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CFD Heat Pipe Simulation of Mass Transfer in NH_3-Water Nanofluid Flow

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In the present study, the enhancement of heat pipe efficiency with nanoparticles mixtures, using Adina AUI software (version 9.0.0) was studied. The effect of the fluid in water and NH_3 concentration on the convective mass transfer coefficient were studied. The study showed that the heat transfer coefficient enhanced by increasing the nanoparticle concentration. According to this research, the CFD is able to simulate mass transfer in a pipe with a nanofluid.

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PACS/topics: nanofluid, heat pipe, mass transfer, NH_3-water nanofluid flow

1. Introduction

Since 1960's, these devices have been developed tested and put into operation in very different types. With developments in devices, the heat pipe is used in many engineering fields nowadays. Due to the heat transport by evaporation and condensation of the fluid researchers, a heat pipe is effective by a simple device, which has a very high thermal conductance [1–3]. The heat pipe can be divided into three sections: the evaporator which is located near the heat source, the condenser which is located near the heat sink and the middle portion called the adiabatic section [3]. Fluid heating and cooling play important role in many industrial processes such as power stations, production processes, transportation, and electronics. Most of the methods for heat transfer are based on the structure variation, the vibration of the heated surface, injection or suction of fluid and applying electrical or magnetic fields [4–7].

In open literature, it is presented that fluids with suspended solid particles are expected to have better heat transfer properties in heat pipes applications. The majority of studies on heat transfer of suspension of metal oxides in fluids were limited to suspensions with a millimeter or μ-sized particles. The large particles may cause severe problems in the heat transfer equipment. In particular, large particles quickly tend to settle out. Therefore, the pressure drop can occur in the microchannels [4, 8, 9]. Furthermore, the abrasive actions of the particles cause erosion of components and pipelines. Small particles and their little volume fractions prevent particles clogging and pressure drop increment in the nanofluids [9, 10]. The large surface area of nanoparticles increases the stability and reduces the sedimentation of nanoparticles. A more dramatic improvement in heat transfer efficiency is expected as a result of the particle size reduction in a suspension because heat transfer takes place at the particles surface [4, 11].

Eastman et al. [8] studied the particles in nanometer dimensions as a suspended solution. Their work showed that the nanofluid thermal conductivity considerably increased. Lee et al. [12] studied that the suspension of 4.0% with 35 nm CuO particles in ethylene glycol had 20% increment in the thermal conductivity. Choi et al. [13] observed 60% enhancement in the thermal conductivity of engine oil with 1.0% carbon nanotube. Das et al. [14] studied the temperature dependence of thermal conductivity in the nanofluids. They observed that a 2–4-fold increase in the thermal conductivity of nanofluid can take place over a temperature range of 21–51 °C. Alumina and copper oxide are the most ordinary and cheap nanoparticles which are used in the applied processes [15]. Xuan and Li [16, 17] experimentally studied the convective heat transfer and friction coefficient for the nanofluid in both laminar and turbulent flows. According to their research, the heat transfer coefficient was affected by the flow velocity and volume fraction of nanoparticles. In the present work, the convective heat transfer and mass transfer in the developed region of a pipe (containing water and NH_3) were simulated using the Adina computational fluid dynamics (CFD). The effect of fluid concentrations on the convective mass transfer coefficient was investigated.

2. Methodology

2.1. Mathematical modelling

The nanofluid as a single phase fluid with different physical properties such as density, thermal conductivity, and viscosity was used. The fluid phase was assumed to be a continuous phase. Flow and heat transfer are considered by the continuity, momentum and energy Eqs. (1)–(3) [12]. The equations are given as following:

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continuity equation:

$$\nabla.\left(\rho_{nf}V_m\right)=0, \tag{1}$$

momentum equation:

$$\nabla\left(\rho_{nf}V_mV_m\right)=-\nabla P+\nabla.\left(\mu_{nf}\nabla V_m\right), \tag{2}$$

energy equation:

$$\nabla\left(\rho_{nf}V_mTC\right)=\nabla\left(k_{nf}\nabla T\right). \tag{3}$$

The physical properties for above equation can be obtained (4) [12]:

$$\rho_n f=(1-\phi)\,\rho_{bf}+\phi\rho_\rho. \tag{4}$$

The effective heat capacity is calculated by [12]:

$$C_{nf}=\frac{\phi\left(\rho C_p\right)+(1-\phi)\left(\rho C_{bf}\right)}{\rho_{nf}}. \tag{5}$$

The viscosities of nanofluid (with the average particle size of 20 and 50 nm) can be predicted by Einstein's equation (6):

$$\mu_{nf}=\mu_{nf}\left(1+2.5\phi\right). \tag{6}$$

In this research, the single-phase approach was applied. Solid particles with less than 100 nm diameter were spotted in the single-phase approach. Moreover, some necessary data for the thermal conductivities determination for various concentrations of nanofluid were obtained from the literature [12]. Choi et al. correlation [13] was applied for the nanofluid effective thermal conductivity determination (7):

$$k_{nf}=\left[\frac{k_p+2k_{bf}+2(k_p-k_{bf})(1+\beta)^3\phi}{k_p+2k_{bf}-2(k_p-k_{bf})(1+\beta)^3\phi}\right]k_{bf}, \tag{7}$$

where β is the ratio of the nanolayer thickness to the original particle radius ($\beta=0.1$) [12]. The rheological and physical properties of the nanofluid were calculated at the average bulk temperature.

2.2. Simulation

Figure 1 presents the flow chart analysis of computational fluid dynamics (CFD) process using CFD. The complete CFD analysis procedure can be classified into the following six stages as shown in Fig. 1. In this study, it summarizes the experimental studies in heat transfer and mass transfer in nanofluids in heat pipes, and it will perform a simulation study of a single phase through a tube coming out. The aim is to know the change in the fluid flow and the mass transfer coefficient along the concentration coefficient convective mass transfer nanoparticles. The maximum will be held with a change in the concentration of NH_3 nanoparticles in water. There were studied the equations of the model CFD to predict the behavior of the heat pipe. In this simulation, a three-dimensional heat pipe was spotted. It was determined the volume flux through the single phase heat pipe. Lastly, the solutions were viewed using multiple cutting planes. Simulated the heat and mass transfer of heat pipe flow containing NH_3-water nanofluid using CFD as shown in Fig. 2.

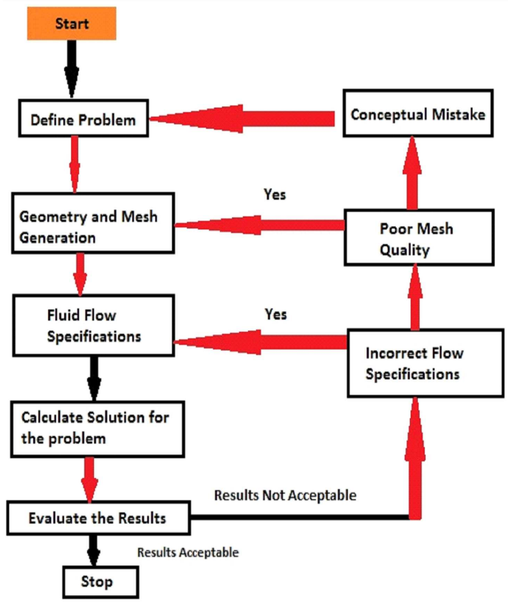

Fig. 1. Flow chart analysis of CFD analysis process.

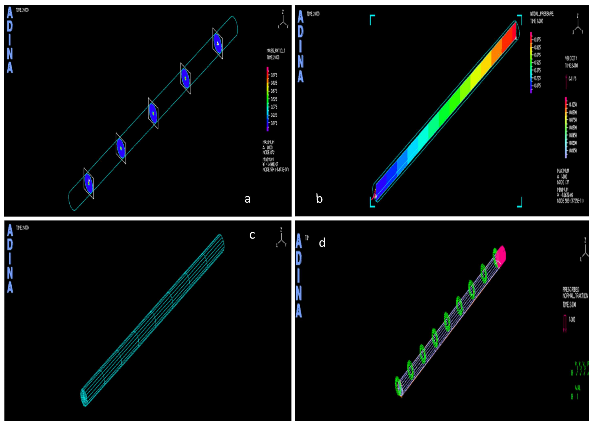

Fig. 2. The simulation of fluid flow model.

3. Conclusion

In this article, the mass transfer coefficient in the developed region of heat pipe flow containing NH_3-water nanofluid during the convective heat transfer was simulated using CFD. The results showed that the heat transfer coefficient enhanced by increasing the nanoparticle concentration. According to this research, the CFD is able to simulate mass transfer in a pipe with a nanofluid.

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