# Enhancing Performance of Shell-and-Tube Economizer with Twisted Triangle-hole Plate

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## Abstract

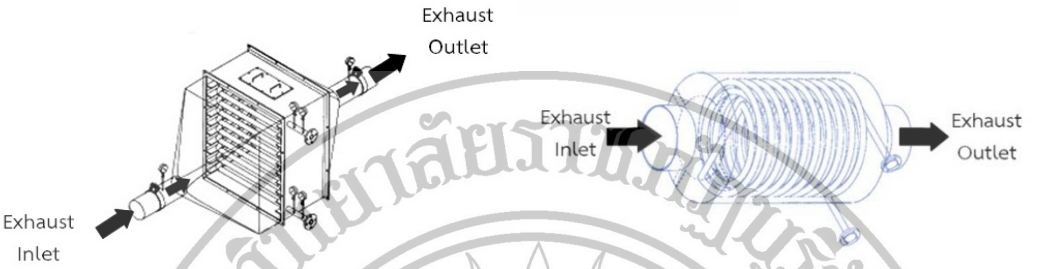
This article presents study of shell and tube economizer with centered triangle-hole aluminums twisted tape for once-through boiler. The exhaust heat from once-through boiler the water heat tube have total surface area 3.55 $m^2$, outside diameter 0.033 m, and total length 34 m. The twisted tape inside the water heat tube have twisted ratio, y/w = 3 and total area of triangle-hole is 0.078 $m^2$. It was found that the designed economizer performed with 5 m/s feed speed, outer and inner tube's heat transfer ratio at 441.53 and 280.41 kW, heat transfer coefficient at 5,422.46 and 23.29 W/$m^{2o}$C, pressure drop at 28.31 and 5.98 Pa. The performance of the designed economizer was at 0.62, which save cost around 61,976.34 Baht/year and the payback was at 2.66 year period of investment. This condition is suitable for the boiler that generates 500 kg/h steam rate with the maximum pressure of 7 kg/$cm^2$.

**Keywords:** Once - through boiler, Shell and tube economizer with centered triangle-hole aluminums twisted tape, Save cost

## 1. Introduction

Research Center Energy at mechanical engineering department of Faculty engineering and technology, Phetchaburi Rajabhat University mainly study how to recover the waste heat loss from exhaust pipe of once-through boiler capacity 500 kg/h at maximum steam pressure 7 kg/$cm^2$ by heat up water tube of shell and tube economizer. The researcher (Uthai et.al., 2013, 2014) had designed economizer type helical tube economizer and shell and tube economizer by using waste heat lost from once-through boiler flow pass economizer, tube normally with both types of helical tube economizer and shell and tube economizer then after heat exchange with water tube the hot air will be sucked by blower to boiler exhaust pipe and the design criteria of helical tube and shell and tube economizer are the same.

The result of the study had found that efficiency of shell and tube economizer was 40 % while helical tube economizer was 36 %. There for shell and tube economizer has higher efficiency and more appropriate to use for small once-through boiler steam capacity 500 kg/h and maximum steam pressure 7 kg/$cm^2$. From the result of higher efficiency of shell and tube economizer, researcher has interest in develop more efficiency by inserted twisted aluminums tape inside water tube of shell and tube economizer.




(a) (b)

*Figure 1.(a) shell and tube economizer (b) helical tube economizer*

This twisted aluminums tape had been cut triangular hole in each twisted section to allow water in tube flow spirally to help increase heat transfer rate.

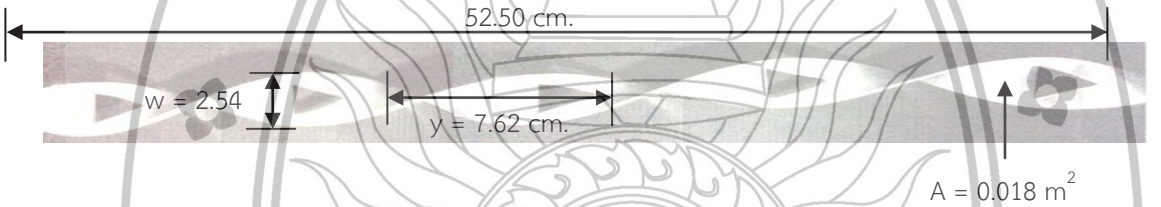



*Figure 2. Twisted aluminums tape with triangular hole in each twist section*

**2. Research objectives**

This research consisted of three objectives

2.1 Design, then build and test prototype of shell and tube economizer with twisted triangle-hole aluminums plate inside water tube.

2.2 To study effect of water heat loss speed flow versus variety variable of shell and tube economizer with inserted twisted triangle-hole aluminums plate inside water tube

2.3 To study the appropriate point of investment and energy saving.

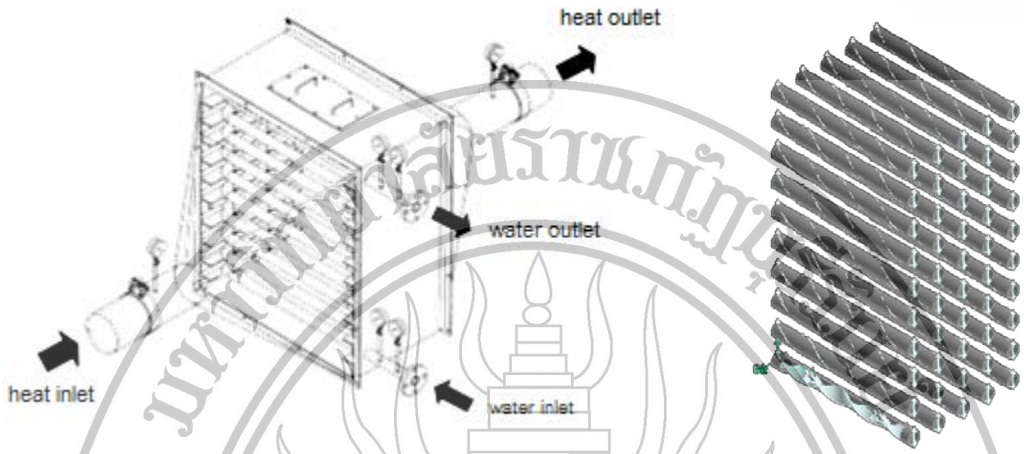
**3. Research Methodology**

3.1 Experimental Equipment and Experiments methodology

The design and experimental equipment of shell and tube economizer with inserted twisted triangle aluminums tape using steel STB 35.8, the tube has diameter 0.033 m, thickness 0.004 m, total length 34 m, each tube long 0.75 m with horizontal pitch 0.072 m. and vertical pitch 0.076 m, all tube arrange as 5x10 rows as shown in figure 3(b). In each tube is inserted twisted triangle-hole aluminums tape with 4 triangle hole of total hole area 0.078 $m^2$. The twisted aluminums tape has twisted ratio y/w equal to 3 along the tube.

3.1.1 Experimental Equipment

Equipment of shell and tube economizer with inserted twisted triangle hole aluminums tape as shown in figure 3(a) and 3(b), is installed with once-through boiler steam capacity 500 kg/h and steam pressure 7 $kg/cm^2$ for recover heat lost from exhaust pipe boiler by letting heat loss flow pass normal with all tube rows that have over all outside surface area 3.55 $m^2$ and shell surface area of 5.17 $m^2$.




**a)** **) )** **b(**

*Figure 3. (a) shell and tube economizer (b) row column of tube with inserted twisted triangle-hole aluminums tape inside shell and tube economizer*

3.1.2 Experiments methodology

- water temperature in tube is 30 – 42 $^{o}$C
- heat loss flow speed 5 – 6.5 m/s ($f$ = 5 – 7 $H_z$)
- heat loss temperature 250 –300 $^{o}$C
- steam pressure 1 – 4 kg/cm$^2$
- data records $T_{s,i}, T_{s,o}, T_{t,i}, T_{t,o}, \dot{m}_s, \dot{m}_t, P_s, P_t, Vs, Vt, CO_2, CO, O_2, \eta_b, \lambda$ and loss (inlet and outlet of shell and tube economizer)

3.1.3 Theory Analysis

Under condition of once-through boiler steam capacity 500 kg/h, steam pressure 7 kg/cm$^2$, water inlet temperature 30-42 $^{o}$C, and under normal operation, the parameter from measurements are waste heat lost speed 5.0 – 6.5 m/s, waste heat temperature at exhaust boiler 250 – 300 $^{o}$C , boiler efficiency 88.97 %, gas carbon dioxide left over after combustion 9.75 %, carbon monoxide 7.25 %, and oxygen 6.45 %, and fuel consumption 31.5 l/h. The efficiency of shell and tube economizer with inserted twisted triangle-hole aluminums tape, then calculated from parameter waste heat transfer of shell and tube ($Q_s$, $Q_t$), heat coefficient transfer ($h_s$, $h_t$), pressure drop ($\Delta P_s$, $\Delta P_t$), Reynold number ($R_{es}$, $R_{et}$), , Nusselt number ($N_{us}$, $N_{ut}$). The efficiency ($\varepsilon$) equation is:

$$\varepsilon = \frac{\dot{m}_s Cp_s \left(T_{s,i} - T_{s,o}\right) + \dot{m}_t Cp_t \left(T_{t,i} - T_{t,o}\right)}{\dot{m}_t Cp_t \left(T_{s,i} - T_{t,i}\right)}$$

## 4. Research Results

4.1 Analysis results of shell part

As shown in figure 4, heat transfer rate in shell, $Q_s$, versus waste heat speed, $v$, 5.00 – 6.50 m/s of once-through boiler steam pressure 1 – 4 kg/cm$^2$ and water feed temperature between 30 – 42 ℃ with water mass flow rate 0.138 kg/s. It is found that waste heat speed 5.0 m/s gave highest heat transfer average of 420.38 – 441.53 kW.

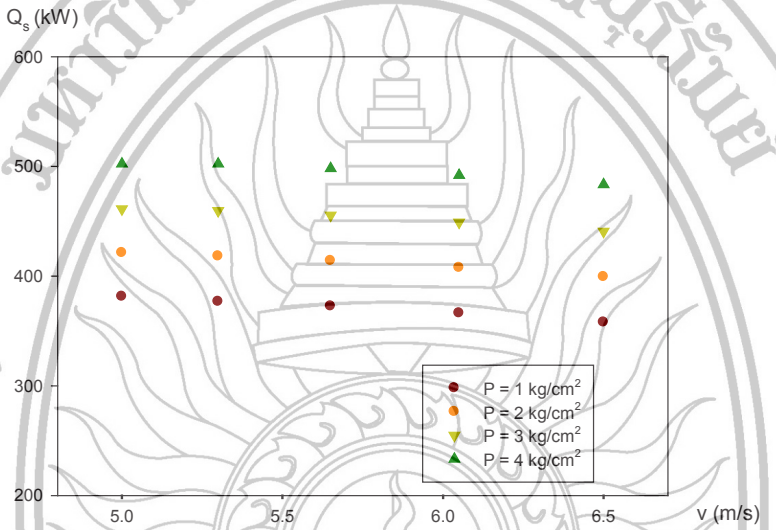



*Figure 4. Relationship between waste heat speed and heat transfer in shell*

Figure 5 indicated the pressure drop in shell, $\Delta P_s$, versus waste heat speed , $v$, 5.00 – 6.50 m/s of once-through boiler steam pressure 1 – 4 kg/cm$^2$ and water feed temperature 30 – 42 $^{o}$C. It is found that waste heat speed 5.0 m/s had highest pressure drop average of 28.31 – 27.94 Pa. When heat transfer rate increase, the pressure drop will increase and when heat transfer rate decrease, the pressure drop will decrease too because waste heat speed increase.

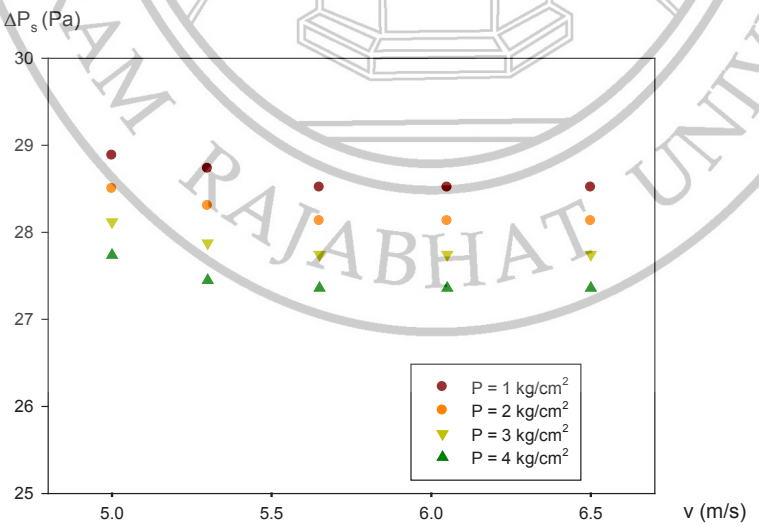



*Figure 5. Relationship between waste heat speed and pressure drop in shell*

Figure 6 showed the heat coefficient transfer of shell, $h_s$, versus waste heat speed, $v$, 5.00 – 6.50 m/s of once-through boiler steam pressure 1 – 4 kg/cm$^2$ and waste heat temperature between 220.5 – 250.3 $^{o}$C. It is found that waste heat speed 5.0 m/s gave highest heat coefficient transfer average of 5.42 kW/m$^2$ $^{o}$C because water feed had low temperature and so at lower waste heat speed the rate of heat transfer get higher.

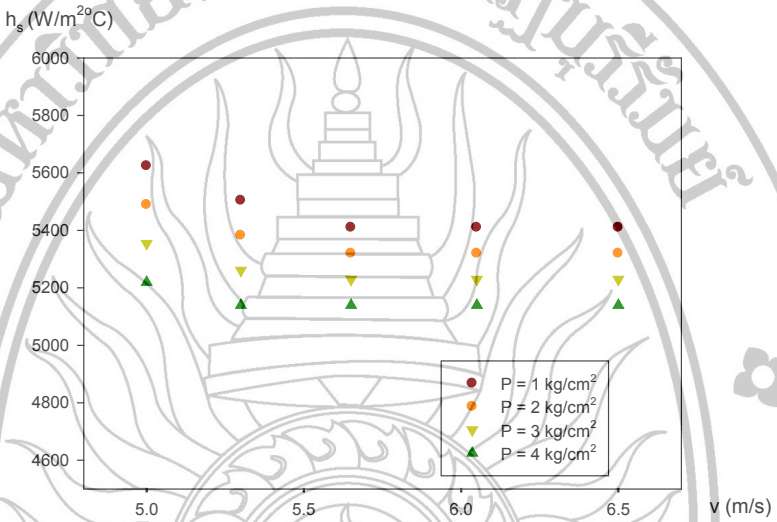



*Figure 6. Relationship between waste heat speed and heat coefficient transfer in shell*

It can be concluded the analysis results of shell and tube economizer with inserted twisted triangle hole aluminums tape of figure 4 to figure 6 that the relationship between waste heat speed of 5.00 – 6.50 m/s with water feed temperature between 30 – 42 $^{o}$C versus heat transfer in shell, pressure drop in shell, and heat coefficient transfer in shell, it is found that waste heat speed 5.0 m/s has highest pressure drop average of 28.31 Pa and heat coefficient transfer average of 5.42 kW/m$^2$ $^{o}$C per surface shell area 5.17 m$^2$. These results are consistent with waste heat speed 5.00 – 6.50 m/s before installation of shell and tube economizer in once-through boiler steam capacity 500 kg/h and steam pressure not over 5 kg/cm$^2$. At waste heat speed 5.30 m/s the heat transfer rate and heat coefficient transfer will drop lower than the waste heat speed 5.0 m/s.

4.2 Analysis results of tube part

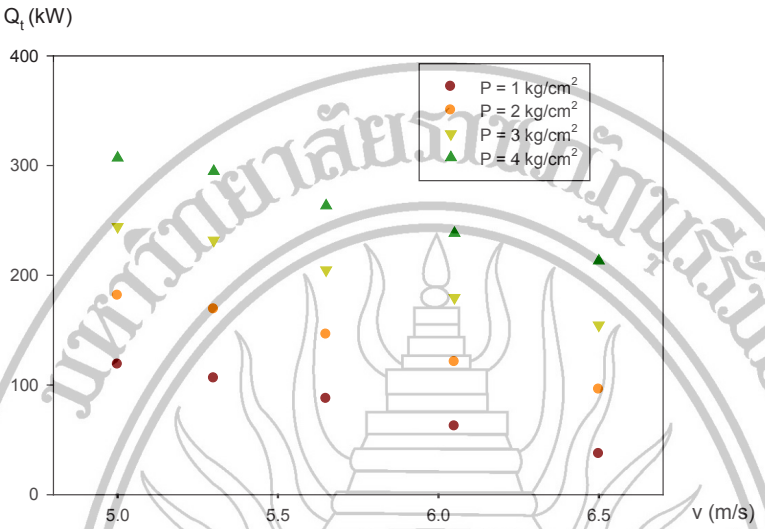



*Figure 7. Relationship between waste heat speed and heat transfer in tube*

Heat transfer rate in tube, $Q_t$, versus waste heat speed, $v$, 5.00 – 6.50 m/s of once-through boiler steam pressure 1 – 4 kg/cm$^2$ and water feed temperature between 30 – 42 $^{o}$C with water mass flow rate 0.138 kg/s were shown in figure 7. It is found that waste heat speed 5.0 m/s gave highest heat transfer average of 477.80 kW and when waste heat speed is increased by increase in sucking speed of blower, the heat transfer rate will decrease as shown.

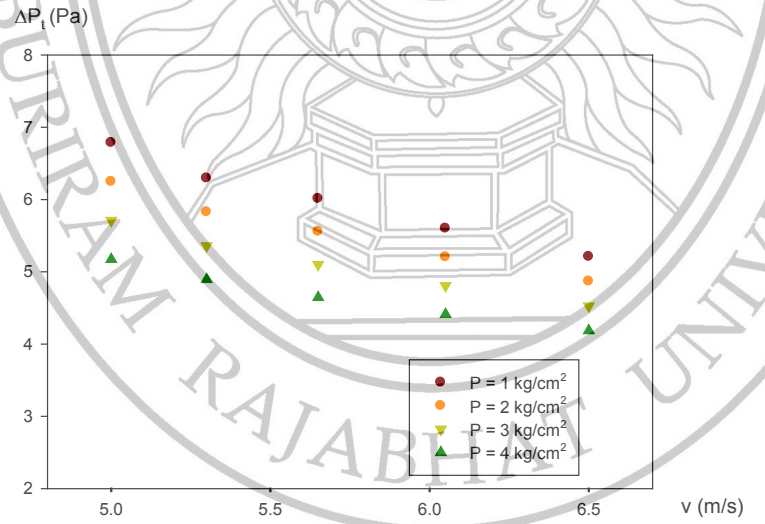



*Figure 8. Relationship between waste heat speed and pressure drop in tube*

In figure 8 pressure drop in tube, $\Delta P_t$, versus waste heat speed , $v$, 5.00 – 6.50 m/s of once-through boiler steam pressure 1 – 4 kg/cm$^2$ and water feed temperature between 30 – 42 $^{o}$C with water mass flow rate 0.138 kg/s can be seen. It is found that waste heat speed 5.0 m/s had highest pressure drop average 5.98 Pa. and increase in waste heat speed

decrease the pressure drop as shown which is consistent with research of the waste heat recovery system for small boiler. (Uthai, et.al., 2013). When waste heat speed is increased, it will reduce heat transfer rate and pressure drop.

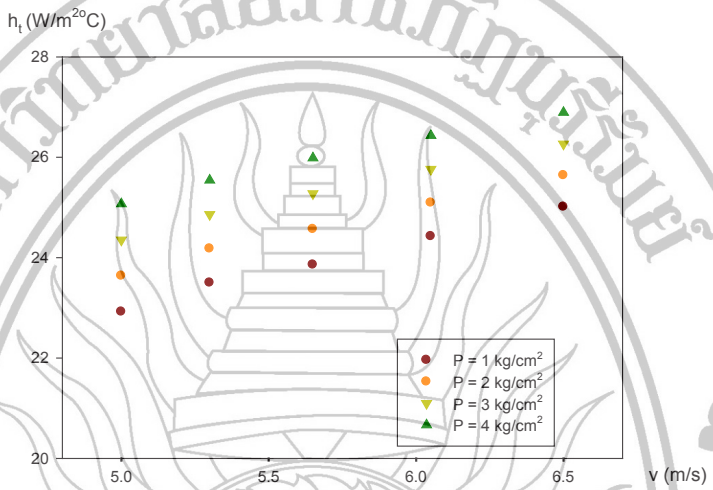



*Figure 9. Relationship between waste heat speed and heat coefficient transfer in tube*

Figure 9 showed the heat coefficient transfer of shell, $h_t$, versus waste heat speed , $v$, 5.00 – 6.50 m/s of once-through boiler steam pressure 1 – 4 kg/cm$^2$ and water feed temperature between 30 – 42 $^oC$ with water mass flow rate 0.138 kg/s. It is found that waste heat speed 5.0 m/s gave highest heat coefficient transfer average of 23.99 kW/m$^2$ $^oC$ and increase in waste heat speed increase the heat coefficient transfer because water feed temperature reach 42 $^oC$.

It can be concluded the analysis results of shell and tube economizer with inserted twisted triangle-hole aluminums tape of figure 7 to figure 9 that the relationship between waste heat speed of 5.00 – 6.50 m/s with water feed temperature between 30 – 42 $^oC$ versus heat transfer in tube, pressure drop in tube, and heat coefficient transfer in tube, it is found that waste heat speed 5.0 m/s has highest heat transfer rate average of 277.80 kW with highest pressure drop average of 5.98 Pa and heat coefficient transfer average of 23.99 kW/m$^2$ $^oC$. These results are optimized for design of shell and tube economizer with inserted twisted triangle-hole aluminums plate, the total surface tube for heat transfer is 3.55 m$^2$ and total tube length 34 m with tube diameter 0.033 m, and twisted triangle-hole aluminums tape area of 0.56 m$^2$. The water temperature inside tube has been increased to 80 – 85 $^oC$ due to heat transfer of waste heat lost. These results are consistent with research of the rectangular in twisted tape economizer shell and tube (Uthai, et. al., 2015), the water temperature inside tube increase to 75 – 80 $^oC$ that save energy cost by 198,406 baht/year.

4.3 Efficiency analysis of shell and tube economizer with inserted twisted triangle-hole aluminums tape within once-through boiler.

Figure 10 represented the efficiency of shell and tube economizer, $\varepsilon$, versus waste heat speed, $v$, 5.00 – 6.50 m/s of once-through boiler steam pressure 1 – 4 kg/cm$^2$ and water feed temperature between 30 – 42 $^oC$ with water mass flow rate 0.138 kg/s. It is found that waste heat speed 5.0 m/s gave highest efficiency average of 0.62 and increase in waste heat

speed dropped the efficiency gradually because waste heat speed has been sucked out faster than appropriate heat transfer rate.

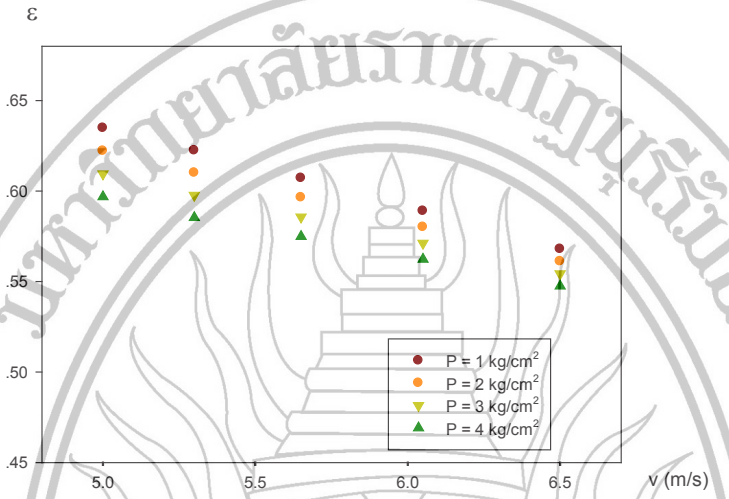



*Figure 10. Relationship between waste heat speed and efficiency of shell and tube economizer*

4.4 Analysis of break even point and energy save of using shell and tube economizer with inserted twisted triangle-hole aluminums tape within once-through boiler.

*Table 1*
*Break even point and energy save analysis of using shell and tube economizer with inserted twisted triangle-hole aluminums tape within once-through boiler.*

| No. | Details | Analysis results |
|---|---|---|
| 1 | Operating hour per day | 6h |
| 2 | ɔst of diesel | 30.15Baht/l |
| 3 | ɔst of shell and tube economizer | 165,000Baht |
| 4 | ɔwer save | 9.24kW |
| 5 | ıergy saving | 198,406Baht/y |
| 6 | Payback period | 2.6 6y |

As shown in table 1, the cost of shell and tube economizer plus maintenance is 165,000 baht. In case of operating hour per day is 6 hours and using diesel fuel (cost of diesel per liter is 30.15 baht). It is found that this shell and tube economizer can save energy cost by 198,406 baht/year and payback period is 2.66 years. This result is consistent with research of (Thanongkiat, et.al., 2004), using waste heat loss of water tube boiler steam capacity 1 ton/h and 3 ton/h to heat water in car radiator. He found that for steam 1 ton/h can save energy cost 18,500 baht/year and payback period is 2.5 years while steam

capacity 3 ton/h can save energy cost 100,000 baht/year and payback period is 0.9 years. It can be seen that smaller boiler have payback period longer that bigger boiler because small boiler has less steam capacity.

**5. Discussion**

The analysis results of shell and tube economizer with inserted twisted triangle-hole aluminums within once-through boiler steam capacity 500 kg/h with technical data of total surface area for heat transfer of tube and shell are 3.55 $m^2$ and 5.17 $m^2$, total tube length 34 m, shell length 2.18 m, waste heat speed between 5.00 – 6.50 m/s, waste heat temperature from exhaust pipe is between 220.5 to 250.3 $^oC$, steam pressure between 1 – 4 $kg/cm^2$. It is found that waste heat speed 5.0 m/s, the results inside shell and inside tube are heat transfer rate average 441.53 kW and 280.41 kW, pressure drop 28.31 Pa and 5.91 Pa, heat coefficient transfer 5422.46 $kW/m^2\,^oC$ and 23.29 $kW/m^2\,^oC$, and the efficiency of shell and tube economizer with inserted twisted triangle hole aluminums tape is 0.62. These results are optimized to use with small once-through boiler. The cost of shell and tube economizer is 165,000 baht which can save energy cost by 198,406 baht/year. It is a good value for money with internal rate of return, IRR, 32.12 %. When compare with bank interest for small industry of 10 %, it can be seen that IRR is a lot higher. There for shell and tube economizer with inserted twisted triangle hole aluminums tape is appropriate to invest with payback period only 2.66 years. This is better than research of (Uthai, et.al., 2013), shell and tube economizer without inserted twisted aluminums plate.

**6. Conclusion**

A enhance performance of shell and tube economizer with twisted triangle-hole plate. The exhaust heat from once-through boiler tube was brought to transfer to the total 3.55 $m^2$ surface area of tube with 0.033 m diameter , 34 m in length , inserted with the twisted aluminums plate with the radio of y/w = 3 . The inserted plat had a triangle-hole total area of 0.078 $m^2$, it was found that the designed economizer performance with 5 m/s feed speed. The performance of the designed economizer was at 0.62 which cloud save the energy 9.24 kW and the payback was at 2.66 year period of investment.

**7. Recommendation**

The shell-tube economizer with centered triangle-hole twisted tape of waste heat boiler increase corrosion resistance. The method is aluminums enamel and precious metal plating.

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