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Co-combustion characteristic of paper mill reject and coal

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Abstract
The paper mill which use recycled paper as the raw material generate paper mill reject (PMR) in the range of about 5-10%. PMR has a high calorific value with low ash and sulfur contents, generally. Processing of PMR into pellet forms as boiler fuel to reduce the use of coal or other fossil fuels has not been done, yet. PMR pellets and coal was mixed in the ratio of 5% PMR and 95% coal (C95R5) and 10% PMR and 90% coal (C90R10). PMR, coal, C95R5 and C90R10 were analyzed for proximate (moisture, ash, volatile matter/VM, fixed carbon/FC), and sulfur contents. Gross calorific value (GCV) of materials was also analyzed. Thermo-gravimetric analysis (TGA) and the derivative thermo-gravimetric analysis (DTG) profile were characterized. To know the possibility of slagging potential trend, analysis of ash mineral content and test of ash fussion temperature (AFT) of materials were carried out. Result indicates that addition of 5-10% PMR to coal affects combustion behaviour of materials. According to base/acid ratio (B/A) and base acid index (BAI) values, and softening temperature (ST) of slagging index, co-combustion of 5% PMR pellet and 95% coal (C95R5) as boiler fuel is still possible without causing indication of slagging tendency.

Keywords: Combustion; Paper mill reject; Coal; TGA; DTG; Mineral ash; AFT; Slagging.

1. Introduction
The decreasing in the availability of fossil fuel in nature causes to look for environmentally friendly fuel sources to substitute fossil fuel [1]. Coal is one of the fossil fuels as a fuel boiler to produce steam which is used to dry paper in paper mill. The paper mill which produces printing and writing paper, news paper, tissue, liner, medium, and cartons use recycled paper such as Old News Paper (ONP), Old Corrugated Carton (OCC) or a mixture of the raw material. In our previous research, Indonesian paper mill produce one of byproducts namely paper mill reject (PMR) in the range of about 5-10% [2]. Components of PMR are consisted of fiber bundles, foils, plastic pieces, and metal pieces that depend on the quality of recycled paper used as raw material. Generally, PMR has a potential to be used as fuel due to high calorific value with low ash and sulfur contents [2-5].
Handling of PMR is generally disposed outside the paper mill through the third party services or by burning it in an incinerators, currently. Processing of PMR into pellet forms as boiler fuel to reduce the use of coal has not been done, yet in Indonesia. Several advantages for the paper mill, such as reducing the cost of handling, improving the cleanliness and reducing the cost of coal procurement, will be obtained by paper mill, when PMR is made to be pellet form and used as fuel mixed with coal [2]. To find out how far the possibility of PMR can be mixed with coal mixture as boiler fuel, it is necessary to analyze and evaluate

energy content, the thermal characteristics, the co-combustion behavior, the ash mineral content and the ash fussion temperature (AFT) properties [1].
Thermo-gravimetric analysis (TGA) was commonly utilized to know thermal behaviour of materials combusted such as coal, biomass and other materials. TGA provides important information for the prediction of combustion efficiency and helps in determining the optimal operating conditions for combustion in power plants [6-8]. Therefore, TGA data can be used to analyze and evaluate the combustion characteristics of coal, PMR and mixture of coal and PMR. The derivative thermo-gravimetric analysis (DTG) profiles of PMR and mixture of coal and PMR can be beneficially to know the combustion profile [8]. Other important factor influencing co-combustion process in boiler is slagging, namely the deposition of melting ash on the heating surface. It is influenced with the ash mineral content which is corelated with the ash fussion temperature (AFT) of fuel materials [8, 9].
The objective of this investigation is to study the combustion characteristics and the possibility of slagging potential of PMR, coal and their mixture. Initial ignition, peak and burnout temperatures related with the weight loss, the derived weight loss and the slagging potential of these materials are described in this works.

2. Experimental

2.1 Materials and methods

Wet PMR as shown in Figure 1(a) was taken from a paper mill's producing corrugating medium and liner papers which was made from recycled paper. Wet PMR containing moisture of 40-50% was dried by heat of the sun to the moisture content of less than 10%. Coal (C) used as a boiler fuel by the paper mill was used as a mixing and as a comparison material. The dried PMR was then shredded by a shredding machine resulting shredded PMR's size of around 4 mm. The shredded PMR was then molded into pellets in a pellet machine. PMR pellets formed as shown in Figure 1(b) had a diameter of 10 mm and a length of about 10-15 mm [2]. PMR pellets and coal was mixed in the ratio of 5% PMR and 95% coal (C95R5) and 10% PMR and 90% coal (C90R10).

(a)

(b)

Figure 1. (a) Wet PMR; (b) PMR pellet.

2.2 Analysis

PMR pellet, coal and their mixture were analyzed for proximate (moisture, ash, volatile matter/VM, fixed carbon/FC), and sulfur contents. Gross calorific value (GCV) of materials was also analyzed. Thermo-gravimetric analysis (TGA) and the derivative thermo-gravimetric analysis (DTG) profile were characterized. To know the possibility of slagging potential trend, analysis of ash mineral content and test of ash fusion temperature (AFT) of materials were carried out. Moisture, ash, fixed carbon (FC), and sulfur contents were analyzed according ASTM methods. Gross calorific value (GCV) and ash fusion temperature (AFT) was also test according ASTM methods. Meanwhile, volatile matter (VM) and ash mineral contents were analyzed according ISO 562 and Atomic Absorption Spectroscopy (AAS) methods, respectively.

2.3 Characterization of slagging potential

The possibility of slagging potential trend of PMR, coal and their mixtures at the time of combustion is evaluated according to ash mineral content using slagging index as in equations 1 and 2 [8, 10].

$$B/A = (Fe_2O_3 + CaO + MgO + Na_2O + K_2O)/(SiO_2 + Al_2O_3 + TiO_2) \quad (1)$$

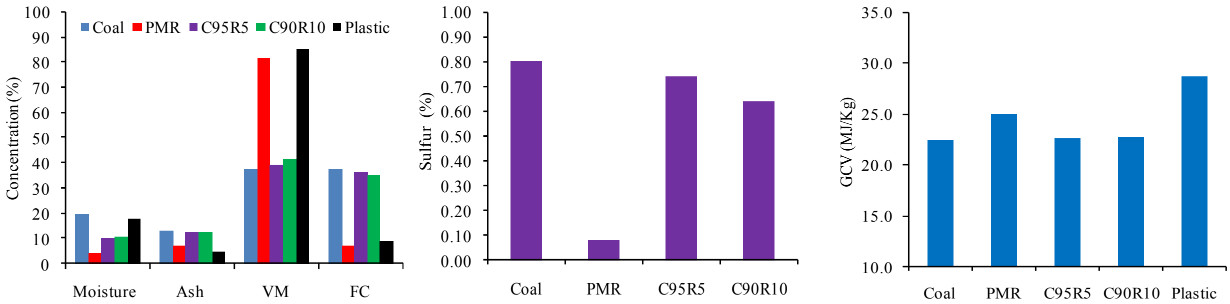
$$BAI = Fe_2O_3/(K_2O + Na_2O) \quad (2)$$

Besides that, it was evaluated according to AFT test results of materials containing initial deformation temperature (IDT), softening temperature (ST), hemisphere temperature (HT) and fluid temperature (FT) [8,11]. Hao et al [8] reported that slagging is usually occurs when IDT and ST are less than 1,289°C and 1,390°C, respectively.

3. Results and discussion

3.1 Characteristic of PMR, coal and their mixture

The proximate analysis of PMR, coal and their mixture is shown in Figure 2(a). It shows that PMR pellet has low content of moisture, ash and FC than that coal. The addition of 5% and 10% PMR pellets with coal results the content of moisture of 10.18% and 10.46%, ash of 12.60% and 12.35%, and FC of 36.61% and 35.49% for C95R5 and C90R10, respectively.



(a) (b) (c)

Figure 2. (a) Moisture, ash, volatile matter (VM) and fixed carbon (FC) content; (b) Sulfur content; (c) GCV.

Meanwhile, PMR has high content of VM than that coal. Therefore, the addition of 5% and 10% PMR pellets to coal increase VM content of their mixture of 39.61% and 41.70% for C95R5 and C90R10, respectively. Comparing to plastic sample from municipal solid waste (MSW), the VM content of PMR is almost similar to plastic from MSW which has been done by Iordanidis et al [15]. High VM content of materials is beneficial during the co-combustion of such materials the mixture starts to decompose in lower temperatures generates a more intensive and stable flame and shorter combustion times [12]. In contrast, the sulfur content of PMR as shown in Figure 2(b) is lower than that of coal. This low sulfur content is beneficial during fuel burning in the boiler where flue gas of boiler will emit low concentration of SO_2 emission. Figure 2(c) show that GCV of PMR pellet (29.3 MJ/kg) is higher than that of coal (21.9 MJ/kg) used as fuel in the paper mill and plastic from MSW [15]. This high GCV value of PMR pellets has advantages when it is mixed with coal. The addition of 5% and 10% PMR pellets to coal produce the GCV of their mixture of 22.2 MJ/kg and 22.7 MJ/kg for C95R5 and C90R10, respectively. This indicates that the addition of PMR pellets into coal will increase the GCV of boiler fuel.

3.2 Combustion characteristic of PMR, coal and their mixture

The most important characteristic temperatures of a combustion profile are ignition temperature (Ti), peak temperature (Tmax) and burnout temperature (Tb) [13-15]. The ignition temperature (Ti) is the temperature in which combustion of the materials begins after drying temperature of materials and the temperature at which pyrolysis is initiated. The ignition temperature of samples was determined from their combustion profiles, TGA and DTG curves. The combustion temperature of less than 150°C is corresponded to the moisture loss and after the temperature more than 150°C is the main mass weight loss due to oxidation and removal of VM and the oxidation of the remaining char from the samples [14-16]. Peak temperature is the temperature that corresponds to the maximum rate of the weight loss Rmax due to volatilization accompanied by the formation of carbonaceous residue [14, 17]. The peak temperature at which we have the maximum rate of weight loss (Rmax) based on the DTG curve is called Tmax [15]. The burnout temperature (Tb) is obtained when the mass weight loss more than 95% of the total loss [14, 15]. TGA and DTA profiles of combustion characteristics of PMR, coal and their mixture is shown in Figure 3(a) and Figure 3(b), respectively. Summary of combustion characteristics of PMR, coal and their mixture is presented in Table 1. Table 1 show the ignition temperature (Ti) of PMR (244°C) which is about 20°C lower than that of coal (264°C). It indicates that the combustion of PMR is faster than coal.

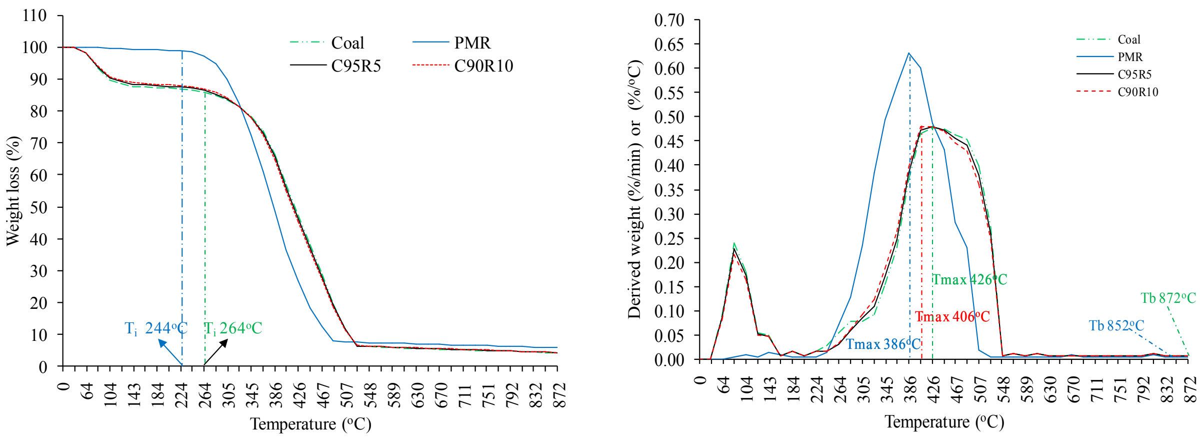
Table 1. Combustion characteristics of PMR, coal and their mixture.

Sample	Ti (° C)	Tb (° C)	Tmax (° C)	Rmax (%/min) or (%/° C)	Total weight loss (%)
Coal	264	872	426	0.48	95.92
PMR	244	852	386	0.63	94.81
C95R5	264	872	426	0.48	95.77
C90R10	264	872	406	0.48	95.69
Plastic from MSW [15]	249	974	328	7	95.95

This result was due to the high content of volatile matter (VM) and low ash content of PMR as indicated in Figure 2(a). Furthermore, the maximum weight loss rate (Rmax) of PMR (0.63 %/min or %/°C) was higher than that of coal (0.48 %/min or %/°C). This finding showed that PMR had higher reactivity and low inflammable material content than that of coal [14, 18]. Therefore, addition of PMR to coal can improve the combustion characteristics of coal. The burnout temperature (Tb) of PMR (852°C) was about 20°C lower than that of coal (82°C). In this burnout temperature (Tb), the total mass weight loss of PMR and coal is 94.81% and 95.92% each. Addition of 5% PMR to coal (C95R5) is not affect to Ti, Tmax, Rmax and Tb values and it is similar with the coal it selves. While, addition of 10% PMR to coal (C90R10), Tmax of C90R10 decrease 20°C (406°C) which is lower than Tmax coal. Addition of 5% to10% PMR to coal is not affect to Ti and Tb values but it decreased a little bit of total weight loss as shown in Table 1. Comparing to experiment resulted by Iordanidis et al [15], however, Tmax of PMR is higher than plastic from MSW, but the maximum weight loss rate (Rmax) of PMR is lower than plastic MSW. It might be caused by the different plastic type contained in PMR and in plastic from MSW.

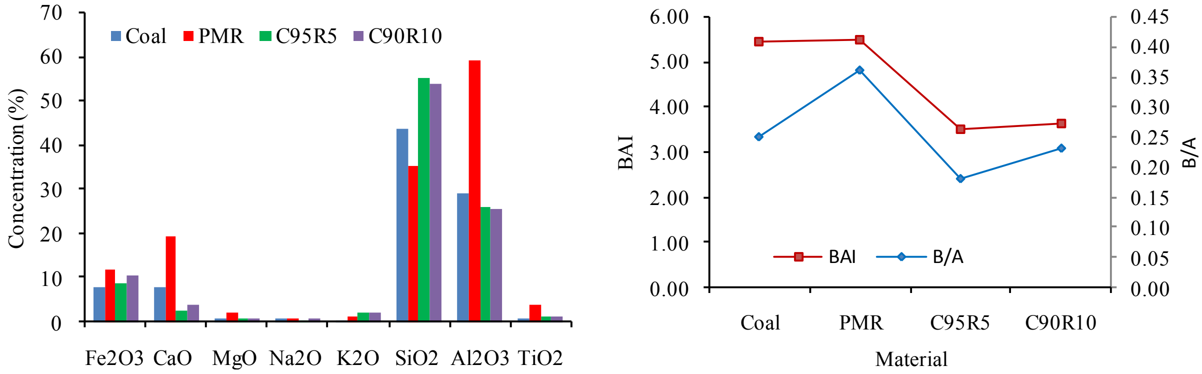
3.3 Mineral ash and ash fusion Temperature (AFT) characteristics of PMR, coal and their mixture

Base acid index (BAI) and base/acid ratio (B/A) as shown in equation (1) and (2) are mostly used to predict slagging phenomena which is based on mineral ashes content [8, 19]. Mineral ashes content of PMR, coal and their mixture can be seen in Figure 4(a). Most of all mineral content of PMR pellet is higher than that of coal, except for Na_2O and SiO_2 contents. Hao et al [8] and Bapat et al [20] reported that slagging is certainly occurs when base/acid ratio (B/A) values are greater than 0.4 and the BAI values are lower than 0.15. According to B/A value as shown in Figure 4(b), PMR, coal, C95R5, and C90R10 has BAI value of 0.36, 0.25, 0.27 and 0.28, respectively, which is still under 0.40. In addition, the BAI value of PMR, coal, C95R5, and C90R10 of 5.46, 5.43, 5.12, and 5.41 which is above 0.15. This indicates that co-combustion of coal and PMR pellet is lower slagging potential.



(a) (b)

Figure 3. (a) TGA and (b) derived weight in (%/min) or (%/° C) profiles of materials.



(a) Mineral ash content of PMR, coal and their mixture

(b) B/A and BAI values of PMR, coal and their mixture

Figure 4. Mineral ash content, B/A and BAI values of PMR, coal and their mixture.

Other key parameter which is used to determine slagging potential in the combustion process is AFT test measuring initial deformation temperature (IDT) regarding as onset of ash sintering, softening temperature (ST) regarding the temperature where ash softens and becomes sticky and allowing further slag formation, hemisphere temperature (HT) and fluid temperature (FT) [1].

Table 2. AFT of PMR, coal and their mixture [2] and slagging index [8].

AFT	Coal	PMR	C95R5	C90R10	Slagging Index [8]		
					Low	Medium	High
IDT (ºC)	1,415	1,193	1,360	1,315	> 1289	1108 - 1288	< 1107
ST (ºC)	1,460	1,243	1,420	1,325	> 1390	1260 - 1390	< 1260
HT (ºC)	1,470	1,258	1,430	1,338	-	-	-
FT (ºC)	1,495	1,300	1,450	1,398	-	-	-

Plaza et al [11] reported that AFT test is important to know the melting characteristics of ash. AFT test results data of PMR, coal and their mixture from our previous research data is presented in Table 2 [2]. IDT and ST, HT and FT clearly decreased with increasing PMR content. In Table 2, slagging usually occurs when IDT and ST are lower than 1,289ºC and 1,390ºC, respectively. It is seen that the possibility of PMR itself has a category of medium slagging index. When the content of PMR is higher than 5%, the possibility of slagging is relatively high due to ST lower than the temperature limit. In this case, the increasing in PMR content, the occurrence of slagging also increases. However, BAI and B/A values comply with BAI and B/A values limit.

4. Conclusion

The PMR pellet has a high calorific value and low ash and sulfur content which is potentially utilized as a coal mixture of boiler fuel. TGA/DTG profile is useful to understand a combustion behavior of materials. Addition of 5% PMR to coal (C95R5) is not affect to Ti, Tmax, Rmax and Tb values and it is similar with the coal it selves. While, addition of 10% PMR to coal (C90R10), Tmax of C90R10 decrease 20ºC (406ºC) which is lower than Tmax coal. Addition of 5% to10% PMR to coal is not affect to Ti and Tb values but it decreased a little bit of total weight loss. Based on base/acid ratio (B/A) and base acid index (BAI) values and softening temperature (ST) of slagging index, co-combustion of 5% PMR pellet and 95% coal (C95R5) as boiler fuel is still possible without causing indication of slagging tendency. This co-combustion with total weight loss up to 95.77% can be achieved. Study to know the possibility of chlorinated hydrocarbons emission in flue gas the co-combustion of coal and PMR pellet in boiler is necessary to be investigated further.

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