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ANALYSIS OF MASS FLOW RATE IN COLD WATER INTO FLOW WITH HOT WATER OUTPUT TEMPERATURE IN SHELL AND TUBE HEAT EXCHANGER

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Abstract

A heat exchanger is a device that is used to exchange heat that functions as a heater or a cooler. There are many types of heat exchangers available today. But the most widely used in industry is the shell and tube heat exchanger. The shell and tube type heat exchanger has the advantages of being affordable, easy to maintain and having excellent heat performance with a small volume. This paper aims to analyze the effect of mass flow rate on the inflow of cold water with the outlet temperature of hot air using water fluid in a shell and tube heat exchanger. The design analysis that I did use the Solidworks 2019 software. This study only made a comparison by changing the mass flow velocity at the inflow of cold water with samples of 5 Kg/s, 10 Kg/s, 15 Kg/s, 20 Kg/s, 25 Kg/s and 30 Kg/s and only sampled the hot water outlet temperature. The material used is stainless steel 321 on the shell and copper on the tube. The test results show that for every increase of a multiple of 5 Kg/s there is a decrease in the average fluid temperature of 1.62^{o}C and the lowest temperature that can be achieved in this test is 52.33^{o}C.

Keywords: Heat, Heat Exchanger, Shell and Tube,

1. INTRODUCTION

Human life today is very dependent on the products produced in industrial factories on a large scale, for example, electricity and petroleum products. In order to meet the growing needs of consumers, large industries often use large machines to produce large amounts of energy. Of course, these machines produce high heat, so if there is no adequate cooling medium, it will be easy for the machine to fail due to overheating.

A heat exchanger is a device that has been designed in such a way as to be able to quickly transfer heat and release heat/excess heat. In the heat exchanger there is a fluid as a heat-dissipating medium. The heat transfer process that occurs is convective heat transfer because it uses a liquid to transfer heat.

The types of heat exchangers that are most widely used in industry are shell and tube heat exchangers. One of the factors that affect heat transfer in a heat exchanger is the mass flow velocity. For this reason, in scientific writing this time, the author will compare the effect of mass flow velocity on the decrease in the temperature of the hot water outlet on the tube. The formulation of the problem in scientific writing is to find out how the effect of mass flow velocity on the performance of heat transfer that occurs in the heat exchanger

Limitation of the problem aims to facilitate the understanding of Scientific Writing so that the problem only focuses on the scope of the purpose of the problem. The following will describe the limitations of the problem at this time:

1. The type of heat exchanger used is shell and tube,
2. The fluid used is water,
3. The material used for both the shell and tube is stainless steel 321,
4. Changed mass flow velocity is in the cold water inlet temperature section on the shell,

Research purposes

The purpose of writing contained in the theme of scientific writing this time aims as follows:

1. Analysis of the heat transfer process that occurs in the shell and tube heat exchanger,
2. Calculating the comparison of the influence of various mass flow velocities on the temperature of the hot water outlet on the tube.

2. LITERATURE STUDY

Heat transfer is a process that can be said to be the transfer of heat from one area to another due to the difference in temperature on the surface of the object. Heat energy will move from a surface with a high temperature to a place with a low temperature.

There are three types of heat transfer processes, namely:

1. Conduction Heat Transfer Process

   Conduction is the process by which heat flows from an area of high temperature to an area of lower temperature in one medium (solid, liquid or gas) or between different mediums that are in direct contact [3]. In conduction heat flow, energy transfer occurs due to direct molecular contact without any substantial molecular transfer. Conduction is the only mechanism by which heat can flow in an opaque solid [4].

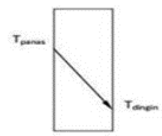

Figure 1. Conduction Heat Transfer Process

To be able to know the value of the rate of heat transfer by conduction, the Fourier's Law equation is as follows [5]:

$$qk = -\,kA\frac{dT}{dX}$$

Where :

qk	: Heat Transfer Rate by Conduction
k	: Thermal Conductivity of Material
A	: Cross-sectional area of heat transfer (m^2)
$\frac{dT}{dX}$	: Temperature Gradient in Cross-section

The following are values of thermal conductivity for some materials

Table 1 Thermal Conductivity for Various Materials.[3]

Material	Thermal Conductivity of Material
Aluminum	205.0 W/m.K
Brass	109.0 W/m.K
Copper	385.0 W/m.K
Silver	406.0 W/m.K

2.1 Heat Transfer By Convection

Convection is a heat transfer process that occurs between the surface of a substance and a moving fluid and both have a temperature difference. The transfer of energy by convection from a surface whose temperature is above the temperature of the surrounding fluid takes place in several stages. First, heat will flow by conduction from the surface to the adjacent fluid particles [6]. Convective heat transfer between solid and fluid boundaries occurs in the presence of a combination of conduction and mass transport. This energy transferred by conduction increases the energy in the fluid and is carried away by the motion of the fluid. When the heated fluid particles reach a region of lower temperature, heat is transferred again by conduction from the hotter fluid to the colder fluid.[7]

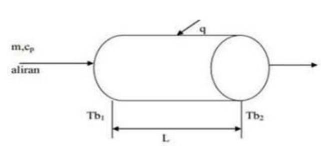

Figure 2. Convection Heat Transfer Process [5]

Free convection is heat transfer caused by temperature difference and density difference only and there is no external force pushing it. Free convection can occur because there is a current flowing due to the buoyant force, while the buoyant force occurs because there is a difference in fluid density without being influenced by forces from outside the system. The difference in fluid density occurs because of the temperature gradient in the fluid. Forced convection is the heat transfer of gas streams or fluids caused by external forces. Forced convection can also occur because the fluid flow that occurs is driven by a mechanical device [8]. Convection heat transfer can be written with the following equation [5]:

$$q = h\,(T_w - T_f)$$

Where :

q : Heat Transfer Rate By Convection (Watt)
A : Cross-sectional area of heat transfer (m^2)
Tw : Wall Temperature (K)
Tf : Fluid Temperature (K)
h : Coefficient of Heat Transfer By Convection

2.2 Radiation Heat Transfer Process

Radiation is the process by which heat flows from a high-temperature object to a low-temperature object when the objects are separated in length of space, even if there is a vacuum between the objects. All objects emit radiant heat continuously. The intensity of the emission depends on the temperature and the nature of the surface. Radiant energy travels at the speed of light (3×10^8 m/s) and its symptoms resemble light radiation.

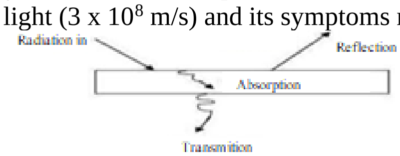

Figure 3. Radiation Heat Transfer Process [3]

To calculate the amount of heat emitted, the following formula can be used [3]:

$$qr = eA\sigma\,(T_1^4 - T_2^4)$$

Where:

qr : Heat Transfer Rate radiation
e : Surface Emittance
A : Cross-sectional area of heat transfer
Name : Stefan's Constant – Boltzmann (5.67×10-8 W/m2 K4)
T1 : Temperature of Gray Body
T2 : Black Body Temperature

2.3 Heat Exchanger

A heat exchanger or better known as a heat exchanger is a device used to exchange heat and can usually function as a heater or cooler. The effectiveness of a heat exchanger can be defined as the ratio between the expected performance of a heat exchanger with the maximum heat transfer that can occur in the heat exchanger. The heat exchanger is designed to be able to carry out efficient heat transfer between fluids [9]. Heat exchangers are typically classified according to their flow arrangement and type of construction. The simplest heat exchanger is a heat exchanger in which the hot fluid and cold fluid move in the same or opposite directions as a pipe [10].

Shell and Tube Heat Exchanger merupakan jenis yang paling banyak digunakan dalam industri terutama insdustri perminyakan. Alat ini terdiri dari sebuah shell dimana didalamnya terdapat suatu bundle pipa dengan diameter yang relative kecil. Untuk meningkatkan efisiensi pertukaran panas, biasanya pada alat penukar shell and tube heat exchanger dipasang sekat (baffle) supaya turbulensi aliran fluida dapat menambah waktu tinggalnya.

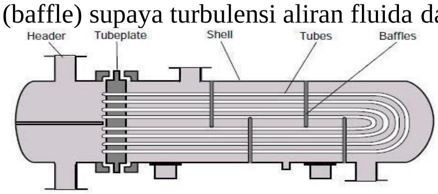

Figure 4. Shell and Tube Heat Exchanger [9]

2.4 Shell and Tube Heat Exchanger Components

The following is an explanation of the components that make up the shell and tube heat exchanger:

1) Shell
The shell is the body of the heat exchanger, which contains the tube bundle. In a shell and tube exchanger, there is a fluid that receives or releases heat, which is the path taken by the fluid flowing inward through the inlet (input nozzle) through the inside of the shell and around the tube and then out through the outlet (outlet nozzle). For very high temperatures the shell is sometimes divided into two and joined by expansion joints. Usually the shell is elongated (cylindrical) which contains a tube bundle as well as a container for flowing substances or fluids.
2) Tube
Tube is a dividing field between the two types of fluid flowing in it and at the same time as a heat transfer field. Tubes can be made from a variety of metals, such as iron, copper, bronze, aluminum and stainless steel. The size of the pipe thickness varies and is expressed in numbers of Birmingham Wire Gage (BWG) and is commonly used following the measurements that are too standard. The larger the BWG number, the thinner the tube [12]. Form This arrangement of square and triangular pipe holes is known as tube pitch. Pitch is the distance from the center or corner line of one tube to the center of another tube.
3. Tube Sheet
Tube Sheet is the part that functions as a place to string the ends so that they become one which is also known as a tube bundle. This component is a plate device mounted inside the tube to divide the tube fluid flow if more than one tube pass is desired. Tube sheet construction is usually made thick, and the tube is installed without leaking on the tube sheet.

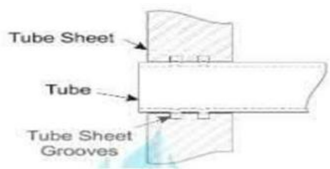

Figure 5. Tube Sheet

4. Baffles
Baffles are used to regulate the flow through the shell so that higher turbulence will be obtained and increase the heat transfer that occurs. Baffles also function to hold the tube bundle to withstand vibrations in the tube and maintain the distance between each tube, as well as withstand turbulence caused by fluid pressure [14].
5. Tie Rod
Tie rods are used to fasten the baffles system together and keep it in position. In general, tie rods can maintain the distance between the tube sheet and baffles and tube joints [14].

2.5 Flow in Heat Exchanger Pipe

There are 3 types of flow that are generally found, namely laminar flow, transitional flow, and turbulent flow. Osborne Reynolds (1841-1912), a scientist and mathematician from England, was the first to distinguish these two flow classifications using a simple apparatus as shown below:

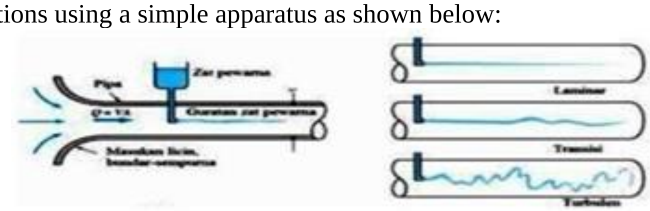

Figure 6. Types of Flow in Pipes

For flow in a pipe having a circular cross section, the Reynolds number is defined as follows:

$$Re = \frac{\rho \mu D}{\mu} = \frac{G\,D}{\mu} = \frac{4\,m}{\pi\,D\,\mu}$$

Where :

Re = Reynolds number
ρ = Density (Kg/m3)
μ = Average fluid velocity (m/s)
D = Pipe Diameter (m)
G = Mass Velocity (Kg/m2.s)
μ = Dynamic Viscosity (N.s/m2)
m = Mass Flow Rate of Fluid (Kg/s)

For pipe flows that are not circular in cross-section, the Reynolds number depends on the hydraulic diameter Dh.

$$Dh = 4\frac{A_c}{P}$$

Where:

Dh = Hydraulic Diameter (m)
Ac = Cross-sectional Area (m2)
P = Perimeter of the cross-section (m)

After calculating the Reynolds number, the type of flow can be determined with the following parameters: Re < 2300 Laminar Flow, 2300 ≤ Re ≤ 10000 Transitional, and Flow Re > 10000 Turbulent Flow. The average Nusselt number for laminar flow developing in a pipe with a circular cross-section can be determined by the Sieder and Tate (1936) equation, namely:

$$Nu = 1{,}86\left(\frac{Re\ \mathrm{Pr}\ D}{L}\right)^{1/3}\left(\frac{\mu b}{\mu\delta}\right)^{0{,}14}$$

Where:

Nu = Nuselt Number
Re = Reynolds Number
Pr = Prandtl Number
D = Pipe Diameter (m)
L = Pipe Length (m)

All fluid properties are calculated at the average fluid temperature, except those calculated at the pipe surface temperature. The empirical equation for fluid flow through a series of pipes is as follows:

$$Nu = C\,(Re)^{n}\,Pr^{1/3}$$

For a fully developed turbulent flow in a smooth pipe, a simple equation for calculating the Nusselt number can be obtained which is

$$Nu = C\,(Re)^{n}\,Pr^{1/3}$$

For a fully developed turbulent flow in a smooth pipe, a simple equation for calculating the Nusselt number can be obtained which is

$$Nu = 0{,}023\ Re\ 0{,}8\ Pr^{1/3}$$

Provided that 0.7 Pr 160 and Re > 10000

The above equation is called the Colburn equation. The accuracy of the above equation can be improved by modifying it to be:

$$Nu = 0{,}023\ Re^{0{,}8} Pr^{\ n}$$

For the heating process used n = 0.4 and for the cooling process used n = 0.3. This equation is called the Dittus Boelter equation (1930) and it is better than the Colburn equation.

Flow Inside Annulus Pipe

Some simple heat transfer equipment, consisting of two concentric tubes which are commonly called double pipe heat exchangers. In such a device, one fluid flows through the pipe and another through the annulus. Assuming the inner diameter Di and the outer diameter Do, the hydraulic diameter of the annulus is:

$$Dh = Do - Di$$

Where:

Dh = Hydraulic Diameter (m)
Do = Tube Outside Diameter (m)
Di = Tube Inner Diameter (m)

In a concentric heat exchanger, there are two Nusselt numbers, namely on the inside of the pipe and on the outside of the pipe. The Nusselt number for laminar flow is fully developed with a constant temperature surface and is adiabatic. There are two values of the heat transfer convection coefficient number that can be searched by first finding the value of the Nusselt number, namely the value of the heat transfer convection coefficient inside the pipe with the following calculation:

$$N\mu_i = \frac{hi\ Dh}{K}$$

Where

$N\mu i$	= Inner Nusselt Number
hi	= Inner Pipe Heat Transfer Coefficient (W/m^2 K)
Dh	= Hydraulic Diameter
K	= Thermal Conductivity (W/m.K)

Meanwhile, to find the value of the convection heat transfer coefficient on the outside of the pipe, it can be searched with the following calculations:

$$N\mu_o = \frac{ho\ Dh}{K}$$

$N\mu_o$	= Nusselt Number of Outer Tube
ho	= Coefficient of Heat Transfer Outside Pipe (W/m2.K)
Dh	= Hydraulic Diameter
K	= Thermal Conductivity (W/m.K)

2.6 Fooling Factor

Fouling factor is the formation of a layer on the heat transfer surface of an unwanted material or compound. To get the value of the effect of the fouling factor, you can use the following equation:

$$\frac{1}{UA} = \frac{1}{Ui\,A} = \frac{1}{Uo\,A} = R\frac{1}{hi.Ai} + \frac{Rf\,i}{Ai} + \frac{\ln\left(\frac{Do}{Di}\right)}{2\pi.k.L} + \frac{Rfo}{Ao} + \frac{1}{ho.Ao}$$

The following are the values of the fouling factor for some fluids commonly used in heat exchangers [3].

Table 2. Fouling Factors for Various Types of Fluids

Fluid	Fouling Factor
Destiled Water, Sea Water, River Water, Boiled Feedwater :	
1. Below	0,0001 $R_{f.}$ $m^2.^oC/W$
2. Above	0,0002 $R_{f.}$ $m^2.^oC/W$
Fuel Oil	0,0009 $R_{f.}$ $m^2.^oC/W$
Steam (Oil Free)	0,0001 $R_{f.}$ $m^2.^oC/W$
Refrigants (Liquid)	0,0002 $R_{f.}$ $m^2.^oC/W$
Refrigants (Vapor)	0,0004 $R_{f.}$ $m^2.^oC/W$
Alcohol	0,0001 $R_{f.}$ $m^2.^oC/W$
Air	0,0004 $R_{f.}$ $m^2.^oC/W$

3. RESEARCH METHOD

In this research, it takes several stages to be able to produce good writing. The following is an explanation of the stages / process of making shell and tube heat exchangers.

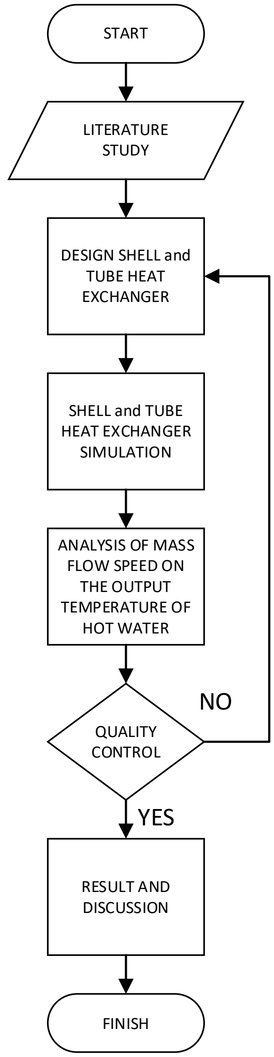

Figure 7. Design Flowchart Shell and Tube Heat Exchanger

3.1 Heat Exchanger Design

The next stage of the literature study that has been carried out previously is to design a Heat Exchanger using the Solidworks 2019 software, by making each part (component) and then assembly it so that it becomes a single unit in the form of a Heat Exchanger tool that can be well simulated.

Figure 8. Heat Exchanger Shell and Tube

3.2 Heat Exchanger Components

The Heat Exchanger in this design has several components, including:

3.3 Shell

The shell is the body of the Heat Exchanger device, where there is a tube bundle inside. Shell construction is largely determined by the capacity and condition of the tube that will be placed in it. The following is an image of the Heat Exchanger tool shell design.

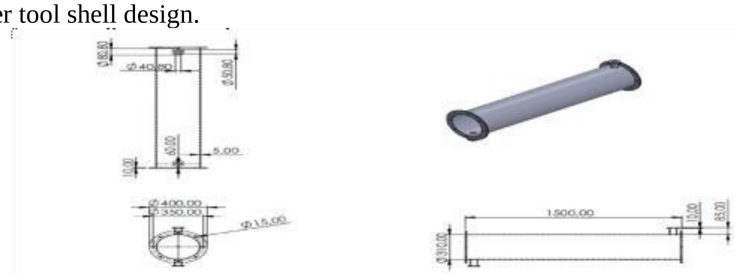

Figure 9. Shell

3.4 Tube & Baffles

Tube is a dividing field between two flowing fluids and at the same time a displacement field hot. The following is a picture of the tube & baffle design for the Heat Exchanger.

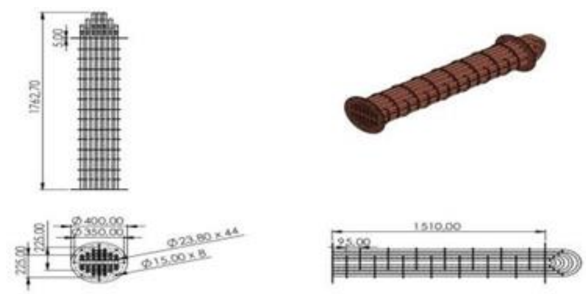

Figure 10. Tube and Baffle

3.5 Stationery Head

Stationery Head is one end of the heat exchanger. In this section there is a fluid inlet that flows into the tube and exits the fluid into the system.

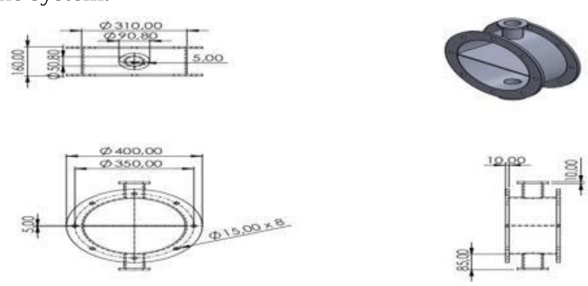

Figure 11. Stationery Head

4. RESULT AND DISCUSSION

The design simulation carried out in this test only varies the mass flow velocity data at the cold water inflow and compares it with the hot water outlet temperature at the tube section. Meanwhile, the mass flow velocity at the hot water inlet uses the same number in this test, namely 1 Kg/s. The following is a simulation result of the shell and tube heat exchanger design with variations in mass flow velocity at the inlet temperature of cold water to the temperature of hot water outlet:

4.1 Mass Flow Rate 5 Kg/s

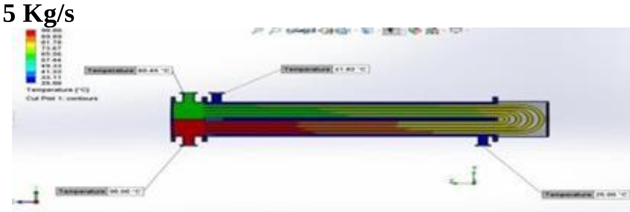

Figure 12. Results of Shell and Tube Heat Exchanger Analysis with Mass Flow Rate 5 Kg/s

At a mass flow velocity of 5 Kg/s for the cold water inlet temperature the results obtained are the hot water outlet temperature is 60.45℃.

4.2 Mass Flow 10 Kg/s

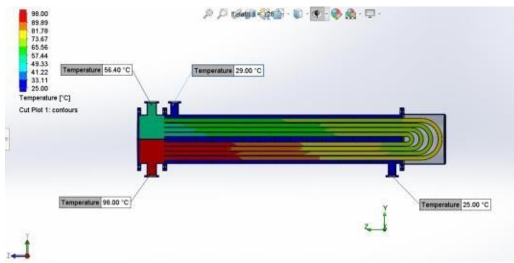

Figure 13. Results of Shell and Tube Heat Exchanger Analysis with Mass Flow Rate 10 Kg/s

At the mass flow velocity, the inlet temperature of cold water is 10 Kg/s the results obtained at the outlet temperature of hot water are 56.40 , which means that there is a decrease in temperature of 4.05.

4.3 Mass Flow 15 Kg/s

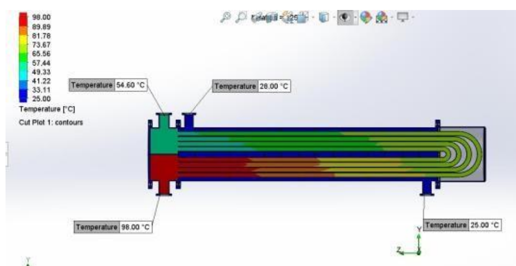

Figure 14. Analysis Results of Shell and Tube Heat Exchanger with Mass Flow Rate 15 Kg/s.

At the mass flow velocity at the inlet temperature of cold water of 15 Kg/s the results obtained at the outlet temperature of hot water are 54.60℃ or a difference of 5.85 from the results of the first test and a difference of 1.8℃ from the results of the second test.

4.4 Mass Flow 20 Kg/s

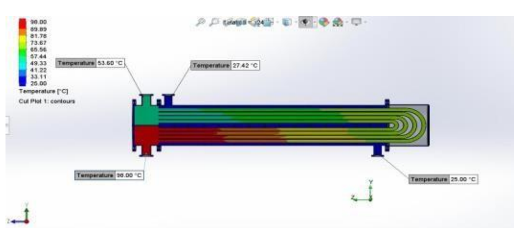

Figure 15. Analysis Results of Shell and Tube Heat Exchanger with Mass Flow Rate 20 Kg/s.

At the mass flow velocity at the cold water inlet temperature of 20 Kg/s the results obtained at the hot water outlet temperature are 53.60ºC or a difference of 6.85 ºC from the first test, 2.8ºC from the second test and 1 from the third test.

4.5 Mass Flow 25 Kg/s

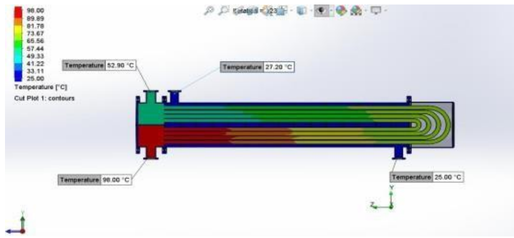

Figure 16. Analysis Results of Shell and Tube Heat Exchanger with Mass Flow Rate 25 Kg/s.

At the mass flow velocity at the inlet temperature of cold water with a value of 25 Kg/s the results obtained at the outlet temperature of hot water are 52.90 ºC or a difference of 7.55 ºC from the first test, 3.5 ºC from the second test, 1.7 ºC of the third and only test 0.7 of the fourth test. 6. 30 Kg/s.

4.6 Mass Flow 30 Kg/s

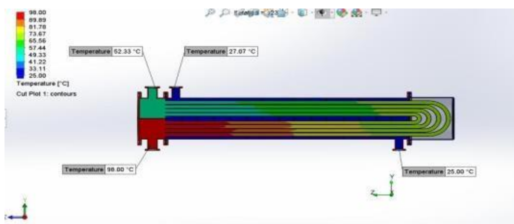

Figure 17. Analysis Results of Shell and Tube Heat Exchanger with Mass Flow Rate 30 Kg/s.

At the mass flow velocity, the inlet temperature of cold water is 30 Kg/s The results obtained at the exit temperature of hot water is 52.33 ºC or there is a difference of 8.12 ºC from the first test, 4.07 ºC from the results of the second test, 2.27 ºC from the third test result, 1.27 ºC from the fourth test result, and only 0.57 ºC from the results of the fifth test. The following is a graph of the results of the comparison of the mass flow velocity at the inlet temperature of cold water with the outlet temperature of hot water at the tube section.

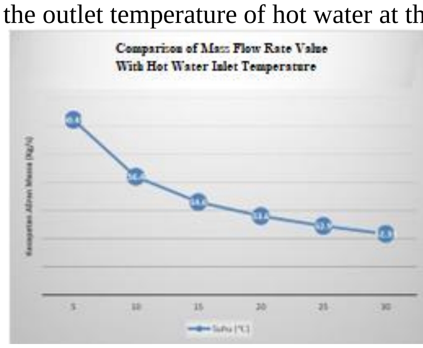

Figure 18. Comparison Graph of Mass Flow Rate Value of Cold Water Inflow with Hot Water Out Temperature

5. CONCLUSION

The following are conclusions that can be drawn from the tests and analyzes that have been carried out:

1. The test results show that every increase of a multiple of 5 Kg/s there is a decrease in the average fluid temperature of 1.44ºC.
2. Accelerating the mass flow rate can be quite helpful in reducing the temperature of the shell and tube heat exchanger.

3. The lowest temperature that can be achieved in this test is 80.63 ºC and there is a difference of 7.18 ºC with a difference in mass flow velocity of 25 Kg/s

5.2 Suggestion

The following are suggestions that can be given by the author regarding the tests that have been carried out and are expected to be evaluation material for students, especially mechanical engineering students:

1. Widening the diameter of the shell and tube will provide better heat transfer performance.
2. Replace the tube material with a material that can transfer and release heat faster, such as Cooper (Copper)

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