Simulation of Heat Dissipation for High Power Electronic Component using Carbon Nanotube Nanofluids

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Abstract- Carbon nanotubes (CNTs) are some of the most valuable materials that have highest thermal conductivity. The thermal conductivity of individual carbon nanotubes is 2000 Wm\(^{-1}\)K\(^{-1}\) compared with the thermal conductivity 419 Wm\(^{-1}\)K\(^{-1}\) of silver. Therefore, carbon nanotubes have opened a new way for heat dissipation for high power electronic components, such as microprocessor, high brightness LED, etc. In this paper, we present the simulation results on heat dissipation for a high power electronic component using carbon nanotube nanofluids.

I. INTRODUCTION

Thermal management is widely recognized to be an important aspect of electronic design, with device performance being significantly affected by temperature. In addition, device lifetime can be decreased drastically because of large thermal stresses. The challenge for thermal management is to develop high-conductivity structures that can accommodate the fixed temperature drop with the increasing power densities that characterize new generations of microprocessors [1]. Nanofluid concept is employed to designate a fluid in which nanometersized particles are suspended in conventional heat transfer base fluids to improve their thermal physical properties. Nanoparticles are made from various materials, such as metals (Cu, Ag, Au, Al, and Fe), oxide ceramics (Al\(_2\)O\(_3\) and TiO\(_2\)), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), semiconductors, carbon nanotubes, and composite materials such as alloyed nanoparticles or nanoparticle corepolymer shell composites. It is well known that conventional heat transfer fluids, such as oil, water, and ethylene glycol, in general, have poor heat transfer properties compared to those of most solids. Nanofluids have enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared with those of base fluids like oil or water [2-7].

Carbon nanotubes (CNTs) are some of the most valuable materials with high thermal conductivity (about 2000 W/m.K compared to thermal conductivity of Ag 419 W/m.K) [8-10]. CNTs have been used as additives in liquids to increase the thermal conductivity, one of the most important issues in industry [11]. Owing to their very high thermal conductivity, CNTs become one of the most suitable nano additives to fabricate the nanofluid for thermal dissipation in many industrial and consumer products [12-13]. CNT-nanofluids or liquids are likely to be the future heat transfer media as their thermal conductivities are significantly higher than those of the parent liquids even when the CNTs concentrations are negligible.

In this paper, we present the simulation results on heat dissipation for a high power electronic component using carbon nanotube based liquid.

II. SIMULATION METHOD

Figure 1 is the diagram of heat dissipation system for high power electronic components using carbon nanotube nanofluids. In this system, the copper heat-sink was set to directly contact with a high power electronic component. The nanofluid was pumped from container to copper heat-sink by using a mini pump. The track inside the copper heat-sink was fabricated to allow nanofluid flows through it and absorb heat from high power electronic component, after that the nanofluid flows from the copper heat-sink to heat radiator and returns the container.

In order to simplify the simulation process, we assumed that the heat exchange process takes place only in copper heat-sink, heat radiator, and nanofluid container. In order to perform the simulation, we divide operation time of electronic component into many very short differential times (\(\Delta t\)). The heat transfer equations were calculated by dedicated software in each very short differential time. These processes are repeated many times to obtain simulation results.

We assumed that:
\[ +v \text{ denote the flow-rate of the nanofluid in system (m}^3/\text{s}) \]
\[ +\Delta t \text{ denote the differential time of the simulation (s)} \]
\[ +\Delta V \text{ denotethe volume of fluid flowing in } \Delta t \text{ (m}^3) \]

![Figure 1. Diagram of the heat dissipation system for high power electronic components using carbon nanotube nanofluid](image-url)
We have:
\[ \Delta V = v \Delta t \]  
\[ (1) \]

The heat transfer equation between nanofluid in copper heat-sink and nanofluid volume \( \Delta V \) flowing from container to copper heat-sink is:
\[ T_h = \frac{C_p D_r [(V_s - \Delta V)T_i + \Delta V T_r] + C_r T_r}{C_p D_r V_i + C_r} \]
\[ (2) \]

Where:
+ \( V_s \) denote the volume of the nanofluid in heat-sink(m\(^3\))
+ \( T_h \) denote the temperature of the nanofluid in heat-sink (°C)
+ \( T_s \) denote the temperature of the nanofluid in heat-sink after the amount of \( \Delta V \) nanofluid flowing from container to heat-sink (°C)
+ \( D_r \) denote the thickness of the nanofluid in the radiator (m)
+ \( C_r \) denote the heat capacity of the radiator (J/K)
+ \( R_h \) denote the heat resistance of the heat-sink (K/W)
+ \( C_p \) denote the specific heat capacity of the nanofluid (J/kg.K)
+ \( D_o \) denote the density of the nanofluid (kg/m\(^3\))

The heat flow from electronic component to nanofluid is calculated by following formula:
\[ I_{p-h} = \frac{(T_p - T_h)}{R_{p-h} + R_h + R_n} \]
\[ (3) \]

Where:
+ \( I_{p-h} \) denote the heat flow from electronic component to nanofluid in the heat-sink (W)
+ \( T_p \) denote the temperature of the electronic component (°C)
+ \( R_{p-h} \) denote the heat resistance of contact layer between electronic component and the heat-sink (K/W)
+ \( R_h \) denote the heat resistance of the heat-sink (K/W)
+ \( R_n \) denote the effective heat resistance of nanofluid (K/W)

The effective heat resistance of the nanofluid is calculated by following formula:
\[ R_n = \frac{1}{2} \frac{k}{S} \cdot \frac{1}{2} \frac{d}{a b} \]
\[ (4) \]

Where:
+ \( k \) denote the thermal conductivity of the nanofluid (W/mK)
+ \( d \) denote the thickness of the nanofluid in the heat-sink (m)
+ \( S \) denote the cross-sectional area of the nanofluid in the heat-sink (m\(^2\))
+ \( a, b \) denote the width and length of the nanofluid in the heat-sink, respectively (m)

We have:
\[ T_r = T_s + \frac{\Delta Q}{C_r} = T_s + \frac{(P - I_{p-h}) \Delta t}{C_p} \]
\[ (5) \]

Where:
+ \( T_r \) denote the temperature of the electronic component after very short differential times \( \Delta t \) (°C)
+ \( \Delta Q \) denote the retain heat in the electronic component (°C)
+ \( C_r \) denote the heat capacity of the electronic component (J/K)
+ \( P \) denote the heat generation power of the electronic component (W)

The temperature of the nanofluid in the heat-sink after very short differential times \( \Delta t \) is calculated by following formula:
\[ T_h = T_h + \frac{\Delta Q_{r-h}}{C_r + C_n} = T_h + \frac{(P - I_{p-h}) \Delta t}{C_p + C_n} \]
\[ (6) \]

\[ T_h = T_h + \frac{I_{p-h} \Delta t}{C_h + C_n} \]
\[ (7) \]

Where:
+ \( T_h \) denote temperature of the nanofluid in the heat-sink after very short differential times \( \Delta t \) (°C)
+ \( \Delta Q_{r-h} \) denote the heat from electronic component to nanofluid and the heat-sink (J)
+ \( C_r \) denote the heat capacity of thenanofluid in the heat-sink (J/K)

The heat transfer equation between nanofluid in radiator and nanofluid volume \( \Delta V \) flowing from copper heat-sink to radiator is:
\[ T_r = \frac{C_p D_r [(V_s - \Delta V)T_i + \Delta V T_h] + C_r T_h}{C_p D_r V_i + C_r} \]
\[ (8) \]

Where:
+ \( V_s \) denote the volume of the nanofluid in radiator (m\(^3\))
+ \( T_r \) denote the temperature of the nanofluid in radiator (°C)
+ \( T_i \) denote the temperature of the nanofluid flow from heat-sink to radiator (°C)
+ \( T_h \) denote the temperature of the nanofluid in radiator after the amount of \( \Delta V \) nanofluid flowing from the heat-sink to radiator (°C)
+ \( C_r \) denote the heat capacity of the radiator (J/K)

The heat flow from radiator to environment is calculated by following formula:
\[ I_{r-e} = \frac{(T'_r - T_e)}{R_{r-e} + R_n} \]
\[ (9) \]

Where:
+ \( I_{r-e} \) denote the heat flow from radiator to environment (W)
+ \( T_e \) denote the temperature of environment (°C)
+ \( R_{r-e} \) denote the heat resistance between the radiator and environment (K/W)
+ \( R_n \) denote the effective heat resistance of the nanofluid in the radiator (K/W)

We assume that the liquid-tracks inside the radiatortorectangular shape. The effective heat resistance of the nanofluid in the radiator is calculated by following formula:
\[ R_n = \frac{1}{2} \frac{k}{S} \cdot \frac{1}{2} \frac{d}{a b} \]
\[ (10) \]

Where:
+ \( d \) denote the thickness of the nanofluid in the radiator(m) 
+ \( S \) denote the cross-sectional area of the nanofluid in the radiator(m\(^2\)) 
+ \( a, b \) denotes the width and length of the nanofluid in the radiator, respectively (m) 

The temperature of the nanofluid in the radiator after very short differential times \( \Delta t \) is calculated by following formula:
\[ T'_r = T'_r - \frac{\Delta Q_{r-e}}{C_r + C_n} = T'_r - \frac{I_{r-e} \Delta t}{C_r + C_n} \]
\[ (11) \]

\[ T'_r = T'_r - \frac{I_{r-e} \Delta t}{C_r + C_oD_nV_r} \]
\[ (12) \]

Where:
+ \( T'_r \) denote temperature of the nanofluid in the radiator after very short differential times \( \Delta t \) (°C)
+ \( \Delta Q_{r-e} \) denote the heat from radiator to environment (J)
+ \( C_r \) denote the heat capacity of the nanofluid in the radiator (J/K)
The heat transfer equation between nanofluid in container and nanofluid volume $\Delta V$ flowing from radiator to container is:

$$\Delta T_c = \frac{C_o D_n V \epsilon}{C_e}$$

(13)

Where:

+ $V_c$ denote the volume of the nanofluid in container (m$^3$)
+ $T_c$ denote the temperature of the nanofluid in container ($^\circ$C)
+ $T_v$ denote the temperature of the nanofluid flow from radiator to container ($^\circ$C)
+ $\Delta T_c$ denote the temperature of the nanofluid in container after after very short differential times $\Delta t$ ($^\circ$C)
+ $C_e$ denote the heat capacity of the container (J/K)

### III. RESULTS AND DISCUSSION

We choose carbon nanotube base distilled water with concentration of CNTs was from 0.0 vol. % to 1.0 vol. % for all simulation. The parameters were used in the simulation process as following:

+ The differential time of the simulation: $\Delta t = 10^{-8}$ (s)
+ The density of the nanofluid: $D_n = 1000$ kg/m$^3$
+ The specific heat capacity of the nanofluid: $C_o = 4200$ J/kg.K
+ The dimensions of the heat-sink: $a \times b \times c = 100$ mm $\times 90$ mm $\times 6$ mm
+ The dimensions of liquid-track in the radiator: $a \times b \times c = 300$ mm $\times 10$ mm $\times 0.5$ mm
+ The volume of container: $V_c = 0.5$ litter
+ The temperature of environment: $T_e = 20^\circ$C
+ The heat power of electronic component: $P = 80$ W
+ The the flow-rate of the nanofluid: $v = 5$(cm$^3$/s)

The thermal conductivity of the nanofluid is calculated by flowing formula [14]:

$$\frac{k}{k_w} = 1 + \frac{k_{CNT} \varepsilon r_w}{3 k_w (1 - \varepsilon) r_{CNT}}$$

(14)

Where:

+ $k_w$ = 0.6 W/mK, denote the thermal conductivity of water.
+ $k_{CNT}$ = 1750 W/mK, denote the thermal conductivity of CNT.
+ $r_w$ = 0.1 nm, denote the radius of water molecule.
+ $r_{CNT}$ = 5 nm, denote the average radius of CNT.
+ $\varepsilon$ = 0.0 vol. % $\div$ 1.0 vol. %, denote the volume concentration of CNTs in nanofluid.

The simulation results on heat dissipation for a high power electronic component using carbon nanotube nanofluid is described as in figure 2. Simulation results showed that the temperature of electronic component increased with exponential growth. The temperature of electronic component reached a saturation value after about 55 minutes. Figure 2 showed that when the concentration of CNTs increases, the saturation temperature of electronic component decreases. This can be explained that the thermal conductivity of nanofluid increased by adding CNTs in nanofluid, and the increasing thermal conductivity of nanofluid helps improve the heat transfer process at substrate and radiator. Simulation results also showed that the saturated temperature of electronic component decreased about 1$^\circ$C $\div$ 4$^\circ$C as described in figure 2. By using nanofluid with 1.0 vol. % of CNTs, the saturated temperature of electronic component decreased 4$^\circ$C compare to only using distilled water.

### IV. CONCLUSION

The thermal dissipation for high power electronic component using the carbon nanotube nanofluid was simulated. Simulation results showed that the saturated temperature of electronic component decreased about 1$^\circ$C $\div$ 4$^\circ$C with the concentrations of CNTs were 0.0 vol. % $\div$ 1.0 vol. % in nanofluid. By using nanofluid with vol. % of CNTs, the saturated temperature of electronic component decreased 4$^\circ$C compare to only using distilled water. The simulation results have confirmed the advantage of the CNTs as an excellent additive component in nanofluid for the thermal dissipation of high power electronic components and devices.

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### REFERENCES


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