Thermal performance of nanofluids in heat transfer loops

N Praveena Devi1, Ch Srinivasa Rao2 and K Kiran Kumar3

1Department of Mechanical Engineering, S R Engineering College, Warangal, Telangana, India-506371
2Department of Mechanical Engineering, Andhra University, Visakhapatnam-530003, Andhra Pradesh, India
3Department of Mechanical Engineering, National Institute of Technology, Warangal-506004, Telangana, India

E-mail: praveenadevi@gmail.com

Abstract. Theoretical investigations have been carried out to find the advantages of using different nanofluids in Forced Circulation Loop (FCL) are presented in this paper. FCL finds its application in different heat transfer systems. Compared to the Natural Circulation Loop (NCL), FCL offers better heat transfer due to the higher heat transfer coefficient and more diffusion. Comparison among different chosen nanofluids has been made. Five different water based nanofluids (Al2O3, CuO, Cu, SiO2 and TiO2) 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 in the way that it brings compactness to the heat transfer loops. Of course, there is trade-off between pressure drop and heat transfer characteristics and these aspects are also discussed.

Keyword: Nanofluid, heat transfer loops, Natural circulation loop, forced circulation

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 system by compromising between pressure drop and heat transfer rate. Review papers on nanofluids in heat transfer applications are presented by several researchers [1-2]. Now-a-days, heat generation rate from the electronic equipment is increasing 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 of working fluids plays vital role for better heat transfer enhancement. Several researchers proposed correlations for the measurement of nanofluid properties [4-6]. Saidur et al [9] presented overall review on applications and challenges of nanofluids in different engineering disciplines. Iskander Tili [10] reported the advantage of nanofluid as working fluid in NCL. Praveena [11] conducted numerical and experimental studies on nanofluid when the nanofluid flows through a circular tube. N. P. Devi [12] presented suitability of magnetic nanofluid in heat transfer loops. S.S. Khaleduzzaman et al. [13] presented energy and exergy analysis with alumina water nanofluid. Praveena [14] reported thermodynamic Analysis of magnetic nanofluid. Natural circulation loops (NCL) and Forced circulation loops (FCL) are the two types of heat transportation methods. Forced circulation
loops gives better heat transfer rate compared to natural circulation loops. Extensive literature is available for natural circulation loops. In this paper five types of nanofluids (Al₂O₃, CuO, Cu, SiO₂ and TiO₂) are chosen for study of its use in FCL in order to increase the heat transfer in Forced circulation loops (FCL).

2. Mathematical formulation
In order to investigate the effect of nanofluids in FCL, a simple mathematical model has been developed. Figure 1 represents the FCL considered for study.

![Figure 1. Schematic of test facility.](image)

By applying assumptions such as, (1) fluid flow is one dimensional, (2) steady state flow, (3) incompressible flow, (4) no density variation along the stream line, pressure drop across the length of the tube L and diameter d is given by eqn.1

Pressure drop: \[ \Delta p = f \rho u \frac{L}{d} \] (1)

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

\[ \Delta p = 0.341 \cdot \frac{L Q^{1/4}}{d^{19/4}} \cdot \frac{1}{\Delta T^{7/4}} \cdot \left[ \frac{\mu^{1/4}}{\rho c_p^{7/4}} \right] \] (2)

Where \( \left[ \frac{\mu^{1/4}}{\rho c_p^{7/4}} \right] \) is termed as figure of merit.

Pumper power can be calculated by: \[ P = \frac{\Delta p \cdot V}{\eta} \] (3)

Rate of heat transfer is given by: \[ Q = mc \Delta T = V \rho c \Delta T \] (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 \( \left( \frac{d_{NF}}{d_F} \right) \) is given by:

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


Table 1. Thermo physical properties of various nanoparticles and water.

| Type of nanoparticle | Density (Kg/m$^3$) | Specific heat (J/Kg-K) | Thermal conductivity (W/m-K) | Thermal expansion coefficient(K$^{-1}$) |
|----------------------|---------------------|------------------------|-------------------------------|--------------------------------------|
| Al$_2$O$_3$          | 3900                | 785.2                  | 40                            | 8.4$x10^{-6}$                        |
| Cu                   | 8933                | 765                    | 400                           | 16.5$x10^{-6}$                      |
| CuO                  | 6350                | 502.8                  | 69                            | 9.3$x10^{-6}$                       |
| TiO$_2$              | 4250                | 686                    | 8.9                           | 10.2$x10^{-6}$                      |
| SiO$_2$              | 2648                | 692                    | 1.4                           | 0.5$x10^{-6}$                       |
| Water                | 997                 | 4181.3                 | 0.6                           | 2.5$x10^{-4}$                       |

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. (6) is chosen for the estimation of density of various nanofluids.

\[
\rho_{NF} = (1 - \phi)\rho_f + \phi\rho_p
\]

Where \( \phi = \frac{\rho_p}{(\frac{m_p}{m_f + m_p})} \times 100 \)

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

3. Results and discussion

Theoretical investigations are carried out to find the advantages of using different nanofluids in Forced Circulation Loop (FCL). Effect of nanoparticle concentration on density of nanofluids is represented in Fig.4. Figure 4 depicts that there is linear increment of density with nanoparticle concentration for nanofluids. Density of nanofluid is directly influenced by density of nanoparticle which is dispersed in the base fluid. From Table 1, it can be noticed that among all nanoparticles, Cu nanoparticle has higher density which is the reason for higher density of Cu/Water nanofluid compared to other nanofluids.
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 diameter ratio 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 particle concentrations. Observation reveals that, diameter of the loop decreases with increase in particle concentration. However, there is magnitude difference from fluid to fluid. The diameter ratio is lower for Cu/water nanofluid than for other nanofluids due to its higher density, low specific heat for a specific concentration. So, Cu/water nanofluid exhibits more compactness compared to other fluids considered for the study. Irrespective of type of nanofluid, one can conclude that the use of nanofluid in place of water offers compactness to FCL.
Figure 6. Variation of Figure of Merit with nanofluid 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 Al₂O₃, Cu, CuO, SiO₂ and TiO₂ water based nanofluids are selected. One can observe that figure of merit increases with increase in the concentration for nanofluids. Observation reveals 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, figure of merit increases by 12% and 18.8% at 3 and 5 % particle concentration respectively.

Figure 7. Variation of Volumetric heat capacity with nanofluid 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 nanofluids.
Types of 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. Conclusion

Advantage of using different nanofluids in Forced Circulation Loop is studied. FCL with different nanofluids is compared with water based FCL in terms of diameter ratio to check the suitability of nanofluids in FCL. Analytical expression for FCL is derived to calculate the size reduction of heat transfer loops.

Following are the conclusions drawn:
- Usage of nanofluid in place of water offers compactness to FCL. Cu/water nanofluid exhibits more compactness compared to other fluids considered for the study.
- Among all nanoparticles, Cu nanoparticle has higher density which is the reason for higher density of Cu/Water nanofluid compared to other nanofluids.
- Volumetric heat capability increases with percentage of particle concentration.
- Among all nanoparticles, copper is having higher thermal conductivity. So, Cu/Water nanofluid is more favourable as far as heat transfer rate is concerned.

Acknowledgement

The present research work is financially supported by UGC, GoI (MRP-6230/15/(SERO/UGC)). The authors wish to thank UGC for providing research grant.

References

[1] Nkurikiyimfur, Yanmin Wanga and Zhidong Pan 2013 Heat transfer enhancement by magnetic nanofluids—A review Renewable and Sustainable Energy Reviews 21 548-561
[2] Bahiraei M and Hangi M 2015 Flow and heat transfer characteristics of magnetic nanofluids: a review J. Magn. Magn. Mater. 374 125-138
[3] Nakayama W 1986 Thermal management of electronic equipment: a review of technology and research topics Appl. Mech. Rev. 39 (12) 1847-1868
[4] Hamilton R L and Crosser O K 1962 Thermal conductivity of heterogeneous two-component systems Ind. Eng. Chem. Fundam. 1 187-191
[5] Brinkman H C 1952 The viscosity of concentrated suspensions and solutions, J. Chem. Phys. 20 571–581
[6] Xiaoke Li and Changjun Zou 2016 Thermo-physical properties of water and ethylene glycol mixture based SiC nanofluids: An experimental investigation International Journal of Heat and Mass Transfer 101 412-417
[7] Pak B C and Cho Y I 1998 Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles Exp. Heat Transf. 11 151-170
[8] Vajhja R S and Das D K 2012 A review and analysis on influence of temperature and concentration of nanofluids on thermophysical properties, heat transfer and pumping power Int. J. Heat Mass Transf. 55 (15–16) 4063-4078
[9] Saidur R Leong K Y and Mohamma H A 2011 A review on applications and challenges of nanofluids Renewable and Sustainable Energy Reviews 15 1646-1668
[10] Iskander Tlili Seyyed Masoud Seyyedi Dogonchi A S Hashemi-Tilehnoee and Ganji D D 2020 Analysis of a single-phase natural circulation loop with hybrid-nanofluid International Communications in Heat and Mass Transfer 112 104498
[11] Praveena Devi N, Srinivasa Rao Ch, and Kumar K K 2019 Numerical and experimental studies of nanofluid as a coolant flowing through a circular tube Lecture Notes in Mechanical Engineering 511-518
[12] Praveena Devi N, Srinivasa Rao Ch, and Kumar K K 2018 Suitability of magnetic nanofluid in heat transfer loops International Journal of Heat and Technology 36(26) 195-200
[13] Khaleduzzaman S S, Sohel M R, Saidur R, Mahbubul I M, Shahrul M, Akas B A and Selvaraj J 2014 Energy and exergy analysis of alumina–water nanofluid for an electronic liquid cooling system *International Communications in Heat and Mass Transfer* **27** 118-127

[14] Praveena Devi N, Srinivasa Rao Ch, and Kumar K K 2019 Thermodynamic analysis of Fe$_3$O$_4$ nanofluid flowing through a circular tube *International Journal of Engineering and Advanced Technology* **8**(6) 530-533

| Nomenclature | Greek Letters |
|--------------|---------------|
| $k$          | $\rho$ Density (kg/m$^3$) |
| $C_p$        | $\Phi$ Volume Concentration |
| $A$          | $\mu$ Viscosity (kg/m s) |
| $f_c$        | |
| $R$          | Subscripts $p$ Nano particle |
| $D$          | $F$ Base fluid |
| $m$          | $NF$ Nanofluid |
| $Q$          | |
| $V$          | |