# Numerical Model for Heat Transfer Analysis of Heavy Earth Moving Machinery Nanofluids Coolant

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**Abstract**

In this study a numerical model has been developed for evaluating thermal performance of nanofluid. Rayleigh dimensionless approach has been used to develop this model. Thermophysical properties of nanofluids extracted from conventional mathematical models. Ethylene glycol (EG) and water coolant used in Heavy Earth Moving Machinery (HEMM) coolants with $Fe_2O_3$, CuO and $Al_2O_3$ nanoparticles. $Al_2O_3$ nanoparticles show better thermal behavior than compares with $Fe_2O_3$and CuO nanofluid at same volume fraction.

**Keywords**

Nananofluid, Rayleigh dimensionless approach, $Fe_2O_3$, CuO, $Al_2O_3$

**Introduction**

Thermal management in Heavy Engineering Mining Machinery (HEMM) is a typical problem. Heavy load, long duration of operation and poor thermal capability of convention coolant (water, ethylene glycol etc) limits their performance. The suspension of high thermal conductivity nanoparticles in convention coolants for enhancing thermal performance is now a broad area of research. Conventional coolant with the suspension of nanoparticles is known as nanofluid [1]. Prediction and measurement of thermophysical properties are wide concern of research community [2-4].There are limited studies in open literature for describing heat transfer performance of nanofluid [5-6], equation (1) shows heat transfer for nanofluid:

$$q = -\left( k_{nf} \frac{\partial T}{\partial r} + k_{d,r} \frac{\partial T}{\partial r} \right)_{|r=R} \quad (1)$$

The expression above shows the heat flow in the tube. Nield and Bejan [7] approach has been used in the dimensionless analysis of equation and is correlated with the heat transfer in nanofluid as [7]:

$$Nu_x = [1 + C^* Pef^{'}(0)]\theta^{'}(0)\,\mathrm{Re}^m \quad (2)$$

$$Nu_x = [1 + C^* Pe^n f^{'}(0)]\theta^{'}(0)\,\mathrm{Re}^m \quad (3)$$

where $Pe = \frac{R u_m}{\alpha_{nf}}$

The value of constant C* is experimentally investigated.

Natural characteristics of water based $Al_2O_3$ nanofluid deteriorates in the natural convective heat transfer with increasing nanoparticles concentration. But, reason for it is not explain, why there is decrease in natural convective heat transfer [8].

Maxwell model [9] of 'k', was proposed for solid-liquid mixtures with relatively large particles and is expressed as :

$$k_{eff} = k_b + 3\phi \frac{k_p - k_b}{2k_b + k_p - \phi(k_p - k_b)} k_b \quad (4)$$

Wasp [10] proposed an alternative formula for this solid-liquid interface as:

$$k_{eff} = \frac{k_p + 2k_b + 2(k_p - k_b)\phi}{k_p + 2k_b - (k_p - k_b)\phi} k_b \quad (5)$$

Viscosity of nanofluids can be evaluated using equation (6):

$$\mu_{nf} = \mu_{bf}(1 + 2.5\phi) \quad (6)$$

Batchelor [13] has modified this equation for spherical particles as follow:

$$\mu_{nf} = \mu_{bf}(1 + 2.5\phi + 6.2\phi^2)\mu_{bf} \quad (7)$$

According to Pak and Cho's [14] equation, the density of the nanofluid is calculated

$$\rho_e = (1-\phi)\rho_m + \phi\rho_p \quad (8)$$

For calculating the specific heat of nano fluids, two different formulas are as following:

$$C_{pe} = \phi C_{pp} + (1-\phi)C_{pm} \quad (9)$$

$$C_{pe} = \frac{(1-\phi)(\rho C_p)_m + \phi(\rho C_p)_p}{(1-\phi)\rho_m + \phi\rho_p} \quad (10)$$

Hwang et al. [16] proposed a model for a nanofluid as:

$$\frac{h_{nf}}{h_m} = \left(\frac{k_{nf}}{k_m}\right)^{0.593} \left(\frac{C_{p,nf}}{C_{p,m}}\right)^{0.407} * \left(\frac{\mu_{nf}}{\mu_m}\right)^{-0.259} \left(\frac{\rho_{nf}}{\rho_m}\right)^{2/3} \left(\frac{\beta_{nf}}{\beta_m}\right)^{1/3} \quad (11)$$

In our previous study the relative enhancement of '*h*' using nanofluid can be expressed as [17]:

$$\frac{h_{nf}}{h_m} = \left(\frac{k_{nf}}{k_m}\right)^{\frac{2}{3}} \left(\frac{\mu_{nf}}{\mu_m}\right)^{\frac{1}{3}} \left(\frac{C_{pnf}}{C_{pm}}\right)^{\frac{1}{3}} \quad (12)$$

The properties of '*nf*' are calculated at '$T_{avg.}$'.

In present study a mathematical model for analyzing thermal performance of nanofluid using Rayleigh approach has been developed. The present model has been used to compare thermal performance of $Fe_2O_3$, CuO and $Al_2O_3$ nano particles in HEMM coolants (EG and water) as base fluids.

## 2. Dimensional Analysis based model:

Xuan and Roetzel [15] proposed a correlation between heat transfer coefficient and thermal conductivity for nanofluids as follows:

$$\frac{h_{nf}}{h_m} \approx \left(\frac{k_{nf}}{k_m}\right)^c \quad (13)$$

Further previous studies confirm dependence of *'h'* on *'k'*, viscosity and heat capacity of base fluid i.e. $h \propto k^a \mu^b C_p{}^c$ . In dimensionless terms, it can be expressed as:

$M^1T^{-3}\theta^{-1} = \left(M^1L^1T^{-3}\theta^{-1}\right)^a \left(M^1L^{-1}T^{-1}\right)^b \left(L^2T^{-2}\theta^{-1}\right)^c$ Equating the dimensions of both sides, we get, a=2/3, b=1/3 and c= 1/3

Again by using Buckingham theorem (value in terms of Re should replace by Ra) and considering the heat transfer coefficient as a function of diameter, density, velocity, viscosity, specific heat and thermal conductivity. After rearranging and writing in terms of relative values, expressed as:

$$\frac{h_{nf}}{h_m} = \left(\frac{\mu_{nf}}{\mu_m}\right)^n \left(\frac{C_{nf}}{C_m}\right)^n \left(\frac{k_{nf}}{k_m}\right)^{1-n} \quad (14)$$

For the power term 'n' and obtained power constant values, the final equation for '*h*' can be expressed as:

$$\frac{h_{nf}}{h_m} = \left(\frac{\mu_{nf}}{\mu_m}\right)^{\frac{1}{3}} \left(\frac{C_{nf}}{C_m}\right)^{\frac{1}{3}} \left(\frac{k_{nf}}{k_m}\right)^{\frac{2}{3}} \quad (15)$$

In above equation (15), the viscosity, $C_p$ and '*k*' value is taken from equation 5, 7 and 10 respectively.

## *3.* Results and Discussions

Figure 1 shows the variation in thermal conductivity of nanofluids using equation (10). It can be observed in both the cases (water and EG) $Al_2O_3$ and CuO nanoparticles shows higher thermal conductivity enhancement than $Fe_2O_3$.

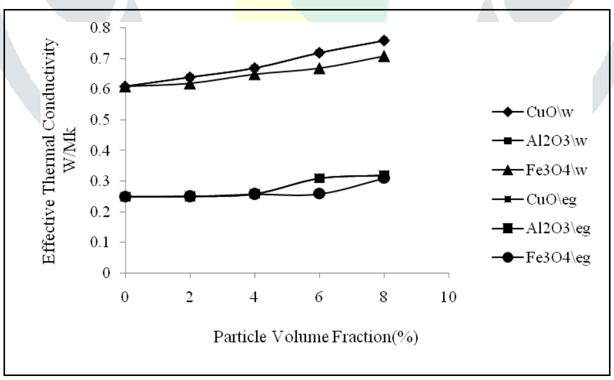


Figure 1: Effective thermal conductivity variation with nanoparticles

Figure 2 (a-b) shows the effect of $Al_2O_3$, $Fe_2O_3$ and CuO oxide nanoparticle on of viscosity and specific heat of ethylene glycol respectively. CuO nanoparticles show least specific heat capacity than $Fe_2O_3$ and $Al_2O_3$ nanoparticles.

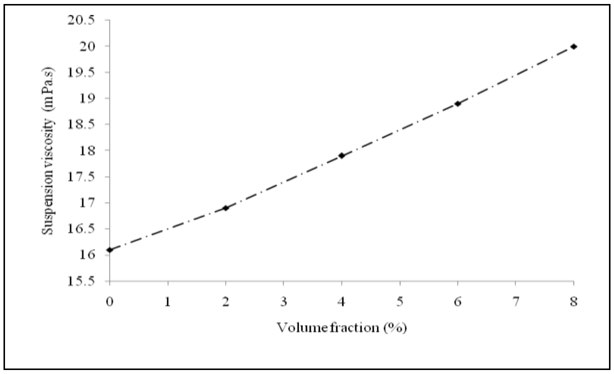


Figure 2 (a): Variation of viscosity with nanoparticle for ethylene glycol based nanofluids

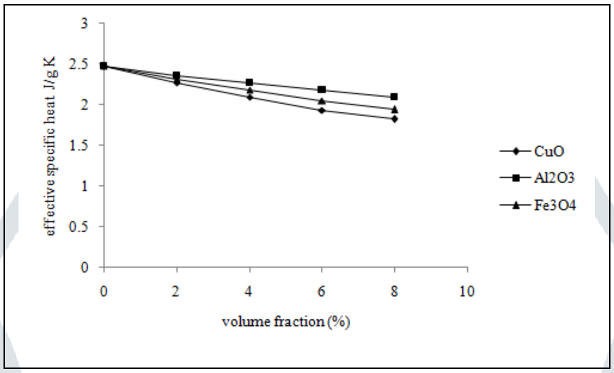


Figure 2 (b): Variation of specific heat for ethylene glycol based nanofluids

Figure 3 shows the effect of $Al_2O_3$, $Fe_2O_3$ and CuO oxide nanoparticle on heat transfer ethylene glycol coolant of HEMM. $Fe_2O_3$ and CuO oxide nanoparticles show almost similar heat transfer enhancement even though CuO nanoparticles have relatively higher '*k'* than $Fe_2O_3$ nanoparticles. This indicates the influence of other parameters (specific heat capacity and viscosity) on thermal performance of nanofluids. Further, $Al_2O_3$ and CuO nanoparticles shows similar enhancement in thermal conductivity value at particular nanoparticle volume fraction, but because of higher value of specific heat capacity of $Al_2O_3$ nanoparticle, It shows greater convective heat transfer property.

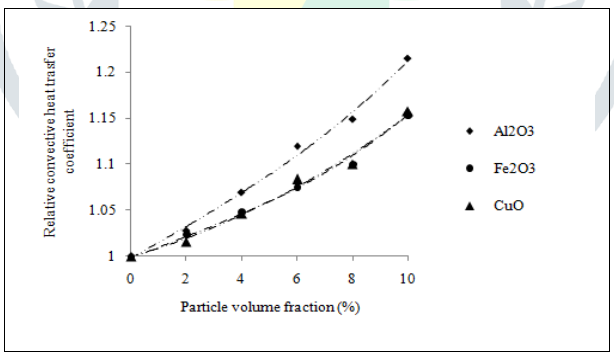


Figure 3: Comparison thermal performance for EG based nanofluids

Figure 4 (a-b) depicts the effect of $Al_2O_3$, $Fe_2O_3$ and CuO oxide nanoparticle on of viscosity and specific heat of water. CuO nanoparticles show least specific heat capacity than $Fe_2O_3$ and $Al_2O_3$ nanoparticles.

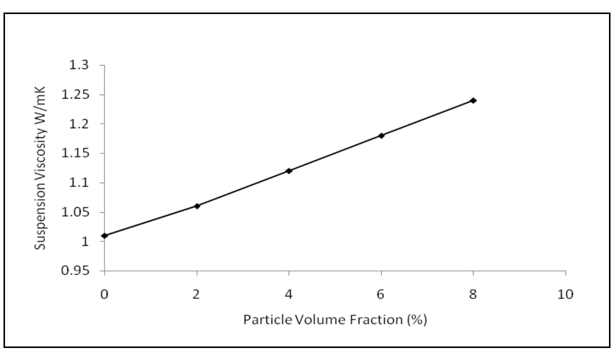


Figure 4(a): Variation of viscosity for water based nanofluids

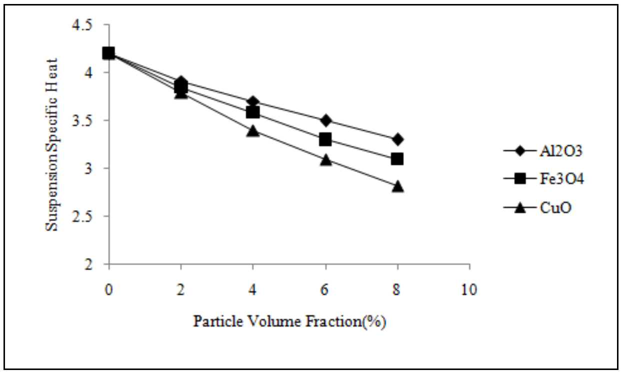


Figure 4(b): Variation in $C_p$ of water based nanofluids

Figure 5 Shows the effect of $Al_2O_3$, $Fe_2O_3$ and CuO oxide nanoparticle on heat transfer of water used as coolant of HEMM. $Al_2O_3$ nanoparticles show highest enhancement in convective heat transfer among $Fe_2O_3$ and CuO nanoparticles based nanofluid.

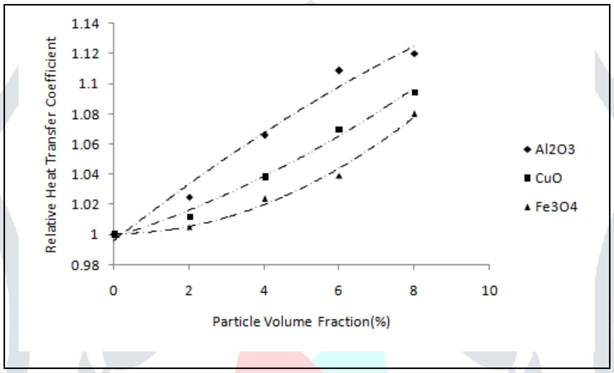


Figure 5: Comparison thermal performance for water based nanofluids

## *4.* Conclusion

The present paper various mathematical models were used to study the variation in specific heat capacity, density, viscosity and thermal conductivity of nanofluids with CuO, Al2O3 and Fe3O4 in the base fluids EG and water . A new mathematical model has been developed using Rayleigh dimensionless approach for evaluating thermal performance of nanofluid. It is observed that in case of water or ethylene glycol, nanofluid based on Al2O3 nanoparticle shows higher augmentation in *'h'* with respect to the nanofluid based on CuO and Fe2O3.

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