IJCPE
Iraqi Journal of Chemical and Petroleum Engineering

Iraqi Journal of Chemical and Petroleum Engineering
Vol.18 No.4 (December 2017) 15 - 23
ISSN: 1997-4884

University of Baghdad
College of Engineering

Study and Analysis of Concentric Shell and Double Tube Heat Exchanger Using Tio_2 Nanofluid

Bassma Abbas Abdulmajeed and Noor Sabih Majeed
College of Engineering- University of Baghdad

Abstract

In this paper, nanofluid of TiO_2/water of concentrations of 0.002% and 0.004% volume was used. This nanofluid was flowing through heat exchanger of shell and concentric double tubes with counter current flow to the hot oil. The thermal conductivity of nanofluid is enhanced with increasing concentrations of the TiO_2, this increment was by 19% and 16.5% for 0.004% and 0.002% volume respectively relative to the base fluid (water). Also the heat transfer coefficient of the nanofluid is increased as Reynold's number and nanofluid concentrations increased too. The heat transfer coefficient is increased by 66% and 49% for 0.004% and 0.002% volume respectively relative to the base fluid. This study showed that the friction factor of nanofluid was decreased as Reynold's number increased.

Key words: nanofluid, TiO_2/water, shell and double tube heat exchanger, enhanced thermal conductivity, enhanced heat transfer coefficient.

Introduction

Nowadays, the world is experiencing many confronts in with heat transfer problems in different engineering processes. To increase heat transfer, many investigators found that nanofluid is one of the suitable coolant which increase the efficiency of various engineering instruments. The nanofluids are the perfect fluids for rapid heating and cooling. [1, 2]

Choi and Eastman in 1990 are the first who started to study nanofluids. Later many researchers continued their studies comprising different nanoparticles such as Al_2O_3, TiO_2 and CuO. [3, 4]

Pak and Cho, 1998 studied the effect of Al_2O_3/water and TiO_2/water nanofluids of concentration 3%volume flowing into horizontal tube, they found that the Nusselt number was increased with increasing volume concentration of nanofluid and Reynold's number was increased too [5]. Ding et al, 2007 investigated the TiO_2/EG nanofluid in forced convection.

The heat transfer coefficient was enhanced relative to base fluid, because of the thermal conduction enhancing [6]. Duangthongsuk and Wongwises, 2009 studied the effect of TiO_2/water nanofluid in a heat exchanger of concentration of 0.2%.

The higher temperature affected the nanofluid working in heat exchanger.

They found that the heat transfer coefficient was increased when the temperature of the nanofluid was low [7]. Yannar et al, 2011 studied different types of nanofluids (Al_2O_3/water, TiO_2/water and CuO /water) of different concentration 1%, 1% and 3% respectively, of spiral pipe heat exchanger. The heat transfer coefficient increased by 28% of 0.8% concentration [8]. Kavitha et al, 2012 studied the effect of TiO_2/water nanofluid used in the transient hot wire device. The thermal conductivity of nanofluid was increased by using spherical shape nanoparticles. The thermal conductivity depended on some factors such as: size, shape and stability of nanofluids [9].

Arani and Amani, 2012 studied the effect of TiO_2/water nanofluid of concentration range from 0.002 to 0.02 by volume and the particle size of 30nm in a double pipe heat exchanger of counter current arrangement. They found that the Nusselt number increased as Reynold's number increased [10]. Abdul Hamid et al, 2015 studied the effect of TiO_2/water-EG (Ethylene glycol) in volume ratio 60: 40 nanofluid of three concentrations of 0.5%, 1% and 1.5% on the pressure drop in a horizontal tube, they found that the pressure drop was increased with the increasing volume concentration and decrease with increasing the temperature of nanofluid [11]. They studied the effect of TiO_2/water of particle size 50nm of three concentrations 0.5%, 1% and 1.5% on heat transfer coefficient. The maximum enhancement was by 22.75% and 28.92% at temperature of 50°C and 70°C at concentration of 1.5% concentration [12].

In this study, investigating the TiO_2/ water nanofluid of two volume concentrations of 0.002, 0.004% of 50 nm particle size in shell and double concentric tubes heat exchanger in turbulent flow region was accomplished.

Experimental Setup

The shell and double concentric tubes heat exchanger constructed by [13] was used in this work.

Three streams of fluids were designed to work in the shell and double concentric tube heat exchanger, two flows as hot fluids and one cold nanofluids in the opposite direction.

The heat exchanger had a (1.3m) length and with effective tube length of (1.08m). The shell inner diameter is (203mm), and the shell outer diameter is (220mm). Baffles of thickness (6mm) were spaced by distance of (100mm). The inner tubes were made of carbon steel, with (20mm) inside diameter and (25mm) outside diameter.

They were divided as triangular (30°) tube pattern. The clearance between two adjacent tubes is (6.25mm), and the tubes pitch is (31.25mm). A second group of 16 carbon steel tubes of (6mm) inside diameter and (10mm) outside diameter, as concentric inner tubes, were used to offer two passes tube side.

Preparation of Nanofluid

Nanofluids were prepared by two step method of preparation. The nanopowders are dispersed in the water (base fluid) at specific concentrations (0.002 and 0.004) % by volume. The nanopowders were weighed by using electronic balance in the hood of laboratory to avoid the pollution with nanoparticles.

A 250 litter of nanofluids were prepared each time using a speed homogenizer (Ultra – Turax Janke &Kunkel KG) to keep the nanoparticles in motion.

This motion stabilizes the suspension and prevents the agglomeration and sedimentation. The shear mixing device is of 10000 rpm. The mixing continued for 2 hours. The shear agitation continued for 48 hours. The densities of nanofluid and oil were measured by pcknometer of 10 ml, while the viscosities were measured by viscometer ASTM D445 Viscometer Bath.

The thermal conductivities for nanofluid and oil was measured by KD2 Pro thermal property analyzer (decagon Device, Pullman, WA, USA). The temperature at which the thermal conductivity of nanofluid was measured was 25°C, while for oil ranged as (85, 75, 65, 55 °C**).**

Procedure

The cold feed or nanofluid tank is of capacity of 300 litter and was supported by a mixer on the top to prevent coagulations and sedimentation of nanoparticles. The mixer has three paddles of width (20cm) and (3mm) thickness, with a speed of (100 rpm).

A centrifugal pump (Type, SP24T) was used to pump the nanofluids. The nanofluid enters the heat exchanger at the annulus side between the shell and inner tubes, and exits from the exchanger to the collector tank.

The nanofluid returns back to the main tank, where it was left for a certain period of time for cooling it to the desired temperature and it's was measured using a portable thermocouple (type k). The hot feed (oil) was entered in a tank with square front face provided by two heaters to reheat the oil at the desired temperature with a thermostat connected to the controlling board to control the temperature.

The oil has been pumped by centrifugal pump with provided by gate valve on the pipes before enter to the flow meter. The feed is divided into two parts supported by pressure gauge at the inlet and outlet of the exchanger.

A second tank was used to collect the oil, which gets out from the heat exchanger. The two oil streams were provided with two thermocouples type (K) to record the temperature for both shell and inner tubes of heat exchanger.

On the cold feed side, the nanofluid is pumped and the oil centrifugal pump is started at the same time at the desired flow rates of both fluids. When the flow of both fluids were in a steady state, the cold side nanofluid flow was at rate of (45) l/min and a temperature of 20 °C, while the hot oil was pumped at varied flow rates (30, 40, 50) l/min, and at in temperatures between 85 °C to 55 °C.

The pressures are recorded at the inlet and outlet of the heat exchanger for both pipe and shell sides, annulus tube and inner tubes. The procedure is repeated for flow rate of cold nanofluid in the annulus side as (15, 25, 35) l/min with fixed temperature of 20 °C.

This step was repeated after changing the setting of thermostat by 10 °C step for temperature of hot oil from 55 to 85°C. Fig.(1) shows the whole equipment's process.

Fig. 1, Rig of Experimental Process

The mass flow rate in the annulus of the concentric tube is a function of the density of the fluid, the velocity of the fluid, flow cross sectional area and the number of tubes, as in [13].

$$m_2 = \frac{\rho_2 u_2 A_{C2} N_t}{N_P} \quad \ldots (1)$$

where the inner flow cross sectional area of the annulus passages is:

$$A_{C2} = \frac{\pi}{4}\left(D_2^2 - d_1^2\right) \quad \ldots (2)$$

and (N_p) is the number of tubes per pass in the heat exchanger, u_2 the velocity of fluid in annulus, Reynolds number is calculated as follows:

$$\mathrm{Re}_2 = \frac{\rho_2 u_2 d_h}{\mu_2} \quad \ldots (3)$$

The hydraulic diameter of the annulus is:

$$d_h = D_2 - d_1 \quad \ldots (4)$$

to calculate the Prandtl Number:

$$\mathrm{Pr}_2 = \frac{\mu_2 Cp_2}{k_2} \quad \ldots (5)$$

By using Colburn equation, the Nusselt number, [14]:

$$\frac{hd_h}{k} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33} \quad \ldots (6)$$

The pressure loss inside tubes of circular cross section or annulus passage in a shell and double concentric tube heat exchangers is the sum of the friction loss within the tubes and the turn losses between the passes of the exchanger.

$$\Delta P_2 = \left(4 f_2 \frac{LN_p}{d_h} + 4N_p\right)\frac{\rho_2 u_2^2}{2} \quad \ldots (7)$$

and the friction factor in annulus passages:

$$f_2 = 0.316\,\mathrm{Re}^{-0.25} \quad \ldots (8)$$

For 2300 $<$Re $<10^5$

Overall heat transfer coefficient U_{12} between (the fluid in the shell side and fluid in the annulus passage), [15].

$$U_{12} = \frac{1}{\dfrac{D_2}{D_1 h_1} + \dfrac{D_2}{2k_w}\ln\dfrac{D_1}{D_2} + \dfrac{1}{h_2}} \quad \ldots (9)$$

The second overall heat transfer coefficient U_{23} between (the fluid in the annulus passage and the fluid in the inner tube side), [15].

$$U_{23} = \frac{1}{\dfrac{d_2}{d_1 h_2} + \dfrac{d_2}{2k_w}\ln\dfrac{d_1}{d_2} + \dfrac{1}{h_3}} \quad \ldots (10)$$

Results and Discussion

Thermal Conductivity of Nanofluid

The thermal conductivity of nanofluid increased due to the thermal properties of nanoparticles which has higher thermal conductivity than water [16]. For 0.002% volume of TiO_2, the thermal conductivity was increased by 16.5% from the base fluid at temperature of 25°C and that is due to the stable nanofluids preparation as in [17].

By doubling the concentration of the titanium oxide, the thermal conductivity was increased by increasing the concentration of nanoparticles by 19% from the base fluid (water). This is in agreement with [18]. Table (1) shows the values of thermal conductivities of base fluid and nanofluid with titanium oxide nanoparticles.

Table 1, thermal conductivity of TiO_2/water

Fluids	TiO_2 Concentration%	Thermal conductivity K (W/m.k)
Base fluid (water)	0	0.612
TiO_2/water	0.002	0.713
	0.004	0.724

The Effect of Nanofluid on Heat Transfer Coefficient

The heat transfer coefficient of nanofluid increased as Reynold's number increased, and this is due to enhancing of thermal conductivity of TiO_2 nanofluid.

Also the Brownian motion of the nanoparticles in the base fluid promoted which led to the good distribution of these particles in the base fluid.

Figs. (2) and (3) showed that the heat transfer coefficient of two concentrations 0.002 % and 0.004% volume of TiO_2 increased as Reynold's number of nanofluids increased.

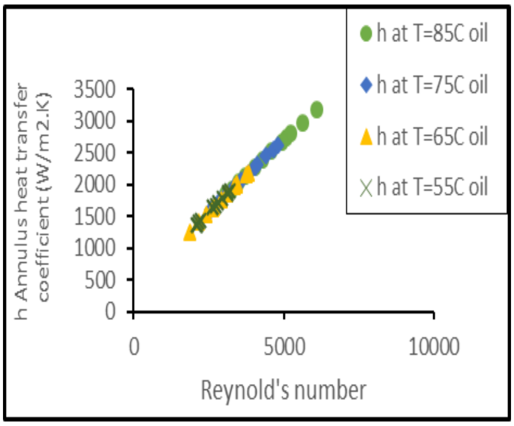

Fig. 2, Heat Transfer Coefficient of Nanofluid of TiO_2 of concentration 0.002 % against Reynold's number at different nanofluid flow rates of (15, 25, 35, 45) l/min with different temperatures of oil.

The maximum value of heat transfer coefficient was at temperature of 85 °C for oil. This is because of the large difference between the inlet temperatures of the two streams entering the heat exchanger. This agreed with Ehsan, 2016 [19]. The heat transfer coefficient of nanofluid increased as volume concentration of TiO_2 was increased. This agreed with Reza A., 2014 [20] of diffident flow rates of nanofluids (15, 25, 35, 45) l/min and different temperatures and flow rates of oil.

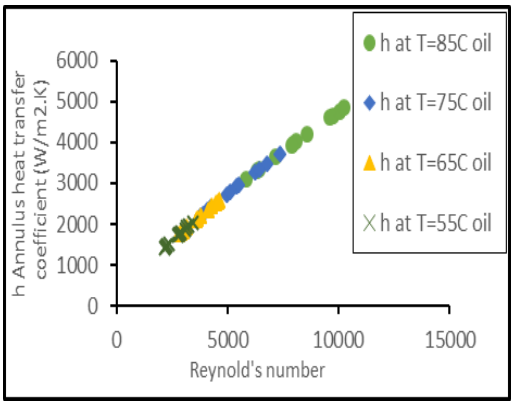

Fig. 3, Heat Transfer Coefficient of Nanofluid of TiO_2 of concentration 0.004 % against Reynold's number at different nanofluid flow rates of (15, 25, 35, 45) l/min with different temperatures of oil

Fig. (4) showed a comparison between three types of fluids, 0.002 % TiO_2, 0.004% TiO_2 and base fluid water. The figure shows that TiO_2 nanofluid of concentration 0.004% volume has high values of heat transfer coefficient with respect other fluids. This enhancement represented by 66% and 49% increase for 0.002 % TiO_2 and 0.004% TiO_2 respectively than the base fluid.

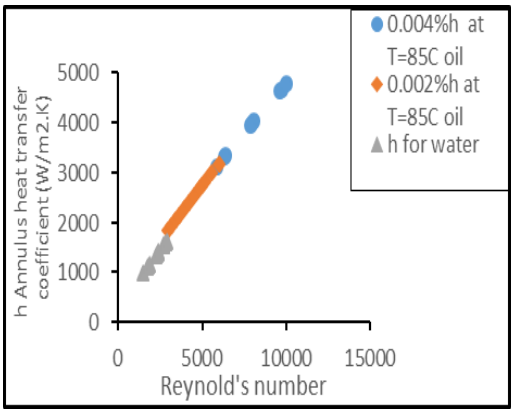

Fig.4, Heat Transfer Coefficient of different fluids Reynold's number at different nanofluid flow rates of (15, 25, 35, 45) l/min with temperatures of 85°C of oil

The Effect of Nanofluid on Friction Factor

The friction factor decreased as Reynold's number increased as shown in Figs. (5) and (6). This is due to the increasing in the flow velocity of nanofluids [21]. The friction factor was increased with increasing in concentration of nanoparticles. This is due to viscosity of nanofluids which increased with increasing of the nanofluids concentration that causes slow motion nanofluids namly increasing friction factor [22]. Figs. (5) and (6) shows that the friction factor was increased when the temperature of oil was decreased, at maximum flow rate of TiO_2 nanofluid of 45 l/min.

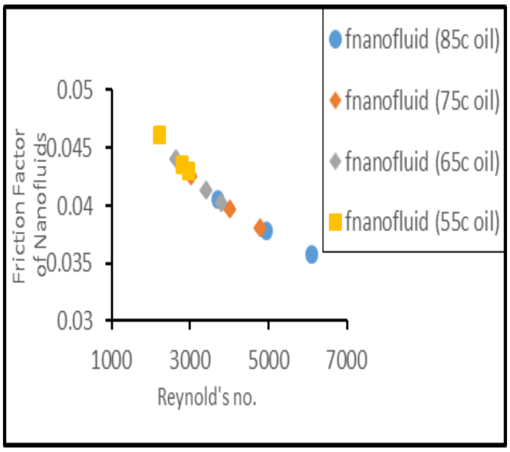

Fig. 5, Friction factor against the Reynold's Number at 0.002% volume of TiO_2 nanofluid of flow rate 45 (l/min) and different oil temperatures at constant flow rate of 50 (l/min)

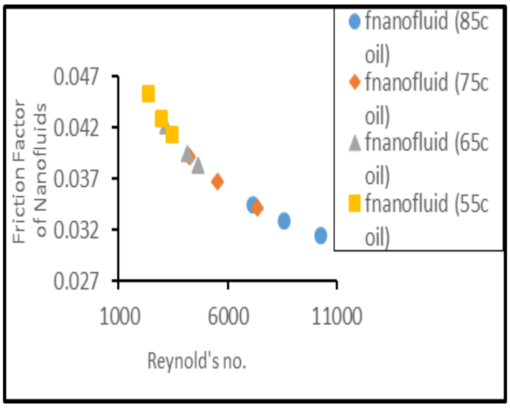

Fig.6, friction factor against the Reynold's Number at 0.004% volume of TiO_2 nanofluid of flow rate 45 (l/min) and different oil temperatures at constant flow rate of 50 (l/min)

In Fig. (7) the comparison between fluids showed that the base fluid water has higher friction factor followed by 0.002% of TiO_2 nanofluid and that was because of the lower Reynold's number of fluid compared to 0.004% TiO_2 nanofluid.

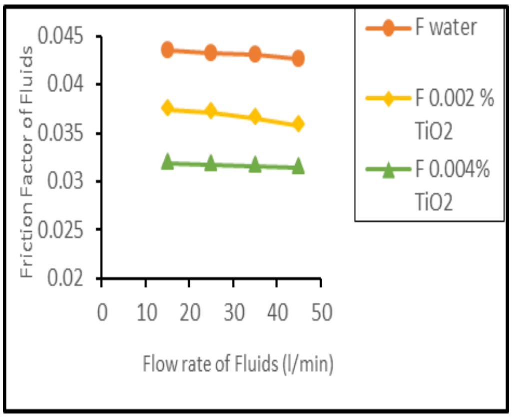

Fig. 7, friction factor against flow rate of nanofluids at constant oil flow rate 50 (l/min) and temperature of 85°C of different fluids and concentration.

Conclusion

1- The thermal conductivity of nanofluids increased with increasing in volume concentrations of TiO_2 nanoparticles at temperature of 20°C. The enhancement in thermal conductivities of 0.004% and 0.002% volume concentration for TiO_2/water nanofluids by 19% and 16.5% respectively over base fluid.

2- The heat transfer coefficient was increased as Reynold's number and volume concentration increased too. This enhancement of heat transfer coefficient for 0.004% and 0.002% of TiO_2/water nanofluids by 66% and 49% respectively from the base fluid.

3- Friction factor of nanofluids decreased as Reynold's number was increased. The friction factor of nanofluids are lower than the base fluid because the flow of the base fluid is in the laminar flow region, so that the high volume of friction factor was appeared.

Nomenclature

Symbol	Description	Units
A_c	Cross sectional area of the tube in conventional heat exchanger	m^2
C_p	Specific heat	J/kg.K
D	Diameter of the tube (first bundle) in new heat exchanger	m
d	Diameter of the inner tube (second bundle) in new heat exchanger	m
d_h	Hydraulic diameter of the annulus in the new heat exchanger	m
f	Friction factor	-
h	Heat transfer coefficient	$W/ m^2.K$
k	Thermal conductivity	W/m.°C
L	length of the heat exchanger	m
m	Mass flow rate	Kg/min
Nu	Nusselt number	$Nu = \frac{hd}{k}$
N_p	number of tubes per pass	-
N_t	total number of the tubes	-
Pr	Prandtl number	$\Pr = \frac{\mu Cp}{k}$
Re	Reynolds number	$\mathrm{Re} = \frac{\rho ud}{\mu}$
T	Temperature	°C
U	Overall heat transfer coefficient	$W/m^2 °C$
u	Fluid velocity	m/s

Greek Symbols

Units	Description	Symbol
ΔT	Temperature difference	°C
ρ	Density	kg/m^3
μ	Dynamic viscosity	kg/m.s
ΔP	Pressure drop	Pa

Subscript

Symbols	Description
1	Oil (shell side)
2	TiO_2/water (annulus side)
3	Oil (inner tube side)
12	shell and annulus
23	annulus and inner tube
f	Base fluid
nf	Nanofluid
t	Tube side
p	Nanoparticle

References

1- Rao G.S., Sharma K.V., Chary S.P., Bakar R.A., M.M. Rahman M.M., Kadirgama K. and Noor M.M., 2011," Experimental study on heat transfer coefficient and friction factor of Al_2O_3 nanofluid in a packed bed column", Journal of Mechanical Engineering and Sciences, Vol. 1, pp. (11-15).

2- Mahendran M., Lee G.C., Sharma K.V., Shahrani A., 2012," Performance of evacuated tube solar collector using water-based titanium oxide nanofluid", Journal of Mechanical Engineering and Sciences, Vol.3, pp. (301-310).

3- Choi U.S., 1995,"Enhancing Thermal Conductivity of Fluids with Nanoparticles", in: D.A. Siginer, H.P.Wang (Eds.) Developments and Applications of Non- Newtonian Flows, American Society of Mechanical Engineers (ASME), New York. pp. (99–105).

4- Eastman J.A., Choi S.U.S., Li S., Thompson L.J., Lee S., 1997," Enhanced Thermal Conductivity Through The Development of Nanofluids", in: Proc. Symposium Nanophase and Nanocomposite Materials II, Materials Research Society, Boston, MA. pp. (3–11).

5- Pak BC., Cho YI., 1998, "Hydrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles", Journal of Experimental Heat Transfer, Vol.11, Issue 2, pp. 151-170.

6- Ding Y, Chen H, He Y, Lapkin A, Yeganeh M, Šiller L, 2007," Forced convective heat transfer of nanofluids", Advanced Powder Technology, 18:813-24.

7- Duangthongsuk W, Wongwises S., 2009," Heat transfer enhancement and pressure drop characteristics of TiO_2/water nanofluid in a double-tube counter flow heat exchanger", International Journal of Heat and Mass Transfer, 52:2059-67.

8- Yanuar, Putra N., Gunawan S.M.Bagi, 2011," Flow and convective heat transfer characteristic of spiral pipe for Nano fluid", International Journal of Research and Reviews in Applied Sciences, IJRRAS 7(3).

9- KavithaT., Rajendren A., Durairajen.A, Syedabuthahir S., 2012. "Advanced heat transfer enhancement using titanium oxide-water based Nano fluid", International Journal of Management in Education, IJMIE, Vol. 2, Issue 4.

10- Arani A.A.A. and Amani J., 2012," Experimental study on the effect of TiO2–water nanofluid on heat transfer and pressure drop", Experimental Thermal and Fluid Science. Vol. 42, pp. (107-115).

11- Abdul Hamid1 K., Azmi1 W.H., Rizalman M., Usri1 N.A., Najafi G., 2015," Effect of Titanium Oxide Nanofluid Concentration on Pressure Drop", ARPN Journal of Engineering and Applied Sciences, Vol. 10, No. 17, pp. 7815- 7820.

12- Abdul Hamid K., Azmi1 W.H., Rizalman M., Usri1 N.A., Najafi G., 2015, "Effect of Temperature on Heat Transfer Coefficient of Titanium Dioxide in Ethylene Glycol-Based Nanofluid", Journal of Mechanical Engineering and Sciences (JMES) Vol.8, pp. 1367-1375.

13- Fadhil A.A., 2013, "Shell and Double Concentric Tubes Heat Exchanger Calculations and Analysis", A Thesis for Master of Science in Chemical Engineering, University of Baghdad.

14- Hewitt, G.F., Spires, G. L., and Bott, T. R., 1994, Process Heat Transfer, CRC Press.

15- Bougriou, C., Baadache, K., 2008, "Shell-and-Double Concentric Tube Heat Exchangers", Patent PCT, DZ2008/000002.

16- Seok P. J. and Stephen U. S. Ch., 2004, "Roles of Brownian motion in the Enhanced Thermal Conductivity of Nanofluids", Applied Physics Letters, Vol. 24, No. 21.

17- Ravi P., Paul M., Jacob F., Patrick Ph., Pawel K., 2006,"Effect of Aggregation on Thermal Conduction in Colloidal Nanofluids", Applied Physics Letters, Vol. 89.

18- Raghu G., Hongwei S., Pengtao W., Majid Ch. Fan G., Zhiyong G. and Bridgette B., 2010,"Effects of Particle Surface Charge, Species, Concentration, and Dispersion Method on the Thermal Conductivity of Nanofluids", Advances in Mechanical Engineering, ID 807610, 10 pages.

19- Ehsan E. B., Mohammad C. M., Hamid N.W., Weerapun D., Somchai W., 2016," Experimental and numerical investigation of nanofluids heat transfer characteristics for application in solar heat exchangers", International Journal of Heat and Mass Transfer, Vol. 92, pp. (1041–1052)

20- Reza A., Heydar M., Malihe Z., Mehdi D., and Sahar G., 2014," Heat Transfer of Nanofluid in a Double Pipe Heat Exchanger", International Scholarly Research Notices, Article ID 736424, 7 pages.

21- Vatsal. S. P., Ragesh. G. K., Dipak A. D., 2013,"An Experimental Study of Counter flow Concentric Tube Heat Exchanger using CuO / Water Nanofluid", International Journal of Engineering Research & Technology, Vol. 2 Issue 6, pp. (914- 920).

22- Adnan M. H., Sharma K. V., Bakar R. A., and Kadirgama K., 2013,"The Effect of Nanofluid Volume Concentration on Heat Transfer and Friction Factor inside a Horizontal Tube", Article ID 859563, 12 pages.