ENHANCEMENT OF HEAT TRANSFER IN DOUBLE PIPE HEAT EXCHANGER USING AL_2O_3-FE_2O_3/WATER HYBRID NANOFLUID

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ABSTRACT

This study aims to enhancement of heat transfer in double pipe heat exchanger by improving the thermal properties of base fluid which is water by adding AL_2O_3-Fe_2O_3 nanoparticles to the water. Al_2O_3-Fe_2O_3/water hybrid Nanofluid were examined experimentally and numerically at different flow rates ranging between (3 -7) Lpm at temperature of 25°C in an external tube while there was a hot water at a temperature of 60°C and a flow rate ranged between (3 – 5) Lpm running in the central tube of a double pipe counter heat exchanger. Also, the effect of various concentrations ranged between (0.05, 0.1, 0.15, 0.2, 0.25 and 0.3%) of Al_2O_3-Fe_2O_3 nanoparticles dispersed in water on the rate of heat transfer, friction coefficient were verified experimentally and numerically . The ratio of Al_2O_3-Fe_2O_3 is 0.5:0.5. The experimental and numerical study indicated that with the rate of heat transfer increases when the concentration of suspended nanoparticles in the base fluid increases , but on the other hand, the skin friction coefficient and pressure drop increases as well with increasing the concentration of nanoparticles. The maximum enhancement in heat transfer for AL_2O_3-Fe_2O_3 is about 6 % . The results from the experimental study were largely consistent with the numerical results.

Keywords: hybrid Nanofluid, double pipe heat exchanger , Heat Transfer Coefficient, Nusselt Number

تحسين انتقال الحراره في مبادل حراري مزدوج الانابيب باستخدام المائع النانوي الهجين Al_2O_3-Fe_2O_3/water

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الخلاصة

تهدف هذه الدراسة إلى تحسين انتقال الحرارة في المبادل الحراري ثنائي الانابيب عن طريق تحسين الخصائص الحرارية للسائل الأساسي وهو الماء عن طريق إضافة جزيئات AL_2O_3-Fe_2O_3 النانوية إلى الماء. تم فحص السائل النانوي الهجين Al_2O_3-Fe_2O_3 /water تجريبيًا وعدديًا بمعدلات تدفق مختلفة تتراوح بينLpm (3-7) عند درجة حرارة 25 درجة مئوية في الأنبوب الخارجي بينما كان هناك ماء ساخن عند درجة حرارة درجة حرارة 60 درجة مئوية ومعدل جريان يتراوح بينLpm(3-5) يجري في الأنبوب المركزي لمبادل حراري ثنائي الأنابيب. ايضا تم استخدام التراكيز (0.05,0.1,0.15,0.2,0.25,0.3%) من جزيئات Al_2O_3-Fe_2O_3 النانوية المشتتة في الماء والتحقق من تاثيرها تجريبيا و عدديا على معدل انتقال الحرارة و معامل الاحتكاك. أشارت الدراسة التجريبية والنظرية إلى أنه يزداد معدل انتقال الحرارة مع زيادة تركيز الجسيمات النانوية المعلقة في السائل الأساسي ، ولكن من ناحية أخرى ، معامل احتكاك السطح وانخفاض الضغط يزداد مع زيادة تركيز الجسيمات النانوية. أقصى تحسين في نقل الحرارة لـ AL_2O_3-Fe_2O_3 هو حوالي 6٪. كانت نتائج الدراسة التجريبية متوافقة إلى حد كبير مع النتائج العدديه

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NOMENCLATURE

Symbol	Description		Unit
A	Area	m^2	
As	Surface area	m^2	
Ac	Cross section area	m^2	
Cp	Specific Heat		J/kg. °C
C_f	Darcy friction factor	…	
D, Ds	Diameter of outer tube (shell)		M
Dh	Hydraulic diameter		M
D	Diameter of inner tube (tube)		M
d_p	Nanoparticle diameter		M
d_f	equivalent diameter of the base fluid molecule		M
F	Correction factor	…	
f	Friction factor	…	
h	Heat transfer coefficient		$W/m^2.°C$
k	Thermal conductivity		W/m.°C
L	Length		M
m	Mass		Kg
$\dot{m}$	Mass flow rate		kg/sec
M	molecular weight of the base fluid		kg/mol
N	Avogadro number		mol^{-1}
Nu	Nusselt number		…
pr	Prandtl number		…
p	Pressure		Pa
Δp	Pressure drop		Pa
Q	Heat dissipation		W
Re	Reynolds number		…
T	Temperature		°C
u	Velocity		m/sec
U	Overall heat transfer coefficient		$W/m^2.°C$
$\dot{v}$	Volumetric flow rate		Lpm

Greek Symbols	Description	unit
μ	Dynamic viscosity	kg/m. sec
ρ	Density	kg/m^3
φ	Volume concentration	…
Δ	Difference between values	…
π	PI equal to 3.145926	…

Subscript	Description
Ave	Average
Bf	Base fluid

nf ,hnf	Nanofluid ,Hybrid Nanofluid
C	Cold
H	Hot
I	Inner
Min	Minimum
max	Maximum
o	Outer
eff	Effective
p	Particle
s	Surface
b	Bulk
w	Wall
f	base fluid

Abbreviations	**Description**
LMTD	Log mean temperature difference
AL_2O_3	Aluminum Oxide nanoparticles
Fe_2O_3	Iron (III)oxide nanoparticles
PEC	performance evaluation criterion

INTRODUCTION

A significant necessity in industries is the heat transfer from one location to another Sharma and Gupta (2016). The process of heat interchange between two fluids at dissimilar temperatures and disconnected by a solid wall happens in many engineering applications. The means used to appliance this exchange is termed a heat exchanger Bergman et al.(2011). There are various forms of heat exchangers. These are commonly utilizing in space heating, cooling, air conditioning, power plants, chemical factory, petrochemical factory, refineries for petroleum, natural gas refining and sewage handling Hassan (2003). Shell and tube heat exchangers worldwide are the most commonly used exchangers. Many techniques were used to increase the heat exchangers thermal performance de Vasconcelos Segundo et al. (2017). One way to attain this objective is to utilize Nanofluids rather than conventional coolants like water , ethylene glycol, and cooling oil Tiwari & Paul, (2015). “Nanofluids are the colloidal suspension of nanometer size particles (1–100 nm) dispersed in conventional heat transfer fluids (called base fluids) such as water, ethylene glycol, engine oil, etc Senthilraja et al. (2015). Despite the benefits of Nanofluid but there are many problems like clogging, corrosion, precipitation, high cost. Nano materials differ from each other in terms of properties, some have high conductivity and poor stability, while others are reversible Hussien (2019) .To develop the properties of nanomaterials and improvement the heat transfer of the Nano fluid , a new fluid with distinct properties called hybrid Nanofluid Babu et al. (2017) (Hybrid Nano fluid) distributed by Mixing two or more forms of Nano-sized particles with traditional liquid through physical or chemical processes Hussien (2019) .Many research study the effect of Nanofluid on heat transfer rate. Esfe *et al*. (2016) examine the influence of temperature and solid volume fraction on CNTs – Al_2O_3 / water Nanofluid thermal conductivity. All the Al_2O_3 nanoparticles and CNTs were distributed with similar solid volume within the base fluid. Experiments were carried out with different solid volume fractions were 0.02, 0.04, 0.1 , 0.2, 0.4, 0.8 and 1.0 per cent and specific fluid temperatures were 303, 314, 323 and 332 K. Measured data showed that Nanofluid thermal conductivity depends heavily on the fraction of the solid volume temperature can also play a significant role in boosting the thermal conductivity of CNTs – Al_2O_3 / water, particularly at high fractions of solid volume. Based on experimental results, the nonlinear regression suggested correlations for various temperatures. Such correlations can predict Nanofluid thermal conductivity with high accuracy .In addition, an overall correlation of thermal conductivity with temperature function and fraction of the solid volume was suggested. Comparing the results of the regression with the experimental values noted that the highest error margin was around ±2.0 percent, which showed the superior accuracy of the correlation proposed. Sahid *et al*.(2017) studied the properties and constancy of (Zno and TiO_2)in the combination of water and ethelene glycol . Experiment was performed for different volume fraction (φ=0.1 % to φ=1.5 %).The particle size of Tio_2 was 21nm and for ZnO was (10 – 30nm).The nanoparticle were suspended in different ratio of TiO_2 : ZnO comprising 70:30, 80:20 and 90:10 by means of volume percent. The viscosity of prepared nanofluid was measured experimentally by Brookfield LVDV III Ultra Rheometer in the range of temperatures from 50℃ to 70℃. The thermal conductivity of prepared Nanofluid was measured experimentally by KD2 PRO. Experimental results showed that the viscosity of hybrid nanofluid and thermal conductivity of it were affected by concentration of hybrid Nanofluid, temperature and base fluid such as water Ethelene glycol vigorously. Allhayer *et al*. (2016) studied the thermal performance of single Nanofluid and hybrid Nanofluid in coiled heat exchanger at operating conditions were flow was laminar and constant wall temperature . The concentration of the Nano particle (φ=0.1% to φ=0.4%) . The synthesized Nano particle composition for hybrid Nanofluid experiments is 97.5 per cent alumina and 2.5 per cent Ag. Experimental results show that Use the hybrid Nanofluid at φ=0.4% which is 31.58% greater than that of the distilled water can get the highest heat transfer rate . Above all , the highest thermal performance factor to hybrid Nanofluid was nearly 2.55 which indicates the excellent performance of the energy intensification approach presented in heat exchangers.

PREPARATION OF NANO FLUID

This experiment was done in the postgraduate laboratories of the Engineering College of Wasit University. The two-step method is used for preparing the Nanofluids . The base fluid used in these experiments is distilled water . Two types of hybrid Nanofluids with diameter (50nm AL_2O_3, 40nm Fe_2O_3) are used. The Sensitive Balance (kern, ABS)-type having 6 digits was used for weighing the nanoparticles. The required weight of the nanoparticles for known volume of the base fluid can be found by assuming the volume concentration of the nanoparticles in the base fluid. The following formula illustrates the relation between the volume fraction, nanoparticles weight, weight of the base fluid and their densities Mohammad (2016).

$$\varphi = \frac{\frac{w_{Particle}}{\rho_{particle}}}{\frac{w_{particle}}{\rho_{particle}} + \frac{w_{base\ fluid}}{\rho_{base\ fluid}}} \tag{1}$$

The Nanofluid which is required is prepared by addition the calculated amount of nanoparticles in a known amount of distilled water. 136.5 g of $Fe_2O_3$and 100.8g of Al_20_3 were used at a concentration of 0.3%. The ultrasonic device of 240W and from 20khz to 135kHz is used to mix the nanoparticles with distilled water. From the above equation, by fixing the water value at (5litter) in all the tests the value of nanoparticle needed to be mixed is calculated. The ultrasonic vibration device was switched for 14hours. To get the best Nanofluid mixture with no sedimentation or agglomeration, many tests were made during the work.

EXPERIMENTAL SETUP

Figures (1 and 2) show the experimental setup. It consists of the test section which constructed of two pipes, Hot Water Vessel with electrical heater with capacity 6000 watt, A cold water vessel connected to a cooling system for cooling the hybrid Nanofluid. Digital Thermometer CE-type is used to measure the inlet and outlet temperature of hot and cold side and along the test section for the outer tube. Two flow meters are used to control and measure the flow rates . The pressure drop between the inlet point and the outlet point in the shell is determined by manometer K‹Moon- type. The cold fluid which contained the Nano particles and flow in the shell side at temperature 25̊ C and the volumetric flow rates were (3,4,5,6,7,)Lpm. The hot fluid flow in the tube side at 60̊ C and the volumetric flow rates were (3, 4, 5)Lpm.

MATHMETICAL AND NUMERICAL MODEL

Numerical simulation is the study of a system in different science departments, such as flowing fluid, heat transfer and other parameters. By utilizing ANSYS FLUENT 20 r1 software, the numerical simulation of the three-dimensional model for the heat exchanger was done.

Assumptions

During the current analysis of hot water and cold water, the following presumptions were shown:

1. The state is Steady-state.
2. Imposed Newtonian fluid.
3. Imposed Incompressible.
4. Three dimensional.
5. Insignificant buoyancy.
6. Heat transfer by radiation is not take into consideration

Governing equations

Single-phase model (laminar flow)

The governing equations for continuity, momentum and energy in dimensional formula for homogenous mixture of hybrid Nanofluid are Fluent (2006):

Continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(\rho r v_r) + \frac{1}{r}\frac{\partial}{\partial \theta}(\rho v_\theta) + \frac{\partial}{\partial z}(\rho v_z) = 0 \quad (2)$$

Momentum equation:

In (r) direction

$$v_r\frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta} + v_z\frac{\partial v_r}{\partial z} - \frac{v^2{}_\theta}{r} = -\frac{\partial \mathrm{P}}{\partial \mathrm{r}} + \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right) + \frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2} + \frac{\partial^2 v_r}{\partial z^2}\right] \quad (3)$$

In (Θ) direction

$$v_r\frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta} + v_z\frac{\partial v_\theta}{\partial z} - \frac{v_r v_\theta}{r} = -\frac{\partial \mathrm{P}}{\partial \Theta} + \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right) + \frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2} + \frac{\partial^2 v_\theta}{\partial z^2}\right] \quad (4)$$

In (z) direction

$$v_r\frac{\partial v_z}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta} + v_z\frac{\partial v_z}{\partial z} = -\frac{\partial \mathrm{P}}{\partial \mathrm{z}} + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2} + \frac{\partial^2 v_z}{\partial z^2}\right] \quad (5)$$

Energy equation:

$$\rho c_p\left(v_r\frac{\partial T}{\partial r}+\frac{v_\theta}{r}\frac{\partial T}{\partial \theta}+v_z\frac{\partial T}{\partial z}\right)=-\left[\frac{1}{r}\frac{\partial}{\partial r}(rq_r)+\frac{1}{r}\frac{\partial q\theta}{\partial \theta}+\frac{\partial q_z}{\partial z}\right] \quad (6)$$

Numerical methods and data reduction

With the assistance of the SIMPLE algorithm, the computational fluid dynamics code FLUENT and ANSYS are used to perform the coupling between pressure and velocity, which is more robust and economical compared to the other algorithm families. The geometry of the problem is created by FLUENT software and the mesh generation is made by the ANSYS Meshing. A non-uniform unstructured mesh is generated for the whole domain, hexahedron and Hexa/Prism volume elements are used in the simulation. The three-dimensional, steady, laminar, and turbulent flows and heat transfer governing equations are solved using the finite volume method (FVM).

The local convection heat transfer coefficient is calculated as follows Mohammad (2016):

$$h_{(z)}=\frac{q}{\left(T_{w_{(z)}}-T_{b_{(z)}}\right)} \quad (7)$$

The average heat transfer coefficient is given as

$$h_{avr}=\frac{1}{L}\int_0^L h_{(z)}\,dz \quad (8)$$

The results of the local Nusselt number is determined by

$$Nu_z=\frac{h_z D_h}{k_{\text{nf}}} \quad (9)$$

The average Nusselt number can be calculated by the following equation:

$$Nu_{\text{avr}}=\frac{1}{z}\int_0^z Nu_z\,dz \quad (10)$$

The velocity of the hybrid Nanofluid is estimated by using the Reynolds number formula:

$$Re=\frac{\rho_{\text{nf}}\,u\,D_h}{\mu_{\text{nf}}}=\frac{4\dot{m}}{\pi\mu_{\text{nf}}D_h} \quad (11)$$

where $\dot{m}$ is the mass flow rate of the hybrid Nanofluid

While the Darcy friction factor and friction coefficient of Nanofluids are estimated by using the following equations, respectively:

$$f=\frac{2D_h\,\Delta P}{L\rho u_m^2} \quad (12)$$

$$C_f=\frac{2\,\tau_w}{\rho_{nf}\,u^2}=\frac{1}{4}f \quad (13)$$

DATA ANALYSIS FOR THE NANOFLUIDS THERMO PHYSICAL PROPERTIES

Thermo-physical Properties of Nanofluid

The effective thermal conductivities of Nanofluids are estimated by using the correlation presented in the study of Prasher et al. (2005):

$$K_{eff}=(1+A\,Re^m Pr^{0.333}\varphi)\left(\frac{K_p+2K_{bf}+2(K_p-K_{bf})\varphi}{K_p+2K_{bf}-(K_p-K_{bf})\varphi}\right)K_{bf} \quad (14)$$

Corcione (2011) developed an empirical correlation for the dynamic viscosity based on a large number of experimental data from literature

$$\mu_{hnf} = \frac{\mu_{bf}}{(1 - 34..87 * \left(\left(\frac{d_p}{d_f}\right)^{-0.3}\right) * (\varphi_{hnf}^{1.03})} \quad (15)$$

The effective density of the Nanofluid is given by Ben-Mansour *et al*. (2013)

$$\rho_{hnf} = \left(1 - \varphi_{hnf}\right) * \rho_{bf} + \varphi_p \rho_p \quad (16)$$

The effective specific heat at a constant pressure of the hybrid Nanofluid $(c_p)_{nf}$ is computed using the following equation

$$cp_{hnf} = [(\emptyset_p * \rho_p * cp_p) + \left(\left(1 - \emptyset_{hnf}\right)(\rho_{bf}\ cp_{bf})\right)/\rho_{nf}]$$
(17)

Data Processing

The equations that are used to calculate the parameters that demonstrate the correctness and effectiveness of the experimental work are listed below Mohammad (2016).

Mass Flow Rate

$$\dot{m}\frac{kg}{sec} = \frac{\dot{v}\ (lpm)}{60} \quad (18)$$

Reynolds Number

$$Re = \frac{\rho u d}{\mu} \quad (19)$$

$$u = \frac{\dot{v}}{\rho A_c} \quad (20)$$

Heat Dissipation

$$Q_c = \dot{m}_c\ cp_c (T_{co} - T_{ci}) \quad (21)$$

$$Q_h = \dot{m}_h\ cp_h (T_{ho} - T_{hi}) \quad (22)$$

$$Q_{ave} = \frac{Q_C + Q_h}{2} \quad (23)$$

Log Mean Temperature Difference (LMTD)

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{ln\ (\frac{\Delta T_1}{\Delta T_2})} \quad (24)$$

$$\Delta T_1 = T_{hi} - T_{co} \quad (25)$$

$$\Delta T_2 = T_{ho} - T_{ci} \quad (26)$$

Overall Heat Transfer Coefficient (U)

$$U_o = \frac{Q_{ave}}{LMTD * A_{os}} \quad (27)$$

Heat Transfer Coefficient (h)

$$h_i = \frac{Nu_i * 0.64}{d_{ip}} \quad (28)$$

$$h_o = \frac{1}{\frac{1}{U_o} - \frac{A_i}{A_o h_i}} \quad (29)$$

Nusselt Number

For hot side in the inner tube (turbulent flow):

$$Nu = 0.023 * Re^{0.8} pr^{n}$$ n= 0.3 for cooling

(30)

$$pr = \frac{\mu * cp}{k}$$

(31)

For cold side in the shell (laminar flow) and Nanofluid

$$Nu_c = \frac{h_c}{D_{hs} * K_{hnf}}$$

(32)

hydraulic

$$D_{hs} = D_{is} - d_{op}$$

(33)

Friction factor calculated from equation (14)

$$\Delta p = \frac{f l \rho u_m^2}{2\, d}$$

(34)

RESULTS AND DISSECTION

Average Nusselt number

The use of hybrid to improve heat transfer has had a very important impact in recent studies. Researchers have focused on several factors including hybrid Nanofluid’s thermal conductivity in the quantity of heat transfer in the heat exchanger. Therefore, recent studies have focused that thermal conductivity is also affected by several factors, including the influence of temperature and the concentration of nanoparticles in the fluid. Figure (3) clearly shows the effect of different concentrations of Al_2O_3-Fe_2O_3 hybrid nanoparticles on the Nusselt number, where the figure demonstrated that the average Nusselt number gradually increases with increasing concentrations, due to the fact that the thermal conductivity of the fluid increases with increasing concentrations of nanoparticles in the fluid, and thus the rate of heat transfer increases.

Average heat transfer coefficient

The heat transfer coefficient is very important in calculating the quantity of heat transfer between hot and cold fluids. The heat transfer coefficient greatly influences the temperature difference between the two fluids, as well as the thermal conductivity of the fluids. Figure (4) clearly shows that the heat transfer coefficient increases with increasing concentration of nanomaterials due to the increased thermal conductivity of the fluid.

Average skin friction coefficient

It is also important to study increasing the nanoparticles concentrations in the fluid on friction loss in order to calculate the performance evaluation criteria of the heat exchanger. As there is no desired benefit in the process of the heat transfer enhancement if the friction is higher than the heat transfer rate Figure (5) displays that the friction coefficient increases with the increasing of suspension of nanoparticles in the base fluid at all the concentrations. The reason for this is due to the fact that adding nanoparticles to the fluid is increased the density and viscosity of the fluid, and thus the increase in friction loss.

Velocity and temperature contour

In this part of the study, for further clarification on improving the heat transfer in the heat exchanger, a temperature and velocity contour is shown by the Ansys Fluent program. Hybrid Nanofluids have been studied with a concentration of 0.3% and the flow velocity is 7 Lpm at a temperature 25̊C while the velocity of the hot water fluid flow in the central tube is 5 Lpm at 60̊ C. In the figure the fluid temperature gradients in the outer pipe are the highest at the entrance of the pipe , and this shows the reason for the higher heat transfer coefficient and Nusselt number in this part of the pipe, while the temperature gradients of the fluids gradually decrease towards the end of the tube due to the heat exchange between the hot fluid in the central tube with the cold fluid in the outer tube.

Validation experimental with numerical work

Figure (6) shows also the comparison between the experimental results and numerical data for all range of flow rates examined here. The figures show clearly that there is a good agreement between the numerical and experimental results for all the fluids. The small deviation between them can be attributed to the losses in heat transfer, losses at pressure taps, and uncertainties of instruments. Whereas these losses are not considered in the CFD simulations. The results show that the values of Nusselt numbers which are measured experimentally are closer to the average Nusselt number that measured numerically with smaller deviation. Figure (7) compares the surface heat transfer coefficient obtained from experimental results with the corresponding numerical results for Al_2O_3-CuO /water hybrid Nanofluid, Al_2O_3-Fe_2O_3/ water hybrid Nanofluid with 0.3% volume fraction and water. It is clearly seen through the comparison that the results of the experimental and numerical study for all the fluids are almost close together with very little deviation. This deviation may be due to the uncertainty of the experimental measurements. The skin friction coefficient for Al_2O_3-Fe_2O_3/ water hybrid Nanofluid with 0.3% volume fraction are computed using single models and compared with experimental results of the current study as depicted in Figure (8). It is clearly seen through the comparison that the results of the experimental and numerical study are almost close together with very little deviation.

CONCLUSIONS

In this work, mixed convection in a double pipe heat exchanger has been studied experimentally. Different parameters have been investigated on their effects on enhancing the heat transfer and fluid flow inside the double pipe heat exchanger such as nanoparticle concentration, and flow rate. The experiments were conducted for different volume fractions of Al_2O_3-Fe_2O_3 nanoparticles dispersed in the distilled water flow in a double pipe heat exchanger overflow rate range of (3 - 7) Lpm and hot water overflow rate range of (3 - 5) Lpm.

1-The average Nusselt number, heat transfer coefficient, as well as the pressure drop in all cases, considerably increased with increasing flow rate.

2-The average Nusselt number, pressure drop, and the heat transfer enhancement increased with the addition of nanoparticles.

3- For Al_2O_3-Fe_2O_3/water hybrid Nanofluid with 0.3% volume fraction and (50nm AL_2O_3, 40nm Fe_2O_3) nanoparticles diameter, the maximum heat transfer enhancement was 6% in the double pipe heat exchanger compare to water.

Table (1): Specifications of the test

Shell	**Inner diameter**	42.6 mm
	Outer diameter	50 mm
	Length	1000 mm
	Thickness	3.7 mm
Smooth tube	**Inner diameter**	17.05mm
	Outer diameter	19.05 mm
	Length	1000 mm
	Thickness	1 mm

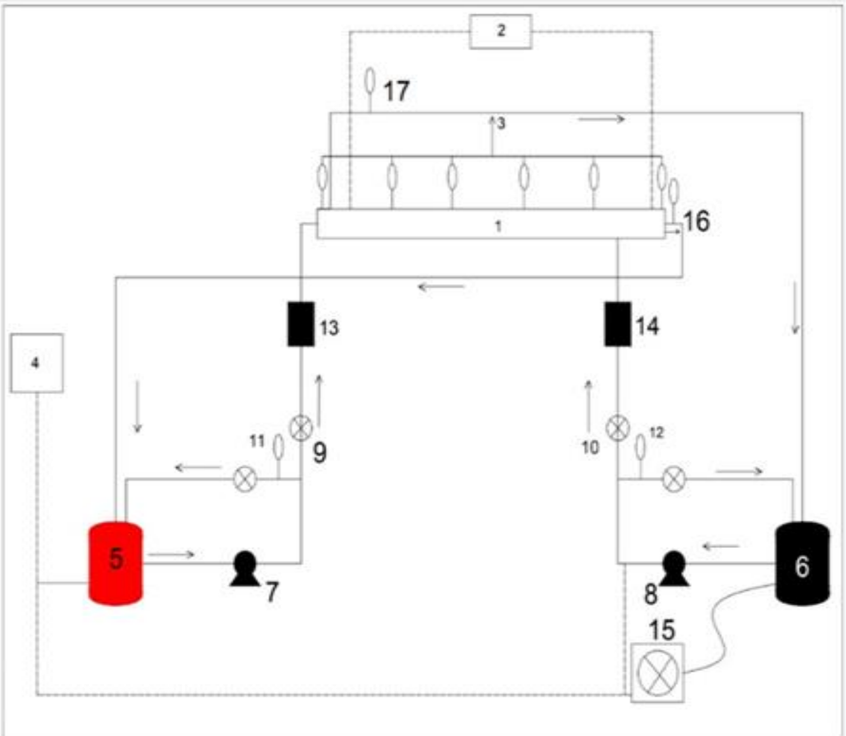

Fig.(1):Schematic diagram of experimental setup

1-Test section , 2- Manometer , 3- Digital Thermometer,

4- Electrical control , 5-Hot water vessel , 6- cold-water vessel

7-Hot water pump , 8- cold water pump , 9-Hot water valves 10- Cold water valves , 11- Digital thermometer for hot entry temperature , 12- Digital thermometer for cold entry temperature

13-Hot water flow meter , 14-Cold water flow meter , 15-Cooling unit

16- Digital thermometer for hot exit temperature , 17- Digital thermometer for cold exit temperature.

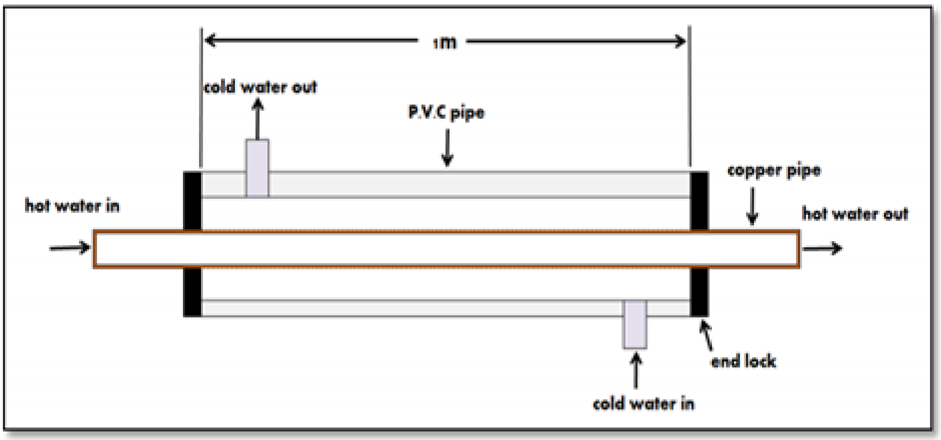

Fig. (2): schematic test section

Fig. (3): photography of total equipment of the system

Fig.(4): Sensitive Balance

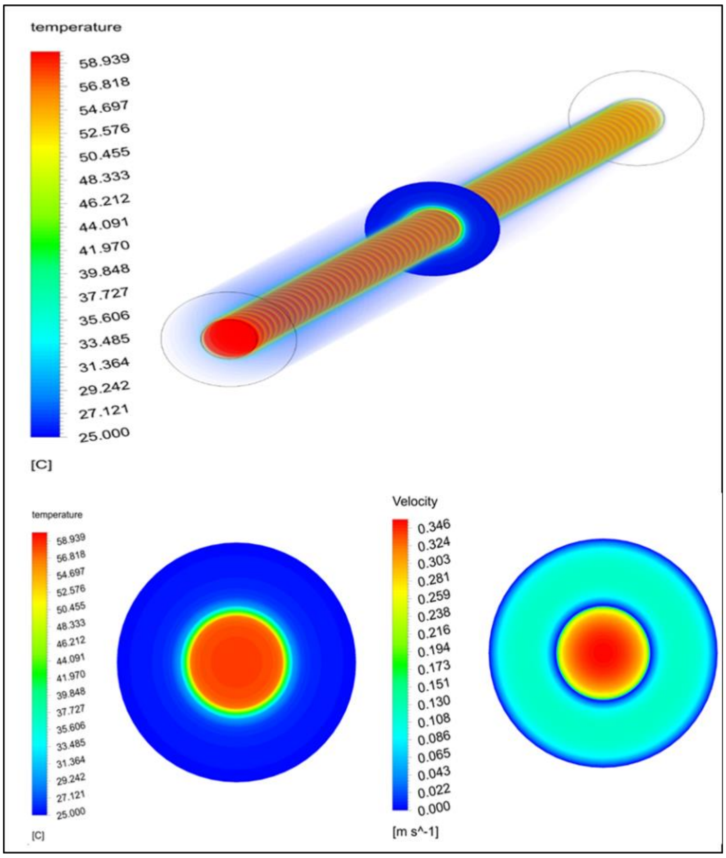

Fig. (5): Temperature and velocity contour for Al2O3-Fe2O3/water hybrid Nanofluid

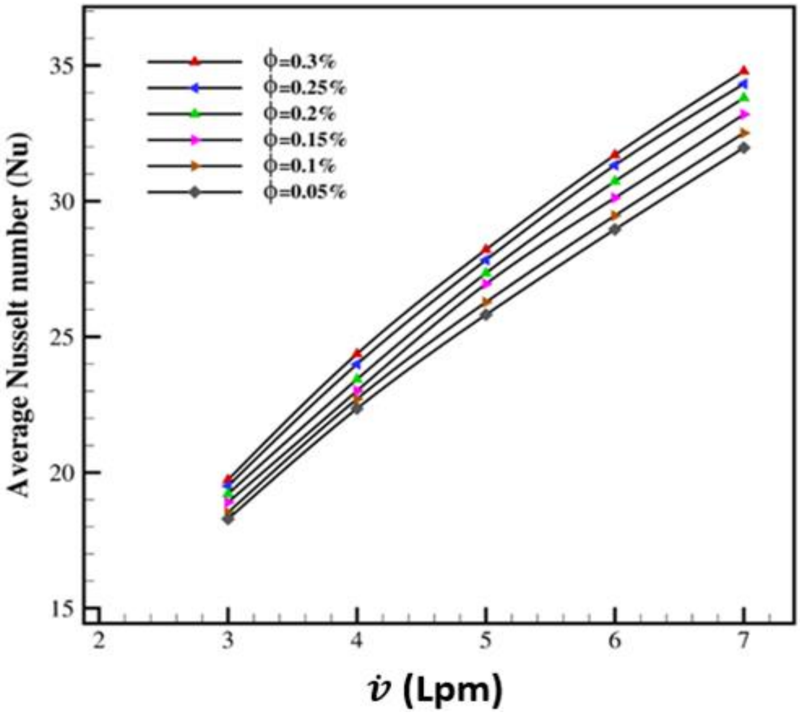

Fig. (6): Effect of nanoparticles volume fraction on average Nusselt number at T_{inc} =25ºC and $v_h^{\cdot} = 3$Lpm ,T_{inh}= 60̊ C

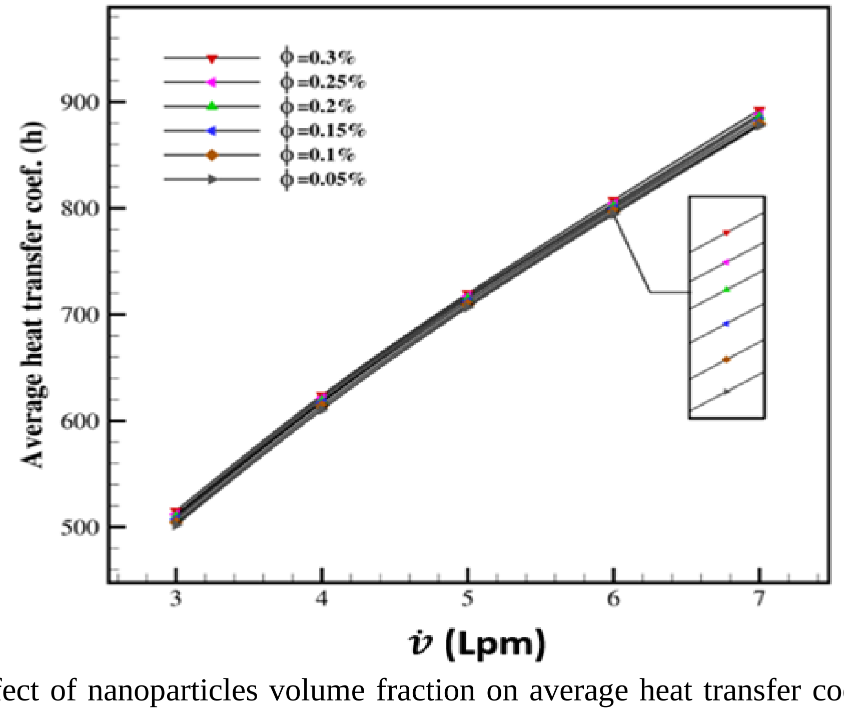

Fig. (7): Effect of nanoparticles volume fraction on average heat transfer coefficient at Tinc =25oC and v_h^.=3 Lpm ,Tinh= 60̊ C

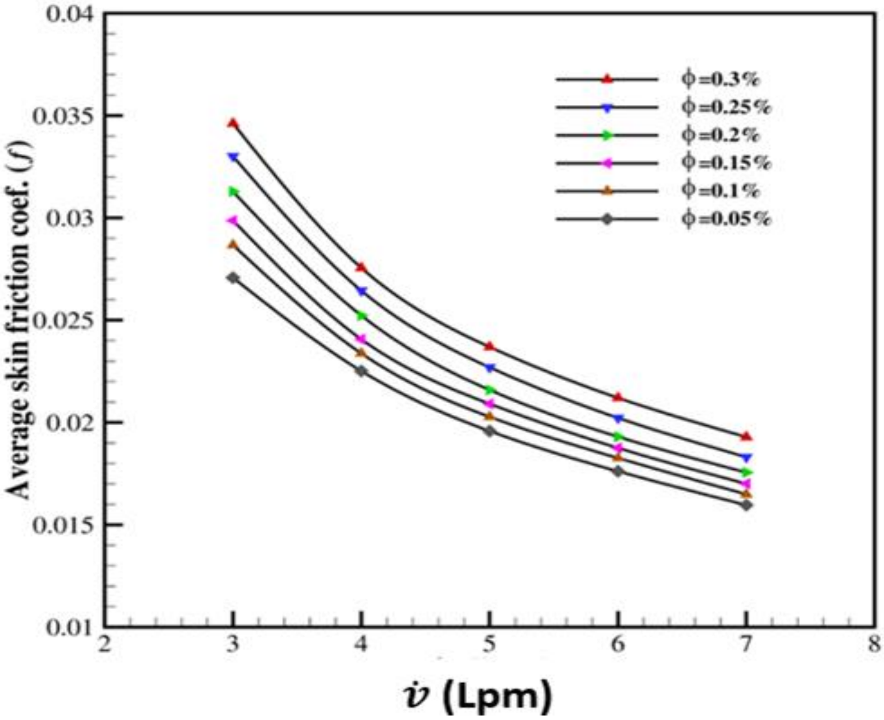

Fig.(8): Effect of nanoparticles volume fraction on the average skin friction coefficient at Tinc =25oC and v_h^.=3 Lpm ,Tinh= 60̊ C

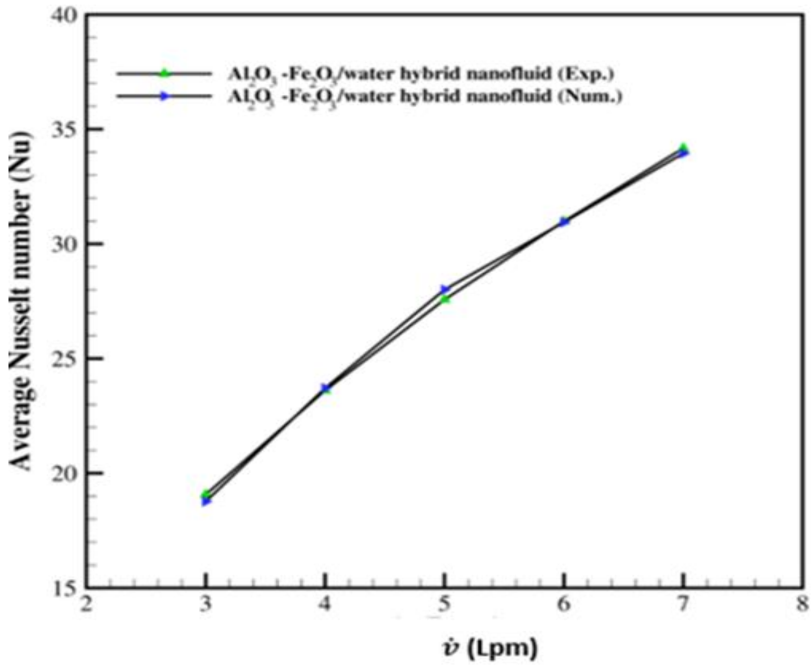

Fig. (9): comparison between experimental work and numerical work for the effect of different fluid on average Nusselt number at φ= 0.3% , T_{inc} =25ºC and $\dot{v}_h = 3$Lpm ,T_{inh}= 60̊ C

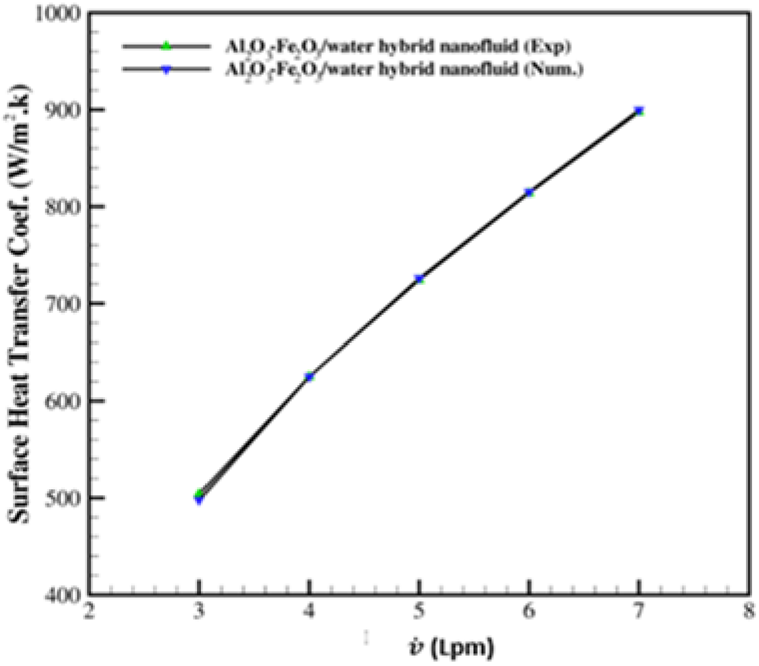

Fig. (10): comparison between experimental work and numerical work for the effect of different fluid on average surface heat transfer coefficient at φ= 0.3 % , T_{inc} =25°C and $\dot{v}_h$ = 3Lpm , T_{inh}= 60°C

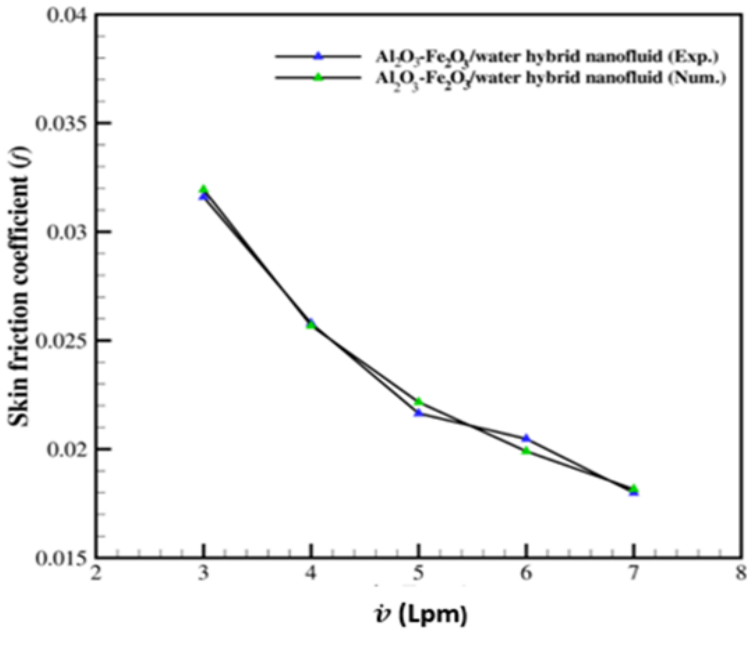

Fig. (11): comparison between experimental work and numerical work for the effect of different fluid on the skin friction coefficient at φ= 0.3 % ,T_{inc} =25°C and $\dot{v}_h$ = 3Lpm ,T_{inh}= 60°C

REFERENCES

Allahyar, H. R., Hormozi, F., & ZareNezhad, B. Experimental investigation on the thermal performance of a coiled heat exchanger using a new hybrid nanofluid. Experimental Thermal and Fluid Science, 76, 324-329, 2016.

Babu, J. A. R., Kumar, K. K., & Rao, S. S. State-of-art review on hybrid nanofluids. Renewable and Sustainable Energy Reviews, 77, 551–565, 2017.

Ben-Mansour, R., & Habib, M. A. Use of nanofluids for improved natural cooling of discretely heated cavities. Advances in Mechanical Engineering, 5, 383267, 2013.

Bergman, T. L., Incropera, F. P., DeWitt, D. P., & Lavine, A. S. Fundamentals of heat and mass transfer. John Wiley & Sons. 2011.

Corcione, M. “Empirical correlating equations for predicting the effective thermal conductivity and dynamic viscosity of nanofluids,” Energy Convers. Manag., vol. 52, no. 1, pp. 789–793, 2011.

Esfe, M. H., Saedodin, S., Yan, W. M., Afrand, M., & Sina, N. Study on thermal conductivity of water-based nanofluids with hybrid suspensions of CNTS/Al_2O_3 nanoparticles. Journal of Thermal Analysis and Calorimetry, 124(1), 455-460, 2016.

Fluent, I. N. C. FLUENT 6.3 user’s guide. Fluent Documentation.2006.
Hassan, “Enhancement of Cross FlowHeat Exchanger performance By Using Intrgral Fins and Nanofluid,” wasit, 2003.

Hussien, A. A. “A Brief Survey of Preparation and Heat Transfer Enhancement of Hybrid Nanofluids,” vol. 65, pp. 441–453, 2019, doi: 10.5545/sv-jme.6077, 2019.
Mohammad, S. A. Heat Transfer Enhancement of a Counter Flow Shell and Tube Heat Exchanger. wasit.2016.

Prasher, R., Bhattacharya, P., & Phelan, P. E. (2005). Thermal conductivity of nanoscale colloidal solutions (nanofluids). Physical review letters, 94(2), 025901, 2005.

Sahid, N. S. M., Rahman, M. M., Kadirgama, K., & Maleque, M. A. Experimental investigation on properties of hybrid nanofluids (TiO_2 and ZnO) in water–ethylene glycol mixture. Journal Of Mechanical Engineering And Sciences, 11, 3087-94, 2017.

Senthilraja, S., Vijayakumar, K., & Gangadevi, R. A comparative study on thermal conductivity of Al_2O_3/water, CuO/water and Al2O3–CuO/water nanofluids. Digest Journal of Nanomaterials and Biostructures, 10(4), 1449-1458, 2015.

Sharma and Gupta, “Preparation and evaluation of stable nanofluids for heat transfer application: a review,” Exp. Therm. Fluid Sci., vol. 79, pp. 202–212, 2016.

Tiwari and Paul, “Experimental Study On Heat Transfer Enhancement By Using Water–Alumina Nanofluid In A Heat Exchanger,” vol. m, no. 4, pp. 192–200, 2015.