

Design and Optimization of Boiler Economizer for Laundry Industry Using Taguchi Method

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ABSTRACT

The exhaust gas from the boiler in the laundry industry can reach more than 300°C. The potential energy can be converted to increase the temperature of feed water through a heat exchanger. In this study, a shell and tube heat exchanger was chosen to increase the feed water temperature with the flow rate of 0.55 kg/s to reach the target of 80°C. Meanwhile, the mass flow rate of the exhaust gas is 0.9 kg/s with a temperature estimated at 300 - 310°C. The basic design of the heat exchanger is created to get the main dimensions such as the cross-sectional area (A), the length of the tube (L), the outer diameter of the tube (do) and the total of tube (N). Finally, the main dimensions are optimized by the Taguchi experimental method to obtain the most optimal design.

Keywords: boiler economizer, laundry industry, taguchi method

1. INTRODUCTION

The use of electrical energy and heat energy today is quite rapid needs as well as its development, not only for the needs of the manufacturing process, but also for supporting operations. Especially in garment/laundry factories, there is a great deal of energy that is not utilized and is simply wasted.

Energy management techniques and heat recovery techniques are important. In an effort to save energy, it is necessary to develop the use of exhaust gases from the laundry industry as water heaters. Boilers are closed vessels where the combustion heat is flowed into the water to form steam. To produce heat that is used in heating the water is needed, namely coal and fuel wood. Exhaust gas resulting from combustion has a temperature that is still high, so it will be a large heat loss if the smoke is directly discharged through the chimney.[1][2] However, there are still many boilers that do not take advantage of the hot smoke gas from the combustion. This smoke gas can be used to increase the temperature of feed water before it is put into the Drum / Kettle, so that the use of fuel is more efficient to produce steam, which is used in the production process. For that, we need a heat exchanger, the economizer. Feed water before entering into the boiler must go through a heat exchanger that utilizes the heat of this burning smoke, so that the temperature of the feed water rises.

Situmorang [3] has designed the utilization of palm oil mill exhaust gas as a boiler boiler water heater with a shell and tube heat exchanger, aimed at saving fuel, increasing effectiveness, in this study obtained better results. The

previous research has not shown optimization, so this study wants to show its optimization using the Taguchi method. Sukarman [4] has optimized the low pressure boiler by adding a Heat Exchanger to the chimney for heating the water into the degreasing process. This optimization of the Heat Exchanger design was carried out using the full factorial method using four independent variables with three levels of experimentation to obtain 81 count data.

2. METHODS

Full Factorial design requires a large number of experiments to be done. To overcome this problem, Taguchi suggested a specially designed method called the use of orthogonal arrays to study the entire parameter space with a smaller number of experiments. So that this method used in the optimization of the economizer design is to pay attention to and use of the boiler boiler/laundry characteristic data for the garment/laundry factory, then the calculation is performed to determine the optimum conditions.

The Taguchi method is a design method that is principled on improving quality by minimizing the effects of variations without eliminating the cause[5]. This can be obtained through product optimization and design. The process for making performance / performance immune to various causes of variations in a process called parameter design.

Using the Taguchi experimental method, Table 1. can be created, which is a table containing the number of variables/factors of the experiment and related levels [6].

Table 1 Configuring variable-level and measured parameters

Code	Factor	Level 1	Level 2	Level 3
A	Tube Diameter (d_o , m)	0.0254	0.03175	0.0381
B	Lay Out (CL,°)	30	45	60
C	Pitch Ratio (PR)	1.25	1.375	1.50
D	Excess Area	1.20	1.25	1.30

The combination of four independent variables / factors and three levels of research as in Table 1, if we use the full

factorial method requires a lot of data calculation (trial). If using the Taguchi method, 9 attempts/design are needed.

Table 2 Configuration of factor-levels and calculated parameters

No	Do (m)	CL (°)	Pitch Ratio (PR)	Af/Ac	Ds (m)	Nt (Tube)
1	0.0254	0.87	1.25	1.2		
2	0.0254	1	1.375	1.25		
3	0.0254	0.87	1.5	1.3		
4	0.03175	0.87	1.25	1.3		
5	0.03175	1	1.375	1.2		
6	0.03175	0.87	1.5	1.25		
7	0.0381	0.87	1.25	1.25		
8	0.0381	1	1.375	1.3		
9	0.0381	0.87	1.5	1.2		

3. RESULTS AND DISCUSSION

3.1. Designing The Economizer

The initial design of the economizer design with the aim is to determine the main dimensions of the boiler economizer in the garment industry, namely the total surface area (A_o) of heat transfer required by the tool in accordance with the thermal load given in accordance with the initial conditions of the device [7], [8]. The calculation steps are as follows:

- Calculation of exhaust gas mass rate (\dot{m}_{gas}) and exhaust gas temperature $T_{h,i}$
- Calculation of mass flow rate of water in the economizer, \dot{m}_{air}
- The temperature of the exhaust gas exits the economizer $T_{h,o}$
- Calculation of heat transfer rate released by gas, Q_h

- Calculation of logarithmic mean temperature difference, $LMTD$
- Calculation of overall heat transfer coefficient, U_f
- Calculation of total heat transfer surface area, A_o
- Calculation of shell diameter (D_s) and number of tubes (N_t)

Preliminary data on operating conditions provided for economists are as follows:

- Water temperature enters economizer (T_{ci}) 28°C,
- Water temperature comes out economizer (T_{co}) 80°C,
- The temperature of the exhaust gas enters the economizer (T_{hi}) 300°C,

In the design of heat exchangers, calculations, temporary data are known, selected and planned [7]. The first design calculation results obtained shell diameter, $D_s = 0.527$ m and the number of tubes, $N_t = 223$ tubes. Furthermore, by doing the same calculation as above but using the design conditions no. 2 to no. 9, you will get the results as tabulated in the following table:

Table 3 The results of calculation of tool design optimization using Taguchi experiment

No	Do (m)	CL (°)	Pitch Ratio (PR)	Af/Ac	Ds (m)	Nt (Tube)
1	0.0254	0.87	1.25	1.2	0.540	235
2	0.0254	1	1.375	1.25	0.650	262
3	0.0254	0.87	1.5	1.3	0.675	254
4	0.03175	0.87	1.375	1.3	0.691	204
5	0.03175	1	1.5	1.2	0.777	201
6	0.03175	0.87	1.25	1.25	0.616	196
7	0.0381	0.87	1.5	1.25	0.810	163
8	0.0381	1	1.25	1.3	0.738	182
9	0.0381	0.87	1.375	1.2	0.728	157

3.2. Analysis of The Mean Effect of Each Factor

Calculation of the average response above is used to determine the effect of each level of factors on the calculation results. The results of the average response calculation are used to identify the level of factors that are dominant to the design calculation results. The following

table presents the results of the average level factor response to the number of tubes and shell diameters.

Table 4 Effect of averaging factors on each level

No	Description	Notation	Ds	Nt
1	Average dimension	\bar{y}	0,69	206
2	Effect of averaging Tube diameter 0.0254	$\bar{A1}$	0,62	251
3	Effect of averaging Tube diameter 0.03175	$\bar{A2}$	0,69	200
4	Effect of averaging Tube diameter 0.0381	$\bar{A3}$	0,76	167
5	Effect of averaging Lay Out 30 °	$\bar{B1}$	0,68	201
6	Effect of averaging Lay Out 45 °	$\bar{B2}$	0,72	215
7	Effect of averaging Lay Out 60 °	$\bar{B3}$	0,67	202
8	Effect of averaging Pitch Ratio 1.25	$\bar{C1}$	0,63	204
9	Effect of averaging Pitch Ratio 1.375	$\bar{C2}$	0,69	208
10	Effect of averaging Pitch Ratio 1.50	$\bar{C3}$	0,75	206
11	Effect of averaging Excess Area 1.20	$\bar{D1}$	0,68	198
12	Effect of averaging Excess Area 1.25	$\bar{D2}$	0,67	213
13	Effect of averaging Excess Area 1.30	$\bar{D3}$	0,70	213

3.3. Identification of Optimum Factor Levers

The identification of the optimum factor lever is needed to determine the level of factors that have the greatest influence on the results of design calculations. The combination of these dominant factor levels is expected to provide optimum parameters.

3.3.1. Level of optimum number of tube factors

The effect of each level and factor on the number of tubes can be seen in the following table:

Table 5 Identifies the optimum factor level in the number of tubes

Level	Tube diameter (A)	Lay Out (B)	Pitch Ratio (C)	Excess Area (D)
1	251	201	204	198
2	200	315	208	213
3	167	202	206	213
Difference	83	14	4	15
Rank	1	3	4	2

From Table 5 it can be seen that the combination of factor levels for obtaining the smallest number of tubes (Nt) is obtained on A3; D1; B1 and C1; that is, the tube diameter is

0.0254 m, Excess area 1.2, Lay Out 30° and pitch ratio 1.2. Figure 1 shows the factor level response to the number of tubes.

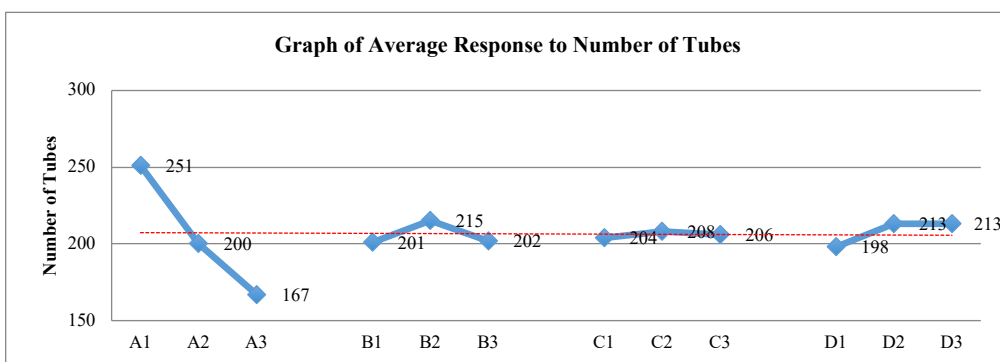


Figure 1 Effect of averaging the response of each level to the number of tubes.

3.3.2. Level shell optimum diameter factor

The influence of each level and factor on the shell diameter can be seen in Table 6. From Table 6, it can be seen that the

combination of factor levels to obtain the smallest shell diameter (Ds) is obtained at A1; C1; B3 and D1; namely the tube diameter 0.0381 m, pitch ratio 1.2, Excess area 1.2, Lay

Out 30° and Excess area 1.2. Figure 2 shows the factor level response to the number of tubes.

Table 6 Identification of the optimum factor levels in the shell diameter

Level	Tube diameter (A)	Lay Out (B)	Pitch Ratio (C)	Excess Area (D)
1	0.62	0.68	0.63	0.68
2	0.69	0.72	0.69	0.69
3	0.76	0.67	0.75	0.70
Difference	0.14	0.04	0.12	0.03
Rank	1	3	2	4

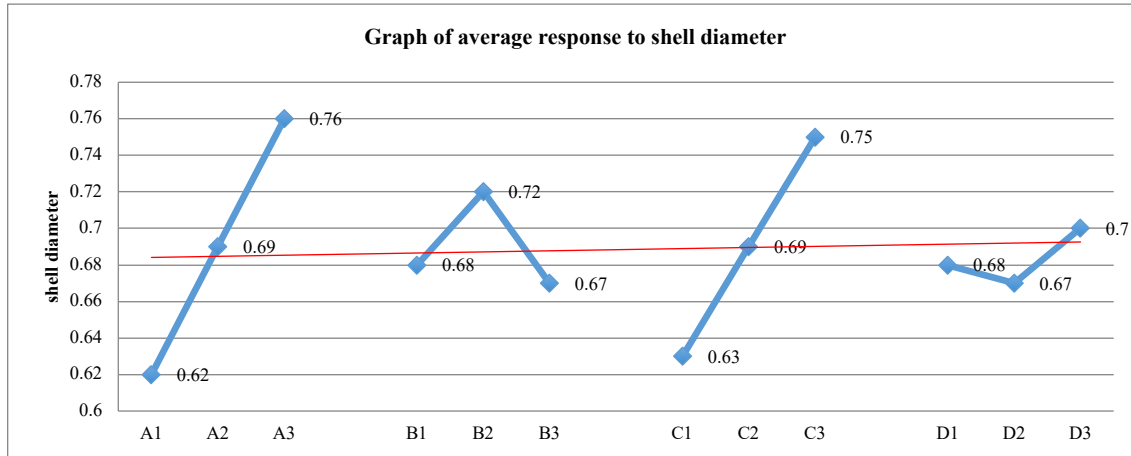


Figure 2 Effect of averaging the response of each level to the Shell Diameter

3.4. Research Result

In this study there are two types of optimization, namely the optimization of the number of tubes (minimum) and the optimization of the Diameter Shell (minimization).

3.4.1. Optimization for tube counts

From table 6, the smallest number of tubes is obtained from a combination of A3, D1, B1 and C1. The results of the optimum tube number prediction calculation are as follows,

$$Nt = N_{rata\ rata} + (A_{min} - T) + (B_{min} - T) + (C_{min} - T) + (D_{min} - T) \quad (1)$$

$$= 206 + (167 - 206) + (201 - 206) + (194 - 206) + (198 - 206)$$

$$= 142 \text{ Tube}$$

so;

$$D_s = 0,637 \sqrt{\frac{0,87}{0,93} \left(\frac{(16,14 \times 1,2)(1,25)^2 0,0381}{1} \right)^{0,5}} \quad (2)$$

$$D_s = 0,66 \text{ m}$$

3.4.2. Optimization for Shell Diameter

From table 6, the smallest shell diameter is obtained from a combination of A1, C1; B3 and D1. The results of the optimum tube number prediction calculation are as follows.

$$D_s = D_{rata\ rata} + (A_{min} - T) + (B_{min} - T) + (C_{min} - T) + (D_{min} - T) \quad (3)$$

$$= 0,69 + (0,67 - 0,69) + (0,67 - 0,69) + (0,63 - 0,69) + (0,67 - 0,69)$$

$$= 0,53 \text{ m}$$

So,

$$N_t = 0,785 \left(\frac{0,93}{0,87} \right)^{0,5} \left(\frac{0,53}{(1,25)(0,0254)} \right)^2 \quad (4)$$

$$N_t = 226 \text{ tube}$$

The dimensions of the best heat exchanger are the smallest number of tubes and the smallest shell diameter. Furthermore, the Taguchi experiment obtained the average effect of each factor on the number of tubes and shell diameters so that the optimum design conditions are obtained. The optimum conditions of the heat exchanger can be seen as in Table 7.

Table 7 Dimensions of the optimum design of the Taguchi experiment

No	Parameter / Dimension	Symbol	value	Unit
1	Shell Diameter	D_s	0,66	M
2	Long	L	1	M
3	Number of Tubes	N_t	142	pcs
4	Tube diameter	d_o	0,0381	M
5	Surface Area of Heat Transfer	A	16,14	m ²
6	Koef. Clean Comprehensive Heat Transfer	U_c	52,63	W/m ² K
7	Koef. Whole Fouling Heat Transfer	U_f	41,54	W/m ² K
8	Fouling Factor	R_f	0,0057	m ² K/W
9	Thermal Load	Q	119.519	W
10	Exhaust Gas Temperature Enter	T_{hi}	300	°C
12	Inlet Water Temperature	T_{ci}	28	°C
13	Outgoing Water Temperature	T_{co}	80	°C
14	Flue Gas Mass Flow Rate	m_h	0,9	kg/s
15	Water Mass Flow Rate	m_c	0,55	kg/s
16	Pitch Ratio	PR	1,25	
17	Arrangement between tubes	CL	30	Degree
18	Number of One Pass	CTP	0.93	

4. CONCLUSION

Based on the analysis of the results of data processing to determine the optimum design of the main dimensions of the economizer at the laundry plant, it is concluded that Tube diameter (d_o) has a significant effect on the number of tubes and shell diameter (D_s), Pitch ratio (P_R) has a significant effect on shell diameter (D_s) but does not have a significant effect on the number of tubes, Excess area has a significant effect on the number of tubes but does not have a significant effect on the diameter of the shell (D_s) and Lay out has the same effect on the diameter of the shell and the number of tubes (N_t) at a combination of tube diameter (d_o) 0.0254 m, Excess area (P_R) 1.2, Lay Out 30° and pitch ratio 1.2. And the optimum shell diameter is obtained at a combination of tube diameter (d_o) 0.0381 m, pitch ratio (P_R) 1.2, Excess area 1.2 and lay out 30°. Suggestions can be given from the results of research for further research using experimental or field test results, and analyzing the economizer's design by including product costs / economic aspects.

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