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Impact of Volume Fraction and Particle Size on Thermal Properties of Nano-fluids

Parvathy Sathyaprakasan
BITS Pilani, Dubai Campus
Dubai International Academic City, Dubai, UAE
parvathys268@hotmil.com

A.M. Surendra Kumar
BITS Pilani, Dubai Campus, Department of Mechanical Engineering
Dubai International Academic City, Dubai, UAE
amskumar@dubai.bits-pilani.ac.in

Abstract- Much attention has been paid in the past decade to nano-fluids because of their enhanced properties and behaviour associated with heat transfer. Its thermal properties imply an enormous potential of nanofluids in process intensification which could have a major impact on many industrial sectors, including chemical, energy and environment. The present work is focused on the thermal properties and methods to enhance it, with respect to nano-fluid properties. This paper aims to introduce four correlations to find out the heat transfer coefficient and thermal conductivity enhancement for Al_2O_3 /water nano-fluid for varying particle size and volume fraction.

***Keywords*:** Nano-fluids, Thermal properties, Heat transfer coefficient enhancement.

1. Introduction

The amount of research done in the field of the thermal properties of nano-fluids and its enhancement is vast. Although it shows many conflicting opinions about the nature of nano-fluids, it helps to study about the various properties and methods used to improve the thermal properties of nano-fluids. Given the aim of this study, to create a correlation for measuring thermal enhancement of Al_2O_3 /water nano-fluid with varying particle size and volume fraction, the empirical correlation by Chon (Chon et. al, 2005) has been used as the central formula.

In the present work, a sample calculation has been done for the determination of average heat transfer coefficient ratio of a laminar nano-fluid, flowing inside a circular tube with a constant wall temperature.

2. Thermal Conductivity Enhancement Calculations

Studies have been conducted in previous literature works about the effect of particle volume fraction, which is the volumetric concentration of the nanoparticles in the nano-fluid and the particle size, on the thermal conductivity of nanofluids. The following correlation by Chon has been considered as the starting point of our calculations.

$$\frac{knf}{kf} = 1 + 64.7\phi^{0.7460}\left(\frac{df}{dp}\right)^{0.3690}\left(\frac{kp}{kf}\right)^{0.7476} Pr^{0.9955}Re^{1.2321} \quad (1)$$

Consider Al_2O_3/water nano-fluid, with particle diameter dp. Firstly, the average heat transfer coefficient enhancement ratio for 2 volume percentage of Al_2O_3 has been calculated. The value of the volume percent was then varied to determine a pattern in its relationship with the enhancement ratio. The particle was assumed to have a diameter of 20nm and later the diameter value was changed to observe its relationship with the enhancement ratio. The diameter of the tube is assumed to be 5mm and the length to be 1mm. The characteristics of the nano-particle and the base fluid are mentioned in Table 1given below and have been used for the calculations (Sezer Özernic).

Table 1. Properties of Nano-particle and Base Fluid.

Symbols	Property	UNIT	Value
	Particle		**Al2O3**
	Sphericity		1
dp	Particle Dia	nm	5
		m	5.00E-09
ρp	Particle Density	kg/m3	3700
Cp	Specific Heat	J/kg/K	880
kp	Thermal Conductivity	W/mK	36
	Base Fluid		**Water**
λ f	Mean Free Path	m	1.70E-10
ρf	Base Fluid Density	kg/m3	9.94E+02
Cf	Specific Heat	J/kg/K	4179
df	Diameter of fluid molecule	m	2.80E-10
knf	Thermal Conductivity	W/mK	6.21E-01
μf	Viscosity of fluid	kg/ms	7.21E-04
αf	Thermal diffusivity of fluid	m^2/s	1.49E-07
	Nanofluid Mixture		
Φ	Vol% of solid in Solution		2%
	Flow System Geometry / Configuration		
d	Tube diameter	m	0.005
T	Wall Temperature	K	308
	CONSTANTS		
Bz	Boltzman's Constant		1.38E-23

2. 1. Calculations

In order to find the thermal conductivity and heat transfer coefficient enhancement, the values of specific heat and density have been calculated first.

Density calculation:

$$\rho nf = \varphi \rho p + (1 - \varphi)\rho f \qquad = 0.023(3700) + (1 - 0.02)(994) = 1050$$

Specific heat calculation:

$$Cp,nf = \frac{\varphi(\rho Cp)p+(1-\varphi)\rho f}{\rho nf} \quad (3)$$

$$= \frac{0.02(3700)(880)+(1-0.02)(994)(4179)}{1050} = 3950$$

The next step is to calculate the Prandtl Number and the Reynold's Number so as to substitute it in equation (1).

Prandtl Number calculation:

$$Pr = \frac{\mu f}{\rho f \ \alpha f} \quad (4)$$

$$= \frac{7.2017 \ \times 10^{-4}}{(994)(1.494 \ \times \ 10^{-7})} = 4.85308$$

Reynold's Number calculation:

$$Re = \frac{\rho f \ \kappa B \ T}{3\pi\mu^2\lambda f} \quad (5)$$

$$= \frac{(994)(1.308 \times 10^{-23})(308)}{3\pi(994)(7.2017 \ \times 10^{-4})(0.17 \ \times \ 10^{-9})} = 0.00508$$

Once the Prandtl and Reynold's Numbers have been calculated, it is substituted into equation (1) in-order to obtain the value of k_{nf}. The value of k_{nf} obtained is:

k_{nf}= 0.733 W/mK

Once the value of has been calculated, it is further substituted in formula mentioned below, in-order to calculate the heat transfer coefficient enhancement ratio (hnf/hf). The value of the heat transfer coefficient enhancement ratio was calculated as follows:

$$\frac{hnf}{hf} = \left[\frac{\rho nf \ Cp,nf}{\rho f \ Cp,f}\right]^{\frac{1}{3}} \left[\frac{knf}{kf}\right]^{\frac{2}{3}} = \left[\frac{1050 \ \times 3950}{994 \ \times \ 4179}\right]^{1/3} \left[\frac{0.733}{kf0.6210}\right]^{2/3} = 1.115$$

Using the method demonstrated above, the heat transfer coefficient enhancement ratio and the thermal conductivity enhancement ratio, for varying values of particle diameter have been calculated and tabulated in Table 2 given below.

Table 2. Variation of Thermal Conductivity Enhancement Ratio and Heat Transfer Coefficient Ratio with Particle Size.

dp	knf/kn	hnf/hn
5	1.180	1.115
10	1.140	1.089
15	1.120	1.077
20	1.108	1.069
25	1.100	1.064
30	1.093	1.060
35	1.088	1.056
40	1.084	1.054
45	1.080	1.051
50	1.077	1.049
55	1.074	1.048
60	1.072	1.046
65	1.070	1.045
70	1.068	1.043
75	1.066	1.042
80	1.065	1.041
85	1.063	1.040
90	1.062	1.039

In-order to analyze the variation of hnf/hf and knf/kf with respect to particle size, a graph has been plotted and shown in Figure 1.

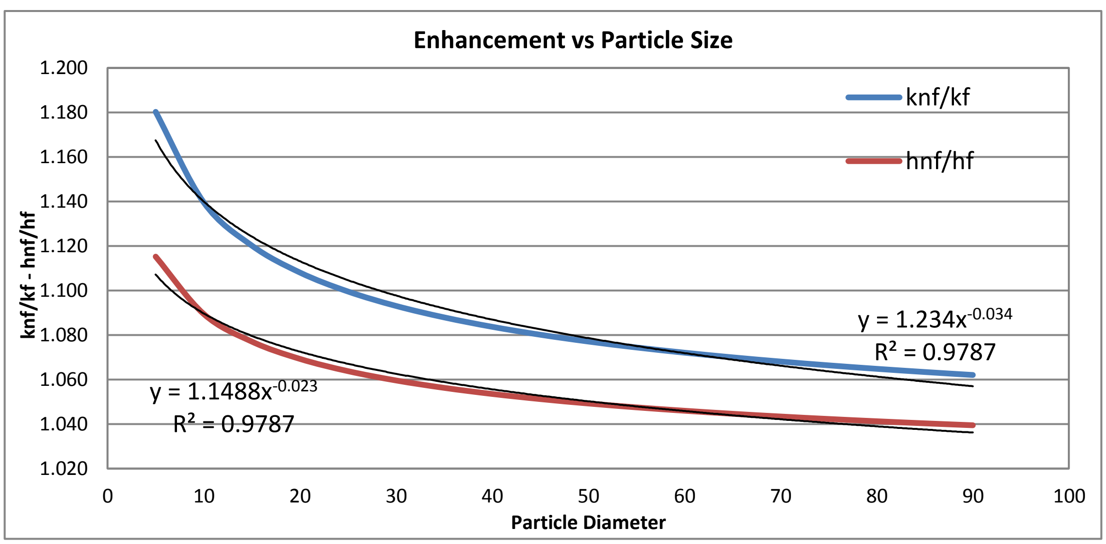

Fig.1. Variation of knf/kf and hnf/hf with particle size.

The heat transfer coefficient enhancement ratio and the thermal conductivity enhancement ratio, for varying values of volume fraction of the nano-particle in the base fluid have been calculated and tabulated in Table 3 given below.

Table 3. Variation of Thermal Conductivity Enhancement Ratio and Heat Transfer Coefficient Ratio with Volume Fraction of Particle.

Φ	**knf/kn**	**hnf/hn**
0.25%	1.038	1.025
0.50%	1.064	1.042
0.75%	1.087	1.056
1.00%	1.108	1.070
1.25%	1.127	1.082
1.50%	1.145	1.094
1.75%	1.163	1.105
2.00%	1.180	1.115
2.25%	1.197	1.125
2.50%	1.213	1.135
2.75%	1.229	1.145
3.00%	1.244	1.154
3.25%	1.259	1.163
3.50%	1.274	1.172
3.75%	1.288	1.181

In-order to analyze the variation of hnf/hf and knf/kf with respect to volume fraction of the particle, a graph has been plotted and shown in Figure 2.

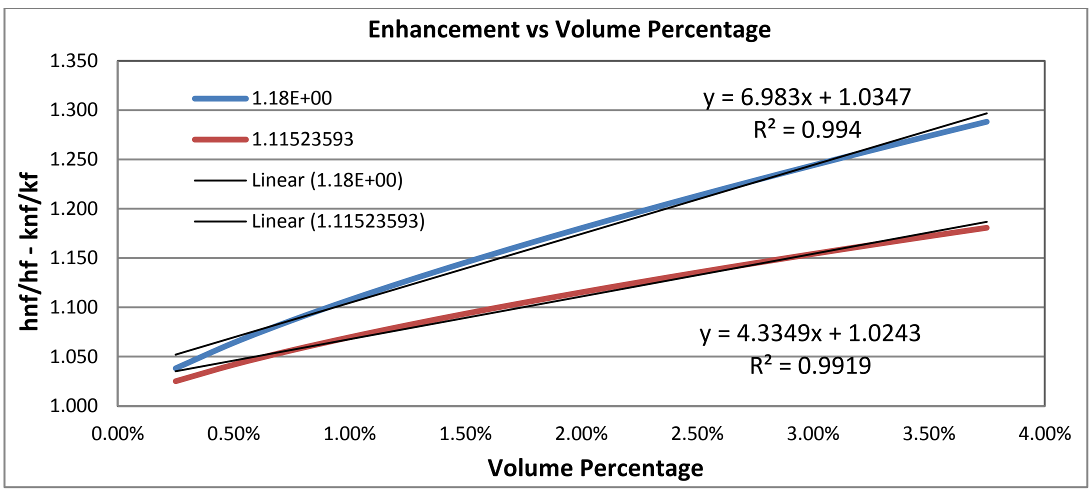

Fig.2. Variation of knf/kf and hnf/hf with volume fraction of particle

3. Result and Analysis

From the above plotted graphs, four correlations have been deduced, relating the heat transfer coefficient enhancement and the thermal conductivity enhancement to the changes in particle size and volume percentage of particles in the base fluid.

knf vs dp : $y = 1.234x^{-0.03}$

knf vs volume % : $y = 6.983x + 1.034$

hnf vs dp: $y = 1.148x^{-0.02}$

hnf vs volume % : $y = 4.334x + 1.024$

From these correlations it has been observed that the enhancement ratios increase with respect to the volume percentage and decreases with an increase in the particle size.

4. Conclusion

The empirical correlation by Chon (Chon et. al, 2005) has been used as the central formula. A sample calculation has been done for the determination of average heat transfer coefficient ratio of a laminar nano-fluid, flowing inside a circular tube with a constant wall temperature. A correlation has been deduced for measuring the heat transfer coefficient and the thermal conductivity enhancement of Al_2O_3 /water nano-fluid for varying particle size and volume percentage, keeping the other parameters constant.

References

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