Journal of Vocational Studies on Applied Research

Feasibility Study and Heat Transfer Analysis of Testbed Shell and Tube Heat Exchanger at Tube Side Fluid Discharge of 5 Lpm and Hot Fluid Temperature of 60 ^{o}C

Devian Arif Firmansyah*[1], Sri Utami Handayani[1]

[1] *Mechanical Design Engineering, Vocational School, Diponegoro University, Semarang, Indonesia*

*) Corresponding author: dephlovers123@gmail.com

Abstract - *A fluid's phase or temperature can be changed by a heat exchanger. To improve students' understanding of heat exchangers, the existence of a heat exchanger is essential. In the Energy Conversion Laboratory, a test bed for a shell and tube type heat exchanger with a 1pass shell - 2pass tubes was created to conduct this study. The performance of the heat exchanger was then evaluated, along with its efficiency and heat transfer coefficient. Heat transfer calculations and the effectiveness of shell and tube heat exchangers were used in this study's experimental methodology, which involved designing and building a test bed heat exchanger. The heat exchanger has 1.5 m of tube length, 19.05 mm of tube diameter, 25.4 mm of tube pitch, and a 10-inch shell diameter. Iron serves as the shell material, while 304 stainless steel serves as the tube material. The heat exchanger performance has a heat transfer coefficient of 133,868 W/m^{2o}C and a heat exchanger actual effectiveness of 58.84%. The theoretical heat transfer coefficient ($U_{theoretical}$) and actual heat transfer coefficient (U_{actual}) values in open systems both rise as the discharge of cold water increases, and the theoretical heat transfer coefficient ($U_{theoretical}$) value is always greater than the actual heat transfer coefficient value (U_{actual}). The heat exchanger needs to be in a very constant state when collecting data since the rise in fluid temperature at T2, T3, and T4 will have an impact on the actual effectiveness calculations. Meanwhile, theoretical effectiveness states that the value of effectiveness will rise with increasing cold fluid discharge.*

Keywords: *heat, heat exchanger, shell, tube, test bed*

Received: July 04, 2023 Revised: September 14, 2023 Accepted: March 24, 2024

Doi: http://dx.doi.org/10.14710/jvsar.v5i2.19173

[How to cite this article: Firmansyah, D.A., and Handayani, S.U. (2023). Feasibility Study and Heat Transfer Analysis of Testbed Shell and Tube Heat Exchanger at Tube Side Fluid Discharge of 5 Lpm and Hot Fluid Temperature of 60^{o}C. *Journal of Vocational Studies on Applied Research, 5*(2), 36-43. doi: http://dx.doi.org/10.14710/jvsar.v5i2.19173]

INTRODUCTION

Background of the Study

Heat exchanger functions to change the temperature or change a phase of a fluid. The way the heat exchanger works is by utilizing heat transfer from a fluid with a high temperature to a fluid with a low temperature. There are many applications of heat exchangers in the industrial world, such as boilers, evaporators, economizers, condensers, and so on.

A fluid's phase or temperature can be changed by a heat exchanger. Heat transfer from a fluid with a high temperature to a fluid with a low temperature is how the heat exchanger functions. Boilers, evaporators, economizers, condensers, and other industrial equipment are only a few examples of the many uses for heat exchangers.

In the Energy Conversion Laboratory of the Mechanical Design Engineering Study Program, there are now two test bed heat exchanger units, although only one of them is being used for practicum. One more heat exchanger test bed unit suffered damage in the meantime. It was discovered that the damaged heat exchanger in the test bed was a shell and tube type with a 1pass shell – 1pass tube. It was discovered that there were still water deposits, such as muck, inside the damaged test bed heat exchanger's shell, which led to the tubes' corroding. This is due to the fact that after finishing the practicum, the water in the shell is not drained. The prior heat exchanger also had the issue of a tiny water heater capacity, which made it take a long time to heat the water, which made the heat exchanger function less efficiently. In the Energy Conversion Laboratory, a shell and tube test bed heat exchanger of the 1pass shell-2pass tube type will be constructed as part of this study, and its performance, including its efficiency and heat transfer coefficient, will be examined.

Research conducted by Septian et al., (2021) in his research designing a shell and tube with an out shell diameter of 300 mm and an in diameter of 293.65 mm with a length of 1000 mm obtained a heat transfer rate of 7117.5 watts, besides that, based on the TEMA standard as well as the use of HTRI surface area applications of 8.27 m^2 while the actual calculation is 9.09 m^2 (Septian et al., 2021). Other research that has been carried out by Napitupulu et al., (2018) each material has a material conductivity value, in the manufacture of shell and tube materials it will also affect effectiveness. The tube material is made of copper with a conductivity of 385 W/mK while the shell material is aluminum with a conductivity of 205 W/mK, the greatest effectiveness is 35.4040% (Napitupulu et al., 2018). Khairuddin (2018) in his research explained that testing the temperature of the transmitter for 30 seconds obtained different results from the design, where the output tube was 39^{o}C and the output shell was 31^{o}C, while the output tube and shell in the design were 35^{o}C and 38^{o}C (Khairuddin, 2018). Other tests carried out by Handy (2011) resulted in a performance research test that referred to the Bell Delaware method, the results showed that the effectiveness of the heat exchanger was quite high, exceeding the theoretical effectiveness (Handy, 2011).

Review of the Literature

Determine the value of the thermal resistance (R_{total}) before calculating the overall heat transfer coefficient (U). The following Eq. 1 by Cengel (2004) can be used to get the R_{total} value:

$$R_{total} = \frac{1}{h_t A_i} + \frac{\ln\left(\frac{d_o}{d_i}\right)}{2\pi k L} + \frac{1}{h_s A_o} \quad \ldots\ldots. (1)$$

The overall heat transfer coefficient (U) is equal to Eq. 1 and Eq. 2, which following the report by Cengel (2004):

$$U = \frac{1}{A_i \sum R_{total}} \quad \ldots\ldots. (2)$$

$$U = \frac{1}{A_o \sum R_{total}} \quad \ldots\ldots. (3)$$

The magnitude of the heat transfer of the hot fluid to the cold fluid can be calculated by following the Eq. 4 by Holman (2020):

$$q = U.A\,.F.\Delta T_{lm} \quad \ldots\ldots. (4)$$

The LMTD equation in Eq. 5 is as follows Cengel (2004):

$$LMTD = \frac{\left(T_{h,i} - T_{c,o}\right) - \left(T_{h,o} - T_{c,i}\right)}{\ln\left(\frac{\left(T_{h,i} - T_{c,o}\right)}{\left(T_{h,o} - T_{c,i}\right)}\right)} \quad \ldots\ldots. (5)$$

Discover the P and R values first; later, these values will be utilized to discover the F value on the graph. This will help you determine the correction factor's (F) value. The values of P and R is equal to Eq. 6 and Eq. 7, which following the report by Byrne (1998):

$$P = \frac{T_2 - T_1}{T_3 - T_1} \quad \ldots\ldots. (6)$$

$$R = \frac{T_3 - T_4}{T_2 - T_1} \quad \ldots\ldots. (7)$$

The following Eq. 8 and Eq. 9 by Holman (2020) can be used to look for the rate of capacity:

$$C_h = m_h c_h = \frac{q}{T_{h,i} - T_{h,o}} \quad \ldots\ldots. (8)$$

$$C_c = m_c c_c = \frac{q}{T_{c,o} - T_{c,i}} \quad \ldots\ldots. (9)$$

Among the C_h or C_c values, the lowest value is used to determine the C_{min} value. On the other hand, to determine the C_{max} value, the highest C_h or C_c value is used. The C value is calculated using the values of C_{min} and C_{max}. The following Eq. 10 by Cengel (2004) represents the C value:

$$C = \frac{C_{min}}{C_{max}} \quad \ldots\ldots. (10)$$

The actual effectiveness Eq. 11 and Eq. 12 can be calculated as follows Handayani (2021):

$$\varepsilon = \frac{C_c(T_{c,o} - T_{c,i})}{C_{min}\,(T_{h,i} - T_{c,i})} \qquad \text{……. (11)}$$

$$\varepsilon = \frac{C_h(T_{h,i} - T_{h,o})}{C_{min}\,(T_{h,i} - T_{c,i})} \qquad \text{……. (12)}$$

The following Eq. 13 by Cengel (2004) can be used to calculate theoretical effectiveness:

$$\varepsilon = 2\left\{1 + C + \sqrt{1 + C^2}\,\frac{1 + \exp\left[-NTU\sqrt{1 + C^2}\right]}{1 - \exp\left[-NTU\sqrt{1 + C^2}\right]}\right\}^{-1} \qquad \text{……. (13)}$$

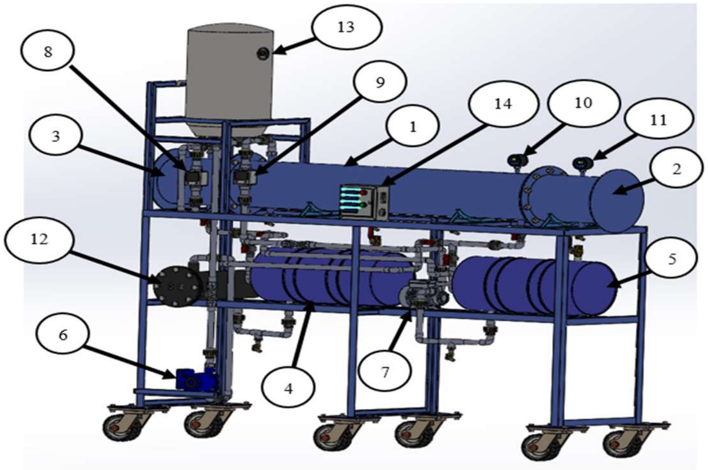
The following Eq. 14 by Cengel (2004) can be used to determine the NTU value:

$$N = NTU = \frac{U\,A}{C_{min}} \qquad \text{……. (14)}$$

METHODOLOGY

Materials

As indicated in Figure 1, the test bed heat exchanger below is composed of various elements:

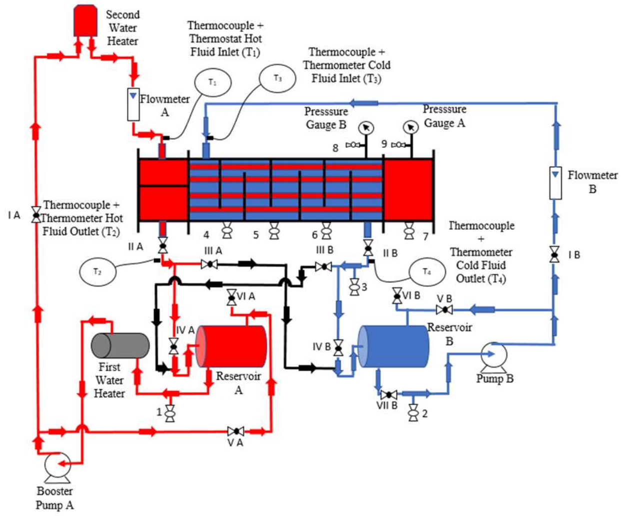


Explanation:
1 = *Shell and Tube*
2 = *Rear Head Shell*
3 = *Front Head Shell*
4 = *Reservoir For Hot Fluid*
5 = *Reservoir For Cold Fluid*
6 = *Booster Pump For Hot Fluid*
7 = *Pump For Cold Fluid*
8 = *Flowmeter For Hot Fluid*
9 = *Flowmeter For Cold Fluid*
10 = *Pressure Gauge Shell*
11 = *Pressure Gauge Tube*
12 = *First Water Heater*
13 = *Second Water heater*
14 = *Control Panel*

Figure 1. Heat exchangers made

Flow Diagram

A shell and tube's flow diagram is shown in Figure 2. A manufactured 1pass shell - 2pass tube heat exchanger



Explanation:
- The letter "A" indicates hot fluid..
- The letter “B” indicates cold fluid.
- Roman numerals indicate globe/ball valve.
- Arabic numerals indicate drain valves.
- The red line shows the flow direction of the hot fluid.
- The blue line shows the flow direction of the cold fluid.
- The black line shows the direction of flow from cold fluid to hot fluid or vice versa.

Figure 2. Fluid flow diagram

Research Procedure

Stage of test preparation

The preparatory stage carried out before conducting the test is as follows:

a. Using a hose that is already connected to the water source faucet, fill reservoirs A and B with water through the valves denoted by numbers VI A and VI B in accordance with the plan shown in Figure 2.

b. The following is how a pump on the heat exchanger can be used if the water source is small and cannot flow into the reservoir:

- In the schematic illustration 2, attach a hose from the water supply faucet to the filling faucet number 2.
- Raising the MCB on the power supply panel, turning on the main power switch on the heat exchanger panel, and then turning on the pump on switch will turn on the heat exchanger.
- In accordance with schematic figure 2, open valves I B, II B, and III B, close valves V B, IV B, VII B, III A, and VI A, and shut off faucets I B, II B, and III B to fill reservoir A.
- According to the design in figure 2, if reservoir A is full, to fill reservoir B, close valves numbers IIIA, III B, V B, and VII B, shut off faucets numbers 1, 3, 4, 5, 6, and 7, and then open valves numbers I B, II B, and IV B.
- Close faucet number two once all reservoirs have been filled, then unplug the hose from the water source faucet.

c. By opening all valves, with the exception of valves III A and III B, and partially opening valves IV A and IV B to release the air trapped in the reservoir, turn on the pump to check for leaks in the fluid flow circuit.

d. Then, turn on the water heater to check that it is functioning properly.

Stage of Testing and Data Retrieval

The following test approach can be used to gather data on an open system:

a. Lifting the MCB on the power source panel will activate the heat exchanger.

b. Both the main switch and the pump switch should be turned on.

c. Close the valves at positions III A, III B, IV B, and VII B for the open system test. As for the faucet, according to schematic figure 2, open the faucet at number 3 which is used to drain the cold fluid that exits the heat exchanger, and open the faucet at number 2 which is used to feed the system with fresh cold fluid.

d. The thermostat (T_1) on the control panel can be adjusted to the desired hot fluid temperature.

- By modifying the ball valve opening number I A and establishing valve opening number V A as a hot fluid pump bypass, you can determine the required hot fluid flow rate. Next, turn the cold fluid pump off by pressing the off button that is located close to the cold fluid pump.
- Next, let the hot fluid reach the desired temperature. After the temperature reaches the set temperature, turn on the cold fluid pump by pressing the button the one near the cold fluid pump.
- By modifying valve opening number I B and configuring the ball valve opening number V B as a bypass for the cold fluid pump, you can determine the required cold fluid flow rate.
- Record the test's data collected. When gathering data, check both pressure gauges. If one of them reads 1 bar, drain the pressure by turning on faucets 8 and 9.
- Turn off the water heater's switch, the pump's switch, and the heat exchanger panel's main power switch once data collecting is complete.
- Then turn off the power source panel's MCB.
- Drain the water from the heat exchanger by turning on all the valves and the faucets at numbers 1, 2, 4, 5, 6, and 7 when data gathering has finished.
- Close all faucets once the heat exchanger's water runs out.

Research variable

The research variable that will be used is listed in Table 1

Table 1. Variables for open systems research

Independent Variable	Control Variable	Dependent Variable
Cold fluid inlet discharge (5 LPM, 6 LPM, 7 LPM and 9 LPM).	Hot fluid Inlet discharge (5LPM). Hot fluid Inlet temperature 60ºC. Cold fluid Inlet temperature.	Hot fluid outlet temperature. Cold fluid outlet temperature.

RESULTS AND DISCUSSION

Correlation between Actual Effectiveness and Variations in Cooling Water Discharge in Open Systems at 60 oC Set Point with 5 LPM of Hot Fluid Discharge

Table 2 shows the results of data collection for a heat exchanger operating at 60 ºC, discharging hot water at a rate of 5 LPM, and varying the discharge of cold water in an open system and figure 4 illustrates the data collecting and data calculation outcomes for an open system with a set point temperature of 60 ºC and a hot fluid flow rate of 5 LPM.

Table 2. The results of data collection for a heat exchanger operating at 60 ºC, discharging hot water at a rate of 5 LPM, and varying the discharge of cold water in an open system

SHELL			***TUBE***		
Cold Fluid Discharge (LPM)	**T4 (ºC)**	**T3 (ºC)**	**Hot Fluid Discharge (LPM)**	**T1 (ºC)**	**T2 (ºC)**
5,1	35,0	29,4	5,1	60,0	43,4
5,9	35,0	29,4	5,1	60,0	43,9
7,9	37,1	27,6	5,1	60,0	41,8
9,1	36,0	27,2	5,1	60,0	40,7

Figure 4 shows that the effectiveness reduces when the cold fluid discharge is 5 LPM and 6 LPM because the incoming cold fluid temperature (T_3) uses PDAM water that is approximately 29 ºC when the discharge is 5 LPM and 6 LPM, In contrast, when the water discharge is 8 LPM and 9 LPM, the incoming cold fluid (T_3) uses water from the bathtub because PDAM water in the afternoon causes the water discharge to become smaller and dead. As a result, when the cold fluid discharge is 8 LPM and 9 LPM, it uses water from the bathtub with a temperature value of T_3 around 27 ºC. According to the graph, the temperature of the cold fluid T_3 influences the values of T_2 and T_4, so the value of efficacy will rise as the temperature of T_3 falls. Additionally, maintaining a constant T_3 temperature is very challenging, particularly when using PDAM water to collect data throughout the day. The PDAM water temperature

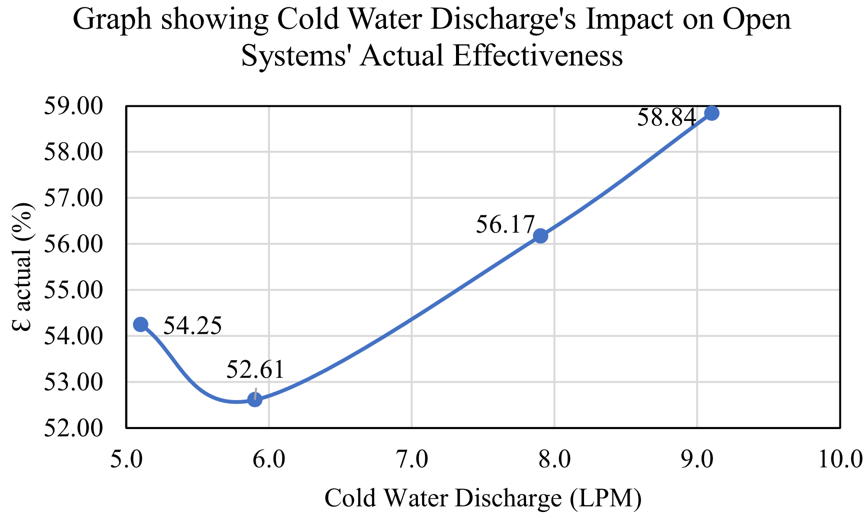


Figure 5. A graph comparing the effectiveness of cold water discharge in open systems in actual and theoretical

changes as a result of the ambient temperature, which results in a variation in the T_3 temperature value.

According to the graph above, the heat exchanger's maximum efficiency is 58.84%. The effectiveness results were 35.4040% when compared to earlier research using the same kind of heat exchanger, specifically a 1pass shell -2pass tube. Because the size of the shell and tube in the prior study was smaller and there were fewer tubes, the heat exchanger created had superior efficiency when compared to earlier studies.

Comparison of Cold Water Discharge's Actual and Theoretical Effectiveness in Open Systems

To determine the variations between the effectiveness values that occur during theoretical calculations and actual calculations when the system is open, the theoretical and actual effectiveness of cold water discharge are compared.

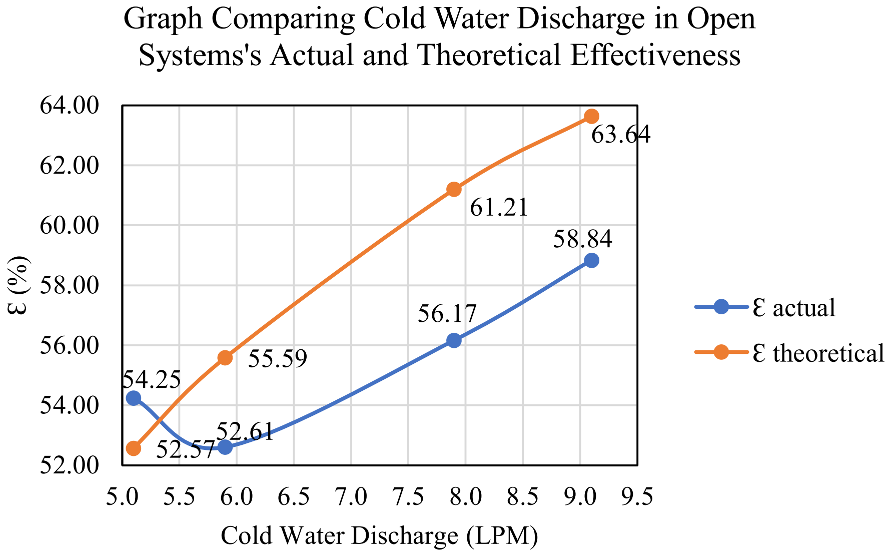


Figure 5. A graph comparing the effectiveness of cold water discharge in open systems in actual and theoretical

Figure 5 shows that having a graph line theoretically tends to increase efficacy. While the graph line for actual effectiveness tends to increase and is still below the graph line for theoretical effectiveness for discharge rates of 6 LPM to 9 LPM, the actual effectiveness graph line at 5 LPM cold water discharge has a graphic line that exceeds the graphic line on theoretical effectiveness. This is because the temperatures T_2, T_3, and T_4 could still vary at the time of data collection. After all, the cold water discharge of 5 LPM was not steady. Figure 5 shows that, aside from at a discharge of 5 LPM, the theoretical effectiveness value is higher than the actual effectiveness value. This is so that the T3 temperature, which can affect the T2 and T4 temperatures, is more stable because the data gathering uses an open system in which the cooling water is constantly replaced.

In contrast to other research that claimed the heat exchanger's efficacy was quite high and beyond its theoretical effectiveness, this investigation demonstrated that the theoretical effectiveness was greater than the actual effectiveness. There is a discrepancy in the results because, theoretically, the value of effectiveness when the tool is designed must be higher than the value of effectiveness when the tool is actually used because theoretical design calculations are more precise and often take into account factors that are not calculated when the actual calculation is made. The theoretical effectiveness value must therefore be higher than the actual effectiveness, it can be said.

Comparison of Cold Water Discharge U_{Actual} Values with $U_{Theoretical}$ Values in Open Systems

To compare the difference in the heat transfer coefficient between theoretical calculations and actual calculations when the system is open, the $U_{theoretical}$ value and the U_{actual} value for cold water discharge are compared.

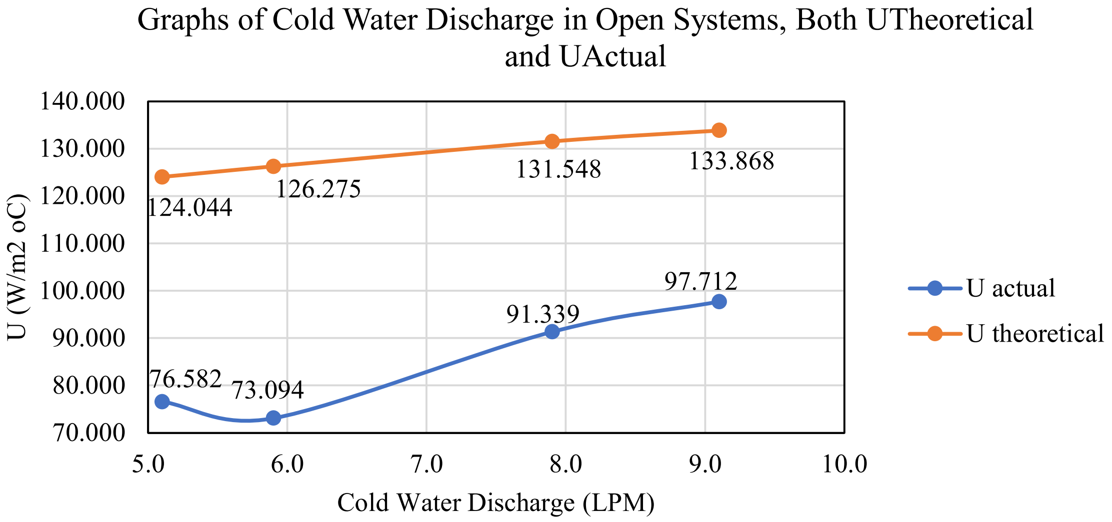


Figure 6. Comparison graph of cold fluid discharge in an open system between U_{actual} and $U_{theoretical}$

Figure 6 shows that the $U_{theoretical}$ graph line has an upward trend line while the U_{actual} value has a slightly unstable graphic line at 6 LPM discharge. This is because the ΔT_{lm} value at 6 LPM discharge is higher than at 5, 8, and 9 LPM discharge, which influences the U_{actual} value. The values of F and q, in addition to the value of ΔT_{lm}, have an impact on the calculation of the U_{actual} value. The temperature of the incoming cold fluid (T_3) will impact the values of T2 and T4 throughout the data collection process, which will affect the value of ΔT_{lm}. The total thermal resistance (R_{total}) value has the biggest impact on the $U_{theoretical}$ value calculation. In reality, the calculation of the value of heat transfer ($q_{teoritis}$) is influenced by the value of the theoretical heat transfer coefficient ($U_{theoretical}$).

CONCLUSION

The discussion above leads to the following conclusion:

- The manufactured heat exchanger is a shell and tube design with a 1pass shell-2pass tube type, 1.5 m of tube length, 19.05 mm of tube diameter, 25.4 mm of tube pitch, and 10 inc of shell diameter. Iron is used for the shell and stainless steel 304 is used for the tubes.
- The created heat exchanger performs with a heat transfer coefficient of 133.868 $W/m^{2o}C$, and its actual efficiency is 58.84%. The theoretical heat transfer coefficient ($U_{theoretical}$) and the actual heat transfer coefficient (U_{actual}) both increase in value as the discharge of cold water increases, and the theoretical heat transfer coefficient ($U_{theoretical}$) is always greater than the actual heat transfer coefficient (U_{actual}). The values of F, q, and ΔT_{lm} have the most effect on how the U_{actual} values are calculated. The total thermal resistance (R_{total}), on the other hand, has the most impact on the determination of the $U_{theoretical}$ value.
- The heat exchanger needs to be in a very steady state when collecting data since the results of the effectiveness calculation will be impacted by an increase in fluid temperature at T_2, T_3, and T_4. Meanwhile, theoretical effectiveness states that the value of effectiveness will rise with increasing cold water discharge. Because the cooling water is constantly changed, the results for an open system are more logical because the actual effectiveness does not surpass theoretical effectiveness. This is because the cooling water temperature causes the T_3 temperature to be more stable, which can affect the T_2 and T_4 temperatures. Maintaining the stability of cold water temperature when utilizing water (PDAM), such that the inlet cold water temperature is always constant so that it will affect the T_2 and T_4 values, presents a challenge when collecting open system data.

List of Notations

A = Heat transfer surface area (m^2)
A_i = Surface area of the tube's inside (m^2)
A_o = Surface area of the tube's outside (m^2)

c_c = The heat capacity of the cold fluid (kJ/kg °C)
c_h = The heat capacity of the hot fluid (kJ/kg °C)
C_c = Cold fluid capacity rate (kJ/s °C)
C_h = Hot fluid capacity rate (kJ/s °C)
d_i = Tube inside diameter (m)
d_o = Tube outside diameter (m)
F = correction factor
h_s = Heat transfer coefficient on the shell side (W/m^2 °C)
h_t = Heat transfer coefficient on the tube side (W/m^2 °C)
k = The thermal conductivity of the material in the tube (W/m °C)
LMTD= Log Mean Tempperature Difference (°C)
m_c = Cold fluid flow rate (kg/s)
m_h = Hot fluid flow rate (kg/s)
N = NTU
$T_{c,i}$ = Cold fluid inlet temperature (°C)
$T_{c,o}$ = Cold fluid outlet temperature (°C)
$T_{h,i}$ = Hot fluid inlet temperature (°C)
$T_{h,o}$ = Hot fluid outlet temperature (°C)
U = Overall heat transfer coefficient (W/m^2 °C)
ε = Heat exchanger effectiveness
ΔT_{lm} = LMTD

REFERENCES

Byrne, R. C. (1998). Standards of the Tubular Exchanger Manufacturers Association Ninth. *Tandards of Tubular Exchanger Manufacturers Association, 6th Ed*.

Cengel, Y. A. (2004). Heat Transfer a Practical Approach. *MacGraw-Hill, 4*(9), 874.

Handayani, S. U. (2021). *Modul Praktikum Konversi Energi Unit Pompa*.

Handy, F. K. N. (2011). Rancang Bangun Heat Exchanger Shell And Tube Single Phase. *Phys. Rev. E*, 24.

Holman, J. P. (2020). *Perpindahan Kalor* (I. M. Hariandja (ed.); cetakan ke).

Khairuddin, H. I. (2018). *Bangun Rancang Exchanger Heat Tipe Shell And Tube*.

Napitupulu, F. H., Sitepu, T., Kusuma, J., & Wijaya, A. (2018). Rancang Bangun Alat Penukar Kalor Shell And Tube Dengan Satu Laluan Cangkang Dan Dua Laluan Tabung Sebagai Pemanas Air. *Talenta Conference Series: Science and Technology (ST)*, *1*(2), 115–134. https://doi.org/10.32734/st.v1i2.289

Septian, B., Aziz, A., & Rey, P. D. (2021). Desain Dan Rancang Bangun Alat Penukar Kalor (Heat Exchanger) Jenis Shell Dan Tube. *Jurnal Baut Dan Manufaktur*, *03*(1), 53–60.