Study and Analysis of Concentric Shell and Double Tube Heat Exchanger Using γ- Al₂O₃ Nanofluid

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ABSTRACT

Heat exchanger is an important device in the industry for cooling or heating process. To increase the efficiency of heat exchanger, nanofluids are used to enhance the convective heat transfer relative to the base fluid. γ- Al_2O_3/water nanofluid is used as cold stream in the shell and double concentric tube heat exchanger counter current to the hot stream basis oil. These nanoparticles were of particle size of 40 nm and it was mixed with a base fluid (water) at volume concentrations of 0.002% and 0.004%. The results showed that each of Nusselt number and overall heat transfer coefficient increased as nanofluid concentrations increased. The pressure drop of nanofluid increased slightly than the base fluid because of the low concentration used.
Key words: heat exchanger, heat transfer, nanofluids, Nusselt number.

الدراسات والتحاليل للمبادل الحراري ذو القشرة والانابيب المتداخلة المتمركزة باستخدام مائع نانوي كاما اوكسيد الالمنيوم

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الخلاصة

للمبادل الحراري اهمية في الصناعة سواء في عملية التبريد او التسخين. لزيادة كفاءة المبادل الحراري استخدم المائع النانوي لتحسين انتقال الحرارة بالحمل بالمقارنة مع السائل الاعتيادي. تم استخدام السائل النانوي المتكون من كاما اوكسيد الالمنيوم مع ماء للتبريد في المبادل الحراري ذو الغلاف والانابيب المتداخلة والمتمركزة والذي يجري باتجاه عكسي مع تيار الزيت الساخن. هذه الدقائق النانوية ذات قطر 40 نانو متر، خلطت مع الماء بتراكيز حجمية 0.002 % مع 0.004 %. اظهرت النتائج ان عدد نسلت و معامل الانتقال الحراري الكلي قد ازداد بزيادة تركيز المادة النانوية. ان فرق الضغط للسائل النانوي قد ازداد زيادة طفيفة نتيجة استخدام تركيز واطئ.
الكلمات الرئيسية: المبادل الحراري، انتقال حرارة، مائع نانوي، عدد نسلت.

1. INTRODUCTION

Heat transfer is one of the most important fields in the industry. Heat can be transferred in many ways like, evaporation, condensation, cooling and is encountered in processes of chemical industries, refrigeration and waste management. Heat exchanger is used to transport heat between two fluid streams of different temperatures. There are many ways to enhance the performance of the heat exchanger by enhancing the design, increasing the contact area and working fluids.

These days many researchers investigate the increasing of heat transfer in heat exchanger by using ultra- fine particles (nanoparticles) of various materials (metal and metal oxide) suspended in the base fluid (water, ethylene glycol, oils) forming nanofluids. **Choi, 1995 and Eastman, 1996** studied many types of nanofluids by adding different nanoparticle materials into different base fluids. Using nanoparticles with conventional liquids is used to enhance the thermal properties of the base fluids. These particles have higher thermal conductivities than the base fluids.

Masuda et al, 1993 studied the thermal conductivity and viscosity of three types of nanoparticles Al_2O_3, SiO_2, TiO_2 in water. **Wen and Ding, 2004** studied the effect of Al_2O_3 nanoparticle in deionized water flowing through copper tube in laminar condition and found that the Nusselt number increased by 47% for 1.6% volume concentration of Al_2O_3 nanoparticle. **Heris et al, 2006** studied the effect of Al_2O_3/water nanofluid of laminar region flow in circular tube of constant wall temperature, the results showed that heat transfer coefficient was enhanced by 40% for 2.5% volume concentration. **Anoop et al, 2009** studied the effect of two size particles of Al_2O_3/ water of (45 and 150) nm in a flow pipe of constant wall flux. They found that the nanofluids of particle size 45nm had higher heat transfer coefficient than nanofluid of particle size 150nm.

Zamzamian et al, 2011 studied the effect of two types of nanofluids Al_2O_3 / EG and CuO/EG in a double pipe heat exchanger, the results showed that the heat transfer coefficient was increased from (2- 50) % by using nanofluids. **Jaafer et al, 2013** investigated the different concentrations of Al_2O_3 nanoparticle between (0.3- 2) % volume concentration of particle size of 30 nm, in horizontal shell and tube heat exchanger of counter current flow in turbulent flow conditions. They found that the heat transfer coefficient, viscosity and friction factor increased with increasing volume concentration of nanofluid. **Chavda et al, 2014** prepared Al_2O_3/water nanofluid of concentration (0.001, 0.002, 0.003, and 0.004) % volume to study the effect of nanofluid upon friction factor. **Chavda et al, 2014** studied the effect of different sizes of Al_2O_3 nanoparticle from 0.001- 0.01% volume concentration in water base fluid working in a double pipe heat exchanger for co-current and counter current arrangement. The results showed that the heat transfer coefficient increased with increasing volume concentration of nanoparticles.

Sudarmdji, 2015 studied the effect of the Al_2O_3/water in laminar flow conditions on pressure drop and friction factor of concentration of 0.5%, the results were compared with theoretical values of deviation of -13.6% to 9.98%. The aim of this work is investigating the γ- Al_2O_3/ water nanofluid of two volume concentration of 0.002, 0.004% in shell and double concentric tubes heat exchanger in turbulent flow region.

2. EXPERIMENTAL SETUP
The shell and double concentric tubes heat exchanger constructed by **Fadhil, 2013** was used in this work. Three streams of fluids were designed to work in the shell and double concentric tube heat exchanger. They were two as hot fluids and one cold nanofluid in the opposite side

direction. The heat exchanger has a (1.3m) length and effective tube length of (1.08m). The shell is made of carbon steel with inner diameter is (203mm), and the shell outer diameter is (220mm). Baffles of thickness (6mm) are spaced by a distance of (100mm).

The inner tubes made of carbon steel with (10mm) thick, (20mm) inside diameter and (25mm) outside diameter were used. They are 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, two passes tubes side were used as concentric inner tubes.

3. PREPARATION OF NANOFLUID

Nanofluids were prepared by taking the two step method for preparation of nanofluids. The nanopowders from (EPRUI Nanoparticles & Microspheres China) were dispersed in the water (base fluid) at specific concentrations (0.002 and 0.004) % by volume. The nanopowders were weighed by using electronic balance and in the hood of laboratory to avoid the pollution of nanoparticles. A 250 litter of nanofluids were prepared each time using a speed homogenizer of (10000) rpm (Ultra – Turax Janke &Kunkel KG) to keep the nanoparticles in motion. This will stabilize the suspension and prevent the agglomeration and sedimentation. The mixing continued for 2 hours. The shear agitation continued for 48 hours, to maintain the nanoparticles in motion and suspended in the base fluids. The density of nanofluid and oil was measured by picknometer of 10 ml, while the viscosity was measured by viscometer ASTM D445 Viscometer Bath. The thermal conductivity 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 set to 25°C, while for oil it ranged as (85, 75, 65, and 55 °C).

4. EXPERIMENTAL PROCEDURE

A tank of capacity of 300 litters containing cold feed or nanofluids with a mixer 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. From the collecting tank the nanofluid enters in a small unit for cooling nanofluids by pumping it through a spiral tube of 5 cm inside diameter, covered with a shell of diameter 20 cm. The cold water enters the shell counter currently to the flow of nanofluid spiral tube. The nanofluid returns back to the main tank, where it was left for a certain period of time and its temperature was measured using a portable thermocouple (type k).

In the other side, hot oil was consisted in a tank of 250 litter capacity supported with two heaters to reheat the oil to the desired temperature by thermostat controller, which was connected to the electric board. The oil has been pumped by centrifugal pump (kind Sp 24T, 2hp) with a flow meter regulated by gate valve on the pipes. The feed is divided into two parts supported by pressure gauge at the inlet and outlet of the exchanger. Second tank was used to collect the oil, which ends out from the heat exchanger. The two oil streams runs out from the heat exchanger to the oil tank collector, at this time two thermocouples type (k) were added to measure the temperatures of the two oil streams 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 attained in a steady state, the cold side nanofluid flow had a rate of (45) l/min and a temperature of 20 °C, while the hot oil side fluid is pumped at varied flow rates

(30, 40, 50) l/min, and with temperatures between 85 °C to 55 °C. The pressures were recorded at the inlet and outlet of the heat exchanger for the pipe and shell sides, annulus tube and inner tubes. The temperature was measured for the same streams.

The procedure is repeated for flow rate of cold water in the annulus side as (15, 25, 35) l/min with a fixed temperature of 20 °C. This step was repeated after changing the setting of thermostat by 10 °C steps for temperature of hot oil from 55 to 85°C. **Fig. 1** shows the equipment's process.

The mass flow rate inside the annulus section of the concentric tube is a function of the density of fluid, the velocity of fluid, flow cross sectional area and the number of tubes.

$$m_2 = \frac{\rho_2 u_2 A_{C2} N_t}{N_P} \tag{1}$$

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

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

and (N_p) is the number of tubes by pass in the heat exchanger, u_2 the velocity of fluid in inner tubes

Reynolds number is calculated as follows:

$$\mathrm{Re}_2 = \frac{\rho_2 u_2 d_h}{\mu_2} \tag{3}$$

The hydraulic diameter of the annulus is:

$$d_h = D_2 - d_1 \tag{4}$$

to calculate the Prandtl Number:

$$\mathrm{Pr}_2 = \frac{\mu_2 Cp_2}{k_2} \tag{5}$$

By using Colburn equation, the Nusselt number is given as, **Hewitt, 1994**:

$$\frac{hd_h}{k} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33} \tag{6}$$

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.

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

and the friction factor in annulus passages used in this calculations is:

$$f_2 = 0.316\,\mathrm{Re}^{-0.25} \qquad\qquad \text{For } 2300 < \mathrm{Re} < 10^5 \tag{8}$$

Overall heat transfer coefficient U_{12} between the fluid in the shell side and fluid in the annulus passage is given as, **Bougriou, 2008**

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

The second overall heat transfer coefficient U_{23} between the fluid in the annulus passage and the fluid in the inner tube side, **Bougriou, 2008**

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

5. RESULTS AND DISCAUTION

5.1 Effect of Nanofluid on Nusselt number

Nusselt number increased with increasing Reynold́s number in turbulent conditions. This is due to the high velocity and increase of the Brownian motion of nanoparticles (nano convection) and this agrees with **Om shank, 2012**.

The new design of heat exchanger allows increasing the convection heat transfer due to the activity of nanoparticles in the base fluid, the heat transfer rate will be higher resulting in increasing the Nusselt number as shown in **Figs. 2 and 3.** These figures show different concentrations for aluminum oxide. They show that Nusselt number increased with increasing inlet oil temperatures (85, 75, 65, 55) °C at a constant flow rate of nanofluid of 45 (l/min) of different oil flow rate of (30, 40, 50) l/min.

The results showed that γ- Al_2O_3 of a concentration of 0.004% volume has the highest value of Nusselt number at different flow rates of nanofluids (15, 25, 35, 45) (l/min) and constant flow rates of oil with 50 (l/min) and temperature of 85 °C than the base fluid as shown in **Fig. 4**. This is in agreement with **Sudarmadji, 2014**.

5.2 Overall heat transfer coefficient

The heat transfer coefficient was enhanced by increasing the cold nanofluid flow rates at constant hot oil flow rate as shown in **Fig. 5** and **6** for the U_{12} and U_{23} at temperature of 85°C which is in agreement with **Reza, 2014**.

For 0.004% by volume of (γ-Al_2O_3), higher heat transfer coefficients U_{12}&U_{23} were encountered. These results are also higher than that of base fluid as can be seen from **Figs**. **7** and **8**. This could be due to that γ-Al_2O_3 has larger surface area. For overall heat transfer coefficient between the annulus and inner tubes U_{23}, higher values than that of U_{12} of alumina nanoparticles of 0.004 volume % were encountered, for different hot oil rates (30, 40, and 50) l/min at temperature of 85°C with different flow rates of nanofluids. The highest value was at flow rate of 50 l/min of hot oil as shown in **Figs. 9** and **10,** where the thermal conductivity of alumina is higher than that of thermal conductivity of base fluid. The overall heat transfer coefficients of both U_{12} and U_{23} of nanofluids are higher than that of the heat transfer coefficient of the base fluid (water) and these increased about 25% for U_{12} and 43% for the U_{23} as shown in **Figs.9** and **10**.

5.3 Effect of Nanofluids on Pressure Drop

The pressure drop increased as flow rate of fluids increased. Also the pressure drop increased when concentration of nanofluids increased too. **Fig. 11** is in agreement with results given by as in **Amani, 2014**. This increment was slightly higher than the pressure of base fluid because of low concentration used of the nanofluid.

6. CONCLUSIONS

Nusselt number increased with the increase in Reynold's number, this is because of the higher velocity of nanofluids and the increasing in Brownian motion of nanoparticles. Nusselt number increased for γ-Al_2O_3 nanoparticles of 0.004% volume concentration by 79.5% for γ-Al_2O_3/water relative to base fluid. Overall heat transfer coefficient of nanofluids had increased as concentrations of γ-Al_2O_3 nanoparticles increased. This increase for overall heat transfer between shell and annulus tubes is represented by U_{12} which was 23.6% for γ-Al_2O_3/water relative to base fluid, while for that between the annulus tubes and the inner tubes represented by U_{23} had increased by 34% for γ-Al_2O_3/water relative to base fluid. The pressure drop of nanofluids was slightly higher than that of base fluid. This is due to the low concentration of nanoparticles in the base fluids and this means no pumping power increased in the process.

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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 annulus tube (first bundle) in 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	$Nu = \dfrac{hd}{k}$
N_p	number of tubes by pass	-
N_t	total number of the tubes	-
Pr	prandtle number	$\mathrm{Pr} = \dfrac{\mu Cp}{k}$

Re	reynolds number	$Re = \dfrac{\rho u d}{\mu}$
T	temperature	$^{\circ}C$
U	overall heat transfer coefficient	$W/m^{2}{}^{\circ}C$
u	fluid velocity	m/s

Greek Symbols

Units	Description	Symbol
ΔT	temperature difference	$^{\circ}C$
ρ	density	kg/m^{3}
μ	dynamic viscosity	$kg/m.s$
ΔP	pressure drop	Pa

Subscript

Symbols	Description
1	oil (shell side)
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

Figure 1. Experimental Rig of Process.
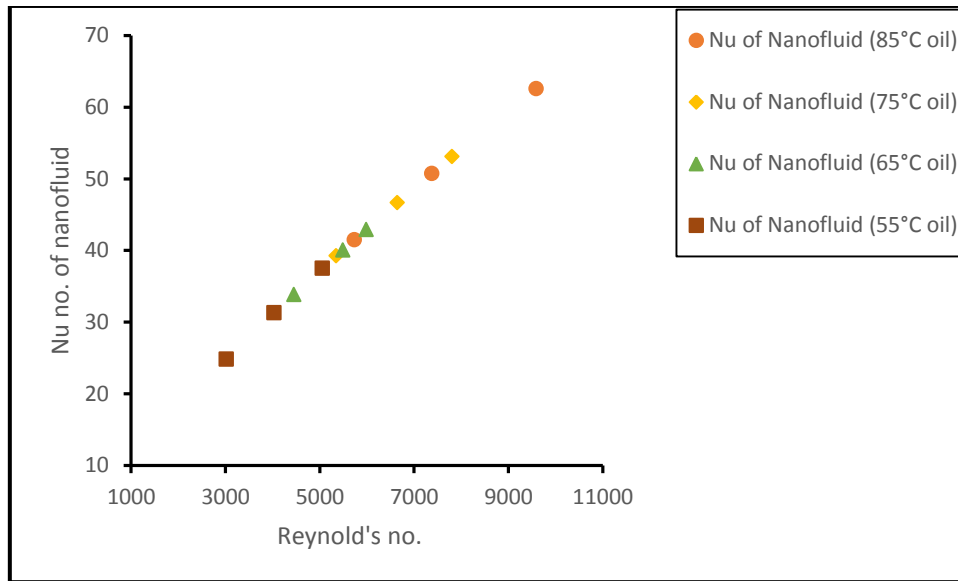
Figure 2. Nusselt number against Reynold at different inlet oil temperature and constant nanofluids flow rate 45 (l/min) for γ- Al_2O_3 of 0.002 % concentration.
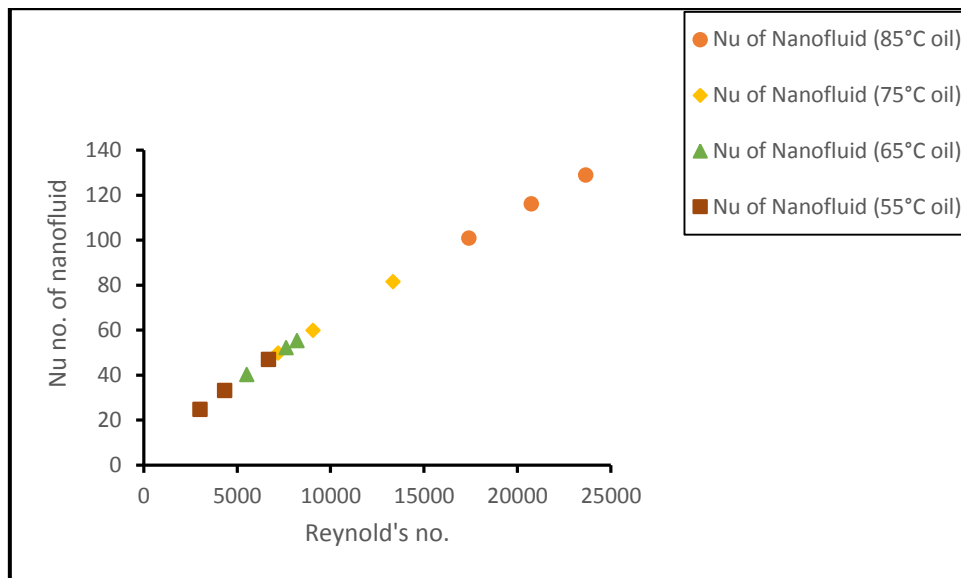
Figure 3. Nusselt number against Reynold at different inlet oil temperature and constant nanofluids flow rate 45 (l/min) for γ- Al_2O_3 of 0.004 % concentration.
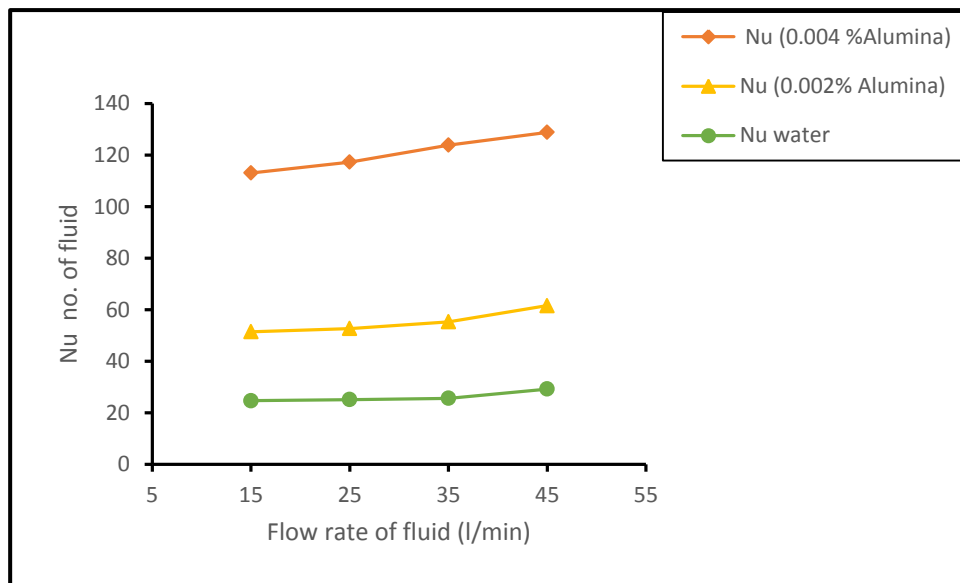
Figure 4. Nusselt number against flow rate of fluids with different concentration
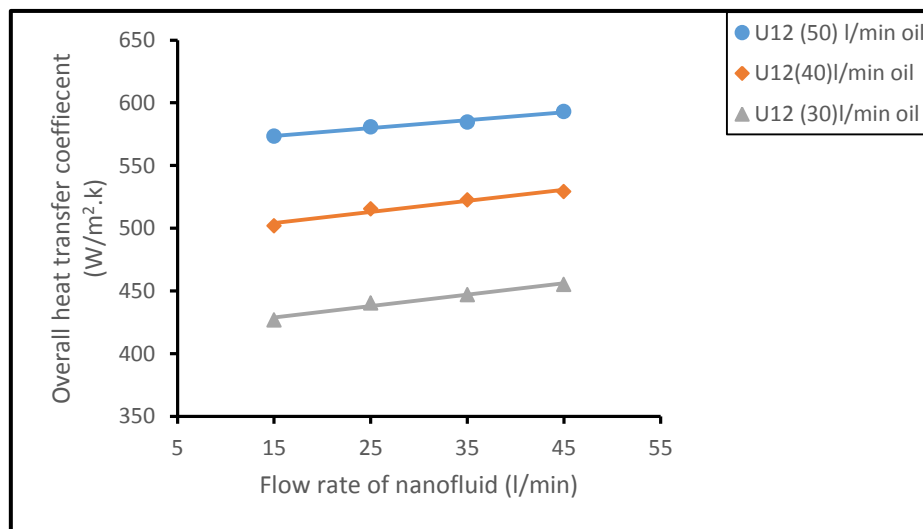
at constant flow rate of oil 50 (l/min) and 85°C.

Figure 5.Overall heat transfer coefficient U_{12} against flow rate of γ-Al_2O_3 nanofluid

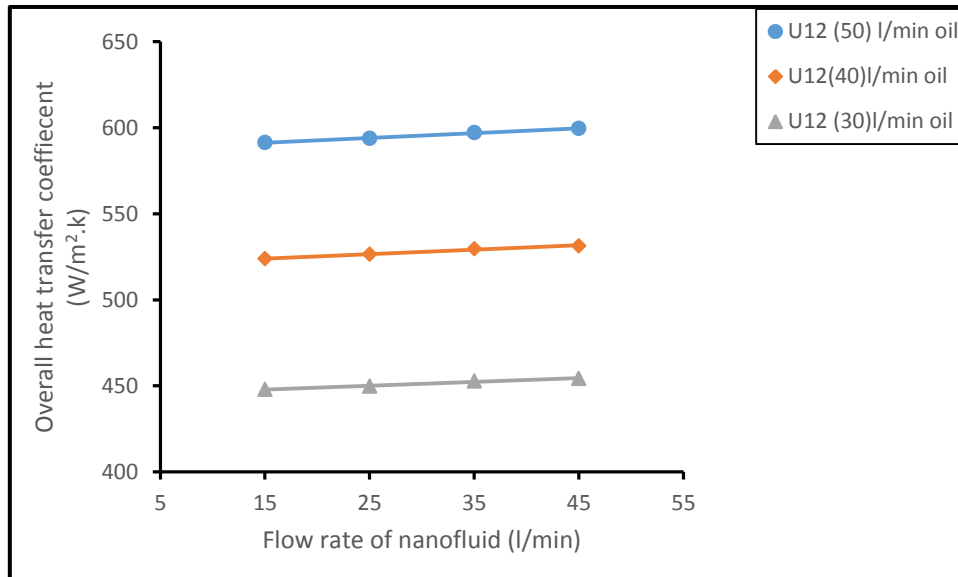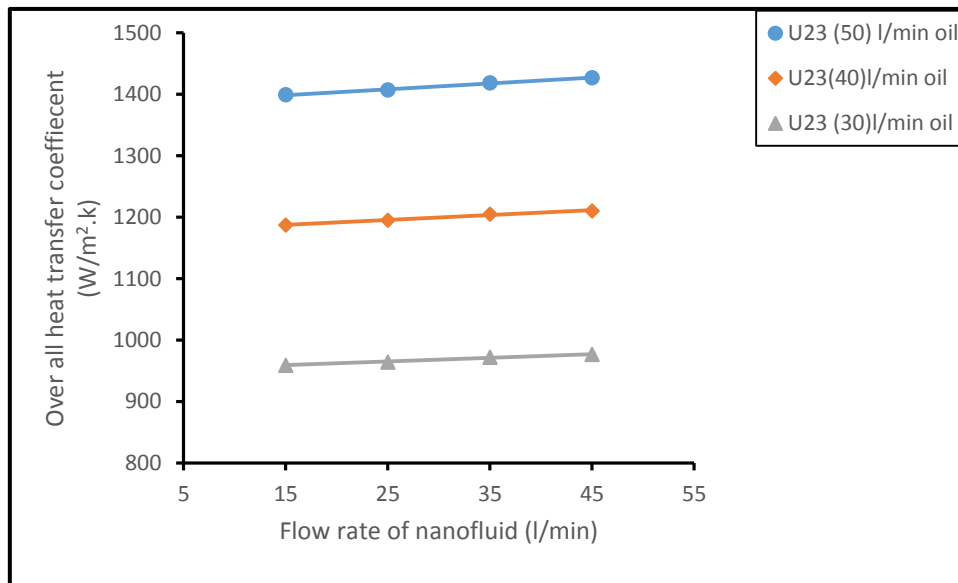at different flow rates of oil at 85 °C and 0.002% concentration γ-Al_2O_3.

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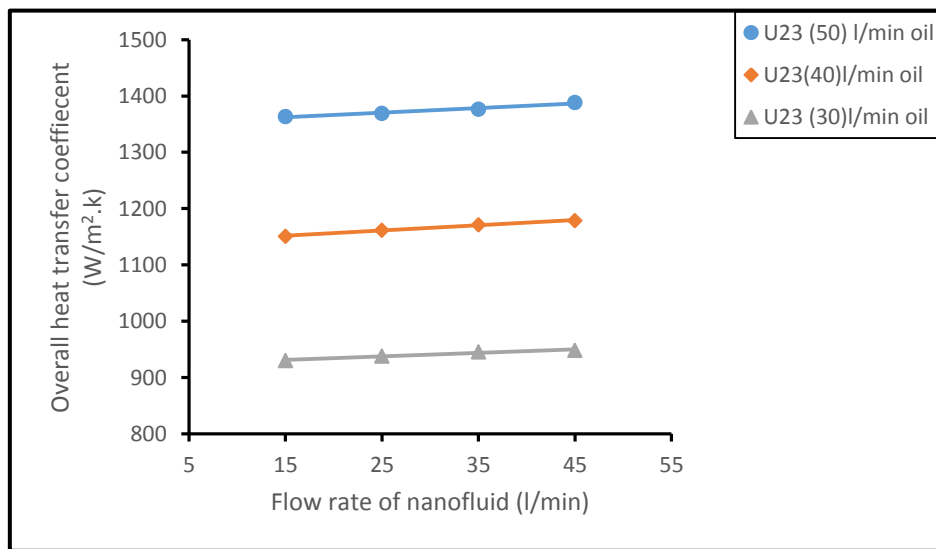
Figure 6. Overall heat transfer coefficient U_{23} against flow rate of γ-Al_2O_3 nanofluid at different flow rates of oil at 85 °C and 0.002% concentration γ-Al_2O_3.

Figure 7.Overall heat transfer coefficient U_{12} against flow rate of γ-Al_2O_3 nanofluids at different flow rates of oil at 85 °C and 0.004% concentration of γ-Al_2O_3.

Figure 8. Overall heat transfer coefficient U_{23} against flow rate of γ-Al_2O_3 nanofluid

at different flow rates of oil at 85 °C and 0.004% concentration of γ-Al_2O_3.
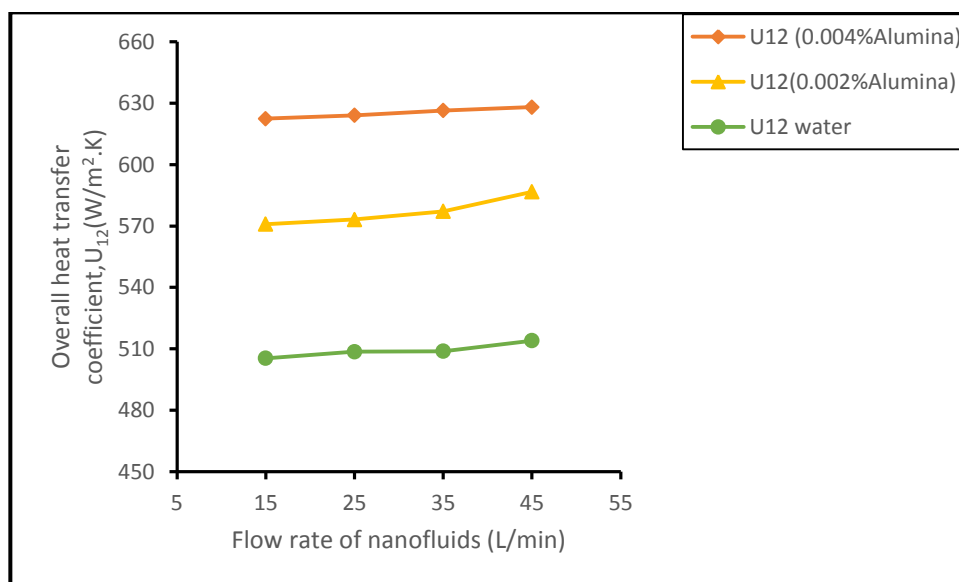

Figure 9. Comparison between nanoparticles dispersed in water for
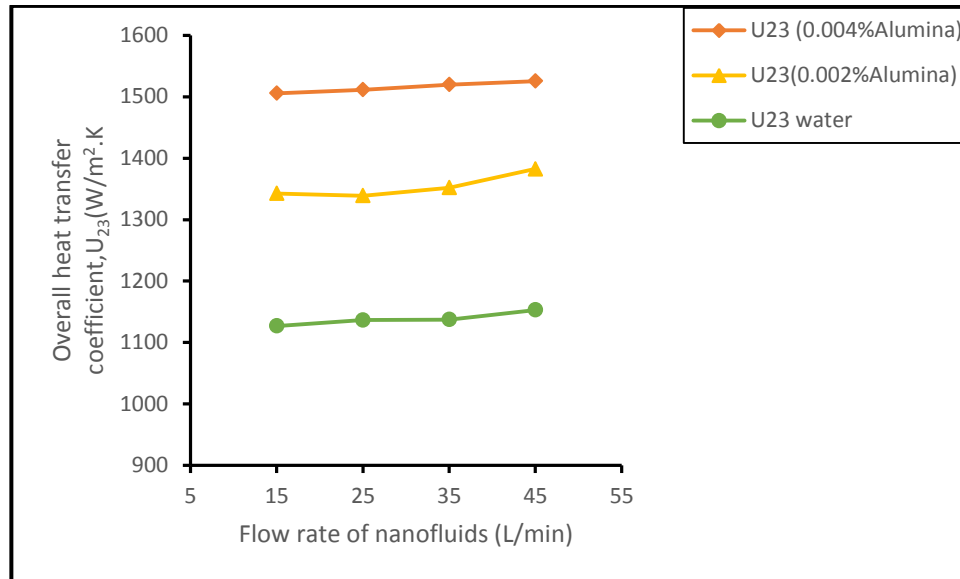
different concentration at 50 (l/min) of hot oil at 85°C.

Figure 10. Comparison between nanoparticles dispersed in water for different concentration at 50 (l/min) of hot oil of U_{23} at 85°C.

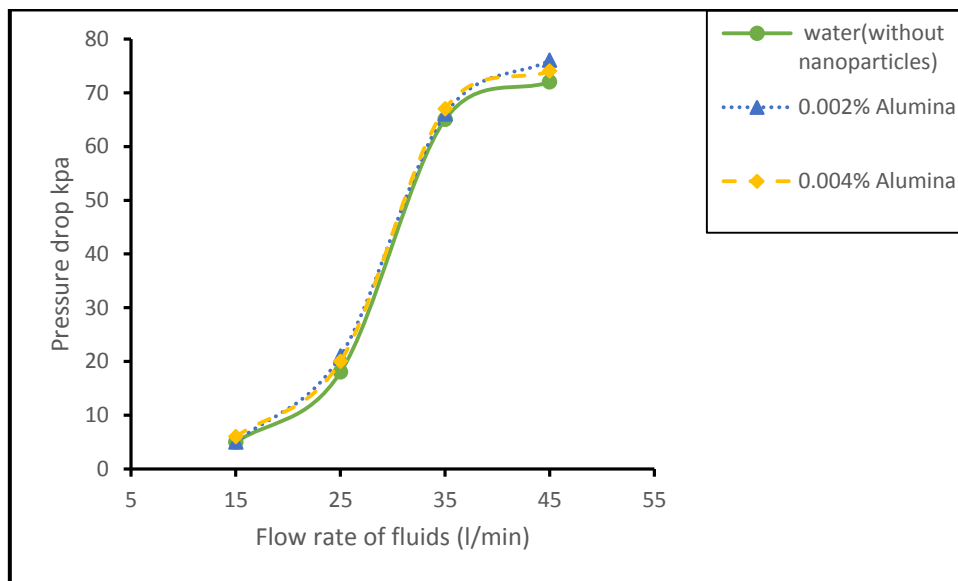**Figure 11**. Pressure drop against fluid flow rate at temperature 85°C and oil flow rate of 50 l/min and different nanofluid concentration and materials.