ANALYSIS ON THERMAL AND FLOW BEHAVIOR OF TRIPLE CONCENTRIC TUBE HEAT EXCHANGER HANDLING MWCNT-WATER NANOFLUIDS

by

***Mukesh Kumar PERIYASAMY CHOKKEYEE*[a] *and Hariprasath VISVANATHAN*[b*]**

[a] Department of Mechanical Engineering, University College of Engineering, Anna University, Dindigul, India
[b] Department of Mechanical Engineering, Chettinad College of Engineering and Technology, Anna University, Karur, India

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Design of heat exchangers and heat transfer enhancement methods are struggling to meet out the cooling demand of present scenario. Many researchers suggested that the addition of nanosized solids particles into traditional base fluids resulting the higher heat transfer rate than the existing coolants and named the new fluids as nanofluids. In this investigation, the effect of microwave carbon nanotube (MWCNT)-water nanofluids on heat transfer rate, pressure drop and pumping power of a triple concentric tube heat exchanger are experimentally investigated and compared the results of MWCNT-water nanofluids with water. The MWCNT-water nanofluids were prepared by two step method at the volume concentrations of 0.2%, 0.4%, and 0.6%. The range of target fluid mass-flow rate is in the range of 0.026 to 0.039 kg per second and the constant heat flux condition is considered. On experimentation, it is noted that the effectiveness and pressure drop of 0.6% MWCNT-water based nanofluids are 27% and 21% greater than water at the maximum mass-flow rate. The reason for improved heat transfer rate of nanofluids is because of higher thermal conductivity, Brownian motion, lower boundary-layer thickness, and lower specific heat capacity of nanofluids. Also found that the pumping power increases with increasing volume concentration and pumping power is 25% higher than water at the 0.6% nanofluids. Therefore, the MWCNT-water nanofluids are good choice for replacing water as coolant in triple concentric tube heat exchanger.

Key words: *triple tube heat exchanger, MWCNT-water, Nusselt number, Reynolds number, pressure drop, pumping power*

Introduction

Many heat transfer enhancement techniques have been proposed by many researchers like passive, active and compound techniques. However most of the heat transfer enhancement techniques are passive methods as they have lower pumping power than the active methods. The one among the suggested heat enhancement techniques is increasing the heat transfer surface are by placing another, outer annulus, tube in the double concentric tube heat exchangers. The triple concentric tube heat exchanger (TCTHE) is identified as higher effec-

* Corresponding author, e-mail: hariprasathv@gmail.com

tiveness than the tube in tube heat exchanger which is designed to meet out the disadvantages of double tube heat exchanger (DTHE). The new design of TCTHE has an additional flow passage for improving the heat transfer rate with the larger heat transfer area. The research and experimental work in the area of TCTHE is limited even though it has lot of advantages.

Zurtiz [1] analyzed the fluid temperatures of TCTHE with the set of equations. Garcia-Valladares [2] performed 1-D transient and steady-state analysis for different model configurations and found that the effectiveness of TCTHE in counter flow arrangement is increased by 12% than the parallel flow. Unal [3] theoretically studied the triple tube heat exchanger and plotted effectiveness versus NTU graph for individual tubes. Sahoo *et al.* [4] proceeded the study in helical triple tube heat exchanger and investigated the fouling factor of milk in the tubes which decreases the effectiveness of heat exchanger. The TCTHE was fabricated by Quadir *et al.* [5] and investigated the heat exchange characteristics of three fluids under different configurations. Quadir *et al.* [6] investigated the triple tube concentric heat exchanger using FEM under steady condition and found out the thermal behavior and overall heat transfer coefficients over the entire length of the heat exchanger. Antony *et al.* [7] carried out the experimental and numerical investigation on TCTHE, thermo-fluid performance and concluded that effectiveness and Nusselt number are higher than that of DTHE in counter flow configuration. Basal and Unal [8] developed new heat storage system in TCTHE using phase change material in the inner annulus. An interrelationship between the convective heat transfer dimensionless number, effectiveness and pressure drop of triple tube heat exchanger was analyzed by Gomaa *et al.* [9] and found that the Nusselt number increase with Reynolds number for both configurations. Mohapatra *et al.* [10] verified the coil side Nusselt number by comparing with Wilson technique value available in the literature. Mohapatra *et al.* [11] experimentally focused on triple tube heat exchanger with the Reynolds number range of 9000 and 54000 and found that the overall heat transfer coefficient increases with increase in hot water-flow rate and the effectiveness decreases. Radulescu *et al.* [12] performed an analysis in DTHE and TCTHE and observed that the area of the heat transferring surface and convective heat transfer of TCTHE are greater than DTHE for the same length. Kumar *et al.* [13] carried out the research for purifying milk using TCTHE and generated simulation model to speculate the fouling thickness and milk outlet temperature. Patrascioiu and Radulescu [14] established a mathematical model of the triple tube heat exchanger by considering several assumptions for predicting fluid outlet temperature and overall heat transfer coefficient. Batmaz and Sandeep [15] and Avudaiappan *et al.* [16] found that the overall heat transfer coefficient values of three tubes were higher in the c1ounter flow arrangement than the parallel arrangement. Also found that the effectiveness of the TCTHE are higher than the DTHE.

Much interest has been shown in modifying heat exchanger design and in improving the heat thermal conductivity of conventional heat transfer fluids with aid of active and passive techniques. Micro-fluids have been derived by dispersing the micro-particles in to the base fluids and suggested that they show very poor stability and hence they have been dropped. In order to overcome the drawbacks of microfluids. Choi [17] first developed a new fluid by dispersing nanosize particles into a base fluid and named as nanofluids. Choi [17] characterized the nanofluids and proposed the nanofluids have enhanced thermal conductivity than the base fluids. Many researchers have investigated the nanofluids by using various types of nanoparticles together with the characteristics of heat transfer. Generally nanoparticles used are metals such as Cu, Ag, Au, and Ni; metal oxides such as CuO, Al_2O_3, TiO_2, Fe_2O_3, Fe_3O_4, SiO_2, and ZrO_2; metal carbides (SiC), metal nitrides such as AlN, and SiN; carbon materials such as graphite, carbon nanotubes CNT, and diamond. Choi *et al.* [18] investigated the thermal conductivity of CNT/engine oil nanofluids experimentally and revealed that there is a huge rise in thermal conductivity for small volume concentration.

Saravanakumar *et al.* [19] found that the nanofluids possess higher thermal conductivity and minimum viscosity for an ideal concentration. They concluded that the replacement of conventional fluid by nanofluid leads to reduction of size of the heat transfer equipment and reduces cost. Govindhasamy *et al.* [20] carried out the investigation on diathermic oil based TiO_2 and established that the base fluid thermal conductivity is lower than the TiO_2 nanofluids. The heat transfer rate is enhanced because of Brownian motion and improved thermal conductivity of nanofluids. Kumar *et al.* [21, 22] investigated the overall heat transfer coefficient in shell and helically coiled DTHE and found heat transfer coefficient increases by 4-9% for 0.4% and 0.8% of Al_2O_3-water nanofluids in counter flow configuration. They concluded that the Nusselt number and pressure drop are increased with increase in particle volume concentration.

In the light of literature review, the experimental works on tubes in tube (Triple) with MWCNT nanofluids is very little. However, the heat transfer and pressure drop analysis in TCTHE using MWCNT-water nanofluids as the heat transfer medium is very limited. Therefore, in this experimental research work, the MWCNT-water nanofluids at different volume concentration are taken as the cooling medium in the TCTHE with the objectives of comparing the heat transfer rate and pressure drop of MWCNT-water nanofluids with water.

Methods and materials

The MWCNT nanoparticle is procured from Nanostructure and Amrophous Materials, Inc. Houston, Tex., USA. The MWCNT-water nanofluids were prepared with the help of two step method. In this investigation, MWCNT-water nanofluids have been prepared at 0.2%, 0.4%, and 0.6% volume concentration. The morphological characteristic of MWCNT were studied with the help of SEM image and observed that the MWCNT are highly agglomerated and entangled in dry condition. The required amount of MWCNT were taken and dispersed in to the water. The process of dispersion was done by the ultrasonification for 5 hours of each sample (sonicator specifications of 40 W at 36 ± 3 kHz) 0.05% volume concentration of sodium dodecylbenzenesulfonate surfactant is added to have uniform dispersion and longer stability of MWCNT-water nanofluids.

Experimentation

Experimental set-up

Figure 1 presents the schematic diagram of the experimental set-up. The inner tube handles nanofluids, the inner annulus handles hot water and outer annulus handles normal water. All the three tubes are made up of copper with different diameters and lengths. The three tubes are connected to three storage vessel. The outside tube is connected with a storage vessel size of 5 L, a mono block pump of 0.5 hp, and a flow regulating valve is fitted along the tube side. The inner annulus is connected with a storage vessel size of 30 cm × 25 cm × 25 cm, with 2 kW heat capacity, hot water pump with thermostat to maintain the temperature of hot water. The heater is used to increase the temperature and maintain the steady-state in the hot water sump. The inner tube is connected with a storage vessel of 5 L capacity, with a mono block pump of 0.5 hp, flow regulating valve is fitted along the tube, test section and cooling unit. The tubes are placed concentrically with a constant space between tubes and

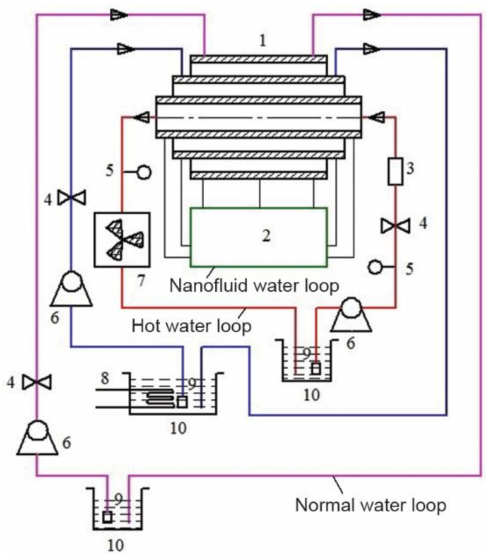

Figure 1. Schematic diagram of experimental set-up; *1 – test specimen, 2 – temperature indicator, 3 – rotometer, 4 – gate valve, 5 – pressure gauge, 6 – feed pump, 7 – cooling unit, 8 – heater, 9 – foot valve, 10 – fluid sump*

welded. Seven K-type thermocouples with 0.09 °C accuracy were used to find out the inlet and outlet temperatures of TCTHE. The outer annulus of TCTHE is insulated with the help of cotton thread to avoid heat loss from the tubes to the surroundings. Nanofluids tube inlet and outlet pressure is measured using pressure gauge and flow of MWCNT-water is controlled with flow control valve and outlet of inner tube is connected with a radiator to cool the hot MWCNT-water nanofluids. Experimental set-up and fittings were checked by circulating water for any leakages before using MWCNT-water nanofluids.

Testing procedure

The following postulations were considered for experimental analysis: the nanofluid is treated as single phase and incompressible fluid throughout the experiment, nanoparticles are concentric in shape, particles in nanofluids were dispersed uniformly, nanofluid properties are constants throughout the experiment, tube inner surface is smooth, and constant tube wall temperature is maintained. Heat conduction through the tube material is low. As shown in the fig. 1 schematic set-up the counter-current flow of nanofluids is measured. MWCNT-water, hot water and normal water were circulated simultaneously in inner tube, inner annulus and outer annulus of TCTHE. Hot water is circulated at different temperature range from 45 °C to 65 °C and it was measured by using K-type thermocouples fixed at inlet and outlet of the tube. Similarly normal water is allowed to flow through the outer annulus and temperatures were noted. The MWCNT-water nanofluids is circulated in counter-current flow arrangement at 0.2%, 0.4%, and 0.6% volume concentration and temperatures were noted using thermocouple fixed at inlet and outlet of the inner tube. During the experiments, flow rate of nanofluids was changed and readings were taken for all concentrations. The pressure was measured with the help of pressure gauge fitted at the inlet and outlet side of the MWCNT-water nanofluids tube.

Data reduction

The specific heat, density, thermal conductivity, and dynamic viscosity of nanofluids are obtained from equations proposed by [18]. The inner annulus heat transfer, Q_h, the inner tube heat transfer rate, Q_{nf}, the outer tube heat transfer rate, Q_n, the average heat transfer, Q_{av}, of the three fluids are calculated from the equations suggested by [9].

The Nusselt number and Reynolds number, are calculated:

$$\mathrm{Nu} = \frac{hD_{id}}{k} \tag{1}$$

$$\mathrm{Re} = \frac{\rho v D_{id}}{\mu} \tag{2}$$

Friction factor, f_{nf}, of the inner tube is calculated:

$$f_{\mathrm{nf}} = \frac{2\Delta p_{\mathrm{nf}} D_{id}}{\rho L v^2} \tag{3}$$

The TCTHE effectiveness, ε, is calculated:

$$\varepsilon = \frac{Q_{\mathrm{av}}}{Q_{\max}} = \frac{Q_{\mathrm{av}}}{(mC)_{\min}(T_{hi} - T_{nfi})} \tag{4}$$

The pumping power is calculated:

$$\text{Pumping power} = \text{pressure drop} \cdot \text{area} \cdot \text{velocity} \tag{5}$$

Results and discussion

In this experimental work, the effect of MWCNT-water nanofluids at different volume concentration on the heat and flow behavior of TCTHE and compared the results with water.

Nusselt number vs. mass-flow rate

Figure 2 illustrates the enhancement of Nusselt number by varying volume concentration with mass-flow rate. It is found that the Nusselt number increases with increasing particle volume concentration and increase in mass-flow rate. The MWCNT-water nanofluids Nusselt number are 15%, 23%, and 28% higher than water at 0.2%, 0.4%, and 0.6% volume concentration, respectively, at the mass-flow rate of 0.034 kg/s. This is because of the enhanced convection current caused by the better fluids mixing, and reduction of thermal boundary-layer thickness. The enhanced convection current is caused by the better mixing tiny MWCNT nanostructure with the water. The mixing is due to more adsorption nature of MWCNT. The boundary-layer thickness is reduced as the MWCNT motion in base fluids is Brownian motion. This motion disturbs the formation of boundary-layer. Hence the resistance to flow is reduced resulting higher heat transfer coefficient.

Effectiveness vs. mass-flow rate

Figure 3 shows the relation between the effectiveness and mass-flow rate at different nanofluids concentrations. From the figure the effectiveness of the TCTHE increases with increasing MWCNT-water nanofluids. At the mass-flow rate 0.0389 kg/s, the effectiveness of TCTHE for the nanofluids at 0.2%, 0.4%, and 0.6% volume concentration are 9%, 21%, and 27% higher than water. The difference in effectiveness is relatively less at the lower concentrations. The maximum effectiveness is found at the lowest mass-flow rate and at 0.6% volume concentration. This is due to lower temperature difference between T_{hi} and T_{nfi}. In particular, the effectiveness is higher at 0.6%. This is due to the lower specific heat capacity and higher thermal conductivity of the nanofluids which carries more heat energy. Adding more MWCNT in base fluid, the gap between the MWCNT is reduced which improves the thermal conductivity. It is found that the effectiveness of TCTHE decreases with increase of mass-flow rate for all concentrations. The reason for decreasing the effectiveness with respect to mass-flow rate is due to the increase in heat capacity of the fluid.

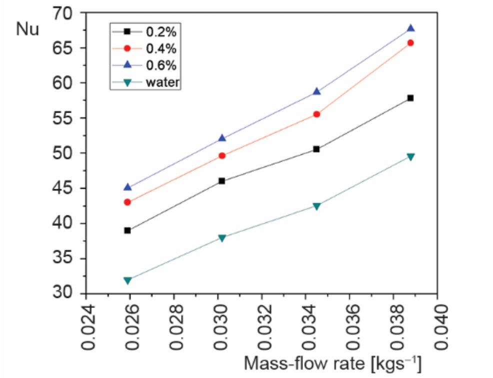

Figure 2. Variation of Nusselt number with mass-flow rate

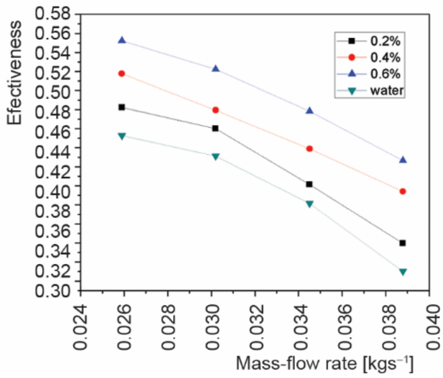

Figure 3. Variation of effectiveness number with mass-flow rate

Friction factor vs. mass-flow rate

Figure 4 shows the effect of nanoparticles volume concentration on friction factor. It can be clearly seen that the friction factor decreases over increase in mass-flow rate. This is because of the higher flow velocity which leads to lesser contact with the tube surface. Observed that the friction factor of MWCNT nanofluids are 7%, 10%, and 14% lower than water at 0.2%, 0.4%, and 0.6% nanofluids concentrations, respectively, at the mass-flow rate of 0.030 kg/s. The friction factor is found to be higher at the lower mass-flow rate 0.026 kg/s. It is remarkable that the 0.6% nanofluids has the highest friction factor at 0.026 kg/s. The reason for this is the improved viscosity of nanofluids when more MWCNT is added. The improved viscosity reduces the Brownian motion of MWCNT in the base fluids and contact with the tube surface is improved.

Pressure drop vs. mass-flow rate

Figure 5 shows the effect of nanoparticles volume concentration on pressure drop at different mass-flow rate. It is clearly seen that increase in particle volume concentration and mass-flow rate increases the pressure drop. The flow characteristics of nanofluids are 4%, 11%, and 21% greater than water at 0.2%, 0.4%, and 0.6% particle volume concentration, respectively, at the mass-flow rate of 0.30 kg/s. In this case, the viscosity of nanofluids plays the vital role. The viscosity of nanofluids increases with increasing MWCNT in base fluids. The inter space between the MWCNT is reduced when adding more MWCNT and the viscosity is increased. At 0.026 kg/s mass-flow rate, the pressure drop is minimal when compared with higher mass-flow rate 0.039 kg/s. This is due to the increase of viscosity at lower flow velocity of mas flow rate.

Conclusion

In this experimental investigation, thermal and flow behavior of MWCNT-water nanofluids is carried out using triple concentric tube heat exchanger. The nanofluids were prepared with three volume concentration and found that the prepared MWCNT-water nanofluids

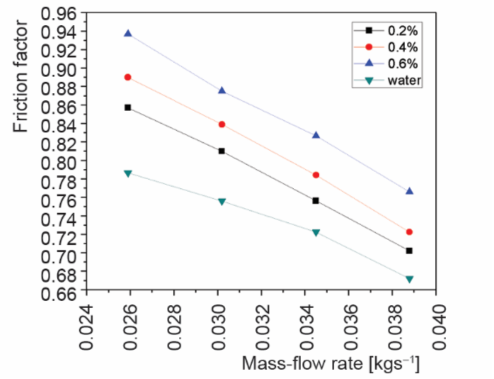

Figure 4. Variation of friction factor with mass-flow rate

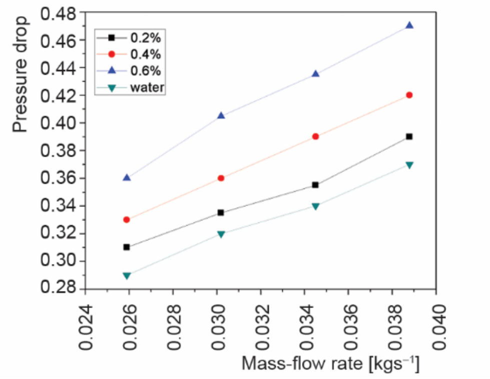

Figure 5. Variation of pressure drop with mass-flow rate

are stable even after 30 days of preparation. It is studied that the Nusselt number of MWCNT-water nanofluids at 0.2%, 0.4%, and 0.6% volume concentration are found to be 15%, 23%, and 28%, respectively, when compared with water at the mass-flow rate of 0.034 kg/s. Found that the effectiveness of MWCNT-water nanofluids is found to be 27% higher than water at 0.039 kg/s. It is also noted that friction factor decreases with increase in volume concentration and mass-flow rate. 0.6% volume concentration nanofluids resulted at 21% pressure drop and 25% pumping power higher than water.

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