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Thermophysical Properties of Nanomodified Liquids

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Abstract

This paper attempts to determine thermophysical properties such as density, heat capacity and thermal conductivity for four types of nanoparticle suspension in water by using theoretical models. Three concentrations of 0.01, 0.05 and 0.1 wt. % nanoparticles were used at temperatures 35, 40 and 45 °C. It also attempts to present the properties of (CNT Taunit M) and the method of its preparation. It was observed that thermal conductivity and density increased, and contrariwise, specific heat decreased with an increase in volume concentration at various temperatures.

Keywords

Carbon nanotubes; Taunit M; Nanofluid; thermal conductivity; nanomaterials; thermophysical.

Nomenclature

CNTs	Carbon nanotubes;
MWCNT	Multi Wall Carbon Nanotube;
DWCNT	Double Wall Carbon Nanotube;
SWCNT	Single Wall Carbon Nanotube;
nf	Nanofluid;
P	Weight, kg;
np	Nano particle;
bf	Base fluid;
φ	Volume concentration, m^3/m^3;
c	Mass concentration, kg/m^3;
μ	Dynamic viscosity, $N \cdot c/m^2$;
Cp	Specific heat, J/(kg·K);
ρ	Density, kg/m^3;
λ	Thermal conductivity, W/(m·K);
V	Voltage, V;
I	Current, A.

Introduction

Improvement of the thermal performance of the heat transferring fluids plays a pivotal role because of the achieved benefits like reducing surface area of heat exchange, minimizing cost, reducing drawn power and maintaining on the application life. Generally, the heat transfer coefficient of these fluids, such as water, oil, ethylene glycol (**EG**) or ethylene glycol-water is low because of their lower thermal conductivity comparison with the solid materials that have high thermal conductivity by tens or hundred times [1]. Blending a little amount of small solid particles with a host fluid can push the fluid possibilities to its limitation in the heat transferring performance.

This idea was introduced by Maxwell at (1873) when he used micrometer and millimeter particles size with a host fluid, but from among the obstacles that appeared were the fast settling, channel clogging, parts erosion and high pressure drop [2]. At 1995, the "Nanofluid" term appeared officially by Choi and Eastman [3] when they experimentally investigated the suspension of copper oxide-water ($CuO–H_2O$) and aluminum oxide-ethylene glycol/water nanofluid (*nf*) (Al_2O_3–EG/H_2O), the results showed a thermal augmentation by 20 % in the heat transfer. Also, they demonstrated the term "effective thermal conductivity ($k/k°$), which means the ratio between nanofluid to base fluid thermal conductivity. So, the nanofluid is a new brand of fluids and could be defined as a suspension consisting of a host fluid and nanoparticles sized less than (100×10^{-9}) meter [4]. As shown in Fig. 1. This study will focus on the thermal properties of four types of nanofluids (Al_2O_3, CuO, CNTs (Carbon Nanotubes) tauint mand TiO_2) in water are measured numerical by using theoretical models. Results were compared with numerical data available in the literature.

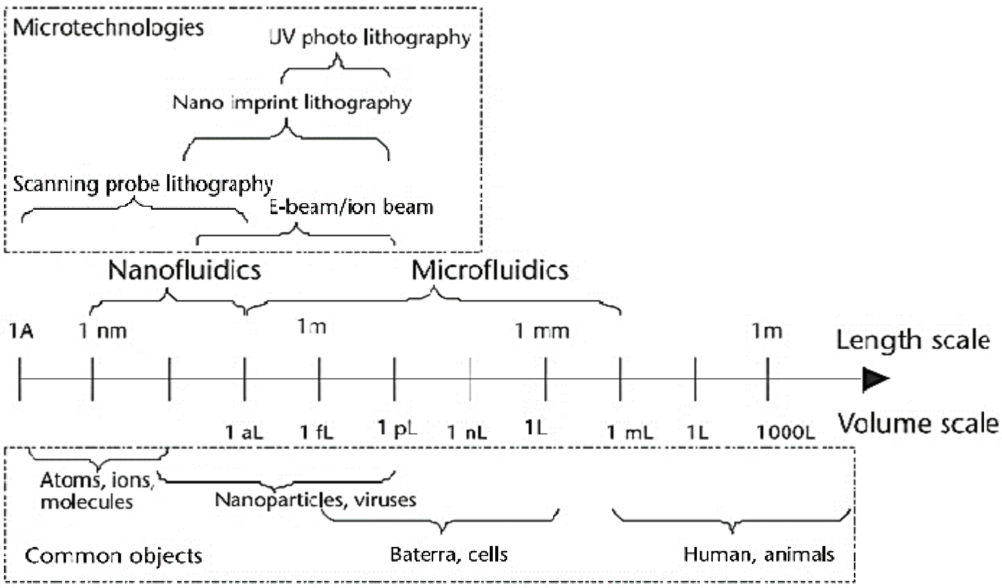

Fig. 1. Length scales and volume scales of nanofluidics, microfluidics, common micro technologies, and common objects [5]

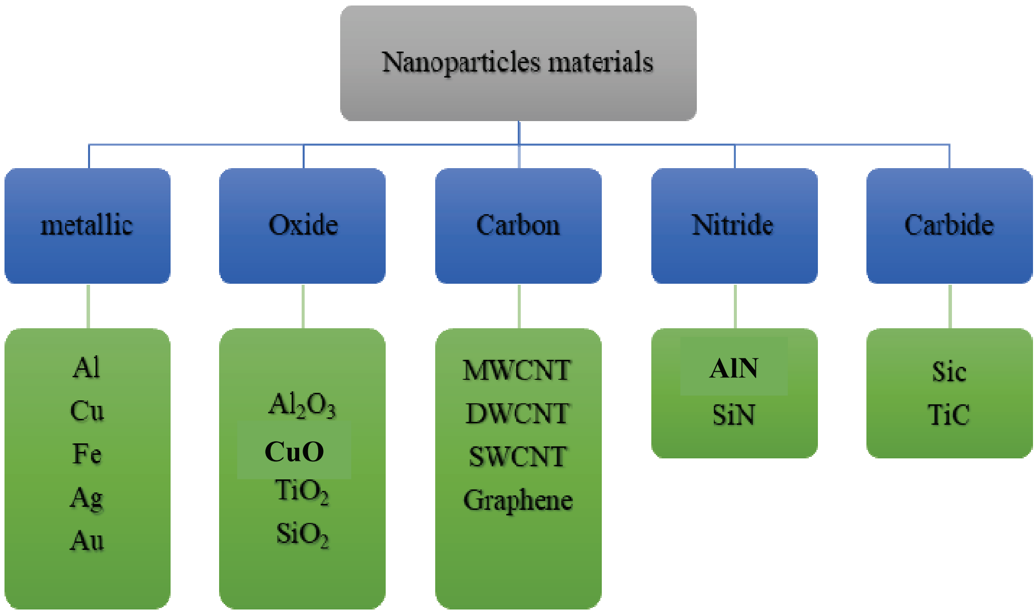

Fig. 2. Nanoparticles materials types [8, 9]

Nanomaterials

The types of nanomaterials that form the nanofluids are metal, metal oxide, carbon, carbides and nitride and the selection of any type from them is not a random process but it is based on some governing characteristics that should be met; thermal conductivity, viscosity and density in addition to obtainable, poisonous, chemical behavior and cost [6]. The widely used material in the nanofluid field is the metal oxides in spite of higher thermal conductivity of metal due to the metal oxides characterized by their lower density which reduce the settling, also they have resistance against the oxidation [7]. Moreover, most studies are utilizing aluminum oxide intensively between all the metal oxides because it has low density and high thermal conductivity [6] as shown in Fig. 2.

Base fluid

To create nanofluid, nanoparticles must be mixed in certain method withbase fluid, such as water, Fat, Ethylene glycol (**EG**), Engine Oil (**EO**) and others at different volume or weight concentrations.

The advantages of using nanofluids are as follows:

– minimal pressure drop because of nanoparticles dimensions;

– thermal conductivity has higher value than the base fluid and that will increase the heat transfer rate;

– small and most efficient heat exchangers can be used;

– a remarkable change in the properties of the base fluid, by suspending the nanoparticles in base fluid;

– increased heat transfer rate due to the large surface area of the nanoparticles in the base fluid;

– appropriate for cooling processing systems and fast heating;

– fluid is considered as integral fluid because of nanoparticles size.

The disadvantages of using nanofluids are as follows:

– high nanoparticles cost;

– toxicity of some types of nanoparticles and the risk of exposure to the body due to the nanosized particles;

– deposition and aggregation of nanotubes through nanofluid.

Transport Properties and Thermophysical Properties

The thermal conductivity of nanofluids has been thoroughly studied and other properties since the beginning of nanofluid. The researchers reported perfect improvement in this area. Also, other properties that could be as essential as the thermal conductivity, such as viscosity, heat transfer coefficient, specific heat, and heat transfer coefficient. All of them were directly influenced by the addition of nanoparticles. But this improvement also depends on several parameters as (volume fraction (vol. %), thermal conductivity of nanoparticles and base fluid, size of nanoparticles, shape of the nanoparticles, acidity, temperature, aspect ratio, additives, and effect of clustering). It worth noting that the improvement may occur to one property and other properties could have a negative impact. For instance, the thermal conductivity could get high improvement, but the viscosity increases to inadmissible level and leads to a high-pressure drop and high pumping power consumption. Therefore, the overall improvement in all relevant properties must be balanced and taken into consideration.

One of the problems in nanofluid technology is the agglomeration of nanoparticles after different time periods. Three methods have been used to avoid sedimentation of nanoparticles and to obtain a stable suspension [10 – 13]:

1) a chemical method by adding surfactants;

2) a physical method using ultrasonic waves at different;

3) an electrical method by controlling the pH.

Applications of nanofluids

Nanofluids have distinct thermophysical properties, to be effective in many various areas and industries; there are many examples available in the literature [14 – 22] as shown in Table 1.

Safety Precautions

Nanoparticles and nanofluids are small in size, making them dangerous to use and touch the human body, it is therefore important to protect the body from these small particles using gloves as well as breathing respirators because of the seriousness of these particles and eye protective glasses from the impact of nanocrystal, as shown in Fig. 3 [23].

Mechanisms of Heat Conduction in Nanofluids

The reality is that the traditional theory cannot predict the substantially higher value thermal conductivity of nanofluids. In many experiments, it has inspired efforts to identify possible mechanisms based on a variety of empirical observations and some numerical simulation. The proposed mechanisms are usually divided into two groups: dynamic mechanisms and static.

Table 1

Applications of nanofluids

No.	Category	Application
1	Electronics	Heat pipe, micro channel
2	Engines	Automobile radiator, fuel
3	Tribological	Engine oil, lubricants, transformers, grinding
4	Aero and defense	Weapons, radars and electronics of military
5	Power plants	Boilers, condensers
6	HVAC	Chillers, air conditioning unit
7	Refrigeration	Domestic refrigerator
8	Alternative energy	Solar energy
9	Biomedical	Tumors treatment and drug or radiation delivery
10	Others	Industry of textile, printing of paper and food

Fig. 3. Safety kit

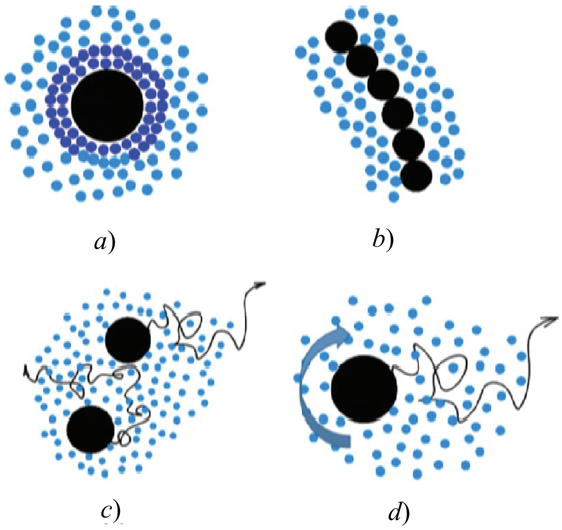

Fig. 4. Four potential mechanisms responsible for the reported conductivity enhancement:
a – liquid-layering; *b* – particle aggregation; *c* – particle Brownian motion; *d* – Brownian-motion-induced convection

Two popular static or structural mechanisms are the liquid-layering at the liquid-particle interface as heat transfer bridge as shown in Fig. 4*a*. Also, the particle aggregation forms a chainlike thermal transport path is shown in Fig. 4*b*. Figure 4*c* shows the dynamic mechanisms include the particle Brownian motion. Convection in the foundation liquid caused by the particle Brownian motion is shown in Fig. 4*d* [24 – 32].

Preparation of (Taunit M) nanofluid

The specifications of the used functionalized carbon nanotubes (FCNT Taunit M) nano powder are listed in Table 2 nanostructured materials manufactured at (NanoTechCenter Ltd.) in Tambov, Russia.

The used nanofluid in this project was prepared by two step method. As the nanofluid is not an ordinary mixture, the following steps are considered through the preparation stages:

1. Calculation of volume fraction of the nanopowder functionalized carbon nanotubes (FCNT Taunit M) and the base fluid (H_2O) for each concentration from the equation [34]:

$$\varphi = \frac{\dfrac{P_{\text{nano particle}}}{\rho_{\text{nano particle}}}}{\dfrac{P_{\text{nano particle}}}{\rho_{\text{nano particle}}} + \dfrac{P_{\text{water}}}{\rho_{\text{water}}}}; \quad (1)$$

$$c = \frac{P_{\text{nano particle}}}{P_{\text{nano particle}} + P_{\text{water}}} \times 100. \quad (2)$$

2. An electronic compact scale BEURER (KS 36) manufactured by BDLT company – Germany was used for weighing the required water with range (0.00 – 2500.00 g), while another electronic scale made by Citizen scale model CNETEK (CT-2460) with range (0.00 – 300.00 g) was used for weighing the required nano powder, as shown in Fig. 5.

3. Adding the nanopowder to the base fluid (distilled water) in the preparation cans, as shown in Fig. 6.

Table 2

Properties of Taunit M functionalized CNTs [33]

Parameter	Value
Outer diameter, nm	8 – 15
Inner diameter, nm	4 – 8
Length, μm	2 and more
Total amount of impurities, %, (after purification)	up to 5 up to 1
Bulk density, g/cm	0.03–0.05
Specific geometrical surface, m^2/g	180–200
Adsorption activity by methylene blue, mg/g	207.5
Thermal stability, °C	up to 600
Color	Black

Fig. 5. Water scale and nanopowder scale

Fig. 6. Preparation cans

Fig. 7. Hand mixer

4. The mixture was blended model GOSONIC (GHM-819) 300W for 30 minutes by the stirrer, as shown in Fig. 7.

Thermophysical properties calculations sample

This section includes a sample for theoretical and experimental thermophysical properties calculations of functionalized carbon nanotubes (FCNT Taunit M) nanofluid with 12 nm particle size and (0.1, 0.05, 0.01) as volume concentration.

Density calculation

Theoretically: The nanofluid density is calculated theoretically straight forward from the mixture equation [35]:

$$\rho_{nf} = \varphi\rho_{np} + (1-\varphi)\rho_{bf} . \tag{3}$$

Experimentally:

$$\rho_{nf} = \frac{w_2 - w_1}{v} . \tag{4}$$

Viscosity calculation

Theoretically: The theoretical viscosity is calculated according to Batchelor model [35]:

$$\mu_{nf} = \left(1 + 2.5\varphi + 6.2\varphi^2\right)\mu_{bf} . \tag{5}$$

Experimentally:

$$\vartheta_{nf} = c \times t \times 10^{-6} ; \tag{6}$$

$$\mu_{nf} = \vartheta \times \rho_{nf} . \tag{7}$$

Specific heat calculation

Theoretically: The specific heat of the nanofluid was calculated theoretically directly based on the familiar relation of mixture principles [33]:

$$Cp_{nf} = \frac{(1-\varphi)(\rho Cp)_{bf} + (\varphi\rho Cp)_p}{(1-\varphi)(\rho)_{bf} + (\varphi\rho)_p} . \tag{8}$$

Experimentally:

$$IVt = m_{nf} Cp_{nf} \Delta T + m_v Cp_v \Delta T . \tag{9}$$

Thermal conductivity calculation

Theoretically: Maxwell correlation was used to calculate the theoretical thermal conductivity [35]:

$$k_{nf} = k_{bf}\left[\frac{\left(k_p + 2k_{bf}\right) + 2c\left(k_p - k_{bf}\right)}{\left(k_p + 2k_{bf}\right) - c\left(k_p - k_{bf}\right)}\right] . \tag{10}$$

Experimentally: The experiment data were measured by the device of thermal conductivity measurement KD2-por [36, 37], as shown in Fig. 8.

$$k = \frac{q(\ln t_2 - \ln t_1)}{4\pi(\Delta T_2 - \Delta T_1)} . \tag{11}$$

Results and Discussion

The thermophysical properties of nanofluids with different types of nanoparticles as a function of concentration were calculated. According to the theoretical models, Maxwell correlation was used to calculate the theoretical thermal conductivity and other models was used to calculate the theoretical specific heat and density. The Batchelor correlation was used to calculate the theoretical viscosity. In this paper, because of the low concentrations used that can be neglected it was as follows: 0.1, 0.05, and 0.001. Thermophysical properties of oxide nanoparticles with (Taunit M) were shown in Table 3. In addition, thermophysical properties of water at 35, 40 and 45 °C were given in Table 4. With different nanoparticles, as water-based nanofluids such as Al2O3–water, CuO–water, (CNT taunit M) – water and TiO_2–water, at temperature 35, 40 and 45 °C an increase in thermal conductivity and decrease in the heat capacity of nanofluid was observed (Fig. 9 – 11).

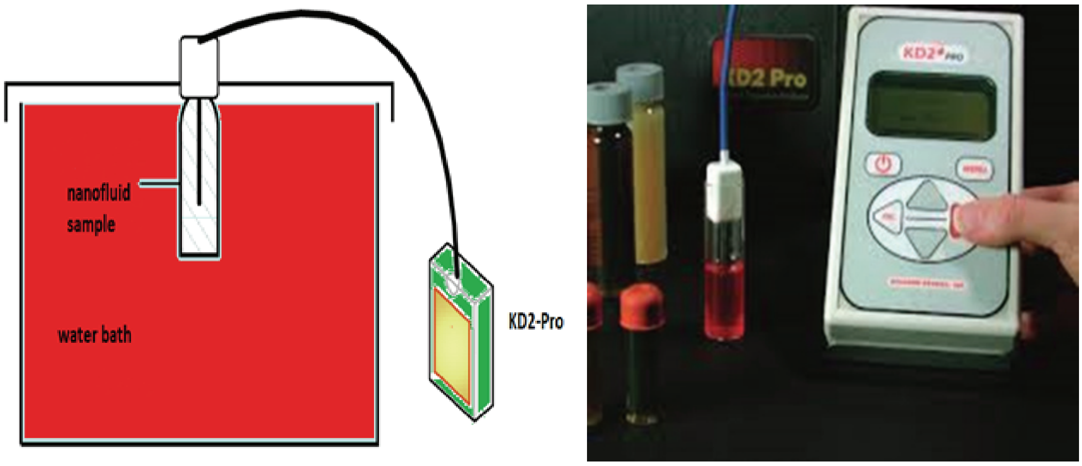

Fig. 8. KD2-por [36]

Table 3

Thermophysical properties of oxide nanoparticles with Taunit M [38 – 40]

Thermophysical properties	Specific heat *Cp*	Density ρ	Thermal Conductivity λ
Copper oxide (CuO)	535.5	6500	76
Alumina oxide (Al_2O_3)	765	3970	40
Titanium dioxide (TiO_2)	686.2	4250	8.5
Functionalized CNTs (Taunit M)	600	1500	3000

Table 4

Thermophysical properties of water at 35, 40 and 45°C [41, 42]

Thermophysical properties of water at 35 and 40 and 45 °C	*Cp*	ρ	λ	μ
35	4178	994.0	0.623	$0.720 \cdot 10^{-3}$
40	4179	992.1	0.631	$0.653 \cdot 10^{-3}$
45	4180	990.1	0.637	$0.596 \cdot 10^{-3}$

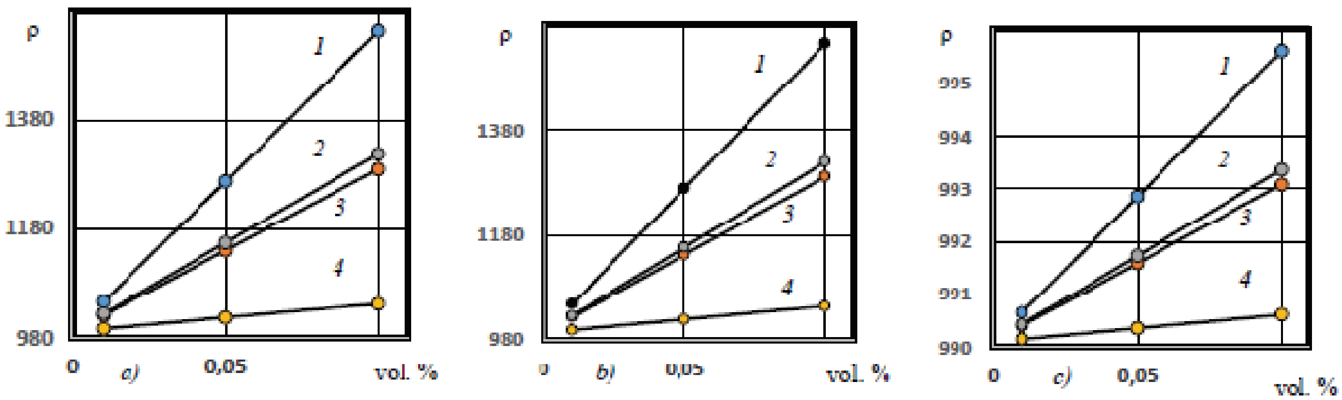

Fig. 9. Density for *nf* vs. vol. % at 35 (*a*), 40 (*b*) and 45 (*c*), °C:
1 – CuO; *2* – TiO_2; *3* – Al_2O_3; *4* – CNT (Taunit M)

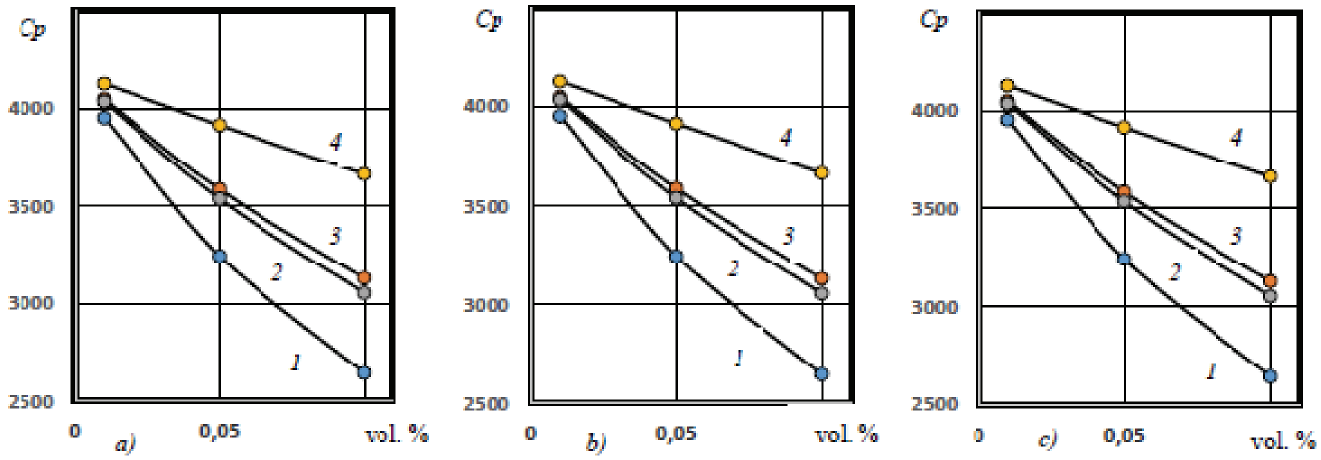

Fig. 10. Specific heat for *nf* vs. vol. % at 35 (*a*), 40 (*b*) and 45 (*c*), °C:
1 – CuO; *2* – TiO_2; *3* – Al_2O_3; *4* – CNT (Taunit M)

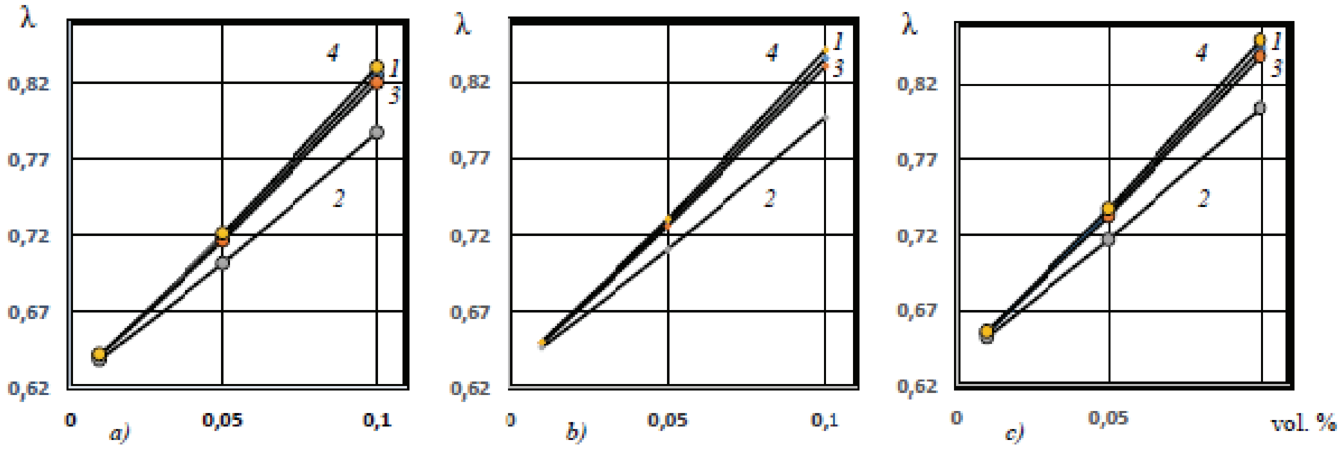

Fig. 11. Termal conductivity for *nf* vs. vol. % at 35 (*a*), 40 (*b*) and 45 (*c*), °C:
1 – CuO; *2* – TiO_2; *3* – Al_2O_3; *4* – CNT (Taunit M)

Conclusion

In this paper, we investigated the thermophysical properties of nanofluids with different types of nanoparticles that were suspended in a base fluid (water) measured numerically. Also, the effect of various concentrations at different temperatures was measured. In this paper, the following points could be concluded:

1. Thermal conductivity and density always increased with the increasing volume concentration at various temperatures.

2. Specific heat significantly decreased with the increasing volume concentration at various temperatures.

3. Results showed that CNT (Taunit) of nanofluid has the highest value of thermal coundivity followed by CuO and Al_2O_3; finally, TiO_2 had the lowest.

4. Results showed that CuO of nanofluid has the highest value of denisty followed by TiO_2 and Al_2O_3; finally, CNT (Taunit) had the lowest.

In this paper, the numerical results showed a good agreement with those obtained in other studies.

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