Performance of Shell and Tube Heat Exchanger 1-1 Counter Current Formalin (Shell) – Water (Tube) Fluid Systems in Industry

Ariani Ariani[1], Abdul Chalim[2], Hardjono Hardjono[3]., Anang T.

[1,2,3] Chemical Engineering, Politeknik Negeri Malang, Malang, Indonesia
ariani@polinema.ac.id, abdul_chalim@polinema.ac.id,
hardjono@polinema.ac.id, anang_takwanto@polinema.ac.id

Abstract. Performance a heat exchanger is an important tool for the adhesive industry as it provides thermal energy between two or more liquids at different temperatures without any mass transfer. One of these is the formalin manufacturing industry. Formalin is produced by a complete conversion process of methanol, a silver catalyst, and formox, which requires a cooling process. Water can be used as a coolant. This study aims to obtain data on the effect of cold fluid flow rate, hot fluid inlet temperature, and concentration on the efficiency of a formalin-water fluid system using a shell and tube heat exchanger type 1-1. The variables used in this study were the flow rate of cold fluid (water):2.0; 2.5; 3.0; 3.5; 4.0 liters/minute, the temperature of the hot fluid (formalin) is 40, 50, 60 oC, and the concentration of the hot fluid (formalin) is 6, 9, 12, 15 and 18% v/v. From the results of the study, it can be concluded that the efficiency of the tool increases with an increase in the flow rate of the cold fluid (water). The highest efficiency of 86% was obtained at a cold fluid (water) of 3.5 L/min. The higher the temperature of the hot fluid (formalin) under various conditions, the lower the efficiency value. The highest efficiency value at a temperature of 40oC. The efficiency of the tool tended to increase as the concentration of hot fluid increased. The optimal concentration of hot fluid (formalin) was 12% v/v, with an efficiency value of 86.33%.

Keywords: Performance, heat exchanger (HE), formalin (shell) – water (tube).

1 Introduction

In today's modern era, energy is a basic requirement that is important for human life. Almost all human activities are related to energy; therefore, the need for these activities is increasing. The increasing demand for energy requires energy efficiency. One way to increase efficiency is to take energy from different sources that can be used, namely heat energy (Kuppan, 2013). Thus, a tool is required to obtain the heat source, namely, a heat exchanger. A heat exchanger (HE) is a device used in the process of fluid heat transfer with other fluids, without mass transfer (Manfred, 2015). Chalim et al. (2020) conducted a study on the effectiveness and efficiency of shell-and-tube heat exchangers 1-1. Water was used as the hot and cold fluid. The variables used were the

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incoming hot-fluid temperature, coolant concentration, and flow rate of the hot and cold fluids. The results showed that the effectiveness of shell and tube type 1-1 was 0.81, and the efficiency of the tool was 76.61% (Chalim et al, 2017) in their research used the variables of cold and hot fluid flow rates, incoming hot fluid temperatures, and the ratio of the volume of the blending solution. The results showed that propylene glycol - ethylene glycol fluid with a volume ratio of 1:1 was more effective than diethylene glycol - methanol fluid. The effectiveness value obtained was 0.95 with an NTU of 3.31. (Pratomo, et.al, 2022) also conducted a similar study. The cold fluid used was glycerin water. The results of this study obtained the best effectiveness value for a 50% volume ratio of 0.97, with an NTU of 5.02. Therefore, in this study, a formalin – water system was used using a shell and tube 1-1 heat exchanger to obtain data on the effects of cold fluid (water) flow rate, incoming hot fluid (formalin) temperature, and hot fluid (formalin) concentration.

2 Literature Review

2.1 Heat exchanger

It is a device with a heat transfer flow between two or more fluids at different temperatures (Mota, et, al, 2015). A fluid with a higher temperature transfers heat to the fluid at a lower temperature (Bizzy, et, al, 2013). There are several types of heat exchangers, one of which is a shell and tube, which is a popular and widely used heat exchanger. The shell and tube consist of several tubes mounted on a cylindrical shell (Kuppan, 2013). The hot fluid in the shell and tube unit is prioritized for flow in the shell, and the heated fluid flows in the tube so that heat can be transferred to the outside (towards the heated fluid) (Eryener, 2006).

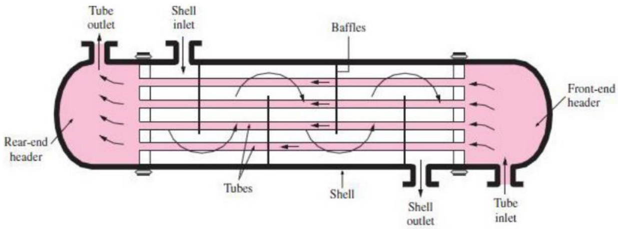

Fig. 1. Shell and tube heat exchanger 1-1 (Kern, 1965)

2.2 Flow type in heat exchanger 1-1

In a heat exchanger, there are two types of flow in the heat exchanger (Reddy, et, al, 2015):

- Counter current flow

is a countercurrent flow, where the fluid enters at one end, whereas the other fluid enters at the other end and flows in the opposite direction. The countercurrent flow type provides better heat than the direct or parallel flow. The number of passes also affected the effectiveness of the heat exchanger used.

- Parallel flow/co-current

is a unidirectional flow, where both fluids enter at the same end and both fluids flow in the same direction towards the other end of the heat exchanger.

2.3 Heat transfer

The energy moves from higher to lower temperatures. The temperature difference is the driving force for the energy transfer. Heat transfer continued until temperature equilibrium occurred in the two media. Heat transfer can occur through conduction, convection, and radiation (Kuppan, 2013), (Egeten, 2014). Heat transfer is concerned with objects that give off and receive heat. The calculation of the amount of heat released and received is the same; this is called heat balance (Kern, 1965).

$$Q = W_h x C_{p,h} x (T_{hi} - T_{ho}) = W_c x C_{p,c} x (T_{ci} - T_{co}) \quad (1)$$

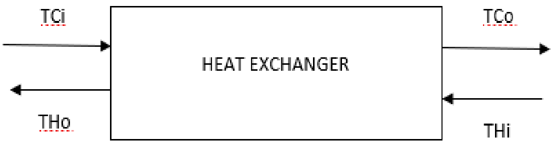

Fig. 2. Skema heat exchanger (Geankoplis, 2003)

2.4 Log mean temperature *difference* (ΔT_{LMTD})

Average value of the temperature difference between hot and cold fluids. TLMTD represents the amount of heat transferred from hot to cold fluids. ΔTLMTD represents the amount of heat transferred from hot to cold fluids. The larger the value of ΔTLMTD, the greater the heat transferred. To determine the value of ΔTLMTD, (Geankoplis, 2003).

$$\Delta T_{LMTD} = \frac{(Thi - Tco) - (Tho - Tci)}{\ln\frac{(Thi - Tco)}{(Tho - Tci)}} \quad (2)$$

2.5 Overall heat transfer coefficient (U)

The amount of heat transfer ability from a fluid that has a higher temperature to a fluid that has a lower temperature is an overall heat flow as a combination of convection and conduction processes. The overall heat transfer coefficient can be expressed as follows in the equation (Geankoplis, 2003) :

$$U = \frac{Q}{A \text{ x } \Delta LMTD} \quad (3)$$

2.6 Effectiveness

Is the heat transfer unit, which is a measure of the heat exchanger. The higher the NTU value, the greater the thermodynamic limit (Hasanuzaman, et. al, 2011).

$$NTU = \frac{\text{U A}}{\text{Cmin}} \tag{4}$$

The effectiveness of heat exchanger is the ratio of the actual heat transfer rate in the heat exchanger to the rate of heat exchange that may occur. The effectiveness of the heat exchanger is defined (Hasanuzaman, et. al, 2011).

$$\varepsilon = \frac{Q}{\text{Qmaks}} \tag{5}$$

To define the effectiveness of a heat exchanger, the maximum possible heat--transfer rate (Qmax) must first be determined. The maximum flow rate is obtained when one of the fluids experiences a temperature change in~~of~~ the maximum temperature difference, that is the difference between the inlet temperatures of the hot (Thi) and cold (Tci) fluids. The fluid experiencing the maximum temperature difference is the fluid with the minimum heat capacity, because the equilibrium energy received by the fluid is the same as the energy released by another fluid. So the maximum heat transfer rate (Geankoplis, 2003) :

$$Q_{\text{mak}} = C_{\text{min}}\ (T_{\text{hi}} - T_{\text{ci}}) \tag{6}$$

Where min is the smallest value between Ch or Cc, for example Cc < Ch then Cc = Cmin or vice versa, (Geankoplis, 2003) :

$$C_{\text{h}} = W_{\text{h}}\ x\ C_{p\text{h}} \tag{7}$$

$$C_{\text{c}} = W_{\text{c}}\ x\ C_{p\text{c}} \tag{8}$$

If Tco = Thi then the effectiveness value is sought by the equation (Geankoplis, 2003):

$$\varepsilon = \frac{C_h(T_{hi}-T_{ho})}{C_c(T_{hi}-T_{ci})} = \frac{C_{mak}(T_{hi}-T_{ho})}{C_{min}(T_{hi}-T_{ci})} \tag{9}$$

If, Tho = Tci then the value of effectiveness can be calculated by the equation (Geankoplis, 2003):

$$\varepsilon = \frac{C_c(T_{co}-T_{ci})}{C_h(T_{hi}-T_{ci})} = \frac{C_{mak}(T_{co}-T_{ci})}{C_{min}(C_{hi}-T_{ci})} \tag{10}$$

The effectiveness of the counter-current flow is calculated by the equation (Geankoplis, 2003)

$$\varepsilon = \frac{1-\exp\left[-\frac{U.A}{C_{min}}(1-\frac{C_{min}}{C_{mak}})\right]}{1-\frac{C_{min}}{C_{mak}}\exp\left[-\frac{U.A}{C_{min}}(1-\frac{C_{min}}{C_{mak}})\right]} \tag{11}$$

Specifications of HE shell and tubes 1-1

Table 1. Specifications for HE shell and tube 1-1

Heat Exchanger	Shell			Tube		
	Notation	Unit	Dimension	Notation	Unit	Dimension
Outside diameter				Odt	inch	0,25
Inside diameter	IDs	inch	7,87	Idt	inch	0,19
Number of baffle	N	unit	8			
Number of pass	N	unit	1	N	unit	1
BWG	22					
Distance between tubes				C"	ft	0,0052
tube length				L	ft	2,296
number of tubes				Nt	unit	72
pitch				Pt	inch	0,026
distance between baffles				B	ft	0,2624
surface per lin ft, ft^2				a'	ft^2	0,065
flow area				a't	$inch^2$	0,0302
tube arrangement	triangular pitch					

2.7 Physical and chemical properties of materials

In the experiment, a formalin - water solution was used. Physical and chemical properties of the materials used, Robert et.al 2016 :

Table 2. Physical and chemical properties of materials

Physical and chemical properties	Chemical compound	
	Water	**Formalin**
Form	liquid	Cair
Chemical formula	H_2O	CH_2O
Molecular mass	18 g/mol	30,026 g/mol

Color	Colorless	Colorless
Scent	No smell	Strong scent
Cp at 25°C	0,9989 cal/g °C	0,78 cal/g °C
pH	7	2,8 – 4,0
Freezing point	0 °C	-8 °C
Boiling point	100 °C	96 °C
Flash point	0 °C	62 °C (close cup)
Density at 25°C	0,997 g/cm^3	1,09 g/cm^3
Specific gravity	0,99823 g/mL (20°C)	1,11 g/mL (20°C)
Viscosity at 25°C	0,8937 cP	2,6 cP
Solubility	Soluble in all organic mate-rials, insoluble in aromatics and ethers	Soluble in water, etha-nol, methanol, acetone
Utility	Good use as solvent and heat transfer agent	As the production of urea formaldehyde and phenol formalde-hyde

Source: (MSDS formalin)

3 Research methods

The method begins by preparing cold fluid in the form of formalin with variable concentrations and water. Furthermore, the two fluids were placed in hot- and cold- fluid tanks . (Alan, E.E, Wijaya, W.H, 2017), The temperature of the fluid to be inserted into the tool is set according to these variable. Then, the flow rates of the hot and cold fluids are regulated, and the process is run. Based on the experimental data, the inlet and outlet temperatures of the cold and hot fluids were obtained. Furthermore, the data wereis used to obtain the overall heat transfer coefficient and effectiveness.

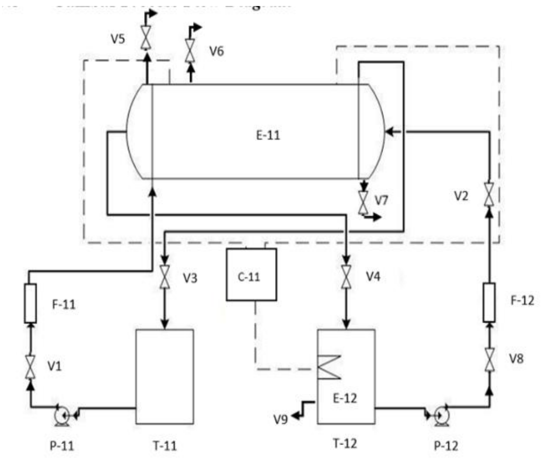

Fig. 3. Process Flow Diagram of HE Shell and Tube 1-1

Experimental variables

- Incoming cold fluid flow rate : 2.0 - 4.0 L/min
- Inlet hot fluid temperature: 40 - 60°C
- Concentration of hot fluid: 6 - 18% v/v

4 Results And Discussion

4.1 Effect of cold fluid flowrate variable

The industrial production process uses a cooling system to maintain the stability during production. The cooling system overcomes the occurrence of excessive heat (overheating) in the tool or reduces heat levels that are not needed so that the tool can operate properly (Muhammad, et.al, 2016), (Egeten, et. al, 2014), (Wicaksono, C., et. al, 2018) The addition of the cold fluid flow rate can affect the efficiency of the tool. A graph of the relationship between the cold fluid flow rate and efficiency at each concentration is presented in the following figure.

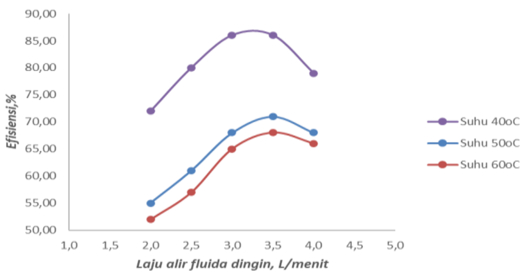

Fig. 4. Graph of relationship of cold fluid flowrate and efficiency value at 12% concentration

Based on Graph 4.1, the greater the flow rate of the cold fluid, the higher the efficiency of the tool tends to increase. This was due to the increase in heat transfer in the system as the flow rate of the cold fluid increased.

1. Effect of inlet hot fluid temperature variable

The change in temperature is a measure of the heat transfer between the two fluids. Heat is transferred from a high temperature to a low temperature. The moving heat undergoes a heat exchange process and then stops when the two fluids have the same temperature.

The temperature of the hot fluid and the cold fluid entering and leaving have different values, so it is necessary to calculate ΔTLMTD to equalize the temperature on all sides of the heat exchanger. The ΔTLMTD value affects the total heat transfer value (U), NTU (number transfer unit), the effectiveness and efficiency of the tool.

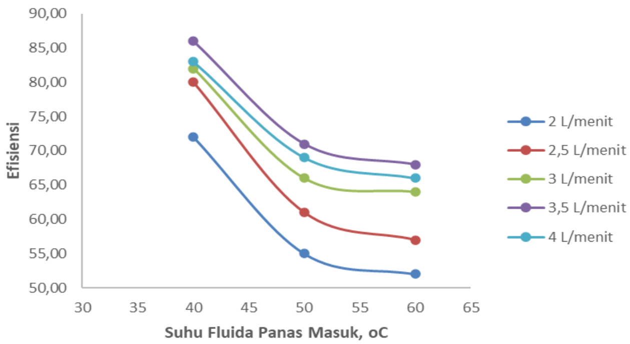

Fig. 5. Graph of the relationship of inlet hot fluid temperature and efficiency values at various flow rates at a concentration of 12%.

Based on the picture above, the efficiency value decreases along with the increase in the temperature of the incoming hot fluid. The greatest efficiency value lies in the concentration of 12% with a flow rate of 3.5 L/minute of 86.33%. The greatest efficiency value at each concentration is always at a temperature of 40oC.

2. Concentration effect

In this study, formalin was used as the hot fluid with variable concentrations of 6%, 9%, 12%, 15%, and 18% v/v at a flow rate of 1 L/min. The following graph shows the relationship between the hot- fluid concentration and effectiveness and efficiency under various conditions.

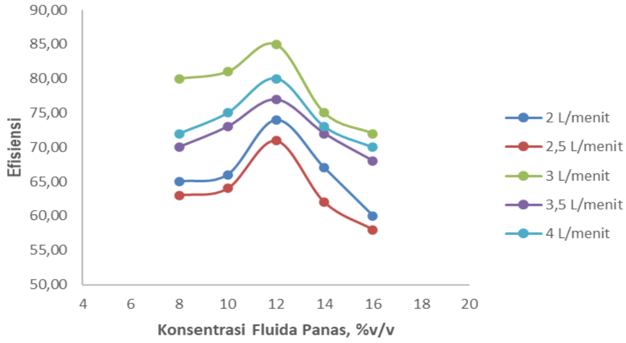

Fig. 6. Relationship of hot fluid concentration to efficiency values at various flow rates

5 Conclusion

Based on the results of research conducted, it can be concluded:

1. The efficiency of the tool increases with an increase in the flow rate of cold fluid. The highest efficiency of 86% was obtained at a cold fluid flow rate of 3.5 L/min
2. The higher the temperature of the incoming hot fluid under various conditions, the lower the efficiency value. The highest efficiency was obtained at a temperature of 40°C.
3. The efficiency of the tool tended to increase as the concentration of hot fluid increased. The best hot- fluid concentration was 12% v/v, with an efficiency value of 86.33%.

Suggestions

1. It is necessary to increase the cold fluid flow rate below the shell and tube floading heat exchanger limits so that the maximum limit can be observed.
2. Before conducting research, it is necessary to conduct a trial process using cold fluid for each compound as a blank.

Notation List

Q : Heat released/received, kJ
Wh : Mass flow of hot fluid, kg/hour
Wc : Mass flow of cold fluid, kg/hour
Cph : Specific heat of hot fluid, kJ/kg.K
Cpc : The specific heat of the cold fluid, kJ/kg.K
Thi : Inlet hot fluid temperature, K
Tho : The temperature of the hot fluid out,K
Tci : Inlet cold fluid temperature, K

Tco : Temperature of the cold fluid out, K
ΔT_{LMTD} : Log mean temp.diff, K
U : Total heat transfer coefficient W/m^2.K
A : Heat transfer area, m^2
NTU : Number transfer unit, dimensionless
Cmin : Minimum heat capacity, kJ/K
Cmak : Maximum heat capacity, kJ/K
Ch : Heat capacity of hot fluid, kJ/K
Cc : Heat capacity of cold fluid, kJ/K
ε : Effectiveness, dimensionless

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