Study The Convective Heat Transfer of TiO$_2$/Water Nanofluid in Heat Exchanger System

Asmaa H. Dhiaa  
College of Engineering, University of Kufa/Al-Najf.  
Email: ce_asmaa@yahoo.com  
Dr. Majid I. Abdulwahab  
Chemical Engineering Department, University of Baghdad, Baghdad  
Dr. S.M. Thahab  
College of Engineering, University of Kufa/Al-Najf.

Abstract

The enhancements of heat transfer coefficient and Nusselt number in a heat exchanger system were achieved by using Titanium-dioxide (TiO$_2$) nanoparticles with an average diameter of 10 nm. TiO$_2$ nanoparticles/water has a better thermal conductivity compared to conventional working fluids (water). The heat transfer rate in a vertical shell and tube heat exchanger counter flow under laminar and turbulent flow conditions were investigated. The liquid flow rate has been varied in the range of 50-300 l/h while the inlet temperature was between 20 to 60 ºC. The effects of factors such as the Reynolds number and the peclet number on the heat transfer and flow characteristics were carried out and investigated. It was observed that the convection heat transfer increased remarkably with the increment of the temperature under various values of the Reynolds number. As well as, the Nusselt number increased about 17% as compared to pure water; at a nanofluid velocity of 0.0192 m/s at inlet temperature of 60°C.

Keyword: Nanofluids, Thermal conductivity, Viscosity, TiO$_2$ nanoparticles

دراسة نقل الحمارة للمائع التيتانيوم/أوكسيذ التيتانيوم/ ماء

في نظام مبادل الحمارة

وقد تم تحقيق تحسينات في معدل انتقال الحرارة و رقم نسلت في نظام مبادل الحرارة باستخدام ثاني أكسيد التيتانيوم (TiO$_2$) النانوية مع متوسط قطر هامان 10 نانومتر. و تتفوق على موادها التقليدية بالفضل من السرعة والسرعة الن郜رات و متزايدات و تعقب. وقد اختلفت معدل تدفق السائل في مجموعة من (50-300) لتر / ساعة داخل درجة حرارة مخلع من 20-60 درجة مئوية. أجبرت اثار المعامل على نظام تدفق عن تدفق peclot عند عدد رينولدز عدد من (20-60) عند عدد رينولدز. وكذلك، ارتفع عدد نسليت حوالي 17% بالمقارنة مع الماء النقي في حين تم زيادة معدل انتقال الحرارة حوالي 37% بالمقارنة مع الماء النقي الذي هو 0.0192 م / ث تحت C600.

الكلمة المفتاحية: Nanofluids، للمواد الحرارية، النانوية، النتيجة، TiO$_2$ نانو.
INTRODUCTION

Nanofluids are engineered by suspending nanoparticles with common sizes below 100 nm in conventional heat transfer fluids such as water, oil, and ethylene glycol. Improvements in the thermal properties of base fluids, was indicated when an extremely small amount of nanoparticles was dispersed regularly and suspended stably in base fluids. Nanoparticles used in nanofluids are typically constructed of metals, oxide, and carbide or carbon nanotubes. Nanoparticles have unique properties, such as the large surface area to volume ratio, which enhance the thermal transport of the fluid, high dispersion stability with the predominant Brownian motion of particles, lower pumping power than pure liquids, reduced particle clogging when compared to other slurries, adjustable properties, including thermal conductivity, viscosity and surface wetability, which can be varied according to nanoparticles concentration (Zawrah et al., 2015).

In the development energy-efficient and the thermal conductivity of the heat transfer fluids plays a vital role in many applications. Heat exchange is a device which transfers the energy from a hot fluid medium to a cold fluid medium through maximum rate, minimum investment and also low running costs. (Alpesh Mehta, 2012). Conventional heat transfer fluids such as water or ethylene glycol, used in cooling or heating applications are characterized by poor thermal properties. In the past years, many different techniques were utilized to improve the heat transfer rate in order to reach a satisfactory level of thermal efficiency. The heat transfer rate can passively be enhanced by changing the flow geometry, boundary conditions or by improving thermo physical properties, for example, increasing fluid thermal conductivity (Bianco, 2011).

Farajollahi et al., 2010 calculated the characteristics of heat transfer of γ-Al$_2$O$_3$-water and TiO$_2$-water nanofluids in a shell and tube heat exchanger in turbulent flow condition. They studied the effects of some parameters such as Peclet number, volume concentration of suspended nanoparticles, and particle type on the heat transfer characteristics. The overall heat transfer coefficient of nanofluids was found to increase considerably with Peclet number. Also, the overall heat transfer coefficient increases with nanoparticle concentration at a constant Peclet number compared to the base fluid. Their results for Nusselt number of γ-Al$_2$O$_3$-water and TiO$_2$-water nanofluids were compared to that predicted by the correlation of Xuan and Li correlation Eq. 1 below.

\[
\text{Nu}_{nf} = 0.0059(1 + 7.6286 \Phi^{0.6886} \text{Pe}_d^{0.001}) \text{Re}_{nf}^{0.9238} \text{Pr}_{nf}^{0.4}
\]  \hspace{1cm} (1)

Where

- \(\Phi\) is volume concentration, \(\%\), \(\text{Nu}_{nf}\) is Nusselt number, \(\text{Re}_{nf}\) is Reynolds number, \(\text{Pe}\) is Peclet number, \(\text{Pr}_{nf}\) is the Prandtl number of nanofluid.

The results showed that at 0.5 vol. % of γ-Al$_2$O$_3$ nanoparticles and at 0.3 vol.% of TiO$_2$ nanoparticles, good agreement exists between the experimental results and the value predicted by Eq. 1 especially at higher Peclet numbers. They noted that the correlation is approximately valid for the prediction of the Nusselt number for nanofluids of low volume concentrations.

Duangthongsuk and Wongwises, 2010 experimentally investigated the heat transfer coefficient and friction factor of the TiO$_2$-water nanofluids flowing in a horizontal
double tube counter flow heat exchanger under turbulent flow conditions. Their test fluid was TiO$_2$ nanoparticles with average size of 21 nm dispersed in water with volume concentrations of 0.2 - 2 vol. %. The heat transfer coefficient of nanofluids was approximately 26% greater than that of pure water. The results also showed that the heat transfer coefficient of the nanofluids at a volume concentration of 2.0 vol. % was approximately 14% lower than that of base fluids for giving conditions. New heat transfer and friction factor correlations (Eqs.2 and 3) for predicting Nusselt number and friction factor of TiO$_2$-water nanofluids were proposed in the form of the majority of the data falls within ±10% of the proposed equation. These equations are valid in the range of Reynolds number between 3000 and 18,000 and particle volume concentration contributions in the range of 0 and 1.0 vol. % for Nusselt number and 0 and 2.0 vol. % for friction factor.

\[ \text{Nu}_{nf} = 0.074 \text{Re}_{nf}^{0.707} \text{Pr}_{nf}^{0.385} \varphi^{0.074} \]  
\[ f = 0.961 \varphi^{0.052} \text{Re}^{-0.375} \]  

Where

- \( f \) is friction factor.

Sajjadi and Kazemi, 2011 investigated the heat transfer behavior of TiO$_2$ (30 nm) – water nanofluid up to 0.25 vol.% in a circular pipe at 5000 < Reynolds < 30000. The results indicated that the addition of small amounts of nanoparticles to the base fluid augmented heat transfer remarkably, also it can be seen that the heat transfer enhancement have a small variation with increasing the volume fraction of nanoparticles. The pressure drop of nanofluid was slightly higher than that of the base fluid and increased with increasing volume concentration.

The effects of the Peclet number (between 20,000 and 60,000) and volume concentration of c-Al$_2$O$_3$ (25 nm)–water and TiO$_2$ (10 nm)-water nanofluids in a shell and tube heat exchanger were investigated. The maximum nanoparticle volume fraction of Al$_2$O$_3$ was 2%, and 0.75% for TiO$_2$. Based on their results, adding nanoparticles to the base fluid causes a significant enhancement of heat transfer characteristics. Two different optimum nanoparticle concentrations exist; for TiO$_2$ nanoparticles, it was 0.3 vol.% (Abbasian and Amani, 2012).

Jin et al., 2007 studied on the heat transfer of TiO$_2$-water nanofluid in a vertical pipe. The maximum Re number was 6000 and the maximum nanofluid concentration was 1.18% vol. The results show that the heat transfer of nanofluid enhances up to 40%.

In the present study, heat transfer coefficient of TiO$_2$ nanoparticles in base fluids of water in the temperature ranges of 20-60°C at 0.1% volume concentrations of nanoparticles, and the velocity has been changed in the range of 0.032 to 0.192 m/s was investigated. In additional these results the enhancement of heat transfer coefficient compares with published models in the literature.

**Experimental Procedures**

**Preparation of nanofluids**

Titanium dioxide nanoparticles, anatase, with an average diameter of 10 nm were used in the this work (ordered from USAnanomaterials Co.). TiO$_2$ nanoparticles with 0.1% volume concentrations were dispersed in DDW and ethanol based fluids. The
suspensions of nanofluids were stirred and agitated for 15 min with an ultrasonic Homogenizer of 1200W power. In order to ensure uniform dispersion of nanoparticles in the base fluid. Table 1 shows the physical properties of TiO₂ nanoparticles.

Table 1: Properties of TiO₂ Nanoparticle

<table>
<thead>
<tr>
<th>Average particle diameter, nm</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purity, %</td>
<td>99.99</td>
</tr>
<tr>
<td>Density, kg/m³</td>
<td>3900</td>
</tr>
</tbody>
</table>

Thermo-physical properties of nanofluid

The thermo-physical properties such as, thermal conductivity was measured using a KD2 Pro in thermal property analyzer (Decagon Devices, Inc., Pullman, WA, USA). The sensor needle of KD2 consists of both elements of calefactory and a thermostat. The module of controller consists a battery, a 16-bit microcontroller/AD converter, and control circuitry of power. The viscosity was measured using Brookfield programmable viscometer (model: LVDV-II+, Brookfield Engineering Labs., Inc, Middleboro, MA, USA). Density and specific heat of the nanofluid are calculated using the following correlations (Pak and Cho, 1998 and Wang and Choi, 1999)

$$\rho_{nf} = \phi \rho_p + (1 - \phi) \rho_f$$  \hspace{1cm} ... (4)

$$\rho_{nf} = \text{density of nanofluid, kg/m}^3$$

$$\rho_f = \text{density of base fluid}$$

$$\rho_p = \text{density of nanoparticles}$$

$$c_{p_{nf}} = \phi c_{p_p} + (1 - \phi) c_{p_f}$$  \hspace{1cm} ... (5)

$$c_{p_{nf}} = \text{Heat capacity of nanofluid, J/kg K}$$

$$c_{p_f} = \text{Heat capacity of base fluid}$$

$$c_{p_p} = \text{Heat capacity of nanoparticles}$$

Heat Transfer Experimental Apparatus

The thermal properties of the prepared nanofluids were tested by a laboratory scale heat exchanger. The experimental rig is shown schematically in Fig. 1. It comprises two flow loops (nanofluid and water flow loops), a heating unit to heat the nanofluid, temperature measurement system, chiller, two pumps in order to provide required flow rates, thermocouples, two flow meters and valves for controlling the flow rates and a test section. The test section made from copper tube is a 35 cm long by 23.5mm inner diameter. The experiments were done using a counter flow mode in a vertical tube and shell pipe heat exchanger, with a nanofluid of 0.1% volume concentration of TiO₂ in DDW. Nanofluid was circulated inside the inner tube while the water flows through the shell.

A chiller with a capacity of five liters were used to keep constant temperature at the inlet of the test section. The temperature measurements were taken at fluid inlet and exit positions after steady state has been reached. Steady state was decided when the temperatures remained constant with time for a period of 10 min. Many experimental runs were carried out for different temperatures and different velocities.
The outer tube was thermally isolated to reduce the heat loss from the system test section. The heat transfer test section is heated electrically by a DC power supply capable of delivering a maximum of 15.4 kW.

**Figure (1) Rig of the experimental heat exchanger**

**Heat transfer calculation**

The performance of heat transfer of nanofluid through the tube was distinct in terms of the convective heat transfer coefficient calculated as follows:

\[
Q_{nf} = m \cdot c_p (T_i - T_i) \quad \ldots (6)
\]

where \(Q_{nf}\) is the heat transfer rate of nanofluid, \(m\) is the mass flow rate of the nanofluid, \(T_i\) is the temperature inlet of the nanofluid, and \(T_o\) is the temperature outlet of the nanofluid. The heat transfer coefficient was calculated by

\[
h = \frac{Q_{nf}}{\pi d L \Delta T_{LMTD}} \quad \ldots (7)
\]

\(h\) is the heat transfer coefficient, \(\Delta T_{LMTD}\) is the log mean temperature difference which can be calculated for counter current flow as

\[
\Delta T_{LMTD} = \frac{(T_{l, shell} - T_{o, tube}) - (T_{o, shell} - T_{o, tube})}{\ln \left(\frac{T_{l, shell} - T_{o, tube}}{T_{o, shell} - T_{o, tube}}\right)} \quad \ldots (8)
\]

Nusselt number of nanofluid is defined as

\[
Nu_{nf} = \frac{h d}{k} \quad \ldots (9)
\]

which is a function of velocity (Reynolds number) and physical properties

\[
Nu = f(Re, Pr) \quad \ldots (10)
\]

Re is the Reynolds number and Pr is the Prandtl number which are defined as:

\[
Re = \frac{\rho u d_i}{\mu} \quad \ldots (11)
\]

\[
Pr = \frac{c_P \mu}{k} \quad \ldots (12)
\]

Also Peclet number can be expressed as...
Study The Convective Heat Transfer of TiO$_2$ / Water Nanofluidin Heat Exchanger System

\[
\text{Pe} = \frac{ud_i}{\alpha} \quad \text{... (13)}
\]

\[
\alpha = \frac{k}{\rho C_p} \quad \text{... (14)}
\]

Pe is peclet number, $d_i$ is the inner diameter of tube, $\alpha$ is thermal diffusivity, $\mu$ is the viscosity of fluid, $\rho$ is density, $C_p$ is specific heat, $u$ is velocity and $k$ is thermal conductivity.

**Results and Discussion**

Figures 2 shows the values of the Nusselt number calculated at different values of Reynolds number (different flow rates) for the base fluid only (water) at three different inlet temperature. It is obvious that increasing of the Nusselt number with the increase in velocity and the rate of increase becomes less steep at large values of the Reynolds number. The corresponding results for using nanofluid are shown in Fig.3. The general influence of Reynolds number and inlet temperature is the same, but it is obviously that the Nusselt number of the base fluid is lower than that of the nanofluid. In Fig. 4 a comparison was made between base fluid and nanofluid at the same temperature. It is observed that in the Reynolds number value of 1500, Nusselt number was enhanced by about 9% as compared to base fluid at 60ºC. At larger values of the Reynolds number (when the flow rates increase the flow converted from laminar to turbulent), the enhancement was larger as shown in Fig. 4 where The Nusselt number enhanced by 17% compared to the base fluid at Reynolds number 9000 and 60ºC.

The convection transfer of heat caused through the existence of the nanoparticle is credited to the interaction of nanoparticle with the wall in addition to the interaction with the surrounding fluids. It was observed by Giraldo, 2008, that the connections involving nanoparticles and walls of solid plays a significant function in the transfer of convection of heat a nanofluid. The nanoparticles, helping as ‘carrier of heat’, regularly conflict with the wall of the tube. The interaction and clash amidst nanoparticles with the wall develop into recurrent, and this reason a greatly high transfer of heat coefficient and Nusselt number.

![Figure (2) The Nusselt vs Reynolds number of pure water at different temperature.](image)

1324
Study The Convective Heat Transfer of TiO$_2$ / Water Nanofluid in Heat Exchanger System

Figure (3) The Nusselt vs Reynolds number of TiO$_2$ NPs/ water at different temperature.

Figure (4) The Nusselt vs Reynolds number of base DDW and TiO$_2$ nanofluid at different temperature.

Figures 5 and 6 show that the Nusselt numbers of the DDW and nanofluid with Peclet numbers under different temperature respectively. The results showed the Nusselt number increases with temperature. Fig. 7, it is clear that the nanofluids show higher Nusselt number than those of the base fluids and enhancement increases with temperature. For example, in Peclet number about 29,378 the enhancement of the Nusselt number for TiO$_2$/water nanofluid under 60$^\circ$C is 17%.
Study The Convective Heat Transfer of TiO$_2$/Water Nanofluid in Heat Exchanger System

Figure (5) The Nusselt vs Peclet number of DDW at different temperature.

Figure (6) The Nusselt vs Peclet number of TiO$_2$/DDW at different temperature.

Figure (7) The Nusselt vs Peclet number of base DDW and TiO$_2$ nanofluid at different temperature.

Figure 8 shows the convective heat transfer coefficient of base fluid and TiO$_2$/water nanofluid with the different velocity. The experimentations explain that the suspended nanoparticles extraordinarily enhance performance of the base fluid.
transfer of heat, and the nanofluid of TiO$_2$/water has a better heat transfer coefficient compared with pure water in the similar Reynolds number. As contrasted with water, the convective heat transfer coefficient of nanofluid has improved to 37% for the nanofluid at 0.192 m/s under 60ºC. The improved transfer of heat with the nanofluid may be caused by the subsequent two parts: One is that increased the thermal conductivity of the mixture of two-phase by using the suspended particles and the other type is that accelerated the process of energy exchange in the fluid of by messy motion of ultra fine particles, [LI Qiang, 2002].

![Figure (8) Heat transfer coefficient of nanofluid Vs velocity of base DDW and TiO$_2$ nanofluid at different Temperature](image)

According to the results that are shown in figure 9, it can be observed that the Nusselt number increase for increasing the Reynolds number. As well, the comparison was prepared between the experimental data and two well-known empirical correlations: one of them optional by [Xuan and Li, 2003], and the other developed by Duangthongsuk and Wongwises, 2010]. These two relations were shown in Eqs. (1) and (2) respectively.

![Figure (9) Comparison between the experimental results and calculated values from correlation.](image)

**Conclusions**

The enhancement of heat transfer due to the TiO$_2$ nanoparticles was presented in the water fluid. Heat transfer coefficient increased by the increasing the flow rate and the
Study The Convective Heat Transfer of TiO$_2$ / Water Nanofluid in Heat Exchanger System

temperature. The forced convective heat transfer coefficients are dependent on Reynolds and Prandtl numbers which in turn are dependent on the nanofluid properties. The presence of TiO$_2$ nanoparticles in fluid changes the flow structure besides of thermal conductivity increment, chaotic movements, dispersions and fluctuations of nanoparticles, especially near the tube wall leads to increase in the energy exchange rates and augments heat transfer rate between the fluid and the tube wall. The increase in heat transfer coefficient due to the presence of TiO$_2$ nanoparticles is much higher than the conventional fluids and hence the shell and tube heat exchanger using nanofluid as a heating has a higher heat transfer rate than the conventional shell and tube heat exchanger. For example nanofluid with 0.1% TiO$_2$ nanoparticle volume concentration possesses at 60°C, 0.192m/s about 37% and 17% higher convective heat transfer coefficient and Nusselt number, respectively.

Acknowledgement
The authors would like to acknowledge the assistance offered by Nanotechnology and Advanced Materials Research Unit (NAMRU), College of Engineering /University of Kufa/IRAQ.

Reference
[10] US Research Nanomaterials, Inc. The Advanced Nanomaterials Provider 3302 Twig Leaf Lane, Houston, TX 77084, USA Phone: 832-460-3661, Fax: 281-492-8628 E-mail: Service@us-nano.com; Tech@us-nano.com Website: www.us-nano.com