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Coefficient Analysis of Shell and Tube Type Heat Exchangers

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Abstract. Heat exchanger is a device used to transfer heat between two fluid systems at different temperatures. In this research, the heat exchanger used is in the form of a shell and tube which studies the mechanism of heat transfer between hot water and cold water both in contra flow. The purpose of this research is to analyze the relationship of heat transfer coefficient with changes in flow regime in shell and tube contra flow heat exchanger. This research was carried out by measuring the inlet and outlet water temperatures for the counter flow configuration, then analyzing the effectiveness calculation using the LMTD method. As a result, the inlet and outlet water temperature values for the counter flow configuration are obtained, then the effectiveness of the heat exchanger is assessed using the LMTD formula where the effectiveness of the heat exchanger for counter flow. The purpose of the research is to understand the heat exchanger system and analyze the performance of the shell and tube heat exchanger.

Keyword: Counter Flow; Heat Exchanger; Shell and Tube.

1. Introduction

Heat exchanger is an important tool in various industrial processes to generate heat or cooling. One type of heat exchanger that is often used is shell and tube. This type of heat exchanger has a main component in the form of a pipe bundle (tube bundle) placed inside the casing (shell). Heat is transferred between two fluids flowing inside the tube and outside the tube. There are several types of fluid flow directions in this heat exchanger, namely parallel flow, counter flow, and cross flow. The type of flow direction affects the performance of the heat exchanger in transferring heat. Counter flow is considered the most effective type because the hot and cold fluid temperatures are opposite (Septian et al., 2021). Therefore, this study aims to analyze the performance of shell and tube heat exchangers with variations in pump discharge. The parameters measured include inlet and outlet temperatures and heat transfer efficiency. The results are expected to show which pump discharge is most effective for transferring heat in shell and tube heat exchangers.

Some types of flow for heat transfer based on a single route are parallel flow, counter flow, cross flow, split flow and devided flow (Wicaksono et al., 2018). However, in reality, many technicians do not fully understand how this heat transfer system in a machine tool, where in the world of work later inevitably students will struggle with these concepts, especially in system systems that use heat exchangers.

2. Method

The methodology used in the preparation of this report is experimental. This research uses theoretical foundations to support this research, including conduction, convection, radiation, thermal conductivity, thermal diffusivity.

2.1 Conduction

Conduction is the process of heat transfer that flows from a higher-temperature object to a lower-temperature object through a stationary connecting object (not in flow). The rate of heat conduction through the medium depends on the geometry of the medium, thickness, and material of the medium, as well as the temperature difference in the medium (Haryanto, 2017). As for calculating conduction heat transfer, the following formula can be used.

$$Q = -kA\frac{\Delta T}{\Delta X} \tag{1}$$

Where is:

Q = Heat transfer rate by conduction
k = Thermal conductivity of the material
A = Surface area
ΔT = Temperature change
ΔX = Distance perpendicular to the surface

2.2 Convection

Convection is the process of heat transfer from a higher temperature object to a lower temperature object through a medium, where the medium must have fluid properties (thermal conductivity, specific heat and density) (convection). An example of convection is water heating, where the rotation of water occurs due to temperature differences (Setyoko, 2008). To calculate the heat transfer by convection between a surface and a fluid, the following formula can be used.

$$q = h\,A_s\,(T_s - T_\infty) \tag{2}$$

Where is:

q = Rate of heat transfer by way of convection
h = Convection heat transfer coefficient
A_s = Heat transfer area
T_s = Surface temperature of solid object
T_∞ = Flowing fluid temperature

2.3 Radiation

Radiation is the process of transferring heat from a high-temperature object to a low-temperature object where no connecting substance or object is needed, and heat radiates by means of electromagnetic wave radiation. Radiation heat transfer in this tool occurs in the solar collector absorber. The radiation event emitted by the sun, and converted in the form of heat occurs on the absorber plate and the influence of the surface emissivity of the black body (absorber plate) (Haryanto, 2017). To calculate the amount of heat emitted, the following formula can be used.

$$Q = \varepsilon\sigma A_s T_s^4 \tag{3}$$

Where is:

Q = Radiation transfer rate (Watt)
ε = Emissivity
σ = Stefen-Boltzmann constant (5,67 x 10-8 W/m2 K4)
A_s = Surface area (m^2)9
T_s^4 = Absolute temperature of the surface of the object emitting radiant heat ^{0}K)

2.4 Thermal Conductivity

Thermal conductivity is a quantity that states the ability of a material to conduct heat. The thermal conductivity value of a material is certainly different. The relationship between the value of thermal conductivity with the ability to conduct heat is proportional. This means that the greater the thermal conductivity value, the greater the ability to conduct heat (Rinaldi, 2016). Conductivity is calculated using the following equation.

$$k = \alpha \times \rho \times C_p \tag{4}$$

Where is :

k = Heat conductivity (W/cm K)
ρ = Specimen density (g/cc)
C_p = Specimen heat capacity (kal/mol K)

2.5 Thermal Diffusivity

In conventional heat application, the thermal diffusivity of a material is a physical property of the material that determines the speed of heat distribution in the material. Thermal diffusivity is a property that naturally distributes heat throughout the product. The greater the thermal diffusivity value, the faster the heat dissipation will occur in the material and apply otherwise (Safitri & Waluya, 2020). Thermal diffusivity properties of materials used to analyze the conduction of heat that occurs in the material. The nature of thermal diffusivity is influenced by the moisture content of the material, the chemical composition of the material and the structure of the material. Thermal diffusivity is formulated by the following equation.

$$\alpha = \frac{k}{\rho c_p} \tag{5}$$

Where is:

α = Thermal diffusivity (m²/s)
k = Thermal conductivity (W/(m.K))
ρ = Densitas (kg/m³)
c_p = Kalor jenis (J/(kg·K))

2.6 Heat Exchanger Effectivities

The LMTD approach in heat exchanger analysis is useful if the inlet and outlet temperatures are known so that LMTD can be calculated, heat flow, surface area and overall heat transfer coefficient (Irwin & Rahmat, 2013). The effectiveness method has several advantages in analyzing and selecting the best type (Mutaqin et al., 2012). Heat exchanger effectivities are defined as:

$$LMFTD_{pf} = \frac{\Delta T1 - \Delta T2}{\ln(\frac{\Delta T_1}{\Delta T2})} = \frac{(th_1 - tc_2) - (th_2 - tc_1)}{ln\frac{(th_1 - tc_2)}{(th_2 - tc_1)}} \tag{6}$$

Where is:

ΔT = Temperature change
th = Hot liquid inlet temperature
tc = Cold liquid inlet temperature

3. Result and Discussion

The following is the data from the input of temperature and hot and cold fluid discharge:

Table 1. Data Observation Results

Cross Flow	Observation Results					
	High Temp			Low Temp		
	Thermometer		Flow Rate	Thermometer		Flow Rate
	Inlet	Outlet		Inlet	Outlet	
	T_1	T_2	W(kg/h)	t_1	t_2	W(kg/h)
A	86,93	71,23	2340	30,4	32,5	1296
C	74,73	69,73	1296	30,73	32,03	1296
E	76,07	72,27	2340	30,6	32,37	2340
G	86,33	67,17	1980	30,4	32,63	1296
I	81,6	68,6	1296	30,6	31,74	1980

3.1 Kinematic Viscosity

Here is the calculation of kinematic viscosity from data E:

3.1.1 High Temperature

$$(T_1 + T_2) / 2 = (76{,}067 + 72{,}267) / 2 = 74{,}167\ oC$$

V_h according to the water property table using the interpolation formula as follows:

$$\frac{\frac{T_1 + T_2}{2} - 80°C}{70°C - 80°C} \; x \; V_h \; 70°C + \frac{\frac{T_1 + T_2}{2} - 70°C}{80°C - 70°C} \; x \; V_h 80°C$$

$$\frac{74{,}17°C \; - 80°C}{70°C - 80°C} \; x \; 4{,}15.10^{-7} + \frac{74{,}17°C - 70°C}{80°C - 70°C} \; x \; 3{,}67.10^{-7}$$

$$= \; 3{,}95 \,.\, 10 - 7 \; m^2/s$$

3.1.2 Low Temperature

$$(t_1 \; + \; t_2)\,/\,2 \; = \; (30{,}6 \; + \; 32{,}367)\,/\,2 \; = \; 31{,}485 \; oC$$

V_i according to the water property table using the interpolation formula as follows:

$$\frac{\frac{T_1 + T_2}{2} - 40°C}{30°C - 40°C} \; x \; V_i 30°C + \frac{\frac{T_1 + T_2}{2} - 30°C}{40°C - 30°C} \; x \; V_i \; 40°C$$

$$\frac{31{,}485 - 40°C}{30°C - 40°C} \; x \; 8{,}04.10^{-7} + \frac{31{,}485 - 30°C}{40°C - 30°C} \; x \; 6{,}61.10^{-7}$$

$$= \; 7{,}82.10^{-7} \; (m^2/s)$$

The following table is the result of the calculation of kinematic viscosity at high and low temperatures at each pump discharge variable.

Table 2. Data Processing Results

Cross Flow	**Processing Results**			
	High Temp		**Low Temp**	
	Kinematic Viscosity			
	(T_1+T_2)/2	**Vh (m^2/s)**	**(t_1+t_2)/2**	**Vi (m^2/s)**
A	79,08	3,71416E-07	31,45	7,83265E-07
C	72,23	4,04296E-07	31,38	7,84266E-07
E	74,17	3,94984E-07	31,485	7,82765E-07
G	76,75	3,826E-07	31,515	7,82336E-07
I	75,1	3,9052E-07	31,17	7,87269E-07

3.2 Variable E Calculation

After calculating the kinematic viscosity, the next step is to calculate the average temperature difference (°C), that is Q_w (heat released) & q_w (heat received), high temperature and low temperature flow velocity, efficiency, heat transmission coefficient obtained from the test with the comparison of each pump discharge variable. Here is an example of the calculation of variable E:

3.2.1 Average Temperature Difference (°C)

$$\Delta T_m = \frac{[(T_1 - t_2) - (T_2 - t_1)]}{[ln(T_1 - t_2) - (T_2 - t_1)]}$$

$$\Delta T_m = \frac{[(76{,}07 - 32{,}37) - (72{,}26 - 30{,}6)]}{[ln(76{,}07 - 32{,}37) - (72{,}26 - 30{,}6)]}$$

$$\Delta T_M = 42{,}671 \; oC$$

3.2.2 Heat Released and Heat Received

a. Heat Released

$$Q_w = W \times C_p \times (T_1 - T_2)$$

$$Q_w = 2340 \; kg/hour \times 1 \times (kcal/kg°C) \times (76{,}07 - 72{,}27)°C$$

$$Q_w = 8915{,}4 \; (kcal/hour)$$

b. Heat Received

$$q_w = W \times C_p \times (t_2 - t_1)$$

$$q_w \; = \; 2340 \; kg/jam. 1 \times \; (kcal/kg°C)\,.\,(32{,}37 - 30{,}6)°C$$

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$$q_w = 4141{,}8\ (kcal/hour)$$

3.2.3 High Temperature and Low Temperature Flow Velocity

a. High Temperature

$$Rew = (D \times V_h(m/s))/V_h(m^2/s)$$
$$Rew = (0{,}02\ m\ .\ 2{,}07\ (m/s))\ /\ 3{,}95\ .\ 10 - 7\ m2/s$$
$$Rew = 104811{,}2288$$

b. Low Temperature

$$Rew = (D \times V_i(m/s))/V_i(m^2/s)$$
$$Rew = (0{,}02\ m\ .\ 2{,}07\ (m/s))\ /\ 7{,}82.\ 10^{-7}\ (m2/s)$$
$$Rew = 52891{,}1$$

3.2.4 Efficiency

$$\eta h\ =\ [(W \times C_p \times (T_1 - t_2))/(W \times C_p \times (T_1 - t_1))]$$
$$\eta h\ =\ [(2340\ kg/jam \times 1 \times (kcal/kg)°C)\ (76{,}07 - 32{,}37)°C/\ 2340/jam \times 1 \times (kcal/kg)°C) \times (76{,}07 - 30{,}6))°C]$$
$$\eta h = 96{,}11\ \%$$

3.2.5 Koefisien Transmisi Kalor

$$U = q/(A \times \Delta T_m) \times 20$$
$$U = 6528{,}6/(0{,}00376\ .\ 42{,}671)) \times 20$$
$$U = 812077{,}4567\ kcal/m^2\ hour\ °C$$

Table 3. Combined Calculation Result

<table>
<tr><td colspan="2" rowspan="5">Instru.
(Equation)</td><td colspan="5">Calculation</td></tr>
<tr><td colspan="3">Logarithmic Mean-Temp Difference</td><td colspan="2">High Temp</td></tr>
<tr><td>T_1-t_2</td><td>T_2-t_1</td><td rowspan="3">ΔT_m</td><td rowspan="3">Q_w</td><td rowspan="3">Reynolds Number</td></tr>
<tr><td colspan="2">Counter Flow</td></tr>
<tr><td>ΔT_1</td><td>ΔT_2</td></tr>
<tr><td rowspan="13">Cross Flow</td><td>A</td><td>54,43</td><td>40,83</td><td>47,30797</td><td>36738</td><td>111473,543</td></tr>
<tr><td>C</td><td>42,70</td><td>39,00</td><td>40,82206</td><td>6480</td><td>56715,714</td></tr>
<tr><td>E</td><td>43,70</td><td>41,66</td><td>42,67187</td><td>8915,4</td><td>104811,2288</td></tr>
<tr><td>G</td><td>53,70</td><td>36,77</td><td>44,70195</td><td>37936,8</td><td>91562,59052</td></tr>
<tr><td>I</td><td>49,86</td><td>38,00</td><td>43,6619</td><td>16848</td><td>58716,41992</td></tr>
<tr><td rowspan="3"></td><td>Efficiency of Heat Exchanger</td><td colspan="2">Coefficient of Everall Heat Trans</td><td colspan="2">Low Temp</td></tr>
<tr><td>Cross Flow</td><td rowspan="2">Q</td><td>Cross Flow</td><td rowspan="2">q_w</td><td rowspan="2">Reynolds Number</td></tr>
<tr><td>ηh</td><td>U</td></tr>
<tr><td>A</td><td>96,29</td><td>19729,8</td><td>2213642</td><td>2721,6</td><td>29274,81287</td></tr>
<tr><td>C</td><td>97,05</td><td>4082,4</td><td>530810,8</td><td>1684,8</td><td>29237,44789</td></tr>
<tr><td>E</td><td>96,11</td><td>6528,6</td><td>812077,5</td><td>4141,8</td><td>52891,09801</td></tr>
<tr><td>G</td><td>96,01</td><td>20413,44</td><td>2423867</td><td>2890,08</td><td>29309,59455</td></tr>
<tr><td>I</td><td>97,76</td><td>9552,6</td><td>1161283,9</td><td>2257,2</td><td>44497,93798</td></tr>
</table>

The table above is the result of the calculation of the 5 variables calculating the average temperature difference (°C), heat released & heat received, high temperature and low temperature flow speed, efficiency, heat transmission coefficient.

3.3 The Results of the Heat Transfer Coefficient Analysis

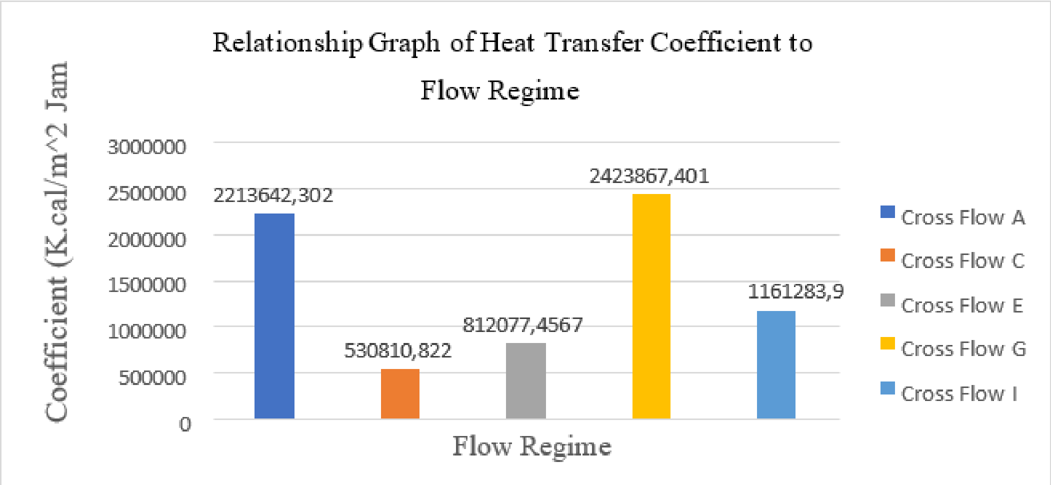

Figure 1. Relationship Graph of Heat Transfer Coefficient to Flow Regime

From the graph above, 5 data on the heat transfer coefficient of the flow regime. Group A has a coefficient of 2213642.302 K.cal/m^2.h °C; group C has a coefficient of 530810.822 K.cal/m^2.h °C; group E has a coefficient of 812077.4567 K.cal/m^2.h °C; group G has a coefficient of 2423867.401 K.cal/ m^2.h °C; group I has a coefficient of 1161283.9 K.cal/ m^2.h °C. Of the 5 groups, 2 of the groups A and G got higher coefficients than 3 groups, namely C, E and I. This is because the 2 groups that get the highest coefficient of the valve opening variable and also the hot fluid flow rate are higher than the cold fluid, inversely proportional to the 3 group variables that have the lowest coefficient. Group E only gets a coefficient of 812077.4567. This is because if the hot fluid inlet temperature (Thi) is fixed, an increase in fluid flow velocity (V) will cause an increase in the overall heat transfer coefficient (U).

The relationship between temperature and heat exchanger length in a cross flow configuration can be analyzed through the temperature profile along the heat exchanger. The longer the heat exchanger, the larger the surface area inside the heat exchanger body. A larger surface area means there are more surfaces for the heat transfer process between the fluid inside the heat exchanger body and the fluid outside the shell. This causes the heat transfer rate to be even greater. In a counterflow configuration, the two fluids move in opposite directions to each other, which usually results in higher heat transfer efficiency compared to a parallel flow configuration.

4. Conclusion

A heat exchanger system is used as a tool to transfer heat between two systems without mass transfer. The type of heat exchanger used in this experiment is shell and tube, which is the most common type of heat exchanger. In general, this system consists of a shell that functions as an outer casing, and tubes that pass through the casing to flow the fluid to be heated or cooled.

The heat transfer coefficient in a heat exchanger is strongly influenced by the flow regime of the fluid flowing in it. If the flow is laminar, the coefficient will be relatively lower due to the dominance of the heat conduction process. Conversely, in turbulent flow, the coefficient will be higher due to convection and intense fluid mixing which facilitates the heat transfer process.

Of the 5 data on the heat transfer coefficient of the flow regime of the 5 groups, 2 of the groups A and G got high coefficients from the 3 groups, namely C, E and I. This is because the 2 groups that get the coefficient are the ones that get the highest coefficients. This is because the 2 groups that get the highest coefficient of the valve opening variable and also the hot fluid flow rate is higher than the cold fluid, inversely proportional to the 3 group variables that have the lowest coefficient.

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