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INFLUENCE OF PARTICLE CONCENTRATION OF AL_2O_3 NANOFLUID ON THERMAL PERFORMANCE OF THE TWO PHASE NATURAL CIRCULATION LOOP

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Abstract: *Natural Circulation Loops (NCLs) are widely used in thermal engineering applications such as cooling of nuclear reactors, geo-thermal heat extraction and waste heat recovery. Performance of NCL could be enhanced by improving the transport properties and heat transfer characteristics of the working fluid. Nanofluid, is a stabilized suspensions of nanoparticles (usually <100 nm size) in conventional fluids. They are evolving as potential enhanced heat transfer fluids in recent time due to their higher thermal conductivity and higher heat transfer coefficient (HTC) compared to the base fluid. This paper presents numerical investigation of the steady state behaviour of a two-phase natural circulation loop filled with Al_2O_3 nanofluid using water as the base fluid. Three nanofluid particle concentrations are (0.001%, 0.01%, and 0.05%) considered in this study. The numerical analysis is carried out by considering, Two-phase Homogeneous Equilibrium Model (THEM) and the systems of equations are solved by an in-house code written in MATLAB. Results demonstrate that increase in nanoparticles volume concentration, increases the mass flow rate of the working fluid inside the loop which results in reduction of thermal resistance.*

Keywords: Natural circulation loop, vapour quality, nanoparticles, Homogeneous Equilibrium Model, Mass flow rate.

1. Introduction

Natural circulation systems arose as an innovative solution in the diverse engineering heat transfer problems. Among the available heat transfer systems heat pipes, thermosyphons and natural circulation loops (NCL) are specially promising nature. These systems have an advantage like dissipating heat from source to sink with the absence of any active control instrumentation and mechanical moving parts. Hence, these are in simple in design and reliable in operation. Nowadays the research focused on NCL and it is used in versatile engineering applications such as nuclear reactor cooling, gas turbine cooling, solar water heater and waste heat recovery boilers. In general, conventional fluids such as water and refrigerants are commonly used as heat transfer fluids. But, the conventional fluids have not capable to dissipate more heat form the systems due to low thermo-physical properties. Hence, researchers are focused to improve thermo-physical properties of the base fluid. The suspension of nano sized solid particles into the base fluid is a key technique to enhance the thermal conductivity and results more heat transfer and this is first done by (Choi and Eastman 1995). Then a new class of fluids called nanofluids introduced into the scientific community. In earlier days the nanofluids are used in single phase heat transfer applications later focused to boiling heat transfer process.

Sun and Yang (2014) experimentally studied the horizontal flow boiling heat transfer characteristics of nano-refrigerants. In their experimental analysis Al, Al_2O_3, Cu and CuO nanoparticles are used. From the

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results, they observed that HTC for the nano-refrigerants is increased while increases of mass velocity, concentration and quality. Sarafraz and Hormozi (2014) experimentally investigated the influence of operating parameters such as heat flux, mass flux and volume concentration of nanofluid. In their experiments a closed test loop designed and conducted experiments for the Al_2O_3/water nanofluid of volumetric concentrations of 0.5%, 1% and 1.5% respectively. For their experimental operated conditions two heat transfer regions (forced convection and nucleate boiling) are observed. The heat transfer is increasing with volume concentration of nanofluid in the forced convection region and deteriorates in the nucleate boiling region. The credible reason for heat transfer deterioration is given by the nanoparticles deposition on the heater surface. Similar studies in the open literature reveal that nanofluid flow boiling heat transfer process is enhanced. In this context, use of nanofluids in NCL is attracted by researchers due to the enhanced thermo-physical properties. However, the use of nanofluid is found in single phase NCLs (K, Bejjam, and Najan 2014), whereas in two phase NCL is scare. So an attempt was made to investigate the performance of loop filled with nanofluid.

In the present work, steady-state analysis is carried out on two phase NCL. For this analysis a one-dimensional homogeneous model is developed. In this model, conservation equations are discretized using finite difference method. A perfect computer code is written in MATLAB to simulate the fluid flow in NCL. A comparison in terms of mass flow rate is made between the water and nanofluid as working fluids in the loop.

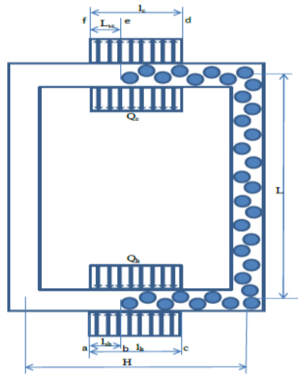

Fig. 1: Schematic diagram of a two phase NCL

2. Mathematical Modeling

The schematic diagram of a two phase NCL shown in Fig.1(Sudheer, Kiran Kumar, and Balasubramanian 2018). The detailed mathematical modelling part for the loop as per the state of the loop fluid is discussed by the authors earlier (Sudheer, Kiran Kumar, and Balasubramanian 2018). So, here the equations related to nanofluid is discussed in this section. In the nanofluid boiling the nanoparticles are stayed with liquid phase base fluid only, this assumption is valid for low concentration nanofluids due to nanoparticles are very much less volatile thanwater molecules. Therefore similar to the water nanofluid exhibits two phases namely nanoliquid (liquid phase) and pure vapour (vapour phase).

The thermo-physical properties of the nano-liquid is estimated as follows

Density

$$\rho_f = \phi\rho_{np} + (1-\phi)\rho_{bf} \tag{1}$$

Heat capacity/Specific heat

$$C_{nf} = \phi C_{np} + (1-\phi)C_{bf} \tag{2}$$

Viscosity

$$\mu_{nf} = (1 + 2.5\phi + 6.5\phi^2)\mu_{bf} \tag{3}$$

In the present homogeneous equilibrium model is used for two phase mixture (nano liquid + vapour). The mean density of the two phase mixture is given by

$$\frac{1}{\rho_m} = \frac{x}{\rho_g} + \frac{1-x}{\rho_f} \qquad 4$$

The mean two phase viscosity (μ_m) is taken from (John G. Collier 1996)

$$\frac{1}{\mu_m} = \frac{x}{\mu_g} + \frac{1-x}{\mu_f} \qquad 5$$

Whereas the subscripts 'f' represents either saturated liquid (water) or saturated nanoliquid (nanofluid) and 'g' represents saturated water vapour.

Solution procedure

The analysis has been performed by considering the following loop configuration and operating conditions as given in Table 1. Fixing the initial condition of the loop and adding the pressure gradient at every section, gives equations in the form of

$$f(G, x) = 0 \qquad 6$$

The steady state solution of two phase NCL is obtained by assuming the mass flux and solve the eq. (6) using a suitable iterative procedure.

Tab. 1: loop configuration and operating parameters

Parameter	Value/Range
Diameter of the pipe	0.01325 m
Height of the loop (L)	1.5 m
Pressure inside the loop (p)	1 bar
Inlet temperature (T_i)	95 ^{o}C
Heat flux in/out in Heating/cooling section ($Q_h = Q_c$)	20-200kW/m^2
Nanoparticle concentration(% by volume)	0.001,0.01,&0.05

3. Result and discussion

Fig. 2 shows the loop fluid mass flow rate variation for the heat flux ranging from 20 kW/m^2 to 200 kW/m^2. As the heat flux increases loop mass flow rate increases initially and starts decreasing after a certain heat flux. The increase in heat flux increases the vapour quality in the riser section. As the low density vapour present in the riser, and high density liquid present in the downcomer leads to more density gradient which results in mass flow rate increase. Further increase in heat flux leads much more vapour quality in the riser. Further increase in the vapour quality results in decrease in mass flow rate due to the drag forces offered by high quality vapour. Hence, for every loop configuration there is a limiting vapour quality in the riser section. Beyond this limiting value, mass flow rate retards. The limiting vapour quality in the loop is dependent on the several operating and geometrical parameters like heater inlet condition (pressure & temperature), heat input, loop height, diameter and the orientations of heater and condenser. By fixing the geometrical parameter, every loop exhibits limiting vapour quality at particular heat input where maximum mass flow rate is observed. This specific heat input called as critical heat input. After the critical heat input the mass flow rate decreases exponentially.

Influence of particle concentration:

Fixing the loop fluid heater inlet conditions at 95 ^{0}C and 1atm, Al_2O_3 nanoparticles concentration in the base fluid is varied (Three particle concentration are considered: 0.001%, 0.01% and 0.05%) in order to assess the performance of the loop. Loop mass flow rate is strongly influenced by particle concentration that can be observed in Fig. 2. As the nanoparticle concentration increases in base fluid, loop mass flow rate is noticeably enhanced. The mass flow rate is high for the 0.001% nanofluid as compared with water and other two nanofluids (0.01% and 0.05% particle concentration). The maximum enhancement in mass flow rate up to critical heat flux is on an average of 10.49% for the particles concentrations of 0.001%, 0.01% and 0.05% respectively. The nanofluid based NCL have high loop mass flow rate as compared with water based NCL. This is due to the magnitudinal difference of buoyancy and gravitational forces. The addition of nanoparticles in the base fluid offers the improved thermo-physical properties like density, specific heat and viscosity. These thermo-physical properties significantly influence the buoyancy and gravitational forces in the loop. So, the net resultant driving force is high for the nanofluids as compared with water that can be observed in local pressure profiles (Fig.3). Fig. 4 depicts the Variation of vapour quality in the loop for different heat fluxes. The nanofluid based NCL have less vapour quality as compared with water based NCL.

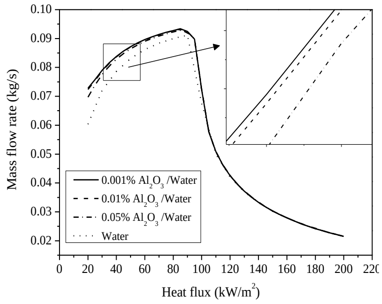

Fig. 2: loop mass flow rate variation with respect to heat flux

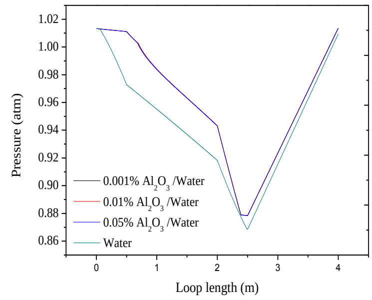

Fig. 3: Local pressure profiles in the loop at heat flux of 50 kW/m^2

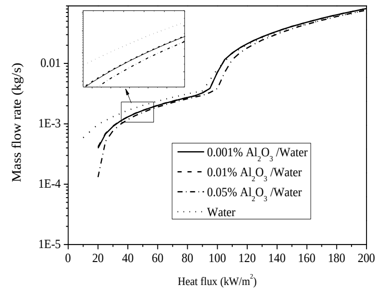

Fig. 4: Riser exit quality variation with respect to heat flux

4. Conclusions

The steady state performance of a boiling nanofluid based natural circulation loop is analysed. One dimensional approximation is considered. The mass flow rate of the loop is obtained by balancing the buoyancy with opposing frictional forces. Loop fluid with particle concentration of 0.001%, 0.01% and 0.05% by volume is examined to know its effect on NCL performance.

The following important findings are noted during the analysis

- In two phase NCL, for a given configuration and operating conditions, loop exhibits an optimum mass flow rate at a particular heat flux. It is advantageous to operate the NCL at a specified range of heat fluxes.
- The increase of quality in the loop is not always favourable. There exists a limiting quality.
- Nanofluids have maximum mass flow rate compared with water.
- The maximum enhancement in mass flow rate up to the critical heat flux is about 10.49% for nanofluids.
- In two phase flows, buoyancy and frictional forces plays a prominent role.

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