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Enhancement of Heat Transfer Using Nanofluids in Forced Circulation Loops

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Theoretical investigations to find the advantages of using different nanofluids in Forced Circulation Loop (FCL) are presented in this paper. Compared to the Natural Circulation Loop (NCL), FCL offers better heat transfer due to better heat transfer coefficient and better diffusion. Comparison among different chosen nanofluids has been made. Five different water based nanofluids (Al_2O_3, CuO, Cu, SiO_2 and TiO_2) have been chosen for the study. In order to calculate performance parameters, thermal conductivity and viscosity of nanofluids are measured and remaining properties are calculated based on the available correlations. From the present investigation it is found that using of nanofluids is beneficial such that it brings compactness to the heat transfer loops. There is trade off between pressure drop and heat transfer characteristics.

Keywords**:** heat transfer, nanofluids, forced circulation loops

1. Introduction

Miniaturization and quick heat transfer are becoming essential in every engineering field. It is always a challenge to an engineer to design an effective heat transfer systems by compromising between pressure drop and heat transfer rate. Review papers on this area are published by few researchers [1-2]. Now-a-days heat generation rate from the electronic equipment increases rapidly. There is a big challenge for researchers to identify better heat transport fluid for cooling of electronic equipments. Nakayama et al [3] presented different types of cooling methods for electronic equipments. Thermo physical properties plays vital role for better heat transfer enhancement. Several researchers proposed correlations for the measurement of nanofluid properties [4-6].Heat transfer loops can be categorized as natural circulation loops and forced circulation loops. Forced circulation heat transfer loops gives better heat transfer rate when compared with natural circulation loops. Extensive literature is available for natural circulation loops. In this paper five types of nanofluids (Al_2O_3, CuO, Cu, SiO_2 and TiO_2) are chosen to carry out research for heat transfer enhancement in forced circulation loops.

2. Mathematical Formulation

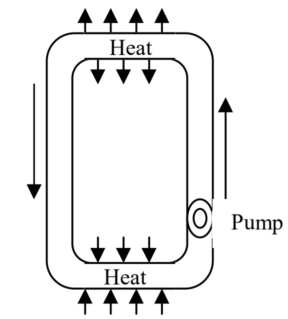

Fig. 1. Schematic of the test facility

Figure 1 represents the FCL considered for study.
Drop in Pressure across length of the tube L and diameter d is given by:

Pressure drop: $$\Delta p = f_c \rho u^2 \frac{L}{d} \tag{1}$$

By applying suitable correlation for friction factor, eqn.1 can be written as:

$$\Delta p = 0.341 \cdot \frac{L_t Q^{7/4}}{d^{19/4}} \cdot \frac{1}{\Delta T^{7/4}} \cdot \left\{ \frac{\mu^{1/4}}{\rho \cdot c_p^{\ 7/4}} \right\} \tag{2}$$

Where $\left\{ \frac{\mu^{1/4}}{\rho \cdot c_p^{\ 7/4}} \right\}$ = figure of merit

Pumper power can be calculated by: $$P = \frac{\Delta p \cdot V}{\eta} \tag{3}$$

Rate of heat transfer is given by: $$Q = mc\Delta T = V\rho c\Delta T \tag{4}$$

The ratio of heat transfer rate to volume flow rate is called as volumetric heat capacity.
From equations 2,3 and 4 an expression for ratio of diameters is derived. By considering heat input, temperature drop across the heat source and total loop length same for the same pumping power, the ratio of the essential diameter of the loop when nanofluid (NF) as working fluid to that of water (d_{NF}/d_F) is given by:

$$\frac{d_{NF}}{d_F} = \left(\frac{\mu_{NF}}{\mu_F} \right)^{1/19} \left(\frac{\rho_F}{\rho_{NF}} \right)^{8/19} \left(\frac{c_F}{c_{NF}} \right)^{11/19} \tag{5}$$

Table 3.1 Thermo physical properties of various nanoparticles and water.

Type of nanoparticle	Density (kg/m^3)	Specific heat (J/kgK)	Thermal conductivity (W/m K)	Thermal expansion coefficient(K^{-1})
Al_2O_3	3900	785.2	40	8.4×10^{-6}
Cu	8933	765	400	16.5×10^{-6}
CuO	6350	502.8	69	9.3×10^{-6}
TiO_2	4250	686	8.9	10.2×10^{-6}
SiO_2	2648	692	1.4	0.5×10^{-6}
Water	997	4181.3	0.6	2.5×10^{-4}

Density of nanofluid is calculated Using Eq. (6) [7]. Vajjha et al.[2] presented that the experimental values of density are well matched with the prediction via Eq. (6) for different nanofluids. So for this present study Eq. (3.2) is chosen for the estimation of density of various nanofluids.

$$\rho_{NF} = (1-\phi)\rho_F + \phi\rho_p \qquad (6)$$

Where $$\phi = \frac{\frac{m_p}{\rho_p}}{\left(\frac{m_p}{\rho_p} + \frac{m_F}{\rho_F}\right)} X100$$

Viscosities of five types of nanofluids are measured using Rheometer. Thermal conductivity of nanofluids are measured using thermal conductivity analyzer.

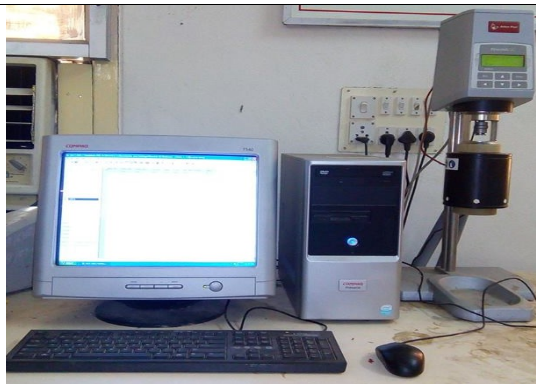

Fig.2:Rheometer with computer interface

Fig.3:Thermal conductivity Analyzer

3. Results and Discussion

Densities of nanofluids are calculated using the equation 6. From the graph it is observed that density of Cu water based nanofluid is higher than the other nanofluids considered for the present study.

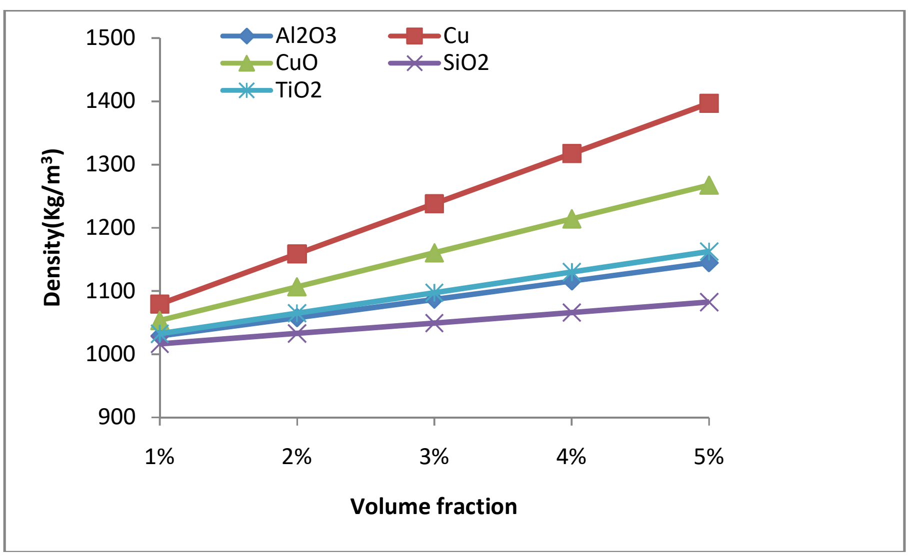

Fig. 4: Variation of density with volume concentration

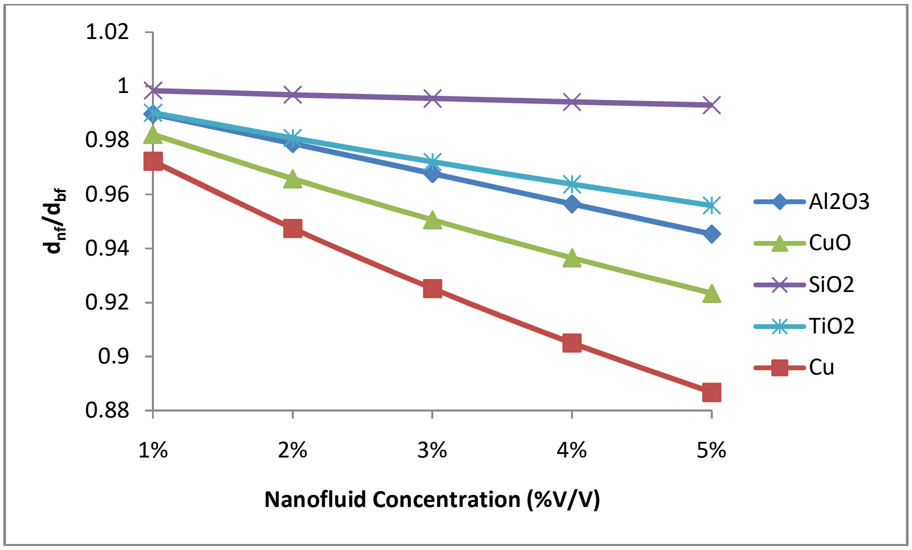

Fig. 5: Variation of diameter ratio with volume concentration

In order to check the suitability of nanofluids for forced circulation loops (FCL) equation 5 has been derived. From the equation it is clear that ratio of diameters depends upon thermo physical properties and also the variation of each property is not similar. Figure 5 represents the variation of diameter ratio for different water based nanofluids with various concentrations. It can be shown that, diameter of the loop decreases with concentration. However, there is magnitude difference from fluid to fluid. Cu/water nanofluid exhibits more compactness compared to other fluids considered for the study.

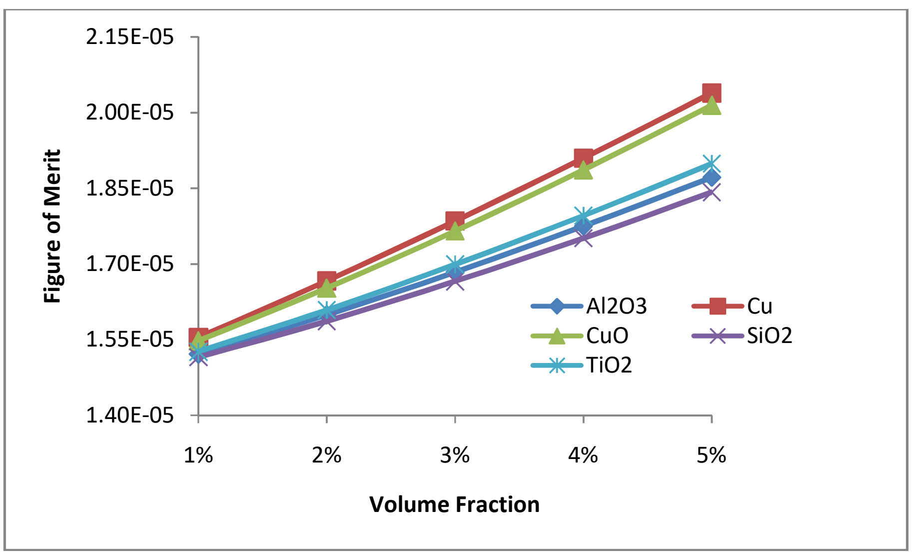

Fig. 6: Variation of Figure of Merit with volume concentration

Figure 6 shows the deviation of 'figure of merit' (term is represented in eqn. (2)) for different nanofluids with nanofluid concentration. For the analysis Al_2O_3, Cu, CuO, SiO_2 and TiO_2 water based nanofluids are selected. From the graph it is clear that figure of merit increases with increase in the concentration for nanofluids. From the graph it is observed that Cu water based nanofluid is having higher figure of merit than other nanofluids. For water, figure of merit is 1.45E-5. For Cu nanofluid at 3 and 5 % of V/V, figure of merit increases by 12% and 18.8% respectively.

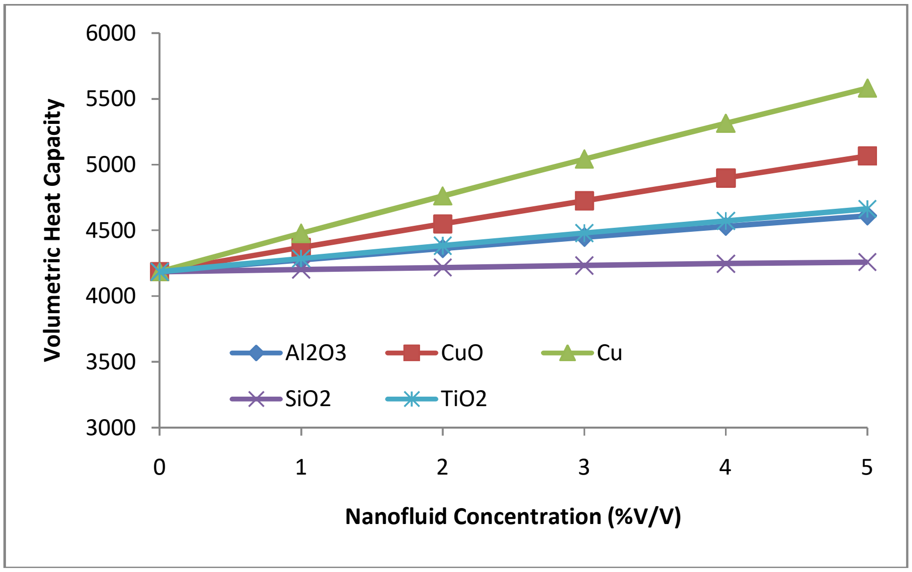

Fig. 7: Variation of Volumetric heat capacity with volume concentration

Thermo physical properties of nanofluid influence the rate of heat transfer. Properties of nanofluids vary with the nanofluid concentration. Density and specific heat are the important thermo physical properties of nanofluids. With increase in nanofluid concentration, density of nanofluid increases and specific heat of nanofluid decreases. Volumetric heat capacity is the evaluation of heat carrying potential of the given loop for the same volumetric flow. Volumetric heat capacity depends on density and specific heat. From the figure 7 it is noted that volumetric heat capacity increases with concentration for all five types nanofluids compared with water. Volumetric heat capacity of Cu-Water nanofluid is higher than the other nanofluids for the concentration of 1 to 5%. At higher concentrations the deviation is more.

4. Conclusions

From the present analysis it can be concluded that:

- Usage of nanofluids brings compactness to the FCL. For more compactness Cu/water nanofluid is suitable for forced circulation loops with increase in volume fraction.
- Volumetric heat capability increases with nanofluid concentration.
- Metal nanofluid (Cu/Water) is more favorable as far as heat transfer rate is concerned.

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Nomenclature

Nomenclature		*Greek Letters*	
k	Thermal Conductivity (W/m K)	ρ	Density (kg/m^3)
C_p	Specific Heat (kJ/kg K)	Φ	Volume Concentration
A	Cross sectional Area of the pipe (m^2)	μ	Viscosity (kg/m s)
f_c	Friction factor	*Subscripts*	
R	Overall resistance parameter	p	Nano particle
d	Diameter of the tube (m)	F	Base fluid
m	Mass flow rate (kg/s)	NF	Nanofluid
Δp	Pressure drop(kPa)		
Q	Heat load (kW)		
V	Volume flow rate (m3/s)		
u	Fluid velocity (m/s)		