Experimental Investigation of Unsteady State Heat Transfer Behaviour of Nanofluid

Yogiraj Bhumkar, A. R. Acharya, and A. T. Pise

Abstract This paper provides the method for preparation of nanofluids and measuring thermal properties of nanofluids by various methods. In this paper, we have focused on effect of variation of temperature, particle size and volume fraction of nanofluid on properties of nanofluid such as density, viscosity, thermal conductivity and heat transfer coefficient. We have made comparison between CuO, ZnO and SiO_2 nanoparticles with particle size 30–50 nm and 50–70 nm and with three volume fractions 0.5, 1 and 1.5%. The heat transfer coefficient (h) of all nanofluids is determined from unsteady state heat transfer apparatus. The results indicate that the thermal conductivity and h of nanofluid enhance with increase in %vol. fraction and decrease in particle size. CuO–DI water nanofluid with 1.5% volume fraction and 30–50 nm particle size has higher heat transfer coefficient, and thermal conductivity is enhanced by 59.59% than de-ionized water. Hence, CuO–DI water nanofluid (1.5% vol. fraction and 30–50 nm particle size) reaches steady state faster than other nanofluids.

Keywords Preparation of nanofluid · Properties of nanofluid: Heat transfer coefficient · Thermal conductivity · Viscosity · Density and specific heat · Unsteady state heat transfer behaviour (Unsteady state heating curves) of nanofluid

1 Introduction

Nanofluids have higher thermal properties than current heat transfer fluids. Hence, nanofluid has future scope in heat transfer fluids. Metal nanoparticles have more thermal conductivity than other nanoparticles but have less dispersion properties and poor stability. Oxide nanoparticles have better dispersion properties and stable suspension. Particle size and volume fraction of particles affect the properties of nanofluid. Researchers have given different correlations for properties of nanofluids. We have to observe important conclusions of some researchers.

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Bashirnezhad et al. [1] concluded that viscosity increases with increase in volume fraction of nanoparticles and decrease in temperature. Author reported the future scope for doing experimental studies by acknowledging temperature, nanoparticle size, volume fraction, sonication time and base fluid.

Liu et al. [2] observed that thermal conductivity of Cu–water nanofluid at 0.1% volume fraction is increased by 23.8%. Researcher performed the experiment on nanofluids without use of surfactant. Due to poor dispersion properties of nanofluid, thermal conductivity depends on time interval.

Gupta et al. [3] provided the correlations for various properties of nanofluid. Researcher reviewed the factors affecting the thermophysical properties of nanofluid. Researcher has mentioned the future scope for cost effective and efficient nanofluid.

Albadr et al. [4] used the Al_2O_3 nanoparticles of 30 nm particle size. The researcher concluded that heat transfer coefficient (h) increases with increase in mass flow rate and volume fraction. But friction factor increases with increase in vol. concentration of nanoparticles, which results in pressure drop.

Li et al. [5] summarized the recent improvement in research of stationary nanofluid. The researcher mentioned that long-term stability of nanofluid is a key issue.

2 Nanofluid

Nanofluid contains nanometre-sized particles made of metal, oxides, carbides, borides, nitrides, etc. There are two ways for the preparation of nanofluids.

2.1 Preparation of Nanofluid

2.1.1 One Step Method

The manufacturing of nanoparticles and dispersion in a base fluid are done simultaneously. Some general one step methods are as follows:

(a) Direct evaporation
(b) Chemical vapour condensation
(c) Chemical precipitation.

2.1.2 Two Step Method

The nanoparticles are first manufactured and then dispersed into the base fluid. Example of two step method is gas condensation. We have preferred the two step method for the preparation of nanofluid. In this method, first of all, we have calculated the

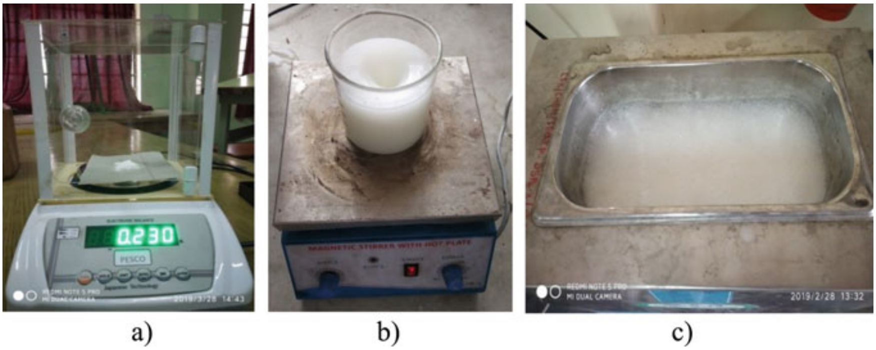

Fig. 1 **a** Weighing machine. **b** Magnetic stirrer. **c** Ultrasonic cleaner

mass of nanoparticles for 0.5, 1 and 1.5% vol. fraction of nanoparticles into the base fluid which is de-ionized water.

$$\text{Mass of Nanoparticles} = \rho_p * \%\text{Vol. Fraction} * \text{Volume of base fluid}$$

where ρ_p = Density of Nanoparticles (gm/cm^3).

Surfactant used: Sodium Dodecyl Sulphate (SDS).

$$\text{Mass of Surfactant} = 10\% \text{ of mass of nanoparticle}$$

We can use different surfactants such as Sodium Dodecyl Sulphate (SDS), Ammonium Cetyl Cetyl (CTAB) and Dodecyl Benzen Sulphonate (SDBS). But SDS is more effective for stability of oxide nanoparticles in base fluid.

2.2 Process of Nanofluid Reparation

This measured quantity of nanoparticles and surfactant are mixed with base fluid in magnetic stirrer for 30 min. After magnetic stirring, the fluid is transferred to ultrasonic bath for 2 h. Ultrasonic waves disperse the nanoparticles into the base fluid and form uniform mixture. Use of ultrasonic bath more than 2 h does not show more effect of dispersion of nanoparticles (Fig. 1).

2.3 Stability of Nanofluid

The long-term stability of nanofluid is the key issue. Metal oxide nanofluids are more stable than metallic nanofluids. Nanofluid becomes stable after the proper dispersion

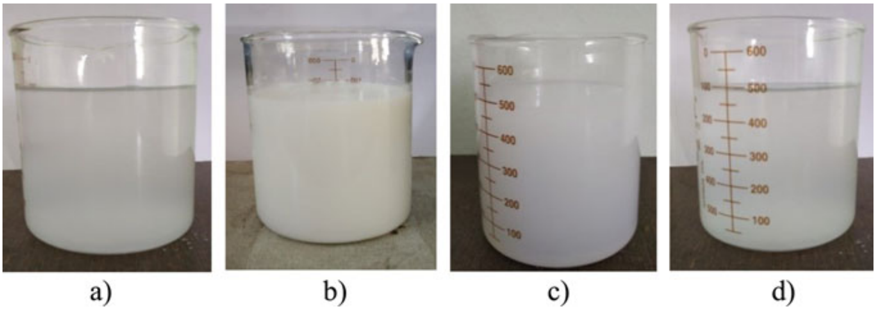

Fig. 2 SiO_2–DI water nanofluid **a** without SDS **b** with SDS after 2 h **c** with SDS after 48 h **d** with SDS after 72 h

of nanoparticles due to existence of Brownian motion. Due to Brownian motion, nanoparticles are in motion and get dispersed properly in base fluid stability can be analysed by the following methods (Fig. 2):

(a) Visual Inspection
(b) Zeta Potential (pH Value).

3 Properties of Nanofluids

After the preparation of nanofluid, it is necessary to find out the following properties of nanofluid. Some important properties are as follows:

1. Density
2. Viscosity
3. Thermal Conductivity
4. Specific Heat.

3.1 Density

Density of nanofluid can be determined from following two methods:

Method 1 Pak and Cho correlation

$$\rho_{nf} = [(1 - \Phi)\rho_{nf}] + (\Phi\rho_{bf}) \tag{1}$$

where ρ_{nf} = Density of nanofluid in gm/cm^3

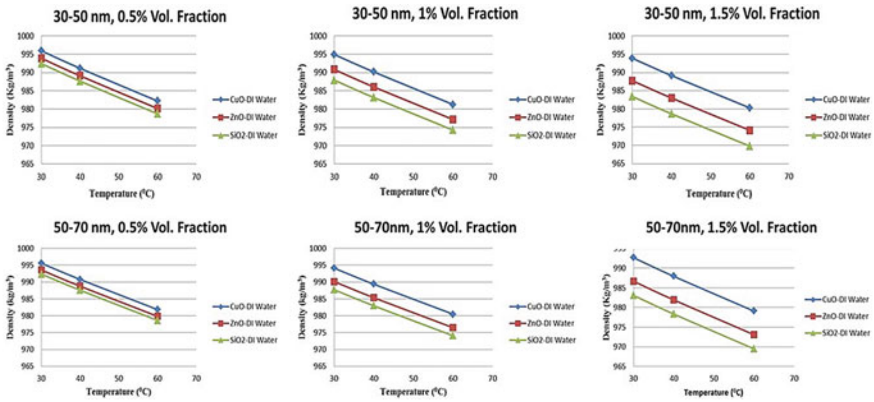

Fig. 3 Variation of density with respect to temperature of different nanofluids

ρ_{bf} = Density of base fluid
Φ = Volume fraction.

Method 2 Experimental Method

$$\rho_{\text{nf}} = \left(\frac{W_2 - W_1}{50}\right) \times 10^3 \tag{2}$$

where W_2 = Weight of jar with 50 cc of nanofluid
W_1 = Weight of empty jar
ρ_{nf} = Density of nanofluid in kg/m^3 (Fig. 3).

3.2 *Viscosity*

Method 1 Einstein correlation

$$\mu_{\text{nf}} = [1 + 2.5\Phi]\mu_{\text{bf}} \tag{3}$$

where μ_{nf} = Density of nanofluid in kg/ms
μ_{bf} = Density of base fluid in kg/ms
Φ = Volume fraction.

Method 2 Redwood Viscometer

$$\gamma = \left(A \times t - \frac{B}{t}\right) \times 10^{-6} \tag{4}$$

where γ = Kinematic viscosity of nanofluid m^2/s
t = Time for collecting 50 cc of nanofluid in sec
A and B = Redwood constants
$A = 0.264$ and $B = 190$.

$$\mu = \rho \times \gamma \tag{5}$$

where μ = Density of nanofluid in kg/ms (Fig. 4).

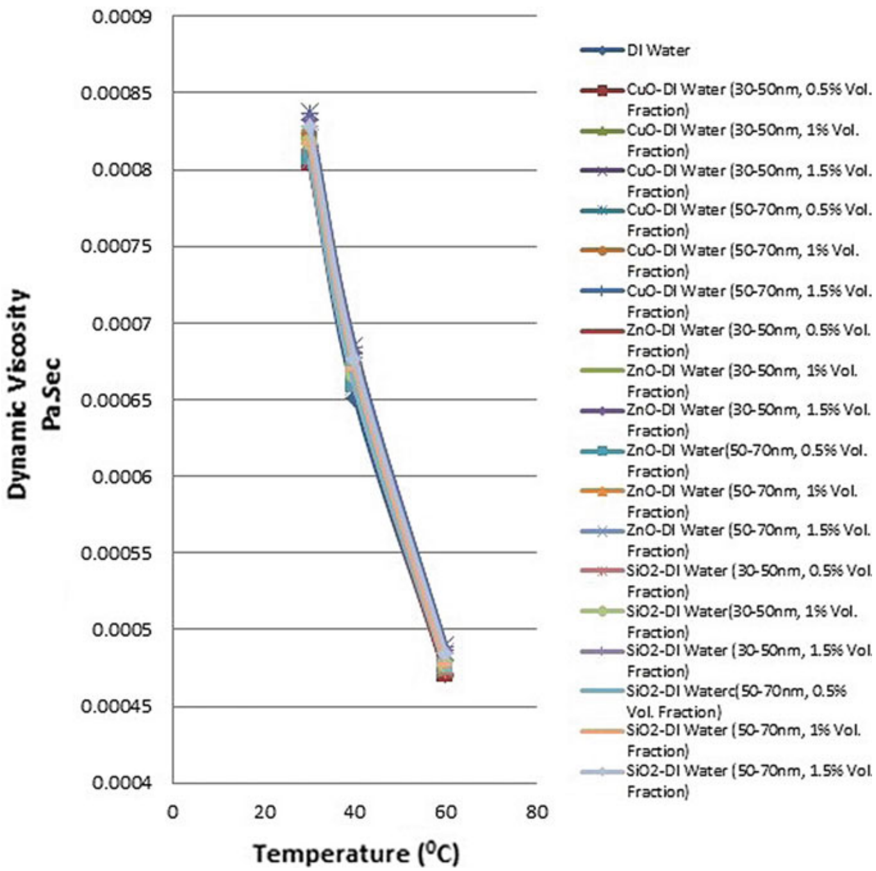

Fig. 4 Variation of dynamic viscosity with respect to temperature of different nanofluids

3.3 Thermal Conductivity

Method 1 Wasp Correlation

$$K_{\text{nf}} = K_{\text{bf}} \times \frac{2K_{\text{bf}} + K_{\text{np}} - 2\Phi(K_{\text{bf}} - K_{\text{np}})}{2K_{\text{bf}} + K_{\text{np}} + \Phi(K_{\text{bf}} - K_{\text{np}})} \tag{6}$$

where K_{nf} = Thermal conductivity of nanofluid in W/mK
K_{bf} = Thermal conductivity of base fluid in W/mK
Φ = Volume fraction.

Method 2 Ultrasonic Interferometer

$$K_{\text{nf}} = 3 \times \left(\frac{N}{V}\right)^{2/3} \times K_{\text{B}} \times v_{\text{s}} \tag{7}$$

where N = Avogadro's Number = $6.02 * 10^{23}$
K_{B} = Boltzmann's Constant = $1.3807 \times 10^{-23} \times 10^{-23}$ J/K
v_{s} = Ultrasound Velocity in m/s
V = Molar Volume = $\frac{m}{\rho}$ (Fig. 5).

3.4 Specific Heat

Pak and Choi have given the following correlation for specific heat:

$$C_{\text{P}_{\text{nf}}} = \Phi(C_{\text{P}})_{\text{np}} + (1 - \Phi)(C_{\text{P}})_{\text{bf}} \tag{8}$$

where $C_{\text{P}_{\text{nf}}}$ = Specific Heat of Nanofluid.

4 Experimental Apparatus

See (Fig. 6).
Specification:

1. Electric Heater: 500 W (1.5 Lit)
2. Digital Temperature Indicator: 0 °C–199.9 °C
3. Thermocouples: Cr–Al type (K-Type)
4. Specimens Material: Copper (Dia—30 mm, Length—30 mm) (K = 386 W/m K).

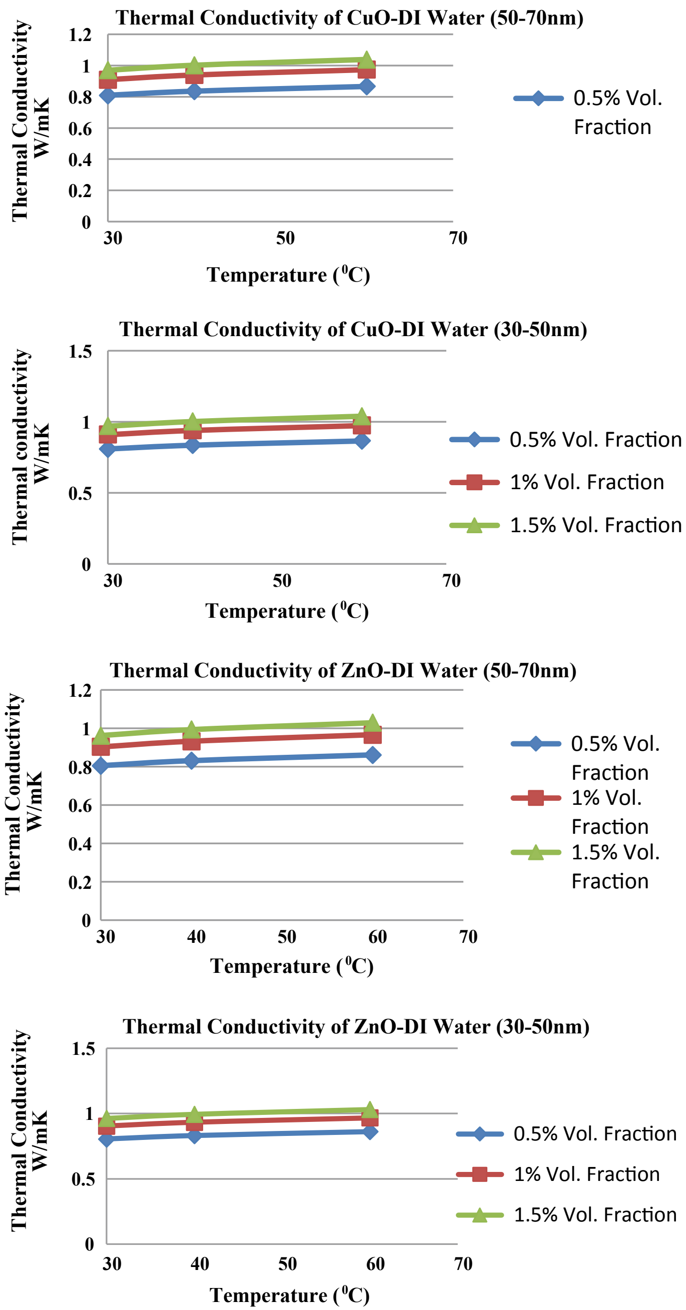

Fig. 5 Variation of thermal conductivity with respect to temperature for various volume fraction of nanofluid

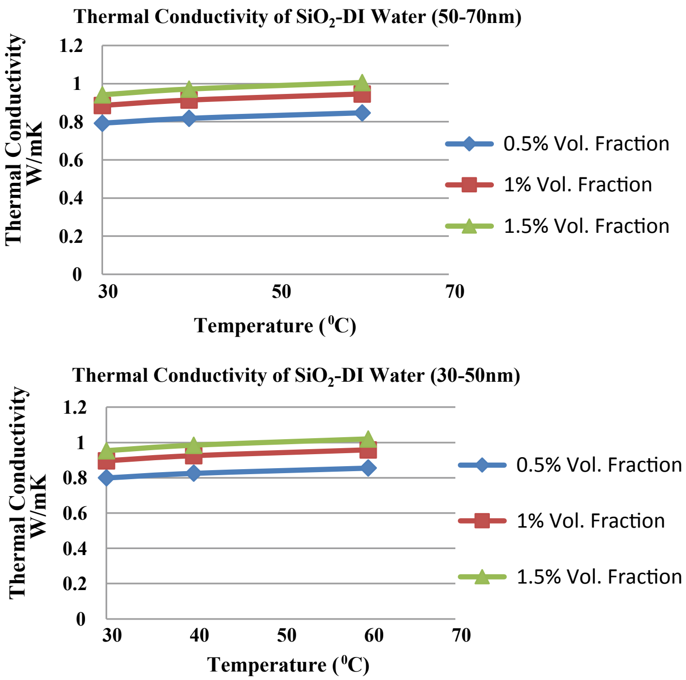

Fig. 5 (continued)

Fig. 6 Unsteady state heat transfer apparatus

After performing the experiments for different nanofluids, we can get the heat transfer coefficient, and also, we can compare these nanofluids by drawing unsteady state heating curves. Following formulas are required to calculate the heat transfer coefficient:

1. Grashof Number

$$\mathrm{Gr} \ = \frac{g\ \beta\ \Delta T\ l^3}{v^2} \tag{8}$$

2. Prandtl Number

$$\mathrm{Pr} = \frac{\mu C_\mathrm{p}}{K} \tag{9}$$

3. Rayleigh Number

$$\mathrm{Ra} = \mathrm{Gr} \times \mathrm{Pr} \tag{10}$$

4. Nusselt Number

$$\mathrm{Nu} = 0.36 + \frac{0.518\mathrm{Ra}^{1/4}}{\left\{1 + \left(\frac{0.559}{\mathrm{Pr}}\right)^{9/16}\right\}^{4/9}} \quad 10^{-6} < \mathrm{Ra} < 10^{9} \tag{11}$$

$$\mathrm{Nu} = 0.6 + \frac{\left(0.387\ \mathrm{Ra}^{1/6}\right)^{4/9}}{\left\{1 + \left(\frac{0.559}{\mathrm{Pr}}\right)^{9/16}\right\}^{8/24}} \quad 10^{9} < \mathrm{Ra} < 10^{12} \tag{12}$$

5. Heat Transfer Coefficient

$$h = \frac{\mathrm{Nu}\ K}{d} \tag{13}$$

See (Figs. 7 and 8).

5 Results and Discussion

1. Heat transfer coefficient of the nanofluid increases with increase in temperature, increase in volume fraction and decrease in particle size.
2. Thermal conductivity increases with increase in volume fraction, increase in temperature and decrease in particle size.
3. Thermal conductivity of CuO–DI water nanofluid (with particle size 30–50 nm, 1.5% Vol. fraction) is 59.59% more than the de-ionized water.

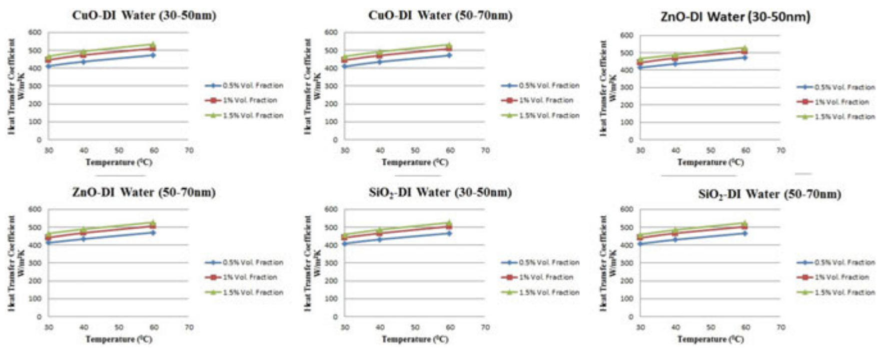

Fig. 7 Variation heat transfer coefficient of with respect to temperature and volume fraction for different nanofluids

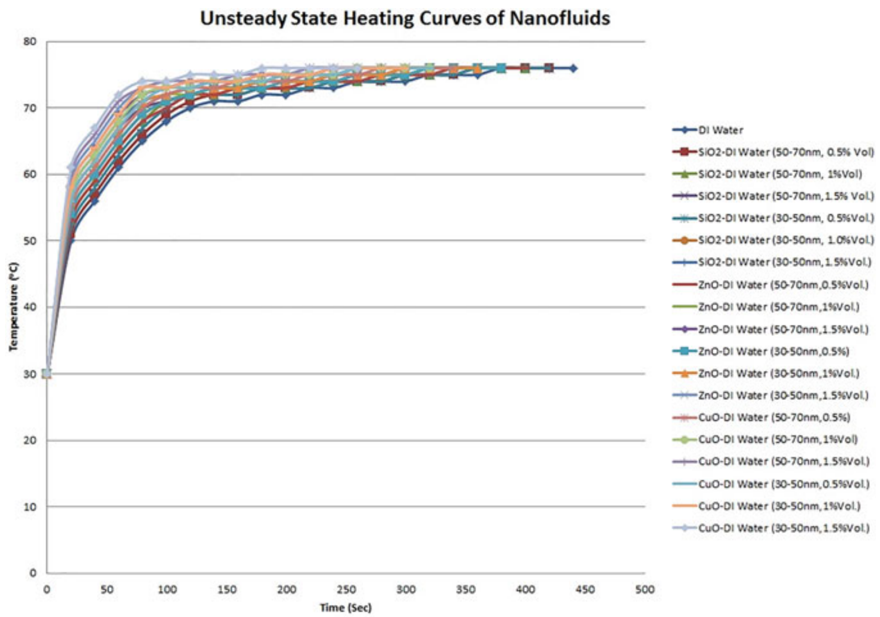

Fig. 8 Variation of temperature with respect to time for different nanofluids during unsteady state heating

4. Viscosity of nanofluid increases with increase in volume fraction and decrease in temperature.
5. Density of nanofluid increases with decrease in particle size, decrease in volume fraction and decrease in temperature.
6. Specific heat increases with increase in temperature, increase in particle size and decrease in volume fraction.

6 Conclusion and Future Scope

In this paper, we studied the thermophysical properties of nanofluids. We can conclude that CuO–DI water nanofluid with 30–50 nm particle size and 1.5% volume fraction has higher heat transfer coefficient. Due to this, CuO–DI water nanofluid reaches the steady state faster than other fluids.

At higher volume fraction, nanofluid has better thermal properties, but stability of nanofluid is a key issue. Further work is required related to the stability of nanofluid. New types of nanofluids having higher thermal properties should be found.

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