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Performance Evaluation of a Triple Concentric Tube Heat Exchanger Using Deionized Water and Oil-40

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Abstract:

This study examines experimentally the performance of a horizontal triple concentric tube heat exchanger TCTHE made of copper metal using water as cooling fluid and oil-40 as hot fluid. Hot fluid enters the inner annular tube of the TCTHE in a direction at a temperature of 50, 60 and 70 ºC and a flow rate of 20 l/hr. On the other hand, the cooling fluid enters the inner tube and the outer annular tube in the reverse direction (counter current flow) at a temperature of 25 ºC and flow rates of 10, 15, 20, 25, 30 and 35 l/hr. The TCTHE is composed of three copper tubes with outer diameters of 34.925 mm, 22.25 mm, and 9.525 mm, and thicknesses of 1.27 mm, 1.143 mm, and 0.762 mm, respectively. TCTHE tube's length was 670 mm. Nusselt number, overall heat transfer coefficient, convective heat transfer coefficient (CHTC), friction factor and pressure drop were measured from the obtained experimental results and plotted in graphs against Reynold number and volumetric flow rate of water. These parameters appeared good results in the cooling process. Nusselt numbers increased linearly with DIW flow rate for both C1 and C2 reaching maximum values of 38.25 and 14.64 respectively. CHTC increased linearly with the DIW flow rate for both C1 and C2 reaching maximum values of 2934.3 and 871.7 respectively. Overall heat transfer coefficient of DIW reached maximum values of 296.36 and 251.4 at 35 l/hr for C1 and C2, respectively. Friction factor DIW in C1 and C2 decreased with the volumetric flow rate increases, reaching minimum values of 0.04 and 0.25 respectively. Pressure drop of DIW increased linearly with flow rate reaching maximum values of 81.4 and 4.31 for C1 and C2 respectively. This in turn leads to reduced TCTHE length and size leading to a decrease in the construction cost of the heat exchanger.

Keywords: Friction factor, Nusselt number, Overall heat transfer coefficient, Pressure drop, TCTHE, Triple concentric tube heat exchanger.

Introduction:

The double pipe heat exchanger (DPHE) is a device used to transfer heat energy between two fluids depending on the temperature gradient between them. It is a basic unit in many industries: including food, pharmaceutical, dairy pasteurization, evaporation, refrigeration, chilling, freezing, etc. Heat is transferred between two fluids in DPHE through the tube wall, thus to increase the heat transfer rate it is necessary to increase the tube surface area by increasing the length of the tubes. This in turn leads to an increase in the heat exchanger (HE) size and cost. For that reason, researchers tried to modify DPHE and reduce its size by using a triple concentric tube heat exchanger (TCTHE). TCTHE is designed of three tubes connected concentrically with each other. It consists of an inner tube, inner annular, and outer annular. For an effective heat transfer rate the hot fluid should flow through the inner annular on the other hand, the cold or normal temperature fluid flow through the inner tube and the outer annular. The heat transfers take place along the outer surface area of the inner tube and the inner surface area of the inner annular.

The flow arrangements in DPHE could be divided into two types co-current and counter current. On the other hand, TCTHE consists of three flowing fluids as a result the flow arrangements could be divided into four types. Using TCTHE could enhance heat transfer by reducing HE size and cost. Water is an essential fluid used as HTF in different heat transfer units such as solar collectors, it is cheap, available thermophysical properties, high thermal conductivity with moderate viscosity. Studying TCTHE began with C. Zuritz in 1990 by deriving three first order differential equations using Laplace transformation for three fluids. By comparing the obtained results, he concluded that using TCTHE causes an overall heat transfer (OHT) efficiency improvement and a HE length reduction by 25% [1].

Radulescu et al. [2] studied experimentally TCTHE by using mineral oil as the heating medium in the inner annular and water as cooling in an inner tube and outer annular. They obtained a deviation range of 3.5 to 4.8 % for temperature prediction. Ghiwala and Matawala[3], studied numerically TCTHE by comparing TCTHE with DTHE and found that the TCTHE shows better heat transfer efficiencies and a large heat transfer area per unit exchanger length. This means a reduction in the space requirement. Hossain et. al [4] studied experimentally TCTHE by designing it and studying its performance using different inlet temperatures and mass flow rates. He found that the overall heat transfer coefficient increases with the increasing mass flow rate for hot and cold fluid In the same year, Pancholi et al. [5] found in their research that TCTHE performs better using counter flow than using co-current flow.

Tamkhade et al. [6] investigated experimentally TCTHE using water as a cooling medium and oil as a hot fluid medium in counter current flow. They found that heat transfer rates increased with increasing water flow rates in the inner tube and outer annular. Furthermore, the heat transfer rate increased with increasing Reynolds number of oil. Dwivedee et. al [7] admitted a review on TCTHE and concluded that it has better performance than double tube heat exchangers. Amanuel and Mishra [8] employed CFD software ANSYS Fluent v17.0 to study heat transfer and pressure drop performance in TCTHE and found that increasing Reynolds numbers cause huge growth in Nusselt number and decreasing friction factor. On the other hand, increasing the length/hydraulic diameter of the tube causes a large decrease in both Nusselt number and friction factor.

Reddy et. al [9] studied experimentally TCTHE made of stainless steel tubes using TiO_2/water nanofluid as a cooling medium in the inner tube and outer annular and water as a hot fluid medium. They found that the heat transfer rate increased with TiO_2 nanoparticle concentration in nanofluid. Nayak et. al [10] studied experimentally the performance in a double and triple concentric tube heat exchanger and found that the effectiveness of the cocurrent flow in TCTHE was not always greater than that of the theoretical current flow in a double tube heat exchanger . Jradi et. al [11] developed and validated theoretically a numerical model for the performance evaluation of TCTHE. Tamkhade and Mandar [12] calculated theoretically heat transfer coefficient of TCTHE using an established empirical correlation using ‘Oil ISO VG 22’ as a hot medium and water as a cooling medium in an inner tube and the outer annular in TCTHE under adiabatic condition and counter current flow.

Rajab et. al [13] investigated and analysed the heat transfer process using water and titanium dioxide (TiO_2) as a cooling medium and air passing through the central tube and hot water circulating in the spiral tube of a triple tube heat exchanger and found that using TiO_2/water nanofluid lead to increase the overall heat transfer.

Kilinç[14] prepared 2% by weight graphene/water nanofluid with 0.2% of sodium dodecyl benzene sulfonate as surfactants and found that using this nanofluid as a cooling medium in TCTHE in counter current flow lead to enhancing the heat transfer coefficient by 9.6%. Hussien et. al [15] studied experimentally the performance by using Alumina (Al_2O_3) and Copper oxide (CuO) nanoparticles mixed with engine oil nanofluid as a cooling medium in a double pipe heat exchanger and found an enhancement of thermal conductivity of the base fluid (oil) this in turn improved the heat transfer rate and thermal performance of the heat exchanger. For that reason, it is recommended to prepare nanofluids using the nanoparticle silver and Pomegranate peel extract (MWCNTs- SNPs - NPGPE) prepared by Hamza et. al [16] and Gold nanoparticles prepared by Saeed et. al [17] separately with deionized water as base fluid and use them as a cooling medium in TCTHE to study the heat transfer performance.

The main objectives of this study are:

1. Studying the performance of TCTHE to give an idea about the efficiency obtained by this type of HE.
2. Using water as a cooling fluid in the inner tube and the outer annular and Oil-40 as hot fluid in the inner annular using a counter current flow arrangement.
3. Investigate counter current flow arrangement.
4. Measuring Nusselt number, pressure drop, heat transfer coefficient, overall heat transfer coefficient and plots them in graphs versus flow rate and Reynold number.
5. Reducing the size and the construction cost of the heat exchanger.

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The novelty of this study:

The novelty of this study is fabricating TCTHE using copper tubes with different and small diameters compared with other research. Furthermore, studying the heat transfer behavior using oil-40 as hot fluid and DIW as cooling fluid using laminar flow.

Materials and Methods:

Materials

Three liters of deionized water (DIW) were used as a cooling fluid medium and three liters of Oil-40 were used as a hot fluid medium. Table. 1 shows the physical properties of Oil-40 measured in Laboratory Research of Oil in Al-Doura Refinery.

Table 1. The physical properties of Oil-40

No.	The property	Value	Unit
1	Specific gravity	0.86	-
2	Kinematic viscosity @ 40 ºC,	16.47	C.st
3	Kinematic viscosity @100 ºC,	3.64	C.st
4	Viscosity index	104	-
5	COC flash point	182	ºC
6	Pour point	-12	ºC
7	Colour, ASTM-D1500, @ 25 ºC	0.5	-
8	Water content %vol.	NiL	-

TCTHE details

Figure 1. shows the front view of the designed TCTHE system. It is shown clearly the TCTHE tubes that are made of copper. TCTHE system consists of:

1- Two stainless steel tanks each of them of 4 liters capacity, one for the Oil-40 and the other for the DIW tanks.
2- Four temperature sensors are used supplied, two of them inside each tank and two to detect the outlet (hot and cold) fluid temperature.
3- Two pumps are used in order to pump the liquids to tubes of TCTHE.
4- Two volumetric flow rate controller is used to control the flow rate of the liquids.
5- Fin and tube heat exchanger for cooling the DIW after leaving the TCTHE.
6- Heater inside the hot fluid tank in order to heat Oil-40 to the desired temperature.
7- TCTHE tubes consist of outer, inner, and intermediate tube with an effective length of 67 cm and dimensions are shown in Table. 2.

Table 2. The dimensions of the TCTHE tubes.

	tube 1	tube 2	tube 3
In diameter, mm	8.001	19.964	32.385
Out diameter, mm	9.525	22.25	34.925
Thickness, mm	0.762	1.143	1.27

Figure 1. The front view of the TCTHE

In this study DIW starts flowing from the water tank through pump 1 passing through volumetric flow rate controller 1, then enters the TCTHE through the inner tube and the outer annular. At the same time, oil-40 starts flowing from the oil tank through pump 2 passing through volumetric flow rate controller 2, then enters the TCTHE through the inner annular in a countercurrent flow. Fig. 2 shows the schematic fluid diagram of TCTHE used in the experiment. The oil and water temperature was measured by a thermocouple inserted in different locations: the oil tanks, the water tank, the outlet Oil-40 and DIW from the TCTHE.

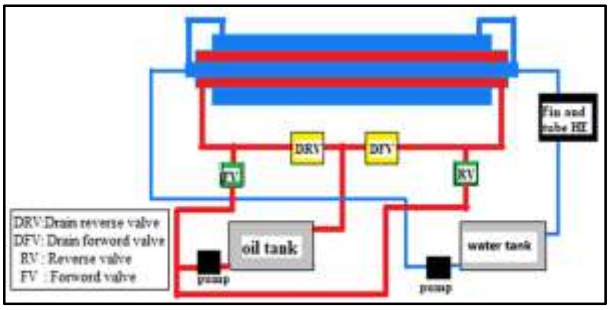

Figure 2. Schematic fluid diagram of TCTHE.

TCTHE calculations

The equations in Table 3. are used to calculate TCTHE parameters.

Table 3. TCTHE Eqs 3 ,4.

	Cooling fluid (DIW) in inner tube	Hot fluid (Oil-40) for inner annular	Cooling fluid (DIW) in outer annular
The mean bulk temperature	$T_{c1} = \frac{T_{c1i}+T_{c2e}}{2}$ … 1	$T_H = \frac{T_{Hi}+T_{He}}{2}$ … 2	$T_{c2} = \frac{T_{c2i}+T_{c2e}}{2}$ … 3
The linear velocity	$v_{c1} = \frac{V_{c1}*4}{\pi * d_{in2}^2}$ … 4	$v_H = \frac{V_H*4}{\pi*(d_{in2}^2 - d_{out1}^2)}$ … 5	$v_{c2} = \frac{V_{c2}*4}{\pi*(d_{in3}^2 - d_{out2}^2)}$ … 6
Reynolds number	$Re_{c1} = \frac{\rho_{c1} v_{c1} d_{h1}}{\mu_{c1}}$ … 7	$Re_H = \frac{\rho_H v_H d_{h2}}{\mu_H}$ … 8	$Re_{c2} = \frac{\rho_{c2} v_{c2} d_{h3}}{\mu_{c2}}$ … 9
The convective heat transfers co-efficient	$h_{c1} = \frac{Nu_{c1}*k_{c1}}{d_{h1}}$ … 10	$h_H = \frac{Nu_H*k_H}{d_{h2}}$ … 11	$h_{c2} = \frac{Nu_{c2}*k_{c2}}{d_{h3}}$ … 12
The frictional pressure loss	$\Delta P1c1 = \frac{f\ l\ *\ \rho*(v_{c1})^2}{d_{h1}\quad 2}$ … 13	$\Delta P1H = \frac{f\ l\ *\ \rho*(v_H)^2}{d_{h2}\quad 2}$ … 14	$\Delta P1C2 = \frac{f*\ l\ *\ \rho*(v_{c2})^2}{d_{h3}\quad 2}$ … 15
The entrance and exit pressure losses	$\Delta P2 = \frac{\rho*(v_{c1})^2}{2}$ … 16	$\Delta P2 = \frac{\rho*(v_H)^2}{2}$ … 17	$\Delta P2 = \frac{\rho*(v_{c2})^2}{2}$ … 18
The hydraulic diameter	$d_{h1} = d_{i1}$ … 19	$d_{h2} = d_{i2} - d_{o1}$ … 20	$d_{h3} = d_{i3} - d_{o2}$ … 21
Nusselt number for laminar flow condition (Re< 2300)	$Nu_c = 0.51 * Re^{0.5} * Pr^{\frac{1}{3}}$ … 22		
	Where f =64/Re_{c1} for laminar regime … 23		

The TCTHE program measured the inlet temperatures, the outlet temperatures and flow rates of the cooling and the heating mediums spontaneously. In addition, the TCTHE computer program calibrated automatically the temperatures and the flow rate. The linear velocity was calculated using Eqs 4-6. The convective heat transfer co-efficient was calculated using eqs 10-12. The frictional pressure loss was calculated using Eqs 13-15. In addition, the entrance and exit pressure losses were calculated using eqs 16-18. Since the flow was laminar (Re< 2300) Nusselt number of the cooling fluid was calculated using Eq 22.

Results and Discussion:

Nusselt Number of DIW in TCTHE

Figures. 3 and 4, show Nusselt number values of DIW against flow rate calculated using Eq.22 in the inner tube and the outer annular of the TCTHE respectively. Nusselt number was increased linearly with the DIW flow rate for both C1 and C2 reaching maximum values of 38.25 and 14.64 respectively. Generally, Nu no. for C1 showed a high Nusselt number of about 2.6 times compared with Nusselt number C2. On the other hand, oil inlet temperature rising from 50 to 70 ºC showed no effect on the Nusselt number. The same behavior is shown in Figs. 5 and 6 of Nu no. against Reynold no. that's agreed with Amanuel and Mishra [8].

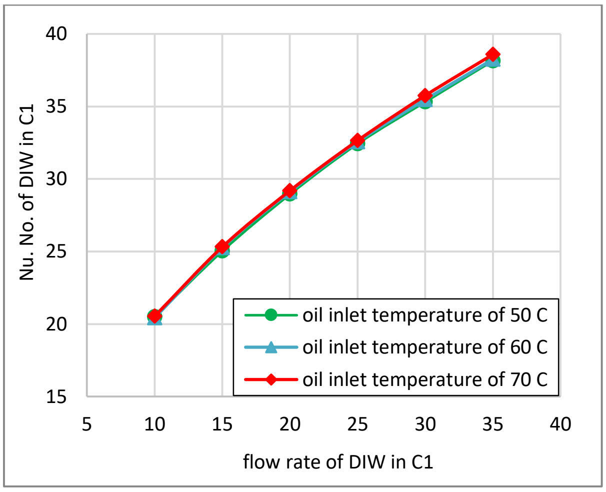

Figure 3. Nu no. of DIW against flow rate using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the inner tube of TCTHE.

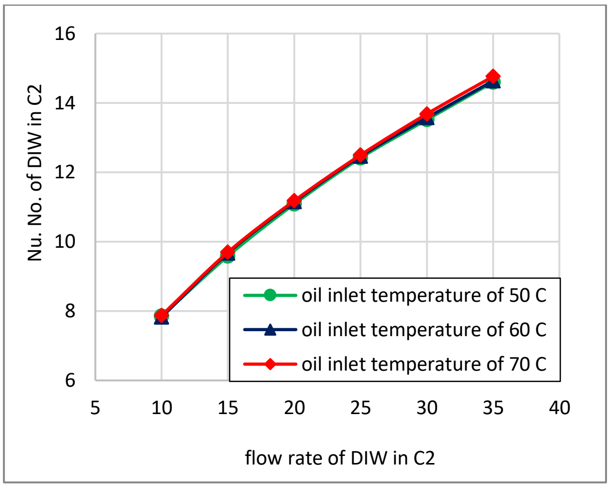

Figure 4. Nu no. of DIW against flow rate using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the outer annular of TCTHE.

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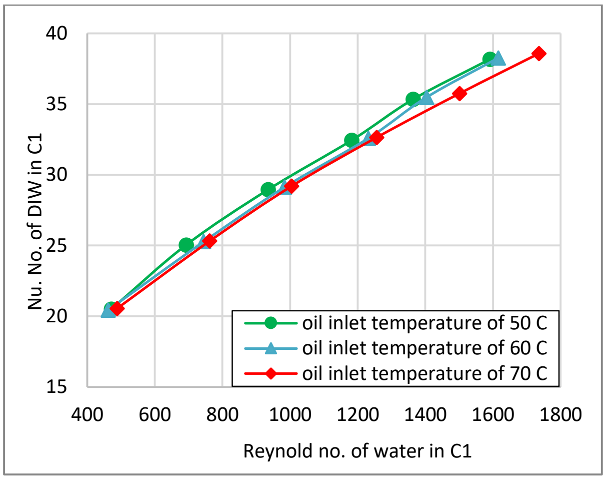

Figure 5. Nusselt number of DIW against Reynold no. using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the inner tube of TCTHE.

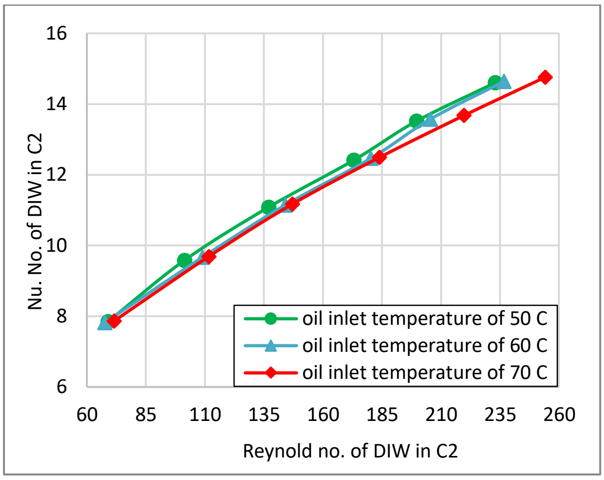

Figure 6. Nusselt number of DIW against Reynold no. using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the outer annular of TCTHE.

Convection Heat transfer coefficient of DIW in TCTHE:

Figures. 7 and 8, show the convection heat transfer coefficient CHTC values of DIW against flow rate calculated using Eqs. 10,12 in the inner tube and the outer annular of the TCTHE respectively. CHTC increased linearly with the DIW flow rate for both C1 and C2 reaching maximum values of 2934.3 and 871.7 respectively. It is clear that CHTC for C1 is higher than that in C2 by about 3.3 times. On the other hand, oil inlet temperature rises from 50 to 70 ºC showing little effect.

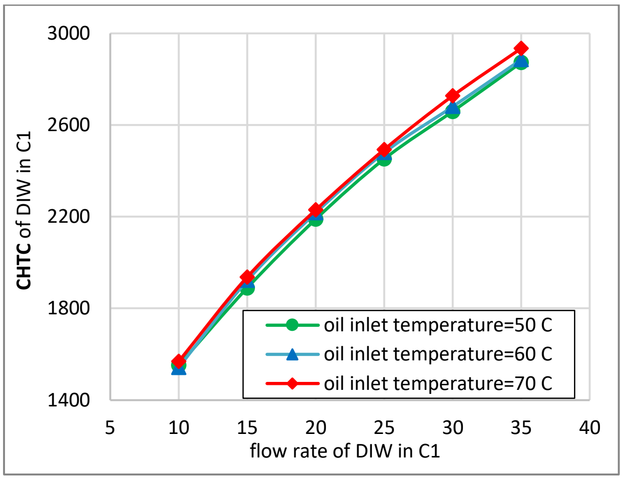

Figure 7. Heat transfer coefficient of DIW against flow rate using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the inner tube of TCTHE.

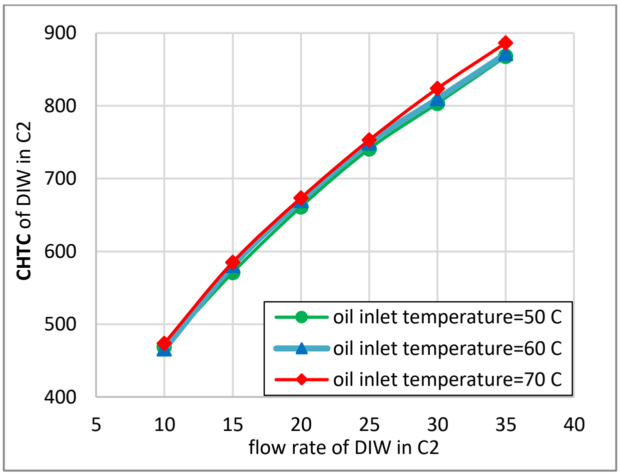

Figure 8. Heat transfer coefficient of DIW against flow rate using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the outer annular of TCTHE.

Over all heat transfer coefficient of DIW in TCTHE:

Figures. 9 and 10 show that the overall heat transfer coefficient of DIW increased with flow rate. On the other hand, the overall heat transfer coefficient in C1 was increased by about 29% over that in C2. Fig. 9 shows that the overall heat transfer coefficient of DIW reached maximum values of 296.36 and 251.4 at 35 l/hr for C1 and C2, respectively. Again Figs. 11 and 12 show that the overall heat transfer coefficient of DIW increased with flow rate. On the other hand, the temperature has no clear effect on the overall heat transfer coefficient for both C1 and C2. That could be related to the constant and stable thermophysical properties including viscosity, density, specific heat, and thermal conductivity with the temperature variation range used in the experiment.

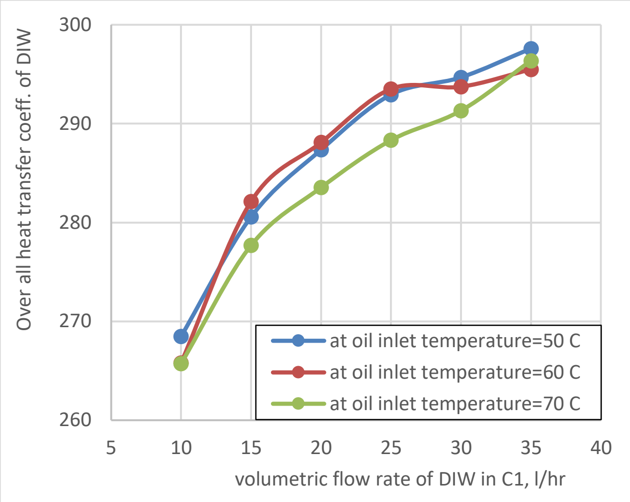

Figure 9. OHT coeff. of DIW against flow rate using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the inner tube of TCTHE.

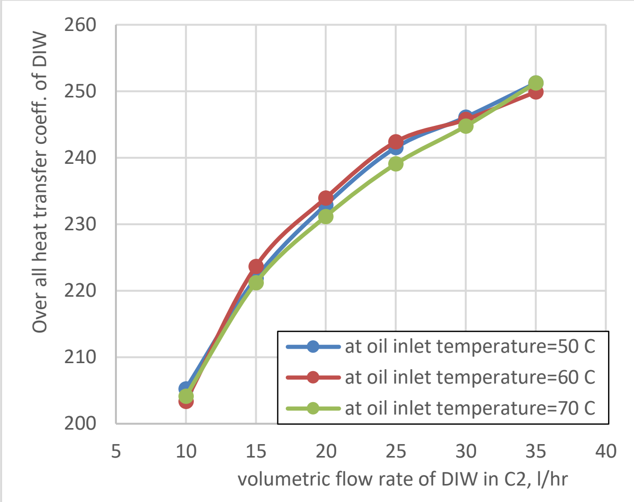

Figure 10. OHT coeff. of DIW against flow rate using oil-40 flow rate 20 l/hr and temperature (50-70 ºC) for the outer annular of TCTHE.

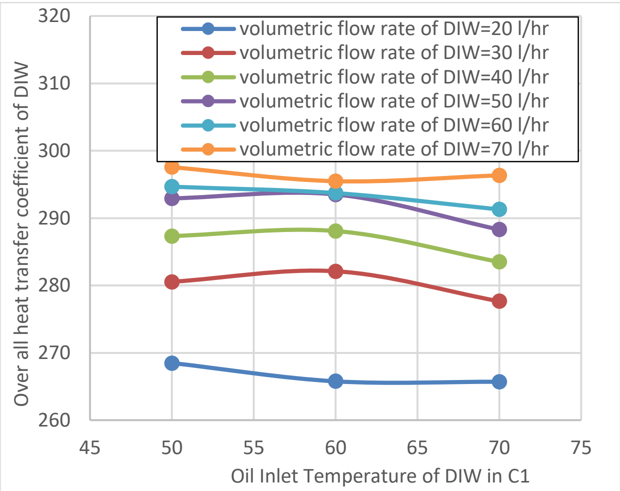

Figure 11. OHT Coefficient against oil-40 inlet temperature using different flow rate of DIW and oil flow rate 20 l/hr for inner tube of TCTHE.

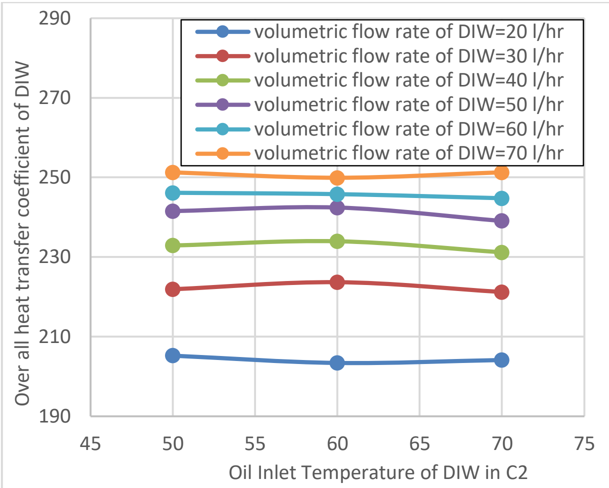

Figure 12. OHT Coefficient against oil-40 inlet temperature using different flow rate of DIW and oil flow rate 20 l/hr for outer annular of TCTHE

Friction factor of DIW in TCTHE

Figures. 13 and 14 show clearly that the DIW friction factor (f-factor) in C1 and C2 was decreased with the volumetric flow rate increasing reaching minimum values of 0.04 and 0.25 respectively. But friction factor slightly reduced with the oil inlet temperature increased. This could be resulted from increasing the DIW velocity. Generally, f-factor of DIW in C2 increased by 5.5 times the f-factor in C1. The f -factor in the outer annular of the TCTHE shows a high value compared with the inner tube. That could be resulted from increasing the velocity in the inner tube, compared with the outer annular, since f-factor is related inversely to velocity as in Eq. 23 shown in Table. 3.

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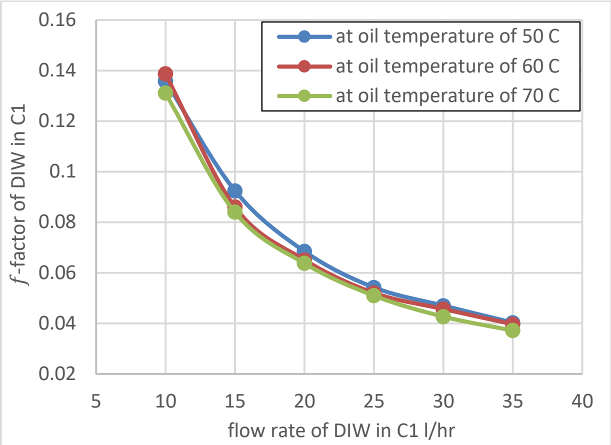

Figure 13. *f* -factor against flow rate of DIW using oil-40 flow rate of 20 l/hr and 50-70 ºC temperature for inner tube of TCTHE.

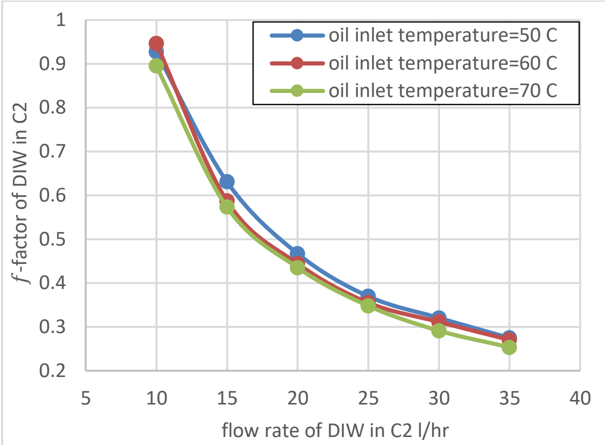

Figure 14. *f* -factor against flow rate of DIW using oil-40 flow rate of 20 l/hr and 50-70 ºC temperature for outer annular of TCTHE.

Pressure drop of DIW in TCTHE

Figures. 15 and 16 show that the pressure drop of DIW increased linearly with flow rate reaching maximum values of 81.4 and 4.31 for C1 and C2 respectively. Plotting pressure drop against Reynold no. appeared the same behavior as shown in Figs. 17 and 18. The pressure drop in C1 increased by about 18 times than in C2, which could be caused by increasing the velocity of DIW inside C1 comparing that in C2 because the pressure drop depends mainly on the fluid velocity, as shown in Eqs 13, 15, 16 and 18 in Table. 3.

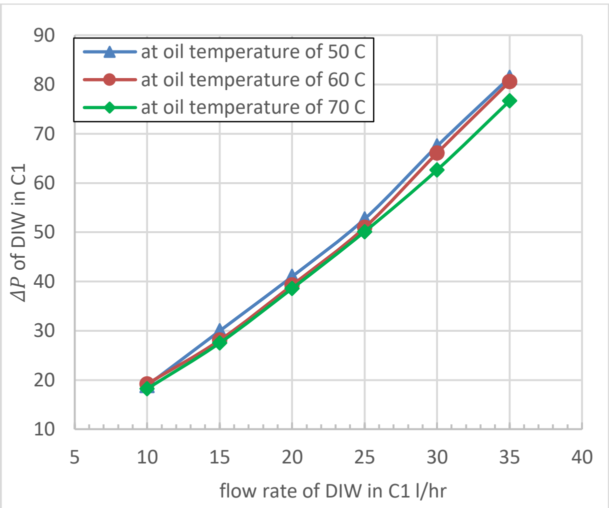

Figure 15. *ΔP* against flow rate of DIW using oil-40 flow rate of 20 l/hr and (50-70 ºC) temperature for inner tube of TCTHE.

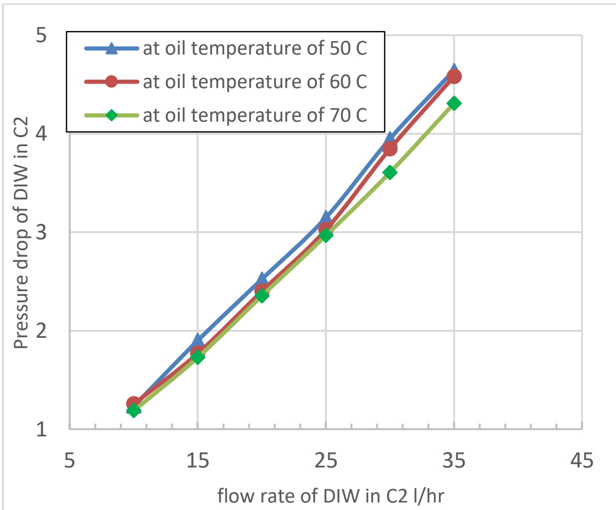

Figure 16. *ΔP* against flow rate of DIW using oil-40 flow rate of 20 l/hr and (50-70 ºC) temperature for outer annular of TCTHE.

Baghdad Science Journal
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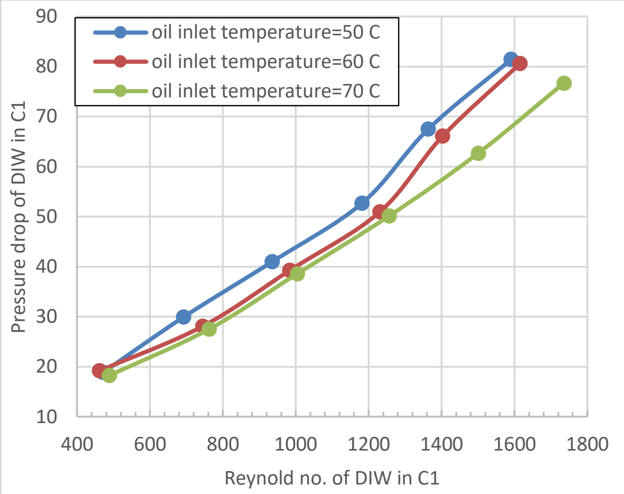

Figure 17. Pressure drop against Reynold no. of DIW using oil-40 flow rate of 20 l/hr and (50-70 ºC) temperature for inner tube of TCTHE.

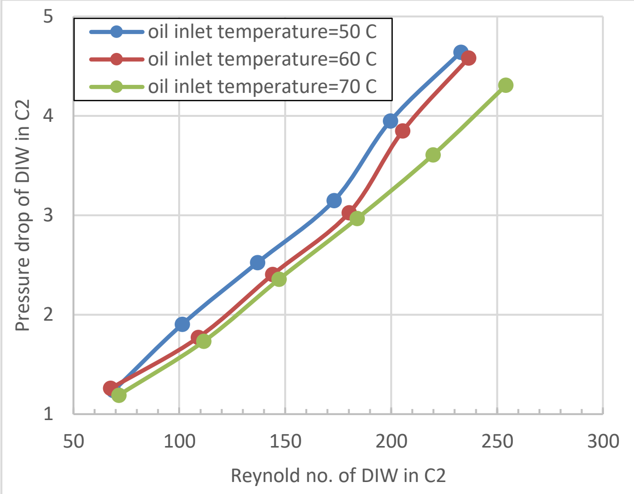

Figure 18. Pressure drop against Reynold no. of DIW using oil-40 flow rate of 20 l/hr and (50-70 ºC) temperature for outer annular of TCTHE.

Conclusions:

In this study, the performance of a TCTHE was investigated using DIW as a cooling fluid medium and Oil-40 as a hot fluid medium. Depending on the used volumetric flow rate and temperature range different heat transfer parameters were measured. These parameters include:

1- Nusselt number increased linearly with DIW flow rate for both C1 and C2 reaching maximum values of 38.25 and 14.64 respectively.
2- CHTC increased linearly with DIW flow rate for both C1 and C2 reaching maximum values of 2934.3 and 871.7 respectively.
3- Overall heat transfer coefficient of DIW reached maximum values of 296.36 and 251.4 at 35 l/hr for C1 and C2, respectively.
4- Friction factor DIW in C1 and C2 decreased with volumetric flow rate increasing reaching minimum values of 0.04 and 0.25 respectively.
5- Pressure drop of DIW increased linearly with flow rate reaching maximum values of 81.4 and 4.31 for C1 and C2 respectively.

These parameters appeared good results in the cooling process. This in turn leads to reduced TCTHE length and size leading to a decrease in the construction cost of the heat exchanger compared with a double pipe heat exchanger. It is also shown a low values of pressure drop in the outer annular compared with the inner tube. In contrast the friction factor in the outer annular of the TCTHE shows a high value compared with the inner tube. That could be resulted from increasing the velocity in the inner tube, compared with the outer annular, since the friction factor is related inversely to velocity as in Eq. 23, shown in Table 3. On the other hand, pressure drop depends directly on the velocity as shown in Eqs 13, 15, 16 and 18 Table 3.

Author's declaration:

- Conflicts of Interest: None.
- I hereby confirm that all the Figures and Tables in the manuscript are mine. Besides, the Figures and images, which are not mine, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Thi-Qar.

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Nomenclature:

ºC	Degree celsius
C.st	Centi stock
C1	The inner tube of the TCTHE
C2	The outer annular of the TCTHE
d	Hydraulic diameter
DIW	Deionized water
CHTC	Convection heat transfers co-efficient
K	Thermal conductivity
l	Tube length
m	Mass flow rate
Nu	Nusselt number
OHT	overall heat transfer
Pr	Prandtle number
Q	Heat transfer rates
Re	Reynold number
T	Temperature
TCTHE	Triple concentric tube heat exchanger
U	Overall heat transfer co-efficient
Greek symbols	
µ	dynamic viscosity
v	Linear velocity
ρ	Density of a fluid. kg/m^3
f	Friction factor
ΔP	Pressure drop
Subscripts	
C	Cooling fluid
C1	Cooling fluid in inner tube
C2	Cooling fluid for outer annular
H	Hot fluid (Oil-40) for inner annular
C1i	Inlet to the inner tube of TCTHE
C1e	Exit from the inner tube of TCTHE
Hi	Inlet to the inner annular of TCTHE
He	Exit from the inner annular of TCTHE
C2i	Inlet to the outer annular of TCTHE
C2e	Exit from the outer annular of TCTHE
T	Total
W	Water

تقييم أداء مبادل حراري ثلاثي الأنابيب المتمركزة المحور باستخدام الماء الخالي من الايونات وزيت-40

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الخلاصة:

هذه الدراسة تتفحص عملياً أداء مبادل حراري ثلاثي الأنابيب الافقية المتمركزة المحور المصنوعة من معدن النحاس باستخدام الماء كوسط بارد وزيت-40 كوسط حار. يدخل المائع الساخن الانبوب الحلقية الداخلية للمبادل في اتجاه بدرجات حرارية مختلفة 50, 60 و 70 ^{o}م ومعدل جريان 20 لتر/ساعة. من ناحية اخرى المائع البارد يدخل الانبوبة الداخلية والانبوب الحلقي الخارجي باتجاه معاكس (جريان متعاكس) في درجة حرارة 25 ^{o}م ومعدل جريان 10, 15, 20, 25, 30 و 35 لتر/ساعة. المبادل الحراري يتألف من ثلاث أنابيب نحاسية بأقطار خارجية 34,925 ملم, 22,25 ملم و 9,525 ملم. وسمك 1,27 ملم , 1,143 ملم و 0,762 ملم على التوالي. طول الانبوب 670 ملم . تم قياس عدد النسلت, معامل انتقال الحرارة الكلي, معامل انتقال الحرارة بالحمل (CHTC), معامل الاحتكاك وهبوط الضغط من النتائج التجريبية التي تم الحصول عليها وتم رسمها في الرسوم البيانية مقابل رقم رينولد ومعدل الجريان الحجمي للماء. أظهرت هذه المعلمات نتائج جيدة في عملية التبريد. ازدادت أعداد النسلت خطياً مع معدل جريان الماء المنزوع الايونات لكل من C1 و C2 لتصل إلى قيم قصوى 38.25 و 14.64 على التوالي. زاد CHTC خطياً مع معدل جريان DIW لكل من C1 و C2 ليصل إلى القيم القصوى 2934.3 و 871.7 على التوالي. بلغ معامل انتقال الحرارة الكلي لـ DIW القيم القصوى 296.36 و 251.4 عند 35 لتر/ساعة لـ C1 و C2 على التوالي. انخفض معامل الاحتكاك DIW في C1 و C2 مع زيادة معدل الجريان الحجمي ، حيث وصل إلى القيم الدنيا 0.04 و 0.25 على التوالي. زاد هبوط الضغط DIW خطياً مع وصول معدل التدفق إلى القيم القصوى 81.4 و 4.31 لـ C1 و C2 على التوالي. وهذا بدوره يؤدي إلى تقليل طول وحجم TCTHE مما يؤدي إلى انخفاض تكلفة بناء المبادل الحراري.

الكلمات المفتاحية: معامل الاحتكاك، رقم النسلت، معامل الانتقال الحراري الكلي، هبوط الضغط، مبادل حراري ثلاثي الانابيب المتمركزة المحور.