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The risk analysis of rice husk of co-firing fuel for boilers in sugar mills

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Abstract. Biomass is a very important energy source in the sugar mill industry as the main fuel in the power plant boilers. The efficiency of boilers for most sugar mills in Indonesia is quite low and the availability of bagasse is lacking so that in its operations, co-firing has to be applied with an alternative biomass fuels such as rice husk, cane trash, wood and saw dust. Based on the analysis, rice husk has a lower calorific (3248 cal/gr) value than that of bagasse (4076 cal/gr), but it has a higher ash content (20.67%) than that of bagasse (3.66%), so adjustments in boiler operation is required when using rice husk as co-firing. The higher ash content in biomass can affect the performance of the furnace and superheater in the boiler and increase the potential for deposit formation. The composition of rice husk ash was dominated by silica (SiO_2) which reached 95.52%. It is higher than the silica content of bagasse which reached 74.99%. The high silica content in rice husks has the potential to conduce melting ash in boiler grate. The alkali content of rice husk which was around 3.64% is less than that found in bagasse which reached 17.33%. Even though, the ash composition analysis shows quite small potential for slagging, fouling, melting, sintering, and agglomeration, but the large amount of ash content in rice husks can increase the potential for the occurrence of the risks.

1. Introduction

The growth of the national sugar industry in the last five years in fulfilling the production capacity has triggered a change in the mass and energy so that the adequacy of the main fuel for processing sugarcane in the form of pulp has diminished because the plant's installed capacity is not fulfilled. According to the mass balance, the amount of the average bagasse yield of sugarcane processing reaches 30%, so the sugar mill should be able to fulfill energy needs during operations and even have a surplus power.

Based on the study of Sugar Research Institute of Indonesia and PTPN IX, Ltd. Surakarta in concerning energy efficiency programs in sugar mills, data were obtained that the processing capacity tended to decrease, the efficiency of boilers was low and the availability of bagasse was less so that the alternative fuels were brought from outside the factory, such as rice husk, cane trash, wood and saw dust which are simultaneously used as boiler fuel (biomass fuel co-firing system). According to milled data in 2014, the number of alternative fuels used reached a value of more than 7.6 billion rupiahs [1].

Based on the ultimate analysis, almost all biomass fuels contain the main elements: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sometimes sulfur (S), chloride (Cl) also appears. Whereas, based on the proximate analysis method on biomass there are fixed carbon (FC), moisture content (MC), volatile matter (VM) and ash content. By analyzing the biomass fuel, it can be estimated the boiler performance and the potential for the emergence of problems in boiler operation related to the potential for fouling and slagging which will disrupt the boiler performance and evoke the potential damage on the side of heating pipes, heat exchangers, boiler furnaces.

Rice husk is a biomass cesspit from the rice milling process which amounts around 15-20% of the total weight of rice. Based on Statistics Indonesia data in 2018 it was found that in Indonesia had rice fields planted with rice with an area of 10.9 million hectares with rice yields of 56.54 million tons [2]. Its means that the amount of rice husk waste available is 8.48 – 11.31 million tons/year which until now has not been used optimally.

Biomass combustion comply a reverse reaction from photosynthesis so that it is known as CO_2 neutral. Therefore, compared to fossil fuels, the use of biomass can reduce greenhouse gas emissions such as CO_2 & CH_4 and acid gases such as SO_x and NO_x. In addition, the use of biomass as an alternative fuel has many advantages, such as the sustainability of supply because it is renewable, environmental protection, a more affordable price compared to fossil fuels and others.

Besides having a several advantages, biomass also have disadvantages; including low energy content and relatively high investment in biomass pretreatment equipment. The combustion temperature of plants with a short or fast growing period is limited to 450 °C because it will contain chlorine in high temperature combustion, so it is concluded technically that biomass combustion can only be applied to small capacity power plants medium because of the limitation [3].

The chemical composition of biomass is influenced by genetic factors and physiological characteristics of different plant species and varieties, growth phases, plant parts, fertilization and chemical protection, nutrient availability, harvesting methods, transportation, storage and other factors [4], [5]. This can lead to differences in the results obtained in studies conducted on the same plant species. Knowledge of the characteristics of plant materials is quite important from an energy point of view, because each of parameter influences the efficiency of biomass combustion [6], [7].

The co-firing system is the combustion process of burning two or more different fuels on the boiler to generate power. The main purpose of this system is to replace the main fuel with alternative fuels to get certain benefits [8]. Co-firing is mostly applied using all types of boilers, even though for some types of boilers initially it was only designed to burn certain types of fuel or not designed for co-firing systems. Co-firing of biomass with coal is considered a process to supplement a portion of coal with biomass in a coal-fired boiler. The co-firing ratio is defined as the ratio between coal and biomass mixed by weight or energy for the combustion process [9].

Ash deposition is an important parameter in biomass combustion, because it is closely related to boiler operating costs. The two types of ash deposition on pipe and boiler walls are known as slagging and fouling. The characteristics of slagging and fouling of biomass both individually and co-firing can affect the heat transfer that occurs and cause heat losses.

Bagasse, which is the main fuel of boilers in sugar mills, is a fibrous fuel that has moisture content of 48 - 52 %, while boilers in sugar mills are usually designed with the ability of pulp fuel with a moisture content of 42 – 57 % and ash content below 2.5 %. Meanwhile, if there are additional biomass fuels such as wood waste, the water content varies from 20 – 60 % and ash content is 1 – 15 %, so the co-firing combustion system results in changes in water content and ash content so that the boiler performance potential will change. Variation in water content and ash content of the fuel both individually and co-firing results in a change in the heat value of the combustion gas flow which affects the performance of the combustion chamber and the superheater in the boiler [10].

In the use of biomass alternative fuels, it is necessary to consider the amount of ash (%) and the elemental content in it which includes alkaline elements, namely Fe_2O_3, CaO, MgO, Na_2O, and K_2O and acidic elements namely SiO_2, Al_2O_3, and TiO_2. Acid and alkaline content in ash has an impact on slagging in the boiler furnace and fouling on boiler heat transfer devices (piping, superheater, air heater). High ash content in bagasse fuel will also reduce steam production. The higher the ash content of the bagasse pulp with the same moisture content, the smaller the amount of steam produced in the boiler [11].

Biomass characteristics are very different from fossil fuels. In general, the differences include water content, ash content, calorific value, and alkali content of metals. The ash content of biomass usually has higher concentrations of alkali metals such as potassium (K), chlorine (Cl), and silicon (Si), and has a high water content variability and lower sulfur content. The difference in biomass and ash content features not only affects combustion, but also significantly changes the potential behavior of ash content to form deposits at temperatures below the boiler furnace and will melt over grate boilers [12].

High concentrations of potassium and chlorine in the biomass fuel ash, especially in the form of inorganic salts, such as oxides, nitrates and chlorides, can be easily evaporated during combustion, resulting in high mobility of the alkali material which causes a tendency towards fouling. The alkali metal content which is very active in ash (for example, K, Na, Ca, Cl) can easily form chloride phase vapor compounds which will then stick and form layers deposits on boiler heat exchangers because these chloride compounds have a low melting point (< 800 °C).

Besides that, some biomass fuels contain significant amounts of silica as in straw containing 10% silica and bagasse containing 54 % silica. Silica contained in alkali metals can melt or sintering at temperatures of 800-900° C. Alkaline silica, a mixture of alkali and/or calcium chloride or sulfate tend to be deposited on the boiler reactor wall and the surface of the heat exchangers, causing fouling, and even corrosion at relatively lower fusion temperatures (< 700 °C). About 1 – 2 % of ash in bagasse has a high content of silica (SiO_2) which varies between 54 - 92.8 % and it is strongly influenced by the percentage of sugar content included in bagasse (brix) [12].

In co-firing fuel with other biomass fuels with a greater amount of potential ash content, the potential for ash deposits containing alkali silica, calcium and potassium is greater, the potential for melting, sintering and fusion in combustion of ash above the boiler grate is greater and is at risk of fouling, slagging and sintering which interferes with boiler performance.

The ash will burn in the boiler combustion frame when the fuel frame temperature reaches 800 °C, and at that time the potential for the release of ash combustion particles consisting of alkali metal condensation in the form of coarse particles from fly ash and the occurrence of clumps of aerosol compounds. When these two elements are pulled by the induced draft fan together with the exhaust gas, these particles will strike the boiler and superheater pipes which result in erosion in the pipe because the exhaust gas speed is above 22 m/sec. Meanwhile, ash deposits will become clinkers that will stick in the boiler grate and need to be immediately removed. Otherwise, it will affect heat transfer and potentially overheat on it. Therefore, the study aimed at investigating the possibility of rice husk to be applied as an alternative fuel for co-firing systems with bagasse by characterizing it in terms of related indexes.

2. Method and Materials

In this study, the researchers using laboratory-scale experimental methods. Samples of bagasse biomass were taken from PG Madukismo Yogyakarta, while rice husk were taken from rice mills in the Klaten area, Central Java. Sample preparation was carried out by reducing the size using a milling machine then weighing and mixing according to the amount needed in the process of characterization. The samples included: bagasse (100 %), rice husk (100 %), mixing of 90 % bagasse with 10 % rice husk, and mixing of 80 % bagasse with 20 % rice husk.

The sample of characterization process consisted of analysis of calorific value, proximate test, ultimate test, and test of the composition of ash from biomass combustion using Atomic Absorption Spectroscopy. Characterization test of bagasse and rice husk in terms of its tendency to form slagging, fouling, melting, coating formation, and agglomeration of heating equipment in boiler furnace, as well as the calculation of several indexes that are often used, based on acidic and alkali oxide levels [13], [14]. The following indices were used:

1. The cm index, which is the ratio of alkalis in acidic oxides [15], which is formulated:

$$C_m = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O + P_2O_5}{SiO_2 + Al_2O_3 + Ti_2O} \quad (1)$$

2. Acid basic index :

$$B/A = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + Ti_2O} \quad (2)$$

If the ratio of B/A < 0.75, the impurity element can be estimated (Viana et al, 2012). If B/A < 0.4 or B/A > 0.7 then the tendency for sedimentation to be low, but if 0.7 > B/A > 0.4 then the tendency for sedimentation will be high.

3. Index R (b/a), with the formula:

$$R_{(b/a)} = \frac{Fe_2O_3 + CaO + MgO}{SiO_2} \quad (3)$$

The lower the value of R (b/a), the higher the melting temperature of ash, so the risk of slagging is also lower. At the value of R (b/a) < 0.15, this temperature exceeds 1600 °C [15].

4. S_R Indek:

$$S_R = \frac{SiO_2\ x\ 100}{SiO_2 + Fe_2O_3 + CaO + MgO} \quad (4)$$

A high SR index value indicates high slag viscosity, which means it has a low slagging tendency. If SR > 72 the tendency for slagging is low, if 72 ≥ SR > 65 is medium, and if SR ≤ 65 is high [15]. If the SRs of 72 - 80 tend to be low in impurities formation, if the SR of 65 - 73 is average and of 50 - 65, the tendency of impurities formation is very high [16].

5. F_u Indeks:

$$F_u = (Na_2O + K_2O)\ x\ C_m \quad (5)$$

The Fu index determines the tendency of the fuel to form sintering and contaminate the heating surface, and has a tendency to initiate slagging. If Fu ≤ 0.6 then the fuel is not too polluting, if 0.6 < Fu ≤ 40 then the tendency towards pollution is high, and if Fu > 40 then it has a very high tendency to create sintering that contaminate the heating surface.

6. The amount of elemental iron and calcium oxide:

$$Fe + Ca = Fe_2O_3 + CaO \quad (6)$$

If the amount of Fe_2O_3 + CaO is not more than 10%, then the fuel has a low tendency to form pollutants [16].

7. The ratio of iron oxide to calcium:

$$IC = \frac{Fe_2O_3}{CaO} \quad (7)$$

If IC < 0.3 or IC > 3.0, the tendency to form pollutants is low, if 0.3 < IC < 3.0 is high [16].

8. Sintering index:

$$SI = \frac{CaO + MgO}{Na_2O + K_2O} \tag{8}$$

If SI > 2, the risk of slagging is low, if SI < 2, then the risk of slagging is high [14].

9. Agglomeration Index:

$$BAI = \frac{Fe_2O_3}{Na_2O + K_2O} \tag{9}$$

This index is related to the potential for the formation of deposits in fluidized beds. If BAI < 0.15, a lump or agglomeration is formed [14].

3. Results and Discussion

The initial characterization which includes analysis of calorific value, proximate, ultimate, and test of the composition of ash from combustion revealed the basic characteristics of the sample material as shown in Table 1.

The results of the calorific value analysis show that bagasse value 4047 cal/gram is greater than the rice husk value of 3248 calories / gram. It means that the rice husk value is only 79.7 % of the bagasse value. If bagasse is mixed with rice husk with a ratio (90 %: 10 %) and (80 %: 20), the calorific value will also change to 4017 cal/gram and 3976 cal/gram respectively.

The moisture value of bagasse, rice husk and its mixture range from 6.98 - 7.85 %, while the volatile value is between 57.96 - 76.72 % with the highest value in bagasse biomass. Ash content in rice husk of 20.67 % is far greater than that in bagasse which is only 3.66 %. Higher ash levels of rice husk than bagasse are one of the drawbacks of rice husk because it can speed up the full combustion chamber of the boiler, so the operating time of the boiler using rice husk-mixed fuel needs to be adjusted. The relatively small sulfur content of bagasse and rice husk and also its mixture (co-firing) becomes an advantage of these biomass because when used as fuel they do not have a negative impact on the environment due to the formation of NOx and SOx gas emissions [17].

The composition of ash in Table 1. shows that bagasse ash and rice husk can be grouped into acid oxides (SiO2, Al2O3, and TiO2) and alkaline base oxides (Fe2O3, K2O, N2O, CaO, MgO, and P2O5). The higher alkali metal content in biomass fuel can lead to losses in boiler equipment such as slagging and acceleration of corrosion in metal components [18]. High alkali content in biomass also indicates the danger of increasing deposits in heating equipment.

The characteristics of bagasse ash are dominated by silica content which is equal to 74.99% and several other elements such as aluminum, potassium, calcium, iron, magnesium, sodium, titanium, and phosphorus with an amount below 6% respectively. The same condition is also found in the composition of ash in rice husk which is also dominated by the silica content which reaches 95.52% and the rest are elements of aluminum, potassium, calcium, iron, magnesium, sodium, titanium, and phosphorus with a number of each below 2%. Very high silica content in rice husk is a separate note in the application of fuel in boilers because a high level of silica in rice husks will increase the potential for melting ash if it burns on boiler burner beds, thus causing many operational problems and disrupting the smooth process of combustion in the boiler. Whereas if the two of biomass are mixed (co-firing), the composition of the ashes has the amount of content which is a combination of bagasse and rice husk in a single (not mixed) condition.

Table 1. Content and composition of bagasse (biomass) and rice husk.

Content	Symbol & Unit	Bagasse	Rice husk	Bagasse & Rice husk (90 %:10 %)	Bagasse & Rice husk (80 %:20 %)
Calorific value	cal/gr	4076	3248	4017	3976
Proximate Test:					
Moisture	% adb	7.08	7.85	6.98	7.16
Ash	% adb	3.66	20.67	5.32	7.06
Volatile	% adb	76.72	57.96	74.83	71.8
Fixed carbon	% adb	12.54	13.52	13.43	13.98
Ultimate Test:					
Carbon	C	45.21	42.03	44.95	43.67
Hydrogen	H	5.57	5.91	5.80	5.69
Oxygen	O	41.43	39.14	41.38	40.97
Nitrogen	N	0.35	0.52	0.39	0.40
Sulfur	S	0.03	0.05	0.048	0.047
Composition of ash					
Acid oxide:					
Silica	SiO_2	74.99	95.52	83.76	80.87
Aluminium	Al_2O_3	5.46	0.33	3.27	4.27
Titanium	TiO_2	0.093	0.001	0.17	0.23
Basic oxide (alkali):					
Iron	Fe_2O_3	3.73	0.13	2.6	3.64
Kalium	K_2O	5.43	1.73	3.19	3.31
Natrium	N_2O	0.78	0.15	0.71	0.64
Calcium	CaO	4.50	0.85	3.04	3.71
Magnesium	MgO	1.62	0.32	1.24	1.41
Phosphor	P_2O_5	1.27	0.46	1.01	0.95

The results of ash characterization and calculation of the index found in Table 2 shows that the ratio of alkali in acid oxide (Cm) in bagasse of 0.22 is greater than in rice husk of 0.04. While the acid index (B/A) in bagasse and rice husk are 0.20 and 0.03 respectively. An acid index value that is still below 0.4 indicates that both these types of biomass and mixtures have a tendency to experience low sedimentation / precipitation [16].

The slagging index (R (b/a)) in bagasse is 0.13 while in rice husk is 0.01. The lower of slagging index, the higher the melting temperature and the flow of ash in the boiler furnace. The slagging index of bagasse and rice husk and its mixture is still below 0.15 so that the melting temperature of ash is still afar above 1600 °C [15].

Rice husk has the highest slag (Sr) viscosity index compared to bagasse as well as a mixture of both which is equal to 98.66 while the bagasse has the smallest viscosity index of 88.39. The higher of the value of Sr, the lesser the possibility of the biomass can experience slagging. Both of biomass has Sr values > 72 so that they have a tendency to experience low slagging [15].

The index of fouling (Fu) bagasse, rice husk, and co-firing of bagasse with rice husk are 1.34; 0.07; 0.53 and 0.63. The rice husk fouling index is smaller than 0.6 so that it does not cause too much air pollution, whereas for bagasse and co-firing bagasse with rice husk the fouling index is greater than 0.6 but smaller than 40 so it tends to lead to high pollution [15].

Iron and calcium (Fe + Ca) oxide content in these two biomass is of 0.98 - 8.23 so it has a low tendency to form pollutants [16]. The lowest ratio of iron oxide with calcium (IC) is owned by rice husk so it has a lower tendency to form pollutants. While the IC value of bagasse is 0.83 so it has a higher tendency to to form higher pollutants [16].

The sintering index (SI) in all tested biomass is < 2, so there is still a risk to be able to experience high enough slagging. While the value of the agglomeration index (BAI) is sufficient, namely 0.07 for rice husk and 0.60 for bagasse. With this value, the bagasse has a higher tendency to form deposits in the fluidized bed boiler which then forms clumps/agglomerations [14].

Table 2. Slagging and fouling index calculated based on the composition of ash from bagasse and rice husk combustion

Indeks	Symbol	Bagasse	Rice husk	Bagasse & Rice husk (90 % : 10 %)	Bagasse & Rice husk (80 % : 20 %)
The ratio of alkali in acidic acid	C_m	0.22	0.04	0.14	0.16
Acid index	B/A	0.20	0.03	0.12	0.15
Slagging index	$R_{(b/a)}$	0.13	0.01	0.08	0.11
Slag viscosity index	S_r	88.39	98.66	92.41	90.23
Fouling index	F_u	1.34	0.07	0.53	0.63
The amount of iron oxide and calcium	Fe + Ca	8.23	0.98	5.64	7.35
The ratio of iron oxide to calcium	IC	0.83	0.15	0.86	0.98
Sintering index	SI	0.99	0.62	1.10	1.30
Agglomeration Index	BAI	0.60	0.07	0.67	0.92

4. Conclusions

The use of different types of biomass as fuel for the boiler can cause a risk of contamination and different damage on boiler heating equipment such as slagging, fouling, corrosion, agglomeration and sintering. Rice husk has a lower calorific value than bagasse but has a higher ash content, so it requires adjustments in boiler operations when using rice husk as an alternative fuel for co-firing systems with bagasse. Based on the ash composition analysis of bagasse and rice husk, the application of rice husk as co-firing fuel to boilers in sugar mills will not evoke a serious potential damage such as slagging, fouling, corrosion, sintering, and agglomeration, but the high percentage of ash content in rice husks can increase the potential for the risks above.

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