Eng. &Tech.Journal, Vol.33, Part (B), No.7, 2015

Study The Convective Heat Transfer of TiO_2 /Water Nanofluid in Heat Exchanger System

The 5th International scientific Conference on Nanotechnology& Advanced Materials Their Applications (ICNAMA 2015) 3-4 Nov, 2015

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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 60^0C.

Keyword: Nanofluids,Thermal conductivity, Viscosity, TiO_2 nanoparticles

دراسة نقل الحمل الحراري للمائع النانوي اوكسيد التيتانيوم/ ماء في نظام مبادل الحرارة

الخلاصة

وقد تم تحقيق تحسينات في معامل انتقال الحرارة و رقم نسلت في نظام المبادل الحراري باستخدام ثاني أكسيد التيتانيوم (TIO_2) النانوية مع متوسط قطرهامن 10 نانومتر. TIO_2 النانوية / الماء له الموصلية الحرارية بشكل أفضل مقارنة مع السوائل العمل التقليدية (المياه). وتتدفق في رأسي قذيفة وأنبوب مبادل حراري تدفق العداد تحت تدفق الطباقي وظروف التدفق المضطرب وتم التحقيق. وقد اختلفت معدل تدفق السائل في مجموعة من (50-300) لتر / ساعة داخل درجة حرارة مدخل من (20-60) درجة مئوية. أجريت آثار العوامل مثل عدد رينولدز وعدد peclet على نقل الحرارة وتدفق الخصائص من والتحقيق فيها. ولوحظ أن الانتقال الحراري زاد بشكل ملحوظ مع زيادة درجة الحرارة تحت قيم مختلفة من عدد رينولدز. وكذلك، ارتفع عدد نسلت حوالي 17٪ بالمقارنة مع المياه النقية؛ في حين تم زيادة معامل انتقال الحرارة حوالي 37٪ بالمقارنة مع الماء النقي الذي هو 0.0192 م / ث تحت C600.

الكلمة المفتاحية : Nanofluids ، الموصلية الحرارية، النانويةاللزوجة، TIO_2

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 Mehta1, 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., 2010calculated the characteristics of heat transfer of γ-Al_2O_3-water andTiO_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 Pecletnumber compared to the base fluid. Their results for Nusselt number of γ-Al_2O_3-water and TiO_2/water nanofluids were compared to that predicted by the correlation of Xuan and Li correlation Eq.1 below.

$$\mathrm{Nu}_{\mathrm{nf}} = 0.0059\left(1 + 7.6286\,\Phi^{0.6886}\,\mathrm{Pe}_{\mathrm{d}}^{0.001}\right)\mathrm{Re}_{\mathrm{nf}}^{0.9238}\mathrm{Pr}_{\mathrm{nf}}^{0.4} \qquad \dots (1)$$

Where

Φ is volume concentration, %, $\mathrm{Nu}_{\mathrm{nf}}$is Nusselt number, $\mathrm{Re}_{\mathrm{nf}}$is Reynolds number, Pe is Peclet number, $\mathrm{Pr}_{\mathrm{nf}}$is the Prandtl number of nanofluid.

The results showed that at 0.5 vol. % of γ-Al_2O_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 numberfor 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 nanoparticleswith 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 Nusseltnumber 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.

$$\mathrm{Nu_{nf}} = 0.074\mathrm{Re_{nf}^{0.707}}\mathrm{Pr_{nf}^{0.385}}\varphi^{0.074} \qquad \ldots(2)$$

$$\mathrm{f} = 0.961\ \varphi^{0.052}\mathrm{Re}^{-0.375} \qquad \ldots(3)$$

Where
f is friction factor.

Sajadi and kazemi, 2011 investigated the heat transfer behavior of TiO_2 (30 nm) – water nano fluid 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_2O_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_2O_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^{o}C at 0.1% volume concentrations of nanoparticles, and the velocity has been changed in the range of0.032 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_2nanoparticles with 0. 1% volume concentrations were dispersed inDDW 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 TiO_2 nanoparticles.

Table (1) Properties of TiO_2 Nanoparticle

Average particle diameter, nm	10
Purity, %	99.99
Density, kg/m^3	3900

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**)**

$$\rho_{nf} = \emptyset\rho,_{p} + (1-\emptyset)\rho,_{f} \qquad \dots(4)$$

ρ_{nf} = density of nanofluid, kg/m^3

ρ_p = density of nanoparticles

ρ_f = density of base fluid

$$cp_{nf} = \emptyset cp,_{p} + (1-\emptyset)cp,_{f} \qquad \dots(5)$$

cp_{nf} = Heat capacity of nanofluid, J/kg K

$c\rho_p$ = Heat capacity of nanoparticles

$c\rho_f$ = Heat capacity of base fluid

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 TiO_2 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.

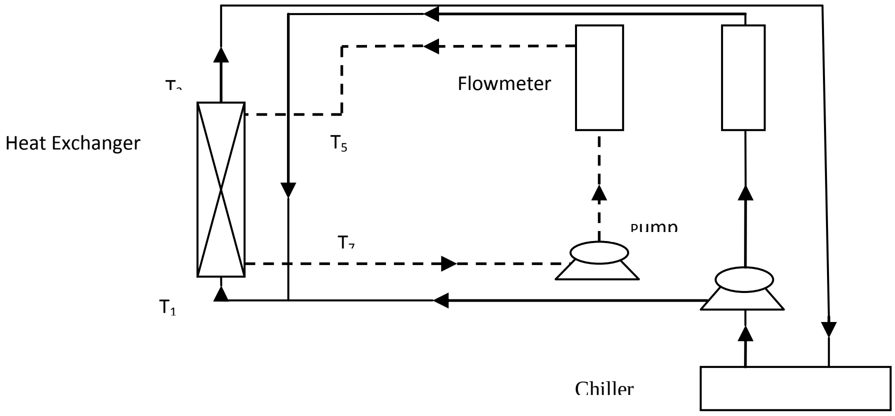

Figure (1) Rig of the experimental heat exchanger

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:

$$Q_{nf} = \dot{m}\,cp(T_{\circ} - T_i) \qquad \ldots (6)$$

Q_{nf}isheat transfer rate of nanofluid**,** $\dot{m}$ **is** mass flow rate of the nanofluid, T_i is a temperature inlet of the nanofluid, T_o is temperature outlet of the nanofluid. The heat transfer coefficient was calculated by

$$h = \frac{Q_{nf}}{\pi d L \Delta T_{LMTD}} \qquad \ldots (7)$$

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

$$\Delta T_{LMTD} = \frac{\left(T_{i,shell} - T_{O,tube}\right) - \left(T_{O,shell} - T_{O,tube}\right)}{LN\left(T_{i,shell} - T_{O,tube}\right)/\left(T_{O,shell} - T_{O,tube}\right)} \qquad \ldots (8)$$

Nusselt number of nanofluid is defined as

$$Nu_{nf} = \frac{hd}{k} \qquad \ldots (9)$$

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

$$Nu = f\,(Re, Pr) \qquad \ldots (10)$$

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

$$Re = \frac{\rho u d_i}{\mu} \qquad \ldots (11)$$

$$Pr = \frac{cp\mu}{k} \qquad \ldots (12)$$

Also Peclet number can be expressed as

$$\mathrm{Pe} = \frac{u d_i}{\alpha} \quad \dots (13)$$

$$\alpha = \frac{k}{\rho c p} \quad \dots (14)$$

Pe is peclet number, d_i is the inner diameter of tube, α is thermal diffusivity, μ is the viscosity of fluid, the, ρ is density, Cp 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 nanoprticles with the wall develop into recurrent, and this reason a greatly high transfer of heat coefficient and Nusselt number.

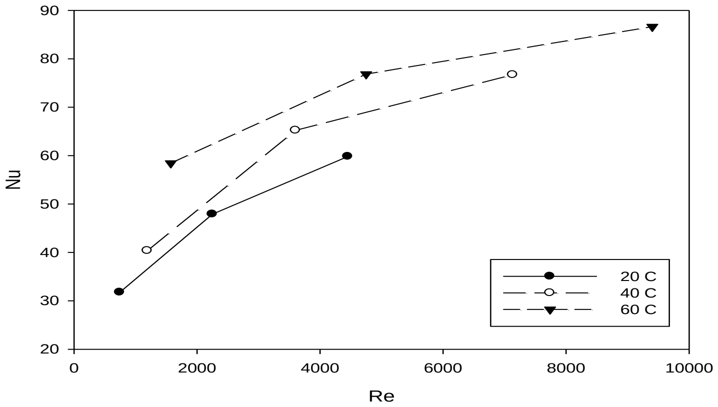

Figure (2) The Nusselt vs Reynolds number of pure water at different temperature.

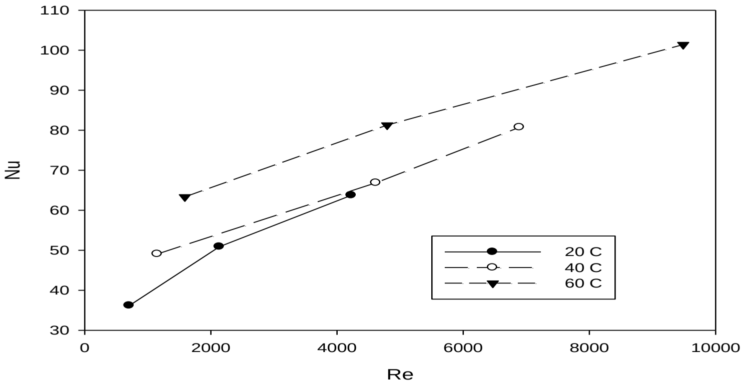

Figure (3) The Nusselt vs Reynolds number of TiO_2 NPs/ water at different temperature.

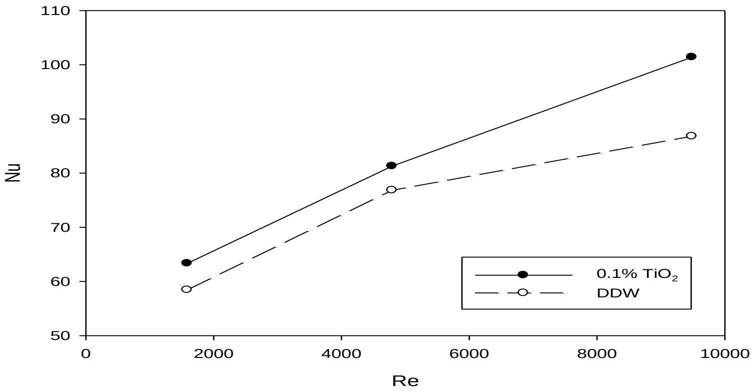

Figure (4) The Nusseltvs Reynolds number of base DDW and TiO_2nanofluid at different temperature

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 60ºC is 17%.

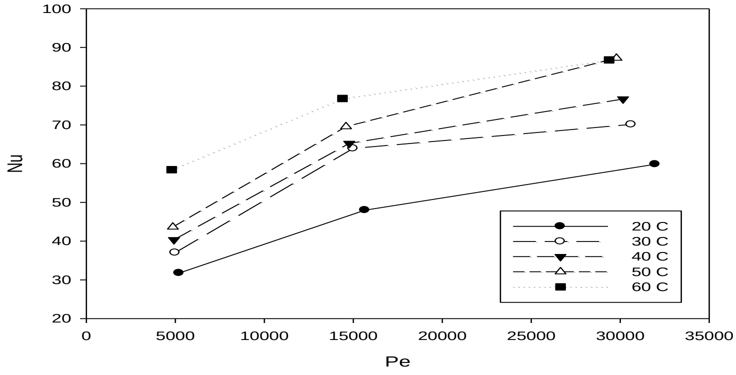

Figure (5)The NusseltvsPeclet number of DDW at different temperature.

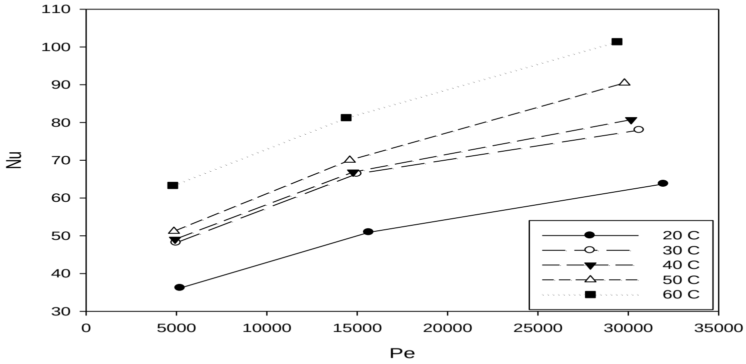

Figure (6)The Nusselt vs Peclet number of TiO_2 / DDW at different temperature.

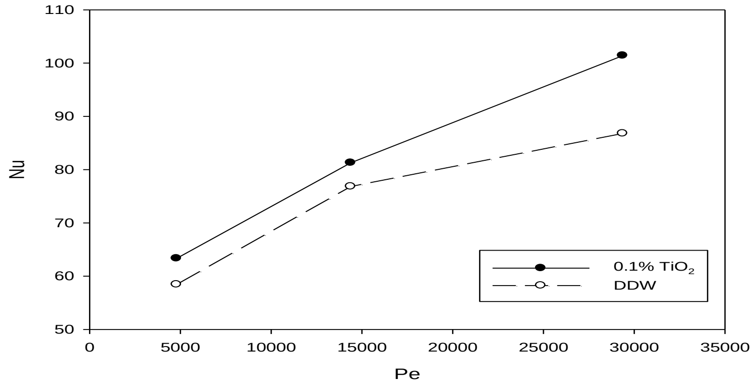

Figure (7)The NusseltvsPeclet number of base DDW and TiO_2nanofluid at different temperature..

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].

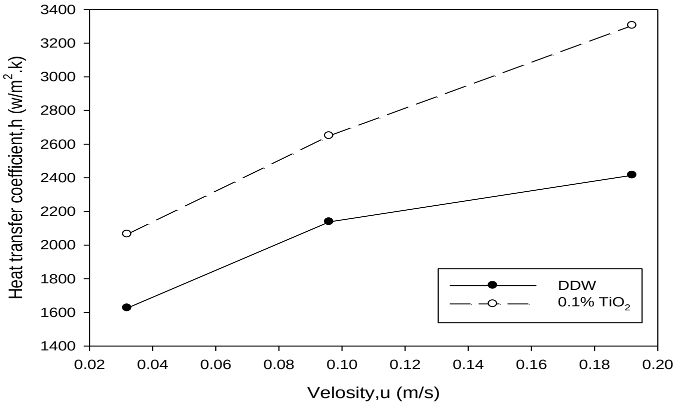

Figure (8) Heat transfer coefficient of nanofluid Vs velocity of base DDW and TiO_2 nanofluid at different Temperature

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.

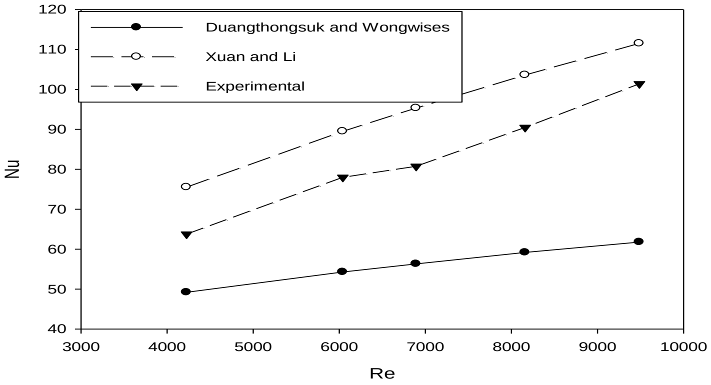

Figure (9) Comparison between the experimental results and calculated values from correlation.

Conclusions

The enhancement of heat transfer due to the TiO_2 nanoparticles waspresented in the water fluid. Heat transfer coefficient increased by the increasing the flow rate and the 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 60ºC, 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

[1] Abbasian Arani, A. A. and Amani, J., "Experimental study on the effect of TiO_2–water nanofluid on heat transfer and pressure drop", Experimental Thermal and Fluid Science, Vol. 42, 107-115, (2012).

[2] Alpesh M., Dinesh k Tantia , Nilesh M Jha , Nimit M Patel, "Heatexchangerusing nanofluid", International Journal of Advanced Engineering Technology, Vol.III, 49-54, (2012).

[3] Bianco, V., Manca, O. and Nardini, S., "Numerical investigation on nanofluids turbulent convection heat transfer inside a circular tube", International Journal of Thermal Sciences, Vol. 50, No. 3, 341-349, (2011).

[4] Duangthongsuk, W., Wongwises S., "An experimental study on the heat transfer performance and pressure drop of TiO2–water nanofluids flowing under a turbulent flow regime", Int. J. Heat Mass Transfer, No. 53, pp. 334– 344, 2010.

[5] Farajollahi B., Etemad S.Gh., Hojjat M., " Heat transfer of nanofluids in a shell and tube heat exchanger", 53, 12 – 17, (2010).

[6] Giraldo, M., Ding, Y. and William, R.A., "Boundary integral study of nanoparticle flow behavior in the proximity of a solid wall, J. of Physics D", Applied Physics, Vol. 41, No. 8, 085503, (2008).

[7] Jin, Y., He, Y., Chen, H., Ding, Y., Cang, D., Lu, H. , "Heat transfer and flow behaviour of aqueous suspensions of TiO_2 nanoparticles (nanofluids) flowing upward through a vertical pipe", Int. J. Heat Mass Transfer, No. 50, pp. 2272– 2281, (2007).

[8] LI Q., XUAN Y."Convective heat transfer and flow characteristics of Cu-water nanofluid", Vol. 45 No. 4, (2002).

[9] Pak, B. C. and Cho, Y. I. , "Hydrodynamic And Heat Transfer Study Of Dispersed Fluids With Submicron Metallic Oxide Particles." Experimental Heat Transfer, 11, 151-170, (1998).

[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

[11] Sajadi, A. R. and Kazemi, M. H., "Investigation of turbulent convective heat transfer and pressure drop of TiO2/water nanofluid in circular tube", International Xuan Y. and Li Q., “Heat transfer enhancement of nanofluids,” International Journal of Heat and Fluid Flow, vol. 21, no. 1, pp. 58–64, (2000).

[12] Zawrah M.F., Khattab R.M., Girgis L.G., El Daidamony H., Rehab E. Abdel Aziz, "Stability and electrical conductivity of water-base Al_2O_3nanofluids for different applications’ HBRC Journal (2015).