Improving the Efficiency of Concentric Heat Exchanger Using Nano Particles in the Fluid and Transitioning

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IMPROVING THE EFFICIENCY OF CONCENTRIC HEAT EXCHANGER USING NANO PARTICLES IN THE FLUID AND TRANSITIONING

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1. **ABSTRACT:** A modification to a shell and tube heat exchanger aimed at improving efficiency. The approach involves using nano particles in the fluid and transitioning the fluid flow from laminar to turbulent. Both parallel and counter flows of acting and act upon fluids are considered. The goal is to maintain turbulent flow, as it increases heat exchange efficiency. The swirling effect created by the fluid's turbulence acts as a catalyst, enhancing heat transfer efficiency. The inner tube is made of copper, while the outer tube is transparent Acrylic Plexiglass. The inner tube rotates at speeds ranging from 0 to 1500 rpm. Results show a significant improvement in heat transfer rate due to inner tube rotation. The study involves adjusting factors, measuring and recording data to optimize the heat exchanger's effectiveness and NTU (Number of Transfer Units).

2. INTRODUCTION

Heat transfer is a fundamental process in which internal energy is exchanged between two substances, resulting in a transfer of thermal energy. This phenomenon is essential in the analysis of thermodynamic processes, particularly those occurring in heat engines and heat pumps. Thermodynamics, a branch of physics, [1, 2] is dedicated to the study of heat transfer and the accompanying changes in systems. It encompasses the principles and laws governing the transformation of energy between different forms, [3] emphasizing the role of heat transfer in understanding and predicting the behavior of physical systems. The study of thermodynamics and heat transfer is crucial in various scientific and engineering applications, providing insights into the efficiency and performance of devices like engines and refrigeration systems [4].

The double pipe heat exchanger is a crucial device widely used in industries such as power generation, chemical processing, refrigeration, and more. [5,6]Heat exchangers play a vital role in energy conservation by transferring heat between fluids at different temperatures through convection and conduction mechanisms. Improving the heat transfer coefficient of fluids is essential for enhancing heat exchanger performance[7,8].

In recent years, nanofluids, which are base fluids containing solid particles with high thermal conductivity at the nanoscale, [9, 10]. have been employed to enhance the thermo-physical properties of fluids. Various types of nanoparticles, including silicon carbide, graphene, and aluminum oxide, have been studied for their impact on heat exchanger performance. [12].Researchers have explored the addition of nanofluids in different heat exchanger types, such as double pipe, shell-tube, and plate heat exchangers.

Studies have shown that nanofluids can significantly improve the heat transfer coefficient, with experiments involving different process parameters[17,18]. and nanofluid variations. For example, experiments with Al2O3 nanoparticles in a double pipe heat exchanger demonstrated increased thermal conductivity with temperature. [15].Other studies investigated the influence of nanofluids on heat transfer in microchannel heat exchangers, indicating notable improvements in heat transfer coefficients.

Research has also delved into modifying geometrical [16].parameters of heat exchangers, such as adding longitudinal fins, helical coils, and spiral-shaped double tubes, resulting in positive impacts on performance. Numerical investigations on conical tube double pipe heat exchangers and optimal design parameters using techniques like Response Surface Method[27,28]. (RSM) have been explored. Additionally, studies on shell-and-tube heat exchangers considered factors like baffle cut and spacing.

Specifically, papers focusing on double pipe heat exchangers with nanofluids highlighted improvements in convective heat transfer coefficients. [30].Results from experiments with alumina nanoparticles and transformer oil showed increased heat transfer coefficients with higher solid concentrations. Other studies examined the impact of water/CuO nanofluid on convection heat transfer coefficients, demonstrating improvements with increased Reynolds number and nanoparticle volume fraction[32]..

While recent literature indicates the potential of nanofluids in enhancing heat exchanger performance, further studies involving different nanofluids and process parameter variations are necessary before practical implementation. The present study [40].contributes significant insights that could aid in the implementation of nanofluid-based heat exchangers.

3. HEAT EXHCANGER SYSTEM DESIGN

Concentric heat exchanger:

Simple Design: Concentric heat exchangers are preferred due to their straightforward and uncomplicated design. This simplicity often translates to easier maintenance and lower chances of malfunction [11].

Ease of Cleaning: The design of concentric heat exchangers allows for easy cleaning of both tubes. This is particularly advantageous when dealing with fluids that may contain impurities or substances that could accumulate [12, 13].over time.

Suitability for Dirty Fluids: Because of their easy-to-clean nature, concentric heat exchangers are well-suited for applications involving dirty fluids. The ability to efficiently clean both tubes helps maintain the heat exchanger's performance over time. [15,].

High Pressure Conditions: Concentric heat exchangers can operate effectively under high-pressure conditions. [20].This makes them suitable for applications where the fluid needs to be processed or transferred at elevated pressures.

Turbulent Flow at Low Rates: At low flow rates, concentric heat exchangers induce turbulent flow. Turbulent flow generally has a higher heat transfer coefficient than laminar flow, which means that it enhances the rate of heat transfer. [19].This is beneficial for efficient heat exchange even when the flow rates are not exceptionally high

In summary, [19].the advantages of concentric heat exchangers lie in their simple design, ease of cleaning, suitability for handling dirty fluids, ability to operate under high pressure, [21].and the promotion of turbulent flow at low rates, leading to enhanced heat transfer efficiency.

Disadvantages:

High Cost per Heat Transfer Area: Concentric heat exchangers can be expensive on a per-unit basis of heat transfer area. [28].This cost factor becomes more pronounced when dealing with high heat duties, as impractical lengths may be required.

Heat Loss through Outer Shell: The large outer shell of concentric heat exchangers can lead to significant heat loss, reducing overall thermal efficiency. [24]. this is a crucial consideration in applications where minimizing energy loss is a priority

Considerations:

Application-specific Requirements: The choice between concentric and other types of heat exchangers depends on the specific requirements of the application. [21].Factors such as fluid characteristics, operating conditions, space constraints, and budget considerations play a role in selecting the most suitable heat exchanger.

Energy Efficiency: While concentric heat exchangers have advantages, their overall efficiency, especially in terms of energy conservation, should be carefully evaluated. [30].Minimizing heat loss and optimizing heat transfer efficiency are critical considerations.

Economic Viability: The cost-effectiveness of a concentric heat exchanger depends on the balance between its advantages and disadvantages, [27] as well as the economic considerations of the specific application

In summary, concentric heat exchangers offer simplicity, [28] ease of cleaning, and suitability for high-pressure conditions, [31]but their high cost and potential for heat loss should be carefully weighed against these benefits in the context of the intended application. [32]Each heat exchanger type has its own set of trade-offs, and the choice should align with the specific needs [33] and constraints of the system in question.

Flow Arrangement

The choice of passing hot fluid through the inner tube and cold fluid through the annulus, [34] or vice versa, lacks a general consensus. Factors like cleaning, pressure, viscosity, [31] and corrosion influence this decision. Nevertheless, in many situations, [38] the convention is to pass the hot fluid through the inner tube and the cold fluid through the shell to minimize heat transfer losses.

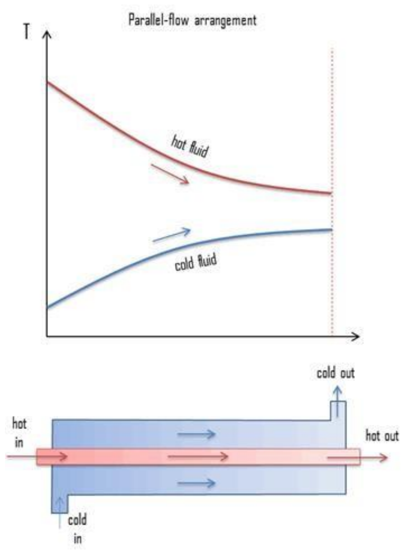

Figure 1-1

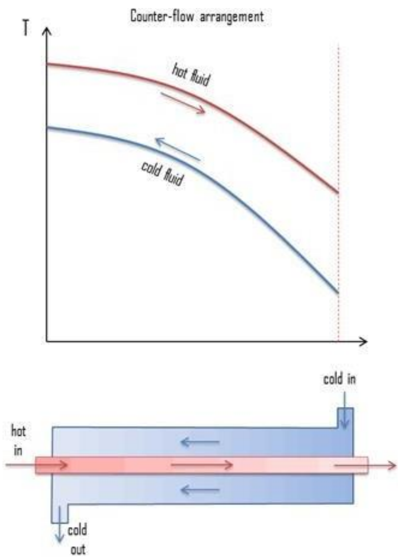

Figure 2-2

Concentric tube heat exchangers have two main configurations: parallel flow and counter flow. **[31]** In the parallel flow arrangement **[28]**, both hot and cold fluids enter the heat exchanger from the same end, flow in the same direction, and exit from the same end. On the other hand, in the counter flow arrangement, the fluids enter from opposite ends, **[33]** flow in opposite directions, and exit from opposite ends.

At the same conditions more heat is transferred in the counter flow than parallel flow [29].
The main disadvantages of using parallel flow in heat exchangers are the occurrence of large thermal stresses due to significant temperature differences between the inlet and outlet[35],

At the same time parallel arrangement is of great advantage if it's required for the two exiting fluids to be at almost the same temperature as shown in Figure 1- 1.and the limitation that the

Maximum temperature of the cold fluid cannot exceed the minimum temperature of the hot fluid. In contrast, counter flow is preferred because it minimizes thermal stresses, [28] ensures more uniform heat transfer, [38] also the outlet temperature of the cold fluid approaches highest temperature of the hot fluid as in Figure 1- 2. And allows the outlet temperature of the cold fluid to approach the highest temperature of the hot fluid. [39]Counter flow arrangements generally require a smaller heat exchanger surface area for the same rate of heat transfer compared to parallel flow. Heat exchangers are designed to increase the surface area between fluids and reduce thermal resistance, [35] and the addition of fins can further enhance surface area and create turbulence for the fluid.

Design Considerations

When designing a heat exchanger multiple factors should be taken into consideration [45]:

1. trying to keep heat transfer resistance as low as possible
2. safety margins in case of emergencies like fouling
3. equipment should be strong
4. cost should be kept low as possible
5. try to avoid corrosion
6. pumping cost should be low
7. heat exchangers weight should be light
8. it shouldn't take much space

Knowing all these factors we try to optimize all these factors in order to try to make an efficient heat exchanger [42].

The Overall Heat Transfer Coefficient

A heat exchanger functions as a device with two fluids, separated by a thin solid wall. Heat transfer occurs in three stages: first, from the hot fluid to the wall through convection; [43] second, through the wall via conduction; and finally, [41] from the wall to the cold fluid through convection.

For the concentric tubes heat exchanger, [44] the Ai = ΠDiL and Ao = ΠDoL, where Ai and Ao are the areas of the pipe from the inside and the outside. So, the thermal resistance of the wall in this case is

$$Rwall = \frac{In(\frac{ro}{ri})}{2\Pi KL}, \qquad (1)$$

where K is the thermal conductivity of the tube and L is the length of it. Then the total[45] thermal resistance becomes:

$$Rtotal = Ri + \ Rwall + Ro = \left(\left(\frac{1}{hiAi}\right) + \frac{\text{In}(\frac{ro}{ri})}{2\Pi KL} + \left(\frac{1}{hoAo}\right) \right) \tag{2}$$

Then the rate of heat transfer between the two fluids is:

$$Q = \frac{\Delta T}{Rtotal} = UA\Delta T = \ UiAi\Delta T \ = \ UoAo\Delta T, \tag{3}$$

where [44] U is the overall heat transfer coefficient (W/m2 oC). Equation (3) can be reduced to:

.

$$\frac{1}{UA} = \frac{1}{UiA} = \frac{1}{UoAo} \ = \ Rtotal = \frac{1}{hiAi} + Rwall + \frac{1}{hoAo} \tag{4}$$

In most cases the thickness of the tube is very small and the thermal conductivity of the pipe material is high[46] (to increase the rate of heat transfer), therefore the resistance of the tube is negligible (Rwall≈ 0) also the Ai ≈Ao≈ A. so the overall heat transfer coefficient becomes:

$$\frac{1}{U} \approx \frac{1}{hi} = \frac{1}{ho}, \tag{5}$$

where i and o represent the inside and the outside of the pipe respectively.

Fouling Factor

Scaling or deposits can lead to a decline in the performance of a heat exchanger, impacting [33] both the interior and exterior surfaces of the tubes. These deposits have a detrimental effect on the overall heat transfer coefficient (U). [23] The relationship between fouled heat transfer conditions (due to scaling or deposits) and clean conditions is significant, highlighting the adverse impact of such deposits on heat exchange efficiency[18].as follows:

$$\frac{1}{Ufoul} = Rf \ + \ \frac{1}{Uclean} \tag{6}$$

So, for fouled conditions:

$$Rtotal = \frac{1}{hiAi} + \frac{Rfi}{Ai} + \frac{In(\frac{ro}{ri})}{2\Pi KL} + \frac{Rfo}{Ao} + \frac{1}{ho} \qquad (7)$$

where Rfi and Rfo are the fouling factors for both inside and outside of the tube respectively.

The Logarithmic Mean Temperature Difference

The LMTD is the log average of the hot and cold streams on both sides of the pipe. [11] The LMTD is when kept constant gives the same rate of heat transfer as that happens with variable conditions of temperature difference.

$$\text{LMTD} = \frac{(\Delta T1 \;-\; \Delta T2)}{In\,(\frac{\Delta T1}{\Delta T2})}$$

Where ΔT1 = T_Hot_In - T_Cold_Out and ΔT2 = T_Hot_Out - T_Cold_In, for counterflow arrangement (for parallel flow ΔT1 = T_Hot_In - T_Cold_In and ΔT2 = T_Hot_Out - T_Cold_Out) [16].

So, the rate of heat energy exchanged is as follows:

Q = U * A * LMTD

So, at constant area and heat transfer coefficient, when the LMTD increase the rate of heat [14] transfer will also increase.

In order to derive the previous expression for LMTD, the following assumptions were made:

In the context described, the overall heat transfer coefficient (U) remains constant. [49] The system assumes steady flow conditions with constant specific heats and mass flow rates for both fluids. There is no heat loss to the surroundings, no phase change in the fluids during heat transfer, and negligible changes in potential and kinetic energies. Additionally, [48] axial conduction along the tubes of the heat exchanger is considered negligible according to Saunders (1981).

Number Of Transfer Units

The Number of Transfer Units (NTU) Method is employed for calculating the heat transfer rate in heat exchangers, particularly in counter-current configurations, when there is insufficient data to compute the Log-Mean Temperature Difference (LMTD). [47] In heat exchanger analysis, the LMTD method is applicable when fluid inlet and outlet temperatures are known or can be determined through simple energy balance. However, when these temperatures are unavailable, the NTU or [23] Effectiveness method becomes a suitable alternative for heat transfer rate calculations.

Heat Transfer Augmentation Techniques

Certainly, let's delve into an analysis of the statement you provided regarding the importance of enhancing the effectiveness of a heat exchanger and the methods used for heat transfer augmentation.

The main priority in improving the performance of a heat exchanger is enhancing its effectiveness[12], which directly impacts heat recovery capacity. Heat transfer augmentation techniques play a crucial role in achieving this goal by increasing the rate of heat transfer without significantly affecting the overall system performance. [23] These techniques are broadly categorized into active and passive methods.

Active heat transfer techniques involve utilizing external sources of power to enhance the heat transfer process. One example is inducing pulsations through mechanisms like cams and reciprocating plungers. Another technique involves employing a magnetic field to disrupt seeded light particles in a flowing stream, thereby optimizing heat transfer.

While passive techniques are the ones that requires the use of surface or geometrical modifications to the flow like the use of inserts (fins) or rough surfaces[21].

Effect Of Swirling On Heat Transfer

The study focuses on the significance of swirl flow in heat transfer enhancement and various engineering applications, particularly when the Reynolds Number is [45] maintained below 2000. The investigation specifically considers water swirling in a circular pipe with stationary heat-resistant blades generating the swirl flow. The study employs the three-dimensional Navier-Stokes equations for incompressible Newtonian fluid flow. [41] Validation of the numerical code is achieved by comparing simulation results with the well-established Hagen-Poiseuille law, showing satisfactory agreement. The validated code is then employed to assess the heat transfer performance of the swirl flow in the present study.

In this study, two scenarios are examined concerning the external surface of a pipe: (i) Constant heat flux and (ii) Constant temperature. The research indicates that swirl flow has a positive impact on the average outlet temperature in both cases. Additionally, [18] the study analyzes the influence of factors such as vane angle, pipe length, and diameter on heat transfer characteristics.

4. SYSYTEM COMPONENTS

Electric circuit, Electrical Motor, Motor Inverter ,heaters , Measuring components as (flow meter, pressure gauge , thermocouple) Mechanical components as (tanks , valves , inner pipe , outer pipe , hot water pump , cold water pump, connecting hoses, pulley , belt , seal) as the following at **Figure 3-3**

Figure 4-3

5. Results and Discussion

The process of assembling the heat exchanger was mainly the work of connecting the hose to the pumps and the tanks. So, the device can be used for both parallel and counter flow. The other arrangement depends on directing the inlet flow whether it introduced to the heat exchanger in direction tangential to the hot pipe or perpendicular to the hot pipe **Figure 5-4**.

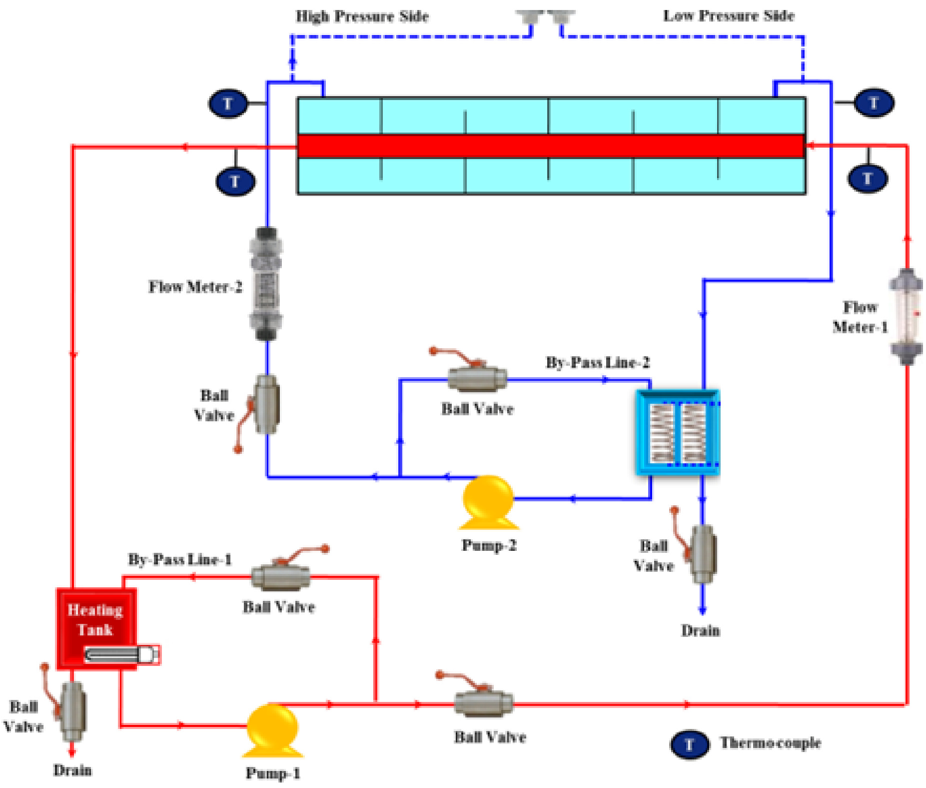

Figure 6-4

Before carrying out the experiment some major factors should be taken into consideration

Making sure that the cold water tank was to be near full and with continuous stream ofcold water to make sure that the pump doesn't get any air to the impeller (if any air got through to the pump's impeller the pump would stop flowing water to the cold pipe and

The experiment should be stopped to get the air out of the impeller) 2. Making sure all thevalves are open except the outlets of the two pipes to keep them filled with water 3. Just before starting the pumps the two drain valves must be open in order not to increase the pressure of the two pipes and risk the failure of the oil seals.

When running the experiment, it was noted that the heat exchanger was leaking a substantial amount of water because we had to use oil seals instead of mechanical seals so it was decided to carry the experiment outdoors for more safety.

Experimental work

The experiments were carried by working with the 1. Tangential cold inlet and parallel flow 2.Tangential cold inlet and counter flow 3.Perpendicular cold inlet and parallel flow. All those experiments will be carried with different flow rates for the hot and the cold fluids 1. Q hot=15 Q cold=25, 2. Q hot =7.5 Q cold=25, 3. Q hot=15 Q cold=19 4. Q hot=7.5 Q cold=15. The results were to be obtained after 2.5 minutes and 5 minutes from setting the new conditions in order to have a better observation of the system.

Results

All the results when carrying the experiments at all the previous conditions are represented in detail in the appendix. One thing that was very noticeable was the very high temperature drop when carrying the experiment at low flow rates with the tangential inlet and rotating the motor with 1500 rpm which reached approximately 10 degrees Celsius with minimal pressure drop. The temperature drop of the hot fluid when comparing the parallel to counter flow when using the tangential inlet flow is shown in Figure 1-5, Figure 1- 6, Figure 1- 7 and Figure 1- 8 .

At Q cold = 25

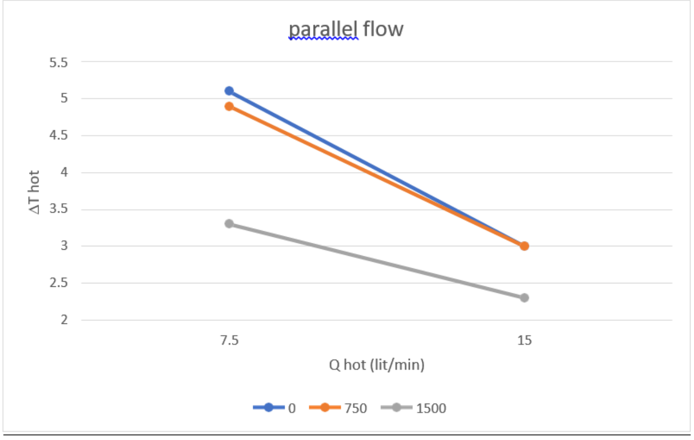

Figure 1- 5

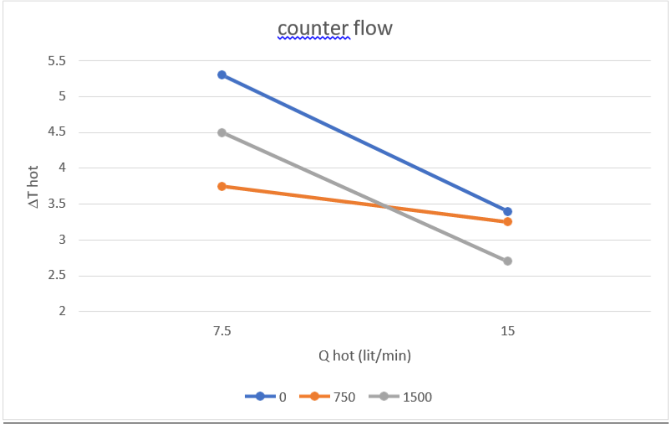

Figure 1- 6

<u>At Q cold=19</u>

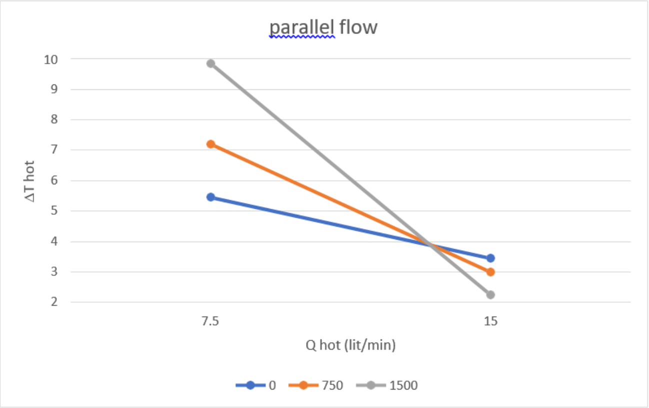

Figure 1- 7

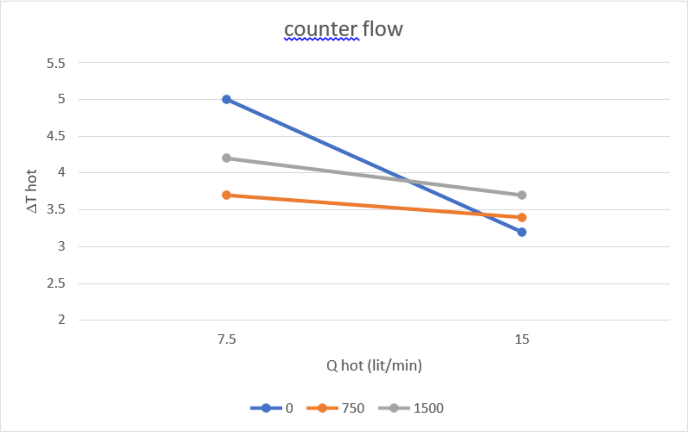

Figure 1-8

Another noticeable thing was the higher efficiency of counter flow compared to parallel flow when using the tangential inlet flow at various flow rates as shown in Figure 1- 9, Figure 1-10, Figure 1- 11 and Figure 1- 12 .

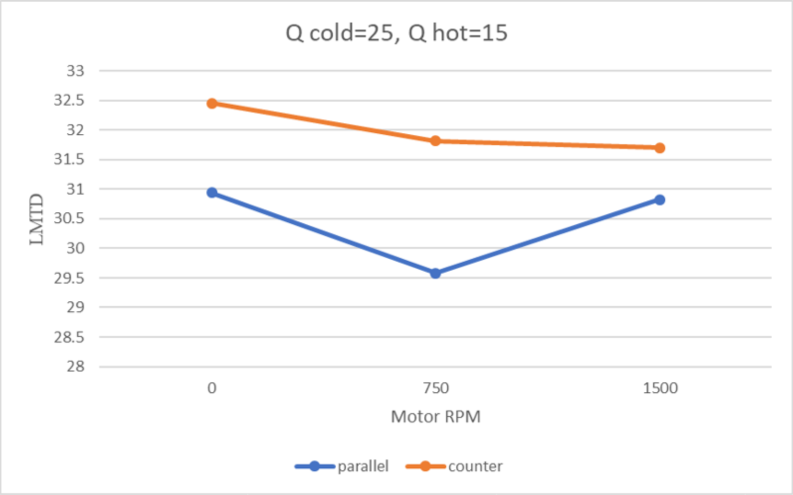

Figure 1-9

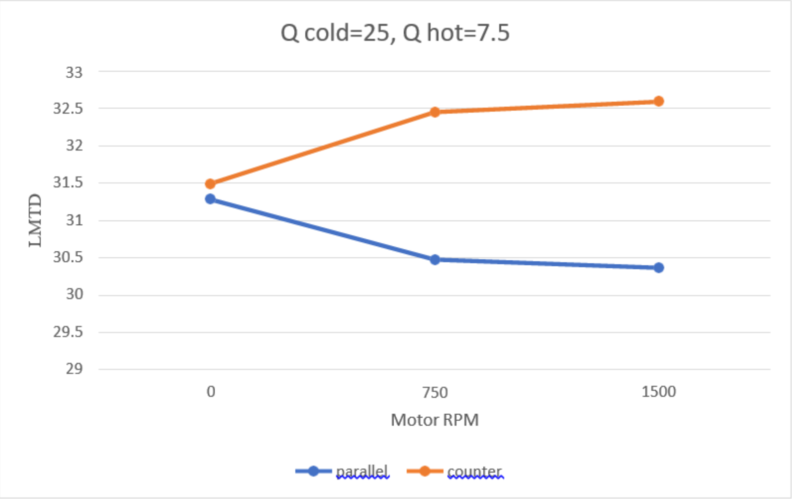

Figure 1-10

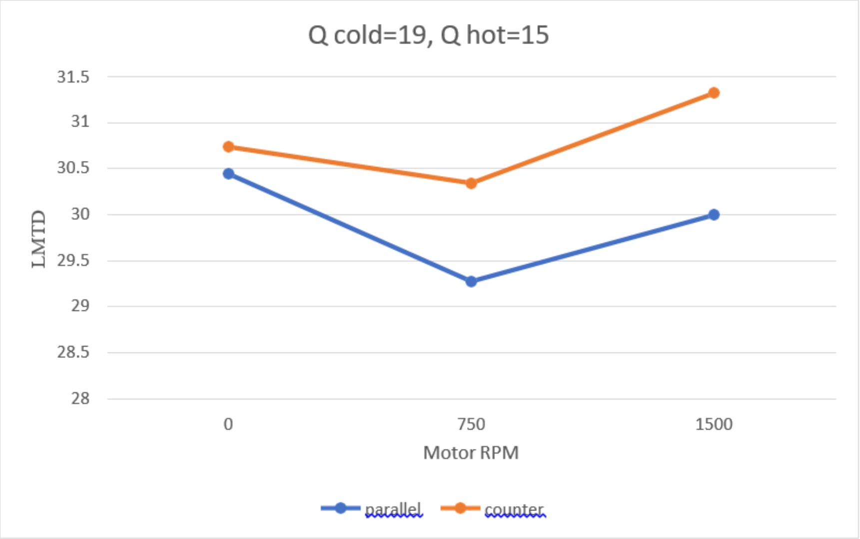

Figure 1-11

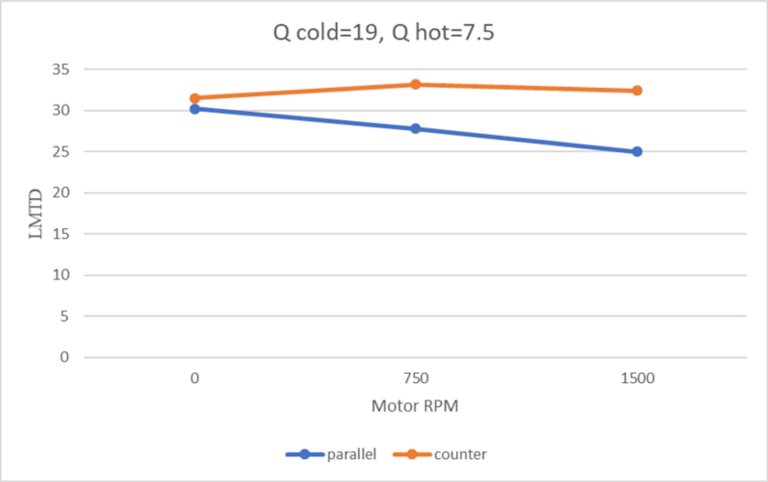

Figure 1-12

The efficiency was also greater in the tangential inlet than the perpendicular because of the extra swirling of the cold fluid around the hot pipe as shown in Figure 1- 13 , Figure 1-14 and Figure 1- 15.

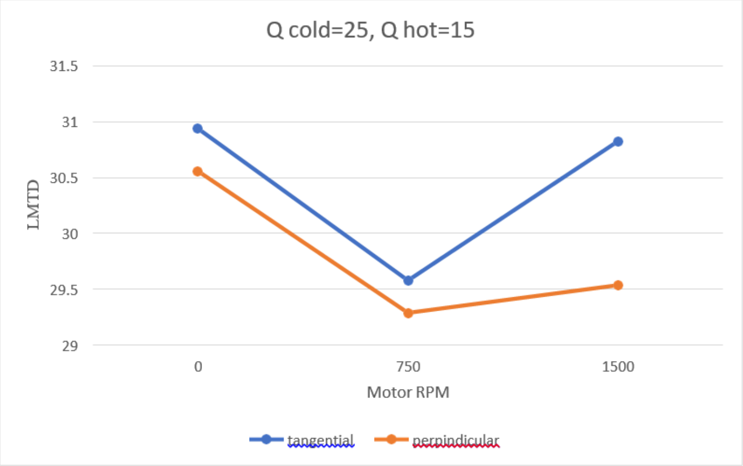

Figure 1-13

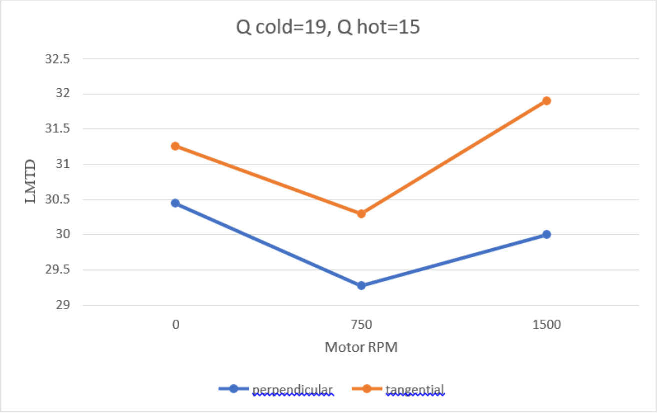

Figure 1-14

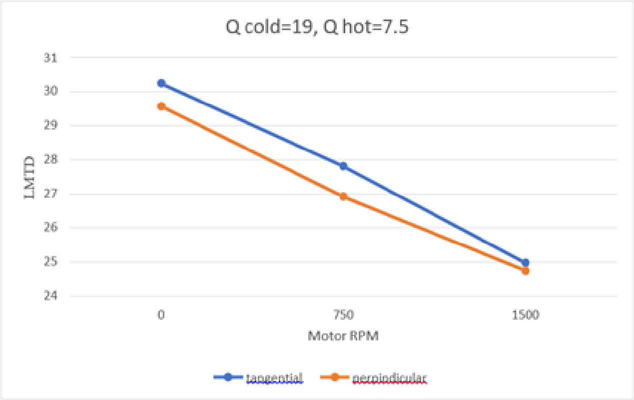

Figure 1-15

The drop in hot fluid temperature

When comparing the temperature drop in the parallel arrangement with tangential cold flow inlet to the parallel arrangement with perpendicular cold flow inlet it was noted thatthe temperature drop in the hot fluid in the second case was also high but not as high as the temperature drop in the tangential inlet. Which shows the effect of increasing the swirlon the heat transfer. Also, the LMTD in the case of tangential inlet is also larger than when using the perpendicular inlet.

The LMTD

The LMTD was the highest when using the counter flow arrangement with tangential inlet. Also, when comparing parallel flow with tangential inlet to parallel flow with perpendicular inlet the LMTD of the parallel one was always higher due to the effect of the extra swirling resulted from the angular inlet.

6. CONCLUSION

The main goal of this project was to perform experimental work to test the effect of rotating the inner tube of the concentric heat exchanger with multiple flows and different inlet angles and flow arrangements and provide reliable data to such settings.

After carrying the later experiments with multiple flows, multiple inlet angles and multiple flow arrangements the following notes were deducted:

- the counter flow has better LMTD than the parallel arrangement at different flows and rotational speeds.
- The temperature drop of the hot fluid was the highest at low flow rates (for both the cold and the hot fluids) and high rotational speeds using parallel arrangement and tangential inlet flow.
- The LMTD was higher when using tangential inlet flow rather than perpendicular inlet flow at different flows and different rotational speeds due to the extra swirling.
- The best temperature drop was found when the Q cold =19, Q hot= 7.5, pipe rotational speed =545 rpm giving ΔT hot = 9.7 C and LMTD = 25C using parallel arrangement and tangential inlet of the cold fluid.
- The best LMTD (efficiency) of the heat exchanger was LMTD=33.2 when Q cold =19, Q hot= 7.5, pipe rotational speed =273 rpm using counter arrangement and tangential inlet of the cold fluid.

The future work that can be held on this project will be to carry out more experiments in order to further validate the previous results.

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