Improvement of boiler efficiency for Rerm-Udom sugar factory

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Abstract. The objective of this study is to conduct a field survey, including data collection and measurements to study the potential of energy conservation measure of Rerm-Udom sugar factory in Udon Thani. The boiler efficiency is measured and calculated using the indirect method. The results of this study show that the most significant loss of the boilers is heat loss due to exhaust gas, which is 17.2%, while the rest heat loss is around 2%. The proposed energy conservation measure to improve the performance of the boiler is to install the economizer, which helps to increase the boiler efficiency for 1.5% and helps to produce additional electricity for 2,362,800 kWh per year or 7,088,400 Baht per year. The investment cost of the economizer is 7,200,000 Baht and the maintenance cost is around 1,000,000 Baht per year. Therefore, the payback period of the energy conservation measure is 1.2 years.

1 Introduction

Thailand is an agricultural country. There is a large amount of biomass energy from agricultural waste after harvesting. The Department of Alternative Energy Development and Efficiency (DEDE) reports that sugar cane harvested in Thailand was 7.8 Mtons/year, equivalent to electrical energy 6,717 GWh/year [1]. Thailand Alternative Energy Development Plan (AEDP2015) indicates that the share of renewable energy in electricity generation is 9.9% in the year 2014, and the target of the use of renewable energy is 30% in the year 2035 [2]. Thailand Power Development Plan (PDP2018) plans to increase electricity generation capacity from biomass powerplant for 520 MW. [3]

Rerm-Udom sugar factory is located in Nonghan district, Udon Thani province. The production capacity of the factory is around 15,000 ton sugarcane per day, and operating time is 110 days per year. The main products of the factory are sugar production and electricity generation, as shown in Figure 1. More than 90 percent of energy use in the factory is in the form of thermal energy in boilers. Bagasse, which is a waste of sugar production is used as biomass energy for steam generation in two boilers, which both capacities are 200 Ton/hr. Steam production from the boilers is around 314.37 Ton/hr, which is used for both sugar

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production process (The boiling process of sugar cane juice) and supply to a steam turbine for electricity production.

The objective of this study is to conduct a field survey including data collection and measurements to study the potential of energy conservation measures of the boilers and the factory.

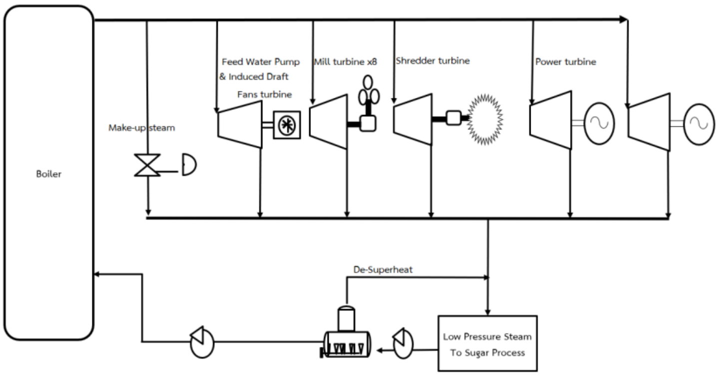

Fig. 1. Process flow of sugar production and electricity generation of Rerm-Udom sugar factory.

2 Research method

The method used in this study is as follows.

2.1 A Survey and measurements of the boilers efficiency

A survey and measurements of the efficiency of the boiler of Rerm-Udom sugar factory were conducted in February 2020. The boiler type is a water tube boiler, and the biomass is fed onto the grate as overfeed in a stoker combustor.

2.2 Equipment and instruments

Equipment and Instruments used in this study are shown in Figure 2, comprise 1) A flue gas analyzer model Testo 330, and 2) A thermal imaging camera model Testo 865.

a) A flue gas analyzer model Testo 865 b) A thermal imaging camera model Testo 330

Fig. 2. Equipment and instruments used for measurement of boiler efficiency.

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2.3 Measuring and calculation method for boiler efficiency

Boiler efficiency calculation is typically calculated using the method in [4], Department of Industrial Works [5], [6]. The method used for boiler efficiency measurement in this study is the indirect method called the "Heat-loss method" which is also used in Prangmanee, Prakaew [7], [8]. The measured parameters are shown in Table 1, and measuring methods are shown in Figure 3.

Table 1. Measured parameters for boiler efficiency calculation.

Parameter	Equipment used/Analysis method
O2, CO, CO2	Flue gas analyzer
Flue gas temperature	Flue gas analyzer
Boiler surface temperatures	Thermal imaging camera
Boiler blowdown	Daily check sheet
Unburned Carbon	Laboratory analysis

a) Surface temperature measurement b) Flue gas analysis c) Ash sample collection

Fig. 3. Measuring Method (Indirect method) for boiling efficiency.

As mentioned before, the calculation method used in this study is called the "Heat-loss method" which is the indirect method. Therefore, five losses of the boilers were calculated, and boiler efficiency can be calculated as follows.

1) Boiler efficiency

Boiler efficiency can be calculated by using Equation 1.

$$\eta_b = \left[1 - \left(\frac{L_l}{H_l + Q}\right)\right] \times 100\% \tag{1}$$

where η_b is boiler efficiency , L_l is summary of heat loss (kJ/kg), $H_l + Q$ is summary of heat input. (kJ/kg)

2) Heat loss due to exhaust gas (L_1)

Heat loss due to exhaust gas can be calculated using Equation 2.

$$L_1 = Gc_g\left(t_g - t_o\right) \tag{2}$$

where L_1 is heat loss due to exhaust gas (kJ/kg), G is the actual amount of exhaust gas per 1 kg. of fuel (m^3/kg fuel), c_g is mean specific heat of exhaust gas, 1.38 kJ/m^3 K ,t_g is the temperature of exhaust gas (°C), t_o is base temperature (°C).

3) Heat loss due to unburned gas (L_2)

Heat loss due to unburned gas can be calculated using Equation 3.

$$L_2 = 126.1\left[G_o + (m-1)A_o\right](CO) \tag{3}$$

where L_2 is heat loss due to unburned gas (kJ/kg) , G_o is the amount of theoretical dry exhaust (m^3/kg), m is excess air ratio, A_o is the amount of theoretical (dry) air.(m^3/kg).

4) Heat loss due to unburned combustibles in the burnt residue (L_3)

Heat loss due to unburned combustibles in burnt residue can be calculated using Equation 4.

$$L_3 = 339c_2 \tag{4}$$

where L_3 is heat loss due to unburned combustibles in burnt residue (kJ/kg), c_2 is unburned carbon content.

5) Heat loss due to radiation (L_4)

Heat loss due to radiation can be calculated using Equation 5.

$$L_4 = \frac{1}{100} l_r H_l \tag{5}$$

where L_4 is heat loss due to radiation (kJ/kg), l_r is the heat loss % due to radiation, which corresponds to a low calorific value.

6) Blowdown loss (L_5)

$$L_5 = m_{bd} \frac{\left(h_{bd} - h_{fw}\right)}{\dot{m}_f} \tag{6}$$

where L_5 is blowdown loss (kJ/kg), $\dot{m}_{bd}$ is blowdown rate (kg/h), h_{bd} is enthalpy of blowdown water (kJ/kg), h_{fw} is enthalpy of feed water. (kJ/kg).

3 Results and discussion

The results of this study are as follows.

3.1 Boiler efficiency

The surveys and measurements of the efficiency of the boiler of Rerm-Udom sugar factory were conducted, and the results of the analysis are shown in Table 2. And after using the Equation 1-6 to calculate the efficiency of the boilers, it is found that the efficiency of the boiler is 81.14%.

Table 2. Parameters measured from the boilers.

Parameter	Abbreviation	Value	Unit
Steam flow rate	m_s	314.37	Ton/hr
Steam pressure	P	29	Bar
Steam temperature	t_s	400	°C
Flue gas temperature	t_g	196	°C
Blow down flow rate	m_{bd}	5.03	Ton/hr
Yearly operation	hr.	2,640	hr/Year
Heat loss due to exhaust gas	L_1	1,041.9 (17.2)	kJ/kg (%)
Heat loss due to unburned gas	L2	12.2 (0.2)	kJ/kg (%)
Heat loss due to unburned combustibles in burnt residue	L_3	15.2 (0.3)	kJ/kg (%)
Heat loss due to radiation	L_4	19.7 (0.3)	kJ/kg (%)
Blowdown loss	L_5	56.6 (0.9)	kJ/kg (%)
Boiler efficiency	η	81.14	%

3.2 A Proposed energy conservation measure

After calculating heat loss using Equation 2-6, it is found that significant loss of the boilers is heat loss due to exhaust gas (L1) with 17.2% and temperature, and flue gas is 196°C that is very high. Therefore, a proposed energy conservation measure for the boilers of Rerm-Udom sugar factory is to use heat recovery equipment called “Economizer”. The advantages of using economizer include: It recovers more heat of flue gases and heating the boiler feed water for reducing the use of fuel and increasing boiler efficiency.

Design of the economizer

For calculating and designing the economizer size, data from the survey is required includes: 1) feedwater temperature and 2) temperature of flue gas. After that, Log Mean Temperature Difference, LMTD is calculated using Equation 7 (Calculation method is in [9, 10]). And calculation criteria are based on the parameters in Table 3.

Table 3. Parameters for calculation of the economizer.

Parameter	Abbreviation	Value	Unit
Overall heat transfer coefficient [6]	U_0	31.71	W. (m² °C)
Log Mean Temperature Difference (LMTD)	ΔT_{lm}	70.23	°C
Inlet Temperature of Economizer	T_{g1}	105	°C
Outlet Temperature of Economizer	T_{g2}	120	°C

$$\Delta T_{lm} = \frac{\Delta T_i - \Delta T_e}{In\left(\frac{\Delta T_i}{\Delta T_e}\right)} \tag{7}$$

where ΔT_{lm} is Log Mean Temperature Difference (LMTD - °C), ΔT_i is the temperature difference between feed water and flue gas (°C), ΔT_e is the temperature difference between outlet water and outlet flue gas from economizer. (use the value in Table 3.)

Next, rate of heat transfer in the economizer can be calculated using Equation 8.

$$Q_{ECO} = \dot{m}_s c_g \left(t_{g1} - t_{g2}\right)$$

$$= U_o A_o \Delta T_{1.m} \quad (8)$$

where Q_{ECO} is heat recovery from the economizer (W), U_o is the overall heat transfer coefficient of the economizer. (W/m^2·°C)

The heating surface area of the economizer (A_o) is calculated using Equation 9.

$$A_o = \frac{\dot{Q}_{ECO}}{U_o \Delta T_{1.m}} \quad (9)$$

And the economizer configuration from the calculation is shown in Figure 4.

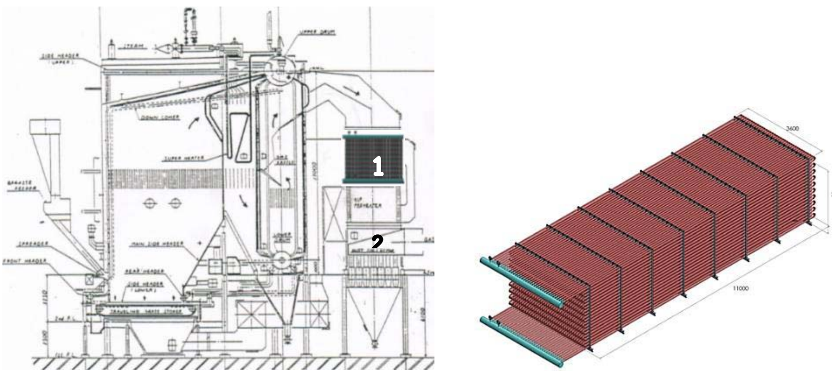

Fig. 4. Configuration of the economizer.

Next, the boiler efficiency after implementing the energy conservation measure (installing the economizer) can be calculated by Equation 10.

$$\eta = \frac{m_s\left(h_s - h_w\right)}{\left(Q_{old} - Q_{ECO}\right)} \quad (10)$$

where h_s is the enthalpy of steam at P and t_s (kJ/kg), h_w is the enthalpy of feed water (kJ/kg), Q_{old} is heat input before implementing the energy conservation measure. (kJ/kg)

After that, fuel conservation, after installing the economizer can be calculated using Equation 11.

$$m_f = \frac{Q_{ECO}}{LHV} \quad (11)$$

where m_f is the mass flow rate of fuel (bagasse - kJ/kg), LHV is the low heating value of fuel (bagasse - kJ/kg)

Next, additional steam produced by the boilers from the recovery heat of the economizer can be calculated using Equation 12

$$m_s = \frac{\dot{m}_f \times \eta \times LHV}{h_s - h_w} \quad (12)$$

The additional steam can be calculated for additional electricity produced from a generator of the factory by using performance curve data of the generator brand SHINKO (As shown in Figure 5) with the capacity of 9 MW. The performance curve data can be regressed using the linear regression least square method. And the relationship of steam flow rate (Ton/hr) and electricity generation (MW) is as Equation 13. Electricity sales price the factory is around 3 Baht per kWh; this data is used to calculate the cost-effectiveness of the energy conservation measure in the next section.

Fig. 5. Steam turbine-generator brand SHINKO with 9 MW capacities.

$$P_e = 6.76m_s + 27 \tag{13}$$

where P_e is power generation from the generator (MW)

The calculation results of the boiler efficiency after installing the economizer (η), heat recovery from the economizer (Q_{ECO}), additional electricity of the factory, additional income from electricity sales, and investment cost of the economizer are shown in Table 4. The boiler efficiency is increased by 1.5% and can produce additional electricity for 2,362,800 kWh per year or 7,088,400 Baht per year. And by considering the maintenance cost of the system is around 1,000,000 Baht per year, therefore the net income is 6,088,400 Baht per year. While the investment cost of the system is 7,200,000 Baht, the payback period of the energy conservation measure is 1.2 years.

Table 4. Boiler performance and cost-effectiveness after implementing the energy conservation measure.

Item	Abbreviation	Value	Unit
Boiler efficiency after installing the economizer	η	82.69	%
Heat recovery from the economizer	Q_{ECO}	5.57	MWt
Additional electricity	-	2,362,800	kWh/year
Additional income (3 Baht/kWh)	-	7,088,400	Baht/year
Investment cost (Installing the economizer)	-	7,200,000	Baht
Payback period	PB	1.2	Year

4 Conclusions

This study aims to investigate the method to improve the boiler efficiency in Rerm-Udom sugar factory in Udon Thani. A field survey and data collection and measurements were conducted in this research. The boiler efficiency is measured and calculated using the indirect method. The results of this study show that the most significant loss of the boilers is heat loss due to exhaust gas, which is 17.2%, and the rest is around 2%. Installing the economizer is the proposed energy conservation measure to improve the performance of the boiler. After calculation the boiler performance after installing the economizer and cost-effectiveness, it is found that the boiler efficiency is increased for 1.5% and can produce additional electricity for 2,362,800 kWh per year or 7,088,400 Baht per year and from the investment cost of 7,200,000 Baht and the payback period of 1.2 years.

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