Research Article

Design and Implementation of Energy Recovery System from Autoclaves in Fiber Cement Industry

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Abstract
The fiber cement composite process has extremely high fuel consumption and a lot of waste energy released. This study focuses on the recovery methods from two waste heat streams; the condensate and the exhaust steam from the autoclaves. An analysis of the heat loss from the autoclave shell showed that the optimum insulation thickness is 0.085 mm. To recover heat from either condensate or exhaust steams, a pinch location can recover the waste heat for fresh boiler feed water at 100°C. Introduction of multiple heat exchanger optimization and control proposed two series of shell and tube exchangers for the condensate and the exhaust steams. The fuel consumption from the heat recovery can approximately be reduced to 8.37 MTHB/year with a payback period of one and a half year.

Keywords: Fiber cement, Autoclave, Energy utilization, Optimum design

1 Introduction

Major fiber cement of Thailand with the capacity of 500,000 ton/year is the focus of this article due to its energy consumption and waste heat (Figure 1).

From an energy point of view, the fiber cement process has extremely high fuel consumption with almost 85% of the steam being used in the autoclave. The major fuel source used in the main boiler is biomass (rice husk). At normal operation of the plant, the boiler is used to heat up water from ambient temperature to steam at an average pressure of 10 bars, requiring the average of the rice husk feed rate of 3 ton/h to produce steam at 15 ton/h [1]. A heavy oil boiler plays a supplementary role about 40% of normal rice husk boiler. The average temperature of the exhaust gas and the unburnt rice husk are relatively high. In the autoclave section, the operating information was studied weekly during normal operation. This plant has 12 autoclaves that operated 16 h/batch, simultaneously. The steam consumption of each autoclave depends on the types of product on the average of 13 ton/batch/autoclave maintained at 180°C and 10 bar. For the last two hours of the autoclave operation, the steam is slowly released through the scrubber tower in order to treat the amount of ammonia. The exhaust steam was approximately at 8 ton/h with 130°C. The condensate of 8–9 ton/batch at 130°C is the other waste heat stream from the autoclave. Both streams have a high potential to implement as heat recovery. The heat lost from the wall of the autoclave is also expected to be significant and will be quantified.

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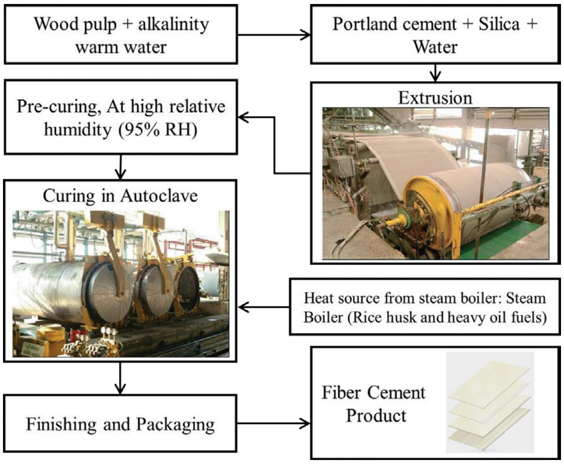


Figure 1: Fiber cement Process diagram [1].

There are a number of waste heat recovery techniques that can reduce both process operation costs and conserve significant amounts of fuel. These can be the major conservation method to be adapted to a wide range of industries, and involve a substantial outlay of capital [2]. Several conventional technologies to recover waste heat from boiler flue gases, such as recuperators, regenerators, finned tube economizers and passive air preheaters are typically used for medium – to – high temperature waste heat and the challenges are the material constraints and temperature restrictions [3]. Boilers and other fired systems are the most significant energy consumers. They were combust fuel with air for the purpose of releasing energy [4], [5]. A heat balance is normally used to determine the points of heat energy enter and leave a system [6]. Considering a boiler system, the energy input comes from condensate return, makeup water, combustion air, fuel, and some others depending on the complexity of the system [7], [8]. Energy departs via steam, blowdown, exhaust gases, surface losses, possible ash, and other discharges [9], [10]. In order to analyze such a complex system, the enhanced mass and energy balances must be used simultaneously [11]. This type of analysis is particularly useful in determining blow down losses, waste heat recovery potential, and other independent opportunities [12].

The heat and mass balances of the major energy consumption sections are studied in order to analysis the heat and mass flow in the system. Commercial simulator with the heat exchanger design module will be used to simulate the proposed heat recovering networks of waste heat from the fiber cement process.

Based on the aforementioned analyses, the exhaust steam from the autoclave is the biggest source of heat loss in this study (12 autoclaves). To recovery this amount of heat, heat exchanger is needed. The contribution of this paper is to propose a design of heat exchanger for the real fiber cement process system which has not been studied in the previous literatures. The objective of this study is implement the energy recovery system to the industrial scale fiber cement focusing on steam utility from two boilers; rice husk and heavy oil. Total steam was scheduled into twelve units of the autoclaves for 24 h operation.

2 Methodology

The systematic approach to energy analysis and recovery system is proposed in this study. The first step is to get all operation information including the process database, equipment, measurement points and operation condition with validation. In the second step, the process evaluation is performed by field measurements and operation parameters. This information provided both quantity and quality to formulate the heat and mass balances. The pinch point of the process is founded on the investigation.

The design of heat exchanger network is best executed using the Pinch Design Method (PDM). The systematic application of the PDM allows the design of a good network that achieves the energy targets within practical limits. The method incorporates two fundamentally important features: 1) it recognizes that the pinch region is the most constrained part of the problem and 2) it allows the designer to choose between match options. The design of network examines which hot streams can be matched to cold streams via heat recovery. This can be achieved by employing tick off heuristics to identify the heat loads on the pinch exchanger. Every match brings one stream to it target temperature. When the heat recovery is maximized the remaining thermal needs must be supplied by hot utility.

In this study have 3 hot streams and 1 cool stream so the pinch design method uses to arrange the sequent of heat exchanger. The dimension of heat exchanger also considers because of it depends on installation area. Therefore, in this case, we select the

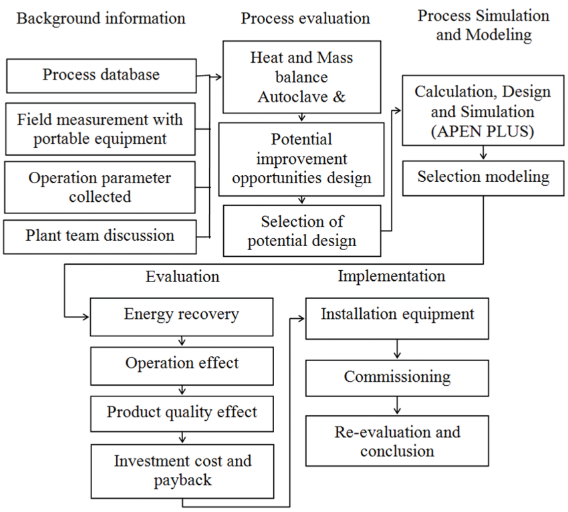


Figure 2: Implementation of heat recovery diagram.

smaller size of heat exchanger more than a bigger one. However, another part such as heat exchanger design, cost estimation and calculation of rate of return also important.

Many potential improvement projects such as rice husk dryer, heat exchanger and recycle of condensate are considered using this relevance information. The heat exchanger is reasonably selected because of the high heat recovery comparing with others. Then, the heat exchanger model and configuration simulation are done in the third step. After that, the proposed project is evaluated in terms of energy recovery, the effect of product quality, operation control and investment cost. All of the evaluation information is considered for investment. The final step; after approved the project is implemented to the existing process and re-evaluation. Figure 2 is the step–by–step of this implementation.

The heat balance considered the heat of combustion and heat loses from the boiler surface area. The equations of calorific energy comprise of sensible and latent heat equations. The sensible heat equation was used to calculate the energy of all material in the mass and energy balance step (refer to a datum of 0°C). The energy released from the solid fuel (rice husk) can be calculated from the combustion equation based on the heating value of the materials.

In this work, the surface heat loss through the wall and from the steam boiler and autoclave shells are also estimated.

2.1 *Heat transfer equation*

In each stream of materials, the physical data are required because of it is represented the condition of that stream. The temperature, pressure, flow rate, pipe diameter, etc. are required to collect. The heat and mass balance cannot be successes without all on this information and it needed to collect the information during the steady state process. If not, the information is not presenting the real operating process. The state condition is used to make the balance of heat at reference state such as 1 bar and 25°C. The equation of sensible heat, latent heat and etc. required to use following the condition of the system.

Sensible heat is heat exchanged for a body or thermodynamic system that has as its sole effect a change of temperature.

Under a phase changed condition, the latent heat equation is used to calculation the heat of the system. Latent heat is the heat released or absorbed by the body or a thermodynamic system during a process that occurs without a change in temperature.

The heat of combustion is the energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon reacting; it is reacted which oxygen to form carbon dioxide, water and heat. All above terms can express by following Equation (1).

$$\dot{Q} = \dot{m}C_p\Delta T + \dot{m}\lambda + \dot{m}\cdot LHV \quad (1)$$

where m is mass rate. C_p is specific heat capacity. T is temperature. λ is latent heat which equal to 540 kcal/kg and LHV is the heating value of rice husk.

Rice husk is used as fuel in the steam boiler which using the ultimate analysis to obtain the hydrogen and oxygen content to calculate the heating value of rice husk as show in following Equation (2).

$$LHV = \left(80.8C + 22.5S + 287\left(H_2 - \frac{O_2}{8}\right) - 6.0m\right)\times 4.187 \quad (2)$$

The transfer of heat through a fixed material is accomplished by a mechanism known as conduction. The rate of heat flow by conduction is proportional to the area available for the heat transfer and the temperature gradient in the direction of the heat-flow path. The rate of heat flow in a given direction, therefore, can be expressed [Equation (3)]

$$\frac{dQ}{dt} = -kA\frac{dT}{dx} + hA\Delta T \quad (3)$$

where k is the proportionality constant designated as thermal conductivity and A is area of heat transfer perpendicular to the direction of heat flow and h is designated as the heat-transfer coefficient.

The thermal conductivity is a property of any given material, and its value must be determined experimentally. For solids, the effect of temperature on thermal conductivity is relatively small at normal temperatures. Because the conductivity varies approximately linearly with temperature, adequate design accuracy can be obtained by employing an average value of thermal conductivity based on the arithmetic-average temperature of a given material.

2.2 *General methods for process design of heat exchangers*

The procedures used for developing the design of heat exchangers vary with the type of problem and the preference of the worker. Some engineers prefer to develop the design for a heat exchanger by a method known as rating an exchanger. In this method, the engineer assumes the existence of an exchanger and makes calculations determine if the exchanger would handle the process requirements under reasonable conditions. If not, a different exchanger is assumed, and the calculations are repeated until a suitable design is developed. For example, with a given set of process requirements, the engineer could assume the existence of an exchanger with a designated tube size, tube spacing, baffle type, baffle spacing, and number of tubes and passes. The engineer might then proceed through the process design calculations by computing an overall heat-transfer coefficient and evaluating all flow rates, areas, lengths, and pressure drops. Repeated trials may be necessary to obtain an accurate overall coefficient. If the results of the final design indicate that the assumed exchanger has reasonable dimensions, reasonable cost, and acceptable pressure drops, the unit is considered as adequate and the design is complete.

3 Results and Discussion

3.1 *Overall balance of boiler*

Field data and yearly information conclude that the average capacity of the boiler is 15 ton of steam per hour. Rice husk is used as fuel for this boiler. Hot gas from the burning chamber is passed through the bag filter to separate the ash before released to the air via the exhaust stack. The average temperature of this exhaust gas from the boiler and the unburnt rice husk were 131 and 180°C; respectively. From the operation information, the total quantity of rice husk and heavy oil consumption per year are approximately 15,000 ton and 1,000,000 L; respectively.

The complete heat and mass balance of the boiler are simulated as shown in Figure 3. One can notice that the main source of energy input to the boiler is the fuel at 12.27 MW. The highest energy output is the steam product at 8.9 MW, but the other major output that also has high energy is the exhaust gas at 3.04 MW or 23.6% of the total energy output.

The heat and mass balance does not include the heavy oil boiler because this boiler is an operation about 30% of the total yearly operation.

3.2 *Overall balance of Autoclave*

The company currently operates 12 autoclaves in a batch schedule following the production plan. Each autoclave has the same configuration about volume (2.0 m diameter and 56.5 m length). The hydration reaction of cement with water can be expressed by following equation [13]. The hydration is reaction between cement compound and water where Tricalcium silicate (C_3S) is the main species in cement and H represent hydrogen in water. Then the hydration products were form as show in Equation (4) where CSH is calcium silicate hydrate and CH is calcium hydroxide.

$$C_3S + (2.5+i)H \rightarrow C_{1.5+j}SH_{1+j+i} + (1.5-j)CH \quad (4)$$

Autoclaves arrangement and operations are shown in Figure 4. Steam is charged to the autoclave to heat up the fiber cement inside until the designed temperature and pressure at 180°C and 10 bar. After that, the condition is maintained according to the

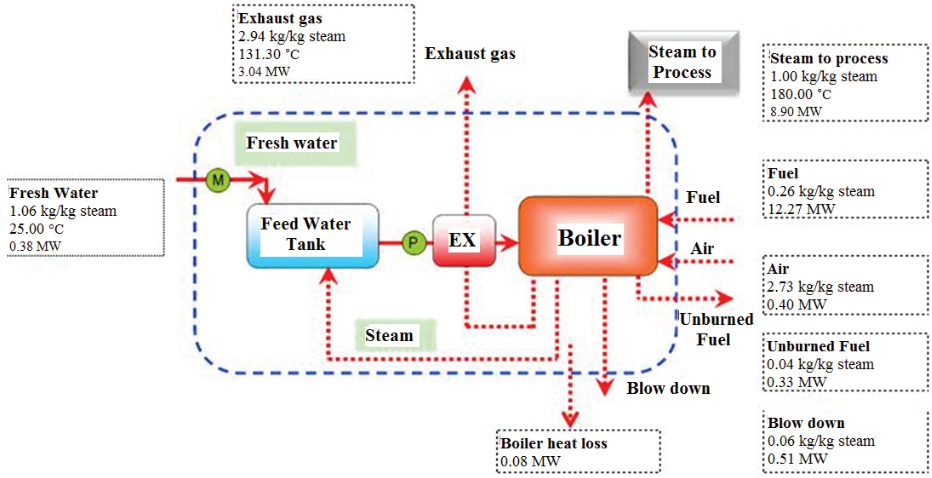


Figure 3: The heat and mass balance diagram of boiler at normal operation.

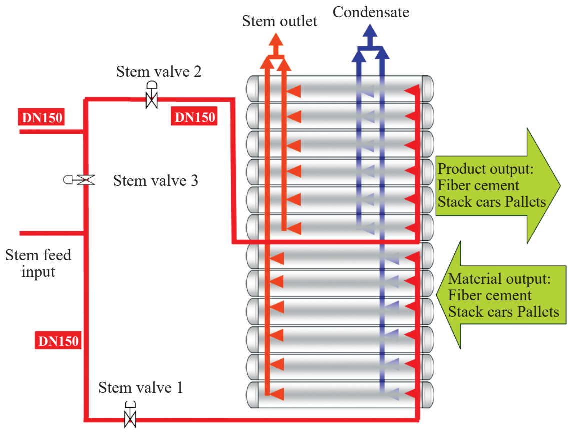


Figure 4: The autoclave system layout.

specific product scheduling (14 h in all products). The exhaust steam is released to the exhaust pipe passing through the scrubbers before being released out to the air during the last 2 h of operation.

3.3 *Waste Heat Utilization Design and Simulation*

The utilization design of the waste heat in the boiler and autoclave system are developed in this section. From previous results of heat and mass balances in the boiler and autoclave, a design of heat exchanger system to recover waste heat is proposed under the constraints of operating conditions and production plan.

The steam boiler was originally designed for using coal as the primary fuel, but the rice husk can be used as an alternative biomass fuel. Anyhow, the rice husk is an agriculture waste. It is not sustainable enough for long term continuing operation because of seasonal effect. In Thailand, a lot of rice husks are available and there is also the need for many industries such as power plants and cement plants. Coal will be used in the steam boiler during rice husk unavailable. Wherever the coal is used, the boiler exhaust gas will release the significant amount of sulfur dioxide to make the exhaust gas corrosive. If the exhaust gases are cooled below the dew point, the sulfuric acid will be formed on the walls. For this reason, the recovery propose of heat from the boiler exhaust gas would not be considered.

The value of the heat loss from the autoclave shell is significant (6.8%). This loss can be reduced by increasing the insulation thickness. The existing insulation of the autoclave is 0.004 m of Rockwool. Figure 6 shows the net cost of fuel as a function of insulation thickness. This calculation has based the assumption of one autoclave with 10 years life of the project and 30% accepted return rate. The optimum of the insulation thickness is 0.085 m (0.081 thicker than the current insulation) with the annual cost of heat losses being 12,922 THB/autoclave and the annual investment cost being 51,627 THB/autoclave. This optimum insulation thickness reduces the energy loss from 6.8 to 4.3% and the annual energy loss by 6,758 THB/autoclave compared with the original 0.004 m the thickness of insulation.

Up to this point, the exhaust steam and condensate are considered as the heat losses from the system. The recovery of both heat sources can dramatically improve the energy efficiency and cost reduction of the plant. Both heat losses are considered as heat sources while the fresh water feed boiler (R.O. water) can be considered as the heat sink at the pinch point of the plant. The average amounts of exhaust steam and condensate are 2,700 kg/h at 130°C and 3 bar and 4,900 kg/h at 130°C. Both show the possibility to preheat the boiler fresh water up to 100°C.

The selection of the heat exchanger configurations is an important part of heat recovery. In this work, the heat exchangers for the heat recovery operations were considered separately for the condensate and the exhaust steam. The study of Vengateson gave the design of multiple shells and tube heat exchangers in the series for an E shell (1 shell pass and 2 tube pass exchanger) [14]. The correction of effectiveness means temperature difference was included in that study. A series of mathematical equations was proposed in order to show the relation of the thermal capacity ratio (R) and the thermal effectiveness ratio (P) as shows in Equations (5)–(7), respectively. Both of these ratios were used to find the correction factor of logarithmic mean temperature difference F_T. The calculation of the number of heat exchanger connections in the series and the correction factor is given as Equations (8) and (9) respectively.

$$R = \frac{mc_p}{MC_p} = \frac{T_{in} - T_{out}}{t_{in} - t_{out}} \tag{5}$$

$$P_{on} = \frac{t_{out} - t_{in}}{T_{in} - t_{in}} \tag{6}$$

$$P_{\max} = \frac{2}{R + 1 + \sqrt{1 + R^2}} \tag{7}$$

$$N_{SHELLS} = \frac{\ln\left[(1 - RP_{on}) / (1 - P_{on})\right]}{\ln\left[(1 - RXp_p P_{\max}) / (1 - X_p P_{\max})\right]} \tag{8}$$

$$F_T = \frac{\sqrt{1+R^2}\,\ln\left[(1-P)/(1-PR)\right]}{(R-1)\ln\left[\left(2 - P\left(R + 1 - \sqrt{1+R^2}\right)\right)/\left(2 - P\left(R + 1 + \sqrt{1+R^2}\right)\right)\right]} \tag{9}$$

where X_p the fractional multiplier of P_{max}, proposed by Ahmad *et al*. [15]. It is used to calculate F_T in order to guarantee that the design of the heat exchanger is feasible. The study of Vengateson proposed that the desired value of F_T for an E shell heat exchanger should be ≥ 0.75 or 0.8. A low value of F_T indicates an inefficient use of the heat transfer area [14]. Equation (9) is used to calculate the F_T when $R \neq 1.0$. In this work, the conservative value of $X_p = 0.75$ was used.

For the exhaust steam heat exchangers, the results showed that two heat exchanges in the series were required. Because the normal operations of the autoclaves are a batch process, the exhaust steam volume is based on the operation schedule. The layout of the autoclaves is separated into two sections as shown in Figure 4. The first section consists of autoclaves 1 to 6 and the second section consists of autoclaves 7 to 12. The steam release period of both sections is independent. The operation conditions of autoclaves in each section are following:

Charging steam conditions:

- Steam can be a charge to the autoclaves not more than two units at the same time because of the steam product are not enough.
- The steam charging process is independent of two autoclave sections.

Releasing steam conditions:

- Exhaust steam can be released from only one autoclave at a time because of the pressure difference from the other autoclave can blow back to the releasing autoclave and damaged the product.
- The releasing process is dependent on two autoclave sections.

From releasing conditions, the heat recovery of exhaust steam is considered separately for each section of autoclaves (Figure 5). Each section will use a heat exchanger to recover the heat from the exhaust steam to prevent blowback and high variations of exhaust steam flow rate. It means that two heat exchangers are in the series with respect to heating water.

The exhaust steam of the autoclave was 2,700 kg/batch, 135°C and 3 bars. This steam is not enough to heat the water to nearly 100°C with only one exhaust steam section. The only way was to connect both heat exchangers in series to maximize the water temperature.

The autoclave is currently insulated with the 4 mm

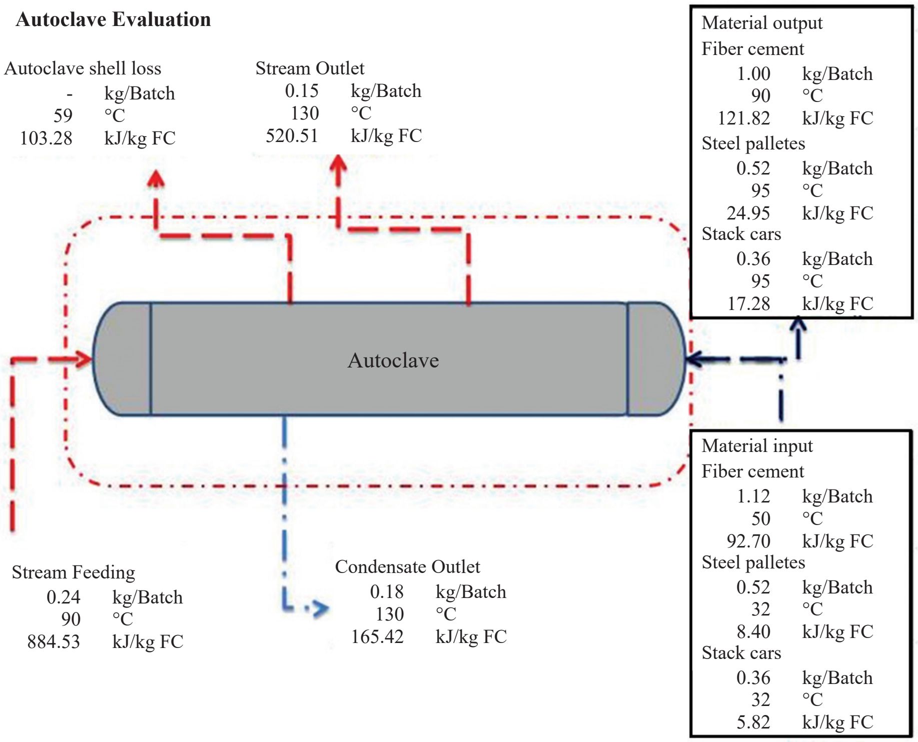


Figure 5: Analysis of heat and mass of normal operation autoclave.

thickness of rock wool insulator, but it still has high heat released from the autoclave shell during the operation. The reduction of this heat is needed in order to save the energy consumption of the in the autoclaves. The increasement of the insulation thickness is one of solution that can reduce the surface heat released under the reasonable investment cost. In the industrial view, the internal rate of return (IRR) is used to justify the optimum of the insulation thickness via compare the annual cost of heat losses with the annual investment cost of the insulation. By using Equations (10)–(12) of energy saving for surface insulated.

$$E_{savings} = Q_{uninsulated} - Q_{insulated} \tag{10}$$

$$Q_{uninsulated} = hA(T_s - T_a) + yA\varepsilon(T_s^4 - T_a^4) \tag{11}$$

$$Q_{insulated} = A \cdot (T_{is} - T_a) / (R_i + \frac{1}{f}) \tag{12}$$

where Q is a total heat loss, T_a is ambient temperature. T_s, T_{is} are hot surface or inner surface temperature. A is surface area. h is convection coefficient. y is Stefan-Boltzman constant. ε is the emissivity factor. f is surface coefficient. R is resistance of the insulation ($R_i = L/k_{in}$). L is thickness of insulation and k_{in} is the thermal conductivity of insulation. $E_{savings}$ can calculated from the difference of $Q_{insulated}$ and $Q_{uninsulates}$. Then it is converted to the steam quantity equivalent based on the enthalpy of the steam feed to the autoclave. The steam production cost is used to multiply with the steam equivalent to be the cost of saving. This cost is representing the saving from the increase of the insulation thickness.

Table 1 shows the costs of annual heat losses, annual investment and net cost of the project based on the increasing of insulation thickness. The first column is the insulation thickness increased from 0.005 m to 0.245 m With this change, the annual costs of heat loss and installation are also changed. The annual cost of heat loss reduces with the increasement of the thickness, but the cost of installation increases.

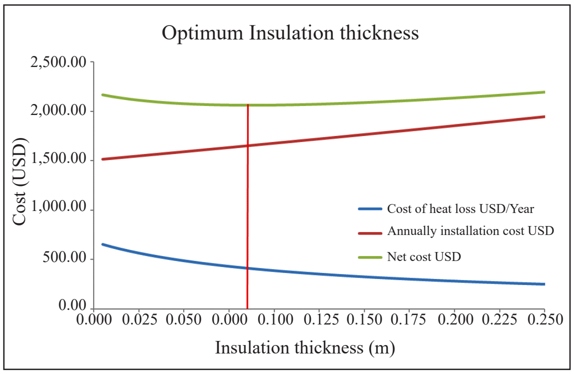


Figure 6: Finding the optimum insulation thickness of the autoclave in USD.

Table 1: The annual cost of heat loss, annual cost of installation and net cost based on the insulation thickness.

Insulation Thickness (m)	Annual Cost of Heat Loss (USD)	Annual Installation Cost (USD)	Net Cost (USD)
0.005	653	1,514	2,167.14
0.025	565	1,547	2,112.81
0.045	501	1,581	2,082.60
0.065	452	1,615	2,067.44
0.085	413	1,650	2,062.54
0.105	380	1,685	2,065.01
0.125	353	1,720	2,073.04
0.145	330	1,755	2,085.38
0.245	253	1,935	2,188.20

The suitable thickness gives the optimum of the annual costs of heat loss and of investment as a net cost. The minimum net cost is the optimum insulation thickness. At the insulation thickness of 0.085 m, the minimum of the net cost is 2,062.54 USD. It means that, at thickness 0.085 m. the annual cost of heat loss is 413 USD, and the annual investment cost of installation is 1,650 USD. This value is acceptable with 30% of the internal rate of return and ten years of the project life.

The Figure 6 showed the optimum insulation thickness of the autoclave. The blue line represented the annual cost of heat loss. The lower annual cost of heat loss, the higher thickness insulation is increasing with the thickness of the insulation. The red line indicates the annual of investment for the insulation. It is increasing with the thickness of the insulation. The green line concludes the net costs of the annual cost of heat lass and annual cost of installation. The optimum insulation thickness is projected at the lowest net cost on the thickness of 0.085 m. of the thickness. At the optimum insulation thickness, the annual cost of heat loss can approximately reduce by 222 USD/autoclave compared with the existing insulation thickness. Figure 7 shows the block diagram used for the simulation program, Aspen plus, of the waste heat recovery system. It consists of four heat exchangers; two condensate heat exchangers are connected in series to exchange heat with fresh water, and then the preheated water is exchanged again with two exhaust steam exchangers.

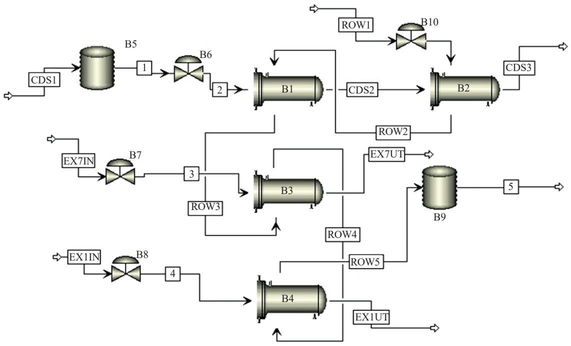


Figure 7: Waste heat recovery block diagram from Aspen plus.

The heat exchangers block B1and B2 exchange heat between freshwater (called R.O. water) and the condensate from the autoclave. Then, the preheated water is passed through the third and fourth heat exchangers to exchange heat with the exhaust steam from the autoclave in block B3 and B4; respectively. Block B3 uses exhaust steam from autoclaves 7 to 12 and block B4 uses steam from autoclaves 1 to 6. The simulation result is calculated in Table 2. The row CDS1 is the condensate inlet to the heat exchanger at 100°C and 4,900 kg/h and leaves the system as CDS3 after being exchanged two times in heat exchangers block B2 and block B1, respectively. The outlet temperature of CDS3 is 65°C. The ROW1 row is the fresh water feed to the heat exchanger. It is exchanged with two condensate heat exchangers. The temperature of ROW3 is 30°C before it passes through the exhaust steam heat exchangers. The exhaust steam inlet to the heat exchanger at block B3 is come from the autoclave section 2, as shown in row EX7IN, is exchanged with preheated water ROW3. The resulting temperature

Table 2: The simulation result of waste heat recovery project

Stream	From Block	To Block	Mass Flow (kg/h)	Temperature (°C)	Pressure (bar)	Vapor Fraction	Liquid Fraction	Specific Heat (kcal/kg·°C)	Heat Capacity Flowrate (kcal/h·°C)*
CDS1(2)**		B1	4,900	100	1.53	-	1	1	4,900
CDS2	B1	B2	4,900	80	1.50	-	1	1	4,900
CDS3	B2		4,900	65	1.47	-	1	1	4,900
EX1IN(4)**		B4	2,700	135	3.00	1	-	0.455	1,228
EX1UT	B4		2,700	100	2.97	-	1	1	2,700
EX7IN(3)**		B3	2,700	135	3.00	1	-	0.523	1,412
EX7UT	B3		2,700	85	2.97	-	1	1	2,700
ROW1		B10	35,000	25	3.00	-	1	1	35,000
ROW2**		B2	35,000	27	3.00	-	1	1	35,000
ROW3	B1	B3	35,000	30	2.97	-	1	1	35,000
ROW4	B3	B4	35,000	74	2.75	-	1	1	35,000
ROW5	B4	B9	35,000	90	2.72	-	1	1	35,000

*Heat capacity flowrate were calculated as : $C_P = m \cdot C_p$ where C_p is specific heat and m is mass flow rate.
**Input stream to heat exchanger.

after the exchanger is 83.1°C, shown in row ROW4. The other exhaust steam inlet to block B4 from the autoclave section 1 is exchanged with ROW4 as the inlet condition shown in row EX1IN. The final temperature of water is shown in row ROW5. The resultant temperature of the hot water is 120°C showing that there is plenty of heat available to heat all the feed water required for both boilers to 100°C.

The waste energy utilization system following the simulation was built with the control objective of a continuous supply of hot feed water at 100°C as shown in Figure 8 because the exhaust steam from the autoclaves are uncontrolled. The flow rate of R.O. water was chosen as the manipulated variable to achieve the control objective. If the exhaust steam is available, the R.O. water flow rate is increased to recovery the heat unless the R.O. water flow rate is reduced enough maintain the temperature of the R.O. water at 100°C. It means that the R.O. water flow rate will not be at its maximum if the exhaust steam from both autoclaves is not available.

Figure 8 shows the process and instrument flow diagram of the system of waste heat recovery. The R.O. water is fed through the pumps and exchanges heat with the condensate water. After that, the preheated water is exchanged again with exhaust steam from the autoclave section 2 and section 1 respectively. The temperature of the outlet heated R.O. water is monitored by the temperature transmitter (TT1). It is transmitted to the flow controller (FC1) to adjust the value of the inlet flow rate to the maximum outlet temperature of 100°C. To prevent overheating of the R.O. water outlet at its maximum flow, the exhaust steam valve (FC2) is adjusted to reduce the steam supply.

The de-aerator tank has two level transmitters. It is used to monitor the high and low level of the tank. If the water in the tank is at the high level (HLT), the flow control (FC3) will open the hot water storage valve and keep hot water inside the tank. The low-level transmitter (LLT) is used to prevent the empty of the de-aerator tank. If this water level is reached, the level control will start the hot storage tank pump to send hot water to fill up the de-aerator tank. The heated R.O. water is sent to the boilers to produce steam.
To prevent back pressure of the autoclaves, pressure transmitters are used to compare the pressure in the system. On both sides, the pressure of the exhaust steam is monitored before the exhaust steam heat exchangers (PT1 and PT3), and they are compared with the main exhaust steam pipe (PT2 and PT4). If the pressure of either PT1 or PT3 is higher, the exhaust steam is released to the wet scrubber or silencer to protect against back pressuring an autoclave.

This heat recovery scheme has been implemented and data from 2 days commissioning stage were collected. Figure 9(a) shows the R.O. water inlet temperature and rice husk consumption during normal operation of the rice husk boiler. The first vertical red line shows the boiler was stopped because of the overproduction

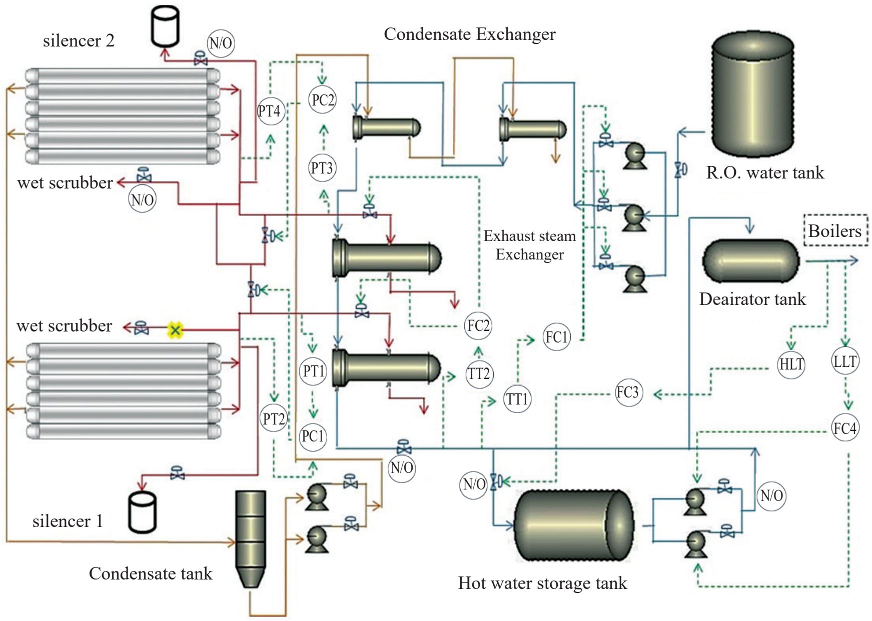
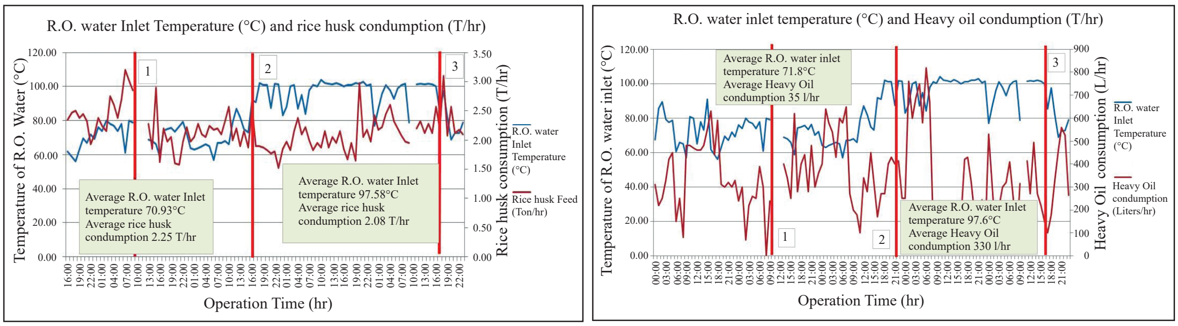


Figure 8: Process flow and instrument diagram of the Waste heat recovery system.



(a) (b)

Figure 9: The R.O. water temperature before feeding to both boilers with and without waste heat utilization system; (a) The R.O. water temperature before feeding to the rice husk boiler; (b) The R.O. water temperature feeding to the heavy oil boiler.

of steam. After start up again until the second red line shows the condition before the heat exchangers start, stream was being used to preheat the R.O. water to approximately 71°C and rice husk consumption is 2.25 ton/h. After the heat exchanger start using at the third red line, the R.O. water feed increased to an average of 97.6°C, usually was at 100°C, and the rice husk consumption decreasing to 2.08 ton/h. Figure 9(b) show the R.O. water inlet temperature and heavy oil consumption during normal operation of the heavy oil boiler. The first vertical red line shows the boiler was stopped because of the overproduction of steam. After start up again until the second red line show that before the heat exchanger starts, the stream was being used to preheat the R.O. water to approximately 71.8°C and heavy oil consumption is 358 L/h. After the heat exchanger started, the R.O. water feed increased to an average of 97.6°C, usually was at 100°C, and the heavy oil consumption decreasing to 330 L/h.

The measurement information from commissioning stage is used to calculate the boiler heat and mass balance again. For the rich husk boiler, the heat

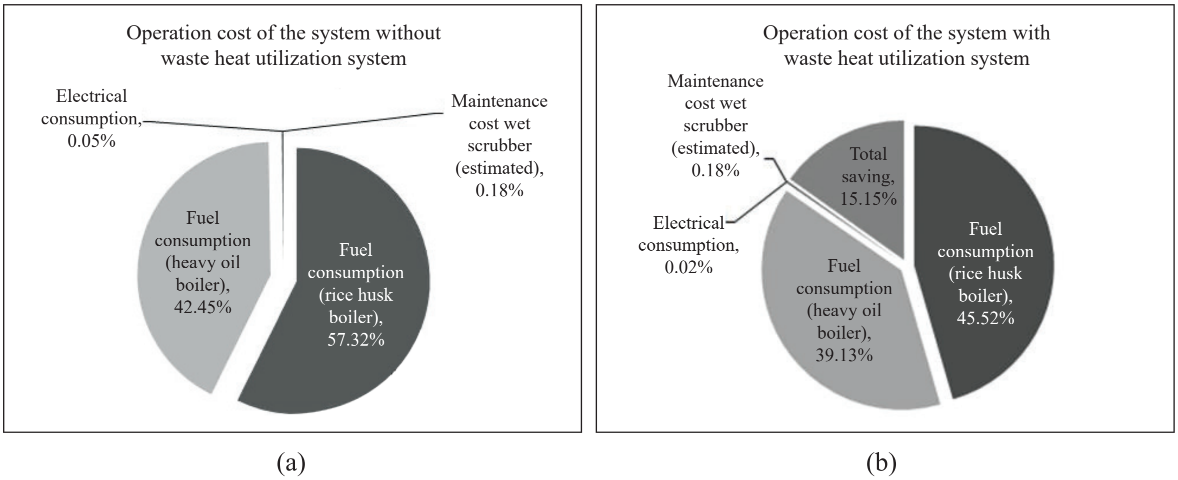


Figure 10: Operation cost of the system with and without waste heat utilization system; (a) system without waste heat utilization; (b) system with waste heat utilization.

consumption is reduced from 3.58 to 2.84 MJ/kg stream (average rice husk consumption decreased 176 kg/h.)

In terms of cost saving, the fuel consumption of both boilers was monitored. The fuel consumption of both boilers was reduced by an average of 176 kg/h of rice husk and 28 L/h of heavy oil respectively.

The payback period calculation was completed after commissioning the project. Table 3 shows the fuel costs and electrical cost per unit.

Table 3: The fuel and electricity cost of the plant

Cost Information		
Electrical cost	1.79	THB/kWh
Rice husk heating Value	3,652.00	kcal/kg
Rice husk cost	2,050.00	THB/ton
Heavy oil cost	22.75	THB/L

The calculation is based on the operating condition and electrical consumption cost is shown Table 4. The total cost saving is 8.37 million Thai baht (MTHB)/year compared with the annualized investment cost of 12 MTHB. The payback period for this project is one and a half years. However, the maintenance cost of heat exchanger system about 120,000 THB/year is recommended to operating cost.

The pie chart is Figure 10(a) is showing the operation cost of the system without waste heat utilization system. The fuel consumption of both boilers is 99.77% of the total operation cost. Comparing with the Figure 10(b) that shows the operation cost with waste heat utilization system the total fuel consumption is reduced to 84.65% with the total energy saving 15.15% from the waste heat utilization system.

Table 4: The existing and new operating condition of the system

	Before	After	Unit
Operating Condition			
Steam production (base on commissioning data)	200	200	Ton/day
Boiler, Autoclave and Wet scrubber operation	330	330	Day/year
Heavy oil boiler operation	100	100	Day/year
Percentage of working hour of wet scrubber/Day	70	30	%
Consumption			
Net heat consumption	855	695	kcal/kg Steam
Net electrical consumption of wet scrubber	82	88.6	kW

It is clearly that waste heat utilization system of the fiber cement composite process is higher efficiency than the normal process. The fuel consumption is decreased in both steam boilers and the system can maintain the normal operation process of the plant.

The implementation of the project is started after the process investigation, design and economic analysis complete. The implementation includes two main activities; installation and commissioning to complete the project. In the installation, the equipment was ordered through the suppliers who produce the heat exchangers. The information of the heat exchanger design, configuration and controller are given to the supplier for considering. Any ways, supplier, who is in this business, is more specialist than our calculation. This design information is used as the guide of the design for them.

There is slightly difference of the design from supplier and our preliminary design. The heat exchangers design from the supplier is four units, two identical units for condensate heat exchangers and other two identical units for exhaust steam heat exchangers.

The installation schedule was within 2 months. Then, the commissioning was done with the normal autoclave operation. During the commissioning, many problems were found such as low sensitivities of the control valves, heat exchangers leakage, boiler shut down and operation sequence problems. All problems have been solved during the commissioning process. At the same time, the operation persons were trained during this commissioning to understand the operation and to solve the problems.

The operation data was collected during the commissioning in order to check the result of the project. Rice husk boiler, heavy oil boiler and autoclave operation data are collected and used to calculate the total saving of the project.

4 Conclusions

Energy recovery system was implemented to the industrial scale fiber cement focusing on steam utility from two boilers; rice husk and heavy oil. Total steam was scheduled into twelve units of the autoclaves for 24 h operation. During this daily operation, the exhaust steam and condensate are released from the autoclave at 130°C. Under normal operating conditions, the four major heat losses were the steam boiler exhaust gas (3.04 MW), autoclave shell loss (103.28 kJ/kg fiber cement product), condensate (165.42 kJ/kg fiber cement product) and exhaust steam from autoclaves (520.51 kJ/kg fiber cement product). The steam boiler exhaust gas cannot be recovered because the quantity of rice husk cannot be guaranteed and coal is the alternative fuel. The gas properties of the rice husk and coal combustion are different; the sulfur dioxide content in the coal flue will form sulfuric acid and cause corrosion to the metal parts of the stack.

The autoclave shell heat loss can be reduced by increasing the shell insulation thickness to an optimum of 0.085 m (0.081 m thicker than the existing insulation). The autoclave shell heat loss would be reduced by 37% with an annualized investment of 51,627 THB/year/autoclave. The waste heat from the condensate and exhaust steam have designed to preheat the fresh water feed to the boilers. To achieve this, two type E shell and tube heat exchanger should be used to recover heat from the condensate and another two would be needed to recover the heat from the exhaust steam. Boiler feed water would be preheated in the heat exchanger to recover this heat. The simulation program Aspen plus was used to simulate the heat exchanger system. The results showed that the freshwater temperature could be increased from 25 to 119°C, 3 bars at a maximum flow rate of 35,000 ton/h, showing that there is more heat available than the need of the feed water to the required temperature at 100°C. The heat recovery project needed an investment cost 12 MTHB. The installation and commissioning processes have been completed at the plant, resulting in a cost saving of 8.37 MTHB/year, calculated during the commissioning period giving a one and a half years payback on the project.

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