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Estimation of Thermo-Physical Properties of Nanofluids using Theoretical Correlations

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Abstract

The major improvement in thermo-physical properties have suffered a lacking as a result and it is important to develop new strategies for improving the effective thermo-physical properties of conventional heat transfer fluids. To improve the thermo-physical properties of conventional fluids the nanoparticles are suspended. In this project the three base fluids are selected namely water, sodium and ethylene glycol. To enhance the thermo-physical properties the Aluminum, copper, and silver nanoparticles are used. The thermo-physical properties of the nanofluids such as density, specific heat and viscosity are calculated by theoretical models. The results show that the thermo-physical properties of nanofluids increases with increase in nanoparticle concentration.

Keywords: Heat transfer; nanoparticles; thermo-physical properties.

INTRODUCTION

Conventional fluids like water, ethylene glycol are normally used as heat transfer fluids. They play an important role in many industry sectors including power generation, chemical production, air-conditioning transportation and microelectronics. Various techniques are applied to enhance the thermo-physical properties; the low heat transfer performance of these conventional fluids obstructs the performance enhancement and the compactness of heat exchangers. The use of solid particles as an additive suspended into the base fluid is a technique for thermo-physical property enhancement. Improving of the thermo-physical properties is a key idea to improve the heat transfer characteristics of conventional fluids. Since a solid metal have large thermo-physical properties than a base fluid, suspending metallic solid fine particles into the base fluid is expected to improve the thermo-physical properties of that base fluid [1-8].

The recent advance in materials technology has made it possible to produce nanometer size particles. The reason for using nanofluids are when the nano-sized particles are properly dispersed nanofluids are expected to give many advantages. Higher heat conduction is a major advantage of nanofluids as the large surface area of nanoparticles allow for more heat transfer. To date, the dispersion stability has been reported as one of the most challenging issues that limit the practical application and the further development of nanofluids. Particles finer than 20nm carry 20% of their atoms on their surface making then instantaneously available for thermal interaction and also stability is another benefit of nanofluid as the particles are small, weigh less and their chances of sedimentation are also less. The dispersion stability is improved by using various approaches like ultrasonic treatment, mechanical stirring, using surface charges or surfactants. The reduced sedimentation can overcome one of the major draw backs of suspensions, the setting particles and make the nanofluids more stable [5].

A recent development is that nanoparticles can disperse in conventional heat transfer fluids such as water, glycol or oil to produce a new class of high efficiency heat exchange media. The superior properties of nanoparticle fluid mixtures relative to those of fluids without particle or with large sized particle include high thermal conductivities, stability and prevention of clogging in micro channels. A liquid suspended with particles of nanometer dimension is termed a nanofluid. The nanoparticles used to produce nanofluids are like metal particles such as Cu, Al, and Ni; oxides such as TiO_2, Al_2O_3, CuO, Fe_2O_3, SiO_2 and Fe_3O_4; and compound materials such as SiC, AlN, and graphene.

Many researches are carried out to improve the heat transfer rate of base fluids using nanofluids. The heat transfer performance increases with the enhancement of pressure drop, thermal conductivity and pumping power increase with the augmentation of density and viscosity. Maheswaran et al. reported that the homogeneous dispersion of nanoparticles into the base fluid improves the thermal stability, thermo-physical and anti-wear behaviour [1-3]. Visinee Trisakri [4] showed that the suspended metallic or nonmetallic nanoparticles change the heat transfer characteristics of base fluid. Eastman et al. [5] showed that 10mm copper particles in ethylene glycol could enhance the conductivity by 40% with small particle loading fraction. These results clearly show the effect of particle size on the conductivity enhancement. Das et al. [6] measured the conductivities of alumina and cupric oxide at different temperature ranging from 20^0C to 50^0C and found linear increase in the conductivity ratio with temperature. However the same load fraction the ratio of increase was higher for cupric oxide than alumina. Lee et al. [7] reported a substantial enhancement of thermal conductivity base fluids with nanoparticles dispersions. Eden et al. [8] shows simple empirical correlation to predict thermal conductivity of various nanofluid mixtures considering the effect of various factors like temperature, volume fraction and particle size is presented and good agreement with experimental results.

In this study, the thermo-physical properties of the nanofluids such as density, specific heat and viscosity are calculated by theoretical models. The results show that the thermo-physical properties of nanofluids increases with increase in nanoparticle concentration.

THERMO-PHYSICAL PROPERTIES OF NANOPARTICLES AND BASE FLUIDS

The nanoparticles are the particles between 1 and 100 nm in size with a circumferential interfacial layer which is an integral part of nanomaterials, fundamentally altering the properties of base fluids. It consists of ions, inorganic and organic molecules. The thermal conductivity estimation of nanofluids was the main focus in the early stages of nanofluid research. Recently studies have been carried out on the heat transfer coefficient of nanofluids in natural and forced flow. The thermo-physical properties of nanoparticles are listed in the Table 1 and thermo-physical properties of the base fluids are listed in Table 2.

Table 1. Properties of nanoparticles

S. No	Property	Aluminum	Copper	Silver
1	Thermal conductivity (K_S)W/mK	237	400	429
2	Density (ρ_p)kg/m^3	2710	8933	10500
3	Specific heat (C_P) J/kg K	900	385	234

Table 2. Properties of base fluids

S. No	Property	Water	Liquid Sodium	Ethylene glycol
1	Thermal conductivity (K_L) W/Mk	0.605	76	0.252
2	Density (ρ_f) kg/m^3	997.1	880	1111
3	Specific heat (C_f) J/kgK	4179	1300	2415
4	Dynamic viscosity (μ_0) Kg/m^3	0.001003	0.34	0.0157

Further, nanoparticles explore great scientific interest as they are, in effect, a bridge between bulk materials and atomic structures. A bulk material has constant physical properties regardless of its size, but at the nano-scale materials have size-dependent properties. The properties of materials change according to their size where the percentage of surface to percentage of volume of material becomes significant. The interesting properties of nanoparticles are due to the large surface area of the material, which dominates the contributions made by the small bulk of the material.

THERMO-PHYSICAL PROPERTIES OF NANOFLUIDS

Before design a thermal system in which a nanofluid is used, it is important to know the thermo-physical properties of nanofluid such as thermal conductivity, heat capacity, viscosity and density. The thermo-physical Properties of nanofluids depends upon the various factors like preparation methods, working temperature, particle size and shape, and volume fraction/concentration. Generally, thermo-physical properties of nanofluids increase with an augmentation of volume fraction of nanoparticles and decreased with the temperature rise.

The density/volumetric mass density, of a substance are its mass per unit volume. For a pure substance the density has the same numerical value as its mass concentration and it is relevant to buoyancy, purity and packaging. Generally, density of any material varies with temperature and pressure which is small for solids and liquids but greater for gases. Increasing the pressure on an object decreases the volume of the object and thus increases its density. In most materials, heating the bottom of a fluid results in convection of heat from bottom to the top, due to the decrease in the density of the heated fluid. This causes it to rise relative to more dense unheated material.The density of nanofluid can be numerically calculated by using the mass balance as:

$$\rho_{nf} = (1-\phi_S)\, \rho_f + \phi_S\, \rho_p \qquad \text{........ (1)}$$

Where, ρ_{nf}- Density of nanofluids (kg/m^3), ϕ_S - nanoparticles percentage (%), ρ_f - Density of Base fluids(kg/m^3) and ρ_p - Density of nanoparticles (kg/m^3). The density of water with Aluminum, Copper and Silver nanoparticle dispersion of 1-30% of particle concentration is given in Table 3.

Table 3. Density of nanofluid (Water + Nanoparticles)

Nanoparticle percentage	Aluminum + water	Copper + water	Silver + water
1	1014.22	1076.45	1092.12
5	1082.74	1393.89	1472.24
10	1168.39	1790.69	1945.34
15	1254.03	2187.48	2422.53
20	1339.68	2584.28	2897.68
25	1425.32	2981.07	3372.82
30	1510.97	3377.87	3847.97

Table 3 show that, the density of all water based nanofluid combinations increases with increase in nanoparticle concentrations. The density of water increases from 997.1

kg/m^3 to 1014.22 kg/m^3, 1076.45 kg/m^3 and 1092.12 kg/m^3 when 1% of Aluminum, Copper and Silver nanoparticles are dispersed, respectively. The silver nanofluid shows more density enhancement than the Aluminum and Copper nanofluids. The density of Ethylene glycol with Aluminum, Copper and Silver nanoparticle dispersion of 1-30% of particle concentration is given in Table 4.

Table 4. Density of nanofluid (Ethylene glycol + Nanoparticles)

Nanoparticle percentage	Aluminum + Ethylene glycol	Copper + Ethylene glycol	Silver + Ethylene glycol
1	1126.99	1189.22	1204.89
5	1190.95	1502.14	1580.45
10	1270.95	1893.46	2049.87
15	1350.85	2284.32	2519.43
20	1430.82	2675.42	2988.83
25	1510.75	3066.53	3458.26
30	1590.72	3457.67	3927.73

Table 4 show that, the density of all ethylene glycol based nanofluid combinations increases with increase in nanoparticle concentrations. The density of water increases from 1111 kg/m^3 to 1126.99kg/m^3, 1189.22kg/m^3 and 1204.89kg/m^3 when 1% of Aluminum, Copper and Silver nanoparticles are dispersed, respectively. The silver nanofluid shows more density enhancement than the Aluminum and Copper nanofluids. Further, the density of Ethylene glycol with Aluminum, Copper and Silver nanoparticle dispersion of 1-30% of particle concentration is given in Table 5.

Table 5. Density of nanofluid (Sodium + Nanoparticles)

Nanoparticle percentage	Aluminum + Sodium	Copper + Sodium	Silver + Sodium
1	898.3	960.53	976.2
5	971.5	1282.65	1361
10	1063	1685.3	1842
15	1154.5	2087.95	2323
20	1246.0	2490.6	2804
25	1337.5	2893.25	3285
30	1429	3295.9	3766

Table 5 show that, the density of all sodium based nanofluid combinations increases with increase in nanoparticle concentrations. The density of water increases from 880 kg/m^3 to 898.3kg/m^3, 960.53kg/m^3 and 976.2kg/m^3 when 1% of Aluminum, Copper and Silver nanoparticles are dispersed, respectively. The silver nanofluid shows more density enhancement than the Aluminum and Copper nanofluids.

The specific heat/heat capacity/ thermal capacity is a measurable physical quantity equal to the ratio of heat added to/removed from an object to the resulting temperature change. The specific heat of nanofluids can be calculated by using mass balance equation as:

$$C_{nf} = \frac{(1-\phi_s)\,\rho_f\, C_f + \phi_s\, \rho_p\, C_P}{\rho_{nf}} \quad \text{……….. (2)}$$

Where, C_{nf} - specific heat of nanofluids (J/Kg K), C_f - specific heat of basefluid (J/Kg K) and C_P - specific heat of nanoparticles (J/Kg K). The specific heat of water with Aluminum, Copper and Silver nanoparticle dispersion of 1-30% of particle concentration is given in Table 6.

Table 6. Specific heat of nanofluid (Water + Nanoparticles)

Nanoparticle percentage	Aluminum + water	Copper + water	Silver + water
1	4146.21	4141.06	4139.55
5	4015.05	3989.75	3981.75
10	3851.12	3799.63	3784.37
15	3687.15	3609.83	3587.62
20	3523.21	3420.26	3390.83
25	3359.25	3230.47	3192.75
30	3195.34	3040.81	2995.59

Table 6 show that the specific heat of all water based nanofluid combinations decreases with increase in nanoparticle concentrations. The specific heat of water decreases from 4179 J/kgK to 4146.21 J/kgK, 4141.06 J/kgK and 4139.55 J/kgK when 1% of Aluminum, Copper and Silver nanoparticles are dispersed, respectively. The silver nanofluid shows less specific heat than the Aluminum and Copper nanofluids. The specific heat of Ethylene glycol with Aluminum, Copper and Silver nanoparticle dispersion of 1-30% of particle concentration is given in Table 7.

Table 7. Specific heat of nanofluid (Ethylene glycol + Nanoparticles)

Nanoparticle percentage	Aluminum + Ethylene glycol	Copper + Ethylene glycol	Silver + Ethylene glycol
1	2399.85	2394.68	2393.19
5	2339.25	2313.67	2305.95
10	2263.54	2212.34	2196.54
15	2187.73	2110.85	2087.85
20	2112.76	2008.17	1978.82
25	2036.27	1907.67	1869.75
30	1960.54	1806.73	1760.74

Table 7 show that the specific heat of all Ethylene glycol based nanofluid combinations decreases with increase in nanoparticle concentrations. The specific heat of Ethylene glycol decreases from 2415 J/kgK to 2399.85 J/kgK, 2394.68

J/kgK and 2393.19 J/kgK when 1% of Aluminum, Copper and Silver nanoparticles are dispersed, respectively. The silver nanofluid shows less specific heat than the Aluminum and Copper nanofluids. The specific heat of liquid sodium with Aluminum, Copper and Silver nanoparticle dispersion of 1-30% of particle concentration is given in Table 8.

Table 8. Specific heat of nanofluid (Sodium + Nanoparticles combination)

Nanoparticle percentage	Aluminum + Sodium	Copper + Sodium	Silver + Sodium
1	1287.933	1214.904	1195.795
5	1244.21	981.3747	926.2858
10	1198.024	815.0006	747.747
15	1159.16	712.7952	643.1446
20	1126.003	643.6365	574.4294
25	1097.383	593.7272	525.8371
30	1072.428	556.0125	489.6575

Table 8 show that the specific heat of all liquid sodium based nanofluid combinations decreases with increase in nanoparticle concentrations. The specific heat of Ethylene glycol decreases from 1300 J/kgK to 1287.933 J/kgK, 1214.904 J/kgK and 1195.795 J/kgK when 1% of Aluminum, Copper and Silver nanoparticles are dispersed, respectively. The copper nanofluid shows less specific heat than the aluminum and silver nanofluids.

Further, the viscosity of any fluid is a measure of its resistance to deformation due to shear stress/tensile stress. It is a property of fluid which opposes the relative motion between the two surfaces of the fluid that are moving at different velocities. The dynamic viscosity of any fluid expresses its resistance to shearing flows, where adjacent layers move parallel to each other with different speeds. The dynamic viscosity of nanofluids can be calculated using different existing formulas that have been obtained for two-phase mixtures. It can be calculated as:

$$\mu = \mu_0 (123\ \phi_S{}^2 + 7.3\phi_S + 1) \qquad \text{... ……(3)}$$

Where, μ - dynamic viscosity of nanofluids (kg/ms) and μ_0 - viscosity of nanofluids (kg/ms). According to this equation, the dynamic viscosity is also found to be increase with increase in nanoparticle concentration.

Nanofluids containing small amounts of nanoparticles have substantially thermo-physical properties than those of base fluids. The thermo-physical propertiy enhancement of nanofluids depends on the particle volume fraction, size and shape of nanoparticles, thermal conductivity, type of base fluid, nanoparticles, $_p$H value of nanofluids, preparation technique and type of particle coating.

CONCLUSIONS

The main factors affecting thermo-physical propertiy enhancement of base fluid are volume fraction, size and shape of nanoparticles, thermal conductivity, type of base fluid, nanoparticles, $_p$H value of nanofluids, preparation technique and type of particle coating whereas the key parameter with most significant effect is nanoparticle concentration. Aluminum, copper, and silver nanoparticles are used to enhance the thermo-physical properties of base fluid. The thermo-physical properties of the nanofluids such as density, specific heat and viscosity are calculated by theoretical models. The results show that the thermo-physical properties of nanofluids increases with increase in nanoparticle concentration.

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