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Improvement of Travelling Grate Boiler Efficiency for Bagasse Fuel

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Abstract

Generally, biomass power plant is operated by many types of boilers such as vibrating grate boiler, stepping grate boiler, reciprocating grate boiler, stationary sloping grate boiler and travelling grate boiler. Bagasse from sugar industry is one of valuable biomass used in power plant and supported as alternative fuel by the government. For sugar industry, travelling grate boiler is used widely as electricity generation. However, many travelling grate boilers in sugar industry were used without good maintenance and operation which also effected to the boiler efficiency. In this study, the boiler efficiency was investigated by indirect method (JIS B 8222:1993) to analyze total losses occurred in travelling grate boiler operated at 120 ton/hr as maximum continuous rating (MCR). Following indirect method, ultimate analysis for bagasse, moisture content and bottom ash and emission characteristics are measured to evaluate the boiler efficiency. As this result based on indirect method, net calorific value (NCV), sensible heat loss, unburned combustible in burnt residue, unburnt gas (CO) loss, radiation loss and unaccounted loss were obtained as 9.63%, 0.70%, 0.23%, 1.27% and 1.27%, respectively. To improve the boiler efficiency, bagasse spreader angle adjustment and reduction in the furnace pressure of the boiler were applied in this study. Regarding the mentioned methods, the increasing of boiler efficiency and energy saving are 5.50% and 6.33% compared with no improvement boiler efficiency due to combustion improvement and heat transfer enhancement.

Keywords*:* Travelling grate boiler, Bagasse, Boiler efficiency, Indirect method, Moisture content, combustion instability

1. Introduction

In this present, biomass is supplied in the field of industry instead of fossil fuel such as wheat straw, rice straw and bagasse etc. For sugar industry, bagasse is the main waste which is a valuable, economical and environmentally friendly biomass. The previous study showed that 5.95 kg of bagasse was equal 1 kg of crude oil [1]. Moreover, 1 kg of bagasse used instead of 0.524 kg of crude oil also decreased 112,660 ton-CO_2/year for 100 ton/h of boiler operated with 4,300 h/year [2]. Basically, there are various compositions in bagasse i.e. cellulose, hemicellulose, ash, lignin and moisture. During 45%-56% of moisture content of bagasse, vaporization load was increased 4.1% for 1% increasing of moisture content [3]. In addition, the limit of moisture content for bagasse is 66% approximately because bagasse has no heating value enough for any combustion owing to all calorific value used for only vaporization [3]. In the past, there were four types of biomass boiler as stationary sloping grate, travelling grate, reciprocating grate and vibrating grate [4]. Normally, steam product from boilers in the sugar industry was used for electricity and sugar mill process. In order to increase the steam product and energy saving, it is important to improve boiler efficiency. For sugar industry, not only the quality of bagasse but also the optimized operation of boiler was concerned for increase of energy saving. Nowadays, less than 1% of boilers were biomass boilers which about 4,000 of boilers were fueled with bagasse [5]. In this amount of boilers, merely 100-150 of boilers were maintenance and improve boiler efficiency annually. This reason showed the boilers fueled with bagasse were not developed continuously. Even though no new technology for boiler fueled with bagasse through 25 years ago, but recently the new technologies such as swirl spreader and secondary air staging. Swirl spreader [5] was developed for 13 years to be the spreader and swirl burner and also applied for the boiler fueled with bagasse in Philippines. The swirl spreader was developed for the air swirling flow, central circulation zone and improved ignition owing to increase long residence time. For secondary air staging [6], the staging combustion was occurred by the separation of secondary air zone for NOx control and CO reduction. However, the disadvantages of secondary air staging method were not convenient to retrofit with boiler and long pay back period.

This study reports efficiency improvement of a typical traveling grate boiler using bagasse as a fuel in a sugar mill industry. The improvement is done by optimizing the spreader angle and an excess air during actual operating condition of the boiler at its maximum continuous rating (MCR). An ultimate analysis of bagasse and bottom ash together with calculation of bagasse heating value is performed to determine boiler efficiency and energy saving using an indirect method. Results of the improved boiler are compared with the unimproved ones of the same boiler for assessment.

2. Experiment

A typical travelling grate boiler of 120 ton/h (MCR) at rated pressure of P = 30 kgf/m^2 and temperature T = 360^{o}C using bagasse as a fuel in a sugar mill industry is considered. Boiler efficiency was investigated during the crushing season of 2013 and 2014. The boiler efficiency was determined by analyzing bagasse and ash compositions (ultimate analysis) to calculate the calorific value, flue gas and wall temperature as illustrated in experimental apparatus (Fig.1). During the 2014 crushing season, the boiler was undergone annually normal maintenance but with a more careful operating procedure than before. Focus has been made on a fine adjustment of spreader angle at a specified furnace pressure and a proper adjustment of an excess air during actual operating condition of the boiler at MCR. Then, the boiler efficiency and energy saving were assessed by comparing with results of the previous 2013 crushing season.

Flue gas analyzer (Messtechnik EHEIM Gmb VISITOR 01 LR) as shown in Fig. 2 was used to measure concentrations of O_2, CO, CO_2, NO_x and flue gas temperature at stack (after economizer).

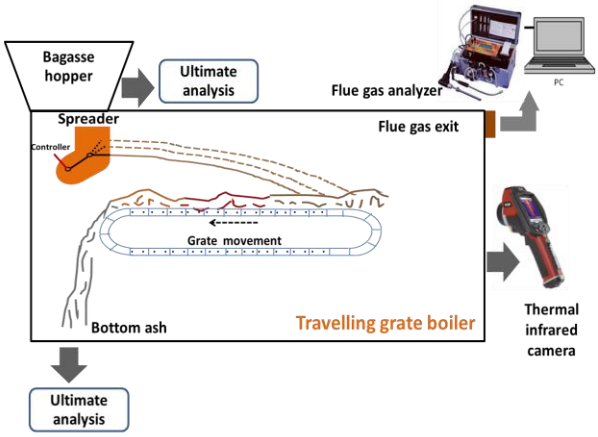

Fig.1 Experimental apparatus

Fig.2 Flue gas analyzer

Fig. 3 Thermal infrared camera (FLIR)

Thermal infrared camera (FLIR i40) as shown in Fig. 3 was used to scan the boiler wall temperature to obtain radiation loss. Results of the flue gas and the boiler wall temperature measurements were analyzed to obtain the boiler efficiency.

3. Methodology

3.1 Bagasse composition analysis and combustion mechanism

In order to understand the bagasse compositions, an ultimate analysis has to be performed. However, the ultimate analysis of the

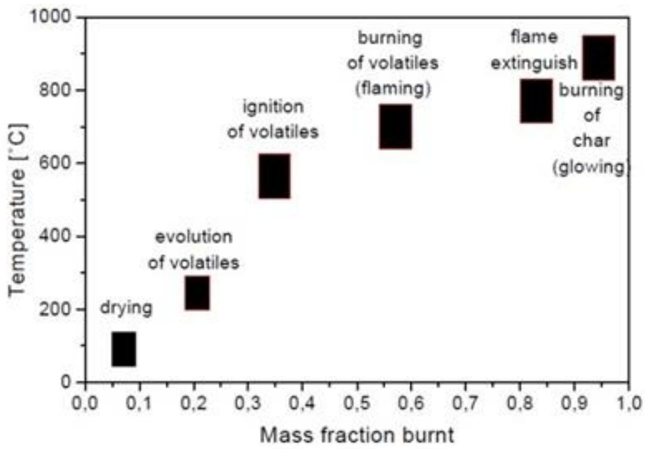

Fig. 4 Biomass combustion mechanism **[8]**.

reference bagasse obtained by analytical method [7] is utilized to express the bagasse compositions which consist of moisture, carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), chlorine (Cl) and ash.

Bagasse can be considered as a type of biomass which has a common combustion mechanism [8] as shown in Fig. 4 irrespective of the types of biomass. Bagasse combustion starts with drying at relatively low temperature before the evolution of volatiles appears as bagasse temperature increases. At a certain value of the temperature, bagasse experiences ignition of volatiles, burning of volatiles and flame extinguishing, followed by the burning of solid carbon residue (char burning). As this mechanism process, the higher the moisture content of the bagasse, the greater the latent heat of evaporation is required for water that contains in the bagasse. This may result in instability of the combustion over the grate of the boiler which is undesirable in combustion practice.

3.2 Calorific values analysis

Calorific value of fuel is the heat released per unit mass of fuel at standard condition (25°C and 1 atm) with completed combustion. Generally, there are two types of calorific values: a gross calorific value (GCV) and a net calorific value (NCV). The GCV is the total energy released during the combustion process and can be accurately measured by using a bomb calorimeter. The NCV is the GCV without the latent heat of the water formed by the combustion process [9]. However, both GCV and NCV can also be obtained by calculation derived from experiment and method of calculation laid down in ISO1928 [10]. For bagasse combustion, calculation of the fiber compositions was resulted in an empirical correlation for GCV and NCV as a function of the moisture content (M), brix (B) and ash (A) shown in Eqs. (1) and (2),

$$\mathrm{GCV} = 19{,}605\text{-}(196.05\times\mathrm{M})\text{-}(31.14\times\mathrm{B})\times\mathrm{A}\ \frac{kJ}{kg} \quad (1)$$

$$\mathrm{NCV} = 18{,}260\text{-}(207.15\times\mathrm{M})\text{-}(31.14\times\mathrm{B})\times(182.60\times\mathrm{A})\ \frac{kJ}{kg} \quad (2)$$

3.3 Boiler efficiency analysis

Basically, boiler efficiency is analyzed by a direct method which is analyzed by heat output from obtained steam directly, and an indirect method which is analyzed by heat loss. In this study, the indirect method was selected to analyze the boiler efficiency. Following the Japanese Industrial Standard (JIS B8222:1993), the boiler efficiency based on the indirect method is calculated by latent heat loss (L1), sensible heat loss (L2), unburned combustible in burnt residue (L3), unburned CO gas (L4), blow down loss (L5), radiation loss (L6) and unaccounted loss (L7) as shown in Eq. (3),

$$Boiler\ efficiency\ (\eta) = (1 + \frac{L_t}{Q_t}) \quad (3)$$

where,

L_t = L1+L2+L3+L4+L5+L6+L7 (kJ/kg)

Q_t = summation of input heat (kJ/kg)

3.4 Energy saving analysis

Energy saving (*EN*) of the boiler is the quantity of saved fuel with the same amount of output of product. Energy saving is determined by the difference between the new boiler efficiency (η_{new}) after boiler improvement and the based value (η_{based}) before improvement as shown in Eq. (4),

$$Energy\ Saving(EN) = \frac{\eta_{new} - \eta_{based}}{\eta_{new}} \times 100\% \quad (4)$$

where,

η_{based} = based boiler efficiency (%)

η_{new} = new boiler efficiency (%)

4. Results and discussion

4.1 Bagasse compositions

Table 1 Average bagasse compositions and carbon content in bottom ash of the crushing season of 2013 and 2014.

Bagasse compositions (d.b.)	2013 (%)	2014 (%)
Moisture	54.28	53.15
Carbon	46.08	47.24
Hydrogen	5.90	5.96
Oxygen	42.38	43.89
Nitrogen	0.28	0.33
Ash	5.38	2.59
Unburnt Carbon	8.28	3.63
Total	100	100

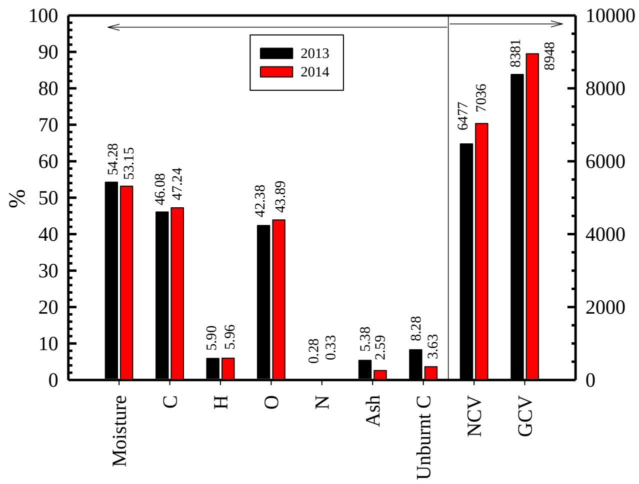

Fig.5 Comparison of average bagasse compositions between the crushing season of 2013 and 2014.

The bagasse and bottom ash samples were taken from the boiler process lines and analyzed by ultimate analysis. The compositions of bagasse were compared between the crushing season of 2013 and 2014 as shown in Table 1 and Fig. 5. The results of all compositions of bagasse in the two seasons were almost the same, except ash and unburnt carbon, where results of the 2014 crushing season show significant reduction of about 50% of both ash and unburnt carbon as compared with the 2013 crushing season.

4.2 Calorific Values

Based on Eqs.(1) and (2), one can see that the calorific values depend on the moisture content, brix, and ash. Thus the bagasse calorific values GCV and NCV increase from 6,477 kJ/kg to 7,036 kJ/kg and 8,381 kJ/kg to 8,948 kJ/kg, respectively due mainly to the decreased moisture content from 54.28% to 53.15% as shown in Fig. 5.

4.3 Boiler efficiency and energy saving

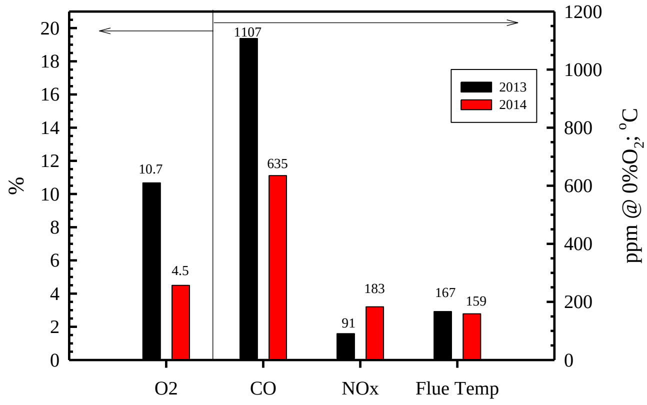

Fig.6 Comparison of O_2, CO, NO_x and flue gas temperature between crushing season of 2013 and 2014.

Fig. 6 shows the comparison of the measured concentration of O_2, CO, NO_x (corrected to 0% O_2) and the flue gas temperature at stack between crushing season of 2013 and 2014. In crushing season of 2014 with 4.5% of excess O_2 and 635 ppm of CO are significantly lower than those of in the crushing season of 2013. This may be attributed to a more complete combustion with properly adjusted spreader angle, furnace pressure and excess air, resulting in a reduction in sensible heat loss, unburned combustible in burnt residue, unburnt gas (CO) loss for the 2014 crushing season as shown in Table 2. Based on the indirect method and net calorific value (NCV), sensible heat loss, unburned combustible in burnt residue, unburnt gas (CO) loss, radiation loss and unaccounted loss for the 2014 crushing season were obtained as 9.63%, 0.70%, 0.23%, 1.27% and 1.27%, respectively. These can result from uniformly spreading of bagasse and better mixing between air and bagasse over the grate of the boiler. Thus lower emission of CO was observed owing to more completed combustion and higher combustion temperature can be expected. An increase of NO_x emission up to 183 ppm in the 2014 crushing season as compared to 91 ppm in the 2013 crushing season was observed. Almost twice of the NO_x emission was found in the present study due probably to increase of nitrogen content of bagasse in the 2014 crushing season. However, the flue gas temperature in the 2014 crushing season was slightly decreased as compared with that of the 2013 crushing season due probably to lowering in the flue loss caused by lower excess O_2.

Table. 2 Heat loss analysis by indirect method for boiler efficiency calculation.

Description	2013			2014		
	Loss (kJ/kg)	GCV-based (%)	NCV-based (%)	Loss (kJ/kg)	GCV-based (%)	NCV-based (%)
1. Latent heat loss	1777	21.21	-	1769	19.77	-
2. Sensible heat loss	786	9.38	12.14	678	7.58	9.63
3. Unburned combustible in burnt residue	224	2.67	3.46	49	0.55	0.70
4. Unburnt gas (CO) loss	27	0.32	0.42	16	0.18	0.23
5. Radiation loss	84	1.00	1.29	89	1.00	1.27
6. Unaccounted loss	84	1.00	1.29	89	1.00	1.27
Total	2982	35.58	18.60	2691	30.08	13.10
Boiler efficiency		64.42	81.40		69.93	86.90

The flue gas measured at stack was analyzed heat losses by indirect method as illustrated in Table 2. For the 2014 crushing season, it is clear that the boiler efficiency based on both NCV and GCV were improved by 5.50% and 5.51%, respectively as compared with the 2013 crushing season. These results shows the boiler efficiency improvement for the 2014 crushing season because the sensible heat loss and unburned combustible in burnt residue decreased due to a more complete combustion enhanced by uniformly spreading of bagasse.

Fig.7 shows the comparison of calculated boiler efficiency based on NCV and GCV and energy saving for crushing season of 2013 and 2014. The corresponding energy saving (*EN*) of about 6.33% was obtained in the 2014 crushing season.

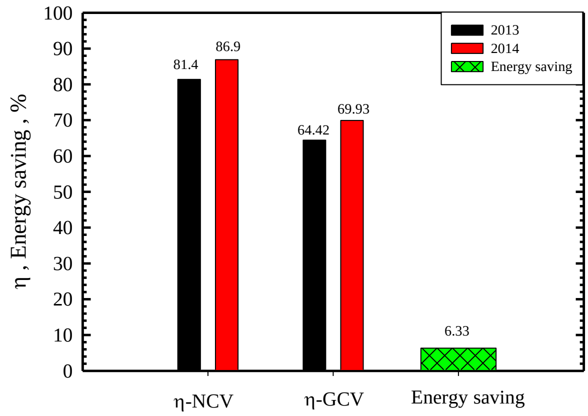

Fig.7 Comparison of boiler efficiency based on NCV and GCV and energy saving for crushing season of 2013 and 2014.

5. Conclusion

In this study, the boiler efficiency was investigated by indirect method (JIS B 8222:1993) to analyze total losses occurred in a typical travelling grate boiler operated at 120 ton/hr (MCR). Following indirect method, ultimate analysis for bagasse, moisture contents and bottom ash and emission characteristics are measured to evaluate the boiler efficiency. To improve the boiler efficiency, bagasse spreader angle adjustment and reduction in the furnace pressure of the boiler were applied in this study. Regarding the mentioned methods, the increasing of boiler efficiency and energy saving is 5.50 and 6.33%, respectively as compared with no improvement in boiler efficiency due to a more complete combustion.

6. References

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