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DESIGN OF LABORATORY SCALE WATER BATH HEAT EXCHANGER WITH SHELL AND TUBE TYPE

Asep Bayu Dani Nandiyanto[1,*], Risti Ragadhita[1], Teguh Kurniawan[2]
[1]Departemen Pendidikan Kimia, Universitas Pendidikan Indonesia, Indonesia
[2]Departemen Teknik Kimia, Universitas Sultan Ageng Tirtayasa, Indonesia
*Corresponding Author: nandiyanto@upi.edu

Abstract

The purpose of this study was to design a shell and tube type water bath heat exchanger for laboratory scale through examining the design in the form of calculating the dimensions of the shell and tube type heat exchanger. For the design to be well directed, several steps must be taken, including (i) determining the material specifications and dimensions of the heat exchanger based on standard, ii) calculating the main components of the shell and tube, (iii) calculating the performance of the heat exchanger, and (iv) making 2D and 3D images of heat exchangers. For the calculation of the main components in the Second step and the calculation of the performance of the shell and tube in the third step, the HRTI application is used. The results showed that the water bath heat exchanger was designed with carbon steel material specifications. The heat exchanger in this study has 13 tubes that operated at a constant thermal load of 839 W with an effect is more than 40%. This research shows that the heat exchanger has been successfully designed with good performance. This design can be used as a reference in a design in a heat exchanger to be more economical, effective, and having high reliable.

Keywords: Effectiveness, Heat exchanger, Laboratory scale, Performance, Shell and tube.

1. Introduction

The apparatus used to change the phase and temperature of a fluid is called a heat exchanger. The process of changing temperature and phase occurs by utilizing the process of heat transfer from a high- to low-temperature fluid [1-3]. This heat exchanger apparatus is very important for industrial process activities and this tool is also very widely applied in industries such as oil refineries, factories chemical and petrochemical, natural gas industry, refrigeration, and power generation [2, 4]. In the development of heat exchanger undergo a transformation of purposeful form increase efficiency according to function work [5]. The most common form of heat exchanger used is shell and tube with various considerations of this form are considered to have many advantages both in terms of fabrication, cost, to performance [5]. Various types of heat exchangers are used to achieve the desired goal, such as to heat a product or to cool the product. To develop technology, especially heat exchanger apparatus, therefore in this case it is necessary to do technological engineering heat exchanger.

Since a heat exchanger is an apparatus that is very important in the process activities industry, where maximum support of the apparatus can affect a process becomes less than optimal, then there is a need for a design plan that precise and economical in the manufacture of the heat exchanger. Thus, it can be well operated and run maximally according to the design predictions that have been designed.

Based on our previous studies on the design of industrial apparatus [6,7], the purpose of this study is to focus on the design and design of a simple heat exchanger for laboratory scale to obtain the main dimensions of the apparatuses, such as the heat transfer surface area (A) that depend on other parameters, namely thermal load (Q), overall heat transfer coefficient (U) and logarithmic mean temperature difference (ΔTlm).

2. Method

In this study, we designed a simple water bath heat exchanger with a one-pass shell and tube type. Here, the apparatus was designed through several steps, namely calculating the main components of the shell and tube, calculating the performance of the heat exchanger, making 2D and 3D images of heat exchangers. The apparatus was designed based on the Tubular Exchanger Manufacturers Association (TEMA) standard. In addition, performance calculations were carried out manually and 2D and 3D heat exchanger drawings were carried out using the HRTI application. The basic design calculations with operating conditions to estimate the performance of the apparatus heat exchanger are presented in equations 1-11 that show in Table 1.

Table 1. Heat exchanger parameter calculation.

Section	Parameter	Equation	Eq.
Basic parameters	The energy transferred (Q)	$Q_{in} = Q_{out}$ $m_c \times Cp_c \times \Delta T_c = m_h \times Cp_h \times \Delta T_h$ Q = the energy transferred (W) m = the mass flow rate of the fluid (kg/s) Cp = the specific heat	(1)

Section	Parameter	Equation	Eq.
		ΔT = the fluid temperature difference (°C).	
	Logarithmic mean temperature differenced (LMTD)	$$LMTD = \frac{(T_{hi} - Tc_i) - (T_{ho} - Tc_o)}{ln\frac{(T_{hi} - Tc_i)}{(T_{ho} - Tc_o)}}$$ T_{hi} = the temperature of the hot fluid inlet (°C) T_{ho} = the temperature of the hot fluid outlet (°C) Tc_i = the temperature of the cold fluid inlet (°C) Tc_o= the temperature of the cold fluid outlet (°C)	(2)
	Heat Transfer Field Area (A)	$$A = \frac{Q}{U \times LTMD}$$ Q = the energy transferred (W) U = the overall heat transfer coefficient $LMTD$ = the logarithmic mean temperature difference.	(3)
	Number of Tubes (N)	$$N = \frac{A}{\pi \times D_o \times l}$$ N = the number of tubes A = the area of the heat transfer area (m^2), π = constant with a value of 3.14 D_o= the tube diameter (m) l = the tube diameter (m).	(4)
	Shell Diameter	$$D_s = 0.63(\frac{\sqrt{\frac{CL}{CTP} \times ((A \times (PR)^2 \times D_o}}{l})^{\frac{1}{2}}$$ D_s = the shell diameter (m) A = the area of the heat transfer area (m^2) P, R = the correction factor D_o = the tube diameter (m). For CTP value (one tube pass = 0.93; two tube pass = 0.90; and three tube pass = 0.85) and CL value (90° and 45° = 1,00; and 30° and 60° = 0.87).	(5)
	Reynold number (*Re,t*)	$$Re_t = \frac{di_t \times Gt,s}{\mu}$$ Re_t = the Reynolds number in tube	(6)

Section	Parameter	Equation	Eq.
		di_t = the inner tube diameter (m), Gt = the mass flow of water in the tube and shell (m^2) μ = the dynamic viscosity (kg/ms).	
	Convection Heat Transfer Coefficient in Shell (ho)	$$ho = \frac{Nu \times K}{d_e}$$ ho = the convection heat transfer coefficient (W/m^2°C) K = the thermal conductivity (W/m°C) d_e = the equivalent diameter (m).	(7)
	Convection Heat Transfer Coefficient in Tube(h_i)	$$hi = \frac{Nu \times K}{d_i, t}$$ hi = the convection heat transfer coefficient in the tube (W/m^2°C) K = the thermal conductivity of the material (W/m°C) d_i, t = the inner tube diameter (m).	(8)
Effectiveness	Heat Exchanger Effectiveness (ε)	$$\varepsilon = \frac{Qact}{Qmax} \times 100\%$$ Q_{act} = the actual energy transferred (W) Q_{max} = the maximum heat transfer (W)	(9)
	Number of Transfer Unit (NTU)	$$NTU = \frac{U \times A}{C_{min}}$$ U = the overall heat transfer coefficient (W/m^2°C A = the heat transfer area (m^2) C_{min} = the minimum heat capacity rate (W/°C).	(10)
	Fouling factor (Rf)	$$Rf = \frac{U_a - U_{act}}{U_a \times U_{act}}$$ Rf = the fouling factor U_a= the overall heat transfer coefficient (W/m^2°C) U_{act} = the actual overall heat transfer coefficient (W/m^2°C)	(11)

3. Results and Discussion

This study made a heat exchanger connected to heat water. We need to know the materials needed in making tools for the heat exchanger. Dimensions can be measured if you know the material and how much cold that needs to be heated with a stream of water as a heating medium. After that, we determined the type of flow and how much water needed to be heated. Furthermore, pipe layout design and the testing mechanism are carried out.

In this design, the material used for the shell and tube type heat exchanger apparatus is assumed carbon steel. Table 2 shows other detailed assumptions regarding the specifications of dimensions material for the designed heat exchanger. Table 3 shows other detailed assumptions regarding the fluid used. Water fluid assumptions were used to heat cold water in the water bath with a capacity of 5 litres. Here, in the heat exchanger design, we used hot water fluid in the shell side and cold water fluid in the tube side. Table 4 shows the physical properties of hot and cold fluids. Based on the assumed specifications, both heat exchanger design specifications, fluid specifications, and fluid properties, the performance results of heat exchanger based on calculation are presented in Table 5. Based on the shell and tube dimensions specifications, which refer to the standards of TEMA and calculations, the 2D tube layout, 3D bundle layout, exchanger drawing, setting plan, and 3D exchanger drawing of the designed heat exchanger apparatus are shown in Figs. 1-4.

Based on the calculation results, the shell and tube type heat exchanger has been successfully designed with a heat transfer effectiveness of greater than 40%. The characteristics of the flow in the shell and tube are turbulent from the Reynolds number. On a laboratory scale, fluid flow is laminar. However, it is different from the process in the industry. There are various uses for turbulent flow in industrial processes such as heating and cooling. To put it another way, most industrial heat exchangers use turbulent flow, which has a larger heat convection coefficient than laminar flow and accordingly a better heat transfer rate [8]. The resulting effectiveness value, which measures the amount of heat carried, will be high if the temperature difference between the input and output is large. So it can also be interpreted that the effectiveness of the Heat Exchanger is directly proportional to the magnitude of the temperature difference [9]. Other factors that affect the heat exchanger's performance include the number and spacing of baffles in the heat exchanger's specs. A close baffle distance will increase the effectiveness of the heat exchanger as well as a small percentage of baffle cut will increase the effectiveness of the heat exchanger [10]. The dirt factor value, the dimensions of the heat exchanger apparatus designed is meet the requirements of the standard that has been set because the standard permissible fouling factor from TEMA for water fluid is 0.0002 °C.m^2/W.

Table 2. Specifications and dimensions of material.

Parameters	Specification
Material Shell and Tube	Carbon Steel
Tube Diameter (m)	0.019
Tube Length (m)	4.267
Wall Thickness (m)	0.0012
Layout Angle (°)	30
Pitch (m)	0.0254
Orientation	Horizontal
TEMA Type	AEW

Table 3. Specifications of fluid.

Parameters	Specification
Input Flow Rate to Shell (kg/s)	0.004167
Input Flow Rate to Tube (kg/s)	0.006382
Temperature Hot Fluid Inlet (°C)	90.000000
Temperature Hot Fluid Outlet (°C)	40.000000
Temperature Cold Fluid Inlet (°C)	20.000000
Temperature Cold Fluid Outlet (°C)	60.000000

Table 4. Specifications of fluid.

Parameters	Hot Fluid Specification	Cold Fluid Specification
Density (kg/m^3)	971.83	998.21
Viscosity (mN.s/m^2)	0.3149	0.001
Heat Capacity (kj/kg°C)	4.206	4.182
Conductivity (W/m°C)	6804	5978

Table 5. Heat exchanger performance based on calculation.

No	Parameter	Results
1	**Initial Heat Transfer Rate (*Q*)**	839 W
2	**Logarithmic Mean Temperature Difference (*LMTD*)**	24°C
3	**Overall Fluid Heat Coefficient of Actual(U_{act})**	3077 W/m^2.K
4	**Area of Heat Transfer (*A*)**	3.272 m^2
5	**Number of Tube (*Nt*)**	13
6	**Shell Inner Diameter (m)**	0.129
7	**Fouling factor**	0.0002 °C.m^2/W
8	**Baffle Spacing (m)**	0.05797
9	**Reynold in tube**	71.435
10	**Convection Heat Transfer Coefficient in the Tube (h_i)**	129 W/m^2.K
11	**Reynold in Shell**	121.73
12	**Convection Heat Transfer Coefficient in the Shell (h_o)**	9.075
13	**Pressure Drop in Shell (kPa)**	0.00014
14	**NTU**	20.34
15	**Effectiveness (%)**	42.86%

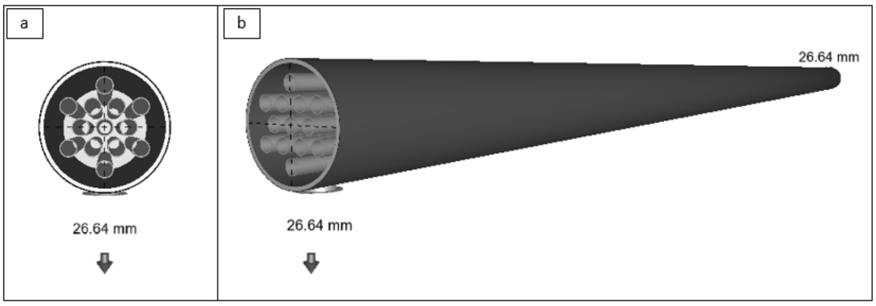

Fig. 1. 2D tube layout (a) and 3D bundle layout (b).

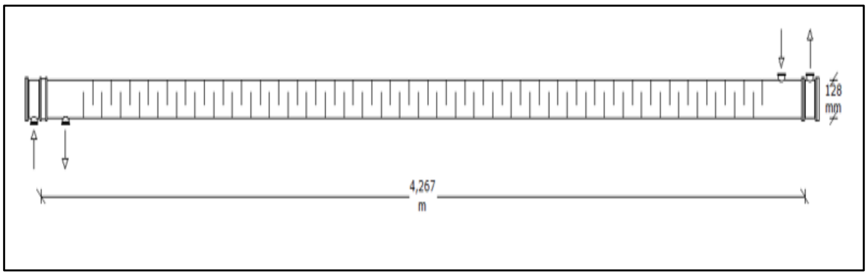

Fig. 2. Exchanger drawing.

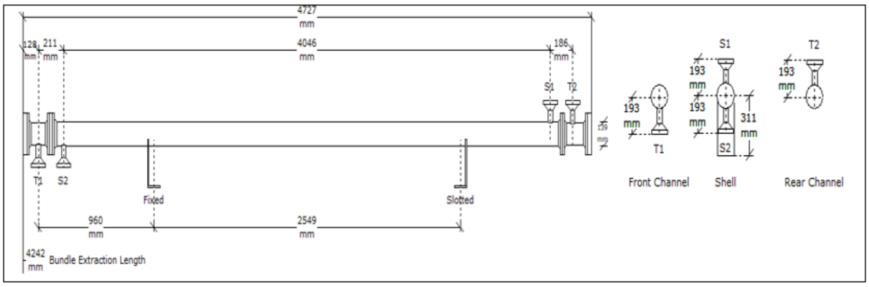

Fig. 3. Setting plan.

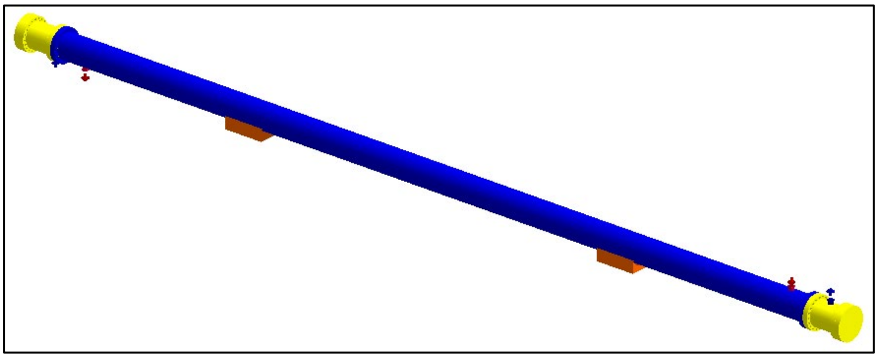

Fig. 4. 3D exchanger.

4. Conclusion

Based on the TEMA standard-based design, the water bath heat exchanger has been successfully designed with the Shell and Tube one pass type with the AEW type. The heat transfer rate generated by the apparatus is 839 W with a heat transfer effectiveness of more than 40%, and the fouling factor that is meet the TEMA standard.

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