Heat Transfer Analysis of a Finned Inner Tube Double Pipe Heat Exchanger

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***Abstract*: A heat exchanger is a device which is used to transfer heat from one medium to another medium. It is used mainly in process industries and power plants. In this study, a double pipe heat exchanger is modelled using SolidWorks software. The overall heat transfer coefficient and effectiveness of the heat exchanger is numerically studied and calculated for a simple double pipe heat exchanger. The properties of water and palm oil are used as the fluid medium for the heat transfer analysis. The results and findings are discussed and compared with the normal tube double pipe heat exchanger. The outlet temperature of the hot fluid in the finless heat exchanger is 329 oC; whereas in the finned heat exchanger it is 326 oC. Also, the outlet temperature of the cold fluid in the finless heat exchanger is 321 oC; whereas in the finned heat exchanger it is 322 oC. It is found that the heat exchanger with fins is more efficient compared with the finless type.**

***Index Terms*: Double pipe heat exchanger, thermal analysis, effectiveness, heat transfer rate**

I. INTRODUCTION

A heat exchanger is a device built for efficient heat transfer from one fluid to another. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants and natural gas processing. To design a heat exchanger, many criteria have to be considered. In this paper, the results from a simulation are compared for both a finned inner tube and a normal tube model, in order to see the enhancements in terms of heat transfer profiles and outlet temperatures for both fluids. In this paper, an attempt has been made to design two types of double pipe heat exchanger. One heat exchanger is designed with normal inner tubes and the other with additional circular fins attached to the inner tubes to enhance the heat transfer of the heat exchanger.

A vast literature review has been conducted on the heat exchangers' design and analysis. Sharqawy and Zubair (2010) conducted a study on heat exchangers' design under a variable overall heat transfer coefficient, using improved analytical and numerical approaches [1]. They analysed the heat transfer enhancements between mediums by adding fins to the heat exchanger. The pressure drop is determined in order to find the pumping power required to drive the fluids. The transfer of heat is done with a separation of a wall to avoid the mixing of the two fluids having different properties [2]. Roetzel and Luo (2011) analysed the mean overall heat transfer coefficient in heat exchangers allowing for temperature-dependent fluid properties [3]. Previously, Shah and Sekulic had discussed the non-uniform overall heat transfer coefficients in conventional heat exchanger design theory [4]. In 2012 Kakac et al. discussed heat exchangers' selection, rating, and thermal design [5]. Vera and Lin˜a´n (2010) proposed a laminar counter-flow parallel-plate heat exchanger with exact and approximate solutions [6]. Then in 2011, Vera and Lin˜a´n proposed an exact solution for the conjugate fluid–fluid problem in the thermal entrance region of laminar counter-flow heat exchangers [7].

II. HEAT EXCHANGER ANALYSIS

Two types of analysis for parallel flow heat exchangers to determine temperature drops are the log mean temperature difference and the effectiveness-NTU method. The equation for heat transfer using the log mean temperature difference is:

$$\dot{q} = UA\Delta T_{LM} = UA \times \frac{\Delta T_2 - \Delta T_1}{LN\left(\Delta T_2/\Delta T_1\right)} \qquad (1)$$

In order to determine the amount of heat to be transferred in a heat exchanger or the intensity at which the heat from the fluid flow will be transferred, the log mean temperature difference is calculated. It is expressed in terms of ΔT_1 and ΔT_2 which are defined depending on whether flow is concurrent or counter current. An approximate value for the overall heat transfer coefficient, U $(W/m^2KK)$is 110-350 for water to oil, which has been considered. The fouling factor in this paper is 0.0009 for fuel oil; while 0.0001-0.0002 is used for seawater and treated boiler feed water. The type of flow is determined by the Reynolds number. Thus, for a laminar flow heat transfer correlation, the resulting average Nusselt number, Nu for a certain tube length is:

$$Nu_{average} = 3.66 + \frac{0.065(Re)(\Pr)(\frac{D}{L})}{1 + 0.04((Re)(\Pr)(\frac{D}{L}))^{2/3}} \qquad (2)$$

The template is used to If the flow is turbulent, then the Nusselt number, Nu is determined by

$$Nu = 0.023\, Re^{0.8} Pr^{0.4} \qquad (3)$$

Then the convective heat transfer coefficient, h and the pressure drop, ΔP is determined by

$$h = Nu * \frac{k}{d} \qquad (4)$$

$$\Delta P = 2f(\frac{L}{D})(\rho V^2) \qquad (5)$$

The effectiveness, of the heat exchanger is determined by using the following relation. In the case of parallel flow:

$$\epsilon = \frac{1-\exp[-NTU(1+C)]}{1+C} \qquad (6)$$

In the case of turbulent flow, the effectiveness of the heat exchanger is given by:

$$\epsilon = \frac{1-\exp[-NTU(1-C)]}{1-C\exp[-NTU(1-C)]} \qquad (7)$$

The schematic of the physical domain is shown in Fig. 1.

III. Thermal Analysis

In the thermal analysis, palm oil is considered as the hot fluid and water is considered as the cold fluid. Table 1 gives the properties of hot and cold fluids which are used in the thermal analysis of a double pipe heat exchanger. The average velocity of the water and the Reynolds number are found to be 2.06 m/s and 34,219 respectively. Since the Reynolds number is greater than 10,000, the flow is treated as turbulent. Assuming that the flow is fully developed, the Nusselt number is calculated as 168.27 and the outer convective heat transfer coefficient, ho is found to be 10,718.8 W/m^{2}K. Then the velocity and the Reynolds number for the hot fluid side is determined as 1.85 m/s and 3,187 respectively. Since the Reynolds number is less than 4000, the flow is said to be laminar. Assuming a developed flow, the Nusselt number for the laminar flow is found as 67.6 and the inner convective heat transfer coefficient, h_i is determined as 566.15 W/m^{2}K. Hence, the overall heat transfer coefficient, U is calculated as 537.75 W/m^{2}K. The number of the transfer unit, NTU is found to be 4.02 and the effectiveness of the heat exchanger is found to be 0.96. The actual heat transfer rate is determined as 33.9 kW. Therefore, the outlet temperatures for both fluids are 55.14 °C and 46.4 °C, respectively. Also, it is found that the pressure drop along the inner tube is 177.3 Pa with a friction factor of 5.02x10^{-3}. The pressure drop along the turbulent annular tube side containing water as the fluid, using the roughness condition of common PVC pipes which is 0.0015×10^{-3} m is 772.9 Pa with a friction factor of 0.03066. In this work, the thermal analysis is done for both the normal inner tube double pipe heat exchanger and the finned inner tube double pipe heat exchanger.

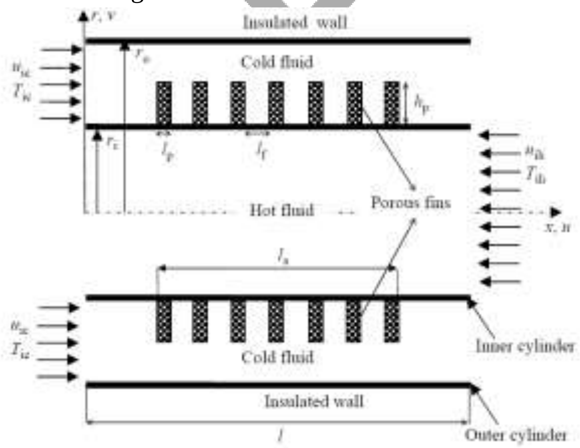

Fig.1. Schematic of the physical domain

Table 1. Properties of hot and cold fluids

Hot palm oil	Cold water
Copper inner tubes (diameter = 2 cm)	Shell tube (diameter = 3 cm)
Flow rate = 0.5 kg/s	Flow rate = 0.8 kg/s
Temperature Inlet = 80 °C	Temperature inlet = 45 °C
Density = 860 kg/m^3	Density = 990.1kg/m^3
k = 0.1675 W/m.K	k = 0.637 W/m.K
P_r = 120.3	P_r = 3.91
$v = 1.161{\times}10^{-5} m^2/s$	$v = 0.602{\times}10^{-6} m^2/s$
$C_p = 2.018 kJ/kg.K$	C_p=4.181$kJ/kg.k$

In this paper, a fully developed laminar and turbulent incompressible fluid flow is simulated and analysed for the counter flow double pipe heat exchanger. The resulting temperature difference is compared with the finned inner tube with the same fluid properties and inlet temperatures. The material for the pipe wall is selected as copper for the inner tube and PVC for the outer tube for minimum heat loss to the surroundings.

IV. Results and Discussion

The solution is obtained after 650 iterations have been done for both types of heat exchanger designs. The temperature contours for the temperatures for the finless and the finned inner tube are shown in Fig.2 and Fig.3, respectively.

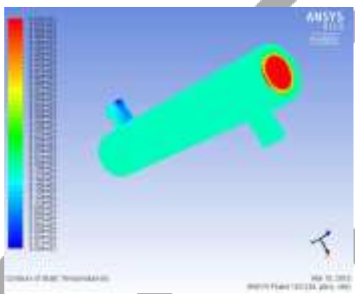

Fig.2. Finless inner tube temperature profile

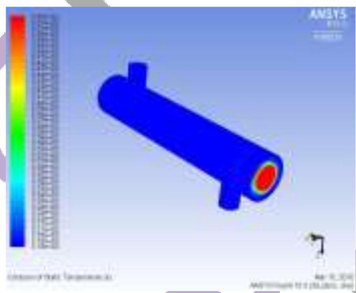

Fig.3. Finned inner tube temperature profile

The difference in the temperature profiles for the heat exchangers can be seen. The finless inner tube provides an overall higher temperature along the outer fluid compared to the finned type. The darker blue colour for the outer fluid in the finned inner tube heat exchanger shows that the temperature is lower. The graph for the inlet and outlet temperatures for the inner fluid and outer fluid as well as temperature along the tube can be shown in Fig.4 and Fig.5, respectively.

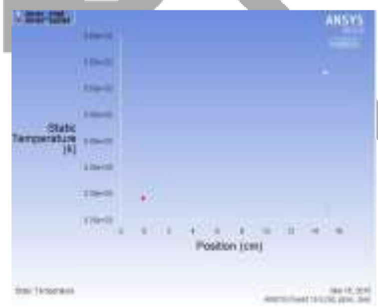

Fig.4. Finless tube inner fluid inlet/outlet temperatures

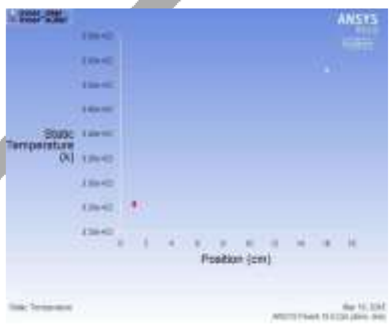

Fig.5. Finned tube inner fluid inlet/outlet temperatures

From Fig.4 and Fig.5, the inlet and outlet temperatures for the inner fluid, which is the hot palm oil, it can be noticed that the outlet temperature for the finned inner tube had a slight decrease compared to the finless inner tube. The initial temperature at the inlet is the same and is 80 °C, since this is the initial parameter of the simulation. The outlet temperature that had been calculated for the finless inner tube was 46.4 °C or 319.4 K. The simulated finless tube outlet temperature for the inner fluid is around 329 K, corresponding to a difference of 9.6 K, which is an acceptable range. The simulated result for the finned side is about 326 K which is closer to the numerical analysis. This temperature is also lower than the finless simulated outlet temperature which is the desired objective of this simulation. The simulation shows that the finned inner tube had a significant increase in performing the amount of heat transferred because of the fin geometry that provides more heat transfer surface area. This in turn gives the inner fluid a better heat transfer rate and thus makes the simulation results match close to the theoretical calculations. The inlet and outlet temperature profiles for the outer fluid, which is water, are shown in Fig.6 and Fig.7. From these two figures, it is found that the outer fluid (water) inlet and outlet temperature is higher when fins are mounted in the heat exchanger, compared to the finless inner tube exchanger. The initial temperature for both designs is 45 °C. The outlet temperature that had been calculated for the outer fluid is 55.14 °C or 328.14 K. The finless inner tube simulated results for the outlet temperature of the outer fluid is 321 K, which corresponds to 7.14 K difference, an acceptable range. However, the simulated results for the finned tube were about 322 K, which is relatively close to the numerical calculation compared to the finless inner tube. This shows that the addition of fins has a positive impact towards the heat transfer rate of both hot and cold fluids.

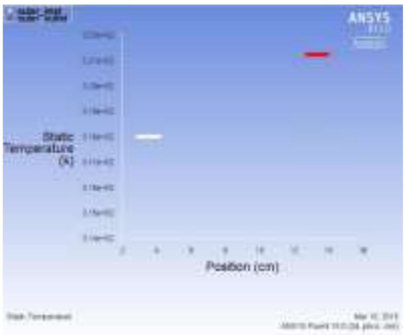

Fig.6. Finless tube outer fluid inlet/outlet

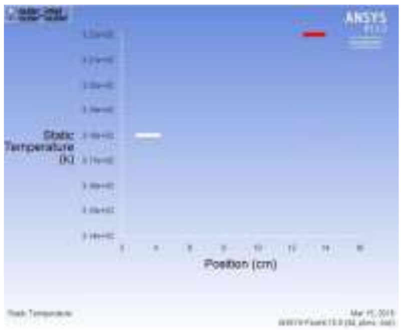

Fig.7. Finned tube outer fluid temperature inlet/outlet temperature

V. CONCLUSION

After The performance and the CFD analysis of the double pipe heat exchanger for the finned and finless inner tube are investigated. The behaviour of the fluid flow in the double pipe heat exchangers for finless and finned inner tube designs has been analysed. In order to do the analysis, the Ansys Fluent finite volume analysis program is used. The model is designed using the 3D modelling software, SolidWorks. The temperature profiles for the outlets for both inner and outer fluids are obtained from the simulations for both finless and finned inner tubes. It is found that in the finless double pipe heat exchanger, the outlet temperature for the inner fluid is 329 K; whereas in the finned type, the outlet temperature is 326 K. The finned results are shown to have a closer value to the numerical value of temperature, 319.4 K.

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