INDONESIAN MINING JOURNAL Vol. 16, No. 1, February 2013 : 37 - 48

STUDY ON ASHES OF BLENDED COAL-BIOMASS FOR CO-FIRING SYSTEM IN A COAL FIRED BOILER

STUDI ABU DARI CAMPURAN BATUBARA BIOMASSA UNTUK SISTEM PEMBAKARAN BERSAMA PADA BOILER BATUBARA

IKIN SODIKIN AND DATIN F. UMAR
R & D Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211, Ph. 022 6030483, fax. 022 6003373
e-mail: ikin@tekmira.esdm.go.id

ABSTRACT

Biomass and coal blend combustion or co-firing is a promising combustion technology. However, significant development work is required before large-scale implementation can be realized. Issues related to successful implementation of coal biomass co-firing mainly for power generation should be identified. This paper presents the results of the study on blended coal-biomass characterisation, particularly the ash chemical composition and ash fusion temperature to predict the slagging and fouling propensity in a coal fired boiler. The coal used in this research has a calorific value of 5,067 cal/g and the ash fusion temperature of softening temperature in oxidation condition (softening temperature-ox) is 1,228ºC, while the biomass used was baggase, straw and rice husk with the calorific value of 4,144; 3,545; 3,301 cal/g and the softening temperature-ox of 1,303; 1,420 and >1,500ºC, respectively. Experimental results for some varieties of fuel blends indicate that the proportion of 95%-5% of coal and baggase has the highest softening temperature-ox of 1,225ºC. The blend of coal and straw resulted in the highest softening temperature-ox of 1,240ºC at 95%-5%, while the blend of coal and rice husk, the highest softening temperature-ox of 1,235ºC was reached at the proportion of coal and rice husk at 90%-10%. According to the slagging and fouling index, blended coal and straw shows the best performance compared to that of blended coal either with baggase or rice husk.

Keywords: coal, biomass, co-firing, ash fusion temperature, slagging and fouling index

SARI

*Pembakaran campuran batubara dan biomassa atau pembakaran bersama merupakan suatu teknologi yang menjanjikan. Namun penelitian dan pengembangan yang cukup luas sangat diperlukan sebelum teknologi ini diterapkan pada skala komersial. Isu-isu penting yang berkenaan dengan keberhasilan penerapan sistem pembakaran bersama, terutama pada pembangkit listrik perlu untuk diketahui. Makalah ini menyampaikan hasil studi tentang karakteristik campuran batubara biomassa, terutama komposisi abu dan titik leleh abu dari bahan bakar tersebut untuk menelaah kemungkinan terjadinya slagging dan fouling pada boiler batubara. Batubara yang digunakan dalam penelitian ini mempunyai nilai kalor sebesar 5.067 kal/g dan titik leleh abu pada softening temperature suasana oksidasi (*softening temperature-ox*) 1.228ºC, sedangkan biomassa yang digunakan adalah bagas, jerami dan sekam padi dengan nilai kalor masing-masing 4.144; 3.545; 3.301 kal/g dan softening temperature-ox masing-masing 1,303; 1.420 dan>1,500ºC. Hasil penelitian dengan berbagai variasi campuran menunjukkan bahwa campuran antara bagas 5% dengan batubara 95% mempunyai softening temperature-ox yang tertinggi, yaitu 1.225ºC. Campuran batubara dan jerami menghasilkan softening temperature-ox tertinggi, yaitu 1.240ºC dengan komposisi batubara dan jerami 95%-5%, sedangkan campuran batubara dan sekam padi softening temperature-ox tertinggi, yaitu 1.235ºC dicapai oleh campuran dengan komposisi 80%-20%. Berdasarkan indeks slagging dan fouling, campuran batubara dengan jerami menunjukkan kinerja yang terbaik dibandingkan dengan campuran batubara dengan bagas mau pun dengan sekam padi.*

Kata kunci: batubara, biomassa, pembakaran bersama, titik leleh abu, indeks slagging *dan* fouling

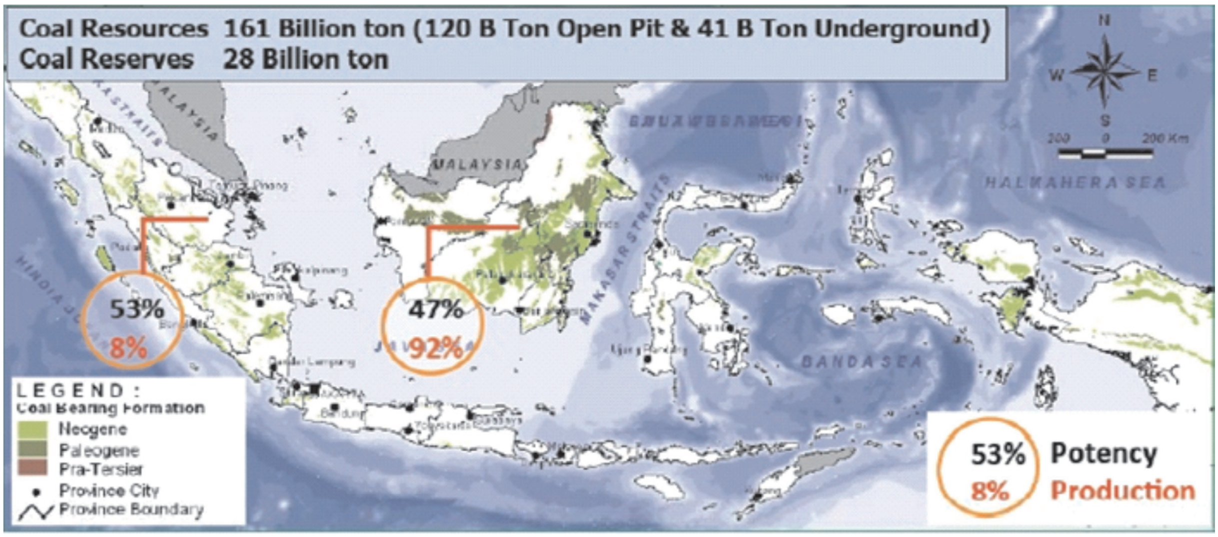
Received : 27 September 2012, first revision : 20 December 2012, second revision : 23 January 2013, accepted : February 2013

INTRODUCTION

Currently, Indonesia's coal resources are estimated at 161 billion tons, which are 120 billion tons open pit and 41 bilion tons underground. Among them of about 28 billion tons are categorized as reserved (Adisoma, 2013). There are two major coal bearing formations by geological age, namely Paleogene and Neogene. Both ages are present in Kalimantan, while in Sumatra mostly Neogene Formation, with the exception in Ombilin, West Sumatera. Resources allocation for coal production is imbalance. Largely coal comes from Kalimantan (92%) and the rest comes from Sumatera, particularly South Sumatera (8%). On the contrary, the coal potential in Sumatra is more than the coal in Kalimantan (Figure 1). This situation mostly due to the infrastructural limitations in Sumatera area. In Kalimantan, most coal mines located near to the coastline or along the rivers were developed fully taking advantage of inland water transportation and loading at the offshore/nearshore coal terminal for shipping to the overseas and domestic markets. While in Sumatera, coal transportation is carried out by using trains and trucks.

Coal has shown its strategic role in development since it creates the multiplied effects on the national and regional economy. From the standpoint of stability of energy supply and economics, coal also has the advantage of being cheaper and not being subject to the price swings characteristic of alternative energy choices. As a result, coal is expected to continue to play an important role among primary energy supplies in the future. In the last fifteen years, coal became another major export commodity to earn foreign exchange for the country. However, the reserves of high rank coal (HRC) such as bituminous and high sub-bituminous coal that are currently exploited are limited.

In general, the strategic planning of coal utilization is derived from the quality proportion of the resources in order to meet the market demand and domestic consumption for energy generation. In the near future, the Indonesia government will encourage to use the low rank coal (LRC) as the main source of energy in the national energy mixed policy. In that sense, the government is encouraging to use more coal domestically, while maintaining the export level. However, the use of coal as a fuel will have a negative impact on the environment. Air pollution from coal-fired power plants is large and varied and contributes to a significant number of negative environmental and health effects. When coal is burned, the combustion releases a combination of toxic chemicals into the environment, and thus the human body. Coal combustion releases nitrogen oxides, sulphur dioxide, particulate matter (PM), mercury, and dozens of other substances known to be hazardous to human health. Carbon dioxide (CO_2) is the most significant greenhouse gas that contributes to global warming. The dangers of global warm-



Source: Adisoma (2013)

Figure 1. Indonesia's coal resources and reserves

ing include disruption of global weather patterns and ecosystems, flooding, severe storms, and droughts.

To reduce the environmental effects due to the use of coal, co-firing of coal and biomass is one of the techniques that can be applied. Co-firing is the combustion of two different types of materials at the same time. One of the advantages of co-firing is that an existing plant can be used to burn a new fuel, which may be cheaper or more environmentally friendly. As a matter of fact, this interest on co-firing has grown in the last decade mainly due to the increasing social concerns on global warming and greenhouse gas (GHG) emissions.

The concept of co-firing is quite simple. It includes in the use of two or more fuels inside the same combustion device. It is applicable to all kind of combustion systems traditionally used for power generation (pulverized fuel, fluidized bed combustion and grate firing). Co-firing in cement kilns is already a quite widespread solution for valorization of waste materials mostly, as well as for biomass. The iron industry (blast furnace) and domestic sector (coal stoves) are also sectors where co-firing could be implemented.

Co-firing between coal and biomass is one of the most easily implemented. Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-derived materials which are specifically called lignocellulosic biomass (Carroll and Somerville, 2009). As a renewable energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel.

Biomass can provide numerous benefits when used as a fuel to supplement coal, including potentially lower fuel costs, reductions in sulphur emissions (vs. burning coal only), reductions in NOx emissions under most combustion scenarios, reductions in mercury emissions (Mentz et al, 2005), and reductions of landfill material when co-firing municipal waste, construction debris, or other biomass material that would otherwise be landfilled, or when larger amounts of ash from coal must be landfilled for disposal (Nichols and Zerbe, 2012). Biomass fuels are considered environmentally friendly for several reasons. First, there is no net increase in CO_2 as a result of burning a biomass fuel (i.e. fossil generated CO_2). Biomass consumes the same amount of CO_2 from the atmosphere during growth as is released during combustion. Therefore, blending coal with biomass fuels can reduce fossil-based CO_2 emissions (Sami et al, 2001).

The implementation of coal biomass co-firing is undebatable, because co-firing with biomass could be an excellent bridge strategy to quickly reduce GHGs for a given facility whether or not coal would be used in the future. To support the successfully of co-firing implementation, some characteristics of the coal and biomass should be identified. The primary objective of this paper is to describe the characteristics of the blended coal and biomass, mainly the chemical ash composition and ash fusion temperature (AFT). Because ashes in coal and in biomass have different characteristics, theoretically it would cause the difference in the AFT. However, a discussion of co-firing combustion of fuel blends is beyond the scope of this paper. Previous works on the use of blended sawdust and coal through co-firing technology were carried out using a cyclo burner (Sodikin, 2013).

METHODOLOGY

Blending of coal and biomass was conducted to obtain a more environmentally friendly combustion through co-firing system. In this case, coal and three kinds of biomass have been used. The coal is categorized as subbituminous coal with relatively high moisture content. While the biomasses are baggase, straw and rice husk.

Bagasse is the fibrous matter that remains after sugarcane or sorghum stalks were crushed to extract their juice. It is currently used as a biofuel and in the manufacture of pulp and building materials. Bagasse is a by-product of the cane sugar industry. The high moisture content of bagasse, typically 40 to 50%, is detrimental to its use as a fuel. In general, bagasse is stored prior to further processing. For electricity production, it is stored under moist conditions, and the mild exothermic reaction that results from the degradation of residual sugars dries the bagasse pile slightly. For paper and pulp production, it is normally stored wet in order to assist in removal of the short pith fibres, which impede the papermaking process, as well as to remove any remaining sugar. Many research efforts have explored using bagasse as a renewable power generation source and for the production of bio-based materials. The resulting CO_2 emissions due to the baggasse burning are equal to the amount of CO_2 that the sugarcane plant absorbed from the atmosphere during its growing phase, which makes the process of co-generation greenhouse gas-neutral (Barosso et al, 2003; Radke, 2012).

Straw is an agricultural by-product, the dry stalks of cereal plants, after the grain and chaff have been removed. Straw makes up about half of the yield of cereal crops such as barley, oats, rice, rye and wheat. The use of straw in large-scale biomass power plants is becoming mainstream in the EU, with several facilities already online. The straw is either used directly in the form of bales, or densified into pellets which allows the feedstock to be transported over longer distances (Evald, 2011).

Rice husks or rice hulls are the coatings of seeds, or grains, of rice. To protect the seed during the growing season, the husk is formed from hard materials, including opaline silica and lignin. The husk is mostly indigestible to humans. Rice husk is a typical dry or membranous outer covering of the rice. When compared to other agro residues, rice husk has higher ash content (20-22.4%), higher potash content, 1.0% crude protein, 0.3% crude fat and 30% carbohydrate. However, rice husk is an exceptional biomass, it has good flow ability, normally available with 10-12% moisture and the ash contain fewer alkaline minerals. In fact, it makes an excellent fuel although its calorific value is less than wood and other agro residues (Yahaya and Ibrahim, 2012). With proper techniques, rice husks can be burned and used to power steam engines. Some rice mills originally disposed of hulls in this way. Unfortunately the direct combustion of rice hulls produces large quantities of smoke. An alternative is gasification. Rice hulls are easily gasified in a moving-bed downdraft gasifier reactor in combination with a gas- conditioning devices that remove impurities from the gas thereby making it highly suitable fuel for heat engines (Belonio et al, 2011).

According to Stams et al (2009), the biomass co-firing in large coal fired utility boilers is relatively low co-firing ratios (in most cases up to 20% mass based). With increase of co-firing level, the impacts on plant performace and integrity will become more significant, particularly with the lower grade biomass material. Principal technical concerns are associated with the behaviour of the mixed coal biomass ashes, and there are significant concerns about the potential impacts of ash deposition on surfaces in the boiler and asscociated equipment. Therefore, in this research the composition of blended coal-biomass was designed limited up to 80% coal and 20% biomass as can be seen in Table 1.

Table 1. Experimental design of the blended coal-biomass composition

Sample mark	Composition of coal	Composition of baggase
CB-1	95%	5%
CB-2	90%	10%
CB-3	85%	15%
CB-4	80%	20%
Sample mark	Composition of coal	Composition of straw
CS-1	95%	5%
CS-2	90%	10%
CS-3	85%	15%
CS-4	80%	20%
Sample mark	Composition of coal	Composition of rice husk
CRH-1	95%	5%
CRH-2	90%	10%
CRH-3	85%	15%
CRH-4	80%	20%

To support this research, the coals and biomasses of baggase, straw and rice husk were analysed for the proximate, ultimate, calorific value, ash composition and ash fusion temperature. The proximate analysis covered the determination of inherent moisture, ash and volatile matter and the calculation of fixed carbon. While the ultimate analysis of coal is the determination of carbon and hydrogen in the material, as found in the gaseous products of its complete combustion, the determination of sulphur, nitrogen and ash in the material as a whole, and the calculation of oxygen by difference. The proximate and ultimate analysis have been conducted according to the ASTM Standard Method.

The calorific value of the coal was determined according to the ASTM D 5865-04. Gross calorific value (gross heat of combustion at constant volume), Qv (gross) was the heat produced by complete combustion of coal at constant volume with all water formed condensed to a liquid under specified conditions, while net calorific value (net heat of combustion at constant pressure) Qp (net), was the heat produced by combustion of coal at constant pressure of 0.1 MPa (1 atm), with any water formed remaining as vapour. This test method pertained for determination of the gross calorific value of coal by either an isoperibol or adiabatic bomb calorimeter. In this investigation the adiabatic bomb calorimeter was used to determine the calorific value. Adiabatic calorimeter was a calorimeter that operated in the adiabatic mode and provided with microprocessor. The initial temperature before initiating the combustion and the final temperature were recorded by a microprocessor.

When coal is used as a fuel in boilers, ash formed after combustion of coal is required to be removed as powder residue. But the characteristic behaviours of the coal ash at high temperature region inside the boiler is very critical since the ash, which melts at below the temperature prevailing in the boiler undergoes glass transitions and fuses to form slag on the wall and the bottom of the boiler. It is therefore of vital importance to determine the ash fusion temperature (AFT) of the coal for determination of its suitability and efficiency of the boiler. The AFT test gives an indication of the softening and melting behaviour of coal ash at high temperatures within the boiler. Blended two types of coal or blended coal-biomass for co-firing sytem, the AFT cannot be calculated directly according to the weight ratio of each material used.

The ash fusion characteristic is directly related to its ash composition. Therefore, the data of ash composition in the coal and biomass are very important. Each sample, which consists of 100 to 200 mg of coal and or biomass ash ground to pass through a 100-mesh sieve, is mixed with a reagent-grade lithium metaborate-lithium tetraborate flux and fused at 1,000° C for 45 minutes in a graphite crucible. Use of a mixed flux (1 part anhydrous lithium metaborate ($LiBO_2$) and 2 parts anhydrous lithium tetraborate ($Li_2B_4O_7$)). The bead that results from the fusion of 0.2 g of sample is dissolved in dilute nitric acid and diluted to 250 mL. Concentrations of major elements in this solution are determined by gravimetry for SiO_2, spectrophotometry for TiO_2 and P_2O_5, turbidimetry for SO_3 and by AAS for Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, and MnO_2 (Speight, 2005).

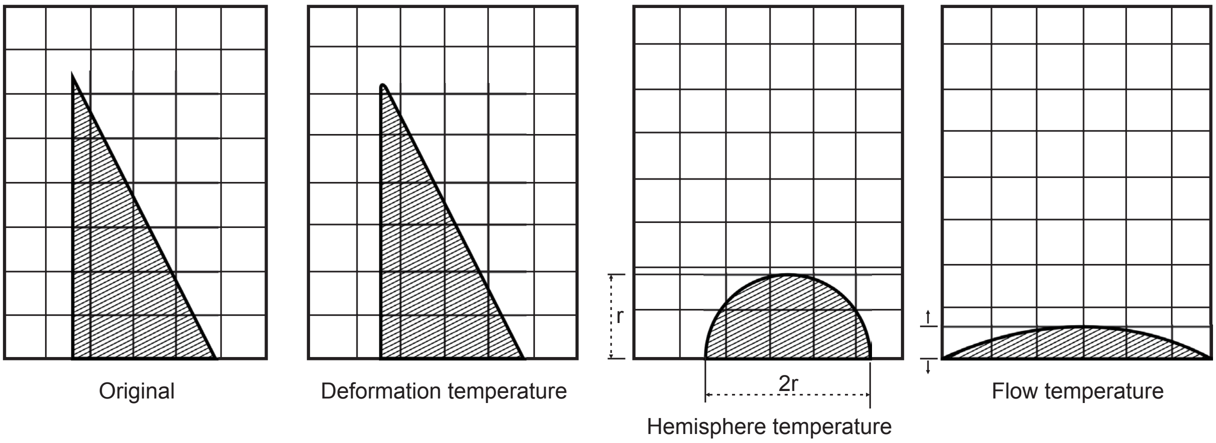
AFT were determined by viewing a moulded specimen of the coal ash through an observation window in a high-temperature furnace in both reducing and oxidizing conditions. The ash, in the form of a cone, pyramid or cube, was heated steadily past 1,000°C to as high a temperature as possible, preferably 1,600°C (2,910°F). The following temperatures either in reduction or oxidation condition were recorded:

- Deformation temperature (DT): This is reached when the corners of the mould first become rounded.
- Softening (sphere) temperature (ST): This is reached when the top of the mould takes on a spherical shape.
- Hemisphere temperature (HT): This is reached when the entire mould takes on a hemisphere shape.
- Flow (fluid) temperature (FT): This is reached when the molten ash collapses to a flattened button on the furnace floor.

The shapes of the DT, ST, HT and FT are shown in Figure 2.

RESULTS AND DISCUSSION

If biomass co-firing is planned for a coal fired boiler, several fuel related impacts have to be considered. Table 2 compares analyses of coal to those of three typical biomasses of baggase, straw and rice husk. The blended coal and biomasses are also presented according to the comparison as can be seen in Table 1.



Original

Deformation temperature

Hemisphere temperature

Flow temperature

Figure 2. Shape characterisitcs of AFT

Table 2. Analysis results of the proximate, ultimate and calorific values of coal, biomasses and blended coal-biomass

Sample mark	IM %	Ash %	VM %	FC %	FR	C %	H %	N %	O %	S %	CV cal/g
Coal	17.69	5.77	40.90	35.64	0.87	55.40	5.77	0.59	32.34	0.13	5067
Baggase	7.17	5.41	73.86	13.56	0.18	44.79	5.96	0.36	43.38	0.10	4144
Straw	6.62	15.50	61.81	16.07	0.26	37.72	5.34	0.87	40.49	0.08	3545
Rice husks	7.77	21.17	57.72	13.34	0.23	35.21	5.00	0.43	38.14	0.05	3301
CB-1	17.16	5.75	42.55	34.54	0.81	54.87	5.78	0.58	32.89	0.13	5021
CB-2	16.64	5.73	44.20	33.43	0.76	54.34	5.79	0.57	33.44	0.13	4975
CB-3	16.11	5.72	45.84	32.33	0.71	53.81	5.80	0.56	34.00	0.13	4929
CB-4	15.59	5.70	47.49	31.22	0.66	53.28	5.81	0.54	34.55	0.12	4882
CS-1	17.14	6.26	41.95	34.66	0.83	54.52	5.75	0.60	32.75	0.13	4991
CS-2	16.58	6.74	42.99	33.68	0.78	53.63	5.73	0.62	33.16	0.13	4915
CS-3	16.03	7.23	44.04	32.70	0.74	52.75	5.71	0.63	33.56	0.12	4839
CS-4	15.48	7.72	45.08	31.73	0.70	51.86	5.68	0.65	33.97	0.12	4763
CRH-1	17.19	6.54	41.74	34.53	0.83	54.39	5.73	0.58	32.63	0.13	4979
CRH-2	16.70	7.31	42.58	33.41	0.78	53.38	5.69	0.57	32.92	0.12	4890
CRH-3	16.20	8.08	43.42	32.30	0.74	52.37	5.65	0.57	33.21	0.12	4802
CRH-4	15.71	8.85	44.26	31.18	0.70	51.36	5.62	0.56	33.50	0.11	4714

Notes:
IM: inherent moisture, VM: volatile matter, FC: fixed carbon, CV: calorific value, FR: fuel ratio (FC/VM)

The data in Table 1 highlight some of the critical differences between the coal and biomasses. The biomasses have low moisture content. It means that the biomasses were in dry condition. If too much moisture is present, the biomass will not spontaneously react. The ash content of the coals were lower than that of the biomasses except the baggase. The low ash of baggase was due to the washing process during sugarcane extraction. Excessive ash in the fuels can cause fouling deposits in the combustion equipment. Ash has an erosive effect on the burner tips, causes damage to the refractories at high temperatures and gives rise to high temperature corrosion and fouling of equipments.

The amount of volatile matter indicates whether the fuel will burn with a short or long flame and whether it will tend to produce smoke. The more volatile in the fuel, the more it will smoke. When compared the coals, biomasses have significantly higher volatile matter contents than that of the coals and their fuel ratio (the content of fixed carbon divided by the content of volatile matter) is much below unity. Volatile matter helps in the ignition of the fuel and high volatile matter in the biomasses indicates a potential for creating large amounts of vapors during combustion.

The content of fixed carbon divided by the content of volatile matter is called the fuel ratio. From the data in the Table 2, it can be seen that the fuel ratio of baggase is the lowest compared to the others. Consequently, the fuel ratio of the blended coal and baggase is also low. Lower fuel ratio are characterized by a greater oxygen, that aids ignition and enhances combustibility and flame stability. High combustibility improves carbon burnout (reduce carbon carryover) and hence boiler efficiency and for pulverized coal fire units, this allows the coal to be ground to a coarser size.

The calorific value of the coal is the highest compared to the biomasses. The rice husk has a lowest calorific value due to its high ash content (21.17% adb). The higher the calorific value, the higher is the combustion efficiency. Carbon content of the coals are higher than that of biomasses in line with the fixed carbon content of them. While the hydrogen content is not significantly different. Low sulphur and low nitrogen contents of the biomasses lead to low SOx and NOx emissions, due to decreased fuel sulphur and nitrogen conversion to SOx and NOx. Thus, biomasses are low NOx fuels and co-firing of biomass and coal can reduce the NOx emissions from coal fired boilers.

The ash fusion characteristic of coal is directly related to its composition primarily SiO_2, Al_2O_3, CaO, Fe_2O_3 and under oxidizing condition, the three component system of SiO_2-Al_2O_3-CaO and SiO_2-Al_2O_3-Fe_2O_3. The alkalis present in the form of oxides as K_2O and Na_2O also contribute to the fusion temperature of the ash as base component in separate three component system, when present in considerable amount. It is also believed that under reducing conditions (CO/CO_2), the base component of iron exist as FeO. Apart from that other reductions in the system also occur reducing the AFT to a lower value. The ash composition of the coal and biomass ashes were analysed through gravimetry, colorimetry and AAS. The result of the ash composition analyses can be seen in Table 3.

From Table 4, it can be seen that the silica oxide (SiO_2) of the biomasses were very dominant and significantly higher than that of the coal. There are 2 types of coal ash, bituminous ash and lignite ash. The bituminous ash, the base/acid ratio is

Tabel 3. Ash chemical composition of coal, biomass and blended coal-biomass

Sample mark	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	K_2O %	Na_2O %	CaO %	MgO %	TiO_2 %	MnO %	P_2O_5 %	SO_3 %
Coal	53.90	15.55	12.97	0.56	0.38	5.76	5.59	0.62	0.21	0.03	3.32
Baggase	71.30	7.21	3.29	7.43	0.58	2.98	2.30	0.16	0.20	0.62	1.38
Straw	94.10	0.49	0.25	1.73	0.29	0.58	0.45	*	0.10	0.87	0.23
Rice Husks	81.30	0.43	0.38	7.86	1.37	2.24	1.36	*	0.20	0.80	0.48
CB-1	54.77	15.13	12.49	0.90	0.39	5.62	5.43	0.60	0.21	0.06	3.22
CB-2	55.64	14.72	12.00	1.25	0.40	5.48	5.26	0.57	0.21	0.09	3.13
CB-3	56.51	14.30	11.52	1.59	0.41	5.34	5.10	0.55	0.21	0.12	3.03
CB-4	57.38	13.88	11.03	1.93	0.42	5.20	4.93	0.53	0.21	0.15	2.93
CS-1	55.91	14.80	12.33	0.62	0.38	5.50	5.33	*	0.20	0.07	3.17
CS-2	57.92	14.04	11.70	0.68	0.37	5.24	5.08	*	0.20	0.11	3.01
CS-3	55.23	13.27	11.05	0.65	0.35	4.95	4.80	*	0.19	0.11	2.85
CS-4	61.94	12.54	10.43	0.79	0.36	4.72	4.56	*	0.19	0.20	2.70
CRH-1	55.27	14.79	12.34	0.93	0.43	5.58	5.38	*	0.21	0.07	3.18
CRH-2	56.64	14.04	11.71	1.29	0.48	5.41	5.17	*	0.21	0.11	3.04
CRH-3	58.01	13.28	11.08	1.66	0.53	5.23	4.96	*	0.21	0.15	2.89
CRH-4	59.38	12.53	10.45	2.02	0.58	5.06	4.74	*	0.21	0.18	2.75

Note:
*: not detected

Tabel 4. Ash fusion temperature of coal, biomass and blended coal-biomass

Sample mark	Reduction				Oxidation			
	DT °C	ST °C	HT °C	FT °C	DT °C	ST °C	HT °C	FT °C
Coal	1,055	1,145	1,163	1,225	1,138	1,228	1,245	1,295
Baggase	1,150	1,240	1,325	1,460	1,210	1,303	1,420	>1,500
Straw	1,283	1,415	1,435	1,465	1,300	1,420	1,445	1,475
Rice husk	>1,500	>1,500	>1,500	>1,500	>1,500	>1,500	>1,500	>1,500
CB-1	1,125	1,160	1,170	1,240	1,165	1,255	1,295	1,355
CB-2	1,100	1,145	1,160	1,300	1,130	1,230	1,255	1,325
CB-3	1,100	1,145	1,165	1,280	1,130	1,220	1,255	1,335
CB-4	1,095	1,140	1,155	1,230	1,130	1,215	1,245	1,345
CS-1	1,095	1,155	1,170	1,220	1,150	1,240	1,285	1,335
CS-2	1,195	1,225	1,260	1,310	1,200	1,235	1,270	1,315
CS-3	1,175	1,220	1,250	1,310	1,175	1,220	1,265	1,320
CS-4	1,165	1,210	1,270	1,325	1,195	1,220	1,275	1,355
CRH-1	1,155	1,215	1,230	1,260	1,170	1,225	1,240	1,300
CRH-2	1,105	1,160	1,180	1,240	1,200	1,235	1,255	1,305
CRH-3	1,105	1,145	1,165	1,270	1,120	1,230	1,250	1,310
CRH-4	1,130	1,160	1,165	1,205	1,190	1,230	1,255	1,325

Notes:
DT: deformation temperature ST: softening temperature
HT: Hemisphere temperature FT: Flow temperature

more than 1 or the Fe_2O_3 more than the total sum of CaO+MgO contents in the coal. While the lignite ash, the base/acid ratio is less than 1 or the Fe_2O_3 less than the total sum of CaO+MgO. From Table 4, all of the fuels, the ash types are characterized as lignite ash with the Fe_2O_3 content is less than the total sum of CaO and MgO.

One difference between biomass and coal is that all of biomasses contain more alkali metals compared to the coal. Alkali metals like potassium (K) and sodium (Na) have lower melting and evaporation point than other inorganic materials in the fuel. The alkali metal in biomass, potassium oxide content is higher than sodium content for all of the biomass. However, elements such as Al, Si and S are able to trap alkalies, limiting the formation of alkalichlorides. These elements (Al, Si and S) exist naturally in coal and it is therefore favourable to mix coal and biomass (Aho and Ferrer, 2005).

The use of coal, biomass or blended coal-biomass as co-firing in coal fired boiler cannot be separated with the fouling and slagging problems. Slagging occurs in boiler furnaces where ash deposits are exposed to the radiant heat of the coal flames, while fouling occurs in the boiler's convective passes. The process of slagging is closely related to that of fouling. Slagging refers to deposition of solid layers on the boiler tube, formed by sintering. Slagging is quite hard to remove (although it is sintered material) and also the slagging material is usually still a good insulator. For these reasons, most modern sootblowing systems are aimed at prevention of slagging.

Fouling occurs in the colder section of the boiler where inorganic volatiles condensate as compounds on the colder tube surface forming a deposit layer. Also particles in melt phase may hit the tube, be cooled down to solid state and get stuck on the tubes. The deposit layer may be porous or it may be sintered to a hard and compact layer as it interact with the surrounding gases or with other components in the deposit layer. On over time the deposit layer grows in thickness and the temperature of outer surface increases as the deposit itself insulates the cooler water or steam inside the tube from the hotter flue gas. The temperature will then eventually reach the melting point of at least some the constituents of the deposit. This process gradually accelerates nearly anything that hits the deposit on the tube may get stuck. Ash particles in solid state as well as small particles from the bed material in the combustion chamber may then continue to build up a thick deposit layer on the tubes. Thus the surface temperature continues to increase and it is possible that a larger part of the deposit is in the molten phase increase and the deposit material may start to flow. In the end the deposit becomes so heavy that it falls off the tube under its own weight. This process is called slagging.

The propensity of coal, biomass and blended coal-biomass for producing slagging and fouling deposits based on the results of either ash fusion or chemical composition of the ash depends on its ash content commontly the ratio of the base metal oxide (Fe_2O_3, CaO, MgO, Na_2O and K_2O) to the acidic oxide (SiO_2, Al_2O_3 and TiO_2). From the results of ash composition analyses of coal and biomasses and the calculated ash composition of blended coal-biomass, it was found that all of the ash type is lignite type. Therefore the calculation to predict the propensity of slagging following the formula:

$$\text{Slagging Index: } \frac{((\text{max HT}) + 4\,(\text{min IT}))}{5},$$

(www.bisyplan.bioenarea.eu)

Where max HT is the highest value of the hemisphere ash fusion temperature under reducing or oxidising conditions and min IT is the lowest initial deformation temperature under reducing or oxidising conditions.

In most of biomass materials, potassium tends to be the dominant alkali metal, and this is generally released by volatilaization (Stams et al, 2009). Therefore, the fouling index that have been developed for the assesment of biomass material tendency, the total alkali metal content of the biomass is a governing factor (Sandberg, 2007).

Fouling Index (Rf) of biomass and blended coal-biomass:

Base/acid x (% Na_2O+%K_2O)

Fouling Index (Rf) of Coal:

Base/acid x % Na_2O

For blended two types of coal or blended coal-biomass for co-firing sytem, the AFT cannot be calculated directly according to the weight ratio of each material. Therefore the AFT had been tested in which the blended coal-biomass sample ratios were prepared according to the experimental design as described in Table 1. The results of the ash fusion temperature test are presented in Table 4.

The ash softening temperature (ST) is the temperature at which the ash softens and becomes plastic. This is somewhat below the melting point of ash. All of the biomasses show that the ST are higher than that of the coal. The best is the rice husk where the ST was >1,500°C. The design of steam generator greatly depends on the ash ST of the fuel. If the furnace temperature is higher than the ash ST, the ash will melt and would come out of the furnace bottom continuously as molten slag. For furnace that would discharge ash in the solid form, as high as softening temperature would be required. A stoker furnace must use coal with a high ash ST otherwise clinkers would be formed. Clinkers which are large masses of fused ash, cause troubles in discharging and also make inefficient combustion. Therefore the ash ST ought to be more than 1,150°C.

It is to be considered that during combustion in pulverized (PF) boilers and in (circulating fluidized bed combustion (CFBC) boilers the furnace temperatures during combustion are different. In PF boilers, the average furnace temperature at the combustion is about 1,400 to 1,600°C, where in CFBC boilers the furnace bed temperature is 880 to 940°C. From Table 4, ash fusion temperature in any fuel was greater than 1,000°C. So in PF boilers, the ash fusion temperature will be achieved, and it is known that clinkers will be also formed, and these clinkers could be collected in the bottom ash hopper. In case of CFBC boilers, the temperature is below the ash fusion temperature of the fuels, so that the bed temperature could not increase beyond the ash fusion temperature.

The coal used in this research has AFT of softening temperature in oxidation condition (ST-ox) of 1,228°C, while the biomasses of baggase, straw and rice husk, blended coal with baggase of 95%-5% has the highest ST-ox of 1,225°C. The blend of coal and straw resulting the highest ST-ox of 1240°C at 95%-5%, while the blend of coal and rice husk, the highest ST-ox of 1,235°C was reached at the proportion of coal and rice husk at 90%-10%. The slaging and fouling indexes related to the slagging and fouling types tend to produce slaging and fouling in coal fired boiler as presented in Table 5. While Table 6 shows the fouling and slagging indexes of the coal, biomass and blended coal-biomass.

As presented in Table 6, according to empirical approach by traditional methods based on the use of simple slagging and fouling indexes using the data normaly available on fuel specification, i.e. the ash chemical composition and the ash fusion temperature, the tendency to produce slagging

Table 5. Slagging and fouling index

Sample mark	Composition of coal	Composition of baggase
CB-1	95%	5%
CB-2	90%	10%
CB-3	85%	15%
CB-4	80%	20%
Sample mark	Composition of coal	Composition of straw
CS-1	95%	5%
CS-2	90%	10%
CS-3	85%	15%
CS-4	80%	20%
Sample mark	Composition of coal	Composition of rice husk
CRH-1	95%	5%
CRH-2	90%	10%
CRH-3	85%	15%
CRH-4	80%	20%

Table 6. The propensity to slaging and fouling of the coal, biomass and blended coal-biomass

Sample mark	Basic/acid ratio	Slagging		Fouling	
		Index, °C	Category	Index	Category
Coal	0.36	1,093	Severe	0.14	Low
Baggase	0.21	1,204	High	1.69	Severe
Straw	0.03	1,315	Medium	0.07	Low
Rice Husks	0.16	>1,500	Low	1.49	Severe
CB-1	0.36	1,159	High	0.46	Medium
CB-2	0.35	1,131	Severe	0.57	High
CB-3	0.34	1,131	Severe	0.68	High
CB-4	0.33	1,125	Severe	0.78	High
CS-1	0.34	1,133	Severe	0.34	Medium
CS-2	0.32	1,210	High	0.34	Medium
CS-3	0.32	1,193	High	0.32	Medium
CS-4	0.28	1,187	High	0.32	Medium
CRH-1	0.35	1,172	High	0.48	Medium
CRH-2	0.34	1,135	Severe	0.60	High
CRH-3	0.33	1,134	Severe	0.72	High
CRH-4	0.32	1,155	High	0.83	High

and fouling were mostly high and severe. For co-firing system between coal and biomass, the propensity of the coal to produce slagging was categorized as severe eventhough the slagging was low. While the rice husk has the lowest propensity to the slagging, but severe to be fouling due to the high total alkali metal content. According to the slaging and fouling propensity, the best material to be blended with coal for co-firing system in coal fired boiler is straw compared to that of baggase and rice husk. The composition of coal 90%, 85% and 80% and 10%, 15% and 20% of straw respectively, best slagging and fouling propensity are obtained eventhough categorized as high slagging and medium fouling.

Based on these results, the control of slagging and fouling in a boiler is a fairly complex issue, involving fuel diet, boiler design and operational factors. The key factors are (Sandberg, 2007):

- The careful design of the furnace and boiler convective section, which recognises properly the characteristics and behaviour of the fuel ashes.
- The incorporation of specific furnace and boiler design features, where appropriate, to minimise ash deposition, to aid the removal of ash, and to avoid the accumulation within the system.
- The correct design, operation and maintenance of the combustion equipment.
- The intensive cleaning of the furnace and boiler surfaces.

CONCLUSION

The coal used in this research is categorized as subbituminous coal with a calorific value of 5,067 cal/g and the AFT of softening temperature in oxidation condition(ST-ox) is 1,228 °C, while the biomass used were baggase, straw and rice husk with the calorific values of 4,144; 3,545; 3,301 cal/g and the ST-ox of 1,303; 1,420 and >1,500 °C, respectively. Experimental results for some varieties of fuel blends indicate that the proportion of coal and baggase of 95%-5% has the highest ST-ox of 1,225 °C. The blend of coal and straw resulting the highest ST-ox of 1,240 °C at 95%-5%, while the blend of coal and rice husk, the highest ST-ox of 1,235 °C was reached at the proportion of coal and rice husk at 90%-10%. According to the slagging and fouling index, blended coal and straw shows the best performace compared to that of blended coal either with baggase or rice husk. To avoid the accumulation of ash deposits in the boiler due to the high slagging and fouling index of the fuels, the correct operation and maintenance of the combustion equipment should be closely controlled.

ACKNOWLEDGEMENT

The authors would like to acknowledge the contribution of the tekMIRA coal utilization group. The authors also gratefully acknowledge financial and other support for this work that was provided by the Republic of Indonesia's Government.

REFERENCES

Adisoma, G.S., 2013. Low rank coal potential and clean technology development, *the 4th Indonesia-Thailand Energy Forum*, May 23-24 2013, Kuta, Bali., 19 p.

Aho, M. and Ferrer E, 2005. Importance of coal ash composition in protecting the boiler against chlorine deposition during combustion of chlorine-rich biomass, *Fuel, 84*, p. 201-212.

Barroso, J., Barreras F., Amaveda, H. and Lozano, A., 2003. On the optimization of boiler efficiency using bagasse as fuel, *Fuel, 82*, p. 1451-1463.

Belonio, A., Ocon, V. and Co, A., 2011. Small-scale rice husk gasifier plant for community street lighting, *Brochure of Garbage-In Fuel-Out (GIFO) Project Suki Trading Corporation*, Lapu-Lapu City, Cebu, Philippines.

Carroll, A. and Somerville, C., 2009. Cellulosic biofuels, *Annual Review of Plant Biology 2009, Vol. 60*, p. 165-182.

Evald, A., 2011. Biomass statistics: Straw, Danish Energy Agency, FORCE Technology, 5th Edition, October 2011, 7 p.

Mentz, K., Pinkerton, J., and Louch, J., 2005. Potential mercury and hydrochloric acid emissions from wood fuels. *Forest Products Journal. 55 (2)*, p. 46-50.

Nicholls, D. and Zerbe, J., 2012. *Co-firing biomass and coal for fossil fuel reduction and other benefits*—Status of North American facilities in 2010, United States Department of Agriculture Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR-867.

Radke, B., 2012. Sugarcane bagasse ash waste, *Internal Report of Civil and Environmental Engineering*, University of Nevada, Las Vegas UNICAMP, Brazil June 5, 2012, 16 p.

Sami, M., Annamalai, K., and Wooldridge, M., 2001. Co-firing of coal and biomass fuel, *Progress in Energy and Combustion Science 27*, p. 171–214.

Sandberg, J., 2007. Fouling in biomass fired boiler. *Malardaren university press licentiate theses, no. 75*, Department of Public Technology, Malardaren University, 54 p.

Sodikin, I., 2013. Pembakaran bersama tepung batubara dan serbuk gergaji menggunakan pembakar siklon sederhana untuk industri kecil menengah, *Jurnal Teknologi Mineral dan Batubara, vol. 09, no. 02*, Bandung, hal. 108-117.

Speight, J., 2005. *Handbook of coal analysis*, A John Wiley & Sons, Inc., Publication Copyright 2005 by John Wiley & Sons, Inc., Hoboken, New Jersey, p.1-222.

Stams, A.F., Livingstone WR., Gremers MFG., and Brem G., 2009. Review of model and tools for slagging and fouling prediction for biomas co combustion, *Workshop on High cofiring percentages in new coal fired power plants*, Hamburg, 18 p.

www.bisyplan.bioenarea.eu/ash_appendix.pdf, accessed on 27 August 2013, 9 p.

Yahaya, D.B. and Ibrahim, T.G. 2012. Development of rice husk briquettes for use as fuel, *Research Journal in Engineering and Applied Sciences 1(2)*, p. 130-133.