Design of New Fin Baffle Shell and Tube Heat Exchanger for Heating of Biodiesel Fuel Based on Simulation

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***Abstract* - Shell and Tube Heat Exchanger (STHE) is a type of heat exchanger that is widely used on an industrial scale. The purpose of the current research builds on previous research, such that a new design of fin baffles (FB-STHE) is investigated to increase the heat flow of diesel fuel on the shell side. The method used includes design using standard equations then proceed to modelling and simulation using Solidworks 2018 software. Simulation results were a comparison between FB-STHE and Segmental Baffle (SB-STHE). The results proved that adding fin to the baffle can increase the average fluid heat flow at the shell side in STHE.**

Keywords - Bioiesel Fuel, Fin Baffle, Heating, Shell and Tube Heat Exchanger, Simulation

I. INTRODUCTION

A heat exchanger is a machinery that is needed in industries such as factories on land and is even needed in ship operations. There are several classifications according to construction including Tubular, Plate, Plate Fin, Tube Fin, Printed Circuit , Regenerative [1].

Included in the tubular classification are shell and tube, spiral tube, pipe coils, and double pipe. Of the several types of heat exchangers, the Shell and Tube type is the most widely used type of heat exchanger.

The standard used in this study is the standard recommended by TEMA (The Tubular Exchanger Manufacturers Association). Standards are a reference standard for engineers, designers and users, and to determine, design, and install tube exchangers. These standards are based on the principles of advice from engineering, research, and field experience in the manufacture, design, installation, and use of tube exchangers. These standards can be revised because further investigation or experience might indicate the need or desirability [2]. Accordingly, researchers need to experiment to develop fin baffles and investigate the effects it causes.

II. LITERATURE REVIEW AND LIMITATION OF CURENT TECHNIQUES

Heat transfer is the science that deals with the degree of heat exchange between cold and hot objects called heat sources and heat receivers. These objects can be solid, liquid and gas [3].

In this modern era, the most widely used heat exchanger in the industrial world is the type of STHE [4-6]. In the shell and tube type heat exchangers, in the shell and tube, two different types of fluids flow and are separate or do not come in contact directly. The process of heat exchange occurs between the fluid in the shell and the tube that flows simultaneously according to the type of flow can be parallel and contra flow [7].

The design of heat exchangers, especially the shell and tube heat exchanger types, has been carried out mainly in the structure of the baffle [8-10]. The baffle is the STHE part to direct the shell side fluid across the tube for optimal heat transfer [2].

The helix type baffle has been investigated by researchers because it produces better performance, although in terms of design this type of design is somewhat complicated [11-22]

The design of the STHE was also carried out by modifying other shapes to obtain a more optimal heat transfer energy in the form of a staggered baffle [23].

Another model design is the louver baffle when compared to conventional segmental models, the louver baffle model is higher in the heat exchange process that occurs within its shell [24].

Flower baffles are another form of design of baffle types that have been studied and prove that this form is more efficient than conventional segmental forms [25].

Various types of baffle designs have been carried out in previous studies, especially the design of helix-type baffles. This is expected to increase the performance of the heat exchanger. However, the type of helix is a rather difficult type in the manufacturing process. Then another type of baffle research is needed.

III. THE PROPOSED NEW TEHCNIQUES

Related to various references in the literature review, it is necessary to propose research about other types of baffles. Experiments have been carried out with techniques design a type of fin baffle to increase the flow of heat exchange in the shell.

Heat exchanger design for heating biodiesel fuel by performing calculations using the Kern equation to get the dimensions and component parameters. The next research stage is modeling and simulation using engineering software, Solidworks 2018.

The proposed new design can be seen in figure 1.

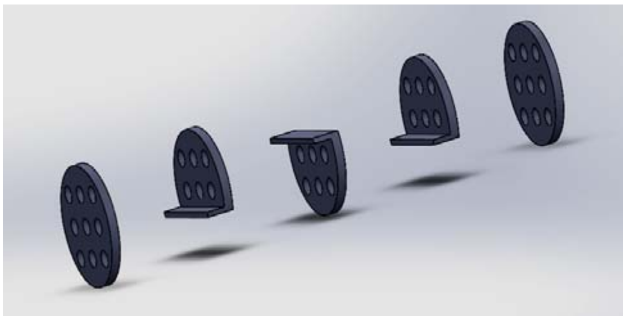

Figure 1. Design of New Fin Baffle

IV. METHODOLOGY AND SHOFTWARE

This research was carried out in several stages, as follows.

A. *Designing Heat Exchanger*

This design is intended for heating biodiesel fuel on diesel engines using a heat recovery jacket cooler. Where does the temperature of STHE inlet side is 83°C and outlet side is 70°C, while the temperature of the biodiesel fuel at inlet side is 30°C and expected to reach 75°C. Heat exchanger design is intended for fluid with the properties showed table 1.

TABLE I. TUBE DIMENSIONS

Water			Biodiesel Fuel		
Nt	***Value***	***Unit***	***Nt***	***Value***	***Unit***
Cp	4181	J/kg.K	Cp	2141	kJ/kg.K
μ	0.00095	Kg/ms	μ	0.00163	Kg/ms
k	0.6065	W/mK	k	0.3	W/mK
ρ	997	kg/m3	ρ	815	kg/m3
Pr	6.548969		Pr	11.63277	
m	0.0008	kg/s	m	0.00042	kg/s

To get the appropriate heat exchanger it is necessary to calculate both the shell and the tube. The method used in this calculation is the Kern Method [3].

- Heat Capacity

Heat capacity is needed to determine the rate of heat transfer. This heat transfer rate can be determined by using the following equation 1:

$$Q = (mCp)(\Delta Tc) \tag{1}$$

- Hot Side Outlet Temperature

The hot side outlet temperature can be determined by the following equation 2:

$$T_{h2} = T_{h1} - \frac{Q}{mCp} \tag{2}$$

- Average Temperature Difference

The Logarithmic Mean Temperature Difference (LMTD) is used to determine the heat transfer in the flow system of the heat exchanger. LMTD is a logarithmic mean of the temperature difference between cold and hot inputs at each end of the pipe.

$$\Delta Tm = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{ln \frac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}} \tag{3}$$

- Shell Side Heat Transfer Coefficient

There are several steps before calculating the shell side heat transfer coefficient, such as area, flow rate, diameter, and Nusselt number.

$$A_s = \frac{(D\ CB)}{Pt}$$

$$G = \frac{m}{A_s} \tag{4}$$

$$D = \frac{4\left(Pt^2 - \frac{\pi do^2}{4}\right)}{\pi\ do}$$

Because it is turbulent on the side of the shell, the Mc. Adam correlation is used to get the Nusselt number

$$Nu = 0.36\left(\frac{D\ Gs}{\mu}\right)^{0.55}\left(\frac{Cp\ \mu}{k}\right)^{0.33}\left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{5}$$

The shell side heat transfer coefficient is calculated as follows:

$$h_o = \frac{Nu\ k}{D} \tag{6}$$

- Tube Side Heat Transfer CoefficientThere are several steps before calculating the tube transfer coefficient of the tube such as area, flow rate, diameter, and Nusselt number.

$$A_t = \frac{\pi\, di^2}{4}$$

$$A_{tp} = \frac{Nt\, A_t}{Number\ of\ passes}$$

$$G = \frac{m}{A_{tp}} \quad (7)$$

$$u_t = \frac{G}{\rho}$$

$$Re = \frac{u\, \rho\, di}{\mu}$$

The fluid on the side of the tube is turbulent, to calculate the Nusselt number using the Petukhov-Kirillov correlation,

$$Nu = \frac{\left(\frac{f}{2}\right) Re\ Pr}{1{,}07 + 12.7\left(\frac{f}{2}\right)^{1/2}\left(Pr^{\frac{2}{3}} - 1\right)} \quad (8)$$

Where:

$$f = (1.58 \ln Re - 3.28)^{-2}$$

The tube side heat transfer coefficient can be calculated as follows:

$$h_t = \frac{Nu\, k}{di} \quad (9)$$

- Overall Heat Transfer Coefficient.

The overall heat transfer coefficient can be determined using the equation:

$$U = \frac{1}{\frac{d_o}{d_i h_i} + \frac{d_o \ln\left(\frac{d_o}{d_i}\right)}{2k} + \frac{1}{h_o}} \quad (10)$$

- Heat Transfer Area

The heat transfer area can be determined by following the heat transfer rate at equation 11.

$$A = \frac{Q}{U\, F\, \Delta T_m} \quad (11)$$

- Heat Exchanger Length.

After the heat transfer area is known, the length of the heat exchanger can be determined using the equation 12:

$$L = \frac{A}{N\, \pi\, D_o} \quad (12)$$

- Pressure drop on shell side

Pressure drop on shell side can calculated using the equation 13:

$$\Delta Ps = \frac{f\, Gs^2 (Nb + 1)\, Ds}{2\rho\, D\, \emptyset s} \quad (13)$$

- Pressure drop on the Tube side

Pressure drop on tube side can calculated using the equation 14:

$$\Delta Pt = \left(4f \frac{L\, Np}{di} + 4Np\right)\frac{\rho\, u^2}{2} \quad (14)$$

B. Modeling.

Modeling is the process of making a model of a Heat Exchanger system. This model is a real form representation that sourced from calculations that have been made in the form of dimensional data. Modeling is done using 3D modeling software, namely Solidworks 2018. According to Solidworks guidance [27], that in modeling there are several stages of work carried out including the following :

- Drawing Components

In modeling, the shell and tube components are drawn separately in the form of sub-components such as shells, baffles, tubes and shell covers following table 2 and 3. The components shown in figure 2:

From the calculation results obtained shell dimensions as table 2 is shell dimension and 3 is tube dimension.

TABLE II. SHELL DIMENSIONS

Parameter	Notation	Dimension	Unit
Pitch	Pt	0,593701	inch
Clearence	C	0,271654	inch
Baffle spacing	B	2,65748	inch
In. diameter	Do	2,25	inch

TABLE III. TUBE DIMENSIONS

Parameter	Notation	Dimension	Unit
Out.diameter	do	0,375	inch
In.diameter	di	0,319	inch
Flow area	a´	0,0731	inch²
No. of tubes	Nt	9	pcs
Lenght	L	10.63	inch

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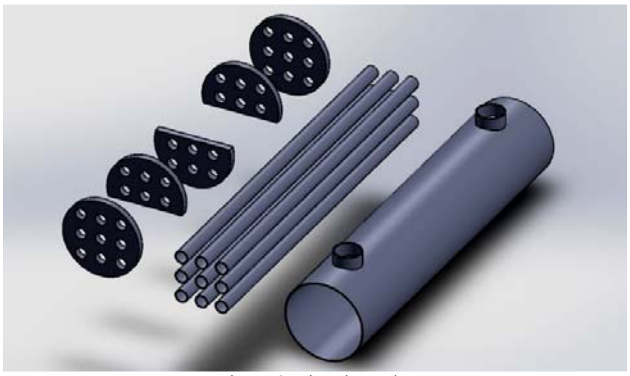

Figure 2. Fin Dimension

- Component Assembly

After drawing shell and tube sub-components, the next stage is assembly. The assembly process still uses the same software. At this stages several components are assembled into one component figure 3.

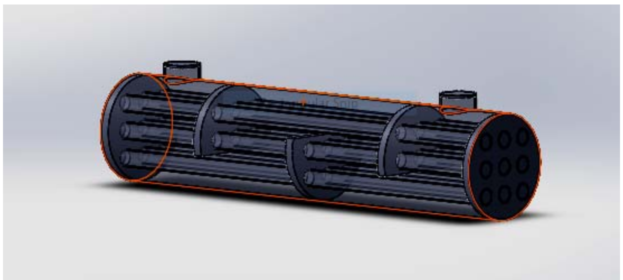

Figure 3. Assembly of SB-STHE

C. Simulation.

Fluid flow simulation using Solidworks 2018 Student License. Just like the modeling stage, in this stage, it creates a fluid flow inside the shell side and the tube side. What needs to be done in a dynamic fluid computation simulation is to choose the required software analysis system. According to the simulation research project chosen, it is flow simulation. This simulation used to solve the flow in the shell and tube heat exchanger. The steps taken in the simulation are as follows:

- Import Geometry

Import geometry into Solidworks simulations and enter certain criteria such as fluid type and material. After that, naming on all surfaces of input and output channels to support the simulation process.

- Input Boundary.

After as geometry has been in the flow simulation panel and all inlets and outlets have been closed, at this stage the input boundary.

- Meshing and Running Process

After importing all components model to the workbench, proceed with the meshing process and running process.

D. Design of New Fin Baffle

The Design a new fin baffle carried out on the heat exchanger is to add fins to the baffle to improve the heat surface process. The fin added has a length of 2.25 inch, the width of 0.6 inches. The results of modeling produced by the Solid works 2018 software are as figure 4 and 5.

Figure 4. Fin Dimension

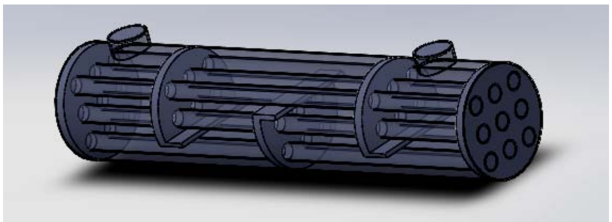

Figure 5. Assembly of FB-STHE.

V. RESULTS AND DISCUSSION

A. Fluid Flow Simulation

This simulation using biodiesel fuel in the shell side that is heated by hot water flowing in tube side, showed figure 6.

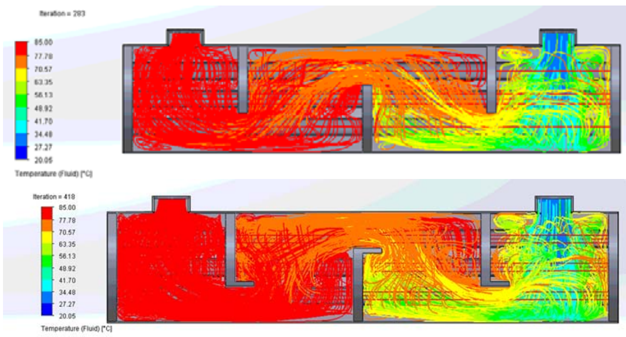

Figure 6. Fluid Flow Simulation

Figure 6 is a comparison of the form of fluid flow between SB-STHE and FB-STHE. The result is that in FB-STHE the fluid flow is more turbulent due to the bending of the flow. In this condition, the fluid flow rate is longer so that it has been receive more heating.

TABLE III. FLUID FLOW TEMPERATURE

Goal Name	Unit	Value	Averaged Value	Min Value	Max. Value
Av.Temp. (Fluid) 1	(°C)	74.69	74.67	74.65	74.69
Av.Temp.(Fluid) 1 (Fin)	(°C)	74.90	74.90	74.90	74.90

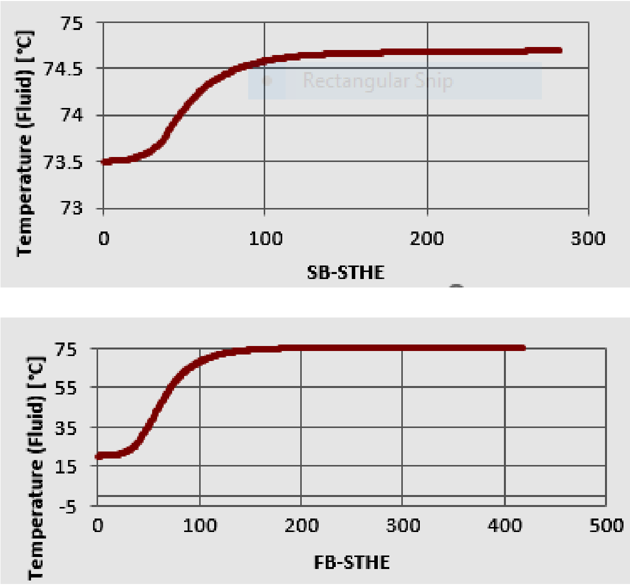

Figure 7. Increasing of Temperature

.Figure 7 and table III. show that the temperature of the biodiesel fuel on the FB-STHE rises to 74.90°C nearly 75°C. The temperature in the FB-STHE is higher than the temperature in the SB-STHE, this is due to the turbulence that occurs in the FB-STHE which is caused by the addition of a fin to the baffle.

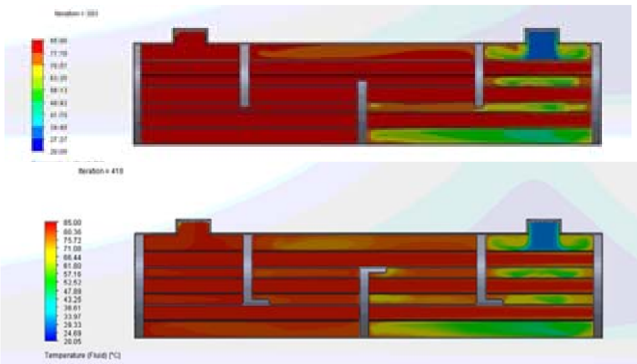

Figure 8. Cut Plane of Fluid Temperature

Figure 8. shows there is a difference in FB-STHE area of the fluid which has a wider increase in temperature this can be interpreted as a better heat exchange process, where the FB-STHE is more visible than the SB-STHE

The simulation calculation results for fluid pressure can be shown table 4.

TABLE IV. RATA-RATA TEKANAN FLUIDA

Goal Name	**Unit**	**Value**	**Avr. Value**	**Min. Value**	**Max. Value**
GG Av Total Pressure 1	(Pa)	101325, 131	101325, 131	101325, 131	101325, 131
GG Av Total Pressure 1 (fin)	(Pa)	101325, 134	101325, 134	101325, 134	101325, 134

In table IV it can be seen that the pressure on the shell of both the shell and the tube heat exchanger is quite the same on the FB-STHE is 101325,134 Pa and SB-STHE is 101325,131 Pa and the cut plane of pressure as figure 9.

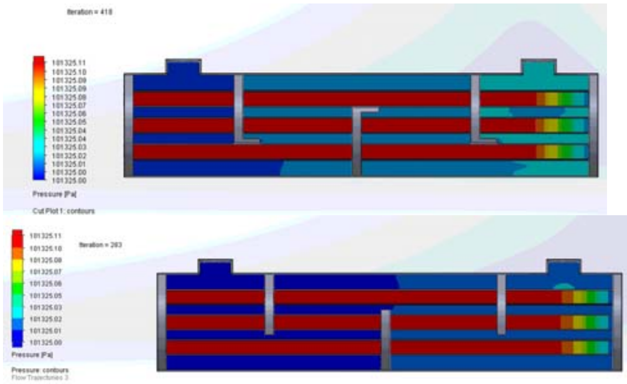

Figure 9. Cut Plane of Pressure

B. Heat Transfer Coefisien

From these results base of formulation, it can be obtained the results of the simulation calculation.

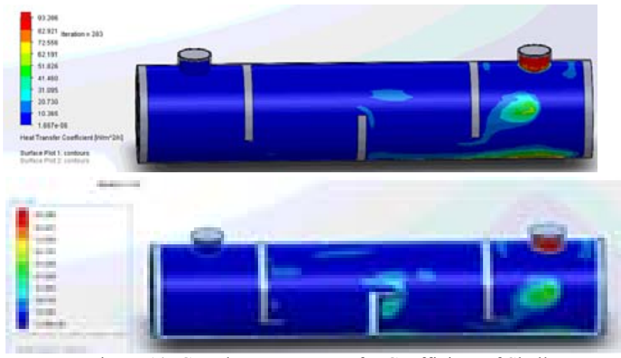

Figure 10. Cut Plane Heat Transfer Coefficient of Shell

Figure 10 shown the fluid flow turbulence in the FB-STHE so that the heat transfer area that occurs in the shell is wider when compared to SB-STHE.

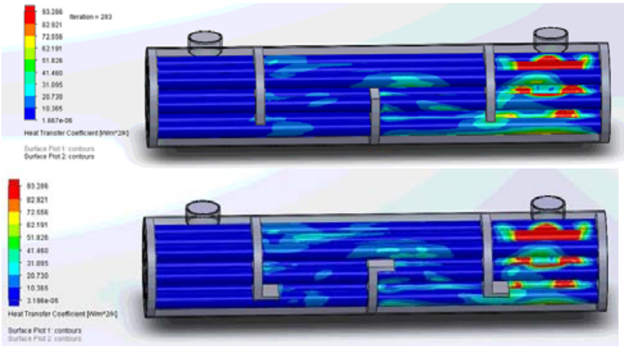

Figure 11. Cut Plane Heat Transfer Coefficient of Tube

Figure 11 shows that the coefficient of heat transfer in FB-STHE is lower because of the addition of fins, causing a wider baffle surface area.

TABLE V. HEAT TRANSFER KOEFISIEN

Goal Name	Unit	Value	Avr. Value	Min. Value	Max. Value
Av Heat Transfer Coef 1	(W/m^2/K)	17, 10597	17, 09128	17, 06366	17, 11700
Av Heat Transfer Coef 1(Fin)	(W/m^2/K)	16, 82440	16, 83461	16, 80558	16, 92564

Table V shows that the average coefficient of heat transfer is SB-STHE is 17.09128 W / m². K while the FB-STHE is 16.834161 W / m². K. There is a difference of 0.25712 where FB-STHE is lower, this is due to the addition of fins which h causes the baffle area to be wider when compared to the SB-STHE baffle area.

VI. CONCLUSION AND FUTURE WORK

The design of FB-STHE based on calculations using standard formulations. From the calculations, the results of several dimensions and parameters of the shell, tube and baffle are obtained. Further modeling, assembly, and simulation are performed.

The simulation results show that the average fluid heat flow in the FB-STHE has increased heat when compared to SB-STHE. This caused due to turbulence on the side of the shell.

The coefficient for heat transfer on the FB-STHE is smaller because there is an addition of fin so that the surface area of the baffle increases. From the above conditions, it concluded that the addition of fin gives the effect of increasing heat to the shell side fluid.

The results of the design and simulation need to be continued future works with be made prototype and tested using experimental methods.

The results of the design and simulation need to made prototypes and tested using an experimental method. Experimental method necessary to measure reliability and accuracy thermal-hydraulic performance [26].

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