CHEMICAL ENGINEERING TRANSACTIONS

VOL. 109, 2024

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Leonardo Tognotti, Rubens Maciel Filho, Viatcheslav Kafarov

ISBN 979-12-81206-09-0; **ISSN** 2283-9216

DOI: 10.3303/CET24109100

Effect of a TiO2/Water Nanofluid on the Thermal Cooling of a Central Processing Unit

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An investigation was conducted to evaluate the impact of TiO_2/water nanofluids on the cooling system of a central processing unit (CPU). Tests were carried out using nanofluids with TiO_2 concentrations of 0.02%, 0.05%, 0.1%, and 0.15% by volume at a Reynolds number of 20,000. Pure water (as the base fluid) was also tested for comparative analysis. The experimental findings emphasized the significant influence of nanofluid application on CPU cooling. Under identical operating conditions, the heat transfer rate of TiO_2/water nanofluids proved more effective compared to pure water. Moreover, the results indicated that the nanofluid with a 0.05% volume concentration reduced CPU temperature by 1%, 0.7%, and 1.5% compared to TiO2 concentrations of 0.02%, 0.1%, and 0.15% by volume, respectively. At the optimal condition, the TiO_2/water nanofluid with a volume concentration of 0.05% exhibited the highest Nusselt number, leading to a 2.4% decrease in CPU temperature compared to the base fluid.

1. Introduction

Computers play a crucial role in human activities. The circuits within computers possess electrical resistance, and the flow of electricity through them generates heat. To maintain the components within their allowable operating temperature ranges, computer cooling is essential to dissipate this heat. CPU cooling systems have been extensively developed. Naphon and Wiriyasart (2009) studied the effect of coolant flow rate on the central processing unit (CPU) temperature using a mini-rectangular fin heat sink. Naphon et al. (2009) employed de-ionized water as a working fluid to examine the fluid flow and heat transfer in a mini-rectangular fin heat sink used as a CPU cooler. Naphon et al. (2012) studied a vapor chamber used to cool a PC employing a closed-loop liquid cooling system compared with a traditional PC using air cooling. At 0% and 90% load, the CPU temperatures of the vapor chamber cooling system were 4.1% and 6.89% lower than those of the traditional cooling system. Yousefi et al. (2013) applied various nanofluids in a CPU-cooling system. Their results indicated that the thermal resistance of the heat conduit increased significantly. Hu et al. (2016) reduced the temperature of a CPU with a water-cooled thermoelectric chiller. They reported that the maximum temperature variation of CPU temperature was below 1.5 °C in severe environments. Sarafraz et al. (2017) investigated the thermal efficacy of a cooling liquid block containing a CuO/water nanofluid. Bahiraei and Heshmatian (2017) examined the cooling efficiency of a hybrid nanofluid containing graphene nanoplatelets adorned with silver nanoparticles. Tang et al. (2020) examined the effect of magnetic nanofluids on the thermo-hydraulic properties of a CPU cooling system. Utilizing TiO_2/water nanofluids, Chen et al. (2021) improved CPU cooling performance.

Nanofluids find applications across various engineering fields. Prior studies have highlighted that increasing nanofluid concentration enhances the heat transfer coefficient. While literature reports the use of nanofluids in CPU-cooling systems, their application remains relatively understudied. Research has shown that nanofluids, as substitutes for water, can more efficiently reduce CPU temperatures.

Paper Received: 29 November 2023; Revised: 10 February 2024; Accepted: 31 March 2024
Please cite this article as: Nanan K., Chuwattanakul V., Pramuanjaroenkij A., Eiamsa-Ard S., 2024, Effect of a TiO_2/water Nanofluid on the Thermal Cooling of a Central Processing Unit, Chemical Engineering Transactions, 109, 595-600 DOI:10.3303/CET24109100

Furthermore, employing nanofluids for CPU cooling holds promise in improving equipment performance, preventing overheating, and boosting operational efficiency. Cost-effectiveness is also a crucial consideration in cooling system design, as emphasized by Xu (2015) and Zhang et al. (2018).

The current study aims to assess how the use of a TiO_2/water nanofluid affects the heat transfer process in a CPU cooling system. The influence of different concentrations of TiO_2/water nanofluid (0.02%, 0.05%, 0.1%, and 0.15% by volume) on CPU heat transfer was examined.

2. Materials and methods

The experimental setup, depicted in Figure 1, operated within a closed fluid loop and comprised a fluid reservoir equipped with a chilling system, an ultrasonic vibrator, a flow meter, a control valve, RTDs (resistance temperature detectors), a data recorder, and a watt meter (Fluke clamp meter model: 325). A Core i5 Processor No. 3450 served as the heat source, and FurMark 1.19.0.0 was employed to simulate the CPU. The CPU cooler with the dimension of 40 mm ×40 mm ×14 mm was fabricated from copper. RTDs were placed to measure CPU, inlet, and outlet temperatures. Nanofluids were prepared using TiO_2 nanoparticles with particle diameters ranging between 30 and 50 nm, sourced from Nanostructured & Amorphous Materials, Inc. (USA). These nanoparticles were mixed with water to formulate nanofluids. Hexamethyldisilazane was introduced to enhance particle dispersion, with a mass ratio of TiO2 particles to hexamethyldisilazane set at 2 to 1. Subsequently, the mixture underwent ultrasonic treatment for one hour. TiO_2/water nanofluids were formulated at concentrations of 0.02%, 0.05%, 0.1%, and 0.15% by volume. Evaluation of nanofluid stability, as illustrated in Figure 1, involved monitoring for deposition, revealing that all nanofluids remained stable for several days without any visible sedimentation. Results obtained using a liquid cooling system employing pure water (as the base fluid) and a conventional air-cooled heat sink were recorded for comparison.

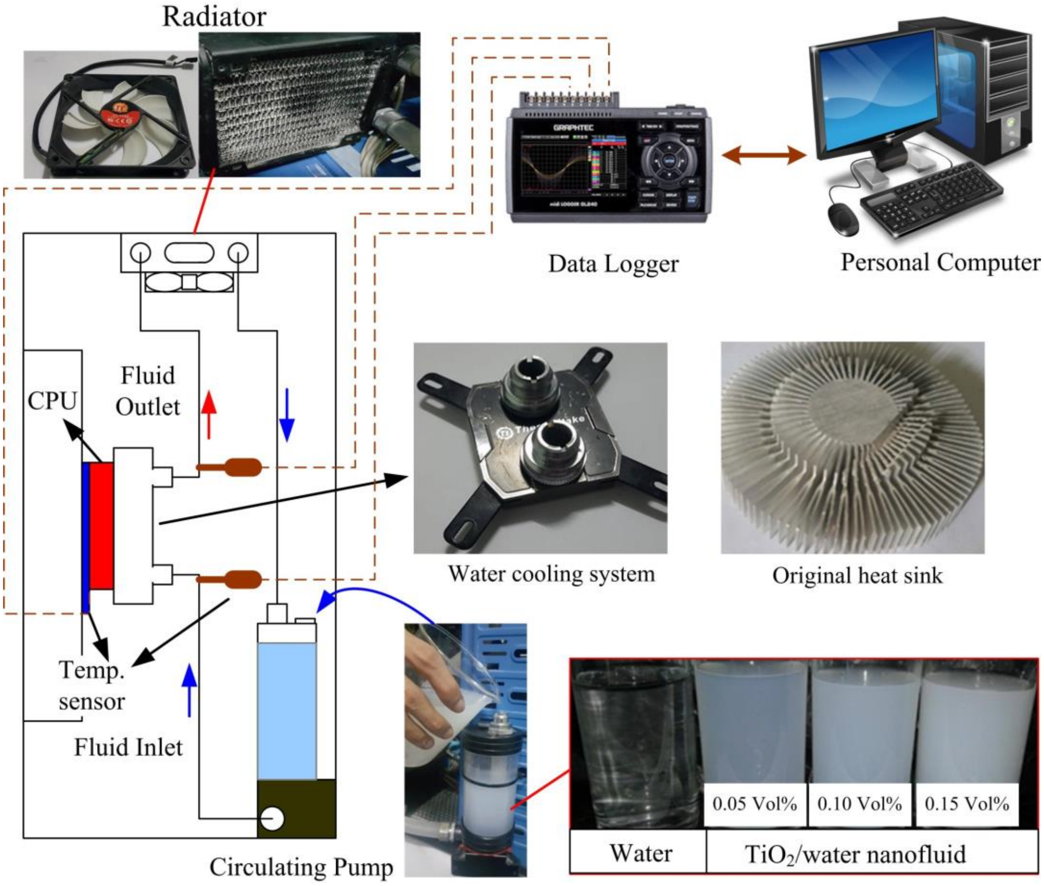

Figure 1. Schematic diagram of the cooling process of a central processing unit (CPU).

Under steady state conditions, the heat transfer rate of a nanofluid flowing through the CPU can be written as:

$$q_{nf} = \dot{m}C_{p,nf}(T_{nf,out} - T_{nf,in}) \tag{1}$$

where $\dot{m}$ and $C_{p,nf}$ are the mass flow rate and the specific heat of the nanofluid. $T_{nf,in}$ and $T_{nf,out}$ are the inlet and outlet temperatures of the nanofluid, respectively .

The Nusselt number can be evaluated as:

$$Nu = h_{nf} D_h / k_{nf} \tag{2}$$

where k_{nf} is thermal conductivity of the nanofluid calculated based on its bulk temperature. D_h is the hydraulic diameter of a micro-fin tube.

The Reynolds number (*Re*) was calculated as

$$Re = \rho_{nf} U_{nf} D_h / \mu_{nf} \tag{3}$$

The Reynolds number from Eq. (3) was applied to both the base fluid and nanofluids using the appropriate fluid properties. The density, specific heat, viscosity, and thermal conductivity of the nanofluids were determined using the nanoparticle volume concentration (ϕ), as well as the base fluid and nanoparticles properties. Utilizing the basic mixing rule for mixtures, the nanofluid density was determined as

$$\rho_{nf} = (1-\phi)\rho_w + \phi\rho_{np} \tag{4}$$

The specific heat of the various nanofluids was calculated from

$$c_{p,nf} = \frac{\phi\rho_{np}c_{p,np} + (1-\phi)\rho_w c_{p,w}}{\rho_{nf}} \tag{5}$$

Experimental validation by Xuan and Roetzel (2000) indicated that Equations (4-5) are applicable for evaluating nanofluid properties. The thermal conductivity of a nanofluid was computed using the Maxwell model (1954), expressed as Eq. (6), which is recommended for homogeneous and low concentration liquid-solid mixtures that are arbitrarily dispersed, uniformly sized, and are comprised of non-interacting spherical particles (Chandrasekar *et al*., 2010).

$$\frac{k_{nf}}{k_w} = \frac{k_{np} + 2k_w + 2\phi(k_{np} - k_w)}{k_{np} + 2k_w - \phi(k_{np} - k_w)} \tag{6}$$

The viscosity of nanofluids was determined using Einstein's general formula (Einstein, 1911).

$$\mu_{nf} = \mu_w(1+\eta\phi) \tag{7}$$

where ϕ = 2.5 is suggested for hard spheres (Chandrasekar *et al*., 2010).

2. 3. Experimental results

3.1 Temperature results

Figure 2 displays the CPU temperature profiles (top), inlet temperature profiles (middle), and outlet temperature profiles (bottom) as a function operating time. In the top graph, CPU temperature began to rise at 120 seconds after powering on the computer (stage 1) due to the conversion of electricity into heat. At 1080 seconds, the FurMark 1.19.0.0 program initiated, resulting in a sudden increase in CPU temperature (stage 2).

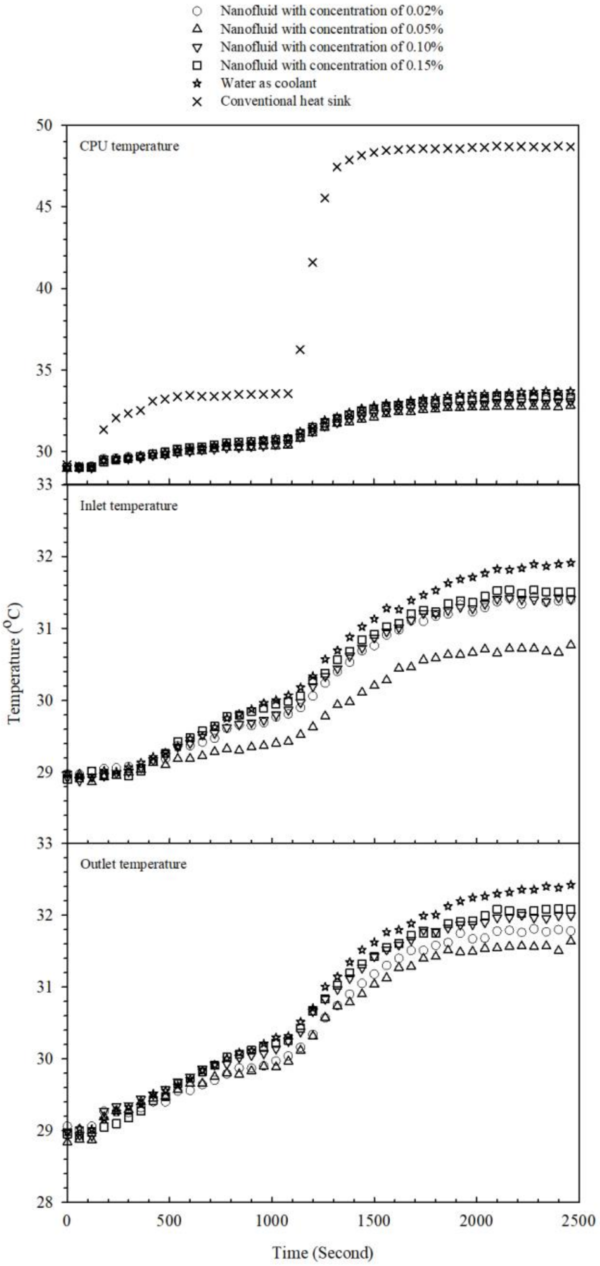

Figure 2 Effect of TiO_2/water nanofluid concentrations on body, inlet and outlet temperatures of the central processing unit.

It is evident that CPU temperatures under liquid cooling systems were significantly lower compared to those using conventional heat sinks. This is attributed to the higher heat capacities of water-based liquids, which are more effective in dissipating heat from the CPU. Inlet and outlet temperature profiles exhibited similar trends, characterized by two distinct CPU temperature stages. With a pure water coolant and an operating duration of 1080 seconds, CPU, inlet, and outlet temperatures were 33.71°C, 31.96°C, and 32.44°C, respectively.

Figure 2 also demonstrates the superior effectiveness of TiO_2/water nanofluids in reducing CPU temperatures compared to pure water (base fluid). Nanofluids have higher thermal conductivities attributed to the presence of nanoparticles. Consequently, particles-particle collisions and particle-base fluid interactions give rise to better heat transfer compared to the base fluid. It was observed that an increased nanofluid concentration, from 0.02 to 0.05% by volume, resulted in lower CPU temperatures (better heat transfer). However, further increases in nanofluid concentration resulted in diminishing heat transfer efficiency. Among the TiO_2/water nanofluids, the one with the concentration of 0.05% by volume proved most effective in reducing CPU temperature, achieving a 6.89% temperature reduction compared to the base fluid. Thus, the optimal nanofluid concentration in this study was determined to be 0.05% by volume. The increase of thermal conductivity with increasing nanofluid concentration is accompanied by the increase of viscosity. The greater viscosities of the TiO_2/water nanofluids at excessively high concentrations (0.1% and 0.15% by volume) impeded fluidity and reduced heat transfer efficiency. In contrast, the poor heat transfer of the TiO_2/water nanofluid with a 0.02% by volume concentration was primarily due to its low conductivity.

3.2 Heat transfer rate results

Figure 3 illustrates the impact of TiO_2/water nanofluid concentrations (0.00%, 0.02%, 0.05%, 0.1%, and 0.15% by volume) on the heat transfer rate (Q). Among these nanofluids, the one with a concentration of 0.05% by volume demonstrated the highest heat transfer rate as discussed in section 3.1.

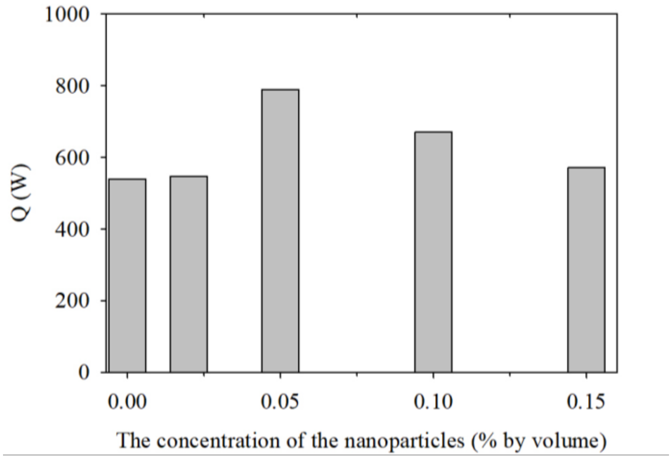

Figure 3 Effect of TiO_2/water concentration on the heat transfer rate from a CPU.

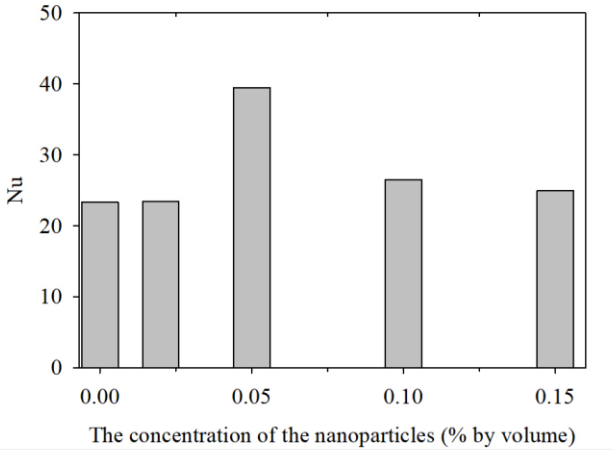

Figure 4: Effect of TiO_2/water concentration on the Nusselt number at a CPU.

3.3 Nusselt number results

Figure 4 depicts the impact of TiO_2/water nanofluid concentration (0.00%, 0.02%, 0.05%, 0.1%, and 0.15% by volume) on the Nusselt number, relative to the base fluid (water). As shown in the figure, an increase in nanofluid concentration from 0.00% to 0.05% by volume correlates with a notable rise in the Nusselt number, indicating improved heat transfer facilitated by higher thermal conductivity or reduced thermal resistance. However, beyond a concentration of 0.05% by volume, further increases in nanofluid concentration, such as from 0.1% to 0.15%, result in a significant decline in the Nusselt number. This decline suggests that at higher nanofluid concentrations, viscosity plays a more prominent role than thermal conductivity in influencing heat transfer. Notably, the 0.05% by volume TiO_2/water nanofluid exhibited the highest Nusselt number, attributed to enhanced convection facilitated by high thermal conductivity and moderate viscosity of the nanofluid. Compared to the base fluid, the utilization of TiO_2/water nanofluids at concentrations of 0.02%, 0.05%, 0.1%, and 0.15% by volume resulted in increased Nusselt numbers of 0.5%, 69%, 13%, and 6.8%, respectively.

4. Conclusions

The heat transfer results using nanofluids containing TiO_2 at concentrations of 0.02%, 0.5%, 0.15%, and 0.1% by volume and a Reynolds number of 20,000 are reported. Experimental results indicate that TiO2/water nanofluids enhance heat transfer in comparison to water (the base fluid) and air (conventional heat sink). In this study, a TiO_2/water nanofluid with a concentration of 0.05% by volume exhibited the highest Nusselt number, resulting in a 2.4% reduction in CPU temperature compared to the base fluid. Compared to the 0.05% TiO_2 nanofluid, the poorer heat transfer of the 0.02% TiO_2 nanofluid was due to its lower conductivity. The reduced heat transfer observed in nanofluids with concentrations of 0.1% and 0.15% is attributed to their higher viscosities, which hinder fluid mobility. Further investigation is required to determine the most favorable parameters for attaining maximum Nusselt numbers utilizing TiO_2-water nanofluids within CPU cooling frameworks. Moreover, exploring the potential enhancement of intrinsic properties of nanoparticles holds promise for enhancing heat transfer efficiency.

Acknowledgment

This work was supported by (i) Phetchaburi Rajabhat University (PBRU), (ii) Thailand Science Research and Innovation (TSRI), and (iii) National Science, Research and Innovation Fund (NSRF) Project No. 179129.

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