

Thermophysical properties of CNT and CNT/Al₂O₃ hybrid nanofluid

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This work presents the thermophysical properties of carbon nanotubes (CNT) and CNT/Al₂O₃ hybrid nanofluids for heat transfer applications. An equal proportion of nanoparticles CNT (50%) and Al₂O₃ (50%) were added to the base fluid for two different concentration of 0.05 and 0.1%. Results show that addition of Al₂O₃ nanoparticles with CNT nanofluid improves the thermophysical properties. The thermal conductivity of hybrid nanofluids improved by 20% with a maximum concentration of 0.1%, while the thermal conductivity of CNT alone improved by only 8% with the base fluid. Similarly, density and viscosity of hybrid nanofluid increased up to 7 and 10%, respectively, while comparing it with the base fluid. The result of specific heat energy capacity of hybrid nanofluids increases to about 138% than CNT nanofluid with a maximum concentration of 0.2%.

Nomenclature

k thermal conductivity (W/mK)
 C_p specific heat capacity (J/kgK)

Greek symbols

ϕ concentration (%)
 μ viscosity (mPa)
 ρ density (kg/m³)

Subscript

nf nanofluid

1. Introduction: Enhancement in heat transfer for thermal application is commonly done with different fluids, and the best method for improving the performance is with the addition of nanoparticles in the base fluids. With increased energy cost and applications, there is a great need in nanoparticle in the fluid for enhanced heat transfer [1–6].

Xie *et al.* [7] enhanced the thermal conductivity of multi-walled carbon nanotube (MWCNT) nanofluid by dispersing the treated MWCNT with nitric acid. The factory made MWCNT was not stable as the interaction of forces on the hydrophilic surfaces was minimum. To increase the stability of nanoparticle and homogeneous fluid, oxygen functionalised group was used on the surface for increasing the hydrophilic surface area by chemical treatment. Assael *et al.* [8] enhanced the thermal conductivity of the C-MWCNT with Sodium dodecyl sulphate (SDS) surfactant by varying the proportion of surfactant with base fluid in the range of 0.1–3% with a constant volume of C-MWCNT (0.6%). Results concluded that the thermal conductivity of nanofluid decreases with increase in volume fraction of surfactant to the nanofluid. Also, the thermal conductivity increases with an increased aspect ratio (L/d). Hwang *et al.* [9] studied the characteristics of MWCNT with two base fluids (water, ethylene). Results concluded that the water with MWCNT exhibits increased thermal conductivity (11.12% increase) followed by EG/CuO (10.1%), CuO/water (5.7%) and SiO₂/water (3.9%) with a maximum concentration of 1%. Amrollahi *et al.* [10] studied the effect of temperature,

volume concentration and sonication time of carbon nanotube (CNT) dispersed in ethylene glycol. Results showed that the settling time and thermal conductivity improved with increased sonication time. With 5 h sonication the particles are in the form of the closed cluster and with 25 h sonication time loose particles were observed as the frequency of vibration over the particle breaks the bond between the interface of a carbon atom. With the increase in volume concentration of nanoparticle in the fluid exhibits a linear increase in the ratio of thermal conductivity. Liu *et al.* [11] enhanced the thermal conductivity of water, ethylene glycol and oil with Cu, CuO and MWCNT. Results showed that the influence of MWCNT nanoparticles increases the heat transfer rate than compared to water. The results of thermal conductivity showed that there is an increase of about 15% as compared to MWCNT/oil nanofluid.

Jha and Ramaprabhu [12] studied the effect of MWCNT in aqueous solution and ethylene glycol in improving the thermal conductivity of the fluid. Results showed that the addition of metal oxide nanoparticles on the outer surface of the tube improves the thermal conductivity of the base fluid. The increase in the concentration of Ag-MWCNT/DI water improves the thermal conductivity by 70% than Ag-MWCNT/EG. Similarly, the addition of silver with MWCNT has improved the thermal conductivity by 15 and 20% than Au and Pd, respectively. Glory *et al.* [13] studied the effect of long length MWCNT dispersed in an aqueous solution in the volume concentration of 0.01–3%. Results showed that the thermal conductivity of nanofluid improves with an average length of the tube in the range of 0.5–5 μ m and the optimum concentration of nanoparticles in the fluid as 0.1% by volume. Nanda *et al.* [14] investigated the effect of SWCNT in poly- α olefins and ethylene glycol for enhancing the thermal conductivity. Results of viscosity over shear rate showed the similar trend with the fluids prepared. Similarly, the thermal conductivity results showed the increase of 15% with ethylene glycol as compared to poly- α olefins on a higher concentration of SWCNT. Morphological results reported that with increased particle loading leads to the formation of a clustered particle with interface molecular interaction force. Chougule and Sahu [15] studied the behaviour of CNT and Al₂O₃ nanofluid in a circular tube with different inserts and varied concentration. Esfe *et al.* [17] studied the

Table 1 Thermal properties of nanoparticles

S. No.	Property	CNT	Al ₂ O ₃ [20]
1	colour	black	white
2	purity	>97%	99.7%
3	particle size	20–30 nm	25–40 nm
4	true density, kg/m ³	2100	3890
5	thermal conductivity, W/mK	3007.4	40
6	specific heat capacity, J/kgK	9124	880
7	morphology	cylindrical	spherical
8	Specific Surface area (SSA), m ² /g	200	138

thermal conductivity of hybrid CNT/Al₂O₃ nanofluids with concentration varied from 0 to 1%. Results showed that the increase in concentration of CNT/Al₂O₃ in the fluid increase the thermal conductivity. Similarly, the increase in temperature relatively increases the relative thermal conductivity. Esfe *et al.* [18] also studied the rheological behaviour of engine oil containing MWCNT/ZnO nanoparticle. With the increase in concentration of nanoparticle in fluid increases the viscosity of fluid. A similar study with MWCNT and Al₂O₃ mixture with engine oil was conducted by Dardan *et al.* [19].

From the literature, it is identified that the thermophysical properties of CNT/Al₂O₃ nanoparticles have not been studied to date.

Also, from the literature, it is identified that the thermal conductivity is not only the important property but all its associated properties such as viscosity, specific heat capacity and density of hybrid nanofluid. In this Letter, the effect of concentration of nanoparticle in the range of 0.05–0.1% is studied, and the thermophysical properties such as viscosity, specific heat capacity and density of hybrid nanofluid were determined (Table 1).

2. Preparation of CNT and CNT/Al₂O₃ hybrid nanofluid: CNT and Al₂O₃ nanoparticles are purchased from United Nanotech (India) and dispersed in deionised water with a volume concentration of 0.05 and 0.1%. Scanning electron microscopic image reveals that the average particle diameter of CNT and hybrid CNT were in the range of 18–25 and 10–30 nm, respectively. In preparing the hybrid nanoparticle CNT and Al₂O₃ nanoparticles are dispersed in equal proportion by weight (50:50). Also, it is observed that the alumina particle dispersed in CNT has a spherical cross-section (Fig. 1b). The average particle diameter of nanoparticles of CNT and hybrid CNT was found to be 25 and 30 nm, respectively. Table 2 gives the stability behaviour of CNT and CNT/Al₂O₃ hybrid nanoparticle dispersed in water under different concentration by weight. It is observed that the stability of nanofluid with increased concentration from 0.05 to 0.1% exhibited good stability. The zeta potential of CNT is found as –27 and –19 ζ/mV for 0.05 and 0.1%, respectively,

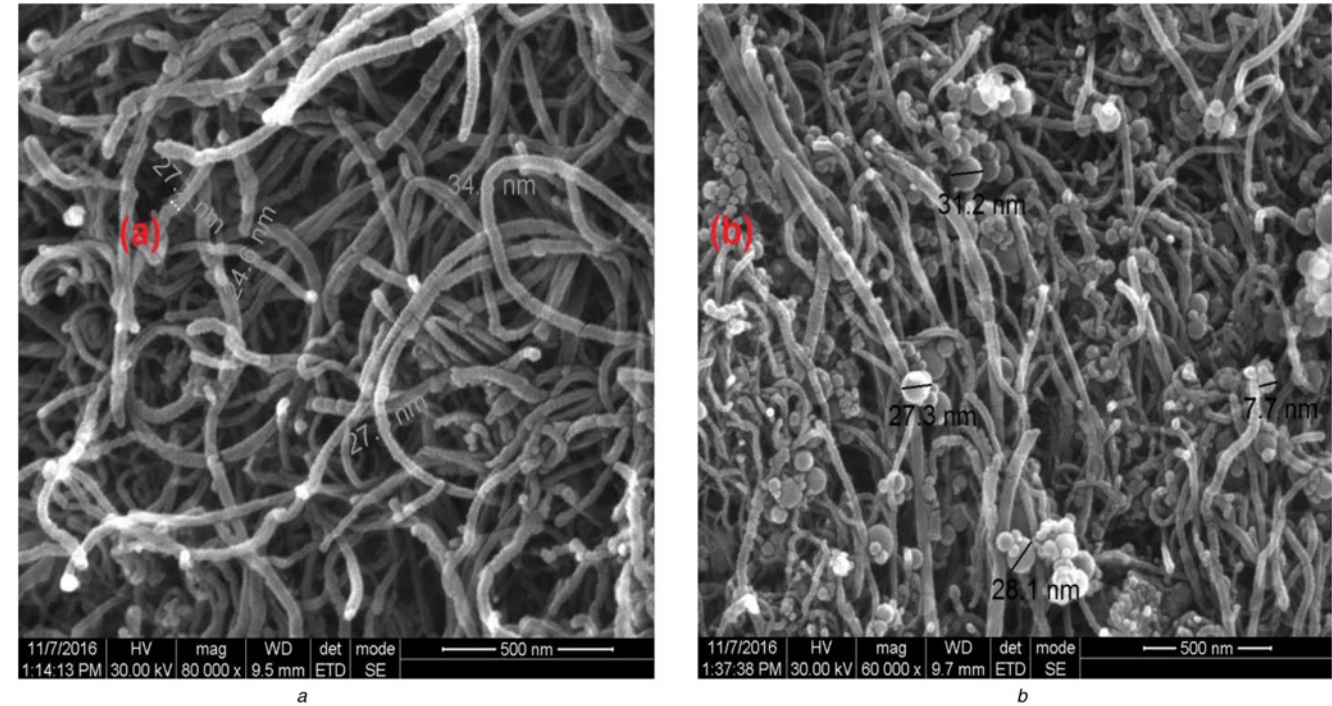


Fig. 1 Scanning electron microscope image of
a CNT
b CNT/Al₂O₃ (hybrid)

Table 2 Stability of CNT and CNT/Al₂O₃ nanofluid

S. No.	Concentration, %	Nanoparticle in fluid	Zeta potential, ζ/mV	Stability behaviour
1	0.05	CNT	–27	good stability
		CNT/Al ₂ O ₃	–26	good stability
2	0.1	CNT	–19	good stability
		CNT/Al ₂ O ₃	–23	good stability

whereas the zeta potential of CNT/Al₂O₃ nanofluid is found as -26 and -23 ζ /mV for 0.05 and 0.1%, respectively.

3. Evaluation of thermal properties: The thermal properties such as thermal conductivity and specific heat capacity are measured using KD2 Pro thermal analyser and thermogravimetric-differential scanning calorimetry. Similarly, the viscosity of the fluid is measured using Brookfield Dial viscometer. Based on the empirical relation from previous literature, the thermal conductivity is measured by (1), specific heat capacity by (2), density by (3) and viscosity by (4)

$$k_{nf} = \frac{k_w k_p + 2k_w + 2k_w \varphi(k_p - k_w)}{k_p + 2k_w - \varphi(k_p - k_w)} \quad (1)$$

where k is thermal conductivity (W/mK) and φ is concentration (%)

$$(\rho C_p)_{nf} = (1 - \varphi)(\rho C_p)_w + \varphi(\rho C_p)_p \quad (2)$$

where ρ is density (kg/m³) and C_p is specific heat capacity (J/kgK)

$$\rho_{nf} = \varphi \rho_p + (1 - \varphi) \rho_w \quad (3)$$

$$\mu_{nf} = \mu_w (1 + \eta \varphi + (\eta \varphi)^2) \quad (4)$$

where μ is dynamic viscosity (mPa s).

4. Results and discussion: Fig. 2 shows the variation of density in two different nanofluids as a function of temperature. It can be observed that the density of both the fluid exhibits similar density with a deviation of $\pm 5\%$ as compared to the nanofluid with 0.1% concentration of CNT with the base fluid. It is also observed that the CNT/Al₂O₃ hybrid nanofluid shows lower density as compared to the 0.1% CNT and 0.05% CNT/Al₂O₃ at a temperature in the range from 313 to 323 K as it is due to the agglomeration of nanoparticles in the fluid. Fig. 3 shows the variation of density in CNT nanofluid with variation in concentration of a particle in the fluid. The measured density of CNT nanofluid from this study matches the predicted value of density using (3). The measured and predicted density of CNT nanofluid is estimated at a temperature of 40°C.

Fig. 4 shows the variation of viscosity as a function of temperature (CNT and CNT/Al₂O₃ nanofluid). It is observed that the viscosity of CNT with maximum concentration ($\Phi=0.1\%$) of nanoparticle in the fluid is 1.2, 0.87, 0.79, 0.75 and 0.72 mPa s

for 40, 45, 50, 55 and 60°C, respectively, while the viscosity of CNT/Al₂O₃ nanofluid is found as 1.35, 1.3, 1.18, 1 and 0.82 mPa s for 40, 45, 50, 55 and 60°C, respectively. It is clear that the addition of another nanoparticle with the base nanofluid

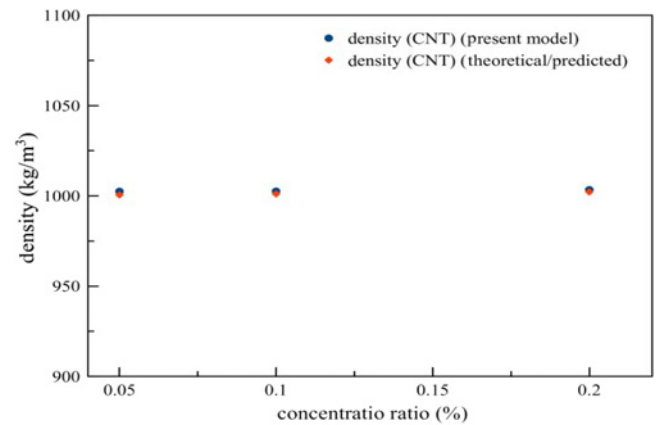


Fig. 3 Variation of density in CNT nanofluid of this study with predicted model

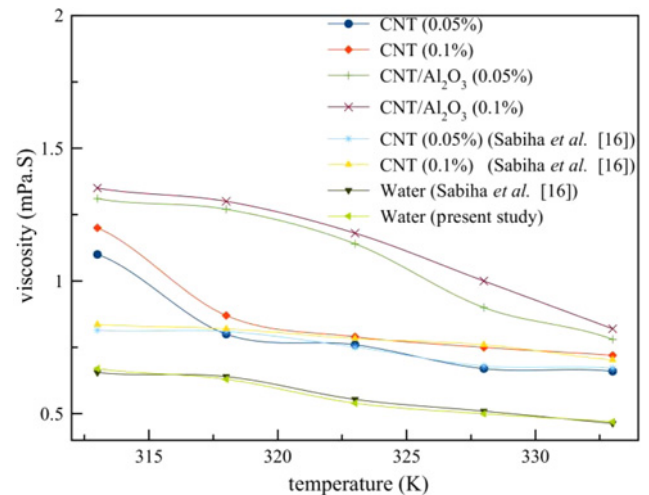


Fig. 4 Variation of viscosity as a function of temperature (CNT and CNT/Al₂O₃ nanofluid)

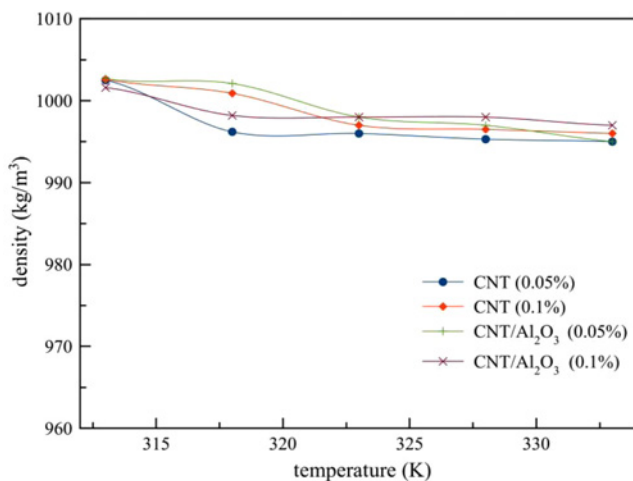


Fig. 2 Variation of density in CNT and CNT/Al₂O₃ nanofluid as a function of temperature

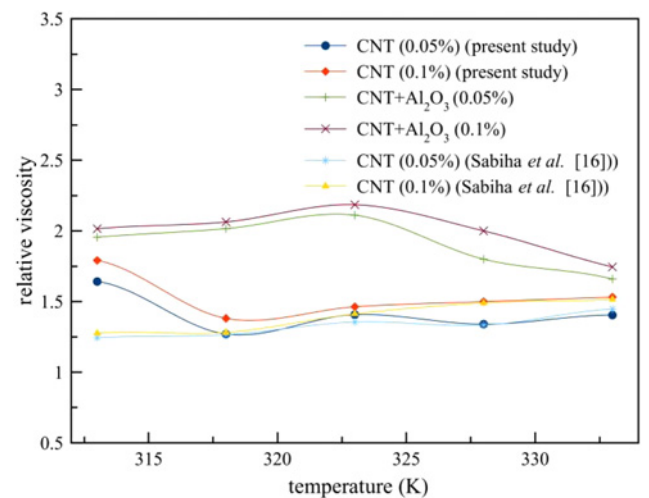


Fig. 5 Variation of relative viscosity as a function of temperature (CNT and CNT/Al₂O₃ nanofluid)

increases the viscosity of hybrid nanofluid. The variation of relative viscosity of CNT and CNT/Al₂O₃ nanofluid as a function of temperature is plotted in Fig. 5. It is observed that the relative viscosity of CNT under different concentration in this study is higher as compared to the previous literature [16]. In the previous study by Sabiha *et al.* [16], they used the nanoparticle in the size of 1–2 nm, and the particle size in the nanofluid under different concentration increased. Similarly, the relative viscosity of the hybrid nanofluid increases with increase in the concentration of CNT and Al₂O₃ nanoparticle in the fluid. Also, with an increase in temperature of nanofluid, the relative viscosities of nanofluids decreases as the intermolecular bonding between the surfaces were reduced.

Fig. 6 shows the variation of thermal conductivity as a function of temperature under different concentration of nanoparticle in the base fluid. It is clear that the thermal conductivity of CNT with a concentration of 0.05% matches with the experimental results of Sabiha *et al.* [16] for the same temperature range and increasing. Similarly, there is a marginal deviation of 3% with the results of Sabiha *et al.* [16] as it is due to the increased particle loading. The thermal conductivity of CNT/Al₂O₃ is higher at a lower temperature and increased by 11.9 and 29.6% for 40 and 60°C, respectively, than pure water at higher concentration, whereas at a lower concentration of nanoparticle the increase is found as 5.6 and 19.65%. The enhancement of nanofluid is mainly due to the

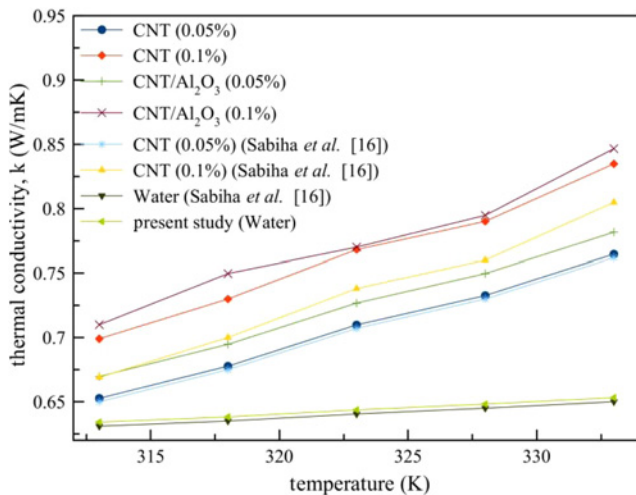


Fig. 6 Variation of thermal conductivity as a function of temperature under different concentration of nanoparticle

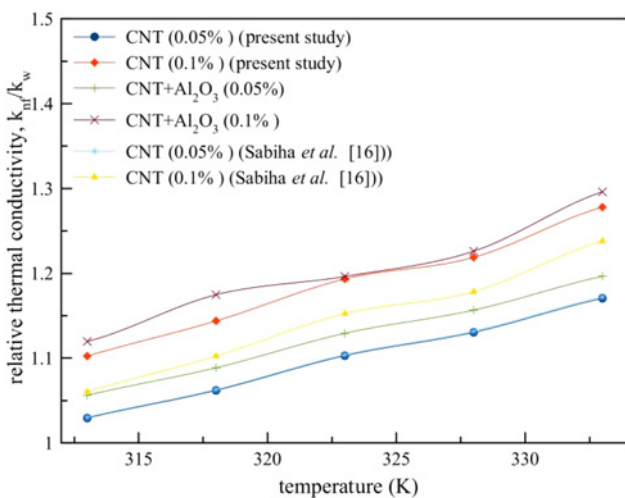


Fig. 7 Variation of thermal conductivity as a function of temperature under different concentration of nanoparticle

effect of Brownian effect and clustering of the particle. Fig. 7 shows the variation of relative thermal conductivity of different nanofluid and the similar trend of thermal conductivity is observed (Fig. 6) as the temperature is increased. The possible deviation between the CNT of this study with the previous study [16] is the length of the nanotube, the diameter of the tube and addition of surfactant with the fluid. Also, the time of sonication plays an important role for this deviation.

Fig. 8 shows the variation in specific heat capacity of CNT/Al₂O₃ hybrid nanofluid under two different concentrations and temperature. It can be observed that the specific heat capacity of hybrid nanofluid increases with increase in temperature. For the working temperature of 60°C, the specific heat capacity of hybrid fluid is found as 17,000 and 5000 J/kgK for 0.1 and 0.05% volume concentration. Also, it is found that the specific heat capacity is predominantly higher as compared to that of base fluid. From Fig. 9, it is also observed that the maximum working temperature of hybrid nanofluid ($\phi = 0.1\%$) is 60–70°C, as the energy absorption thereafter falls. From 80 to 90°C temperature range, there is a possible increase in the energy absorption and almost similar trend to that of 0.05% with a marginal deviation of about 15%. It is clear that the increase in the concentration of nanoparticle in the fluid increases the specific heat capacity of nanofluid as the temperature increases. This is due to the effect of rapid coagulation between the two different nanoparticle on an aqueous solution. Using (3), it can be observed that there is an increase in specific heat capacity of CNT nanofluid with an increase in concentration. Also, it is observed that the CNT nanofluid of the present model is lower by

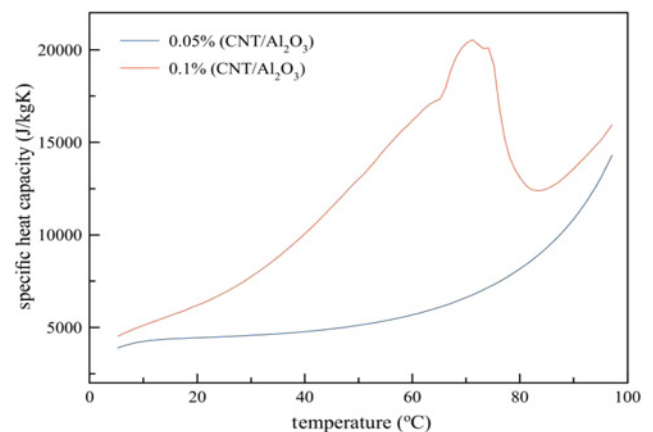


Fig. 8 Variation in specific heat capacity of CNT/Al₂O₃ hybrid nanofluid under different concentration and temperature

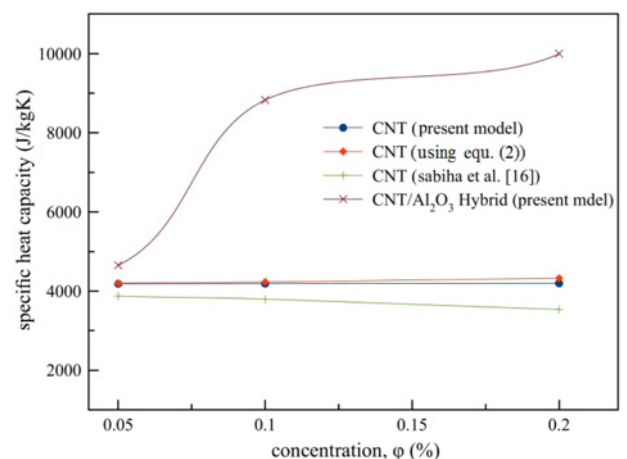


Fig. 9 Variation in specific heat capacity under different concentration

1% as compared to (3). There is also an increase of about 8, 10 and 18% in specific heat capacity of CNT nanofluid as compared to Sabiha *et al.* [16] for 0.05, 0.1 and 0.2%, respectively (Fig. 9). Similarly, the specific heat energy absorption of CNT/Al₂O₃ hybrid nanofluid increases by about 11, 110 and 138% as compared to that of CNT nanofluid (present model) for 0.05, 0.1 and 0.2%, respectively. The increase in the specific heat capacity of hybrid nanofluid is because of its homogenous mixture of Al₂O₃ and CNT dispersed in water. From the studies of Chougule and Sahu [15] it is inferred that the enhancement of the present study with CNT and water nanofluid is enhanced by 30% as it is due to the effect of nanoparticle diameter and tube length of CNT.

5. Conclusions: From the experimental study on thermal conductivity, and viscosity of CNT and CNT/Al₂O₃ nanofluid, the following conclusions arrived:

- The viscosity of nanofluid increases with increase in the concentration of nanofluid and the hybrid nanofluid is suitable while the operating temperature is more than 40°C with higher concentration as the viscosity of nanofluid is lesser.
- The relative viscosity of CNT and CNT/Al₂O₃ nanofluids decreased from 1.73 to 1.53 and 2.01 to 1.65 for the temperature in the range of 40–60°C, respectively.
- The thermal conductivity of the fluid is increasing as the temperature increases.
- The relative thermal conductivity of CNT and CNT/Al₂O₃ nanofluids increased from 1.02 to 1.27 and 1.11 to 1.29, respectively, for the temperature in the range of 40–60°C.
- With the concentration of nanoparticle $\{\phi = 0.1\%$ [CNT (50%)/Al₂O₃ (50%)] in the base fluid, the thermal conductivity increase is found as 29 and 27% than base fluid and CNT-based nanofluid.
- The result of specific heat energy capacity of hybrid nanofluids increases to about 138% than CNT nanofluid with a maximum concentration of 0.2%.

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7 References

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