Experimental Investigation of Double Pipe Heat Exchanger Using Al_2O_3 and TiO_2 Nanofluid

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Abstract:

Laminar counter and parallel flows in a double pipe heat exchanger is studied experimentally using two types of nanofluids as a cooling medium. The nanofluids consist of Al_2O_3 and TiO_2 nanoparticles, which were added to the base fluid (deionized water). The average diameter of nanoparticles is approximately 20 nm for both Al_2O_3 and TiO_2 nanoparticles. The volume concentrations of nanofluid was varied with a range of (0.05- 0.3) percentage and the flow rates of the base and nanofluids were varied with a range of (0.5-2) L/min. Hot fluid (water) is flowing in the inner tube of heat exchanger with constant inlet temperature and the cold fluid (nanofluid) is introduced in the outer tube with constant inlet temperature. Compared to the base fluid, the results showed that the nanofluid containing Al_2O_3 and TiO_2 nanoparticle exhibits enhanced heat transfer, and this enhancing is clearly reflected by the increase in the inside and outside heat transfer coefficients, thus the overall heat transfer coefficient, where the percentage enhancement in heat transfer coefficient of nanofluid per base fluid is (18.25 and 15.5) % for Al_2O_3-water and TiO_2-water nanofluid respectively. The enhanced performance of heat exchanger is due to high value of thermo physical properties of fluid when dispersing nanoparticles in the base fluid.

Keywords: Nanofluid; The performance of double pipe heat exchanger; laminar parallel and counter flows.

1. Introduction:

Heat transfer is one of the most important industrial processes. Heat exchangers are the most effective units in various processes. For decades, extensive efforts have been dedicated to enhance the efficiency of heat exchangers utilizing different heat transfer techniques. Due to the easiness of design and low inventory, the double pipe heat exchanger is considered to be the simplest, most effective and efficient heat exchanger **[1]**.

Heat transfer fluids, such as ethylene glycol, water, and engine oil are used in many cooling and industrial applications such as air conditioning, energy supply, heat exchanger, and transport. Conventional fluids however have low thermal conductivities so their heat transfer performance is poor **[2]**.

Nanofluids present a new family of fluids which prepared by dispersing nanoparticles in the base fluids such as water, oils or glycols. In general, the used particles are metals, metal oxides or carbon, in different forms.

Thermal conductivity of non-metallic materials (such as Copper Oxide and alumina,) and solid metallic materials (such as copper) have thermal conductivities much higher than that for pure fluids **[3]**. There is innovative idea to enhance the thermal conductivity of heat transfer fluids by adding solid particles into these fluids. This idea was used about two decades ago, where at beginning it used micrometer-sized solid particles even millimeter, but the large size of the solid particles caused annoying problems, such as block out channels, corrosion of the surface, increasing the pressure drop and driftage of the pipeline, which virtually limits the workable applications. In order to enhance the thermal conductivity of heat transfer fluids, the small quantity of nanoparticles with a diameter range of (1-100 nm) can be added to the base fluid to make suspensions. This type of fluid is called nanofluid. This small amount of nanoparticles in the heat transfer fluids enhances their thermal conductivity **[4]**.

The positive results, related to the enhanced thermal performance of double pipe heat exchangers, have motivated many researchers to further investigate the potential of the nanofluids.

The thermal conductivity and viscosity at temperatures ranging from 283.15 K to 323.15 K using an apparatus based on the hot-wire method and a rotational viscometer, respectively is determined. It was found that both thermal conductivity and viscosity increased with increasing the concentration of nanoparticles, whereas when the temperature increases, the viscosity decreased and the thermal conductivity increased. Thermal conductivity and viscosity of Fe_3O_4 nanofluid for heat transfer applications were studied experimentally and theoretically **[5]**. Both experiments are conducted in the volume concentration range from 0.0% to 2.0% and the temperature range of 20 °C to 60 C°. The thermal conductivity and viscosity of the nanofluid increased with an increase in the particle volume concentration. **Reza D. et al (2013) [6]** numerically investigated the heat transfer characteristics of nanofluid in laminar flow with constant heat flux in the circular tube using alumina nanoparticles in water with volume concentrations (0.5, 1, 1.5, 2, 2.5)%. They used two particles sizes 50 and 20 nm and assumed all thermo physical properties of nanofluid to be temperature independent. They found that the heat transfer coefficient increased with increasing the Reynolds number and with the increase of volume concentration of nanoparticles in water and the maximum heat transfer coefficient at the highest concentration of nanoparticles in the base fluid is (2.5%). In addition, the two nanofluids have heat transfer coefficient higher than that for water, although the nanofluid with 20 nm of nanoparticles had the highest heat transfer coefficient. **Mushtaq I. H. (2014)[7]** Numerically investigated (Al_2O_3-water and Diamond-water) as cooling fluids in addition to pure fluid with concentration at rang (1-4)% flowing in "micro pin fin heat sink" in two cases un finned micro channel and fined micro channel with three geometries of fins (circular, triangular and square). He used constant wall temperature boundary condition and same Reynolds number at range (100-900) to remains in laminar flow. He found that the using of nanofluid as a cooling fluid lead to enhance the heat transfer performance because of increasing heat dissipated but this increasing leads to increase the pressure drop. The fluid flow and heat transfer of nanofluids with uniform heat flux flowing inside a horizontal circular tube with laminar flow was investigated experimentally **[8]**. Two types of nanoparticles are used (Al_2O_3 of 80 nm) and (TiO_2 of 50 nm) with distilled water. Different values of volume concentration are used (0.1, 0.2, 0.3, 0.4, 0.5, and 0.6) %, the range of Reynolds number is (785-1962) and heat flux ranging are chosen to be (50-400 w/m^2). It was found that the heat transfer increased with Reynolds number and volume concentration increases where the highest enhancement was obtained at 1962 for Reynolds number and 0.6% for volume concentration. In addition, the type of nanofluid effect on the range of heat transfer where the Al_2O_3-disilled water Nanofluid gave value of enhancement more than the TiO_2-distilled water Nano fluid, where the enhancement was (26% and 22%) for Al_2O_3 and TiO_2 respectively. Recently**, Hsien H. T. et al. (2015) [9]** investigated numerically the convective heat transfer of nanofluids AL_2O_3/water flowing inside duct with a square cross section under laminar flow conditions with a constant heat flux. Six particle concentrations were considered (2.5 %, 2%, 1.5%, 1%, 0.5%, and 0.2%) with 25 nm in diameter. They studied the effects of Peclet number and concentration of nanoparticle on the heat transfer characteristics ofAL_2O_3/water nanofluids. They found that increasing the particle volume concentration and peclet number causes an increase in Nusselt number and heat transfer coefficients of Al_2O_3/water nanofluid. It was also found that the nanofluids heat transfer coefficient increased by about 25.5% at a peclet number of 7500 and 2.5% particle volume concentration compared with pure water. On the other hand, the enhancement of the effective thermal conductivity of AL_2O_3/water nanofluid was (9.98%), which is much lower than that of convective heat transfer coefficient (25.5%). **More recently, Adel Y.A. (2016)[10]** performed experimental work to enhance heat transfer using MgO nanoparticles with 40 nm in diameter with distilled water as nanofluid flowing inside cross flow finned tube heat exchanger. The test section is made from Pyrex glass and single copper tube with eight passes. Air was passed through test tube as cooling fluid with different velocity (1, 2, 3 and 4) m/s. Water and nanofluid flowing inside inner tube with different flow rates (2, 3, 4, 5 and 6) L/min and inlet fluid temperature is (50, 60, 70 and 80) C°. The nanoparticles dispersed in base fluid with volume concentration of (0.15, 0.35, 0.55 and 0.75) Vol%. It was found that the density and thermal conductivity increases when using nanofluid, results in enhancing the heat transfer characteristics.

Motivated by the above enhancement in the literature, the objective of this work is to study experimentally Al_2O_3 and TiO_2/water nanofluids as coolants to enhance the thermal performance of two flow patterns in double pipe heat exchanger. The parameters (flow rate and volume concentration) are varied to represent its effect on heat transfer.

2. Mathematical S

Table (1) Thermo-physical properties of Al_2O_3-water nanofluid

Concentration%	Density Kg/m^3	Specific heat J/kg.K	Thermal conductivity W/m.K	Viscosity N.s/m^2
Al_2O_3	3890	880	32	_
Pure water	994.158	4178.4435	0.6215	0.000738
0.05	995.605	4176.794	0.62238	0.000739
0.1	997.053	4175.145	0.62326	0.00074
0.15	998.636	4173.4958	0.62414	0.000741
0.2	1000.129	4171.8466	0.62502	0.000742
0.3	1003.1155	4168.548	0.62679	0.000744

Table (2) Thermo-physical properties of TiO_2-water nanofluid

Concentration%	Density Kg/m^3	Specific heat J/kg.K	Thermal conductivity W/m.K	Viscosity N.s/m^2
TiO_2	3996	690	10.2	_
0.05	995.6589	4176.699	0.622281	0.000739
0.1	997.1598	4174.955	0.623062	0.00074
0.15	998.66	4173.21	0.623844	0.000741
0.2	1000.161	4171.4666	0.624627	0.000742
0.3	1003.1635	4167.478	0.626194	0.000744

3. Experimental Procedure:

3.1 Preparation of nanofluid:

Preparation of nanofluid with no agglomeration is the first key step in experimental work. Nanofluid is produced by dispersing nanoparticles into pure fluid such as oils, ethylene glycol and water, but the major problem is agglomeration of nanoparticles in fluid. Therefore, there is some essential requirements to get a stable and durable suspension, no chemical reaction of fluid and negligible agglomeration of particles. There are two techniques for preparation of nanofluid: the two-steps method and single-step method **[15]**.

1- Single step method: preparation of nanofluid in this method includes synthesis of nanofluid, nanoparticles produced by chemical and physical process, but it is difficult to produced dry nanoparticles subsequently by separate the particles from the fluid, this method used only for fluids that have low vapor pressure **[10]**.

2- Two steps method: In this method, nanoparticles are manufactured as a powder then dispersing the nanoparticles in the pure fluid; however, during storage and transport the nanoparticles may agglomerate. There are some techniques used to decrease agglomeration of nanoparticles such as homogenizer and ultrasonic. In this study, two-steps method is used using homogenizer **[10]**.

Two types of nanoparticles are used in this work, which are Al_2O_3 and TiO_2 and deionized water was used as a base fluid. In this method, the nanoparticles were supplied from (Iranian Saman Company for the Lovers of Technology and Chemistry) company, and then homogenizer device is used for mixing the nanoparticles with base fluid. Five volume concentrations are used (0.05, 0.1, 0.15, 0.2, 0.3)% with 10 liter of deionized water. The nanoparticles were weighted using a sensitive balance for each concentration, and then the nanoparticles added to 10 liter of the deionized water. The mixture is placed in a homogenizer about 8 hours to get homogeneous suspension. Finally, the nanofluid is ready to be introduced into the test section.

3.2 Nanofluid Stability:

Many mixing processes have been made utilizing two devices with different mixing time to get uniform nanofluid with longer sedimentation time. Homogenizer is used with different mixing times (4, 6 and 8 hours) and ultrasonic mixer is used with mixing time about (1 hour). The sedimentation of suspensions with mixing times of 4, 6, and 8 hours started after 13, 19, and 25 minutes, respectively. These observations were similar to those results from ultrasonic after 6 minute of sonication. As shown in Fig. 1. Hence, the nanofluid prepared by the homogenizer with a mixing time of 8 hours was chosen.

3.3 experimental device

The experimental rig consists of the following parts:
1- Bench-Top heat exchanger from (TEC QUIPMENT) which is consist of:
A-Double pipe: circular copper pipe is inner pipe (D_o=12mm and D_i=10mm) and circular glass pipe is outer pipe (D_o=30 and D_i=20 mm).
B- Heater and Hot fluid tank.
C- Hot system board.
D-Digital Temperature Recorder and digital flow rate recorder.
E- Electronic flow meter for hot fluid.
F- Hub board to connect the device with computer.
G-Thermo couples (six thermo couples for hot and cold fluids).
H- Pump for hot fluid.
2- Pump for cold fluid.
3- Flow-meter for Nano fluid.
4- Refrigerator and tank for Nano fluid.
5- Pressure measurement sensors.
6- Digital pressure recorder.
7- Water pump.

3.4 Procedure of Experimental Test Rig.

Two types of fluids flow in this device, hot fluid (deionized water) and cold fluid (nanofluid), where heat transfer occurs due to a temperature difference of two fluids. Deionized water set as a hot fluid and heated by heater to 60 C°, then pumped by a pump from tank into the inner tube. While the nanofluid placed in a refrigerator tank and cooled to 30 C°, then it is pumped into the inside outer tube with constant inlet velocity and temperature. This procedure was repeated for with different types, concentration, and flow rate of nanofluids.

4. Results and Discussion.

The inlet temperatures of cold and hot fluids used as boundary conditions, which are measured to be T_{hi}=333 k and T_{ci}=303 k. Different flow patterns(parallel and counter) were studied for double pipe heat exchanger . The results of nanofluids were compared with the reference fluid (base fluid). .

Fig.3 shows the variation of thermal conductivity of nanofluids with concentration for Al_2O_3 and TiO_2 / water nanofluids. From this figure, it can be observed that the thermal conductivity increased with increasing the volume concentration of nanoparticles due to higher values of thermal conductivity of solid nanoparticles compared with pure fluid. In addition, it can be noted that, the thermal conductivity of Al_2O_3-water nanofluid is higher than that for thermal conductivity of Tio_2-water nanofluid due to higher thermal conductivity of Al_2O_3 nanoparticles compared with that for TiO_2 nanoparticles.

Fig.4 shows the variation of specific heat of nanofluid with volume concentration for Al_2O_3 and TiO_2 / water nanofluids. It can be seen that the specific heat decreased with increasing the volume concentration of nanoparticles due to the lower specific heat of nanoparticles compared with pure fluid. The specific heat of nanofluid decreased as the volume concentration of nanoparticles increased. In addition, the specific heat of Al_2O_3-water nanofluid is higher than that for TiO_2-water nanofluid due to the highest value of specific heat of Al_2O_3 nanoparticles compared with that for TiO_2 nanoparticle.

Variation of viscosity with volume concentration of nanoparticles for two nanofluids is shown in Fig.5. It can be noted that the viscosity increased with increasing in volume concentration because of the amount of nanoparticles in pure fluid increased with increasing in volume concentration.

Variation of logarithm mean temperature with volume concentration for two nanofluids and two flow directions is represented in Fig.6 it can be noted that the logarithm mean temperature decreased with increasing in volume concentration for all cases due to improving the thermal properties of fluid when adding nanoparticles to pure fluid with different concentrations. It can also be observed that the LMTD for Tio_2-water nanofluid is higher than that for Al_2O_3-waterand equations (3, 4, 5) represent the comparison, which lead to the cold and hot difference temperature for Al_2O_3-water nanofluid, is higher than that for TiO_2-water nanofluid. In addition, the counter flow arrangement is the best one when compared with parallel flow.

The variation of heat transfer rate with flow rate for both base fluid and nanofluids is shown in Fig. 7 .The heat transfer increased with increasing the flow rate due to increasing of mass flow rate as observed from Fig.7. It can also be noted that the heat transfer rate for Al_2O_3 and TiO_2 / water nanofluids is higher than that for base fluid (water) due to the higher thermal conductivity of nanofluids.Fig.8 shows the variation of heat transfer rate of nanofluid with volume concentration of nanofluid. From this figure, it can be noted that as the volume concentration of nanoparticles increases, the heat transfer rate increased for all cases because of increasing of the thermal conductivity of nanofluid. In addition, it can be noted that the counter flow arrangements is the best one for all cases compared with parallel flow. From Fig (7 and 8), it can be noted that the heat transfer of Al_2O_3-water nanofluid is higher than that for TiO_2-water nanofluid for all values of selected concentration due to the fact that the thermal conductivity of Al_2O_3 nanoparticles is higher than that for TiO_2 nanoparticles.

Variation of pumping power (P.P) with volume concentration for nanofluids and different flow arrangements is indicated in Fig.9. From this figure, it can be noted that the pumping power increased with increasing the volume concentration of nanoparticles due to the enhanced total pressure drop caused by increasing the viscosity of nanofluid. Moreover, it can be noted that the pumping power forAl_2O_3-water nanofluid is higher than that for TiO_2-water nanofluid due to the higher viscosity for Al_2O_3-water nanofluid than that of TiO_2-water nanofluid, leading to higher total pressure drop. . In addition, the counter flow requires higher pumping power than that for parallel flow direction. . Fig.10 shows variation of heat transfer rate over pumping power with volume concentration for Al_2O_3-water and TiO_2-water nanofluids in parallel and counter arrangements. From this figure, it can be noted that the q/P.P increased with increasing the value of volume concentration because of the positive effect of increasing of nanoparticles concentration on heat transfer rate. . It can also be noted that the increase in q/P.P of Al_2O_3-water nanofluid is higher than that for Tio_2-water nanofluid due to the enhanced heat transfer rate and pressure drop for Al_2O_3-water nanofluid compared to TiO_2-water nanofluid. In addition, the counter flow arrangements is best one compared with parallel flow.

Fig.11 shows variation of heat transfer coefficient with Reynolds number for Al_2O_3 and TiO_2 / water nanofluids and different flow arrangements. From this figure, it can be noted that the heat transfer coefficient increased with increasing in Reynolds number for all cases. .it can also be observed that the heat transfer coefficient of Al_2O_3-water nanofluid is higher than that for TiO_2-water nanofluid because of the thermal conductivity of Al_2O_3 nanoparticles is larger than that for TiO_2 nanoparticles. In addition the counter flow is best than parallel flow arrangement which exhibits higher values of heat transfer coefficient of nanofluids. Fig.12 shows the variation of heat transfer coefficient with volume concentration for water-water and two nanofluids with two flow arrangements. From this figure, it can be observed that the heat transfer coefficient increased with increasing in volume concentration for all cases due to enhancing heat transfer process as results of improving thermal physical properties of fluid. In addition can be noted that the heat transfer coefficient for two type of nanofluid are higher than that for water-water (base fluid). So the heat transfer coefficient for Al_2O_3-water nanofluid higher than that for TiO_2-water naofluid. The percentage enhancement in heat transfer coefficient of nanofluid per base fluid is:

1- For Al_2O_3/water nanofluid (5.173%, 10.194%, 12.856%, 15.54%, 18.25%) for (0.05, 0.1, 0.15, 0.2, 0.3)% volume concentration respectively.

2-For TiO_2/water nanofluid (2.575%, 7.3%, 10.1%, 12.8%, 15.5%) for (0.05, 0.1, 0.15, 0.2, 0.3)% volume concentration respectively.

The variation of outer and inner overall heat transfer coefficient with volume concentration for Al_2O_3 and TiO_2 / water nanofluids with parallel and counter arrangements is shown in Fig. 13. From this figure, it can be noted that the outer and inner overall heat transfer coefficient increased with increasing of volume concentration of nanoparticles for all cases, Overall heat transfer coefficient depends on specific heat, thermal conductivity, and heat transfer coefficient. Heat transfer coefficient and thermal conductivity for nanofluids are higher than that for pure water, which leads to increment in overall heat transfer coefficient with increasing volume concentration of nanoparticles.

Fig.14 indicates the variation of outer and inner overall heat transfer coefficient with flow rate for pure water and Al_2O_3 and TiO_2 / water nanofluids, with two flow arrangements. The outer and inner overall heat transfer coefficient increased with increasing flow rate for all cases due to increasing the amount of heat transferred. Figures (13 and 14) reveals that the overall heat transfer of Al_2O_3-water higher than that for TiO_2-water nanofluid since the thermal conductivity and specific heat for Al_2O_3-water nanofluid are larger than that for TiO_2-water nanofluid. The performance of the double pipe heat exchanger with counter flow arrangement is higher that of parallel flow since it causes higher values of overall heat transfer coefficient for all types of fluids studied.

5. Conclusions:

The effect of two types of nanofluid as cooling medium is investigated to evaluate the performance of parallel and counter flow double pipe heat exchanger. The results with using $Al_2O_3$and TiO_2-water nanofluid tend to the following conclusions:

Pumping power and heat transfer rate of both counter and parallel flow double pipe heat exchanger increased. The overall heat transfer coefficient increased with increasing volume concentration of nanoparticles , and the individual heat transfer coefficient increased with increasing the Reynolds number of counter and parallel flow double pipe heat exchanger. The Al_2O_3-water nanofluid is more efficient in transferring the heat than TiO_2-water nanofluid because of the higher thermal conductivity of Al_2O_3 nanoparticles compared to TiO_2 nanoparticles. The counter flow arrangement exhibits better efficiency than that of parallel flow arrangements for all types of nanofluid studied. The enhancement of thermal performance is caused by the higher thermal conductivity nanofluid compared to the base fluid. Heat transfer process is enhanced with increasing volume concentration.The effect of nanofluid is related inversely with fluid flow rate.

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Nomenclature

CP	Specific heat (J/kg.K)
K	Thermal conductivity (W/m.K)
Q	Heat transfer rate (W)

h_{nf}	Heat transfer coefficient of nanofluid (W/m^2.K)
Nu_{nf}	Nusselt's number of nanofluid
Re_{nf}	Reynolds number of nanofluid
U	Overall heat transfer coefficient (W/m^2.K)
T	Temperature (C°)
V	Flow Rate (m^3/s)
ΔP	Pressure drop (bar)
D_h	hydraulic diameter (m)
A_i	inner area of heat exchanger (m^2)
A_o	outer area of heat exchanger (m^2)
μ	Dynamic viscosity (N.s/m^2)
ρ	Density (kg/m^3)
ε	effectiveness
φ	volume concentration %

Subscripts

C	cold
H	Hot
co	cold outlet
ci	cold inlet
ho	hot outlet
hi	hot inlet
act	actual
av	average
nf	nanofluid
nm	nanometer
p	particles
f	fluid
b	base fluid

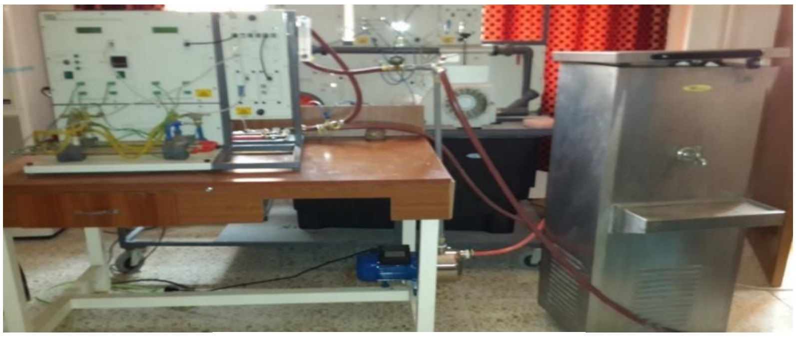
a- Sedimentation of mixture which mixing by homogenizer for 4 hours

b- Sedimentation of mixture which mixing by homogenizer for 6 hours

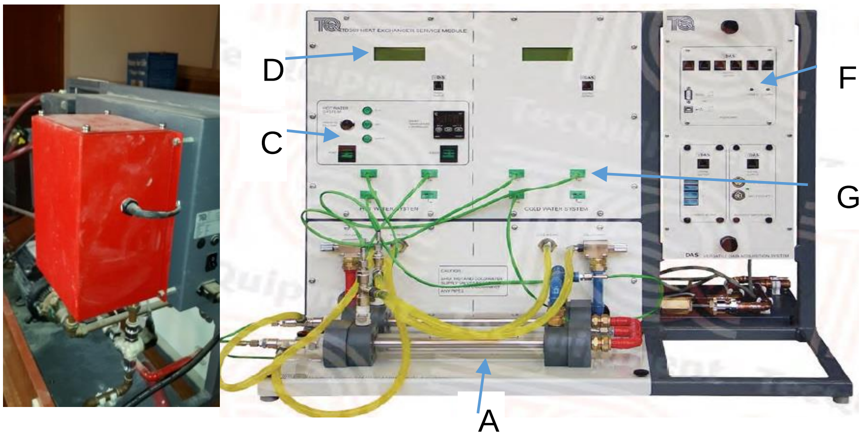
c- Sedimentation of mixture which mixing by homogenizer for 8 hours

d- Sedimentation of mixture which mixing by Ultrasonic for 1 hours

Figure (1) Show sedimentation of nanoparticles for different cases of mixing



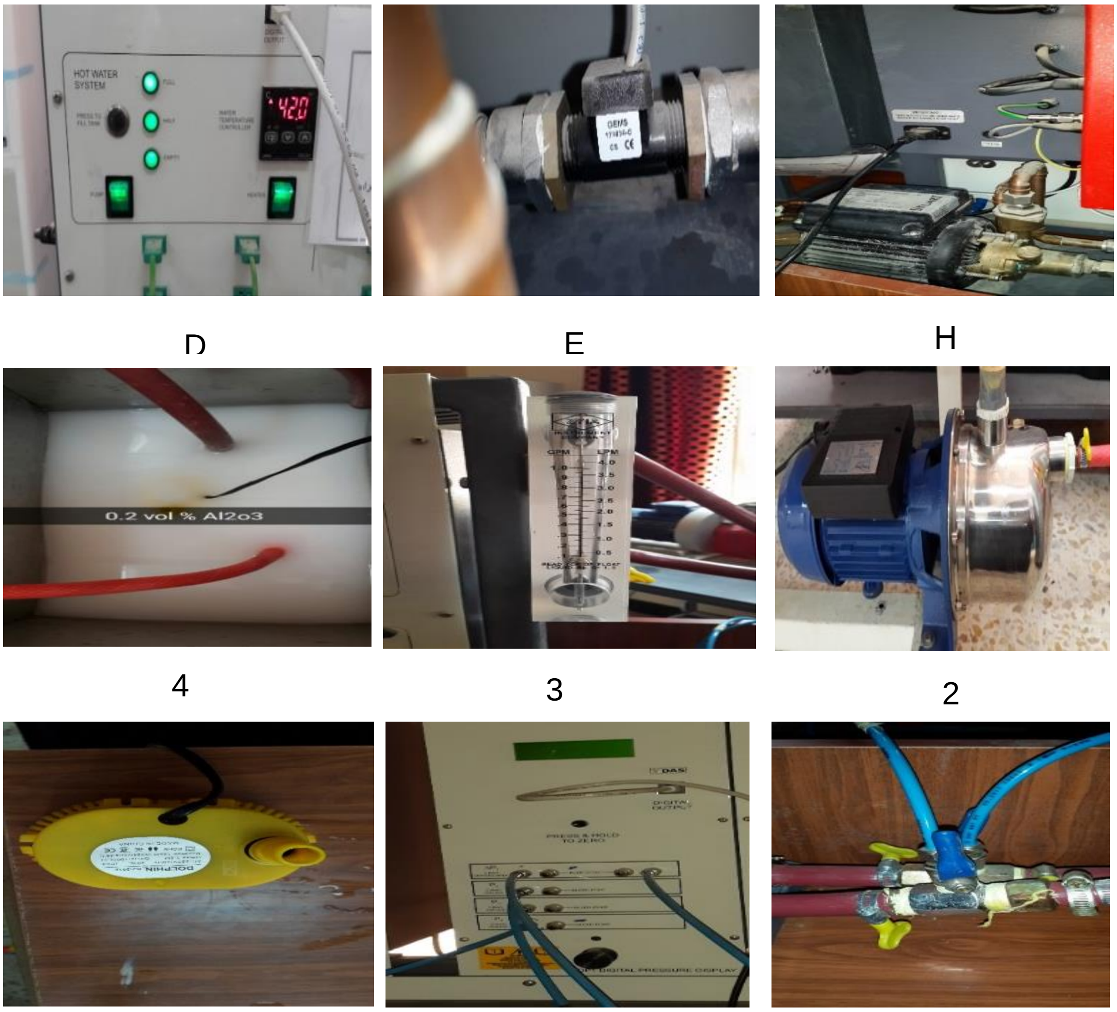
Experimental system



B- Heater and hot fluid tank

1- Bench top heat exchanger

gure (2.a) test rig used



D E H

4 3 2

7 6 5

Figure (2.b) measuring instruments used with test rig

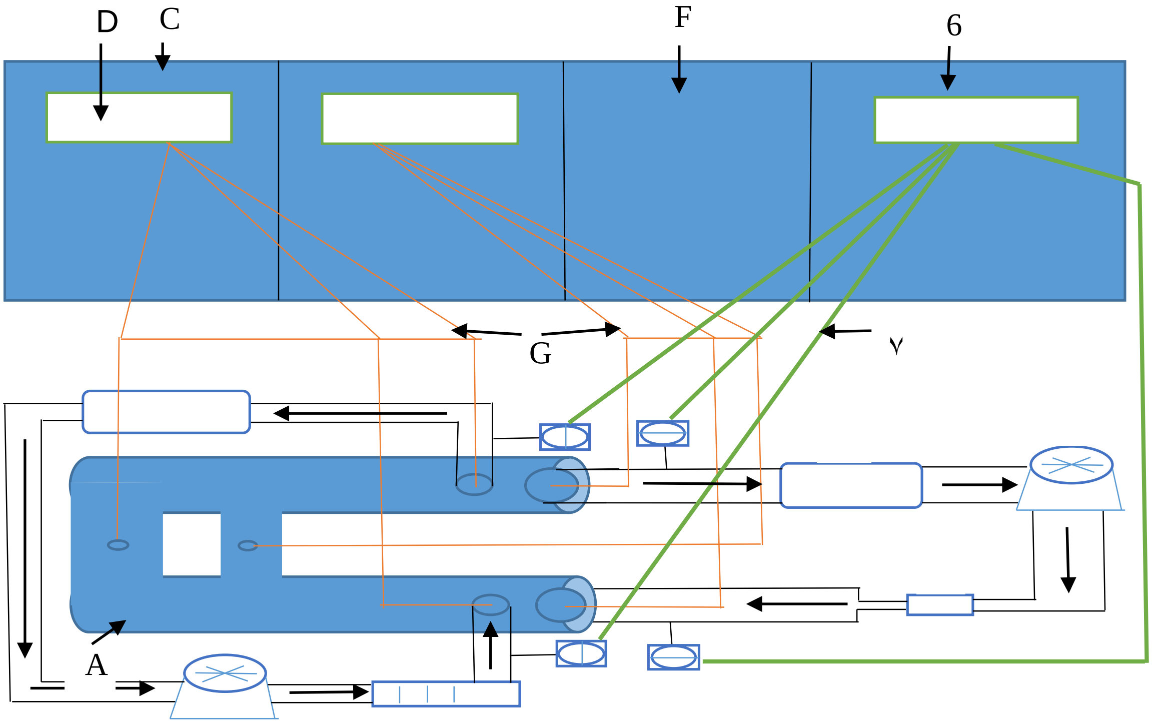


Figure (2.C) schematic the diagram for the rig test

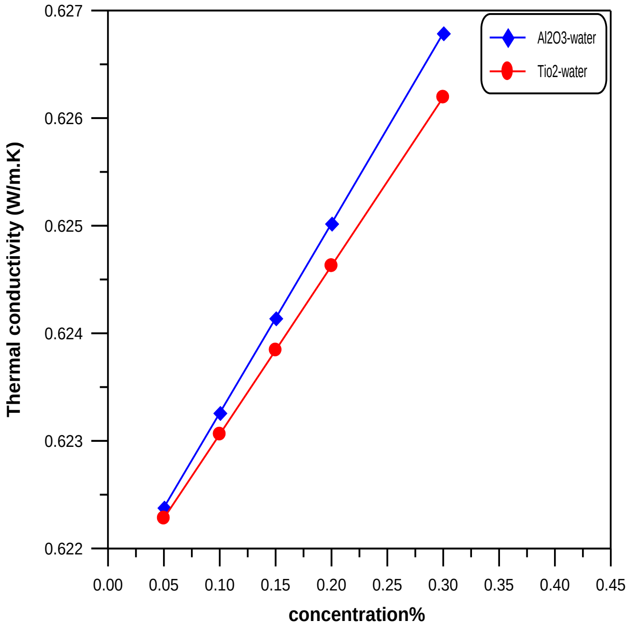


Fig (3) Variation of thermal conductivity with concentration for Tio_2-water and Al_2O_3-water nanofluids

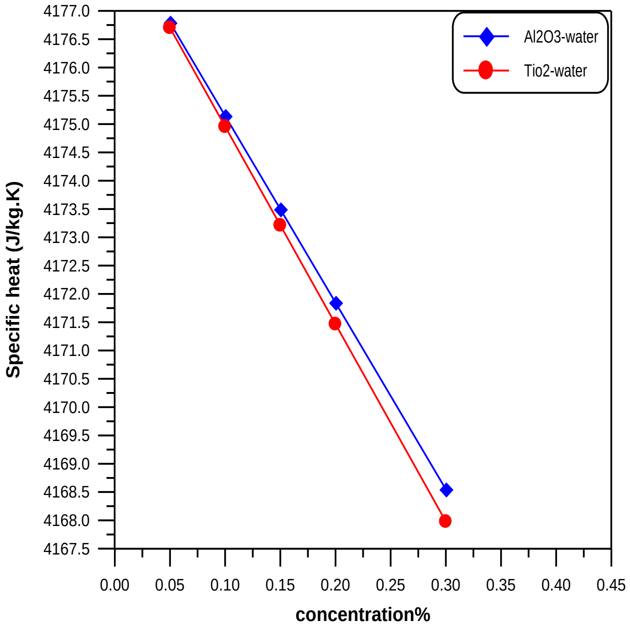


Fig (4) Variation of specific heat with concentration for TiO_2-water and Al_2O_3-water nanofluids

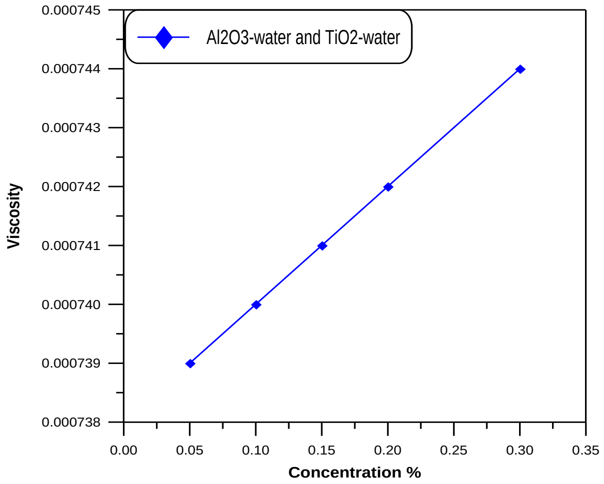


Fig (5) Variation of viscosity with volume concentration for Al_2O_3-water and TiO_2-water nanofluid.

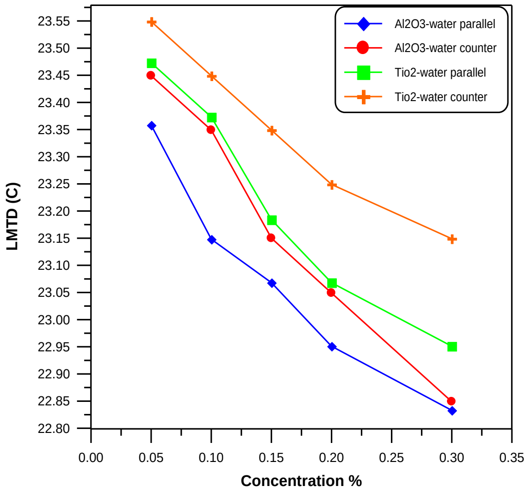


Fig (6) Variation of logarithm mean temperature with volume concentration for Al_2O_3-water and

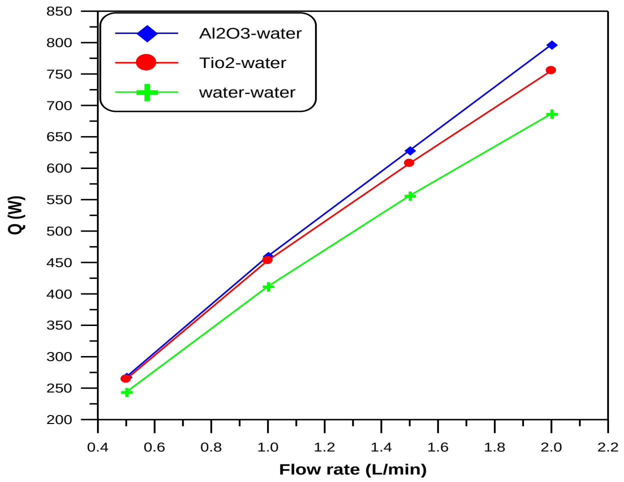


Fig (7) Variation of heat transfer rate with flow rate for Al_2O_3-water, TiO_2-waer nanofluid and water-water.

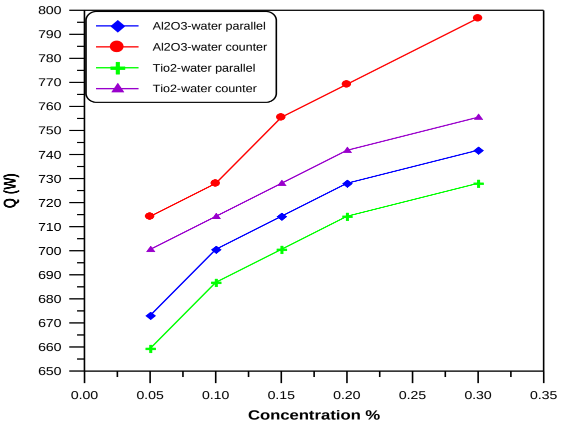


Fig (8) Variation of heat transfer rate with volume concentration for Al_2O_3-water and TiO_2-water nanofluids in parallel and counter arrangements

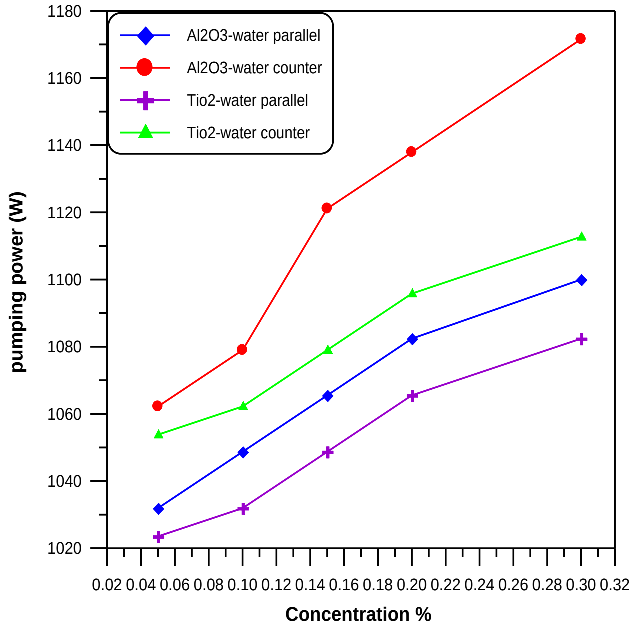


Fig (9) Variation of pumping power (P.P) with volume concentration for Al_2O_3-water and TiO_2-water nanofluids in parallel and counter arrangements

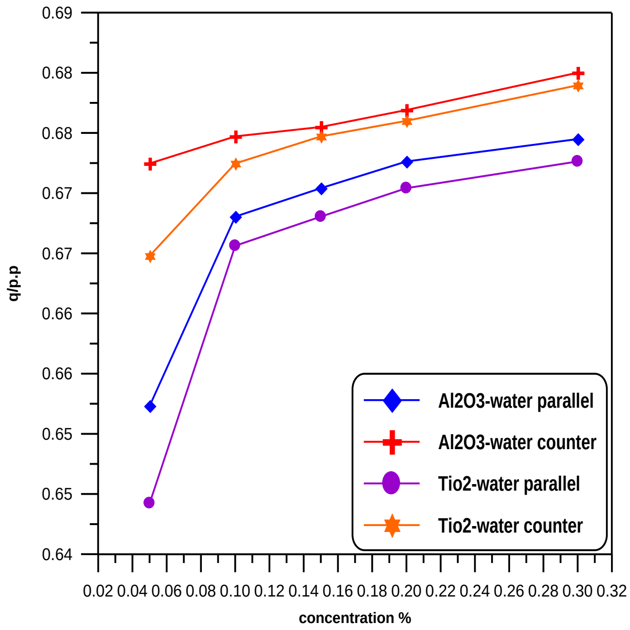


Fig (10) Variation of heat transfer rate over pumping power with volume concentration for Al_2O_3-water and TiO_2-water nanofluids in parallel and counter

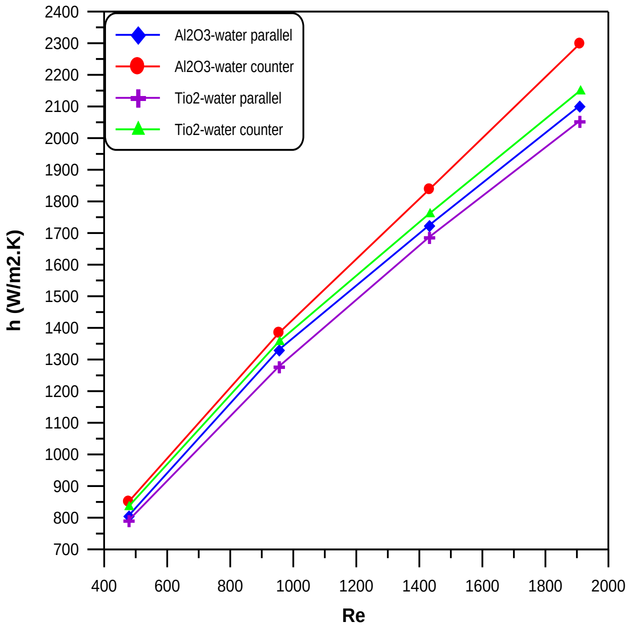


Fig (11) Variation of heat transfer coefficient with Reynolds number for Al_2O_3-water and TiO_2-water in parallel and counter

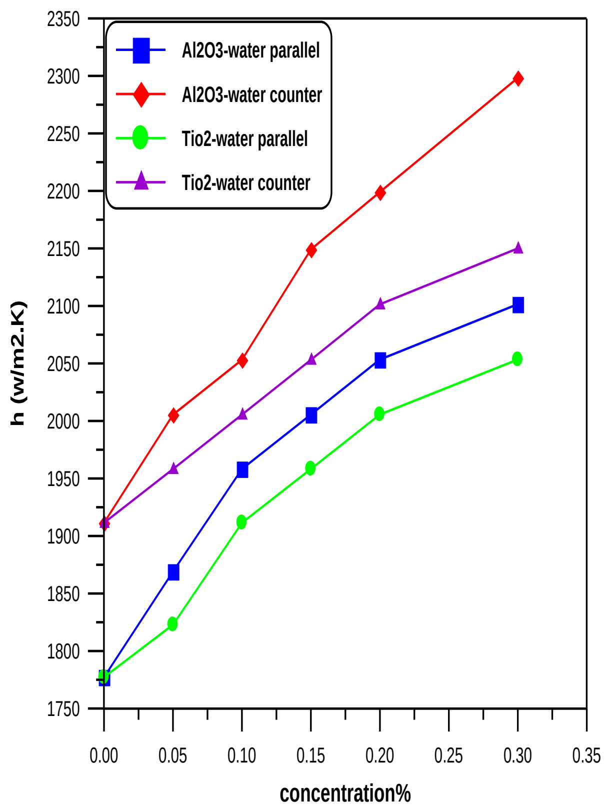
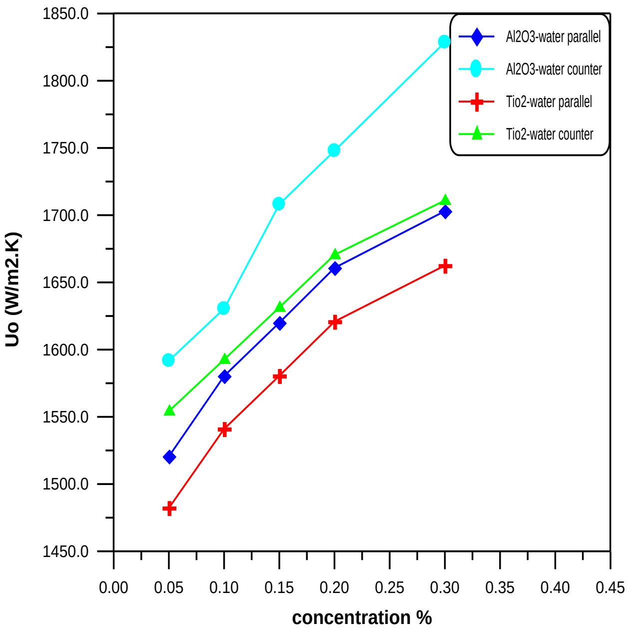
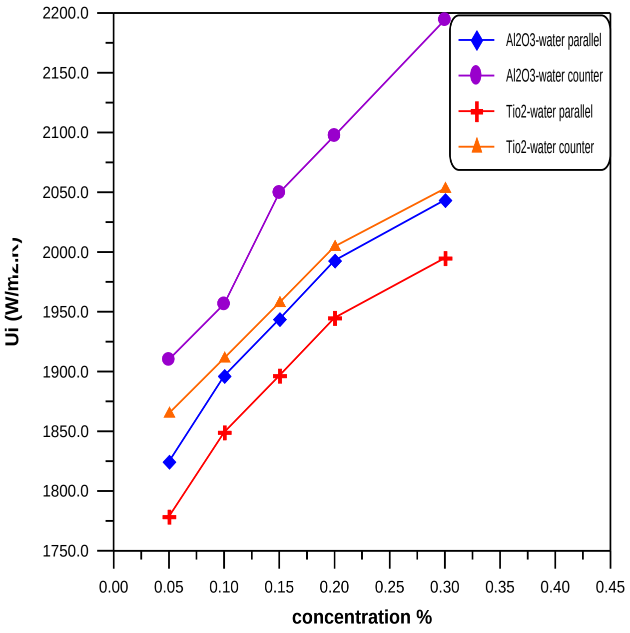


Fig (12) Variation of heat transfer coefficient with concentration for water-water, Al_2O_3-water and TiO_2-water nanofluids in parallel and counter directions

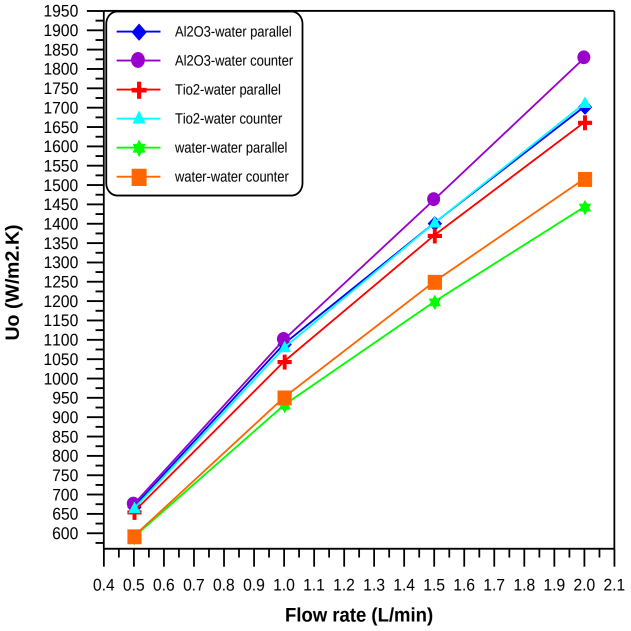


A-Outer overall heat

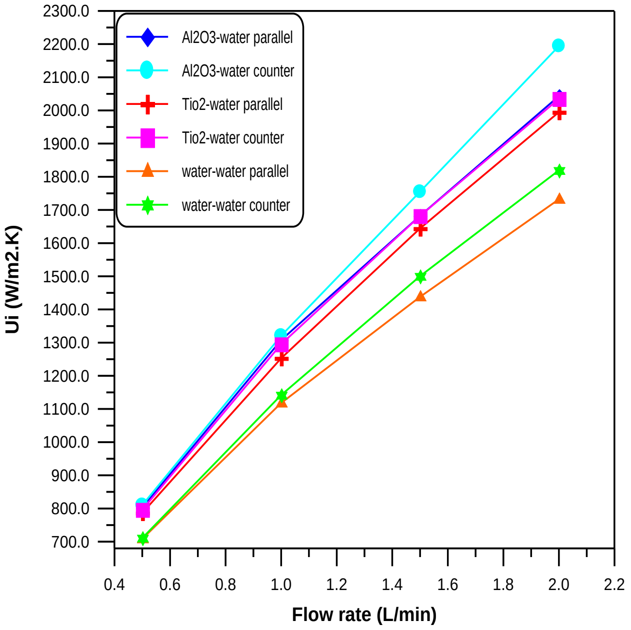


B-Inner overall heat transfer

Fig (13) variation of outer and inner over all heat transfer with concentration for TiO_2 and Al_2O_3 in parallel and counter directions



A- Outer overall heat transfer



B-Inner overall heat transfer

Fig (14) variation of outer and inner over all heat transfer with flow rate for TiO_2 and Al_2O_3 in parallel and counter