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Performance Analysis of Three Channel Single Pass Heat Exchanger with Flow Divided In Counterclockwise and Unidirectional Flow Configurations

M. Yoki Al Mahir

Faculty of Engineering, University of North Sumatra, Indonesia

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ABSTRACT

The triple concentric pipes heat exchanger is an improved or the repair version of double pipe heat exchanger. The research of triple concentric pipe heat exchanger have enough developed, especially by C.L.Ko dan G.L. Wedekind who have given theoretically and experimentally analysis. This research was conducted to determine the output of temperature of each channel and find out perfomance heat exchanger effectiveness is based on experimentally and theoretically. In this essay, the development is doing with a broader scope of research C.L. Ko and G.L. Wedekind, the experiment have done with $C1/Cs \leq 1$ and $C1/Cs \geq 1$ in both counter flow and paralel flow configuration aheat exchan ger used according to the size used C.L. Ko and G.L. Wedekind. The result experiment that average effectiveness is ± 60% with the higgest effectiveness is ± 80.4 % in counter flow configuration and the average effectiveness is ± 43.4% with the higgest effectiveness is ± 55.1 % in paralel flow configuration. Theoretically predicted heat exchanger effectiveness are found on the average different of the experiment ± 9,06% in counter flow configuration and 5,67% in paralel flow configuration. The experiment also show different result of optimum point that predicted by C.L.Ko dan G.L. Wedekind.

Corresponding Author:

M. Yoki Al Mahir
Faculty of Engineering
University of North Sumatra
Jln. Dr. T. Mansur No. 9, Medan City, North Sumatra, 20222, Indonesia
Email: yoki@gmail.com

1. INTRODUCTION

The era of globalization began with the emergence of various usability technologies that made it easier for humans to carry out various activities (Fonna, 2019). Technology was created not only to facilitate human work, but also to increase economic value which has an impact on the level of human welfare as well (Cholik, 2021). Nowadays human needs are increasing and varied so that we need an appropriate way to meet human needs themselves (Zainur, 2020). It is undeniable that the development of the times has an impact on human needs (Krismajayanti & Darma, 2021). The development of technology created today is an effort to make it easier for humans to carry out various activities (Marpaung, 2018). Technology was created not only to facilitate human work, but also to increase economic value which has an impact on the level of human welfare as well (Ngafifi, 2014). For example, a heat exchanger is a device used to transfer heat from one fluid to another or in other words, the heat transferred from a hot fluid is the same as the heat received by a cold fluid (Supu et al., 2017). In the industrial world, this heat exchanger is very widely used

(Septian et al., 2021). Various types of heat exchangers are used to achieve the desired purpose, such as to heat the product or to cool the product (Oktavianus et al., 2019). In order to develop technology, especially heat exchangers, in this case it is necessary to engineer heat exchanger technology, in this case (Energi & Panas, 2005)carried out the development of a heat exchanger with a three-layer tube type (three concentric heat exchanger) (Utomo, 2017), this type has advantages in terms of effectiveness and efficiency of performance of this type of heat exchanger, therefore this type of heat exchanger needs to be developed and researched further (Habib, 2019).

The objectives of this test are: (1) To determine the output temperature of each channel of the heat exchanger that is, which occurs experimentally and theoretically. (2) To determine the maximum effectiveness that occurs experimentally and theoretically. (3) To determine the effect of the actual heat transfer rate and the mass flow rate of hot or cold fluids on the effectiveness of a three channel divided heat exchanger. (4) To determine the effect of the distributed flow distribution on the optimum design based on the maximum effectiveness of the heat exchanger

2. RESEARCH METHOD

2.1 Research Methods

This research was carried out using an experimental method and is a quantitative research, which is to clearly explain the results of experiments in the laboratory on the variables that have been previously determined (Nugroho, 2018). Then the data obtained from the experimental results will be presented in the form of a graph of the relationship between the independent and dependent variables. After obtaining experimental data, theoretical calculations are then carried out (Payadnya & Jayantika, 2018).

The experimental method according to Suharsimi Arikunto (1996) is a way of looking for a causal relationship (causal relationship) between two factors deliberately caused by researchers by setting aside other factors that can interfere with research (Iqbal et al., 2019). This research was conducted to determine the effect of variations in flow capacity with constant temperature (Umurani et al., 2021) on the effectiveness of a concentric tube heat exchanger where the flow direction is counterclockwise.

2.2 Population and Sample

The population and the sample really need to be considered because both of them will be analyzed for their value so that the qualitative value is obtained (Ramdhan, 2021).

2.2.1 Research Population

The population is the whole object of research. The population in this study is the mass flow rate that varies with the constant inlet temperature of the hot fluid (Hastuti, 2010).

2.2.2 Research Sample

In the study of a three-channel heat exchanger with divided flow, research samples for the input temperature of cold water fluid with a temperature of 3°C-30°C and hot water fluid with a temperature of around 45-62°C are not expected to change the temperature of each fluid. more than ±1°C (Prabowo, 2018). The measurements were carried out with many different flow velocity variations, for the inflow velocity on channel 1 which was 0.42 – 1.2 ltr/min and for the inflow velocity on channel 2 and 3 which varied (Karminto & Suhartoyo, 2015).

2.3 Data Processing Method

2.3.1 Experimental Data Processing

After conducting the experiment, the data for the exit temperature of each channel will be obtained. To test that heat transfer actually occurs between the three channels and is in a steady state, it is necessary to test the energy balance criteria of at least 20% the difference between the energy changes that occur between channel 1 and channel 2 and 3. Data above 20% will not be processed (not followed up) in finding the effectiveness of the heat exchanger. After it is in accordance with the energy balance criteria, the output temperature will be used to calculate the ratio of heat capacity and effectiveness. The following is a flow chart of the experimental data processing process.

2.3.2 Theoretical Data Processing

To validate the measurement results, it is necessary to compare them with the theoretical data. For this reason, data on the input temperature of the hot and cold fluids of each channel and the flow rate of the fluid are used as the basis for theoretical calculations to obtain the value of the output temperature of each channel and the effectiveness of the APK according to theory. In determining the effectiveness and the output temperature, the assumptions used in determining the overall convection heat transfer coefficient are also used, and these assumptions are in accordance with the state of the heat exchanger. The following figure 3.14 flow diagram of the data processing in theory.

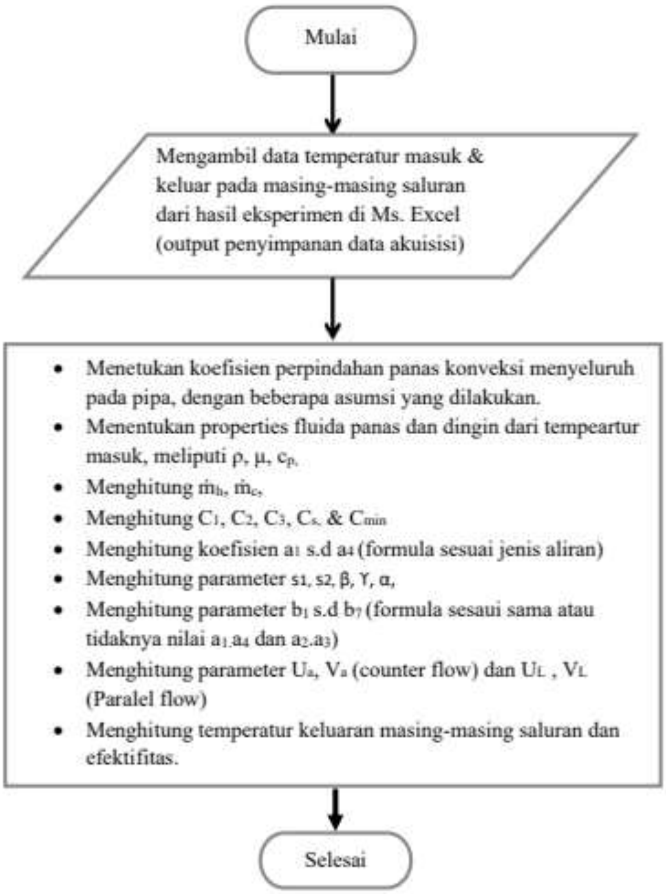

Figure 1. Theoretical Data Processing Process Flowchart

3. RESULTS AND DISCUSSIONS

3.1. Determination of the Convective Heat Transfer Coefficient in Pipes

In testing this heat exchanger, the flow that occurs is laminar flow and the temperature profile has been fully developed with a constant heat flux, so that in determining the value of the convection heat transfer coefficient in the pipe it is obtained through the interpolation of Table 2.2, with the assumptions made are: (1) There is no heat transfer from copper wire in a pipe with a diameter of 6.35 mm or in equation 2.3b, the value of qi" is equal to zero and equation 2.3a is considered equal to zero. (2) There is no heat transfer from the outside on the outer pipe (12.7 mm diameter) because the outer pipe is perfectly insulated or the wall is considered to be adiabatic, so that the heat transfer process actually occurs in the three pipes. (3) Heat transfer in the center pipe (9.53 mm diameter), The temperature difference between the outside and the inside is considered the same at the point $z = 0$, so the ratio of qi"/qo" is the ratio of hi/ho. From the assumptions above, the values are as follows: By interpooling in Table 2.2 or the graph in Figure 2.23, the following Nuoo and Nuii values are obtained, $r^* = r_3/r_4 = 0.329$ then Nuoo = 4.933, $r^* = r_1/r_2 = 0.872$ then, Nuii = 5.53.

3.2. Data Processing and Analysis of Experimental Results and Theoretical Calculations

The input temperature from the experiment will be used as the basis for theoretical calculations and will be used to find properties including density (ρ) , viscosity kinematic (μ) and heat specific (cp) for each hot fluid and cold fluid.

3.2.1. Heat Exchanger with Counterflow Configuration

In theoretical calculations, for the output temperature in the third line pipe for opposite flow for equation 2.63 produced by CL Ko and Wedekind gives results that are far different from the experimental results and after being examined mathematically there is an error in determining the temperature T3o in Equation 2.63 the results of CL Ko and Wedekind.

Experimental and theoretical results on a heat exchanger with a counterflow configuration have an average output temperature difference in each channel, T1o, T2o and T3o, respectively, namely 5.8%, 5.4% and 6.6 % while the effectiveness is ± 7.9%

The biggest temperature difference between the experimental results and the theory is at the outlet temperature of pipeline 3, this is because equation 4.6 uses the output temperature difference at the outlet of pipe 1 as a multiplier to determine the parameters at the outlet temperature of pipe 3, so the percentage difference in the output temperature of pipe 3 is (T3o) is greater than the parameter determining the outlet temperature of pipeline 2 (T2o). For determining the output temperature of each channel, in Equations 2.59 and 2.60 there are several parameters determining the output temperature for the counterflow profile, namely parameters b1, b2, b3, b4, b5, b6, and b7 which in determining these values there are several cases , that is, if 1.α4 α2.α3 and 1.α4 = α2.α3 has its own formula in determining the parameters b1, b2, b3, b4, b5, b6, and b7 as contained in chapter II. In the theoretical calculation, the value of 1.α4 2.α3 is obtained, but the difference in values between 1.α4 and 2.α3 is not large but the output temperature on each channel has a fairly large difference in value with the experimental results when using the formula for determining the output temperature for the case 1.α4 2.α3. However, if we use the determining formula for the case of 1.α4 = 2.α3 the output temperature of each channel in the above case is obtained theoretically the difference is not that much from the experimental results. So that in determining the output temperature if the difference between 1.α4 and 2.α3 is not large or close to the same, then use the case parameter formula approach 1.α4 = 2.α3 and vice versa, if the difference between 1.α4 and 2. 3 is very large, so we use the case parameter formula approach 1.α4 2.α3. In theoretical calculations there are cases where if the heat capacity ratio the divided flow (C1/Cs) is equal to 1 and 1.α4 = 2.α3, in this case using the formula for determining the output temperature for each channel in Equations 2.106, 2.107 and 2.108.

Likewise in the case of the divided flow heat capacity ratio (C1/Cs) equal to one or close to one which in determining theoretical calculations the ratio of divided flow heat capacity (C1/Cs) is equal to one but with 1.α4 2.α3, in this case to determine the output temperature using the formula approach in Equations 2.106, 2.107 and 2.108. In theoretical calculations there are cases where the ratio of heat capacity the data used in the calculation of the overall convection coefficient value in a three-channel single-pass heat exchanger with divided flow. The following Figures 4.1 to 4.3 graphs of the effectiveness to the ratio of the heat capacity of the divided flow when C1/Cs is equal to one or close to one.

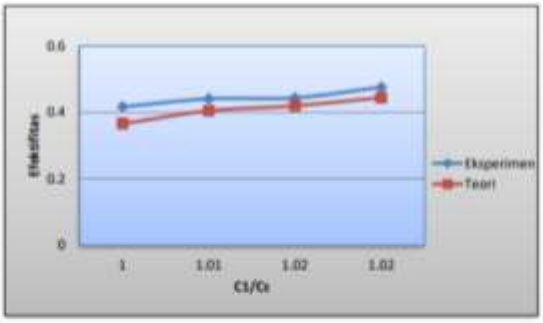

Figure 2. Relationship between Flow Capacity Ratio (C1/Cs) and Effectiveness (E) of Counterflow Heat Exchanger With 1.02 C1/Cs 1

From the graph in Figure 4.1, it can be seen that the highest effectiveness is ±48% when C1/Cs = 1.02, this is directly proportional to the actual increase in heat transfer due to the magnitude of the hot fluid flow rate being equal to the cold fluid flow rate. specifically C1 = Cs

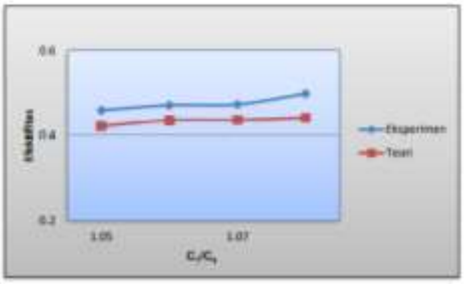

Figure 3. The Relationship between Flow Capacity Ratio (C1/Cs) And Effectiveness (E) Counter Flow Heat Exchanger With 1.07 C1/Cs 1.05

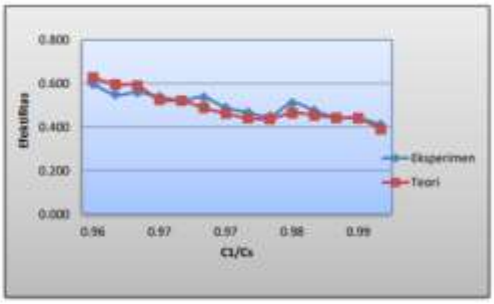

Figure 4. The Relationship between Flow Capacity Ratio (C1/Cs) And Effectiveness (E) Counter Flow Heat Exchanger With 0.99 C1/Cs 0.95

From the graph in Figure 4.2, it can be seen that the highest effectiveness of ±50% when C1/Cs = 1.07 is directly proportional to the increase in actual heat transfer due to the large flow rate of hot fluid equal to the flow rate of cold fluid, this occurs in special cases C1 = Cs.

For the results of theoretical calculations with experiments on C1/Cs greater than one, there is a difference in effectiveness greater than on C1/Cs which is the same as the results of theoretical calculations with experiments, as shown in the following graph:

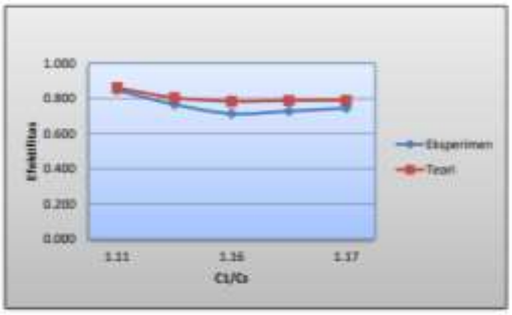

Figure 5. Relationship between Flow Capacity Ratio (C1/Cs) And Effectiveness (E) Counterflow Heat Exchanger With 1.17 C1/Cs 1.11

From the graph in Figure 4.4. it can be seen that the highest effectiveness of ±85% when C1/Cs = 1.11 is directly proportional to the increase in actual heat transfer caused by the large flow rate of the hot fluid.

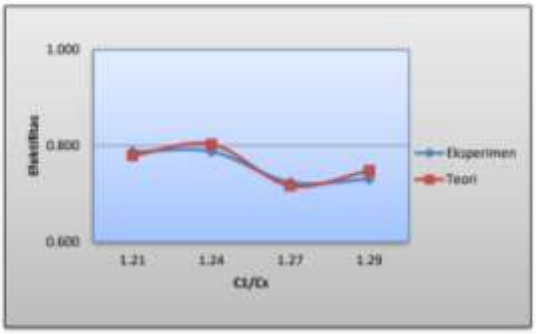

Figure 6. The Relationship between Flow Capacity Ratio (C1/Cs) And Effectiveness (E) Counter Flow Heat Exchanger With 1.29 C1/Cs 1.21

From the graph in Figure 4.5. it can be seen that the highest effectiveness of ±78% when C1/Cs = 1.24 is directly proportional to the increase in actual heat transfer caused by the large flow rate of the hot fluid.

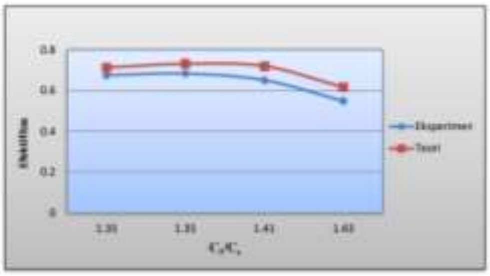

Figure 7. The Relationship between Flow Capacity Ratio (C1/Cs) And Effectiveness (E) Counter Flow Heat Exchanger With 1.43 C1/Cs 1.35

From the graph in Figure 4.6. it can be seen that the highest effectiveness of ±71% when C1/Cs = 1.35 is directly proportional to the increase in actual heat transfer due to the large flow rate of the hot fluid. From the graphs in Figures 4.4, 4.5 and 4.6 it can be seen that the difference in effectiveness is greater when C1/Cs is greater than 1, this is because the heat transfer that occurs is convective heat transfer which is not constant and the heat transfer between the three channels is influenced by the air in the third channel. fluid enters the channel causing unstable heat transfer. For the results of theoretical calculations with experiments at C1/Cs less than one, there is a difference in effectiveness greater than C1/Cs equal to one, as shown in the following graph:

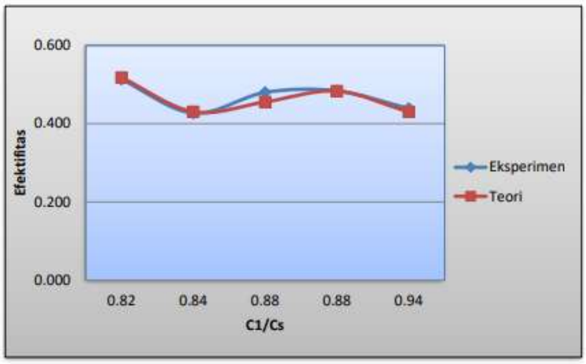

Figure 8. The Relationship between Flow Capacity Ratio (C1/Cs) And Effectiveness (E) Counterflow Heat Exchanger With 0.94 C1/Cs 0.82

From the graph in Figure 4.7. it can be seen that the highest effectiveness of ±51% when C1/Cs = 0.82 is directly proportional to the increase in actual heat transfer caused by an increase in the flow rate of the cold fluid which is greater than the flow rate of the hot fluid.

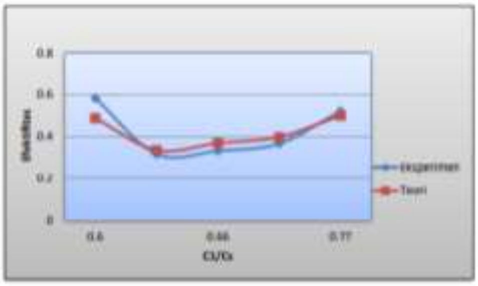

Figure 9. The Relationship between Flow Capacity Ratio (C1/Cs) And Effectiveness (E) Counter Flow Heat Exchanger With 0.77 C1/Cs 0.6

From the graph in Figure 4.8. it can be seen that the highest effectiveness of ±58.8% when C1/Cs = 0.6 is directly proportional to the increase in actual heat transfer caused by an increase in the flow rate of the hot fluid which is greater than the flow rate of the cold fluid. From the graphs in Figures 4.7, 4.8, it can be seen that the difference in effectiveness is quite large when C1/Cs is smaller than 1 because the heat transfer that occurs in convection heat transfer is not constant and the heat transfer between the three channels is influenced by the air in the third channel, the fluid entering the channel causes heat transfer is not steady. The error rate of effectiveness between experimental and theoretical results in countercurrent flow when is close to zero, precisely between 0 to 0.3, the error rate is greater than , ranging from 0.4 to 0,

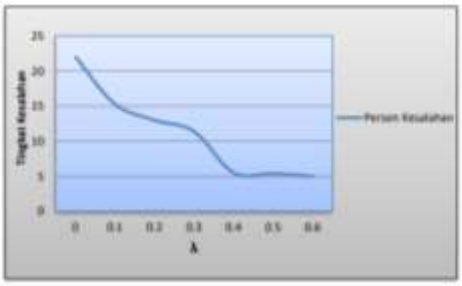

Figure 10. Error Rate Between Experimental And Theoretical Effectiveness

Optimum Design of Divided Flow Heat Exchanger

3.3. Optimum Design of Divided Flow Heat Exchanger

The optimum design based on the optimal effectiveness of the divided flow distribution parameters of the heat exchanger obtained by CLKo and GL Wedekind can be obtained by equation 2.113, namely

$$\lambda_{optimum} = \frac{1}{\left(1+\frac{U13.P13}{U12.P12}\right)} \quad (1)$$

From equation 2.113, the three-channel heat exchanger with divided flow has a value of optimum = 0.724. The results of the experiment show that the maximum effectiveness value for C1/Cs, which is close to 1 or greater as shown in Figures 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.9, 4.10, 4.11 is in the range of values = 0.33 – 0.6 as the data attached in the attachment. The optimum design based on the optimal effectiveness of the divided flow distribution parameters for C1/Cs which is smaller than one as shown in Figures 4.7, 4.8, 4.12, 4.13 the average is in the range of values of = 0.5 – 0.6. The optimum design graph based on the optimal effectiveness of the divided flow distribution parameters, for C1/Cs = 1, C1/Cs 1, and C1/Cs 1 is shown in Figures 4.16 and 4.17 below:

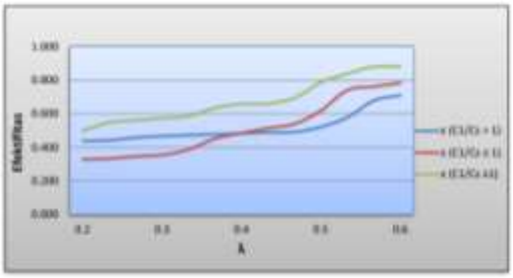

Figure 11. Effect of Divided Flow Distribution on Performance of Three Channel Heat Exchanger With Counter Flow Configuration

From the graph in Figure 4.16 it can be seen that the effectiveness when C1/Cs = 1, C1/Cs 1, and C1/Cs 1 increases in direct proportion to the increase in the ratio of the divided flow distribution, The graph also shows the highest effectiveness of ±86% when the flow distribution ratio is divided, = 0.6 and C1/Cs 1. And the optimum design is based on the optimal effectiveness of the divided flow distribution parameters at the value range of = 0.3 – 0.6, as shown in the graph of Figure 4.16 for the counter-flow configuration.

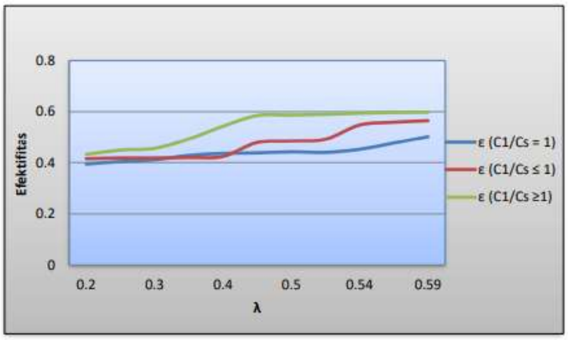

Figure 12. Effect of Divided Flow Distribution on Performance of Three Channel Heat Exchanger With Unidirectional Flow Configuration

From the graph of Figure 4.17 it can be seen that the effectiveness when C1/Cs = 1, C1/Cs 1, and C1/Cs 1 increases in direct proportion to the increase in the distribution ratio of the divided flow, . The graph also shows the highest effectiveness of ±56% when the ratio of the flow distribution is

divided, = 0.59 and C1/Cs 1. The optimum design is based on the optimal effectiveness of the divided flow distribution parameters at
the range of values of = 0.3 – 0.59. The optimum design of a three-channel heat exchanger with divided flow based on effectiveness will increase directly proportional to the increase in the distribution ratio of the divided flow capacity, so that the design of a heat exchanger with a divided flow type can improve performance based on the heat effectiveness of the heat exchanger, and the design of a heat exchanger with The divided flow type can be an alternative for improving the performance of the heat exchanger.

4. CONCLUSION

The conclusions in this study are: (1) The heat exchanger in opposite and unidirectional flow configuration has an experimental output temperature of channel one (T1o) and two (T2o) which tends to be lower than theoretical, while the outlet temperature of channel three (T3o) experimentally tends to be higher. when compared theoretically. (2) The maximum effectiveness of the APK in the opposite direction flow configuration is obtained by ±85% (experimental) and ±86% (theoretical) when the flow capacity of channel one is 1.1 lpm, the flow capacity of channel two is 0.28 lpm and the flow capacity of channel three is 0.61 lpm with a hot fluid inlet temperature of 42.5°C and a cold fluid inlet temperature of 5.6°C, while the maximum effectiveness of the APK in a direct flow configuration was obtained at ±56% (experimental) and ±52% (theoretical) when single line flow capacity 0.74 lpm, the second channel flow capacity is 0.80 lpm and the third line flow capacity is 0.63 lpm with the hot fluid inlet temperature of 49.80°C and the cold fluid inlet temperature of 31.50°C. (3) The greater the actual heat transfer of the heat exchanger, the higher the effectiveness of the heat exchanger, besides that, the faster the mass flow rate of the hot fluid (Qh) if the rate of flow capacity of the hot fluid (Ch) is greater than the rate of flow capacity of the cold fluid (Cc) then the resulting effectiveness will be greater as well as the faster the cold fluid mass flow rate (Qc) if the cold fluid flow capacity rate (Cc) is greater than the hot fluid flow capacity rate (Ch) then the resulting effectiveness will be even greater . (4) Divided flow distribution,

Suggestions in this research are: (1) Testing this heat exchanger can be continued by using a flowmeter that is directly connected to the data acquisition, so that the measuring instrument is more accurate and makes data processing easier. (2) This test can be continued by performing numerical analysis, so as to develop the flow rate in a divided channel. (3) This test can be further developed with the type of three-channel heat exchanger with different flow types such as dived flow.

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