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# An Experimental Study of Heating Heavy Fuel Oil by Hot Air using Helical Fins in a Double-Pipe Heat Exchanger

Safaa Abdul Adheem Saleh[1,*], Zena Khalefa Kadhim[1], Kamil Abdulhusein Khalaf[1]

[1] Department of Mechanical Engineering, College of Engineering, Wasit University, Wasit, Iraq

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**ABSTRACT**

In present work, the effect of helical fins with height 20 mm and pitch 100 mm on the performance of the double pipe heat exchange investigated experimentally. The heat exchanger had been chosen as a heat recovery device in bricks factory to recover heat from exhaust gases to preheat the heavy fuel oil. Air had been chosen as a hot gas instead of furnace exhaust gases because of the similar thermal properties and it flows in the inner pipe with different velocity (20, 27, and 34) m/s and inlet temperature (200, 225) °C while, heavy fuel oil enters shell side with counter flow at mass flow rates (0.06, 0.08, and 0.1) kg/s and constant inlet temperature of 40 °C. Both of pipes and helical fins are made from stainless steel. The experimental results show that increasing Reynolds number from 139139 to 333934 led to increase heat transfer rate, oil outlet temperature, overall heat transfer coefficient and effectiveness of heat exchanger with (8%, 4%, 5% and 5%) respectively while, increasing oil mass flow rate from (0.06 to 0.1) kg/s cause decreasing oil outlet temperature and effectiveness of with (10% ,14%) respectively. The results shown the double pipe heat exchanger with helical fins produce heat transfer rate and oil outlet temperature higher than smooth double pipe heat with average 15% and 8.6%, as well as increasing Nusselt number, Overall heat transfer coefficient and effectiveness of heat exchanger with average 26%,15% and 13% respectively. The results clear that, for 225°C exhaust air and velocity 27 m/s, the application of double pipe with helical fins by preheat heavy fuel oil could reduce the viscosity and reduce electric power required and save 1.69 MW annually for one factory.

## 1. Introduction

A significant amount of energy nowadays is wasted through thermal processes, this has led researchers to develop strategies that assist people in using, recycling, and converting that wasted energy into other types of energy by creating systems and equipment that can transmit heat at the lowest costs. The heat exchanger is one of these essential equipment. It is a device used to transfer the heat from the hot fluid to cold fluid with maximum rate and minimum investment. The heat exchanger is an important device in various thermal systems for e.g. condenser and evaporator in refrigeration systems, boiler and condenser in steam power plants etc. The heat

* *Corresponding author.*
*E-mail address: safaasalah302@uowasit.edu.iq*

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exchanger has wide variety of industrial applications such as process industries, chemical industries, food industries etc [1]. Now there is need of the compact heat exchangers to give required heat transfer rate with minimum space requirement. The helical fins on the inner tube increase the area available for the heat transfer and the helical fins on inner tube increases the turbulence. With helical fins at larger height, the efficiency of the heat transfer enhancement however is rather low when the total length of heat exchanger is fixed. At high Reynolds number, pressure drop will increase sharply if the helical pitch decreases. Due to this reason the heat transfer enhancement with helical fins is more suitable at low Reynolds number. The worldwide researchers are making hard efforts to find out suitable alternatives for heat exchangers with different geometry and varying parameters which effects on performance of heat exchanger. Now days helical fins have become blessings for researchers. Many numerical and experimental studies that have dealt with the effect of helical fins on the performance and effectiveness of the heat exchanger, including; El Maakoul *et al.,* [2] presented predict numerically the performance of the heat exchanger with helical fins of pitch (0.05–0.2) m, height 4.025 mm and longitudinal fins in annulus section of heat exchanger. The study showed that helical fins produce a heat transfer surface area that is between 3% and 20% larger than longitudinal fins and helical fin with a pitch of 10 cm provides the optimal thermohydraulic performance. Mule *et al.,* [3] studied numerically and experimentally performance of heat exchanger with helical fins for different angles (0°, 5°, 10°, 20°and 25°). The result of study showed that enhance overall heat transfer coefficient with an average of 53% and heat exchanger with 20° helical fins has a higher heat transfer rate. Amini *et al.,* [4] studied numerically effects of increase helical fin height from (10 to 30) mm and fin pitch from (10-40) mm by using ANSYS FLUENT and results which obtain are increasing fin height is more effective than pitch increasing and heat transfer rate and total pressure drop rise greatly due to the vortex shedding caused by the fins. Mozafarie and Javaherdeh [5] achieved numerically analysis of a heat exchanger by changing pitch values from (25 to 100) mm and the results exposed the maximum percentage increase in heat transfer of 39% obtained in pitch of 25 mm. Sivalakshmi *et al.,* [6] carried out the effect of helical fins on performance of the heat exchanger experimentally and results of study showed that heat exchanger effectiveness and heat transfer rate are 35% and 38.46% higher with helical fin than that of smooth inner pipe. Salman *et al.,* [7] studied performance of heat exchanger made of stainless-steel used to preheat heavy fuel oil by using helical fins with variable pitch (10, 20, and 30 cm) and research showed that higher overall heat transfer coefficient and heat transfer rate when helical fin with pitch equal 10 cm. Mao *et al.,* [8] examined the heat transfer and pressure loss characteristics of supercritical water in helical finned double pipes using a CFD numerical simulation method. The width and height of the pipes varied from 2 to 4) mm, and the pitch range was from 15 to 25 mm. The main conclusions were that the overall heat transfer coefficient improved with increasing mass flux on both the tube-side and the shell-side, and the pressure drops increased with increased fin width and height. Eltoukhey *et al.,* [9] investigated experimentally heat transfer rate and pressure dops in the heat exchanger with and without helical fins with different pitch ratios 0.275, 0.333 and 1. The results showed that increase Nu and friction factor with an average of (156.6 - 70.8%) and (54.6 - 44.7%) respectively when pitch ratio decreases from 1 to 0.333. After reviewing previous studies, we found that studies related to heating heavy fuel oil by hot air are very few. In this study, the effect of adding helical fins on the inner pipe of the heat exchanger, which used to preheat heavy fuel oil by recovering waste heat in the exhaust gases emerging from the chimney of brick factories is studied.

## 2. Aim of Study

This research aims to study the effect of adding helical fins on the thermal performance of double pipe heat exchanger in brick factories.

## 3. Problem Statement

In brick kilns, generally solid fuels like coal, wood, sawdust, and industrial waste are burned. In addition to solid fuels, natural gas, diesel, biogas, producer gas, etc. are also used to fire bricks. Due to its high energy content and low cost since it is a product of the oil refining process. Fuels with a very high viscosity that are burned to create motion and/or heat are referred to as heavy fuel oil (HFO). HFO contains a significant number of heavy molecules, including aromatics with long side chains and long-chain hydrocarbons. It has a dark colour; it cannot pump under low temperatures and should be preheated in the tanks. To ensure HFO is remains pumpable, it must be heated to at least 40°C [10]. In winter, due to lower temperatures, the viscosity of the heavy oil increases and therefore large amount of electrical energy are expended for the purpose of heating the oil up to a temperature of 90°C because flash point of HFO > 90°C [11]. The purpose of heating is to reduce the high viscosity of the oil and to prevent wax crystal forming to maintain it good for satisfactory pumping.

## 4. Proposed System

This work's main objective is to assess how installing helical fins over a heat exchanger's inner pipe. The setup schematic diagram is displayed in Figure 1. A steel helical fin that is used to increase the rate of heat transfer from hot air to cold heavy fuel oil. Its dimensions are 20 mm height, 2 mm thickness, and 100 mm pitch. The effect of an air-oil heat exchanger with helical fins is assessed and compared with that of smooth pipe.

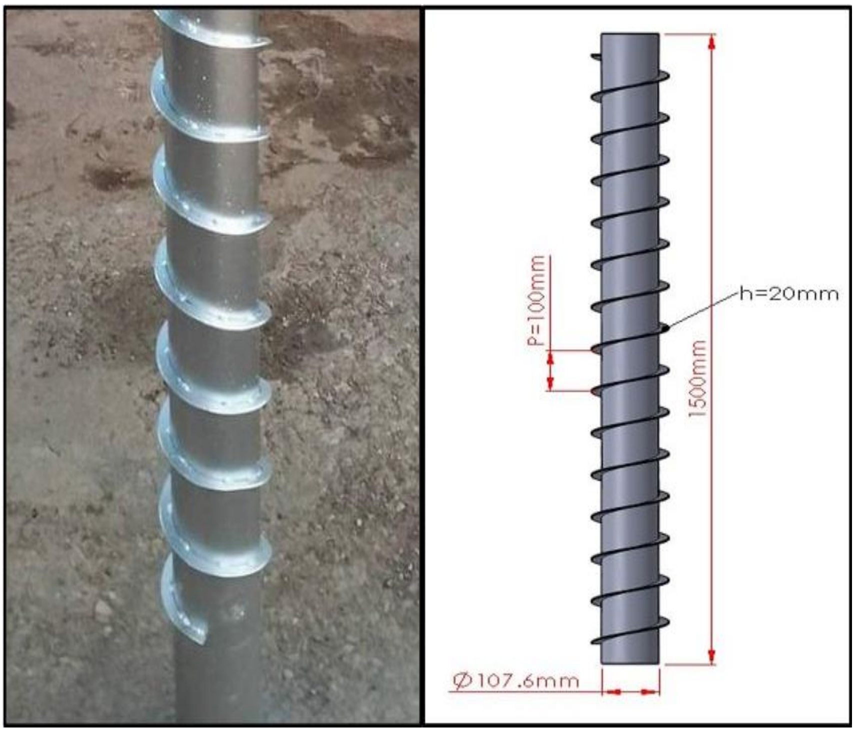


**Fig. 1.** Inner pipe with helical fins

## 5. Methodology

### *5.1 Experimental Setup*

To complete the experimental study, the test rig manufactured to deal with all measurements cases requirements: Test section, Hot air supply, Heavy fuel oil supply and measuring devices. The test section involved three parts. The first part is outer pipe which has been manufactured from stainless steel of 152.4 mm outer diameter, length 1.5 m and 3 mm thickness insulated from outside by three layers of glass wool. The second part is an internal pipe from stainless steel has 2 m length and 101.6 mm inner diameter. The inner and outer pipes are assembled so that (250 mm) from the inner pipe appear at both ends to connect later with the air duct by welding two annular caps (flanges) at the end. The shell is equipped with four inlets (25.4 mm) all the four inlets connected to one manifold (50.8 mm) also its equipped with pressure safety valve for safety purpose. The third part is the helical fins on internal pipe in which is manufactured from stainless steel. These parts have been fixed vertically on the air duct structure and it fixed all to the frame structure.  All these parts of test rig appear in the schematic diagram in Figure 2 and Figure 3.


**Fig. 2.** Illustrated flow diagram of the test rig

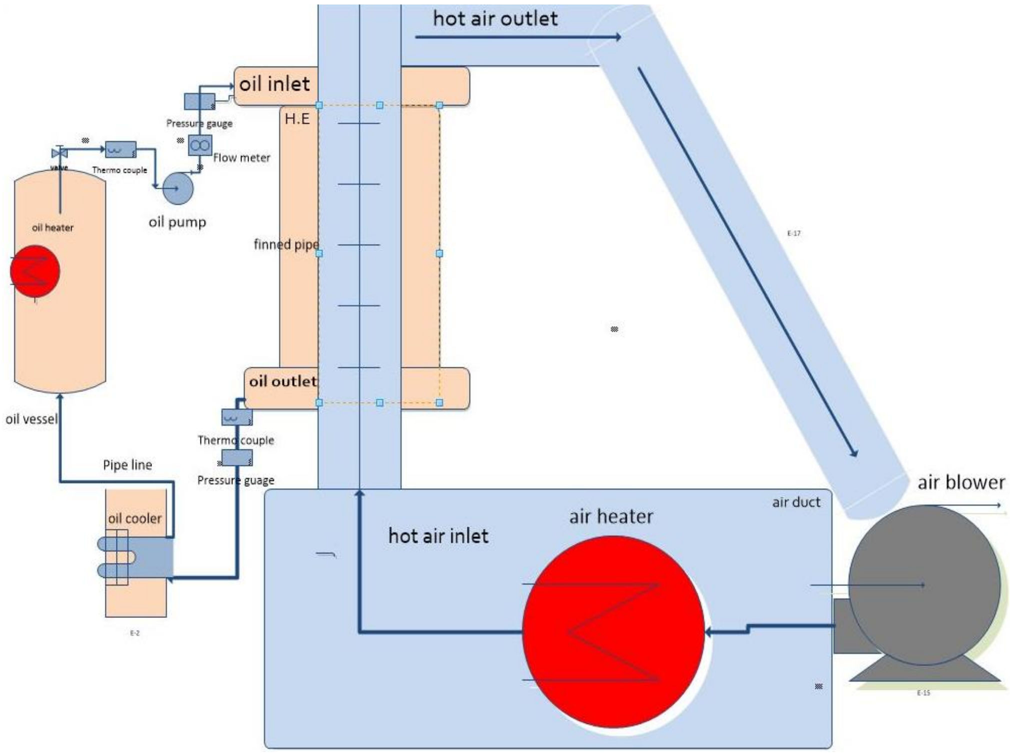


**Fig. 3.** Schematic diagram of test section

## *5.2 Measured Parameters*

The performance of the current heat exchanger is studied, the oil outlet temperature is increased for each smooth and finned pipe and this will be achieved by changing the air and oil flow rate for the above conditions, as well as changing the air velocity and temperature for different conditions. Table 1 shows summary of all the criteria studied by the experiment tests.

**Table 1**
The parameters range of the experimental work

| Type of pipe | Air Inlet temp (°C) | Oil Flow rate(kg/s) | Air Velocity (m/s) |
|---|---|---|---|
| Smooth | 200-225 | 0.06, 0.8, 0.1 | 20, 27, 34 |
| Finned | 200-225 | 0.06, 0.8, 0.1 | 20, 27, 34 |

## *5.3 Calculation's Procedure*

The heat released from the hot air and absorbed from the cold oil must be calculated according to the first law of thermodynamic. The overall energy balance for the two-fluid HE is as shown [12]:

$$Q = \dot{m}_h \, C_{ph} \, (T_{hi} - T_{ho}) = \dot{m}_c \, C_{pc} \, (T_{co} - T_{ci}) \tag{1}$$

$$Q = \dot{m}_{\text{air}} \, C_{p\,\text{air}} \, (T_{\text{air}\,i} - T_{\text{air}\,o}) = \dot{m}_{\text{oil}} \, C_{p\,\text{oil}} \, (T_{\text{oil}\,o} - T_{\text{oil}\,i})$$

LMTD represents a mathematical formula for the difference rate of temperatures (inlet and outlet) of two fluids used in in counter flow heat exchanger [10].

$$LMTD = \frac{\Delta T1 - \Delta T2}{Ln\left(\frac{\Delta T1}{\Delta T2}\right)} \tag{2}$$

$$\Delta T1 = Th_1 - Tc_2 \tag{3}$$

$$\Delta T2 = Th_2 - Tc_1 \tag{4}$$

$$\mathrm{A_i = \pi D_i L} \quad \text{and} \quad \mathrm{A_o = \pi D_o L} \tag{5}$$

The rate of heat transfer become:

$$\text{Q=} \; \mathrm{U.A.\Delta T = U_i.A_i\,.LMTD = U_o.A_o\,.LMTD} \tag{6}$$

Nu for smooth passage is provided using Dittus-Boelter equation as follow and ($h_i$) obtained from recommended correlation are taken from Thulukkanam [13] to predict the heat transfer coefficient:

$$\mathrm{Nu = 0 \cdot 023Re^{0 \cdot 8}Pr^{0.4}} \tag{7}$$

$$\mathrm{Re} = \frac{\rho_{air} u_{air} d_h}{\mu_{air}} \tag{8}$$

$$\mathrm{P_r} = \frac{\mu C_p}{k} \tag{9}$$

$$\mathrm{N_u} = \frac{h_i d_h}{k} \tag{10}$$

Inner pipe

$$\mathrm{d_h = D_i} \tag{11}$$

Outer pipe

$$\mathrm{d_h = D_{o\,i} - D_{i\,o}} \tag{12}$$

Outer pipe with helical fins is taken from Firas [14].

$$\mathrm{d_h} = \frac{4\{\frac{\pi}{4}\left(D_{o\,i}{}^2 - D_{i\,o}{}^2\right) - N.t.h\}}{N(2h+t) + \pi D_o - N.t} \tag{13}$$

The calculations of average heat transfer coefficient ($h_o$) is achieved by the Newton's law of cooling which [15]:

$$\mathrm{Q = h_o A_o (T_s - T_m)} \tag{14}$$

$$\mathrm{T_m} = \frac{(T_{ci} + T_{co})}{2} \tag{15}$$

$$\mathrm{T_s} = \frac{T_1 + T_2 + T_3 + \cdots + T_n}{n} \tag{16}$$

$T_s$: average surface inner pipe temperature

Then Nusselt's number in outer tube can be calculated as follows:

$$h_o = \frac{Q}{A_o(T_s - T_m)} \tag{17}$$

Oil side

$$Nu_{ave} = \frac{h_o \times d_h}{K_{oil}} \tag{18}$$

The effectiveness is the ratio of actual heat transfer to maximum heat transfer during the process of heat exchanger. It can be written as follows [16].

$$\epsilon = \frac{Q_{act}}{Q_{max}} \tag{19}$$

The pressure drops are a vital limit in heat exchanger analysing because it is related to pumping power [17].

$$\Delta P_{tube} = f \times \frac{L}{d_i} \times \frac{\rho_a \ {u_a}^2}{2} \tag{20}$$

For laminar flow:

$$f = \frac{60}{Re} \tag{21}$$

## 6. Results and Discussion

### *6.1 Heat Transfer Rate*

The effect of helical fins on heat transfer rate of heat exchanger displays in Figure 4. It is clear that the rate of heat transfer increased by using helical fins due to swirls in annuals side which increase turbulence in flow and this helps in production best mixing in the flow. As a result, at air inlet temperature 200$^o$C, the finned pipe produces heat transfer rate higher than smoot pipe with average 14% at different oil flow rate and constant Re. Similarly, from the graph it is seen that heat transfer rate higher than smooth pipe with average 15% at different Re and constant oil flow rate.

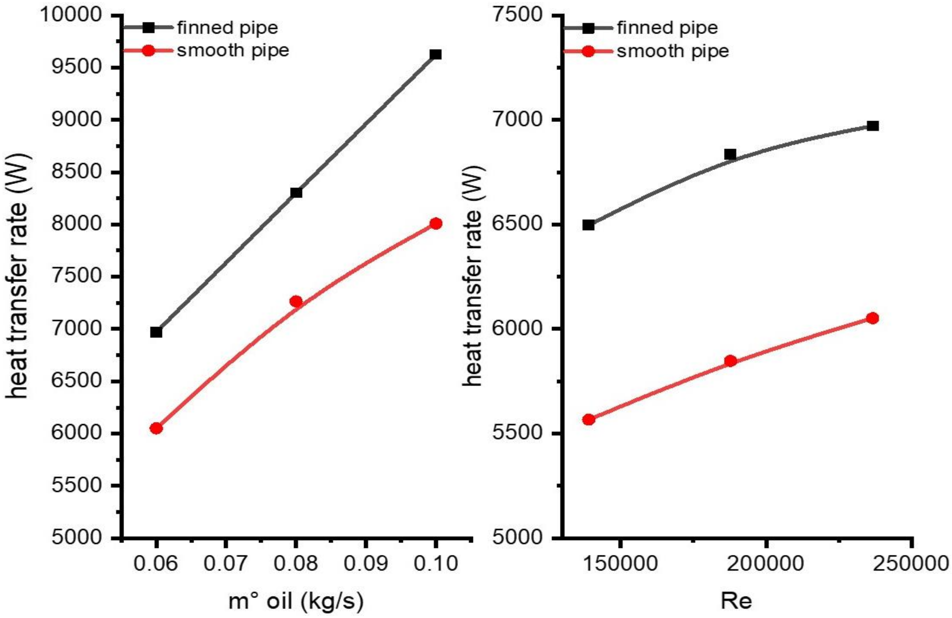


**Fig. 4.** Effect of helical fins on heat transfer rate at air inlet temperature 200°C

### *6.2 Oil Outlet Temperature*

As a result of the enhancement heat transfer rate due to the addition of helical fins, the temperature of the oil outlet temperature increased as shown in Table 2.

**Table 2**
Experimental results of oil outlet temperature

| Oil outlet temperature °C | | | | |
|---|---|---|---|---|
| Air inlet temperature | Air Re | Finned pipe | Smooth pipe | Enhancement ratio % |
| Oil flow rate 0.06 kg/s | | | | |
| 200°C | 139139 | 89.3 | 83.6 | 6.3 |
| | 187837 | 92.8 | 84.8 | 8.6 |
| | 236536 | 95 | 86.8 | 8.6 |
| 225°C | 139139 | 97.6 | 89.35 | 8.4 |
| | 187837 | 100.6 | 91.84 | 8.7 |
| | 236536 | 101.8 | 93.65 | 8 |
| Oil flow rate 0.08 kg/s | | | | |
| 200°C | 139139 | 85.4 | 78.8 | 7.7 |
| | 187837 | 87.5 | 79.3 | 9.3 |
| | 236536 | 89.2 | 80.8 | 9.3 |
| 225°C | 139139 | 91.8 | 84.7 | 7.7 |
| | 187837 | 94.5 | 86.2 | 8.7 |
| | 236536 | 95.2 | 88.3 | 7.2 |
| Oil flow rate 0.1 kg/s | | | | |
| 200°C | 139139 | 82.3 | 75.5 | 8.2 |
| | 187837 | 83.4 | 76.3 | 8.5 |
| | 236536 | 84.3 | 76.7 | 9 |
| 225°C | 139139 | 89.2 | 80.3 | 10 |
| | 187837 | 90.4 | 81.2 | 10.1 |
| | 236536 | 91.2 | 82.6 | 9.4 |

Figure 5 shows that oil outlet temperature decreased with average 10% when oil flow rate increased from (0.06 – 0.1) kg/s because the low velocity means that more time for the fluid to pass through the heat exchanger, this additional time led to increase oil temperature. While, increasing air side Re from (139139 - 236536) led to increase oil outlet temperature with average 4% because a higher Re will transport the heat away faster influence on the temperature of the fluid. Also, from figure it is clear that oil outlet temperature increased with average 8.4% at different oil flow rate and 8.8% at different Re due to effect of helical fins.

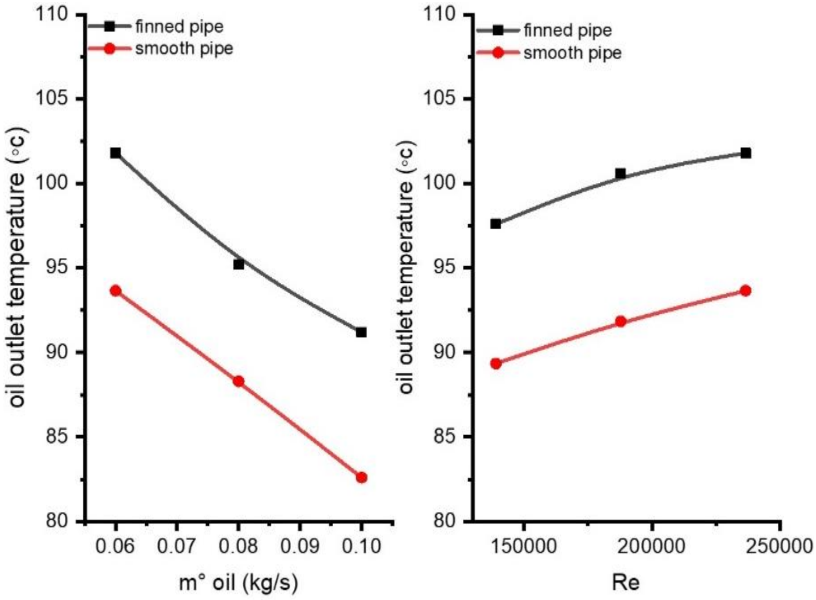


**Fig. 5.** Effect of helical fins on outlet oil temperature

*6.3 Nusselt Number (Nu)*

In all the forms, the annulus-side Nu increases with increasing fluid velocity, using helical fin led to increase fluid path and results development in thermal performance in double pipe heat exchanger [18]. The parameter which has effect on the Nu for annulus - side one is the mass flow rate and the second is the fins. Figure 6 represent the Nu in annulus- side finned pipe higher than smooth pipe with average 25% at different oil flow rate and 27% at different Re.

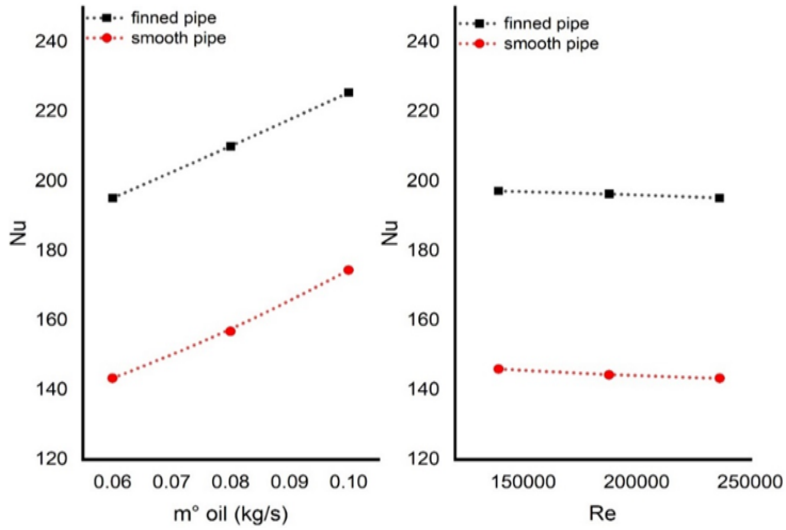


**Fig. 6.** Effect of helical fins on Nusselt number (annulus- side)

### *6.4 Overall Heat Transfer Coefficient*

Figure 7 shows the variation of overall heat transfer coefficient with different air Re and different oil flow rate. It is show that the overall heat transfer coefficient increased slowly for finned pipe in both cases where, it increased with average 19% at different oil flow rate and 12% at different Re compared with smooth pipe.This is due to decreas the thermal resistance and more heat transfer rate in finned pipe than from the smooth pipe.

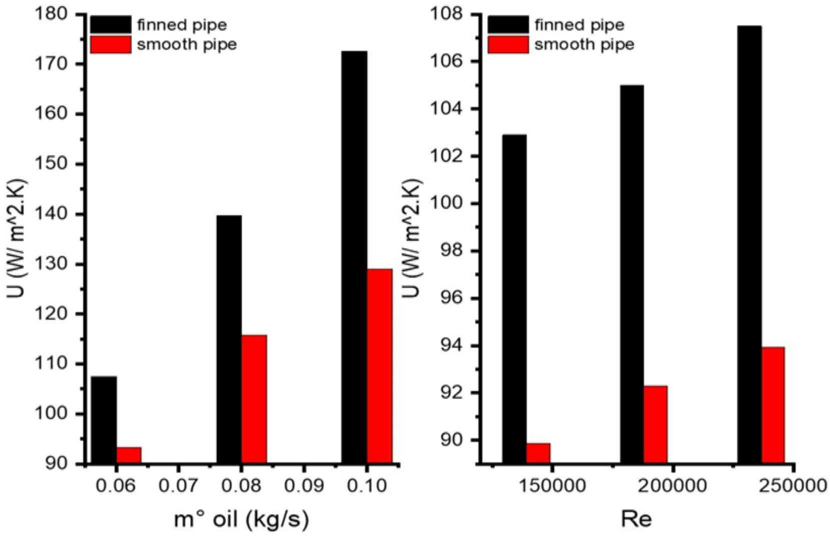


**Fig. 7.** Effect of helical fins on Nusselt number (annulus-side)

### *6.5 Effectiveness*

Figure 8 shows the effect of helical fins on heat exchanger effectiveness (ε) with different air Re, different oil flow rate and a constant air inlet temperature 200ºC. The effectiveness of finned pipe increased by 12% for different values of Re and 14% for different values of oil flow rate compared with smooth pipe.

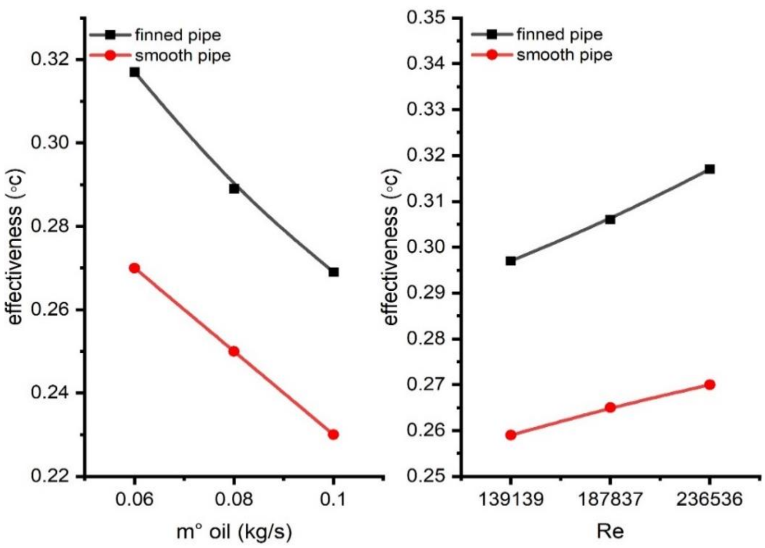


**Fig. 8.** Effect helical fins on effectiveness

### *6.6 Pressure Drops (Oil Side)*

Pressure drops is the maximum important variable in reduce size and cost of heat exchanger. The variation of the pressure drop in the annulus side is shown in Figure 9. The usage of helical fin with height 20 mm causes increasing pressure drops equal on average 9 times in comparison with smooth pipe at oil flow rate 0.06 kg/s while, increasing in pressure drops equal on average 12 times at oil flow rate 0.1 kg/s. Low velocity and the sudden change in the flow pattern the main cause of the high pressure drops.

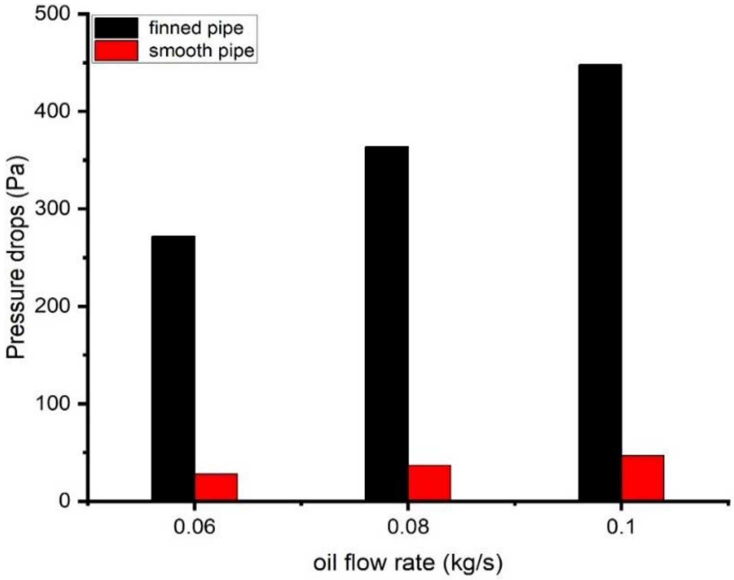


**Fig. 9.** Effect helical fins on pressure drops (oil side)

## 7. Comparison Current Study Results with Previous Studies

Comparison was done between the current study (finned pipe) and Kamel *et al.,* [19] study which used helical tape in inner pipe of heat exchanger and with Salman *et al.,* [7] which used twisted tapes in inner pipe of heat exchanger to estimate which heat transfer enhancement device gives better influence on the hydrothermal performance of double pipe of heat exchanger. The boundary condition is air inlet temperature (200-300) $^{o}$C , oil inlet temperature 40 $^{o}$C , oil flow rate (0.06 kg/s), air velocity is (20, 27 and 34) m/s. Figure 10 show comparison between experimental results of heat transfer rate. It is clear that maximum heat transfer rate in current study and it increased with enhancement ratio 30%, 65% respectively compared with previous studies.

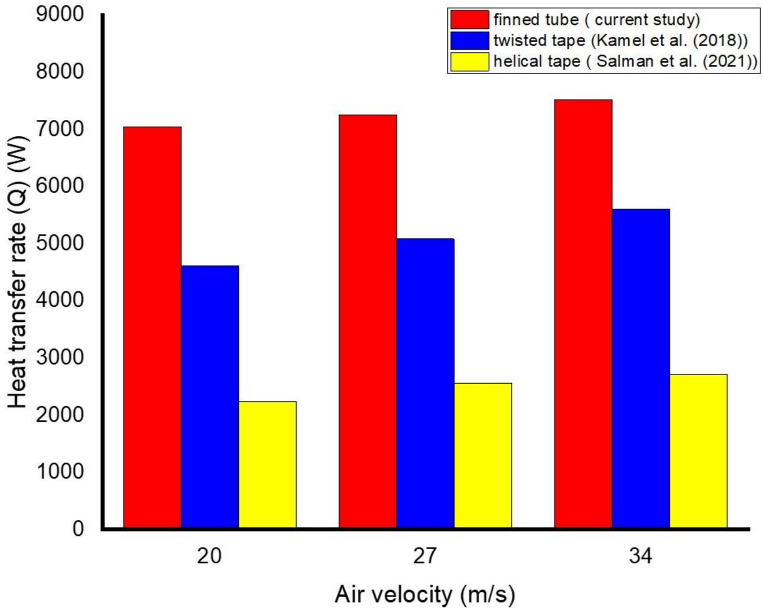


**Fig. 10.** Comparison between current and previous studies

## 8. Power Consumption

The rapid growth of the world's population has increased the use of finite fossil resources. In good light. For this reason, researchers studied modern methods and methods to reduce the use of fuel and energy and reduce emissions [20]. In the brick factory in Iraq as shown in Figure 11 there are two heaters, first one is the diesel burner which is heating the oil in the tank directly to 40°C using the burner hot gases, and the second one is the electrical heater on the discharging pipe. The idea is to replace electrical heater with a double pipe heat exchanger with helical fins and recover waste heat from the flue gases for the purpose of raising heavy fuel oil temperature more than 90°C. The amount of heat required to raise the heavy oil temperature from 40°C to 90°C is shown below

$Q = \dot{m}_{\text{oil}}\ C_{p\ \text{oil}}\ (T_{\text{oil}\ o} - T_{\text{oil}\ i})$

$Q$ = 0.06 * 1880 * (90 – 40)

$Q$ = 5640 W/day * 300 days = 1.69 MW annually for one factory

By using a double pipe heat exchanger with helical fins instead of an electric heater, this amount of electrical energy will be saved.

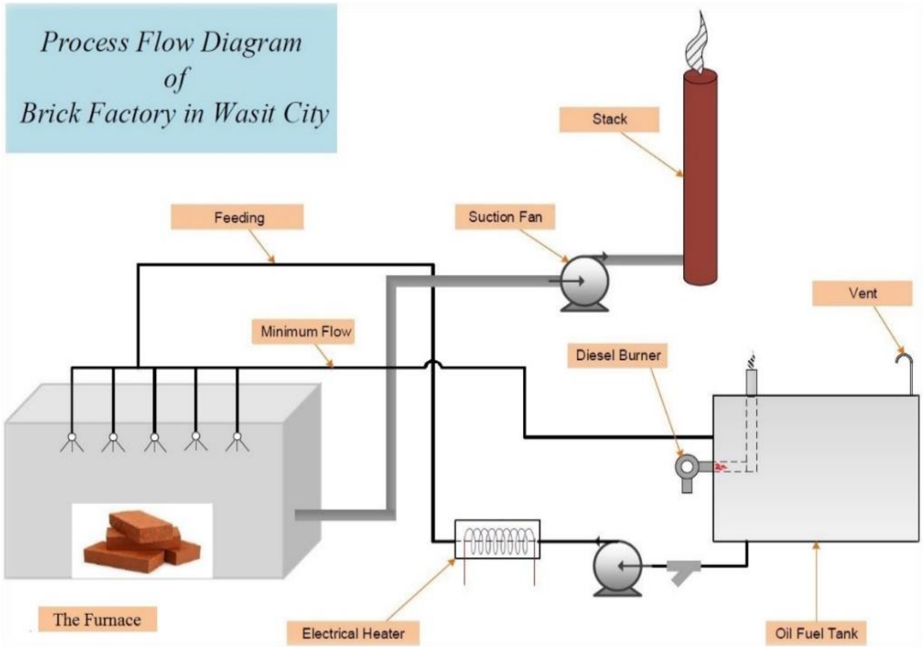


**Fig. 11.** Process flow diagram of brick factory

## 9. Conclusions

The conclusions obtained from this study are listed as follows:

i. Increasing Re from 139139 to 333934 led to increase heat transfer rate, oil outlet temperature, overall heat transfer coefficient and effectiveness of heat exchanger with (8%, 4%, 5% and 5%) respectively while Nu (oil side) decreased with percentage 7% at the same values of Re.
ii. Increasing oil mass flow rate from (0.06 - 0.1) kg/s cause increasing heat transfer rate, Nu (oil side) and overall heat transfer coefficient with (30%, 13% and 38%), while, oil outlet temperature and effectiveness of heat transfer decreased with (10%, 14%) respectively.
iii. The heat exchanger with helical fins of height 20 mm produce heat transfer rate and oil outlet temperature higher than smooth pipe with average 15% and 8.6% respectively.
iv. Oil side Nu in double pipe heat exchanger with helical fins higher than smooth double pipe by 26%.
v. Overall heat transfer coefficient and effectiveness of heat exchanger increased with average 15% and 13% respectively in heat exchanger with helical fins.
vi. Using helical fin with height 20 mm causes increasing in the pressure drop equal on average 9 times in comparison with smooth pipe.

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