NUMERICAL STUDY ON PERFORMANCE OF FLAT TUBE WITH WATER BASED COPPER OXIDE NANOFLUIDS

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ABSTRACT

The purpose of this research is to conduct a numerical analysis of the performance of a flat tube filled with copper oxide nanofluids. A virtual 3D replica of a flat tube was used to pass the nanofluid through. The benefits of employing nanofluids rather than pure base fluid were assessed. The thermophysical characteristics of the nanofluid were computed using experimentally obtained correlations (function of temperature and volumetric concentration nanoparticles). The heat transmission performance of a flat tube was found to improve when particle concentration, temperature, and Reynolds number increased. With increasing volumetric concentration of nanoparticles and Reynolds number, the pressure loss across flat tube increased. The performance of nanofluids has been numerically compared to that of a base fluid. The thermophysical properties of nanofluids were evaluated using well-developed models for each thermophysical parameter at varied nanoparticle concentrations, ranging from 0.1 to 0.5 percent. The heat transfer performance of the compact channel was examined, and it was observed that when the nanoparticle concentration grew, the heat transfer rate of the compact channel increased dramatically. At the same temperatures, the heat transfer rate of the nanofluids was roughly 23% higher than that of the base fluids.

Key Words- Copper oxide, flat tube, heat transfer performance, pressure drop, heat transfer coefficient

1.INTRODUCTION

Over time, the property of nanofluids being superior to conventional fluids as a heat transfer agent has been proved by extensive research. Nanofluids are the suspension of nanometre sized particles, metallic in nature present in a base fluid. Nanofluids are highly used as a coolant in automotive engines. To quantitatively evaluate the enhanced heat transfer characteristics of a standard automobile radiator, we use two nanofluids in its flat tubes, which will be discussed in this paper[1]. In Addition, the frictional loss associated with the nanofluids is computed with the increase in concentration of the nanoparticles. Until now, the numerical studies which involves the nanofluids in the flat tubes of a radiator is still not done completely. This paper mainly evaluates the importance of nanofluids as automotive coolants. Nanofluids could have a marked impact on the size of the radiators by reducing the size given that the nanofluids yields better heat transfer[2]. This study aims towards developing new correlations for the thermophysical properties of the nanofluids and then use it for the numerical modelling which will help in the determination of the heat transfer.

For heat exchanger applications such as automotive radiators, the recently introduced designs are the Flattened Tube designs. A flattened tube has a higher surface to cross-sectional flow area ratio in comparison to a circular tube, which helps in enhancing the heat transfer rate and also to increase the compactness of heat exchangers. Flattened tube has small wake size which makes its noise and vibrational characteristics better in comparison to a circular tube. Nanotechnology is considered to be one of the most significant driving forces for the next major industrial revolution of this century by many researchers. Significant researches have been going on to explore the thermal transport properties of colloidal suspensions of nano sized particles[3]. The presence of nanoparticles in fluids have been seen in increasing the effective thermal conductivity of the fluid and also enhance the heat transfer characteristics. Nanofluids are said to be the new generation of fluids in heat exchangers, technological plants, automotive cooling applications and many more because of their unique features.

Due to rising prices of energy nowadays industries are applying energy saving methods as much as possible. Energy can be saved in different processes using the heat transfer enhancement techniques. Solid particles can be really useful to enhance heat transfer and hence it has been used for decades in conventional fluids. Problems like fouling, sedimentation and increased pressure drop that occurs in daily practice in this heat transfer technique reduces the interest of the industries[4]. But in recent times, there has been significant advances in nanomaterials technology. These advancement produces desirable particles in nanometer size ranges which have helped in overcoming these problems. These nanoparticles have made a new innovative category of fluids called the nanofluids which have the nanoparticle suspensions present in fluid. These fluids have many advantages due to which these are of great interest nowadays. These fluids not only modify heat transfer performance of fluids but also improve other characteristics such as rheological properties and mass transfer of fluids[5].

Many researches focused on nanofluids that are made of metal or metal oxide particles which are typically suspended in a base fluid and less than 100nm in size and their major role in heat transfer have been done in the recent years. Nanofluids also play a major role as a vehicle engine coolant. Even at low concentrations, nanoparticles increases thermal conductivity because of its high surface area. In recent years, these thermal properties of nanofluids have attracted scientific attention. The term "Nanofluids" was first used by Choi for describing fluids with suspended nanoparticles and several studies of various fields have also examined these fluids. The effect of convective heat transfer in nanofluids was experimentally investigated by Kim et al. under laminar and turulent flow regimes[6]. A straight circular cross-section of a tube was used for laminar and turbulent flow regimes with constant wall heat flux. Duangthongsuk and Wongwises studied the effect of thermo-physical properties on models on low concentrations which predicted the convective heat transfer coefficients. The validity and accuracy of the experimental convective heat transfer coefficient of the nanoparticles in the base fluids at low concentrations depended o empirical calibration of the system much more as compared to the thermo-physical models of the nanofluids. These were the results of the studies[7].

A significant amount of increase in the heat transfer coefficient of the nanofluids from that of their base fluids have been observed by a number of studies. The conventional fluids are nowadays very costly and hazardous to the environment that are used in different applications and hence it is of utmost importance to find an alternative to these conventional fluids. This technology is considered as an alternative as it can be obtained easily at a minimum cost which improves the thermal properties of fluids. Transportation, defence, space, electronics cooling, nuclear system cooling etc are some of the applications of nanofluids. A first order approximation for thermal conductivity was given by Maxwell after the analytic investigation of the problem[8]. He was the first to study conduction through suspended particles.

2. LITERATURE REVIEW

In heat transfer applications of nanofluids, the preparation of stabilized nanofluids play a vital role. Nanofluids can also render the biphasic heat transfer if prepared poorly. Nanoparticle aggregation can also lead to the creation of larger particles which are of micrometer order which is another challenge and thus it eliminates the nano-related discussions. Also, particle fouling in reservoir, pumps, pipes and other equipment of thermal cycle occurs due to particle instability. These are considered as the undesirable factors in the experiment. The nanoparticles used here in the study are copper oxide which are approximately spherical with diameter of about 60nm[3].

Adding solid particles to the existing fluids enhances the thermal conductivity of the fluids. The increase in the particle fraction leads to the rise in the conductivity of the liquids-solids mixtures. This is the first step which enhances the conductivity of fluids including small particles into the liquids for different applications. Particles of size of millimetre or micrometre were there in the beginning. In 1995, "Nanofluid" was the term first used by Choi which meant the mixture of base fluid nanoparticles. These have one principle dimension less than 100nm. Various fields have carried out numerous studies with nanofluids like electronic cooling, heat exchangers and biomedical, etc[6]. As an alternative of the conventional heat transfer fluids, nanofluids showed considerable potential for the heat transfer enhancement. In an experiment and numerical study, there is an enhancement of 8% in the heat transfer performance of a circular tube as compared to the pure base fluid.

2.1 Boundary Conditions

Above mentioned conservation equations of mass, momentum and energy are nonlinear and coupled systems that are solved subjected to the following boundary conditions. Uniform axial temperature and velocity are prescribed at the inlet of the flat tube. Reynolds number of the flow is determined by the inlet velocity and the temperature of 90 C i.e. 363 K has been taken as the inlet temperature[1]. This temperature is typically used for automotive radiators. The improvement in heat transfer performance is seen in the flat tube with a high surface-to cross-section area ration as compared to the circular tube.

2.2 Nanofluid preparation and stabilization

In heat transfer applications of nanofluids, the preparation of stabilized nanofluids play a vital role. Nanofluids can also render the biphasic heat transfer if prepared poorly. Nanoparticle aggregation can also lead to the creation of larger particles that are of micrometer order which is another challenge and thus it eliminates the nano-related discussions[15]. Also, particle fouling in reservoir, pumps, pipes, and other equipment of the thermal cycle occurs due to particle instability. These are considered as undesirable factors in the experiment. Table 1 shows other properties of nanoparticles[3]. Variations of pH and SDS i.e. Sodium Dodecyl Sulfonate surfactant are used to stabilize the nanofluids. The optimum value of the pH of the suspension was used using NaOH 1M solution for the stabilization of the nanofluid.

2.3 Effect of nanoparticle concentration on heat transfer coefficient

The heat transfer coefficient at a temperature of 50C effected by the nanoparticle concentration. The increase in volumetric concentration of CuO nanoparticles and Reynold number increases the heat transfer coefficient. At a 0.1% volumetric concentration of CuO nanoparticles, the heat transfer coefficient is higher than the base fluid at an inlet temperature of 50 C and at a constant Reynolds number of 9000. The heat transfer coefficient is 14% higher than the base fluid at 0.5% volumetric concentration of CuO nanoparticles[4]. The increase in volumetric concentration of nanoparticles leads to the enhancement which results in increase in the thermal conductivity. The increase in the inlet temperature also increases the heat transfer coefficient.

2.4 Effective thermal conductivity

For heat transfer applications of nanofluids, thermal conductivities is considered to be an important parameter. With the increase in fluid inlet temperature and addition of nanoparticles, there is an increase in the thermal conductivity of nanofluids[14]. The increase in the thermal conductivity of base fluid leads to the heat transfer enhancement which is caused by the increase in nanoparticles concentration. Since the thermal conductivity of nanoparticles is higher than the base fluid, it leads to the thermal conductivity enhancement. One more factor which leads to the enhancement of the thermal conductivity is the Brownian motion of nanoparticles in the base fluids at higher temperatures[10]. As compared to the thermal conductivity of base fluids for 0.1% v/v concentration of copper oxide nanoparticles, the thermal conductivity of copper oxide nanofluids was found to be 3% higher.

3. Thermophysical properties of nanofluids

The calculation of thermophysical properties of the nanofluids was important for the application of nanofluids. The calculation of various properties like thermal conductivity, specific-heat, dynamic-viscosity and density was carried out in various studies with well-developed relations.

3.1 . Viscosity

In 2007, the viscosity of an Al2O3 nanoparticle suspension of particle volumetric concentration up to 10% in 64:40 EG/W base fluid was done by Mburu et al. within a temperature range of 35 C to 50 C. It was used in the applications in cold regions which used the Brookfield viscometer designed in 1999. An empirical correlation was proposed from this experimental data. This correlation was limited to less than 50 C and was better at sub zero temperatures. Only within a temperature range of 80-90 C, the coolant operation could be performed in a radiator[5]. Hence, additional viscosity measurements for this nanofluid up to 90 C was performed by Sahoo et al. in 2009. This also lead to the proposal of a new correlation which stated that the correlation is better suited for temperature till 90 C.

3.2 Thermal conductivity

The measurement of the thermal conductivities of CuO nanoparticle dispersions in 60:40 EG/W was done using the apparatus of Hilton, designed in 2005. It was used for the measurement of the thermal conductivities of the liquid and gases within a steady-state condition. The apparatus, the experimental procedure and their validation for different benchmark test cases for water and 60:40 EG/W was described by Vajjha and Das in 2009[1,2].

3.3 Specific heat and density

The equation given by Xuan and Roetzel in 2000 tells about the assumption of thermal equilibrium between the base fluid and the nanoparticles. Specific heat of the nanofluids was also obtained from this equation[13].

4. Result and discussion

4.1 Thermophysical properties

The estimation of the thermophysical properties play an important role in the heat transfer applications of the nanofluids. The estimation of the different thermophysical properties i.e. specific heat capacity, density, thermal conductivity and viscosity are done with the wel developed models only. The fluid temperature for the estimations of the thermal physical properties for 0.1, 0.2, 0.3, 0.4 and 0.5% nanoparticles concentrations ranges from 35 C to 50 C. With the addition of nanoparticles in the base fluid, the specific heat capacity of nanofluids reduces[3,5]. The particle concentration effected this specific heat capacity of nanofluids much more than the temperature. There was only an increase of 0.7% in the specific heat of base fluid when the temperature was increased from 30 C to 50 C. There was a decrease in the specific heat with the increase in particle concentration and increase in specific heat with the increase in temperature, which was the concluded from the above results. This is due to the higher specific heat of the base fluid than that of the base fluid[9].

4.2 Heat transfer performance

The Nusselt number calculated using the Dittus and Boelters relation was compared to the Nusselt number calculated by the CFD method. Error in average between between the numerical calculation and the correlation results is 13.23%. The CFD results with a good approximation is shown in figure 7. At a temperature of 35, 40, 45 and 50 C , the effect of nanoparticle concentration on heat transfer coefficient is calculated. The increase in volumetric concentration of CuO nanoparticles and Reynolds number leads to the increase in heat transfer coefficient[5,7]. In comparison to base fluid at constant Reynolds number of 9000 the heat transfer coefficient is 5.103% higher at 0.1% volumetric concentration of CuO nanoparticles.

4.3 Effect of nanoparticle concentration on local heat transfer coefficient

The variation of a peripheral average local heat transfer coefficient have, along the tube length for various particle volumetric concentrations of CuO nanofluid for a uniform inlet velocity.

With the increase in the nanoparticle volumetric concentration at a particular Z-location, it is observed that there is an increase in the peripheral average local heat transfer coefficient also[10]. The lengths of thermally developing regions are 2.41 m and 3.84 m respectively for a Reynolds number of 725 with 6% concentration and a Reynolds number of 2000 for 0% concentration and hence in this case the flow is not thermally fully developed[11].

5. Conclusion

As compared to the base fluid at a constant inlet velocity of 0.3952 m/s, for a 6% CuO nanofluid in the fully developed region the average skin friction coefficient is around 2.75 times. For similar heat transfer, in comparison to the base fluid, the pumping power requirement is 82% lower for a Al2O3 nanofluid of 10% concentration and 77% lower for a CuO nanofluid of 6% concentration. For the entrance as well as the fully developed regions and the nanofluids circulating in the flat tubes of a radiator new Nusselt number correlations have been proposed.

With the increase in volumetric concentration of CuO nanoparticles and Reynolds number, the heat transfer coefficient also increases. This is because of the increase in thermal conductivity of nanofluids with addition of nanofluids. This increase in the temperature also increases the Brownian motion which further enhances the heat transfer. There is an increase in the pressure drop with the increase in as the volumetric concentration of CuO nanoparticles. The pressure drop at 0.1% volumetric concentration of CuO nanoparticles. In conclusion with the above study, it can be said that for the same amount of heat transfer the use of nanofluids instead of the conventional fluids such as water, ethylene glycol leads to reduce the size of channel.

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