and tube heat exchanger (H.X) has been fabricated to perform experimentation in accordance with standard. The present study has been carried out to determine the heat transfer rate (Q) and overall heat transfer coefficient (U) of a shell and tube heat exchanger using alumina oxide nanofluids and distilled water for parallel flow configurations. Nanofluids with a concentration of 0.22% passed through the tubes while water entered through the shell of the heat exchanger in parallel flow. Rotameters were used to regulate and monitor flow rates of 6, 8, and 10 liters per minute (LPM) and K-type thermocouples were used to measure temperatures at the inlet and outlet of the shell and tubes. The research compares these values against water in a parallel flow arrangement, with an emphasis on the heat transfer rate and overall heat transfer coefficient. The results show that, as compared to water, the nanofluid significantly enhances heat transfer rates by 22.56%, 14.51% and 10.25% for the flow rates 6, 8, and 10 LPM, respectively. Similarly, the overall heat transfer coefficient of nanofluids increased by 23.76%, 16.54%, and 12.35% at flow rate of 6, 8 and 10 LPM. These results highlight the improved performance of alumina nanofluid over distilled water in parallel flow.

Keywords: Parallel flow, STHX, Flow rates, Overall heat transmission coefficient, Heat transmission rate.

1. Introduction

Shell and tube Heat Exchangers (STHX) are widely utilized in power plants, chemical plants, oil refineries and refrigeration plants. These types of STHX are selected on the basis of Simple structure, high K, large flows of the transferring fluid. The efficiency of the STHXs has a direct link with the energy needed as well as the productivity of industrial processes. Therefore, improving the thermal performance of STHE’s is considered as one of the more dominant research and technological development fields [1] . Over the past few years nanofluids have been viewed as a potential way of increasing the of the basic Heat transmission fluids. Nanofluids refer to colloidal suspensions comprised of nanoparticles and a base fluid, the base fluid commonly being water, with enhanced thermal conductivity (K) compared to the base fluid. The most common nanoparticles studied for their use are Al_2O_3 (Alumina-Oxide) due to the factors such as, high K, chemical stability and cost efficiency. In nanoparticle system the size of particle and the surface area to volume ratio is high that is why Q is high at molecular level resulting in higher U and thermal utilization ratio [2]. The researchers used nanofluids composed of a mixture of TiO_2 and Al_2O_3 suspended in water. The Re number (Re) and the Nu number (Nu) both exhibited a proportional rise with the increase in the quantity of dispersed nanoparticles [3]. Liu et al.[4] investigated CuO nanoparticles added in ethylene glycol without the use of surfactant, showing significant enhancement in thermal conductivities. The uniform spherical CuO nanoparticles, ranging from 30–50 nm, displayed a crystalline structure demonstrated by XRD peaks. The K increased in a linear way as the volume fraction of CuO nanoparticles is increased, with enhancements of up to 22.4% observed at a concentration of 0.05. Duangthongsuk and Wongwises [5] conducted an experiment in an H.X. with a double-pipe counterflow setup to examine the parameters of the heat exchange and pressure drop of a N.F made up of TiO_2 particles distributed in water, mainly focus was to look into the properties of the N.F. The whole volume was comprised of 0.2% nanoparticles, using N.F as a water alternative resulted in an increase in the HTC by around 6-11% while the pressure experienced an insignificant drop. The convective heat transmission and flow dynamics of an Al_2O_3 N.F in a STHE under turbulent circumstances have been studied [6]. This study clarifies the effects of changing the volume concentration of nanoparticles and the Re number on the efficiency of Heat transmission and flow behaviour at various mass flow rates. Important discoveries show that nanoparticle dispersion improves K and viscosity, which improves Heat transmission efficiency. This is especially noticeable at a 2.5% particle volume percentage. Pantzali et al. [7] conducted a study using theoretical and experimental approaches to examine the impact of Nanofluids on the performance of small plate H. X's that had been subjected to surface changes. The results of the experiment indicated that when the volume quantity of dispersed nanoparticles was 4%, the heat transmission of CuO N.F enhanced by around 18% when comparatively with water. Khedkar et al. [8] has informed a 16% increase in total heat transmission in a concentric tube H.X, At Re numbers 15,000, a double pipe H.E is used to flow a TiO_2 N.F consisting of a 40:60% combination of ethylene glycol and water, with a volume concentration of 0.02%. Majdi and Abed [9] found that SiO_2 N.F in water showed an increase in heat transmission rate. Tiwari et al. observed a 28% increase in total heat transmission while using a concentration of 0.75% of CeO2 N.F at a flow rate of 3 litters per minute also a circular tube containing Cupric Oxide-water N.F at 0.24 volume concentration was tested for heat transmission and the drop in pressure by Fotukian [10]. The findings demonstrated a penalty of 20% drop in the pressure and an improvement in HTC of almost 25%. Barzegarian et al. [11] explored the thermal performance of a STHX using Al_2O_3-water nanofluid under various conditions. They found that the application of nanofluids significantly enhanced heat transmission, with a Nu number increase of up to 29.8% and overall heat transmission coefficient improvement by 19.1% at higher nanoparticle concentrations. These findings align with the trend of improved thermal performance when incorporating nanofluids in heat exchangers in order to maximize efficiency in these systems, they stressed the significance of optimizing nanoparticle concentration and flow rates. Alazwari et al. [12] comprehensive study on STHXs showed how nanofluids significantly affect thermal performance. They found that because of their excellent thermal characteristics, alumina oxide (Al_2O_3) nanofluids in particular increase heat transmission rates. To get the highest level of efficiency in these systems, they underlined the need of maximizing nanoparticle concentration and flow rates.

In this research, the thermal characteristics of a shell and tube H.X with Al_2O_3-gamma nanofluid through the parallel flow configurations were studied from the previous literature, it has been observed that Al_2O_3 nanoparticles can improve Heat transmission significantly, but not enough research has been done on the effects of concentration and the flow. Thus, the current study focuses on filling this research gap by analyzing the thermal characteristics of STHE with Al_2O_3-gamma nanofluid at 0.22% concentration of Nanofluid with parallel flow configuration of the STHX. The experiment arrangement includes a change in the flow rates of nanofluid and the flow rate of water on the shell side kept constant. The nanofluid with volume concentration of 0.22% is circulated through the tubes while shell side water is at ambient temperature. The results derived from this research will offer significant benefits to the existing knowledge base in nanofluids, particularly to H.X with relevance to energy saving and cost reduction impacting on the efficiency of industrial and organizational processes.

2. Experimental Setup

The test bench used in process was developed earlier, the basic elements of the test bench were hot and cold fluid tanks with the electrical heater 1.5 KW to set right temperatures of the fluids and the pumps for the circulation of fluid through the H.X. The flow rates were measured and regulated by rotameters while the temperatures were measured by K-type thermocouple at the inlet and outlet of the H.X. The detailed description of the shell and tube H.X used in the experiments is given in table 1.

Table 1. Specifications of the shell and tube H.X apparatus

Components	Specifications
Inside Dia of shell	90 mm
Thickness of shell	5 mm
Shell material	Steel
Length of tubes	300 mm
Tubes Material	Copper
Tubes inside Dia	12 mm
Tubes Thickness	1 mm
No of baffles	6
Baffles spacing	42.8 mm
Baffle type	Single segmental
Tubes arrangement	Parallel Triangular with 30°Angle

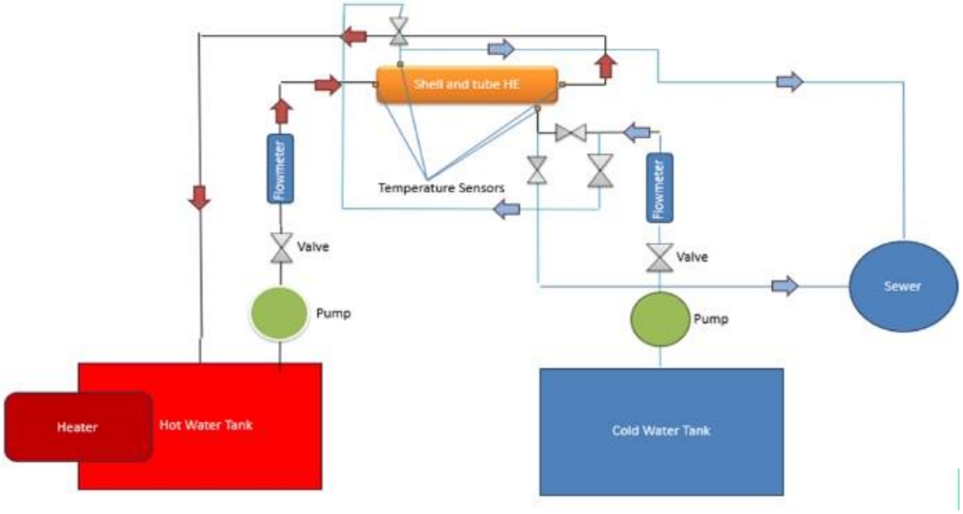
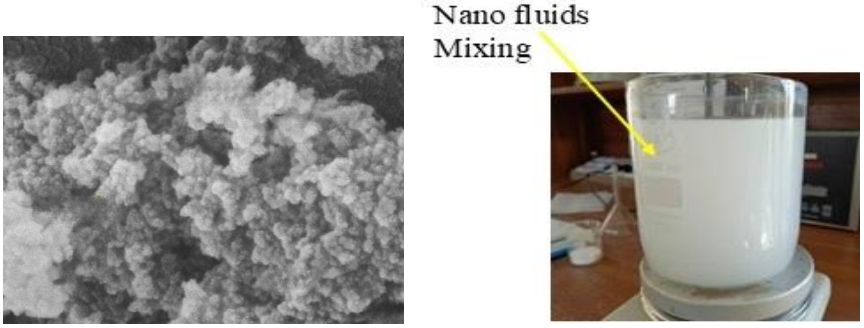


Fig 1: Schematic diagram of the experimental apparatus



(a) (b)

Fig 2: (a) SEM Image of Nanoparticles (b) Nano fluid

2.1 Nanofluid Preparation

For preparing the nanofluid, Al_2O_3 nanoparticles having average diameter of 10-15 nm and 99% purity were used. Nanoparticles were then dissolved in distilled water and the required amount to make the Nanofluid. Magnetic stirring and ultrasonic agitation methods were used in order to homogenize and avoid the sedimentation of the nanoparticles. The thermophysical properties of the nanoparticles are indicated in table 2.

Table 2. Thermophysical Properties of the Nanoparticles

Nanoparticles	Diameter (nm)	Specific Surface area (m^2/g)	Density (kg/m^3)	Specific Heat Capacity) (J/kg-K)	K (W/m-K)
Al_2O_3-gamma	12	120	3690	880	18

The experiment was carried out by heating the nanofluids up to 60°C with the help of circulating them through the tubes of the H.X while at the same circulating water having low temperature through the shell side. The experiment was conducted at three different nanofluid flow rates 6, 8, and 10 LPM. Inlet and outlet temperature of both the fluids was taken when the flow rates were in different configurations.

$$Q_h = \dot{m}cp_h(\Delta T) \quad (1)$$

$$U = \frac{Q}{A\Delta T_{LMTD}} \quad (2)$$

3. Results and Discussion

The experiment was carried out using 22% concentration of alumina oxide nanofluid at flow rates of 6 LPM, 8 LPM and 10 LPM and this gave deeper insights about the thermal improvements given by the nanofluid to the coolant. Comparisons for the Q and the U between both water and the nanofluid were made. These results show an enhancement of the Q by a percentage of 22.56%, 14. 51%, and 10. 25% for flow rates of 6, 8 and 10 liters per minute respectively. The U was augmented by 23. 76%, 16. 54%, and 12. 35% at the same flow rates. The findings derived from this study point very much to the supporting evidence that the Heat transmission of the system is indeed improved by the use of the nanofluid, particularly in the flow rate of 6 LPM. From the study it is observed that with increase in the flow rate of the fluids the advantage or the enhancement achieved for both Q and U reduces which is in agreement with the expectation that the baseline thermal performance of water is also enhanced with increase in the flow rate hence the gap between the two fluids reduces.

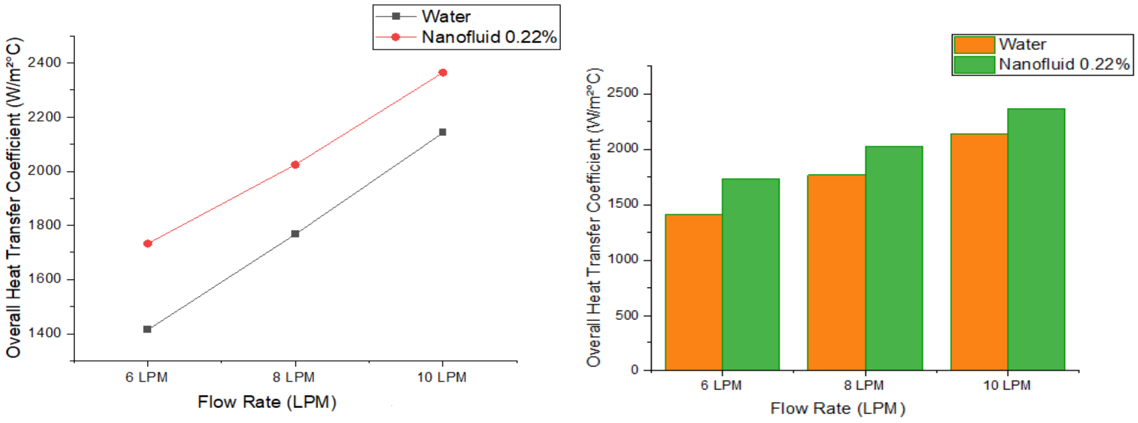


Fig 3: Relation between Overall Heat transmission coefficient and Flowrate

Re Number is one of the most crucial parameters that helps in understanding the flow regime of the tubes of the H.X. For the water, the Re numbers were calculated to be 324 for 6LPM, 440 for 8LPM and 557 for the 10LPM of flow rate. For the nanofluid, the corresponding Re numbers were higher, 344, 468 and 593 because of higher viscosity and density due to the addition of alumina oxide nanoparticles.

The Re numbers of the flow within the tubes stay therefore in the range characterizing the change from the laminar to a turbulent regime with higher flow rate enhance this towards a turbulent flow domain. Turbulence deforms the fluid layers and breaks their layers so that there is improved Heat transmission because the thermal boundary layer is reduced. Higher K of the nanofluid as well as slight increase in Re number can both be asserted for convective enhance heat transmission. For the purpose of calculations, the LMTD values taken were 2.5°C, 4°C, and 5. The temperature drop is 5°C for the flow rates of 6LPM 8 LPM and 10 LPM respectively. Since Q is directly proportional to both A and U, a constant ratio of areas provided an opportunity to study the effects of the nanofluid and flow rate on the Heat transmission performance.

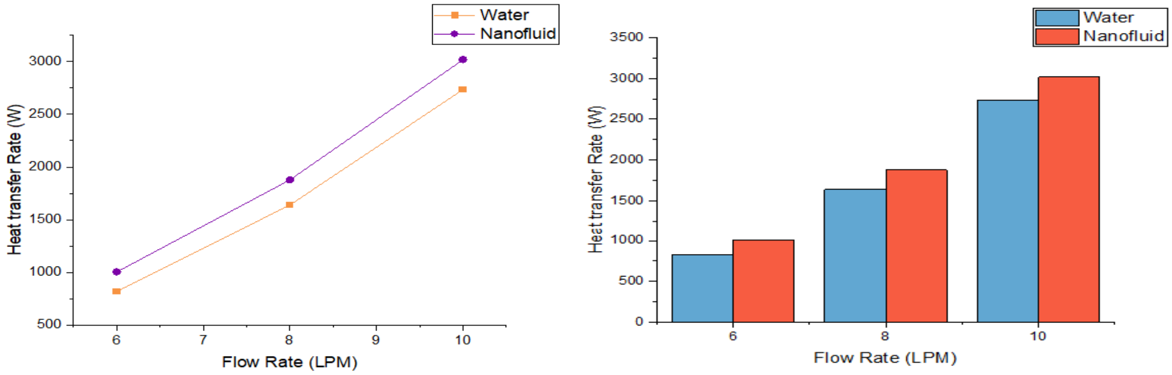


Fig 4: Relation between Heat transmission Rate and Flowrate

By adding alumina oxide nanoparticles to the base fluid, the STHX's thermal performance was successfully improved. The improvements in Q and U were observed to be more significant at low flow rates and this indicated that nanofluids would be suitable for use in systems where maximum heat transmission is required at moderate flow rates. Nevertheless, the decreasing flow rate efficiency, which is evident at higher flow rates, indicates that the nanofluids' performance may not be as significant in highly turbulent flow conditions. The study supports the notion that when designing thermal systems, it is crucial to account both for the properties of the fluid and the nature of its motion. Further studies can be dedicated to investigating the effects of altering nanoparticle concentrations, and applying different nanomaterials to elucidate the optimal and non-optimal characteristics of nanofluids in industrial H.X systems.

4. Conclusions

This study shows that utilizing a 0.22% concentration of alumina oxide nanofluid instead of water significantly improves the thermal performance of a STHX, the findings consistently demonstrate significant improvements in Q and U. The increased thermal characteristics of the nanofluid led to a 22.56% increase in heat transmission rate and a corresponding improvement in the total heat transmission coefficient. These results suggest that the nanofluid plays a role in improving heat exchange efficiency. The experimental design guaranteed the accuracy of the data gathered by using rotameters for precise flow rate control and K-type thermocouples for temperature monitoring. The optimized nanoparticle concentration in conjunction with the parallel flow design used in this study showed to be beneficial in greatly improving the heat exchanger's performance. The nanofluid showed its resilience in a range of operating situations, proving its superior performance over water, despite initial worries about declining returns at higher flow rates. This shows that, independent of flow rate, alumina oxide nanofluid is a very effective medium for enhancing heat transmission in STHXs. According to the study's findings, alumina oxide nanofluid at a concentration of 0.22% provides a consistent and significant improvement in H.X performance. This discovery creates opportunities for a wider use of nanofluids in industrial heat exchangers, which might result in thermal systems that are more efficient.

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