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Research Article

The evaluation of the performance of the heat exchanger of a triple concentric tube configuration with ionic liquid (imidazolium) and MWCNT ionanofluid

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ABSTRACT

In this study, a triple concentric tube heat exchanger (TCTHE) was designed. It had three copper concentric tubes. Their thicknesses were 0.762 mm, 1.143 mm, and 1.27 mm. The diameters were 9.525 mm, 22.25 mm, and 34.925 mm, respectively. The tube's length was 670 mm. The cooling medium used was the ionic-liquid (IL) 1-Ethyl-3-methylimidazoliumtetra-flouraborate [EMIM][BF_4] and the ionanofluid (INF) prepared of 0.5% Multi walled carbon nanotubes (MWCNT) in [EMIM][BF_4], while oil forty stock was the hot fluid, to investigate TCTHE performance. The volumetric flow rate (VFR) of the cooling medium was 20-55 l/hr, with a 25-27 °C temperature (temp). VFR of the hot fluid was constant and equal 20 l/hr. The inlet oil temp was 50, 60, and 70 °C, respectively. The type of flow was countercurrent. The heat transfer was investigated by calculating different parameters for the cooling medium. There was an improvement in the Nusselt number (NU) of INF of 5% compared to the IL. A 75% increase in the friction factor of INF was found compared to that of IL. A 95% increase in the pressure drop was calculated in the inner tube using INF compared with that of IL. The overall heat transfer coefficient (U) was enhanced by 3% using INF in comparison with IL. Finally, U showed some improvement, resulting in increased heat transfer. In conclusion, using the prepared INF lead to improve the heat transfer in the TCTHE.

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INTRODUCTION

Ionic Liquids

One of the necessities that must be considered is to enhance the lifetime of a heat exchanger (HE) and to increase its efficiency. Also, some main issues must be reduced, e.g., corrosion, erosion, and explosion problems. Instead of conventional HTFs such as water and ethylene-glycol (EG), the idea of using a new heat-transfer fluid (HTF) must be investigated. This is important if operating was done in a high-temp operation up to 200 °C.

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Two non-symmetrical parts are included in ILs, which are pure salts. These parts are a cation of organic nature or an anion of inorganic nature. The presence of these parts gives a low melting point in the range of (25–100) °C for these salts. Some common cations and anions of IL are shown in Figure 1 [1, 2]. Some studies are concerned with using ILs as heat transfer fluids in different applications due to their extensive properties. Imidazolium type of ILs is used. A study by Castro et al. in 2009 showed for the first time the enhancement of thermophysical properties for both imidazolium and pyrrolidinium ILs [5].

Some of the properties of IL make them highly recommended to be used in HE as HTFs. Some of these properties are thermal stability, the somewhat low vapor pressure at saturation considered at standard conditions, being non-volatile, high flash-point, and they are also considered environmentally friendly. The important thermophysical properties values of IL s, e.g. the density (ρ), the viscosity (μ), the thermal-conductivity (K), the thermal-stability, and the vapor pressure, make them an excellent candidate to be used in HEs used in solar power plants and chemical processes, taking into consideration, how efficient is the cooling or heating processes, depends greatly on the design of the HEs.

The main objective of this paper is to investigate the performance of counter-current flow in TCTHE, where [EMIM][BF_4] and its INF of 0.5% MWCNT in [EMIM][BF_4] were used as fluids for cooling, with hot fluid as forty stock oil. A comparison was conducted considering the performance of the two selected fluids. The parameters studied were the inlet temp of IL and INF (the hot fluid medium), VFRs of the two fluids, in addition to Reynold number (Re). Investigation of the Nusselt number (NU) and pressure drop (ΔP) were considered. The investigation also considered the friction factor (f), and the overall heat transfer coefficient (U).

Applying INFs and Nanofluids in different HEs

Recently, there have been a large number of investigations that considered the replacement of conventional HTFs in HEs by nanofluids (NFs) and ILs with nanoparticles (NPs). Wen and Ding used Al_2O_3/water NFs. NU was measured during the flow in a tube made of copper. An increase of 47% in the values of NU was achieved for Al_2O_3 with a 1.6% fraction volume [6]. Two types of NFs were prepared by Zamzamian et al. They dispersed Al_2O_3 and CuO in the ethylene glycol with differing concentrations. The experiments in a DPHE gave an increase of (2-50)% in the HTC [7].

Al_2O_3 of 30 nm NPs in diameter was dispersed in water by Jaafer et al. The volume fraction was between (0.3- 2%). The experiments were done in a countercurrent shell and

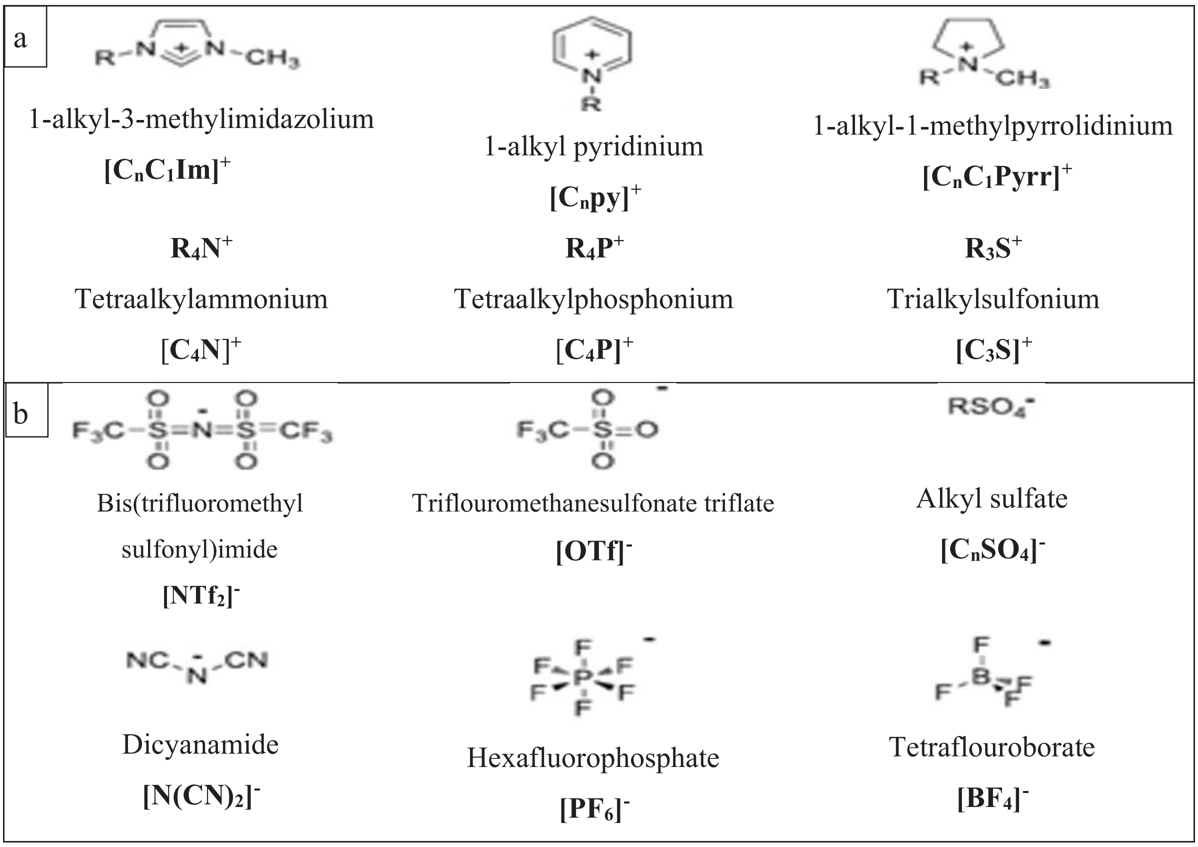

Figure 1. Preparation of IL (a) Cations and (b) Anions [1].

tube HE with turbulent flow. It was found that raising the volume fraction of Al_2O_3 raised the viscosity and friction factor [8]. The thermal behavior of NF as γ- Al_2O_3 in distilled water (DW) was studied by Ezzat and Hasan. It was used for cooling in an annulus channel. Forced convection was used. The result showed heat-transfer-coefficient enhancement of (1.2 - 4.7%) using different ratio of NF/DW [9].

Different volume fractions of Al_2O_3 in water were prepared by Chavda et al. They investigated the effect of NFs on the friction-factor [10]. They also studied the NFs in double pipe heat exchanger DPHE using countercurrent and co-current flow. It was shown that increasing Al_2O_3 increased HTC [11]. Sudarmdji investigated the laminar flow of Al_2O_3 /water NFs. The measurement was for ΔP in addition to the friction factor [12].

NFs of Al_2O_3 in water were prepared by Basma and Noor. The NFs were used in a shell and DCTHE using countercurrent flow. Increasing the NFs concentrations increased NU and overall HTC [13]. A review by Perumal et al. showed the applications of NFs in HEs of the type concentric tube (CTHE). They also studied the thermal behaviors of the properties of the used NFs. Cp, K, ρ, and μ, in addition to the performance of CTHE, were studied [14]. Two separate papers [15] and [16] prepared ILs with distilled water and 1-Butyl-3-methylimidazolium chloride [Bmim][Cl] with different values of fractions or concentrations. They were studied in shell and tube-heat-exchangers. The excellent thermophysical properties of these INFs compared with their base fluids make them very promising HTF to be used in HEs specially the type shell and tube HEs.

Palanisamy and Kumar used three concentrations of MWCNT in DW to prepare. The fractions were 0.1%, 0.3%, and 0.5% in volume. A cone helically coiled tube HE was used in this research. A 52% improvement was noted when using 0.5% MWCNT in water compared with water. A 14%, 30%, and 41% enhancement was noticed when using the 0.1%, 0.3%, and 0.5% MWCNT in water. NU improvement was 28%, 52%, and 68%, respectively, for the same concentrations. No significant deposit of MWCNTs was noticed on the inner surface of the coiled cone tube inner surfaces. This was improved after several experimental tests [17].

Activated carbon in solar glycol-based NFs was used by Kumar et al. This study was accomplished in a HE of double-pipe type (DPHE). NU were studied to show the variations in heat transfer. ΔP of water was also studied [18]. Different concentrations of MWCNTs in isopropyl alcohol were prepared by Logesh et al. [19]. The investigation considered the thermophysical properties. The flow was laminar. Increasing the MWCNTs concentration improved the HTC and NU. Nasirzadehroshenin. et al. [20] prepared NF of carbon-nanotube (CNT) in water, and investigate the performance of heat-transfer-process. The flow regime was a horizontal tube. The temp of the wall was constant. The flow was turbulent. Comparing the results showed that the HTC was improved using NF.

TCTHE Literature

To increase the heat transfer area by adding other cooling liquid passages, TCTHE was developed. This will increase the transfer of heat between the hot and cold fluids. This means increasing the heat transfer rate and the heat transfer efficiency by increasing the area of contact between the two fluids. TCTHE could be represented as a double HE, and there is an intermediate tube between the double tubes.

The simulations made by Zuritz on TCTHE showed that the overall-heat-transfer-coefficient (U) is improved by adding an annular-pipe within the inner tube. This raises the total efficiency. Also, the length of the heat-exchanger is decreased by about twenty-five %. They introduced an approximate equation with a simple type to estimate the overall heat-transfer rate. This equation employs logarithmic-mean temp difference. This HE is considered well-insulated. The test on the model was done by the analytical equations [21].

Saeid and Seetharamu presented an experimental study to study the thermal performance of TCTHE using finite element method. They used different flow arrangements, and the HEs used were insulated and non-insulated [22]. Quadir et al. [23, 24] in their studies used different flow arrangements of a TCTHE with conditions of insulation and non-insulation.

Hossain et al. designed TCTHE. They fabricated it from copper tubes. They showed that U increased experimentally with the increase in the mass-flow rate for both cold -temp water and hot one. Furthermore, U of TCTHE good performed compared to the direct contact heat-exchanger DCTHE. A reduction of 65.17% in the length of the TCTHE concentric heat-exchanger used was noticed compared with direct contact heat-exchanger taking into consideration the same values of area of heat-transfer, and rate of heat-transfer [25].

[14, 26] and [27] published reviews on TCTHE. They included the research development of TCTHE.

Several ILs, such as [BMIM][BF4], [BMIM][PF6], and [HMIM] [BF4], were selected to be used as HTFs by Meikandan et al. [28]. A tube HE was used for solar application. The flow was laminar with the application of CFD to study the heat-transfer.

MATERIALS AND METHODS

Materials

The hot fluid

The heating fluid used was three liters of oil (forty stock). The flow of the hot liquid was inside the inner space of TCTHE. Different physical-properties of the oil introduced in Table 1. The Laboratory Research of Oil in Al-Doraa Refinery introduced the properties.

Table 1. Physical properties of the oil (forty stock)

No.	Specification	The values	units
1	Specific gravity	0.86	-
2	Kinematic viscosity @ 40°C,	16.47	C.st
3	Kinematic viscosity @100°C,	3.64	C.st
4	Viscosity-index	104	-
5	COC flashpoint	182	°C
6	Pour-point	- 12	°C
7	(ASTM-D1500) for Colour, @ 25°C	0.5	
8	H_2O content %vol.	NiL	

Cooling fluid

Cooling fluid used was IL of [EMIM][BF_4] with INF of 0.5% MWCNT in [EMIM][BF_4]. The two fluids' thermophysical properties were measured previously [29], [30]. Table (2) shows these properties. The flow of the cooling fluid is in both the inner tube and the outer annulus tube of HE.

INFs preparation

The two-step method was used to prepare INFs. The amount needed of MWCNT was dispersed in an amount of 3 liters of the 1-ethyl-3-methyl imidazolium tetrafluoroborate with a weight percent. The following equation was used:

$$\begin{matrix}\text{NPs weight}\\ \text{percent in INF}\end{matrix} = \frac{\text{Weight of NPs}}{\text{Weight of NPs} + \text{Weight of IL}} * 100\% \tag{1}$$

The dispersing process was followed, where a magnetic stirrer was used with a time of 10 minutes at room temp. Then it was followed by another 10 minutes of homogenizing. This step prevents, to some extent, the particles from being aggregated, which could happen after the INF is prepared and during the storage period. Another step must be done to homogenize the prepared INFs. This is a sonication step or process and is done by an ultrasonic probe for a time of 20 minutes.

TCTHE design

Copper tubes were used for TCTHE tubes. It has a value of 385 W/ m.°C for thermal conductivity. It has a low cost compared with other metals. The designed TCTHE system with its 2D front side and top views are given in Figure (2). The supply of power, the sensor of the rate of volumetric-flow, the fin-and-tube HE, the pump, and the mixer of cooling fluid, are considered as supporting devices. They are also shown in this figure. The system has two stainless steel tanks. One of these tanks is used for heating fluid (oil-forty-stock). The second tank is for the cooling liquid (IL or INF). The capacity of these tanks is 4 liters. To detect the fluid temp inside each of the tanks, a temp sensor is supplied. At the output of each tank, a valve is supplied so it can be closed when not in use. TCTHE tubes are mounted in a horizontal mode above the tanks by almost 40 cm. This will ensure the pumping of the fluid to TCTHE tubes by the two pumps. Directing and controlling the flow was made using a VFR controller. After the cooling liquid leaves TCTHE, it passes through fin and tube HE occupied with a fan. This is important to decrease the temp of the cooling liquid. The medium of cold-fluid uses a mixer inside it. This step is necessary in the case of the cooling liquid was NF or INF to prevent NPs from being aggregated or precipitate inside the tank.

for heating the hot fluid to the desired temp, a heater is put inside the tank. There is no change in the flow direction of the cold fluid. In case it is needed to change the flow arrangement to the countercurrent mode or co-current one, the direction of flow of the hot-fluid medium can be changed manually or automatically using the program. Two screens were supplied to the TCTHE system. All of VFRs, the temp of the inlet, and the outlet of TCTHE, in addition to the two tanks temp of both the cooling and hot liquids, are displayed on the screens. The three tubes consisting of the TCTHE are outer, inner, and intermediate tubes. Table 3 shows the outside diameter, the inside diameter, and the thickness. Countercurrent flow was used. Each of the cooling liquid used flows in the outer-annular (P2) and the inner-tube (P1), respectively in the same direction. On the other hand, the hot medium flows in the opposite direction inside the inner annular. The effective length of HE is (67) cm.

Table 2. Thermophysical-properties of [EMIM][BF_4] and the prepared INF [29,30]

	[EMIM][BF4]				INF			
T, °C	ρ, kg/m³	μ, kg/m.sec	K, w/m.k	Cp, kJ/kg.k	ρ, kg/m³	μ, kg/m.sec	K, w/m.k	Cp, kJ/kg.k
20	1.283	0.03386	0.18	1.548	1.2855	0.06042	0.182	1.558
30	1.274	0.02679	0.181	1.565	1.277	0.04929	0.184	1.575
40	1.267	0.0188	0.182	1.582	1.27	0.03572	0.185	1.593
50	1.259	0.01413	0.184	1.6	1.261	0.03144	0.186	1.611

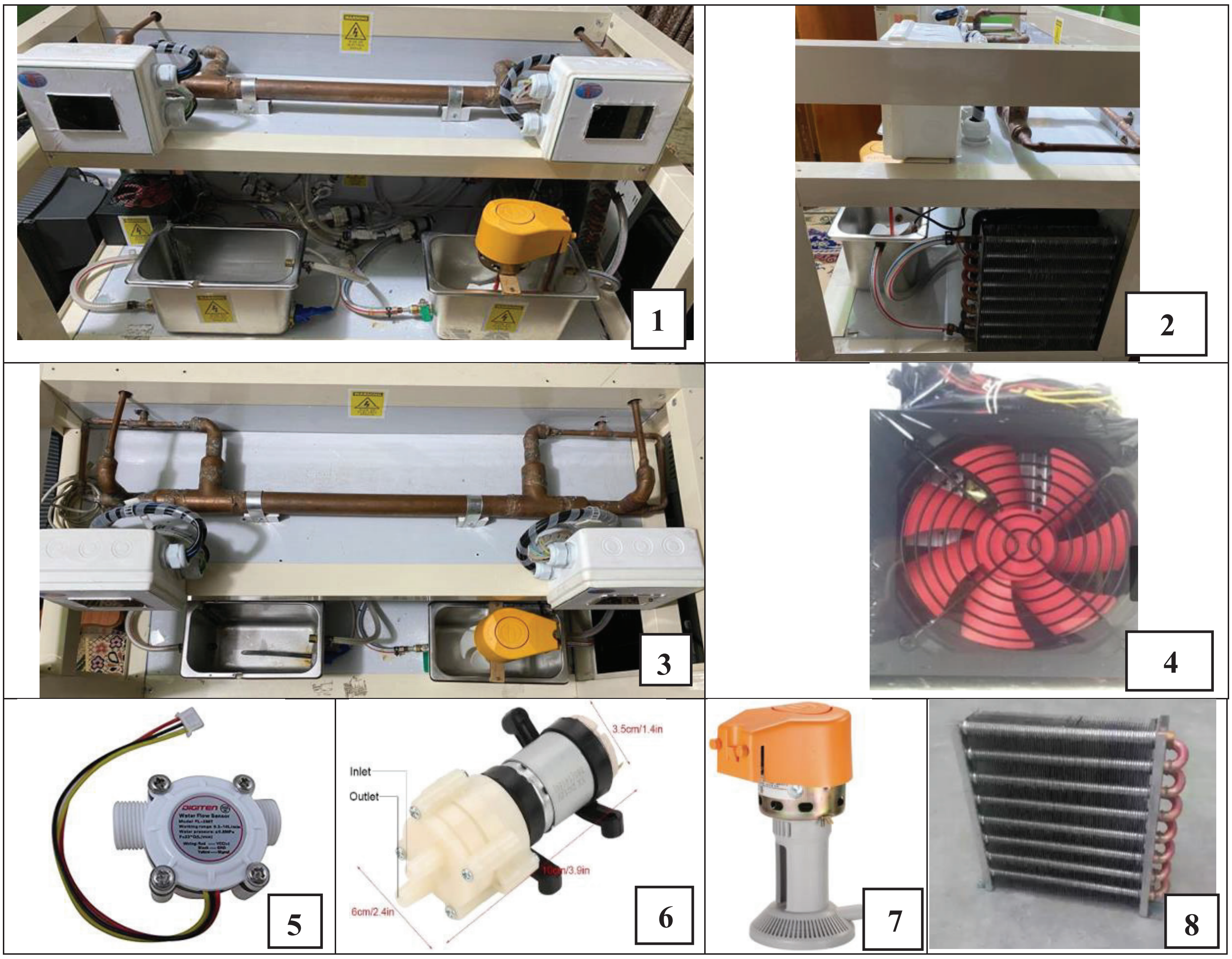

Figure 2. Experimental setup (1) Front, (2) Side, (3) Top, other parts are (4) Power-supply, (5) Flow sensor, (6) Pump, (7) Mixer of cooling liquid, and (8) Fin-and-tube HE.

Table 3. Dimension of TCTHE tubes

	Inside diameter, mm	Outside diameter, mm	Tube thickness, mm
Tube1	8.001	9.525	0.762
Tube2	19.964	22.25	1.143
Tube3	32.385	34.925	1.27

TCTHE calculations

Equations given in Table 4 can be used to calculate the parameters of TCTHE. In TCTHE, the inlet and outlet temp with VFRs of the cooling and heating mediums were limited and measured directly by the TCTHE program. The temp and flow rates were calibrated automatically by TCTHE computer program. Equations (5-7) were used to calculate the linear velocity. The convective heat transfer coefficient was calculated using equations (11-13), while equations (14-16) were used to calculate the rate of heat transfer. Also, the pressure loss due to friction was calculated using equations (17-19). In addition, equations (20-22) were used to calculate the entrance and pressure losses at the exit. Equation (26) was used to calculate the total pressure-drop. Equation (27) was used to calculate **NU** because of the laminar nature of flow (Re< 2300). Finally, the inner and outer annular space's overall heat transfer coefficient was measured using the equations (28- 29), respectively.

Table 4. TCTHE equations [25,31]

	Cooling fluid (IL or INF) in P1	Eq. No.	Hot-fluid (Oil) for inner-annular	Eq. No.	Cooling-fluid (IL or INF) for P2	Eq. No.
The mean bulk temp	$T_{P1} = \frac{T_{P1i} + T_{P2e}}{2}$	(2)	$T_H = \frac{T_{Hi} + T_{He}}{2}$	(3)	$T_{P2} = \frac{T_{P2i} + T_{P2e}}{2}$	(4)
The linear velocity	$v_{p1} = \frac{VFR_{P1} * 4}{\pi * d_{in2}^2}$	(5)	$v_H = \frac{VFR_H * 4}{\pi * (d_{in2}^2 - d_{out1}^2)}$	(6)	$v_{p2} = \frac{VFR_{P2} * 4}{\pi * (d_{in3}^2 - d_{out2}^2)}$	(7)
Reynolds number	$Re_{P1} = \frac{\rho_{P1} v_{p1} d_{h1}}{\mu_{P1}}$	(8)	$Re_H = \frac{\rho_H v_H d_{h2}}{\mu_H}$	(9)	$Re_{P2} = \frac{\rho_{P2} v_{p2} d_{h3}}{\mu_{P2}}$	(10)
The convective heat transfers co-efficient	$h_{P1} = \frac{Nu_{P1} * k_{P1}}{d_{h1}}$	(11)	$h_H = \frac{Nu_H * k_H}{d_{h2}}$	(12)	$h_{P2} = \frac{Nu_{P2} * k_{P2}}{d_{h3}}$	(13)
Heat Transfer Rates	$Q_{P1} = m_{P1} * C_{PP1} * (T_{P1e} - T_{P1i})$	(14)	$Q_H = m_H * C_{PH} * (T_{Hi} - T_{He})$	(15)	$Q_{P2} = m_{P2} * C_{PP2} * (T_{P2e} - T_{P2i})$	(16)
Frictional pressure loss	$\Delta P1_{P1} = \frac{f * l * \rho * (v_{p1})^2}{d_{h1} \quad 2}$	(17)	$\Delta P1_H = \frac{f \; l * \rho * (v_H)^2}{d_{h2} \quad 2}$	(18)	$\Delta P1_{P2} = \frac{f * l * \rho * (v_{p2})^2}{d_{h3} \quad 2}$	(19)
The entrance and exit pressure losses	$\Delta P2 = \frac{\rho * (v_{p1})^2}{2}$	(20)	$\Delta P2 = \frac{\rho * (v_H)^2}{2}$	(21)	$\Delta P2 = \frac{\rho * (v_{p2})^2}{2}$	(22)
Hydraulic diameter	$d_{h1} = d_{i1}$	(23)	$d_{h2} = d_{i2} - d_{o1}$	(24)	$d_{h3} = d_{i3} - d_{o2}$	(25)
Total ΔP	$\Delta P_T = \Delta P1 + \Delta P2$					(26)
NU for laminar flow condition (Re< 2300)	$\mathbf{Nu}_c = 0.51 * Re^{0.5} * Pr^{\frac{1}{3}} * (\frac{Pr}{pr_w})^{0.25}$					(27)
U for inner annular space	$\frac{\mathbf{1}}{\mathbf{U_{o1}}} = \frac{\mathbf{d_{o1}}}{\mathbf{d_{i1} * h_{c1}}} + \frac{\mathbf{d_{o1} * \ln(\frac{d_{o1}}{d_{i1}})}}{\mathbf{2 * k_{copper}}} + \frac{\mathbf{1}}{\mathbf{h_H}}$					(28)
U for P2 space	$\frac{\mathbf{1}}{\mathbf{U_{i2}}} = \frac{\mathbf{d_{i2}}}{\mathbf{d_{o2} h_{C2}}} + \frac{\mathbf{d_{i2} \ln(\frac{d_{o2}}{d_{i2}})}}{\mathbf{2 k_{copper}}} + \frac{\mathbf{1}}{\mathbf{h_H}}$					(29)
Where $f = 64/Re_{P1}$ for laminar regime						(30)

RESULTS AND DISCUSSION

The Relationship Between IL and its INFs with NU

There was a linear increase in NU (calculated using eq. 27) of the cooling fluid with VFR of both IL and the prepared INF. This could be seen in both Figures 3 and 4 for P1 of TCTHE. Raising the values of the cooling fluid velocity caused this behavior. Generally, INF had high-values of NU compared to that of IL. An improvement of about 5% in NU of the INF was shown compared with IL. The increase in the Brownian motion of MWCNT in IL could be the main reason for this improvement. A slight increase in NU was noticed as the inlet oil temp rose from 50 to 67 °C.

A similar trend was shown for NU of the outer-annular, P2. This is noticed in both Figures 5 and 6. There was a minor enhancement of NU, which can be attributed to the decrease in the values of Re in P2, as compared with that of P1.

A decrease in the values of Re from the range of 19 - 58 in P1 to the range 3 - 8 in P2 for the IL and from the range of 11 - 23 in P1 to the range 1.6-3.4 in P2 for the INF is shown in figures 7, 8, 9, and 10. The decrease in Re is due to an increase in the laminar-flow. In the case of MWCNT, no effect to improve the process of cooling was noticed.

The Relationship Between IL and its IL and the Friction Factor

A clear decrease in the values of the friction-factor with the increase in the volumetric rate of flow for both IL and the prepared INF is shown in both figures 11 and 12. It is slightly decreased by the increase in the temp of the oil at the inlet. This is due to the increase in the values of the velocity of the cooling liquid. An increase of 75% in the friction-factor values of INF is noticed compared to that of IL. The reason for this behavior could be attributed to an increased IL Re compared with that of IL. Also, the viscosity of IL is increased compared with that of IL. It was found that f values were lower considering P1 because P1 has an increased value Re compared to that of P2. This is seen in Figures 15 and 16 with Figure 17 and Figure 18 of IL and the prepared INF.

The relationship between IL and its INF and ΔP

A linear increase in ΔP of IL and the prepared INF was seen as VFR increased, as in Figures 19 and 20. In addition, the drop of pressure values for INF in P1 was higher than that of IL in P1, by a value of 95% or even double. That could be because ρ of INF was larger than that of IL due to the existence of the MWCNT. The same behavior is noticed

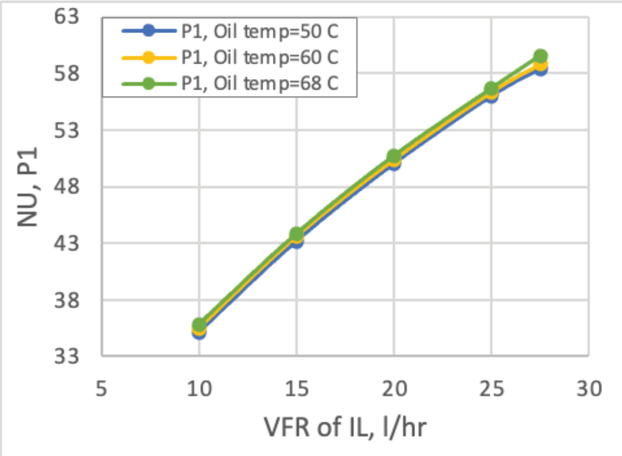

Figure 3. The relationship between NU of IL versus VFR, (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

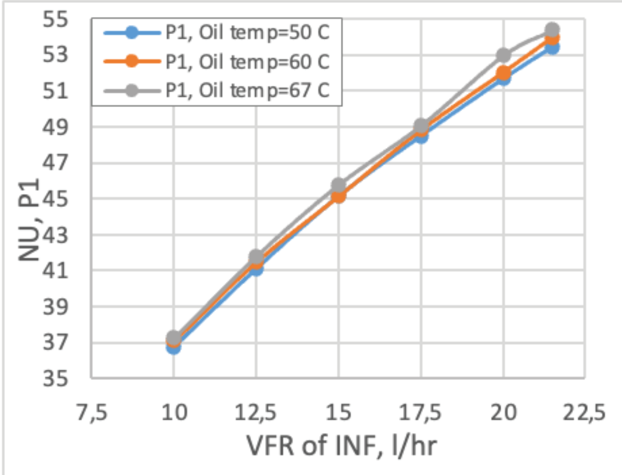

Figure 4. The relationship between NU of INF versus VFR, (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

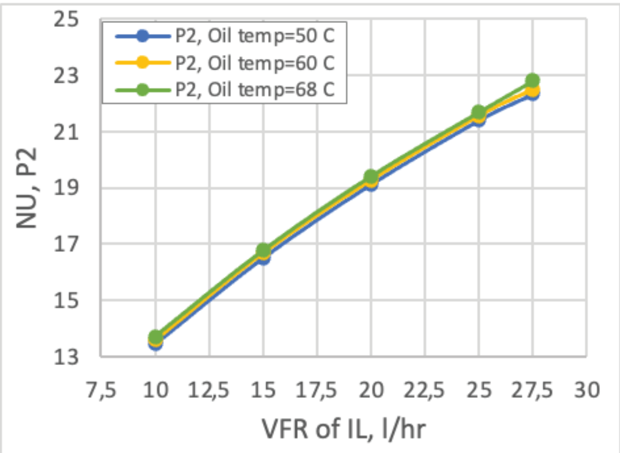

Figure 5. The relationship between NU versus VFR of IL (VFR of oil was constant at 20 l/hr and temp 50-67°C for P2).

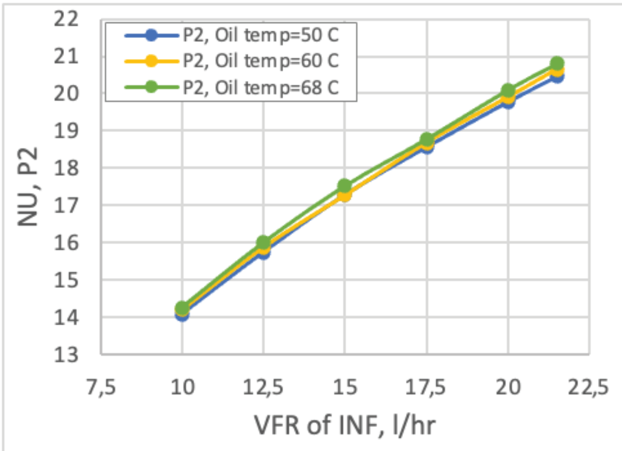

Figure 6. The relationship between NU versus VFR of INF (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P2).

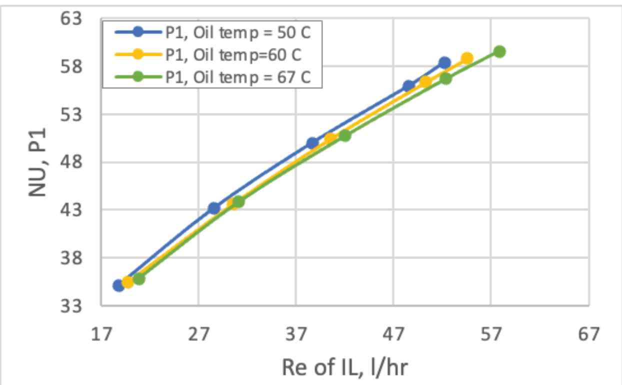

Figure 7. The relationship between NU and Re of IL (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1 of HE).

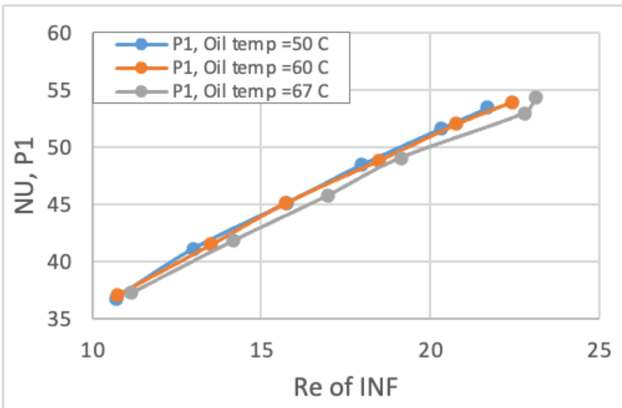

Figure 8. The relationship between NU and Re of INF (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1 of HE).

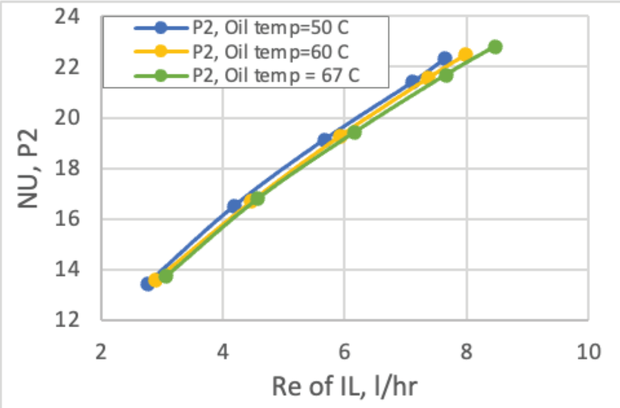

Figure 9. The relationship between NU and Re of IL (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P2).

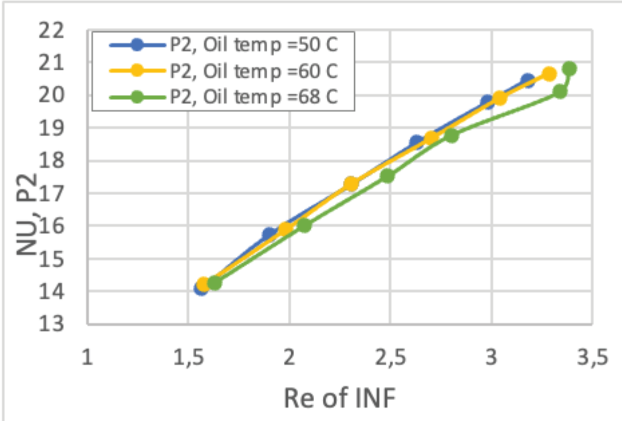

Figure 10. The relationship between NU and Re of INF (VFR of oil was constant at 20 l/hr and of temp 50-68°C for P2).

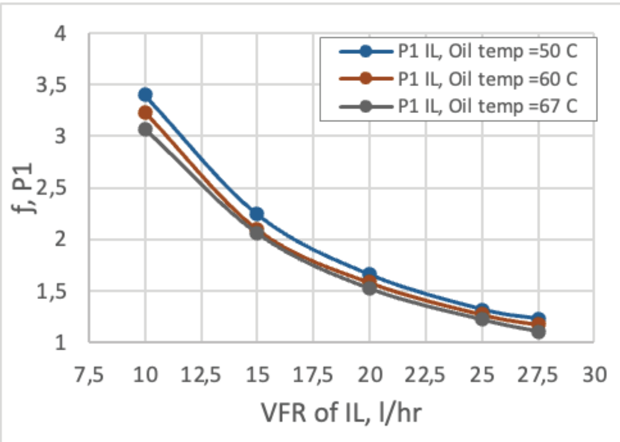

Figure 11. The relationship between f and VFR of IL (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

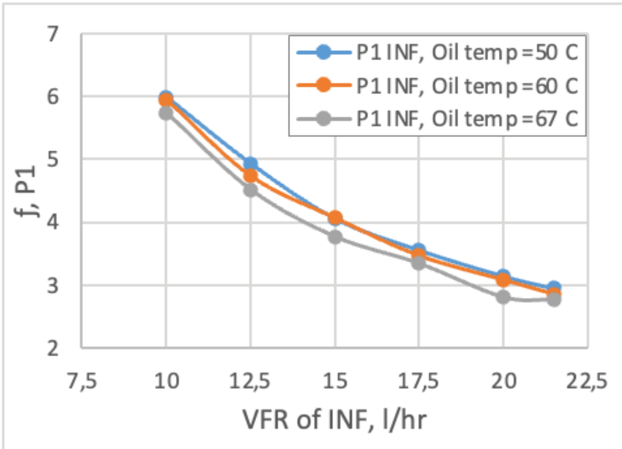

Figure 12. The relationship between f and VFR of INF (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

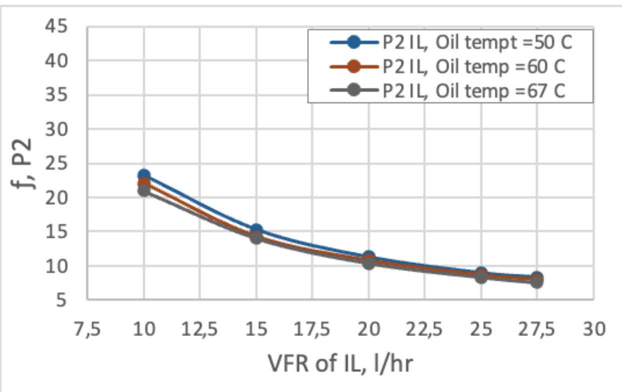

Figure 13. The relationship between f and VFR of IL (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P2).

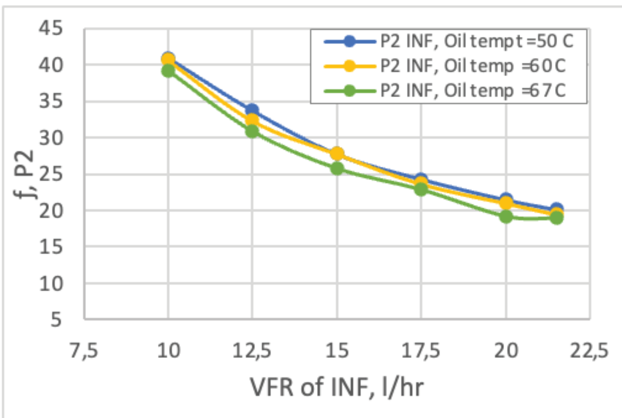

Figure 14. The relationship between f and VFR of INF (VFR of oil was constant at 20 l/hr and temp of 50-68°C for P2).

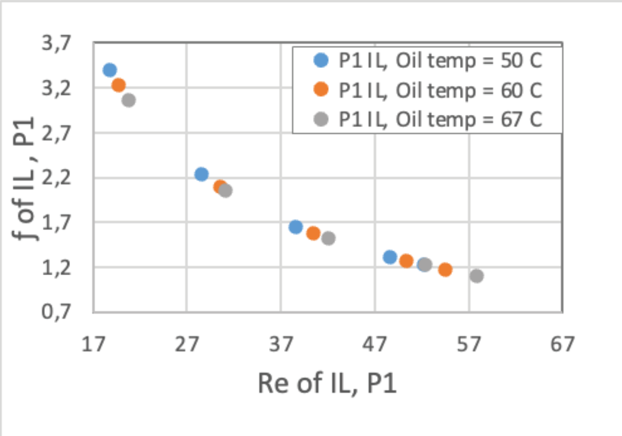

Figure 15. The relationship of f versus Re of IL (VFR of oil was constant at 20 l/hr and temp of 50-67 °C for P1).

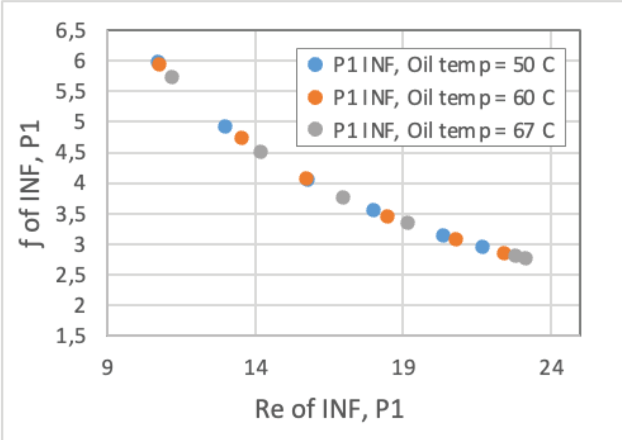

Figure 16. The relationship of f versus Re of INF (VFR of oil was constant at 20 l/hr and temp 50-70 °C for P1).

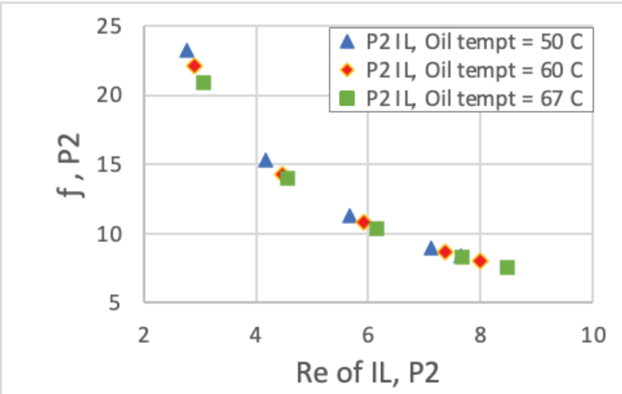

Figure 17. The relationship between f and Re of IL (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P2).

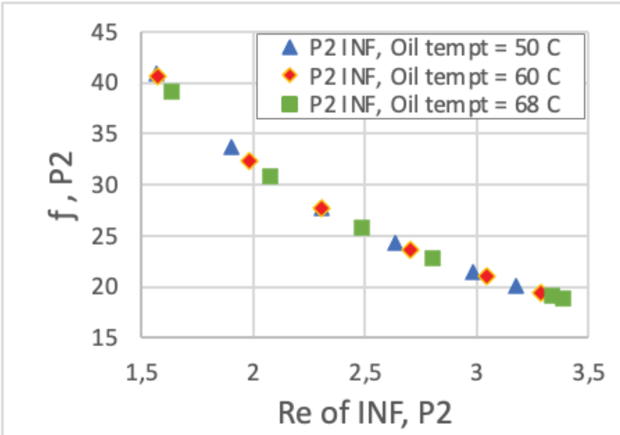

Figure 18. The relationship between f and Re of INF (VFR of oil was constant at 20 l/hr and temp of 50-70°C for P2).

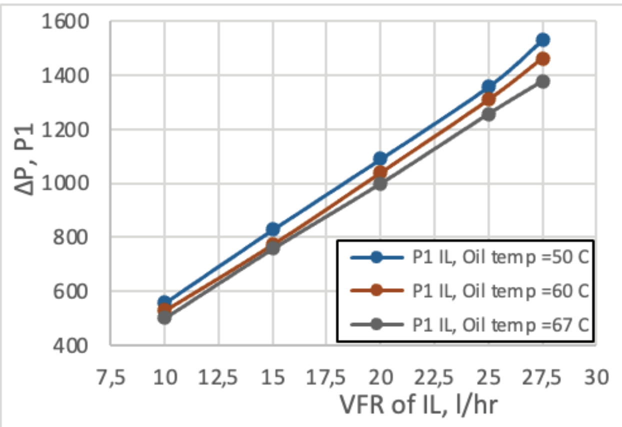

Figure 19. The relationship between ΔP and VFR of IL (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

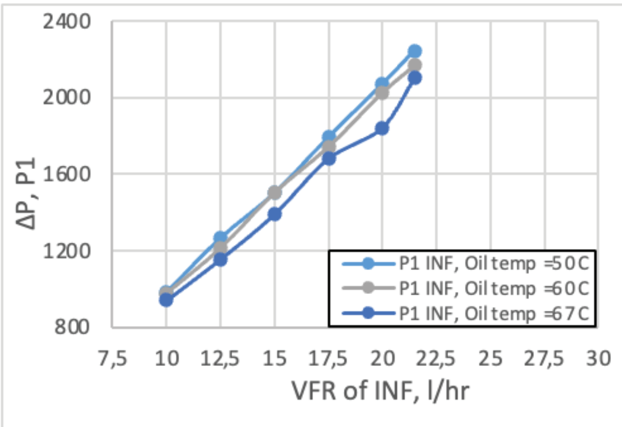

Figure 20. The relationship between ΔP and VFR of INF (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

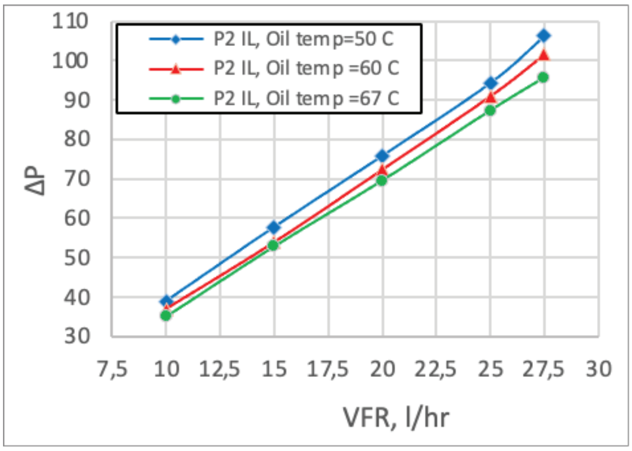

Figure 21. The relationship between ΔP and VFR of IL (VFR of oil was constant at 20 l/hr and temp of 50-67 °C for P2).

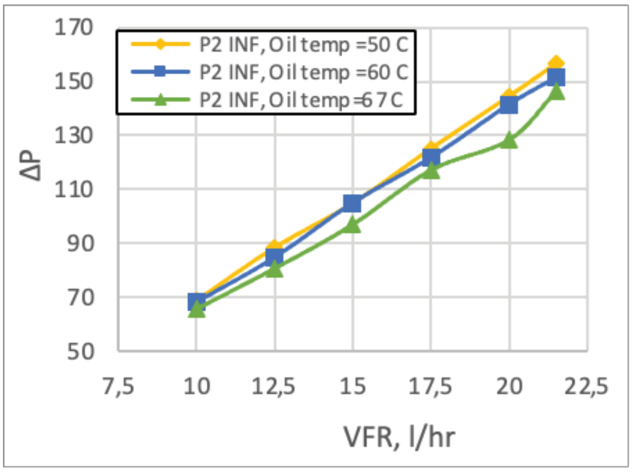

Figure 22. The relationship between ΔP and VFR of INF (VFR of oil was constant at 20 l/hr and temp of 50-67 °C for P2).

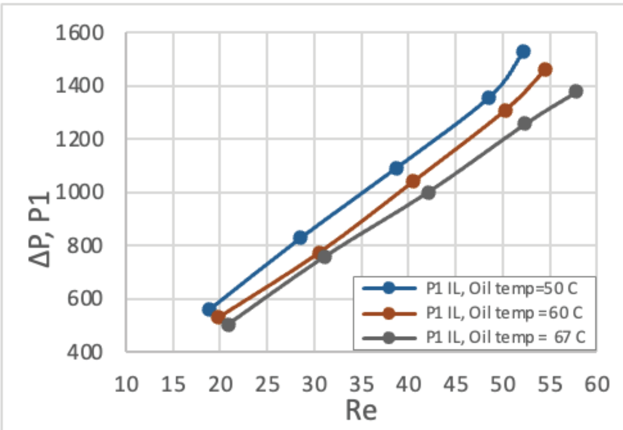

Figure 23. The relationship between ΔP and Re of IL (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

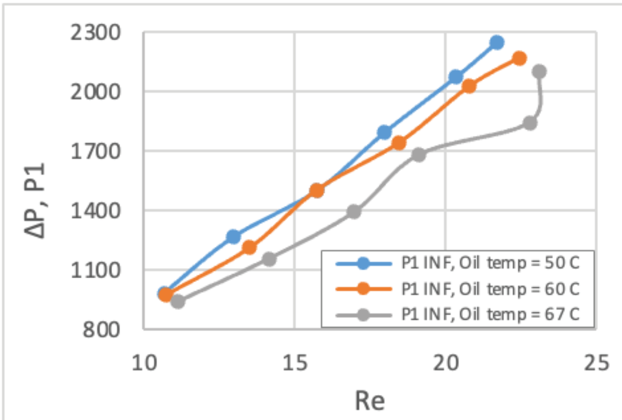

Figure 24. The relationship between ΔP and Re of INF (VFR of oil was constant at 20 l/hr and temp of 50-67°C for P1).

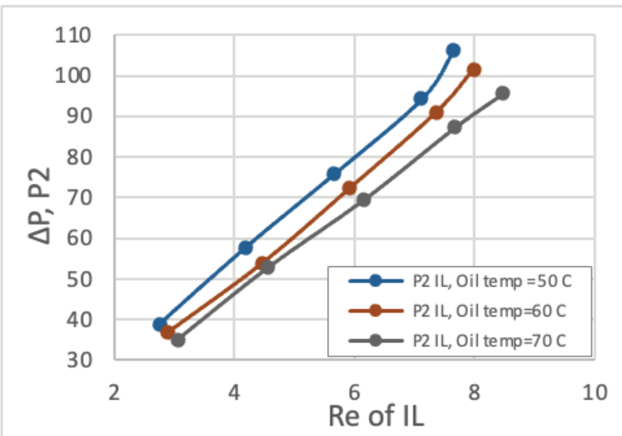

Figure 25. The relationship of ΔP against Re of IL (VFR of oil was constant at 20 l/hr and temp of 50-70°C for P2).

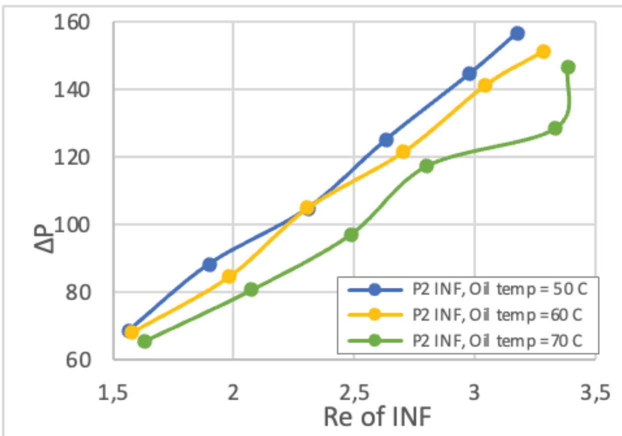

Figure 26. The relationship of ΔP against Re of INF (VFR of oil was constant at 20 l/hr and temp of 50-70°C for P2).

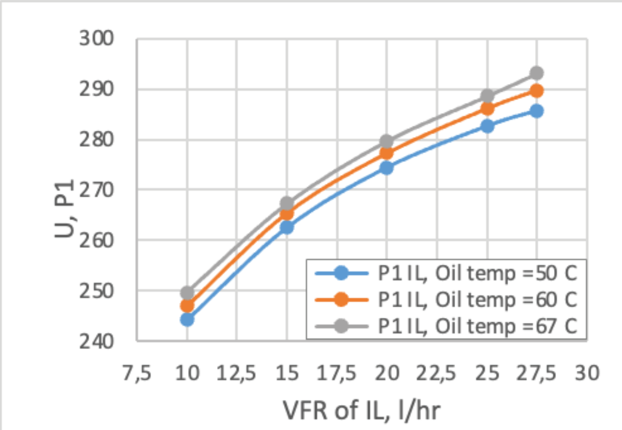

Figure 27. The relationship between U and VFR of IL (VFR of oil was constant at 20 l/hr and temp of 50-70°C for P1).

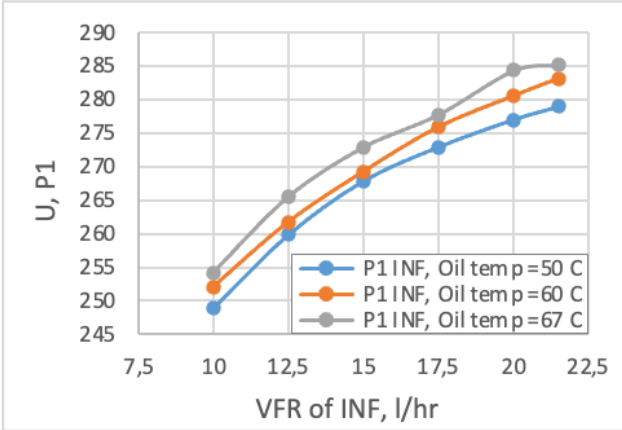

Figure 28. The relationship between U and VFR of INF (VFR of oil was constant at 20 l/hr and temp of 50-70°C for P1).

for P2. ΔP in P1 were higher than about 10 times that in P2 for both IL and the prepared INF. This behavior can be attributed to increase the velocity of the liquid in P1, compared with that in P2. ΔP depends mainly on the values of the velocity of the fluid, seen clearly by equations (17) and (20) in Table 4. An increase in the drop in pressure of IL and INF for P1 is noticed in figures 23, 24, and 25, 26 compared to that of IL and INF of P2, with the increase in Re. This trend agrees with [32].

The values of U of IL and its INF

The values of IL's U and INF increased highly with VFR values. This is shown in Figures 27 and 28. The improvement of U of INF was 3% when comparing it with that of IL. The thermophysical-properties of INF were enhanced with MWCNT. The more pronounced enhancement was in the values of Cp and K.

U of IL and INF in P1 was higher by about 50% than that in P2. A comparison between figures 27 and 28 with 29 and 30 shows this behavior.

Figures 31 and 32 show the increase in the values of U of IL and INF of P1 of HE with flow-rate. The highest values noticed were 293 at 27.5l/hr and 285 at 21.5 l/hr, respectively, for IL and the prepared INF. There was an increase in U values with both IL and INF temp. However, there was a slight enhancement in the values of U for INF compared with that of IL using the same VFR.

Similar trending behavior is noticed in Figure 33 and Figure 34, where values of U of both the IL and the INF are in the case of P2 of HE. An increase in the values of U of P1 by about 40-50% compared to that of P2 is noticed.

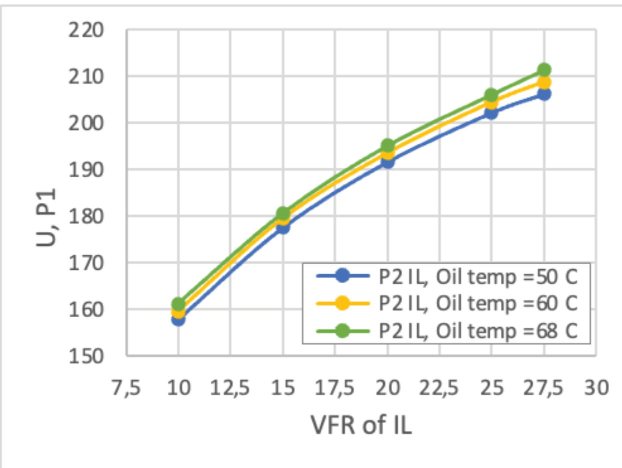

Figure 29. The relationship between U and VFR of IL (VFR of oil was constant at 20 l/hr and temp of 50-70°C for P2).

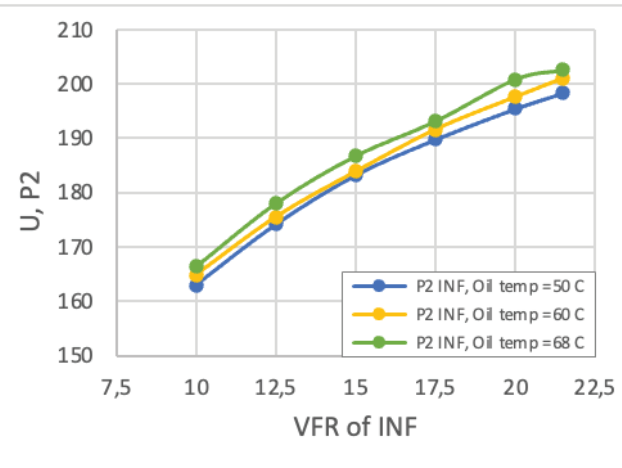

Figure 30. The relationship between U and VFR of INF (VFR of oil was constant at 20 l/hr and temp of 50-70°C for P2).

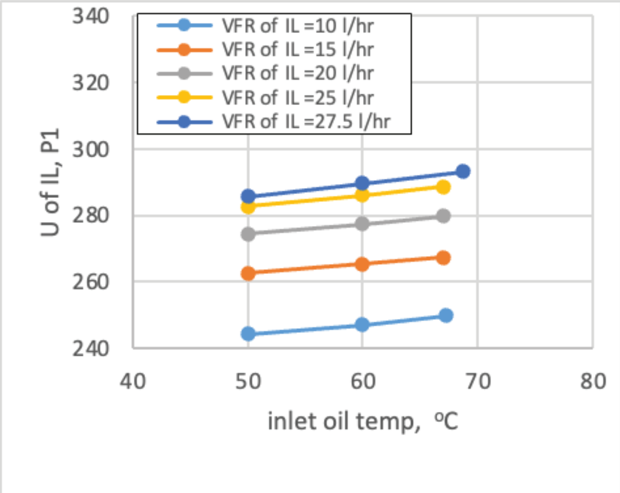

Figure 31. The relationship between U and inlet-oil-temp at various VFR of IL (VFR of oil was constant at 20 l/hr for P1).

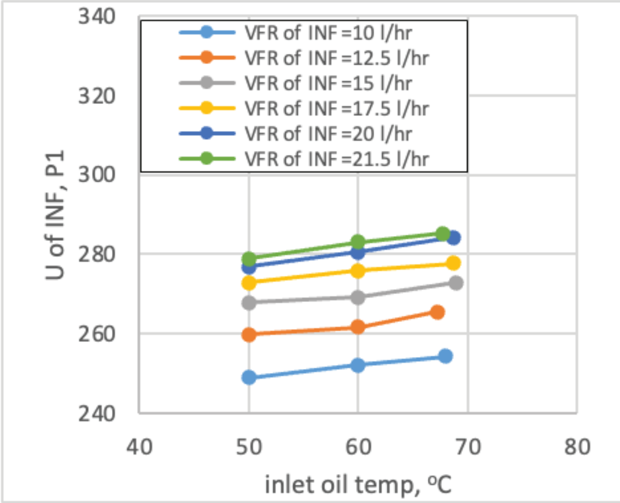

Figure 32. The relationship between U and inlet-oil-temp at various VFR of INF (VFR of oil was constant at 20 l/hr for P1).

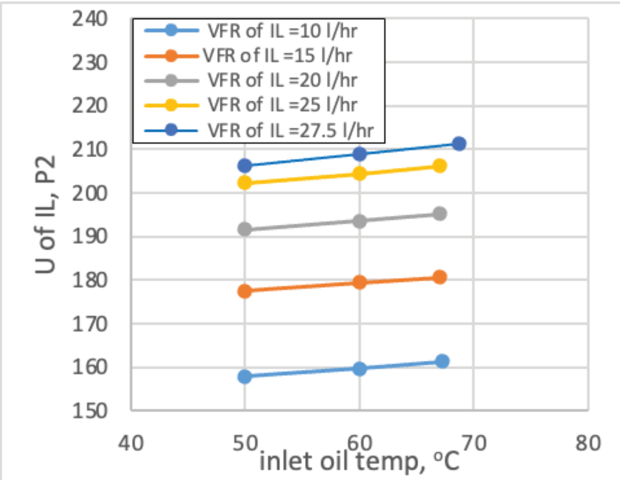

Figure 33. The relationship between U and inlet-oil-temp at various VFR of IL (VFR of oil was constant at 20 l/hr for P2).

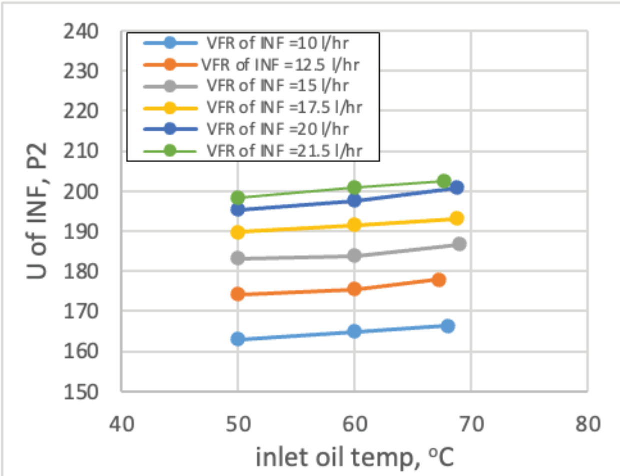

Figure 34. The relationship between U against inlet-oil-temp at various VFR of INF (VFR of oil was constant at 20 l/hr for P2)

CONCLUSIONS

TCTHE was designed and investigated in the present study. A hot fluid of oil forty stock was used, and [EMIM][BF_4] IL and the prepared INF of 0.5% wt. MWCNT in [EMIM][BF_4] in a separate way as the cooling-fluid. The different flow-rates of (20-55 l/hr) were used. The counter-current flow was used in this study. Different values of Re were used for IL and INF as cooling liquid, with (20 l/hr) flow-rate. The inlet temp of hot-fluid was (50-67°C).

It was noticed from the results that NU increased for both the cooling fluid [EMIM][BF_4] IL and the prepared INF. Also, U showed an increase with the values of flow-rate and Re for P1 and P2 of TCTHE considering same fluids. Also, a decrease in *f*-values for both the used cooling liquids with the values of VFR and also with the values of Re for both P1 and P2 of HE was noticed.

A linear increase in ΔP of both IL and the prepared INF with VFR was noticed. A 95% increase or even more in the values of ΔP in P1 for INF was noticed compared with that of IL. Finally, both the cooling liquids [EMIM][BF_4] and the prepared INF, showed an increase in the value of U with temp values of the inlet oil.

Clearly, the results showed that [EMIM][BF_4], when used as a cooling fluid, gave accepted results. Also, using the prepared INF instead of IL enhanced the heat transfer rate. This could be attributed to the increase in the values of NU, with U of INF being increased compared with that of IL.

NOMENCLATURE

[EMIM][BF_4]	1-Ethyl-3-methylimidazoliumtetraflouraborate
[Bmim][Cl]	1-Butyl-3-methylimidazolium chloride
2D	Two dimension
AC	Activated carbon
CTHE	Concentric tube heat exchanger
CHTC	Average convective heat transfer coefficient
CNT	Carbon nanotube
°C	Degree centigrade
C.st	Centi stock
P1	The inner tube of the TCTHE
P2	The outer-annular of the TCTHE
Cp	Specific heat
d	Hydraulic diameter
DPHE	Double pipe heat exchanger
DW	Distilled water
h	Convective heat transfers co-efficient
IL	Ionic liquid
INF	Ionanofluid
K	Thermal conductivity
l	Tube length
HE	Heat exchanger
HTF	Heat transfer fluid
m	Mass flow rate
MWCNT	Multi-walled carbon nanotubes
NF	Nanofluid
NU	Nusselt number
Pr	Prandtle number
Q	Heat transfer rates
Re	Reynold number
SG	Solar glycol
temp	Temperature
TCTHE	Triple concentric tube heat exchanger
U	Overall-heat-transfer-coefficient
VFR	Volumetric flow rate

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 (IL or INF)
$P1$	Cooling fluid (IL or INF) inside the inner tube
$P2$	Cooling fluid (IL or INF) for outer annular
H	Hot fluid (Oil forty stock) for inner annular
$P1i$	Inlet to the inner tube of TCTHE
$P1e$	Exit from the inner tube of TCTHE
Hi	Inlet to the inner annular of TCTHE
He	Exit from the inner annular of TCTHE
$P2i$	Inlet to the outer annular of TCTHE
$P2e$	Exit from the outer annular of TCTHE
T	Temperature
T	Total
W	Water

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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