ISSN 2250-3153

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

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Abstract- Carbon nanotubes(CNTs) aresomeof 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 micro-processor, 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_2O_3 and TiO_2), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), semiconductors, carbonnanotubes, 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) aresome of the most valuable materials with high thermal conductivity (about2000 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 ones 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 electroniccomponent.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 incopper 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 (Δt).The heat transfer equationswere calculatedby dedicatedsoftware in eachvery short differential time.These processes are repeated many times to obtain simulation results.

We assumed that:

+ v denote the flow-rate of the nanofluid in system (m^3/s)
+ Δt denote the differential time of the simulation (s)
+ ΔV denotethe volume of fluid flowing in Δt (m^3)

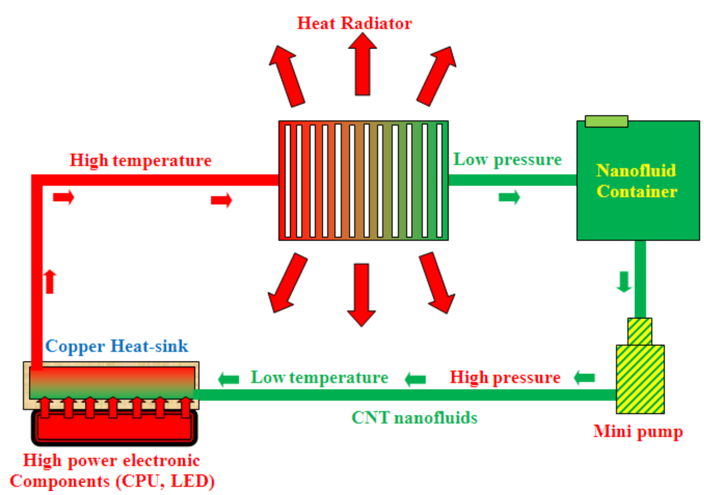

Figure 1. *Diagram of the heat dissipation system for high power electronic componentsusing carbon nanotube nanofluid*

We have:

$$\Delta V = v.\Delta t \tag{1}$$

The heat transfer equation between nanofluid in copper heat-sink and nanofluid volume ΔV flowing from container to copper heat-sink is:

$$T_h^{'} = \frac{C_0 D_n \left[(V_h - \Delta V) T_h + \Delta V . T_c \right] + C_h . T_h}{C_0 D_n . V_h + C_h} \tag{2}$$

Where:

+ $V_h$denote the volume of the nanofluid in heat-sink(m^3)
+ T_h denote the temperatureof the nanofluid in heat-sink (^oC)
+ $T^{'}_h$ denote the temperature of the nanofluid in heat-sink after the amount of ΔV nanofluid flowing from container to heat-sink (^oC)
+ $T_c$denote the temperature of the nanofluid in container (^oC)
+ C_h denote the heat capacity of the heat-sink (J/K)
+ C_0 denote the specific heat capacity of the nanofluid (J/kg.K)
+ D_n denote the density of the nanofluid (kg/m^3)

The heat flow from electronic component to nanofluid is calculated by following formula:

$$I_{p-h} = \frac{(T_p - T_h^{'})}{R_{p-h} + R_h + R_n} \tag{3}$$

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 (^oC)
+ 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:

$$R_n = \frac{1}{2} . \frac{1}{k} . \frac{d}{S} = \frac{1}{2} . \frac{1}{k} . \frac{d}{a.b} \tag{4}$$

Where:

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

We have:

$$T_p^{'} = T_p + \frac{\Delta Q}{C_p} = T_p + \frac{(P - I_{p-h})\Delta t}{C_p} \tag{5}$$

Where:

+ $T^{'}_p$denote the temperature of the electronic component after very short differential times Δt (^oC)
+ ΔQ denote the retain heat in the electronic component (^oC)
+ C_p 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 Δt is calculated by following formula:

$$T_h^{"} = T_h^{'} + \frac{\Delta Q_h}{C_h + C_n} = T_h^{'} + \frac{I_{p-h} . \Delta t}{C_h + C_n} \tag{6}$$

$$T_h^{"} = T_h^{'} + \frac{I_{p-h} . \Delta t}{C_h + C_0 D_n . V_h} \tag{7}$$

Where:

+ $T^{''}_h$denote temperature of the nanofluid in the heat-sink after very short differential times Δt (^oC)
+ ΔQ_h denote the heat from electronic component to nanofluid and the heat-sink (J)
+ C_n denote the heat capacity of the nanofluid in the heat-sink (J/K)

The heat transfer equation between nanofluid in radiator and nanofluid volume ΔV flowing from copper heat-sink to radiator is:

$$T_r^{'} = \frac{C_0 D_n \left[(V_r - \Delta V) T_r + \Delta V . T_h \right] + C_r . T_r}{C_0 D_n . V_r + C_r} \tag{8}$$

Where:

+ $V_r$denote the volume of the nanofluid in radiator (m^3)
+ $T_r$denote the temperature of the nanofluid in radiator (^oC)
+ $T_h$denote the temperature of the nanofluid flow from heat-sink to radiator (^oC)
+ $T^{'}_r$denote the temperature of the nanofluid in radiator after the amount of ΔV nanofluid flowing from the heat-sink to radiator (^oC)
+ C_r denote the heat capacity of the radiator (J/K)

The heat flow from radiator to environment is calculated by following formula:

$$I_{r-e} = \frac{(T_r^{'} - T_e)}{R_{r-e} + R_n^{'}} \tag{9}$$

Where:

+ I_{r-e}denote the heat flow from radiator to environment (W)
+ T_e denote the temperature of environment (^oC)
+ 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 radiatorare rectangular shape.The effective heat resistance of the nanofluid in the radiator is calculated by following formula:

$$R_n^{'} = \frac{1}{2} . \frac{1}{k} . \frac{d^{'}}{S^{'}} = \frac{1}{2} . \frac{1}{k} . \frac{d^{'}}{a^{'} . b^{'}} \tag{10}$$

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 Δt is calculated by following formula:

$$T_r^{"} = T_r^{'} - \frac{\Delta Q_{r-e}}{C_r + C_n^{'}} = T_r^{'} - \frac{I_{r-e} . \Delta t}{C_r + C_n^{'}} \tag{11}$$

$$T_r^{"} = T_r^{'} - \frac{I_{r-e} . \Delta t}{C_r + C_0 D_n . V_r} \tag{12}$$

Where:

+ $T^{''}_r$denote temperature of the nanofluid in the radiator after very short differential times Δt (^oC)
+ ΔQ_{r-m} denote the heat from radiator to environment (J)
+ $C^{'}_n$ denote the heat capacity of the nanofluid in radiator (J/K)

The heat transfer equation between nanofluid in container and nanofluid volume ΔV flowing from radiator to container is:

$$T_c^{'} = \frac{C_0 D_n \left[(V_c - \Delta V) T_c + \Delta V . T_r \right] + C_c . T_c}{C_0 D_n . V_c + C_c} \quad (13)$$

Where:

+ $V_c$denote the volume of the nanofluid in container (m^3)
+ $T_c$denote the temperature of the nanofluid in container (^oC)
+ $T_r$denote the temperature of the nanofluid flow from radiator to container (^oC)
+ $T^{'}_c$denote the temperature of the nanofluid in container after after very short differential times Δt (^oC)
+ C_c 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 wereused 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: $C_0 = 4200$ J/kg.K
+ The dimensions of the heat-sink: a x b x c = 100 mm x 90 mm x 6 mm
+ The dimensions of liquid-track in the radiator: a x b x c = 300mm x 10 mm x 0.5mm
+ The volume of container: $V_c = 0.5$ litter
+ The temperature of environment: $T_e = 20^oC$
+ 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]:

$$\frac{k}{k_w} = 1 + \frac{1}{3} \frac{k_{CNT} \varepsilon r_w}{k_w (1-\varepsilon) r_{CNT}} \quad (14)$$

Where:

+ k_w= 0.6 W/mK, denote the thermal conductivity of water.

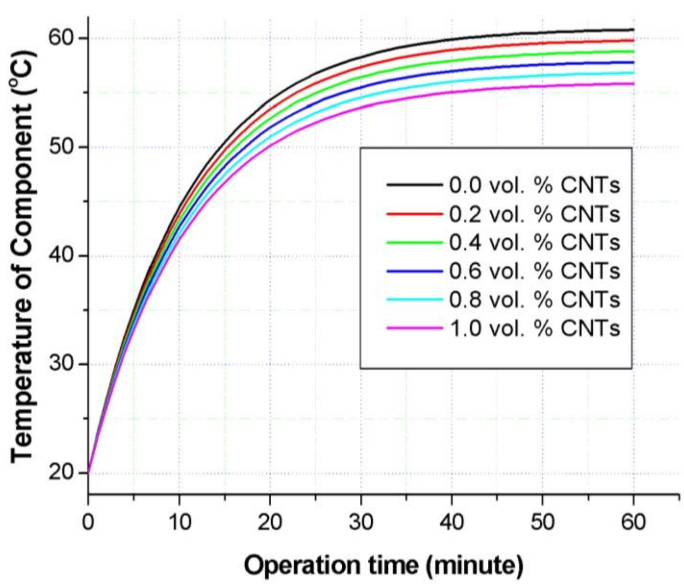

Figure 2. *Simulation resultsonheat dissipation for high power electronic components using carbon nanotube nanofluid*

+ 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.
+ ε= 0.0 vol. % ÷ 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, andthe increasingthermal conductivity of nanofluid helps improve the heat transfer process atsubstrate and radiator. Simulation results also showedthat the saturated temperature of electronic componentdecreased about 1°C ÷ 4°C as described in figure 2. By using nanofluid with 1.0 vol. % of CNTs, the saturated temperature of electronic component decreased 4^{o}C compare to only using distilled water.

IV. CONCLUSION

The thermal dissipation forhigh power electronic component using the carbon nanotube nanofluidwassimulated. Simulation results showedthat the saturated temperature of electronic component decreased about 1°C ÷ 4°C with the concentrations of CNTs were 0.0 vol. % ÷ 1.0 vol. % in nanofluid. By using nanofluid with vol. % of CNTs, the saturated temperature of electronic component decreased 4^{o}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.

ACKNOWLEDGMENT

The authors acknowledge financial support from the VAST Program for Young Scientist (Project No. VAST.ĐLT.05/13-14). The authors also thanks for the financial support of the Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 103.99-2012.35.

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