http://jurnal.unmer.ac.id/index.php/jtmt
TRANSMISI
ISSN (print): 9-772580-228020
ISSN (online): 2580-2283

Evaluation of Fluid Flow Velocity Variations on The Plate Heat Exchanger Performance

Andika Syahputra, Asnawi*, Ahmad Nayan, Alchalil, Nurul Islami

Department of Mechanical Engineering, Faculty of Engineering, University of Malikussaleh, JL. Batam, Lhokseumawe, 24352, Indonesia
**Corresponding author email:* asnawi@unimal.ac.id

ARTICLE INFORMATION

Received: 20 February 2023
Revised: 1 March 2023
Accepted: 7 March 2023
Published: 15 March 2023

ABSTRACT

Heat exchanger expected to high effectiveness of the heat transfer. Type of plate heat exchanger was more efficient compare to another heat exchangers in industrial applications with pressure less than 30 bar. The increased velocity of cold fluid flow has an impact to increase the performance of heat exchanger by heat transfer rate (Q), heat transfer coefficient (U), and the effectiveness of heat exchanger (ε). The increased velocity of cold fluid flow also increasing the heat transfer rate. The study carried out by variation of the cold fluid velocity at 0.03 m/s, 0.037 m/s, 0.045 m/s, 0.051 m/s and 0.059 m/s. Inlet hot fluid temperature (Th,i) at 45˚C and cold fluid temperature (Tc,i) at 27˚C constant. The results shows Q value from the original 1570.71 Watt to 1916.16 Watt on the hot side and 1751.89 Watt to 2187.01 Watt on the cold side. The U value from the original 1180.46 W/m^2.˚C becomes 1408,75 W/m^2. ˚C. The ε value increased from 60.33% to 75.69%. The increasing of cold fluid velocity directly proportional to the the heat transfer rate (Q) and performance of the plate heat exchanger. This Phenomenon due to the faster circulation of the cold fluid, which causes the cold fluid to quickly return to its initial temperature (Th,i), an than increasing the plate heat exchanger's performance.

Keywords: Velocity of cold fluid flow, plate heat exchanger,heat exchanger performance.

ABSTRAK

Penukar panas diharapkan memiliki efektivitas perpindahan panas yang tinggi. Penukar panas tipe pelat lebih efisien dibandingkan dengan penukar panas lain dalam aplikasi industri dengan tekanan kurang dari 30 bar, secara teoritis kecepatan aliran fluida dingin yang ditingkatkan berdampak pada meningkatnya unjuk kerja dari alat penukar panas berupa laju perpindahan panas (Q), koefisien perpindahan panas (U), dan efektivitas dari alat penukar panas (ε). Peningkatan kecepatan aliran fluida dingin akan menyebabkan laju perpindahan panas juga semakin meningkat. Pengujian ini dilakukan dengan memvariasikan kecepatan aliran fluida dingin pada 0,03 m/s, 0,037 m/s, 0,045 m/s, 0,051 m/s, dan 0,059 m/s. Temperatur fluida panas masuk (Th,i) 45 ˚C dan temperatur fluida dingin (Tc,i) 27 ˚C yang di buat konstan. Hasil pengujian didapatkan nilai Q dari semula 1570,71 Watt menjadi 1916,16 Watt pada sisi panas dan 1751,89 Watt menjadi 2187,01 Watt pada sisi dingin, nilai U dari semula 1180,46 W/m^2. ˚C menjadi 1408,75 W/m^2. ˚C, dan ε dari semula 60,33% menjadi 75,69%. Peningkatan kecepatan aliran fluida dingin berbanding lurus dengan meningkatnya laju perpindahan panas (Q) dan unjuk kerja *plate heat exchanger*. Hal ini dikarenakan sirkulasi fluida dingin yang semakin cepat membuat fluida dingin cepat kembali ke temperatur awal (Th,i) sehingga meningkatkan unjuk kerja *plate heat exchanger* dalam mendinginkan fluida panas.

DOI: 10.26905/jtmt.v19i1.9650

Kata Kunci: Kecepatan aliran fluida dingin, *plateheat exchanger*, performa *heat exchanger.*

1. Introduction

In the industrial world, increasing the efficiency of a technology is needed because the equipment that operation continuously. In conditions where the optimum reaction temperature of the machine or equipment is not reached, heating or cooling is necessary to increase the reaction efficiency and ensure the safety of the equipment during operation [1].

Heat control of the equipment is necessary so that overheating does not occur which can reduce its efficiency. Excess heat can be minimized by having equipment that can transfer heat. So that the work done by a machine or equipment can be optimal even though it is operated continuously [2].

Heat exchanger was tool that used as a heat transfer medium that occurs at two or more fluids that have a temperature difference. So that heat exchanger widely used in applications in the industrial world, one example is power generation. In the automotive world heat exchanger applied to car radiators, whereas in HVAC (heating ventilating air conditioning) namely evaporators, cooling towers, refrigeration systems, and others. Performance of heat exchanger could be monitoring from the effectiveness of its heat transfer. The effectiveness of heat exchanger can be defined as the ratio of the actual heat transfer rate from the hot fluid to the cold fluid of the maximum heat transfer rate [3].

The science of heat transfer attempt to explain the thermal energy could be displaced and to predict the degree of heat transfer that occur under certain conditions. Heat transfer is the process of energy transfer that occurs due to temperature differences in a system. Based on the concept of thermodynamics, energy that moves is thermal energy. Energy cannot be measured or observed directly but its influence can be measured and observed. There are three different mechanisms in the heat transfer process namely, conduction, convection, and radiation [4].

Plate heat exchanger (PHE) was type of heat exchanger consisting of thin plates arrange in parallel and frame. Where the heat transfer process occurs between two fluids through the gaps of the plates, so that is no mixing between hot and cold fluids. In the plate heat exchanger, the plate arrange form two paths called the hot side and the cold side [5].

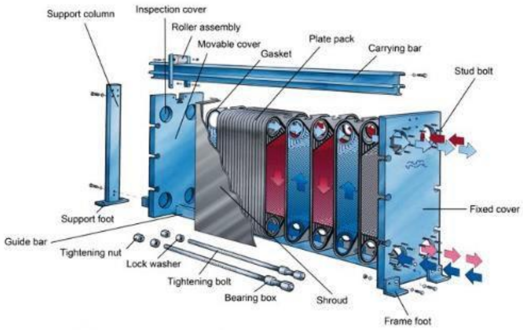


Figure 1. Construction of PHE and direction of fluid flow

Calculations of the heat transfer rate are needed in analyzing of heat exchangers. The first law of thermodynamics says that the rate of heat transfer from hot fluid is same to the rate of heat transfer to cold fluid [6]. So that it could be formulated using formula:

a. Heat transfer rate on the cold side ($\dot{Q}_{cold}$)

$$\dot{Q}cold = \dot{m}cold \times Cp,cold \times (Tc,o - Tc,i) \quad (1)$$

b. Heat transfer rate on the hot side ($\dot{Q}hot$)

$$\dot{Q}hot = \dot{m}hot \times Cp,hot \times (Th,i - Th,o) \quad (2)$$

Where:

$\dot{Q}$ = heat transfer rate (Watt)
$\dot{m}$ = mass flow rate (kg/s)
Cp = specific heat of the fluid (J/kg.˚C)
Tc,i = temperature of cold fluid in (˚C)
Tc,o = temperature of cold fluid out (˚C)
Th,i = temperature of hot fluid in (˚C)
Th,o = temperature of hot fluid out (˚C)

If the mass flow rate of a heat exchanger is not known, it could to determined using the formula:

$$\dot{m} = v \times \rho \times A_c \quad (3)$$

Where:

A_c = cross section area of the plate (m^2)
v = fluid velocity (m/s)
ρ = fluid density (kg/m^3)

Reynolds number is the ratio between the inertia force to viscosity force that quantifies the relationship of the two forces to a given flow condition, where the Reynolds number is used to determine type of flow in the heat exchanger [6]. Thus could to determined using formula:

$$Re = \frac{v \times \rho \times D_e}{\mu} = \frac{v \times D_e}{v} \quad (4)$$

Where:

Re = *Reynolds number*

D_e = plate equivalent diameter (m)

v = kinematic viscosity of the fluid (N.s/m)

Nusselt number said a turbulent flow if (Re > 10000), it said a transitional flow if (2300 ≤ Re ≤ 10000), and it said a laminar flow if (Re < 2300) [6]. So that the nusselt number could to determined using the formula:

a. For laminar flow (Re < 5 × 10^5)

$$Nu = \frac{hD_h}{k} = 0{,}664\ Re^{0,5} \times Pr^{\frac{1}{3}} \quad (5)$$

b. For turbulent flow (5 × 10^5 ≤ Re ≤ 10^7)

$$Nu = \frac{hDh}{k} = 0{,}037\ Re^{0,8} \times Pr^{\frac{1}{3}} \quad (6)$$

Where:

N_u = *Nusselt number*

P_r = *Prandtl number*

μ = dynamic viscosity (kg/m.s)

k = thermal conductivity (W/m.˚C)

The overall heat transfer coefficient is the total thermal resistance between two fluids undergoing heat transfer in a heat exchanger [7]. The heat transfer coefficient in general that occurs in the plate heat exchanger could be determined using the formula:

$$U = \frac{1}{\frac{1}{h_h} + \frac{1}{h_c} + \frac{\delta p}{k_p}} + R_{f,h} + R_{f,c} \quad (7)$$

Definition:

U = overall heat transfer coefficient (W/m^2.˚C)

h = convection coefficient (W/m2.˚C)

δp = plate thickness (m)

k_p = conductivity of plate material (W/m. ˚C)

$R_{f.h}$= impurity resistance on the surface of the hot side plate (W/m2. ˚C)

$R_{f.c}$= impurity resistance on the surface of the hot side plate (W/m2. ˚C)

Rf is considered 0 if there are no impurities

Logarithmic average temperature difference or called log mean temperature difference (LMTD) is a calculation of the average temperature difference that varies on the inlet and outlet sides of a heat exchanger. The measured temperature on the inlet and outlet sides of a heat exchanger is not the same [8]. To determine the LMTD of the opposite flow on the plate heat exchanger can use the formula:

$$\Delta Tlm = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln\left(\frac{T_{h,i} - T_{c,o}}{T_{h,o} - T_{c,i}}\right)} \quad (8)$$

Where:

ΔTlm = logarithmic average temperature difference (˚C)

The effectiveness of heat exchanger can be interpreted as a comparison between the actual heat transfer rate (Q_{act}) with maximum heat transfer rate (Q_{max}) [9]. So that the effectiveness of the plate heat exchanger can be determined using the formula:

$$\varepsilon = \frac{Q_{act}}{Q_{max}} \times 100 = \frac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}} \quad (9)$$

$$\varepsilon = \frac{Q_{act}}{Q_{max}} \times 100 = \frac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{c,i}} \quad (10)$$

To find the maximum heat transfer rate and actual heat transfer of the plate heat exchanger can use the formula:

$$Qact = C_c \times (T_{c,o} - T_{c,i}) = C_h \times (T_{h,i} - T_{h,o}) \quad (11)$$

$$Q_{max} = C_{min} \times (T_{h,i} - T_{c,i}) \quad (12)$$

Where:

ε = effectiveness (%)

Q_{act} = actual heat transfer (kW)

Q_{max} = maximum heat transfer (kW)

However, if the heat transfer rate in the hot and cold fluids is the same then the value $Qact$ is the value of the heat transfer rate (Q). $Qact$ can be calculated using Cc if the value of Cc is smaller than Ch and vice versa. The effectiveness of the heat exchanger can be calculated using equation (9) if the heat capacity rate for cold fluid (Cc) is greater than the heat capacity rate for hot fluid (Ch). And versa, the effectiveness of the heat exchanger can be calculated using equation (10) if the rate of heat capacity for cold fluid (Cc) is less than the rate of heat capacity for hot fluid (Ch).

Research objectives To determine effect of cold fluid flow velocity on the heat transfer rate (Q) on the plate heat exchanger. To find out of the effect variations in the flow velocity of cold fluid on the performance of plate heat exchanger.

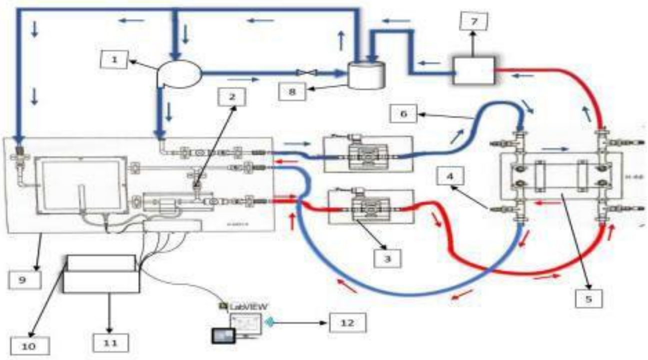
2. Methodology of Research

Data analysis in this study used experimental methods conducted in the laboratory. The experimental method can be interpreted as cause-and-effect method, where research is carried out by looking for the influence of certain treatments on the output produced under controlled conditions. Data obtained are entered into Table for analysis using formula in calculating the evaluation of heat exchanger performance as follows.

a. Calculation of the value of the heat transfer rate (Q) using the formula 1 dan 2.
b. Calculation of the overall heat transfer coefficient (U) using the formula 7.
c. Calculation of the effectiveness of heat exchangers (ε) using the formula 9.

2.1. Test Equipment Scheme

The following is presented the schematic of testing on the plate heat exchanger.



No	Equipment name	No	Equipment name
1	Pump	7	Radiator
2	Valve	8	Drum
3	Flow transmitter	9	Service module
4	Thermocouple	10	Data logging, I/O
5	Plate heat exchanger	11	Control module
6	Pipe/hose	12	Computer

Figure 2. Set-up of plate heat exchanger testing circuit

2.2. Research Location

This research was carried out at the Laboratory of Materials and Energy Conversion, Department of Mechanical Engineering, Faculty of Engineering, University of Malikussaleh.

2.3. Research Variables

In this study there were 3 variables observed. Detail the three variables are presented in Table 1 below.

Table 1. Research variables

No	Variables type	Variables
1	Independent variable	Variations of flow velocity at 0.03 m/s, 0.037 m/s, 0.045 m3/s, 0.051 m/s, and 0.059 m/s.
2	Control variable	Hot and cold fluid temperature constant at 27 °C and 45 °C.
3	Dependent variable	a. Heat transfer rate (Q) b. Overal heat tansfer coefficient (U) c. Effectiveness of heat exchanger (ε).

2.4. Research Flowchart

The series of completing this research is presented in the following figure

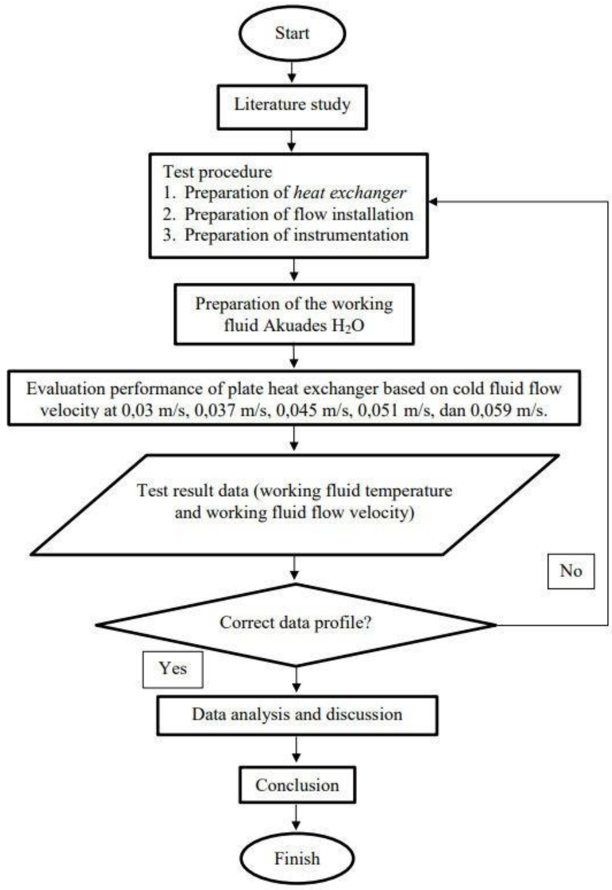


Figure 3. Research flowchart

3. Result and Discussion

The test data in the analysis and the results will be presented in the form of a graph of the relationship between the performance of the plate heat exchanger with the variation in the flow velocity cold fluid.

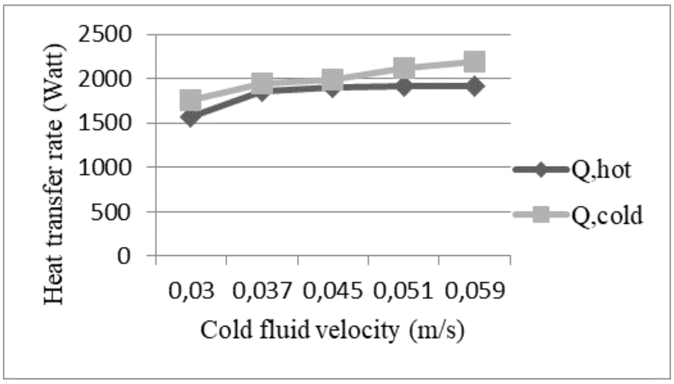


Figure 4. Graph of changes in heat transfer rate to variations in cold fluid flow velocity

Figure 4 shows the effect of increasing the flow velocity of cold fluid on the rate of heat transfer. This phenomena suggests heat transfer is influenced by temperature differences in incoming and outgoing fluids. The greater temperature difference, the greater the heat transfer that occurs, and conversely the smaller the temperature difference, the smaller the heat transfer occurs [6]. It can be seen that at a speed of 0.059 m/s the increase in the value of the heat transfer rate reaches the optimum and at a speed of 0.03 m/s the heat transfer rate gets the minimum value. This is almost the same as the research conducted by Burmawi et al, where the magnitude of the fluid flow velocity is proportional to the value of the heat transfer rate that occurs [10].

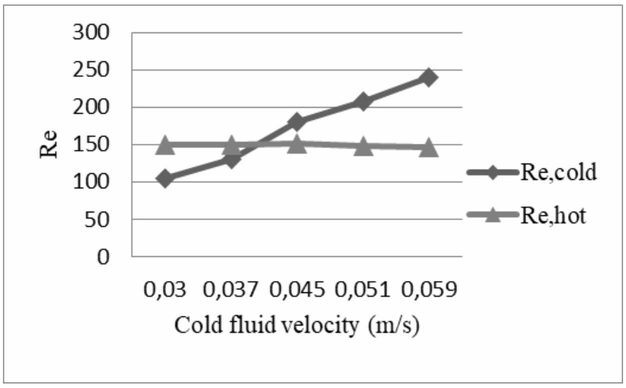


Figure 5. Graph of reynolds number change to cold fluid flow velocity variation

Figure 5 shows that the reynolds number in cold fluids increases significantly as the velocity of cold fluid flow increases, where the increase in the value of reynolds is directly proportional to the increase in the value of the convection heat transfer coefficient on the cold side, which will have an impact on increasing the value of the overall heat transfer coefficient on the plate heat exchanger [6]. Can be seen that at a top speed of 0.059 m/s, reynolds value of 239.55 was obtained and at the lowest flow velocity a reynolds value of 104.37 was obtained. While on the hot side, the reynolds value does not increase because the speed of the hot fluid flow is constant. This is in accordance with the research of Cholis et al, where the results obtained are an increase in effectiveness along with an increase in the flow velocity of the cold fluid [11].

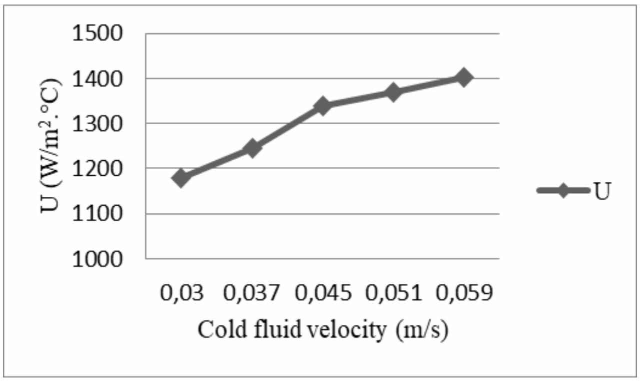


Figure 6. Graph of the influence of cold fluid flow velocity variations to overall heat transfer coefficient

Figure 6 shows that an increase in the flow velocity of cold fluid has impact on increasing the value of the overall heat transfer coefficient (U) on the plate heat exchanger. In this test, the highest (U) value of 1402,95 $W/m^2.^{\circ}C$ was obtained at the highest flow velocity variation of 0,059 m/s and the lowest value of 1180,46 $W/m^2.^{\circ}C$ at the lowest flow velocity variation 0,03 m/s. The results of this study lead to research that has been carried out by Burmawi et al before, where an increase in the flow velocity of cold fluid will increase the heat transfer rate which will have an impact on increasing the overall heat transfer coefficient [10].

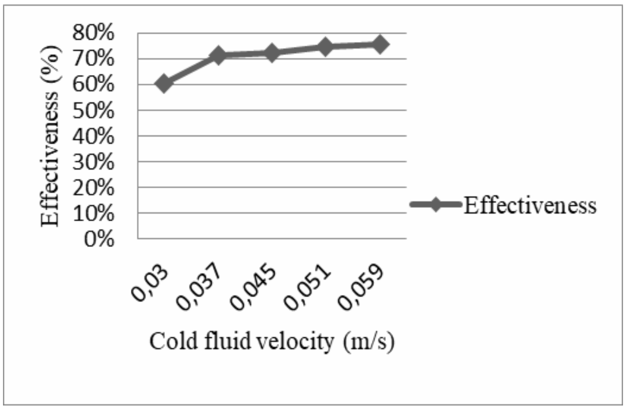


Figure 7. Graph the effect of variations cold fluid flow velocity to plate heat exchanger effectiveness

Figure 7 shows that an increase in the flow velocity of cold fluid also has an impact on increasing the effectiveness of the plate heat exchanger. This is due to the good heat transfer between hot and cold fluids along with the increase in the flow velocity of cold fluids. The greater flow velocity of cold fluid, the better the temperature drop in the hot fluid and the greater the temperature difference. The increasing temperature difference on the heat side causes Q_{actual} to increase, this increase will have an impact on increasing the effectiveness of the plate heat exchanger. In other words, the greater flow velocity of the cold fluid then the ability of the plate heat exchanger in cooling the hot fluid will also be better [12]. In this test, the highest effectiveness value was obtained, namely 75.69 % at the highest cold fluid flow speed variation of 0.059 m/s, and the lowest effectiveness value was 60.33 % at the lowest cold fluid flow discharge variation of 0.03 m/s. This is in accordance with the research of Cholis et al, where the results obtained are an increase in effectiveness along with an increase in the flow velocity of the cold fluid [11].

4. Conclusion

Based on the results of data obtained from testing and calculating the performance of the plate heat exchanger, it can be said that the increase in the flow speed of the cold fluid has a good effect on each performance parameter. In detail, the conclusion of the effect of increasing the flow velocity of cold fluid on the heat transfer rate (Q) and the performance of the plate heat exchanger is as follows.

1. The increase in the flow velocity of the cold fluid is directly proportional to the increase in the rate of heat transfer (Q). Where the heat transfer process occurs between the hot fluid and the cold fluid in the opposite flow direction, it results increase in the heat transfer rate which is influenced by the temperature differential. The greater the flow velocity of the cold fluid, the greater the temperature differential that occurs, because the more energy that can be transferred from the cold fluid to the hot fluid.
2. An increase in the flow velocity of cold fluid results in increased performance. The most optimum performance value is at flow speed of 0.059 m/s and the minimum is at a flow speed of 0.03 m/s. The increase in flow velocity of cold fluid increases the performance value of the plate heat exchanger in the form of a displacement rate (Q), overall heat transfer coefficient (U), and its performance or effectiveness (ε).

References

[1] J. Ronald and N. Jose Roberto, "Numerical Prediction of a Nusselt Number Equation for Stirred Tanks with Helical Coils," *AIChE J.*, vol. 59, no. 4, pp. 215–228, 2012, doi: 10.1002/aic.

[2] M. R. Zain and Asalil Mustain, "Evaluasi Efisiensi Heat Exchanger (He - 4000) Dengan Metode Kern," *Distilat J. Teknol. Separasi*, vol. 6, no. 2, pp. 415–421, 2020, doi: 10.33795/distilat.v6i2.133.

[3] S. Nandiati, M. R. Kirom, and T. A. Ajiwiguna, "Evaluasi Kinerja Pada Berbagai Variasi Susunan Heat Exchanger Menggunakan Metode LMTD Dan NTU," *e-Proceeding Eng.*, vol. 6, no. 2, pp. 5058–5065, 2019.

[4] H. M. Ma'ruf, "Perpindahan Panas Pada Permukaan Luar Pipa Dengan Aliran Fluida Tegak Lurus Sumbu Pipa Yang Disusun Secara Zizag/Staggered," 2007.

[5] R. Walikrom, A. Muin, and Hermanto, "Studi Kinerja Plate Heat Exchanger Pada Sistem Pendingin Pltgu," *J. Tek. Mesin*, vol. 1, no. 1, 2018, [Online]. Available: www.univ-tridinanti.ac.id/ejournal/

[6] Y. A. Cengel, *Heat and Mass Transfer: A Practical Approach*. Singapura: :Mc.Graw-Hill Book., 2006.

[7] L. Wang, B. Sundeen, and R. M. Manglik, *Plate heat exchangers : design, applications and performance*. 2007. [Online]. Available: https://lib.ugent.be/en/catalog/rug01:001252671

[8] A. D. Cappenberg, "Analisa Kinerja Alat Penukar Kalor Jenis Pipa Ganda," *J. Kaji. Tek. Mesin*, vol. 1, 2016, doi: 10.52447/jktm.v1i2.459.

[9] J. E. Hesselgreaves, *Compact Heat Exchanger Selection, Design and operation*, no. January. lanark: Elsevier Science & Technology Books,

2001.
[10] Burmawi, Mulyanef, and A. P. Saputra, “Analisa Unjuk Kerja Dari Heat Exchanger Tipe Shell And Tube Menggunakan Air Sebagai Fluida Panas Dan Fluida Dingin,” *Menara Ilmu*, vol. 15, no. 1, pp. 1–8, 2021.
[11] N. Cholis, A. Husen, and M. I. Akbar, “Analisis pengaruh kecepatan aliran fluida dingin terhadap efektivitas shell and tube heat exchanger,” *Bina Tek.*, vol. 16, no. 1, pp. 1–10, 2020.
[12] B. Yunianto, D. Cahyo K, and Arijanto, “Pengaruh Perubahan Debit Aliran Fluida Panas Dan Fluida Dingin Terhadap Efektifitas Pada penukar Kalor Tipe Plat Aliran Silang,” *rotasi J.*, vol. 4, pp. 13–16, 2013, [Online].Available:http://ejournal.undip.ac.id/index.php/rotasi%0APENGARUH