International Journal of Research Publication and Reviews, Vol 5, no 5, pp 3271-3279 May 2024

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Increase in Performance Efficiency of a Heat Exchanger Through Construction Modification

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DOI: https://doi.org/10.55248/gengpi.5.0524.1221

ABSTRACT

The aim of the research is to increase performance efficiency of a heat exchanger through construction modification. This was done by adding fins to the regular or existing heat exchanger and performance efficiency analysis carried out on the regular and modified heat exchanger to see which performed better. The results shows that the overall heat transfer for a modified heat exchanger is way more than the regular heat exchanger about 1200kw to 950kw for same input data. Conclusively, the rate of heat transfer varies with variation of the air inlet temperature for different water mass flow rates. Measurements and calculations reveal that the heat transfer rate increases as temperature and mass flow rate also increase. The result also confirms that the rate of heat flow increases with an increase in inlet temperature. Also, higher inlet temperature rate results in a greater heat transfer rate the fact that the greater flow rate causes a higher convective heat transfer coefficient of the waterside, the greater flow rate results in a higher heat transfer rate.

Conversely, for a corresponding LMTD, it is observed that the LMTD of the air-added heat exchanger component is higher than that of the normal heat exchanger. One can easily say the higher the inlet temperature the higher the LMTD. The LMTD of the air-added heat exchanger ranges from 48.19 to 175oC while the normal heat exchanger LMTD ranges from 18.9 to 32oC.

Keywords: Heat Exchanger; Heat Transfer; Fins; Effectiveness; Log Mean Temperature Difference; Mass of Air.

INTRODUCTION

In Many engineering practical applications and operations, the heat exchanger has played an important role in removing heat in a system. According to Wikipedia, A heat exchanger is a system or an equipment which is used to transfer energy from hot fluid to a cold fluid; it can also be defined as a system used to transfer heat between the producing source and a working fluid between two fluids which may be separated by a solid wall to prevent it from mixing together or it can possibly be in direct contact with the fluid. The heat exchanger is used in many operations such as in power plants, air conditioning, space heating, sewage treatment plant, chemical plant, refrigeration's. The common examples of a heat exchanger are the intercoolers which cools the system before the main cooling, boilers, condensers, automobile radiators. In designing a heat exchanger many criteria are to be considered before coming up with a final decision in making one. Heat exchanger effectiveness depends on the area being used which makes the parameters that are to be used very crucial. The software needed to configure the parameters for its effective design and to make sure the desired output is achieved is also considered. The heat exchangers are basically of two types which are the recuperative type, in which the flowing fluid or energy are exchanged on either side of the wall whereas the other type which is the regenerative type is one in which the hot and cold fluid pass alternatively through in the same space [1], although there are further classifications which contributes to the nature of heat exchanger which can be direct contact or indirect contact, the other type is Direction of flow (parallel flow, counter flow, cross flow), Design and construction.

This research focuses on enhancing the performance of heat exchanger that is lost through some factors such as fouling, type of plates being used. The advantages of improving the heat exchanger include: i). Increasing the energy efficiency of the heat exchanger. ii). Decreasing thermal and corrosion drastically.

Figure 1 is a typical Shell and Tube Heat Exchanger

There are many and different types of heat exchangers that is invoke in the society today. It is important to select and design the most suitable heat exchanger to be implied to the system with a better effective performance. There are many ways in which the effective improvement of a heat exchanger can be improved.

[2] work on an investigation into the possibility of reducing the size of a shell-and-tube heat exchanger by the implementation of swirl. Swirl which is being generated by using a twisted- tape which when inserted inside tube, the effects of these tapes on the heat transfer rate and pressure drop were theoretically studied. The results showed that a half-length regular spaced twisted-tape insert gave the lowest Nusselt number while a full-length twisted-tape insert gave the maximum Nusselt number and hence the highest rate of heat transfer. The length of the heat exchanger could be reduced by 13.3% with a full-length twisted tape and this would be result in 6.8% of reduction of the fabrication cost. Therefore, addition of swirl into the fluid flow should help to design compact and low-cost heat exchanges with improved performance but the pressure drop increased leading to an increase of the required pumping power. According to [3] they made an investigation by the potential use of ultrasounds for improving the performances of heat exchangers. In a heat exchanger, they stated that the effect of ultrasonic vibrations is important both for heat transfer intensification and for the possibility of obtaining fouling reduction. After a general analysis of their investigation, the results recently obtained was that there was a heat transfer coefficient enhancement and fouling reduction. The positive effect of ultrasonic vibrations on heat transfer enhancement was reported by several authors has been recently reviewed also [4] stated methods in which heat transfer of a heat can be increased which he mentioned that of passive and the active methods or either a combination of both in his work. The Passive methods increase heat transfer in heat exchangers that do not require an external energy supply for which the method is to change the thermal properties of the cooling fluid by adding solid particles with a much higher thermal conductivity than the thermal conductivity of the liquid While active methods was to increase heat transfer in heat exchangers whose systems require external energy by which ultrasonic frequency is used in vibrating the fluid in the heat exchanger. In his work he used both methods to improve the heat exchanger where he modified the cooling fluid by adding nanometer sized particles and the ultrasonic frequency at same time to get a maximum increase in heat transfer.

Many authors also worked in a different dimension to see how the heat exchanger can be improved in the likes of [5] investigated on heat transfer coefficient and pressure drop obtained from their experiments which centered when on different copper tubes (microfins, smooth and corrugated). Also, the experimental obtained data which was carried out validated with analytical data. Higher Nusselt number and pressure drop was observed with respect to analytical method based on Bell's method [6]. In their studies it involved various problem-solving parameters which according to nature of problem that includes heat transfer area, restrictions, selection of different equations for solving pressure drop and velocity bound, which after his work was considered to have reduced thermal stresses developed by the heat exchanger.

[7] in his study it the author focused on the design variable parameter of shell and tube heat exchanger and to solve these algorithms he applied the optimization problem which was observed from the experiment that the effectiveness of heat transfer increased drastically.

METHODOLOGY

Working principle of Shell and tube Heat Exchanger

The essential parts of a shell-and-tube heat exchanger are shown in Figure 2, which depicts a heat exchanger with one shell-side pass and two tube-side passes. From the tube fluid inlet (1) into the front-end head (11), the tube-side fluid enters the heat exchanger before going into the tubes (4). The tube fluid departs the first pass' tubes into the rear-end head (6), travels back into the second tube-side pass, and then ultimately exits the heat exchanger from the tube fluid outlet (9). The shell-side fluid enters the heat exchanger via the shell inlet (2), flows on the shell side under the control of baffle plates (8) in a cross-parallel flow pattern for the first pass and a cross-counter flow pattern for the tube pass, and ultimately departs from the shell outlet (7). The tube sheets (5) keep the tube bundle in place, and the baffle plates support it inside the shell.

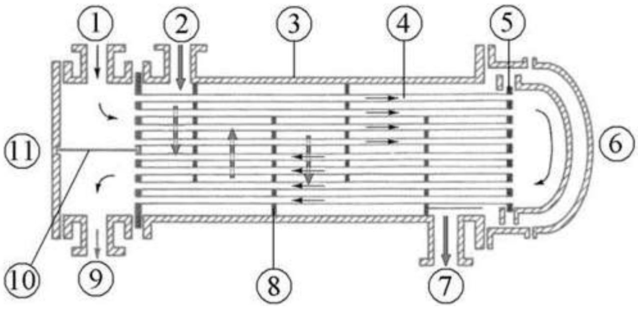

Figure 2: Shell-and-tube heat exchanger

The Combined Method to Improve Cooling Effect of Heat Exchanger using fins

The heat transfer process occurs all the time around us, from simple household appliances to equipment used in large industries. Energy efficiency in large-scale use in industry is necessary because it is related to company profits. One way to save energy use in heat exchangers is to change the thermal properties of the cooling fluid. The heat transfer process certainly involves an essential tool, including a heat exchanger, which is expected to have high performance with smaller dimensions. For large power, the increase in the performance of the heat exchanger will impact financial reductions in a company. Of course, efforts are needed to increase the heat transfer coefficient of a heat exchanger with various methods.

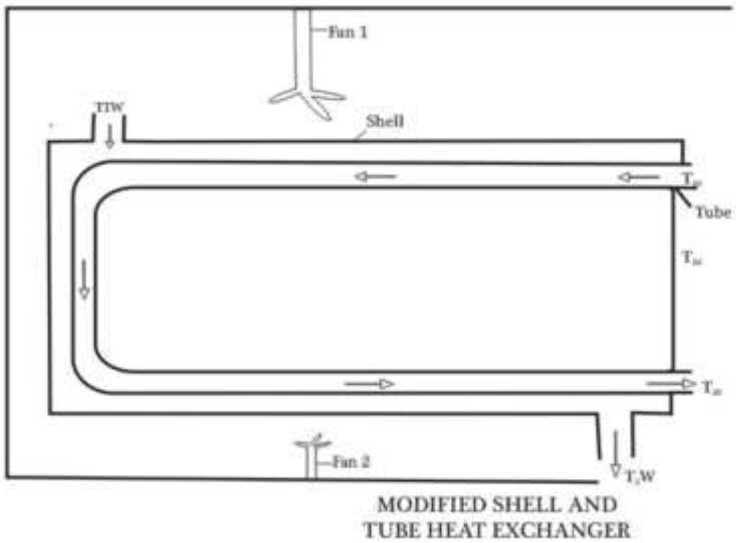

Figure 3: A Modified Heat Exchanger using Fins

As shown in Figure 3, one of the fluids flows inside the tubes while other fluid is forced through the shell and over the outside surfaces of the tubes. Baffles are placed inside the shell to ensure a good circulation of the fluid within the shell across the tubes and hence they help to induce a high rate of heat transfer. Moreover, the baffles in various shapes/arrangements/spacing are used in practical applications. One or more tube passes may be utilized depending on the head arrangement at the ends of the exchanger. Furthermore, the heat transfer performance of the heat exchangers may reduce as they become older particularly due to fouling and scaling.

Figure 3 is a representation of a modified double heat exchanger whose aim is to increase the cooling effect and performance of the heat exchanger. In fact, the performance of heat exchangers can be improved passively by incorporating a fin into the system. Placing a fin is an excellent way of improving the cooling effect or rate of fluid flow. The introduction of a fins device to a heat exchanger changes the flow pattern from parallel to cross flow. Hence, the flow is spread across the entire system. In a continuous fins flow, the fluid motion exists over the entire length of the tube and the pressure drop and heat transfer coefficient remain constant with the axial distance. To improve the rate of cooling and heat transfer, it is required to increase the convective heat transfer coefficient which comes under forced convection. This can be achieved by incorporating a fan device, increasing the convection coefficient or/and by increasing the convection surface area, and schematic diagrams showing some of the possible methods of improving the cooling rate and heat transfer.

$$Q = m_c \times C_{ph} \times (T_{hi} - T_{ho}) = m_c \times c_{pc} \times (T_{co} - T_{hi}) \quad (1)$$

Where Q is the rate of heat transfer, A is the total hot or cold side heat transfer area, m is the mass flow rate and Th- Tc is the temperature difference between the hot and cold fluids. The overall heat transfer is obtained from the relation

Modified heat exchanger equation

Since the fins were added to the normal Heat Exchanger in the modified Heat Exchanger as shown in the in the figure 3, Heat Transfer due to the fin's additions.

$$Q_a = M_a CP_a (T_{a2} - T_{a1}) \quad (2)$$

Total heat transfer for the modified Heat Exchanger (Q_m)

$$Q_m = Q_a + Q_n \quad (3)$$

Where,

Q_a is the Heat Transfer due to air from fins

Q_n is the normal heat exchanger heat transfer without fins

Since other factor remain constant on the heat exchanger

$$LMTD_M = \frac{Q_m}{U \times A} \quad (4)$$

Where U is the overall heat transfer coefficient of the heat exchanger.

A is the Area of the exchanger

Modified Heat Exchanger Effectiveness Em

$$E_m = \frac{Q_m}{M_a CP_a (T_{a2} - T_{a1})} \quad (5)$$

Where, Ma is the air mass flow rate of the fin, CPa is specific heath coefficient of air, T2a is exit temperature of air Ta1 is inlet temperature of air.

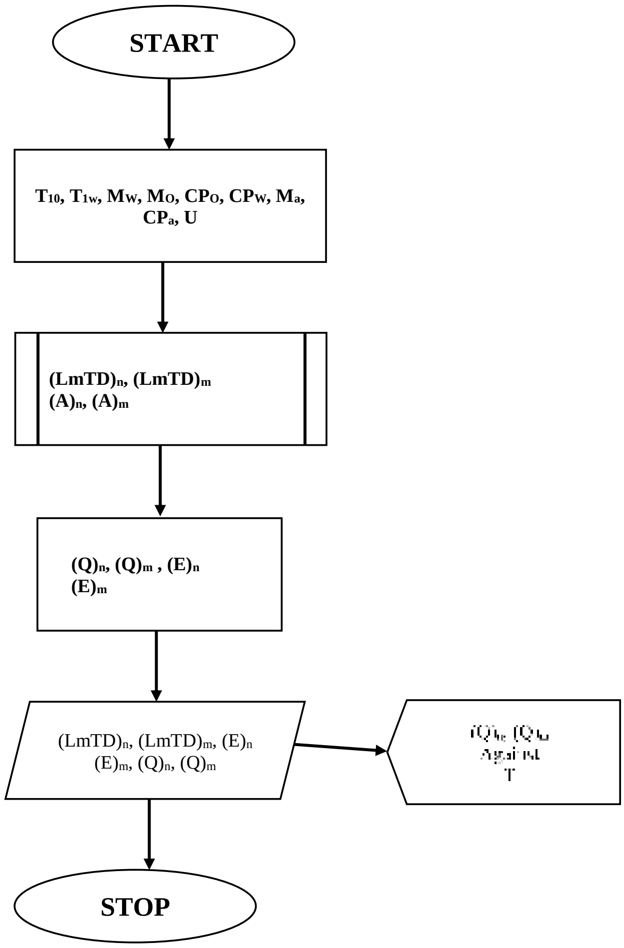

Figure 4: A modified Heat Exchanger Flow Chart

The program starts by manually entering the basic parameter a heat exchanger as shown in the table above. The basic parameter is used to predetermine the LMTD for both the normal heat exchanger and modified heat exchanger. The computed LMTD and Areas (A) for the normal and modified heat exchanger are used to compute the overall heat transfer, for normal heat exchanger (Q)n and modified heat exchanger (Q)m, the predetermined LMTD, and Areas are also used to compute the heat exchanger effectiveness for normal heat exchanger (E)n and modified heat exchanger (E)m. The program proceeds to output section and display a graph of normal heat exchanger (Q)n and modified heat exchanger (Q)m against Time (T), before the program (MATLAB) come to stop.

Table 1: MATLAB Heat Exchanger Input Parameter

Input parameter	**Parameter values**
CP_w	$4.197\ \frac{KJ}{kg\ k}$
CP_o	$2.47\ \frac{KJ}{kg\ k}$
CP_a	$1.004\ \frac{KJ}{kg\ k}$
M_w	$105.1389\ \frac{kg}{s}$
M_a	$228.98\ \frac{kg}{s}$
M_o	$12\ \frac{kg}{s}$
T_{w1}	20^0c
T_{w2}	30^0c
T_{o1}	46^0c
T_{a1}	27^0c
T_{a2}	31^0c
U	$500\ \frac{w}{m^2\ {}^0c}$
A	$0.2685m^2$

RESULTS AND DISCUSSION

LMTD with Respect to Heat Exchanger Performance

From the heat exchanger data shown in table 1, it is established that the LMTD increased as the inlet temperature increased. The LMTD depends on the flow rate of cold-water mass. The inlet hot water temperature has a significant effect on the heat exchanger LMTD at an accepted Rate of flow of cold-water mass.

Figure 5, for corresponding LMTD it is observed that the LMTD of the air-added heat exchanger component is higher than that of the normal heat exchanger. One can easily say the higher the inlet temperature the higher the LMTD. The LMTD of the air-added heat exchanger ranges from 48.19 to 175oC while the normal heat exchanger LMTD ranges from 18.9 to 32oC. Figure 6 shows the rate at which mass flow affects the LMTD of the heat exchanger as observed the modified heat shows more increase in LMTD value as the mass flow rate increases.

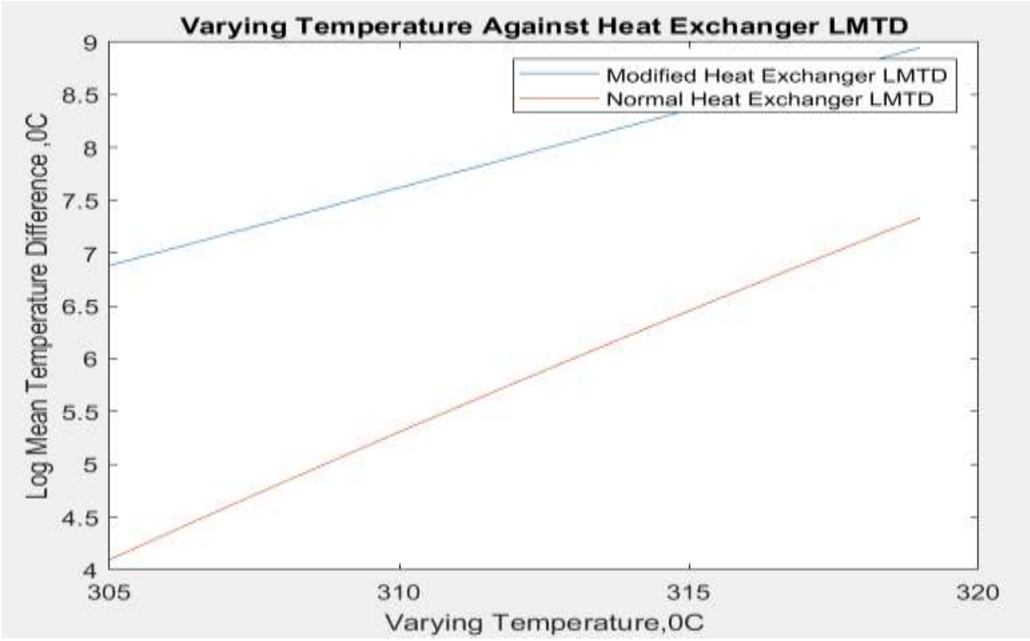

Figure 5: LMTD against Varying Temperature

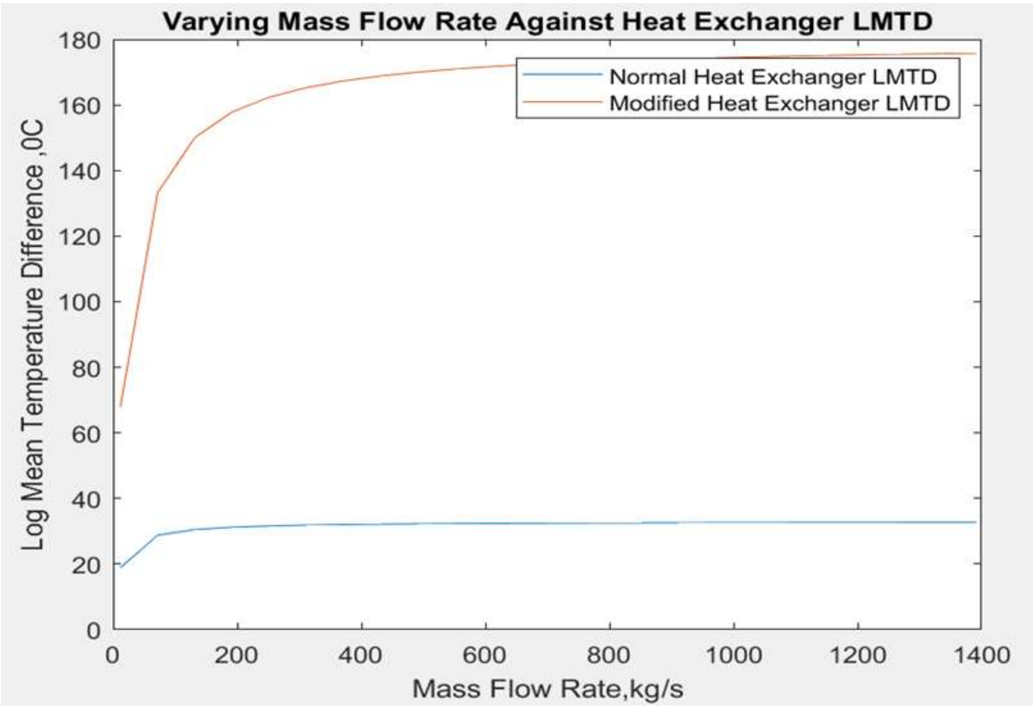

Figure 6: LMTD against Mass Flow Rate

Effectiveness with Respect to Inlet Temperature and Mass Flow Rate

The effectiveness of the heat exchanger transfer units for different volume concentrations of the fluids in the shell and tube are analyzed and shown in figure 7 and 8. The heat exchanger shows a constant value for the air-added component due to a constant rate of cooling as observed from the external cooling of the heat exchanger. The effectiveness of the modified heat exchanger is 1.048 while the normal heat exchanger ranges from 0.0624 to 0.0859.

Water is used as a cooling agent because of its higher specific heat capacity, density, and thermal conductivity. In this project, the effectiveness of the normal heat exchanger increases steadily as temperature and mass flow rate increase while the modified heat exchanger is constant. The effectiveness of the modified heat exchanger is observed to be higher than that normal heat exchanger.

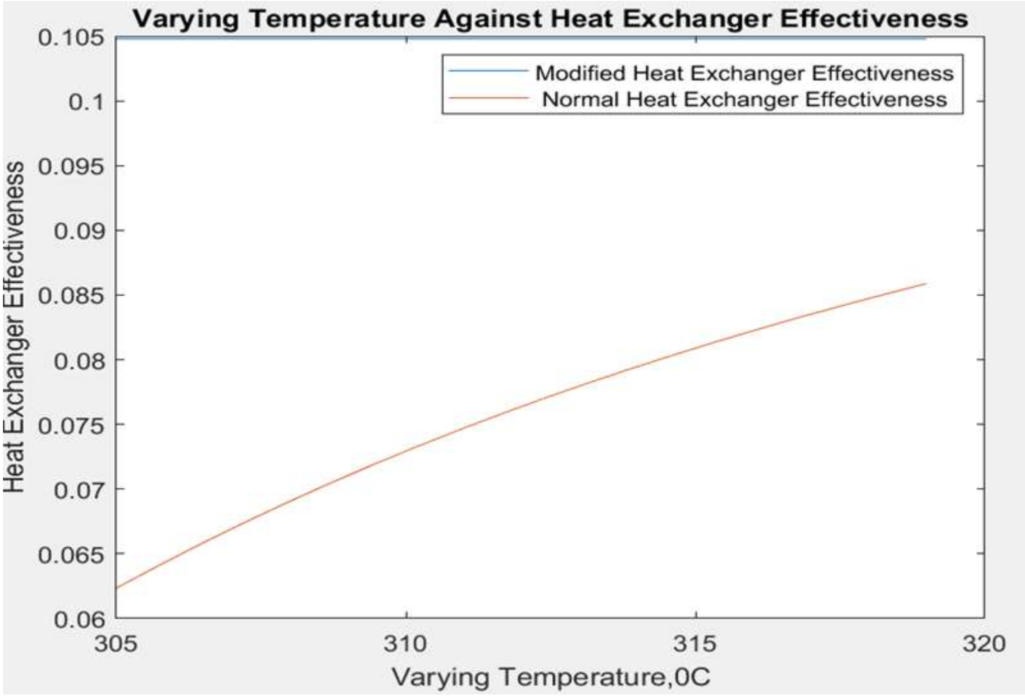

Figure 7: Effectiveness against Temperature

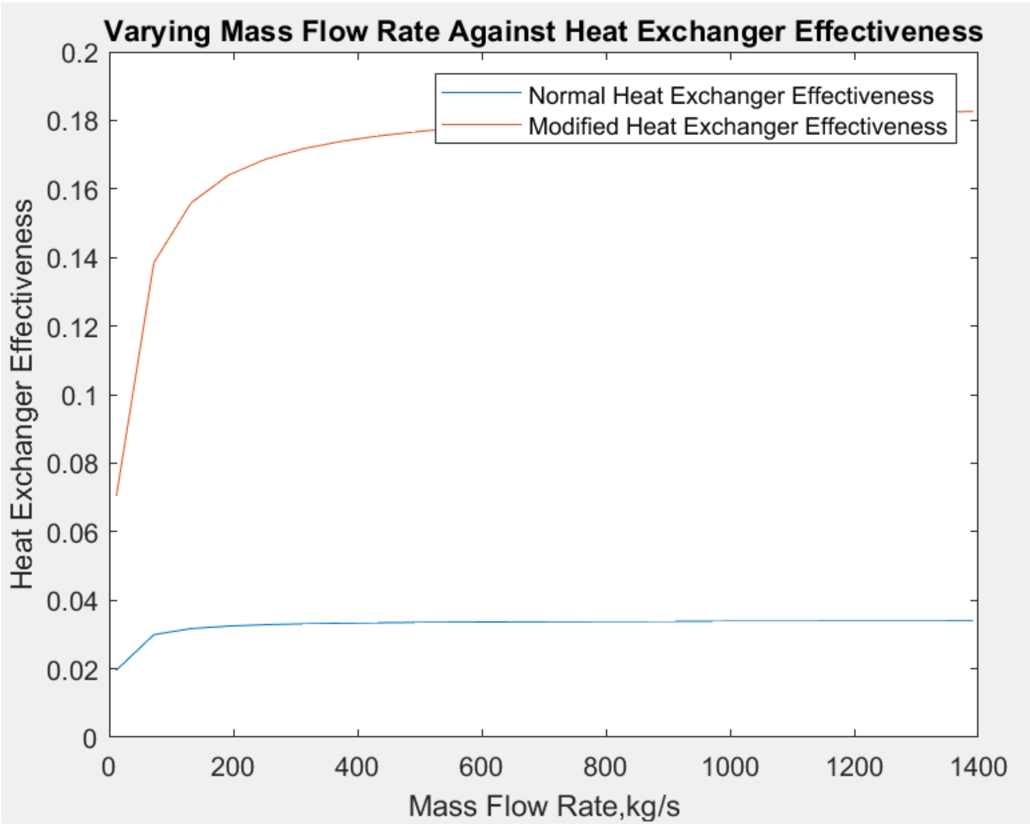

Figure 8: Effectiveness against Mass Flow Rate

Rate of Heat Transfer of the Heat Exchanger

The variation of the heat transfer rate with air inlet temperature for different water mass flow rates. Measurements and calculations reveal that the heat transfer rate increases as temperature and mass flow rate also increase as shown in figures 9 and 10. The rate of heat flow increases with an increase in inlet temperature. Also, higher inlet temperature rate results in a greater heat transfer rate the fact that the greater flow rate causes a higher convective heat transfer coefficient of the waterside, the greater flow rate results in a higher heat transfer rate.

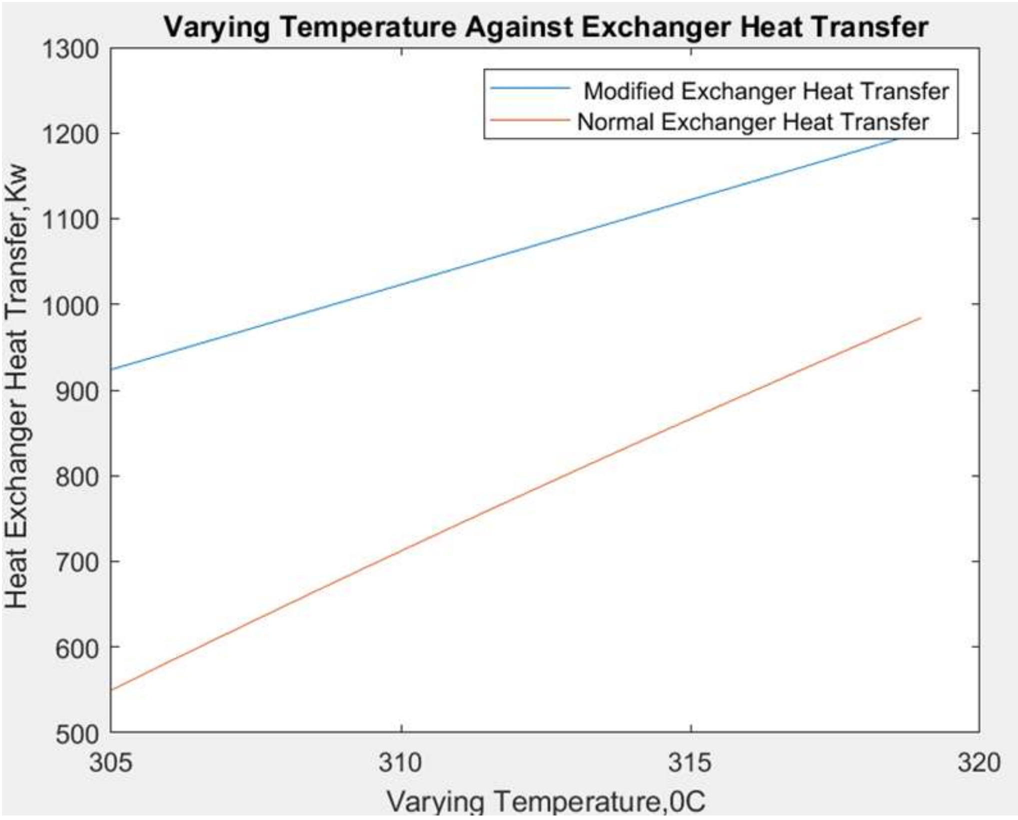

Figure 9: Plot of Heat Transfer against Varying Temperature

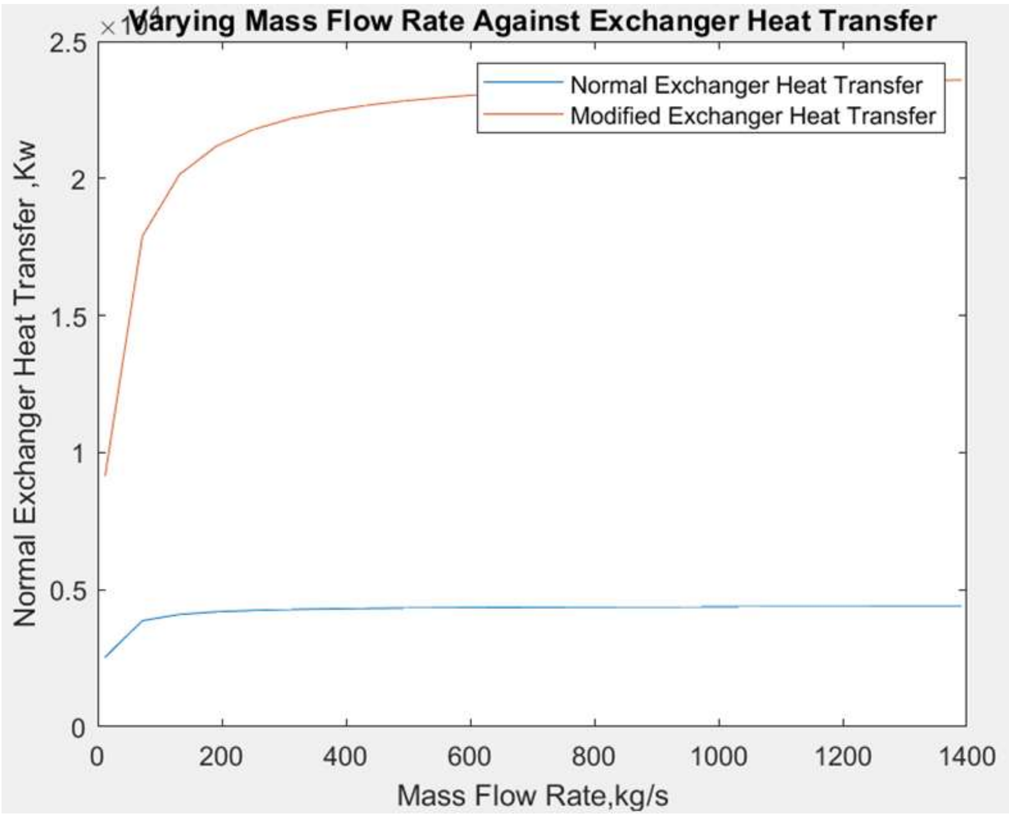

Figure 10: Plot of Heat Transfer against Mass Flow Rate

CONCLUSIONS

This study was mainly centre on increasing the cooling rate of a heat exchanger in order to improve its performance. The combined method was considered by introducing fins device to increase the rate of heat transfer from hot fluid. A case study was shown for determining the rate of heat transfer, the variation of the heat transfer rate with air inlet temperature for different water mass flow rates. Measurements and calculations reveal that the heat transfer rate increases as temperature and mass flow rate also increase. The result also confirms that the rate of heat flow increases with an increase in inlet temperature. Also, higher inlet temperature rate results in a greater heat transfer rate the fact that the greater flow rate causes a higher convective heat transfer coefficient of the waterside, the greater flow rate results in a higher heat transfer rate.

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