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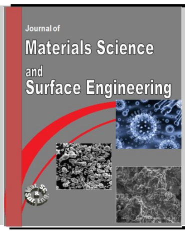

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Experimental Pressure Drop Study with Nanofluids

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Abstract

This paper reports an experimental study on the pressure drop characteristics of ZnO-water nanofluids through the horizontal annulus. Experiments were performed in single phase and boiling flow of nanofluids under turbulent flow with different low particle concentrations (≤0.01 vol. %). Experiments were conducted at flow rates from 0.1 to 0.175 lps, heat fluxes from 0 to 550 kW/m^2 and 1 bar constant inlet pressure. The results show that the pressure drop of the nanofluids is very close to that of the base liquid flows for given flow rates. The pressure drop of the water and nanofluids increases with an increase in the flow rate and remains almost constant with increase in the heat flux.

Introduction

In recent years, fluids containing suspension of nanometer-sized particles (nanofluids) which were first pioneered by Choi[1] in 1995 have been an active area of research due to their enhanced thermal properties over the base fluids. This makes them very attractive as heat transfer fluids in many applications. In the past, particles of millimetre or micron scale have been added to fluids by many researchers to enhance the thermal conductivity; however, all of the studies using the concept have been faced with severe problems including sedimentation, erosion of the components by abrasive action, clogging in small passages and increased pressure drop of the flow channel due to large size of the particles. The nano-particles used in nano-fluids commonly have a small average size, below 100 nm in diameter. Relative large surface area of nanoparticles increases the stability and reduces the sedimentation of nanoparticles[2].

Several studies have discussed about the thermal properties, convective and boiling heat transfer coefficient and critical heat flux (CHF) of the nanoparticles suspended fluids. However, there are just a few researchers who have considered the increased amount of nanofluid pressure drop besides their heat transfer evaluation.

Xuan and Li[3] investigated on convective heat transfer coefficient and friction factor of Cu/water nanofluids for both laminar and turbulent flow in a tube. Their pressure drop studies revealed no significant augmentation in pressure drop for both the laminar and the turbulent flow. This indicates that the nanofluids will not cause extra penalty in pumping power.

He *et al.*[4] studied the heat transfer and flow behaviour of TiO_2/distilled water nanofluids flowing upward through a vertical pipe in both the laminar and turbulent flow regimes under a constant heat flux boundary condition. Pressure drop of nanofluids was very close to that of the base liquid given the flow Reynolds number. Predictions of the pressure drop with the conventional theory for the base liquid agreed well with the measurements at relatively low Reynolds numbers. Deviation occurred at high Reynolds numbers possibly due to the entrance effect.

Ko *et al.*[5] measured the viscosity and the pressure drop of carbon nanotube (CNT) nanofluids flowing through the horizontal tube and investigated the effects of CNT concentrations and preparation methods. Two different methods were used to prepare stable nanotube suspensions. The first one was to disperse nanotubes by using surfactant, known as pristine CNT (PCNT) nanofluid; the second one was to introduce oxygen-containing functional groups on the nanotube surfaces by the acid treatment, known as treated CNT (TCNT) nanofluids. Both PCNT and TCNT nanofluids showed the characteristics of shear thinning fluids, for which viscosity increases with decreasing shear rate. Especially, for PCNT nanofluids, the increase in the viscosities at low shear rates was much larger compared to TCNT nanofluids, and this causes significant increase in pressure drops under the laminar flow condition. At the turbulent flow conditions, however, the pressure drops of both nanofluids presented similar values to those of the base fluid due to the shear thinning nature of CNT nanofluids. It was also shown that laminar regime of PCNT nanofluids has been extended to further higher flow rates than pure water case, therefore, nanofluids could have low friction factors than pure water flows at certain range of flow rates.

Duangthongsuk *et al.*[6] studied experimentally the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and 0.2 vol. % TiO_2 nanoparticles in a double-tube counter flow heat exchanger. They observed that the use of nanofluid instead of base fluid has a little penalty in pressure drop.

Saeedinia *et al.*[7] investigated the heat transfer and pressure drop characteristics of CuO/Base oil nanofluid laminar flow in a smooth tube with different wire coil inserts under constant heat flux. For highest concentration of nanofluid, 63% penalty in pressure drop was observed at the highest Reynolds number inside the wire coil inserted tube with the highest wire diameter. They also developed the empirical correlation for friction factor of nanofluids inside wire coil inserted tubes.

Mashaei *et al.*[8] analyzed the flow and heat transfer characteristics of Al_2O_3/water nanofluid in a parallel plates channel with discrete heat sources. A maximum value of 68% increase in pressure drop was obtained for all the considered cases when compared to basefluid (water).

It is necessary to study the flow resistance of nanofluids in order to apply the nanofluid for practical applications. This study

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focuses on ZnO-water nanofluids with low nanoparticle concentrations (≤0.01 vol.%), aiming at measuring the effect of nanoparticle concentration, heat flux and flow rate on the pressure drop, in order to compare the difference in pressure drop between the nanofluids and pure water in a horizontal annulus.

Experimental

Preparation of Nanofluid

Preparation of nanofuids is the first key step in applying nanophase particles to changing the heat transfer performance of conventional fluids. The nanofluid does not simply refer to a liquid-solid mixture. Some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles and no chemical change of the fluid. In general, these are effective methods used for preparation of suspensions: (1) changing the pH value of suspension, (2) using surface activators and/or dispersants, (3) using ultrasonic vibrations. The use of these techniques depends on the required application of the nanofluids [9].

In this study an Ultrasonic Vibration Mixer (UVM) was used to prepare the nanofluid. In UVM machine, the ultrasonic energy is produced by converting electrical energy into mechanical vibrations by using generator and piezo-electric transducers. ZnO nanomaterials and distilled water were used to prepare nanofluids. Nanoparticles of 40 nm diameter were used in the present study. However, the dry nanoparticles are in the form of large agglomerates. In order to break down the large agglomerates, ultrasonication was applied for 5–7 hours to mix a preset amount of nanoparticles with water to give certain nanoparticle concentration. The power available in the ultrasonic bath is 300 W and the ultrasonic frequency is 27±3 kHz. The prepared Nanofluids concentrations were very low (≤ 0.01 vol. %) in this study. Therefore, agglomeration of nanoparticles is expected to be less.

Experimental Setup

The schematic diagram of the experimental flow loop used for the pressure drop measurement is shown in Fig. 1. The closed loop test facility mainly consists of ultrasonic vibration mixer, storage reservoir, circulating pump, flow meter, heater inserted horizontal annular test section, condenser and heat exchanger. The working fluid is pumped from the reservoir to the test section via flow meter. The working fluid or the mixture of working fluid and steam from the exit of the test section passes through a horizontal condenser and counter flow heat exchanger before returning to the reservoir. In boiling flow, condenser condenses the steam into water and heat exchanger reduces the excess temperature and controls the temperature of working fluid before recirculation. The inlet temperature of the working fluid at test section is maintained constant by using an electrical heater associated with a temperature controller in the reservoir tank. The loop allows for varying the heat supply, flow rate, inlet pressure and temperature of the fluid.

The annular test section used for the pressure drop measurement as shown in Fig. 2 is 780 mm long and consists of an electrically heated rod and an outer borosilicate glass tube of 21.8 mm inner diameter. The heater is 12.7 mm diameter hollow stainless steel rod welded to solid copper rods at both ends. The test section is easily dismountable. The heater rod is fitted with transparent glass tube by two teflon corks at both ends. In the glass tube, fluid flows over the surface of heater rod. The heated length of 500 mm is located 230 mm downstream of the inlet plenum and thus allowing for the flow to fully develop. An input 415 V, 3 phase AC power is stepped down to 0–32 V DC power by using 64 kVA DC regulated power supply by which a large range of heat fluxes are applied to the test section.

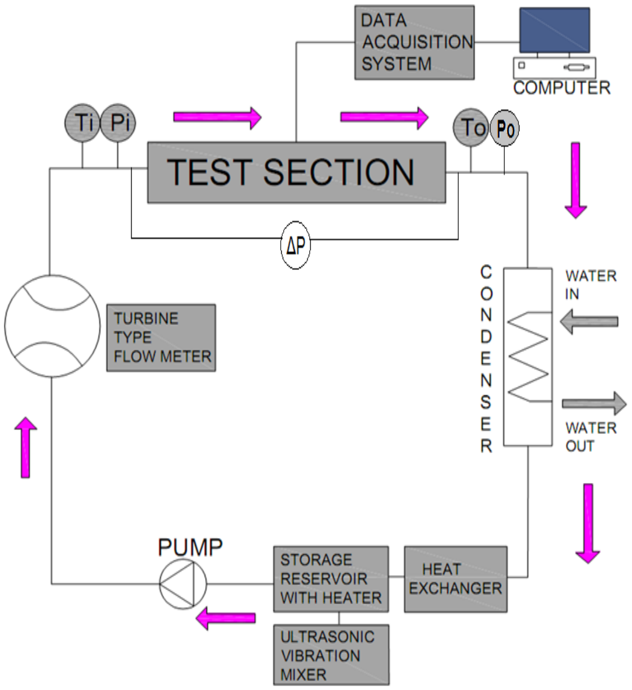

Figure 1: Schematic of Experimental Flow loop

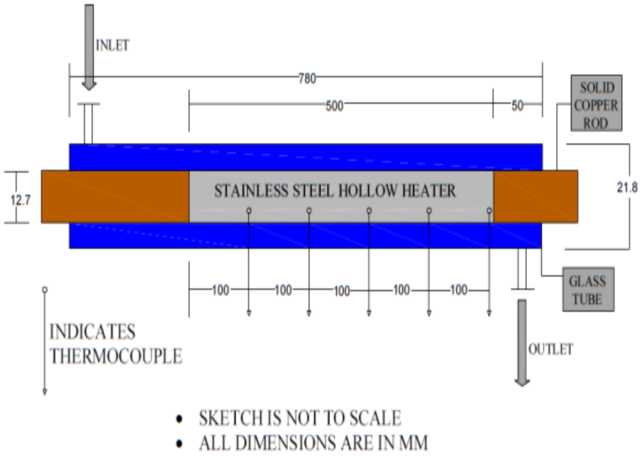

Figure 2: Test section

Two pressure transducers are installed at both ends of the test section to measure the pressure drop of fluid. Static pressure at the inlet and outlet of the test section are measured using Keller make pressure sensors which have a range of 1–10 bar with an accuracy of ±0.1%. The test section allowed the pressure drop measurement in single phase flow as well as in boiling flow. Measured data including pressures and temperatures are acquired by data acquisition system (Omega make-OMB-DAQ-55) which is further connected to computer. Data can be recorded and stored in the computer at any point of experiment. Temperatures at inlet and outlet of test section and heater surface were measured with miniature J-type ungrounded thermocouples. Surface temperature of heater rod at various locations can be measured by five miniature thermocouples which are embedded on it for calculating the heat transfer performance (not reported in the present work). All thermocouples are connected to Data Acquisition System. Electronet make, FL-204, 4-wire turbine type flow meter with flow range of 0.02–0.3 lps was used for measuring the flow rate. It has less than 100 ms response time with an accuracy of ±1%. Before every test run, the experimental test loop was cleaned with acetone and rinsed with distilled water to remove oxides and fouling residue that could affect the flow. The test section heater rod was replaced for every test. Other details of the experimental apparatus can be found in our previous study [10].

The experiments were carried out using water and ZnO-water nanofluids (concentration 0.001–0.01 vol. %) at constant inlet pressure (1 bar) and temperature (80 ºC) for different flow rates (0.1–0.175 lps) and heat fluxes (0–550 kW/m^2).

Results and Discussion

Experiments on experimental pressure drop were performed in single phase and boiling flow of water and nanofluids under turbulent condition with different low particle concentrations (≤0.01 vol. %). Figure 3 illustrates the pressure drop of distilled water and nanofluids in annulus as a function of flow rate at single phase flow where the inlet temperature of working fluid is 80ºC. In single phase flow, no heat flux is applied to the test section for heating the heater rod. Pressure drop increases with flow rate in water as well as in nanofluids. Compared with water, no significant augmentation in pressure drop for the nanofluid is found at any flow rate, which reveals that dilute nanofluids will cause no extra penalty in pumping power.

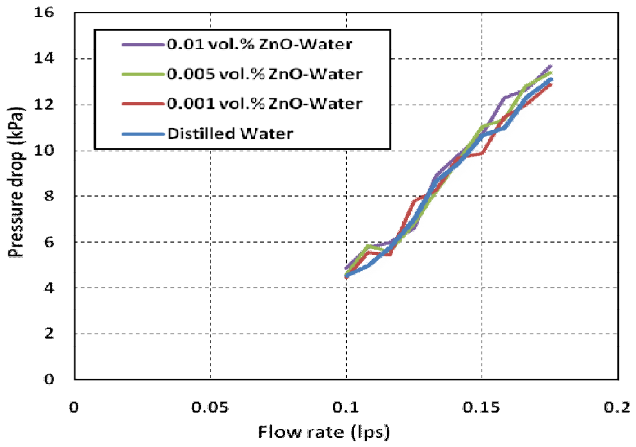

Figure 3: Comparison of pressure drop for water and nanofluids in single phase flow

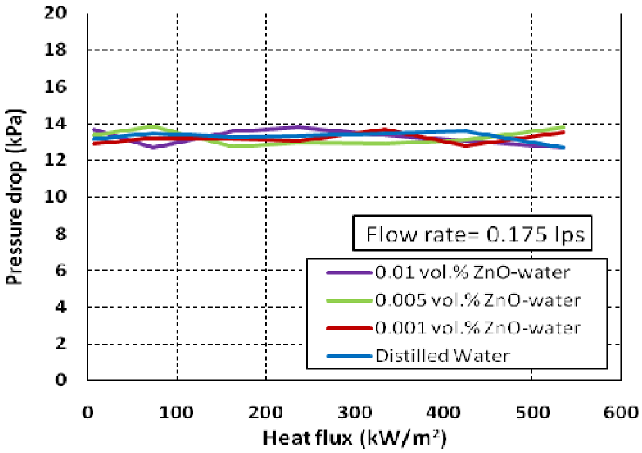

Figure 4: Pressure drop in boiling flow as a function of heat flux.

Large range of heat fluxes are applied to the test section in two phase (boiling) flow. Effect of heat flux on pressure drop of ZnO-water nanofluids is shown in Fig. 4. For all concentrations of nanofluid and water, the pressure drop almost remains same with an increase in the heat flux at given flow rate due to high temperature of entering fluid and low particle concentration of nanofluid.

Conclusions

Experiments were carried out on single phase and boiling flow of ZnO-water nanofluids under turbulent flow in horizontal annulus with different low particle concentrations (≤0.01 vol. %) under constant inlet pressure, varying flow rates and heat fluxes. Effect of nanoparticle concentration, flow rate and heat flux on pressure drop of nanofluids with respect to water were investigated and following conclusions are drawn:

- Pressure drop of the nanofluid flows is very close to that of the base liquid flows for given flow rates, because the nanoparticle concentrations in base fluid are low. No augmentation of pressure drop is a hopeful sign for practical applications.
- The pressure drop of water and nanofluids increases with an increase in flow rate.
- Pressure drop of nanofluids and water remains almost constant with increase in heat flux.

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