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ASH DEPOSIT CHARACTERISTICS OF BLENDED COAL IN COAL COMBUSTION PROCESS

SIFAT ENDAPAN ABU PADUAN BATUBARA DALAM PROSES PEMBAKARAN BATUBARA

IKA MONIKA and FAHMI SULISTYOHADI
Research & Development Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211
Ph. (+6222) 6030483, Fax. (+6222) 6003373
e-mail: ika@tekmira.esdm.go.id

ABSTRACT

Coal combustion process often occurs the problems in the reactor which is caused by fouling and slagging. One of the procedures to reduce the risk of fouling and slagging by blending the coal of Pendopo, Palangkaraya, Muara Enim and Samarinda, with the ratio of 25:75, 50:50, and 75:25. The ash deposit tendency is known by analyzing the composition and ash fusion temperature of coal, determining the ash type and calculating of the fouling and slagging. The results showed that the Pendopo and Palangkaraya coal with a ratio of 25:75 and 50:50 were classified as lignite with fouling and the slagging index was classified as a high and medium tendency. While the other blended coal was classified as a low and low-medium tendency.

Keywords: coal blending, ratio, slagging index, fouling index

ABSTRAK

Dalam proses pembakaran batubara seringkali terjadi permasalahan di dalam reaktor yang disebabkan penerakan dan pembekuan uap terak. Salah satu cara untuk mengurangi resiko penerakan dan pembekuan uap terak yaitu dengan melakukan paduan batubara dari Pendopo, Palangkaraya, Muara Enim dan Samarinda, dengan nisbah pencampuran 25:75, 50:50, dan 75:25. Potensi pengendapan abu diketahui melalui analisis komposisi dan titik leleh abu batubara, menentukan tipe abu dan menghitung indeks penerakan dan pembukuan uap terak. Hasil penelitian menunjukkan tipe abu paduan batubara Pendopo dan Palangkaraya dengan nisbah pencampuran 25:75 dan 50:50 diklasifikasikan sebagai lignit dengan indeks penerakan dan pembekuan abu terak diklasifikasikan sebagai potensi tinggi dan medium. Sedangkan paduan batubara lainnya dikategorikan berpotensi rendah dan rendah-medium.

Kata kunci: paduan batubara, nisbah, indeks penerakan, indeks pembekuan uap terak

INTRODUCTION

The successful operation of gasification depends on coal characteristics. The suitable of feedstock material is important to inhibit ash-related problems including, agglomeration and slagging in the furnace and fouling on the hot surfaces during coal gasification (Qi *et al.*, 2017). Gasification is an incomplete combustion process, converting a variety of carbon-based feedstock into a clean synthetic gas (syngas), which is primarily a mixture of hydrogen (H_2) and carbon monoxide (CO) as fuels. The feedstock is partially reacted with oxygen at high temperature and pressurized condition, using less than 30% of the oxygen required for complete combustion. The syngas produced can be used as a fuel, usually in boilers or gas turbines to generate electricity (Lu and Wang, 2015).

In gasifiers, the carbon in the coal particles is converted into syngas, and the mineral

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matters in the coal are transformed into ash/slag. The majority of the ash is melted and deposited on the walls of the gasifier, forming a liquid slag, which flows out of the bottom of the gasifier and finally solidifies in a water bath (Wang and Massoudi, 2013). The ash problems are mainly rooted in its deposits of slagging and fouling and sintering/agglomeration. It is therefore essential to predict ash-related problems in a thermal environment, particularly when a variety of coal materials are used. These ash deposition problems are influenced by ash fusibility which, in turns, associated with ash composition (Pintana *et al.*, 2014).

Ash slagging and fouling are problem cause the unstable operation of gasification. Ash can be released infused or plastic form. As a result, it will affect on the furnace wall and the other hot wall surfaces. Although ash slagging and fouling occurs in small portions, it can be a big effect in the operation of the boiler. The accumulation of the ash deposits on the furnace wall will affect heat transfer, decrease heat absorption, delay the cooling of flue gas and increase the output temperature of the furnace (Amaliyah and Fachry, 2011).

Several researches have been conducted to study the relationship between the coal ash fusibility and its ash composition. Lolja *et al.* (2002) found that the oxide composition plays a more important role in fusibility than that of the mineral composition. According to their diverse effects on ash fusibility, the minerals in coal ash are classified as refractory minerals such as quartz, metakaolin, mullite, and rutile, or fluxing minerals gypsum, potash feldspar, fayalite, and almandine (Gupta *et al.*, 2007). Song *et al.* (2010) reported that the ash fusion temperatures (AFTs) of coal ashes were found to decrease first, reach a minimum, and increase again when the contents of CaO, Fe_2O_3, and MgO increased**,** while it decreased continuously with the increase SiO_2 to Al_2O_3 ratio. Furthermore, Li *et al.* (2016) also reported that the too high content of alkali and alkaline metal elements in coal has been considered as the main reason for slagging and fouling.

Blended coal is an effective way to organize and control coal ash fusibility of coal gasification in fired power plants (Shen *et al.*, 2015). Therefore, the blended coal characteristic analysis was conducted to study ash deposition and slag formation behaviors. A better understanding of this study is important to optimize the operation and maintenance of the equipment.

METHODOLOGY

The samples used in this study are the coal from Palangkaraya, Samarinda, Pendopo and Muara Enim. The study consists of five stages as can be seen in Figure 1.

In the first stage, the coal was pulverized into -60 mesh particle size by determining the size referring to the Standard Method ASTM D 2013-12 (ASTM D2013-12, 2017).

In the second stage, coal characterization consisted of proximate analysis, total sulfur, calorific value, AFT and ash composition. The proximate analysis, total sulfur, and calorific value were used to determine coal classification. The direct analysis included determining water content, ash, volatile material, and fixed carbon.

After coal characterizations, the third stage was blending the coal. In the fourth stage, AFTs and ash composition analyses were conducted before and after blending the coal. AFTs was analyzed to study the temperature of the ash fusion behavior. AFTs was carried out using coal ash as the sample. This analysis refers to ASTM Standard D 1857-17, Standard Test Method for Fusibility of Coal and Coke (ASTM D1857/D1857M-17, 2017). The temperature was observed when the ash form reached the initial phase of deformation, for example: softening, hemispherical, and fluid.

AFTs analysis can be carried out in reducing or oxidizing condition. To prepare the AFTs analysis, dextrin solution is added into coal ash and formed in a mold to make a triangular pyramid (cone) with a height of 0.75 inches and a base pyramid of 0.25 inches. A mixture of dextrin and coal ash was placed in the electric furnace with a temperature of 699-743 °C. The initial deformation temperature (IT) is the initial temperature of formation. It happens when the pyramid peak starts changing to form a second pyramid as shown in Figure 2.

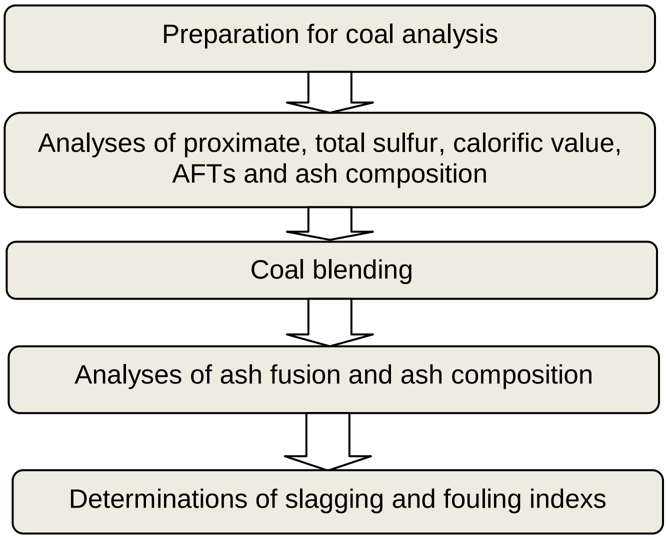

Figure 1. Flow chart of the experiment

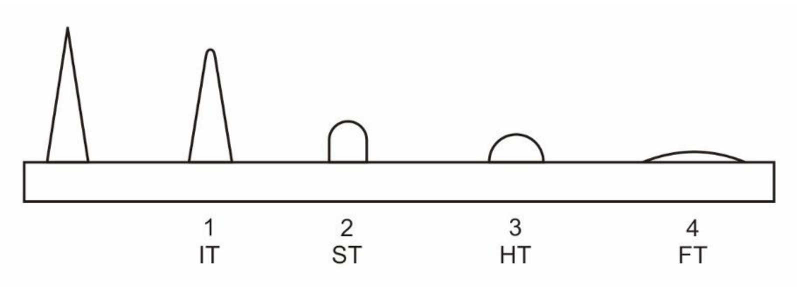

Figure 2. Form of ash fusion (Amaliyah and Fachry, 2011)

Typically, the softening temperature (ST) leads to the fusion temperature. The hemispherical temperature (HT) is temperature which the triangle is formed to a hemispherical lump and the height is equal to half of its width. While fluid temperature (FT) is temperature which ash triangle has been fused with the limit maximum of 0.0625 inches (Amaliyah and Fachry, 2011). Ash composition analysis was conducted by Atomic Absorption Spectrophotometer (AAS). AFTs and ash composition were used to calculate the slagging index and study the potential of coal slagging.

The investigated three blended coal ratios can be seen in Table 1. The total amount of blended coal was 100 gr each.

Table 1. The ratio of blended coal

Blended compositions	Sample codes	Blended ratio
Pendopo : Palangkaraya		25 : 75
Pendopo : Palangkaraya	PP	50 : 50
Pendopo : Palangkaraya		75 : 25
Pendopo : Samarinda		25 : 75
Pendopo : Samarinda	PS	50 : 50
Pendopo : Samarinda		75 : 25
Pendopo : Muara Enim		25 : 75
Pendopo : Muara Enim	PM	50 : 50
Pendopo : Muara Enim		75 : 25

RESULTS AND DISCUSSION

Coal Classification

The four coal samples were primarily pulverized into a particle size of -60 mesh for coal characterizations. Pendopo coal has the highest ash content than that of Palangkaraya, Samarinda and Muara Enim coals. The proximate analysis, total sulfur, and caloric value were characteristics for classifying types of coal.

Coal classification referred to the Annual Book of ASTM Standard D 388-15 (ASTM D388-15, 2017). The basic classification is in accordance with the fixed carbon and gross calorific value calculated to the mineral matter free basis (mmmf). The higher rank coals are classified according to the fixed carbon on a dry basis. The lower rank coals are classified according to the gross calorific value on the moist basis. While the fixed carbon on the dmmf basis is used for classifying coals which have gross calorific values of 14000 Btu/bl (mmmf), fixed carbon of 69 % or more on the dry mineral matter free (dmmf) basis, and coals having fixed carbon of 69 % or more on dmmf basis. Coal classification which has gross calorific values less than 14000 Btu/lb on the mmmf basis and fixed carbon on the dmmf basis is less than 69 %, according to the gross calorific value on the mmmf basis, provided the fixed carbon on the dmmf basis is less than 69 %.

Results of coal characterization analysis (Table 2) were reported in air-dried basis (adb). To convert the adb into the dmmf, it was used Parr Formulas:

$$FC(dmmf)=\frac{100(FC-0.15S)}{(100-(M+1.08A+0.55S))}$$

VM (dmmf) = 100 – FC (dmmf)

$$Btu\ (dmmf)=\frac{100(1.8 \times CV-50S)}{100-(1.08A+0.55S)}$$

where:

Btu = gross calorific value, Btu/lb,
FC = fixed carbon, %,
VM = volatile matter, %,
M = moisture, %,
A = ash, %,
S = sulfur, %
CV = caloric value, cal/g

The results of proximate, sulfur and calorific value analyses from the coal samples were presented in Table 2 and Table 3.

Based on the classification by ASTM (Table 4), the coals are grouped into different ranks, namely lignite, sub-bituminous, bituminous, and anthracite. Each rank has the limit value. The result classification of calorific value analysis of the coal samples are presented in Table 5.

Table 2. Result of proximate and sulfur analyses

Sample names	Moist. (%) adb	Ash (%) adb	Volatile matter		Fixed carbon		Total sulfur (%) adb
			(%) adb	(%) dmmf	(%) adb	(%) dmmf	
Pendopo	11.90	16.67	40.26	55.50	31.17	44.50	0.26
Palangkaraya	17.84	8.70	37.33	50.31	36.13	49.69	0.23
Samarinda	12.33	6.47	40.10	48.99	41.10	51.01	0.43
Muara Enim	16.06	4.79	39.43	49.54	39.72	50.46	0.24

Table 3. Result of calorific value analysis

Sample names	Calorific value		
	Cal/g (adb)	Btu/lb (dmmf)	Btu/lb (mmmf)
Pendopo	4,287	7,717	9,412
Palangkaraya	4,767	8,581	9,471
Samarinda	5,548	9,986	10,740
Muara Enim	4,969	8,944	9,432

Table 4. Classification of coals by rank (ASTM D 388-2015)

Class/group	Fixed carbon limits (%) dmmf		Volatile matter limits (%) dmmf		Gross calorificvalue (Btu/lb) mmmf	
	Equal or greater than	Less than	Greater than	Equal or less than	Equal or greater than	Less than
I. Anthracitic						
1. Metaanthracite	98			2		
2. Anthracite	92	98	2	8		
3. Semianthracite	86	92	8	14		
II. Bituminous						
1. Low volatile	78	86	14	22		
2. Medium volatile	69	78	22	31		
3. High volatile A		69	31		14,000	
4. High volatile B					13,000	14,000
5. High volatile C					11,500	13,000
III. Sub-bituminous						
1. Sub-bituminous A					10,500	11,500
2. Sub-bituminous B					9,500	10,500
3. Sub-bituminous C					8,300	9,500
IV. Lignitic						
1. Lignite A					6,300	8,300
2. Lignite B					<	6,300

Table 5. Coal sample classifications

Sample names	Classifications
Pendopo	Sub-bituminous C
Palangkaraya	Sub-bituminous C
Samarinda	Sub-bituminous A
Muara Enim	Sub-bituminous C

AFTs and ash compositions analyses

Coal gasification has four main processes, namely drying, pyrolysis, oxidation, and reduction. The purpose of the drying stage is to remove the moist content, while the pyrolysis stage will decompose the coal from its charcoal, tar, and gas. The oxidation stage is pyrolysis gas combustion, which is part of charcoal is oxidized into carbon dioxide and others will be in reduction condition. The charcoal reduction process used to steam and carbon dioxide to produce hydrogen and carbon monoxide. Usually, the reduction process occurs at the temperature of 800-1,000 °C, but the reduction temperature occasionally happens at more than 1,000 °C. Therefore, the AFTs analysis was carried out in a reduction condition by considering the occurrence of gasification process under the same conditions. The AFTs are determined in order to provide an indication of how the mineral matter in the coal may behave in the furnace The fusion behavior of the coal ashes is based on the measurement of three major temperatures of IT, HT and FT. By having slag characteristics information, the research can be investigated further by predicting slagging trends. The result of AFTs analysis and ash composition are presented in Table 6 while coal ash composition is presented in Table 7.

Tables 6 shows that the Pendopo coal has the highest AFTs value, however, Muara Enim coal has the lowest AFTs. The low temperature of ash fusion indicates the possibility of slagging problems. The observations are mostly made by considering the IT because most of the melting point takes place in this temperature range. The IT is used to determine the predictive indices for slagging, fouling, and abrasion tendency during combustion practices.

Table 6. AFTs analysis in the reduction atmosphere

Sample names	temperature changes of coal ash fusion			
	IT(°C)	ST(°C)	HT (°C)	FT(°C)
Pendopo	1,379	1,468	>1,500	>1,500
Palangkaraya	1,262	1,263	1,299	1,342
Samarinda	1,245	1,254	1,302	1,340
Muara Enim	1,213	1,238	1,254	1,271

Table 7. Ash composition analysis

Sample names	CaO (%)	MgO (%)	Fe_2O_3 (%)	Na_2O (%)	K_2O (%)	Al_2O_3 (%)	SiO_2 (%)	TiO_2 (%)
Pendopo	3.58	0.94	10.44	0.24	0.22	32.58	44.10	1.64
Palangkaraya	16.16	2.99	7.22	0.27	0.36	24.99	36.90	1.61
Samarinda	7.60	2.17	8.10	0.88	0.32	23.93	45.95	1.18
Muara Enim	21.11	8.88	28.24	3.56	0.37	1.85	18.05	0.25

The main constituents of coal ash are silica, alumina and iron oxides with a small percentage of other oxides such as CaO, MgO, and other alkalis. The ash fusibility is reported as a function of these major oxides present in coal ash. The characteristics of coal ash fusibility are difficult to determine precisely because many of the coal ash components do not have a sharp melting point like a pure compound (Sharma *et al.*, 2014). Alkalis oxide, CaO, MgO, K_2O, and Na_2O influence of ash fusibility, especially Na_2O which shows the occurrence of the slagging and fouling propensities. The fluid form of an alkaline element will be evaporated on the combustion temperature and can be reacted with the sulfur and other ash elements to form a bond. This condition causes the occurrence of slagging and fouling areas (Amaliyah and Fachry, 2011). The result of the ash composition analysis will be used to determine of slagging and fouling indices.

Table 7 shows an increase in the content of Fe_2O_3 and the ratio of SiO_2/Al_2O_3 except for the Pendopo coal which has a greater content of Fe_2O_3 than Palangkaraya and Muara Enim coal. Increasing the content of Fe_2O_3 and the ratio of SiO_2/Al_2O_3 causes degradation of AFTs.

Slagging index classification

Coal ash characteristics of bituminous and lignite are very significantly. The first step for calculating of the slagging and fouling index by determining coal ash types (Amaliyah and Fachry, 2011). Ash is classified as bituminous, if:

$Fe_2O_3 > CaO + MgO$

Ash is classified as lignite ash, if:

$Fe_2O_3 < CaO + MgO$

Table 8 shows that the ash Pendopo coal was classified as a bituminous, while the Palangkaraya, Samarinda and Muara Enim coals were classified as lignite.

The slagging index (R_s) of solid fuel has been taken as a measure of the slagging propensity of the ash (Russell, Wigley and Williamson, 2002). The ash content is a good indicator of the problematic nature of coal. The propensity of ash deposition may be evaluated in terms of base-to-acid (B/A) ratio. The B/A ratio is an indication of the fusion characteristics and the slagging tendency of coal ash and metal-containing ash to combine in the combustion process to produce low melting salts (Pintana *et al.*, 2014).

The slagging index classification of bituminous ash was calculated using equation (1), while the slagging index of lignite ash by equation (2) (Amaliyah and Fachry, 2011).

$$R_s = \frac{B}{A} \times S \quad \text{..........} (1)$$

where;

B = $CaO + MgO + Fe_2O_3 + Na_2O + K_2O$ = base compound, %

A = $SiO_2 + Al_2O_3 + TiO_2$ = acid compound, %

S = wt % of sulfur content in adb

Table 8. Ash coal classification

Sample names	Fe_2O_3 (%)		CaO+MgO (%)	Ash classification
Pendopo	10.44	>	4.52	bituminous
Palangkaraya	7.22	<	19.15	lignite
Samarinda	8.10	<	10.59	lignite
Muara Enim	28.24	<	29.99	lignite

The calculation of slagging index (R_s*) for Palangkaraya, Samarinda, and Muara Enim coals (as the lignite ash) depends on the temperature of ash fusion formation. The slagging indices are averages of(HT) and (IT) formations.

$$R_s^* = \frac{(\text{Max HT}) + 4(\text{Min IT})}{5} \quad \text{.....................(2)}$$

where;

Max HT = Hemisphericalmaximum temperature under reduction or oxidation conditions (°F)

Min IT = Initial deformation temperature under reduction or oxidation conditions (°F)

Table 9 shows the Pendopo coal base and the acidic ratio is about 0.05. The calculated value of 0.05 indicates that the tendency a slagging of ash bituminous classification was low. The results of slagging index calculation of lignite ash in Table 10 indicate that the Palangkaraya and Samarinda coals were classified as a medium slagging tendency, while Muara Enim coal was classified as a high slagging tendency. Besides that, the presence of high iron oxide content amount of 28.24 % in Muara Enim coal ash leads to slagging in radiative heat transfer section in the boiler (Vijay, Lawrence and Arthanareeswaran, 2017).

Fouling Index Classification

Fouling refers to the dry deposition of ash particles or condensation of volatile inorganic components on heat transfer surfaces. The fouling index (*Rf*) of solid fuel is a measure of the fouling propensity of the ash (Pintana *et al.*, 2014).

The calculation of the fouling index (R_f) of bituminous ash (Pendopo coal) was obtained by sodium and potassium contents and base to the acid ratio (Eq. 3).

$$R_f = \frac{B}{A} \, x \, Na_2O + K_2O \quad \text{............................ (3)}$$

Where;

B = $CaO + MgO + Fe_2O_3 + Na_2O + K_2O$ = base compound %

A = $SiO_2 + Al_2O_3 + TiO_2$ = acid compound %

Na_2O = wt % of sodium

K_2O = wt % of potassium

Table 9. Slagging index classification of bituminous ash

Sample name	Acid compound (%)	Base compound (%)	Sulfur content(% adb)	Slagging index (R_s)	Slagging index(R_s)	Classification
Pendopo	78.32	15.42	0.26	0.05	R_s < 0.6 0.6 < 2.0 2.0 < R_s < 2.6 2.6 < R_s	Low Medium Medium Medium

Table 10. Slagging index classification of lignite ash

Sample names	HT		IT		R_s*	Slagging index(Rs*)	Classfication
	(°C)	(°F)	(°C)	(°F)		2.450 < Rs*	low
Palangkaraya	1,299	2,370	1,262	2,303	2,316	2.250 < Rs* < 2.450	medium
Samarinda	1,302	2,375	1,245	2,273	2,293	2.100 < Rs* < 2.250	high
Muara Enim	1,254	2,289	1,213	2,215	2,230	Rs* < 2.100	Very high

Results of the fouling index calculation for Pendopo coal was 0.27. Refers to Table 11, this value was between 0.2 and 0.5 and it was categorized as a medium occurrence of fouling propensity.

Table 11. Fouling index classification of bituminous ash

Fouling index (R_f)	Classification
R_f< 0. 2	Low
0.2 < R_f< 0.5	Medium
0.5 < R_f< 1.0	High
1.0 < R_f	Highest

Fouling index classification of lignite ash was based on the total amount of CaO, MgO and Fe_2O_3 and sodium contents in coal ash. Palangkaraya coal has a total amount of CaO, MgO and Fe_2O_3 is 26.37 %, more than 20 % (Table 13), therefore the fouling index of Palangkaraya coal was classified as a low-medium, with a sodium content of 0.27 % (Table 7). The Samarinda coal has a total amount of CaO, MgO, and Fe_2O_3 is 17.87 %, less than 20 %, however, the sodium content in the coal ash is 0.88 %. Based on those numbers, then the Samarinda coal was classified as a low medium one. The Muara Enim coal has a total amount of CaO, MgO and Fe_2O_3 of 58.23 %, more than 20 %, with the sodium content of 3.56 %, then the fouling tendency of Muara Enim coal was classified as a high occurrence fouling. Table 13 presented the fouling propensity classification of lignite ash.

Coal blending Analysis

After slagging and fouling propensities of each coal were classified by slagging and fouling index determinations, the next step was analyzing the blended coal. Pendopo coal has a low slagging tendency, therefore it was used as the main material for blending to the other coals. This research was conducted to study the effects of blended coal on the decrease of the slagging and fouling propensities. Results of blended coal analysis can be seen in Table 14 and 15.

Results in Table 15 indicated that the ash fusion temperatures of the blended PP coal initially decreased and then increased with the increase of blended ratio. The increased temperature is in line with the raising amount of Pendopo coal. When these results were compared with the fusion temperature of Palangkaraya coal, blended PP coal with a ratio of 75:25 caused the increase of fusion temperature.

The blended PS coal showed that the ratio of 25:75, fusion temperature decreased to 1,209 °C. It was less than the IT of the Samarinda coal that was in 1,245 °C. Fe_2O_3 content and SiO_2/Al_2O_3 ratio of the blended PS coal was 11.67 % and 1.37 more than the blended PS coal with the ratio of 50:50 and 75:25. The increase of Fe_2O_3 content and SiO_2/Al_2O_3 ratio can be caused by a decrease of AFTs. The data also indicated that the amount of Pendopo coal was bigger likewise the ash fusion temperature.

The blended PM coal shows the temperature of 25:75 and 50:50 were 1,062 and 1,183 °C or less than AFTs of Muara Enim coal. The blended PM coal with a ratio of 25:75 and 50:50 have a high Fe_2O_3 content of 17.94% and 14.70% each. The low temperature of ash fusion indicates the possibility of slagging problems.

Data in Table 16 showed the coal ash type blended coals of PP, PS, and PM. The coal ash type of Palangkaraya before being blended with Pendopo in the form of lignite, the changes occurred into bituminous with the ratio of 75:25. The type of ash coal from Samarinda and Muara Enim coals become bituminous on the ratio of 25:75, 50:50 and 75:25.

Table 12. Fouling index classification of lignite ash

If CaO + MgO + Fe_2O_3 > 20 % weight of ash content		If CaO + MgO + Fe_2O_3 < 20 % weight of ash content	
Fouling index (R_f)	Classification	Fouling index (R_f)	Classification
Na_2O < 3	Low-medium	Na_2O < 1.2	Low-medium
3 < Na_2O < 6	High	1.2 < Na_2O < 3	High
Na_2O > 6	Highest	Na_2O > 3	Highest

Table 13. Fouling classification of lignite ash samples

Sample names	CaO (%)	MgO (%)	Fe_2O_3 (%)	Total amount (%)	Classification
Palangkaraya	16.16	2.99	7.22	26.37	Low-medium
Samarinda	7.60	2.17	8.10	17.87	Low-medium
Muara Enim	21.11	8.88	28.24	58.23	High

Table 14. Ash composition of blended coal

Sample codes	Blended coal ratio	CaO (%)	MgO (%)	Fe_2O_3 (%)	Na_2O (%)	K_2O (%)	Al_2O_3 (%)	SiO_2 (%)	TiO_2 (%)
PP	25 : 75	15.84	3.29	10.18	0.40	0.24	26.90	32.73	1.28
	50 : 50	10.20	2.23	10.79	0.31	0.19	31.20	37.4	1.35
	75 : 25	6.31	1.53	10.88	0.30	0.23	33.40	41.20	1.38
PS	25 : 75	7.46	2.27	11.67	0.57	0.31	27.76	38.00	1.20
	50 : 50	5.22	1.63	11.15	0.55	0.27	30.90	41.40	1.28
	75 : 25	4.35	1.21	10.97	0.19	0..22	32.30	43.00	1.41
PM	25 : 75	10.63	4.52	17.94	1.36	0.34	16.98	38.50	0.90
	50 : 50	7.28	2.67	14.70	0.70	0.25	25.20	41.40	1.07
	75 : 25	5.04	1.65	12.42	0.62	0.23	29.33	43.10	1.33

Table 15. AFTs analysis of blended coal in reduction condition

Sample code	Blended coal ratio	Change temperatures of coal ash form (°C)			
		IT	HT	FT	ST
PP	25 : 75	1,208	1,233	1,284	1,314
	50 : 50	1,274	1,294	1,340	1,366
	75 : 25	1,313	1,382	1,421	1,443
PS	25 : 75	1,209	1,242	1,249	1,274
	50 : 50	1,276	1,357	1,391	1,432
	75 : 25	1,355	1,411	1,474	>1,500
PM	25 : 75	1,062	1,107	1,116	1,136
	50 : 50	1,183	1,211	1,231	1,236
	75 : 25	1,315	1,247	1,381	1,431

Table 16. Coal ash type of blended coals

Sample codes	Ratio	CaO+MgO (%)		Fe_2O_3 (%)	Ash type classification
PP	25 : 75	19.13	>	10.18	Lignit
	50 : 50	12.43	>	10.79	Lignit
	75 : 25	7.84	<	10.88	Bituminous
PS	25 : 75	9.73	<	11.67	Bituminous
	50 : 50	6.85	<	11.15	Bituminous
	75 : 25	5.56	<	10.97	Bituminous
PM	25 : 75	15.15	<	17.94	Bituminous
	50 : 50	9.95	<	14.70	Bituminous
	75 : 25	6.69	<	12.42	Bituminous

Slagging Tendency of Blended Coal

After data coal ash type each was known, the next step was the determination of the slagging classification of the blended coal. The first stage was determined by the coal ash type. The blended PP coal on the ratio of 25:75 and 50:50 were classified as lignite (Table 16). The second stage, the slagging classification using AFTs analysis. Data in Table 17 shows that blended coal of PP on the ratio of 25:75 was categorized as a high slagging tendency. While the ratio of 50:50 was categorized as a medium tendency.

The determination of slagging tendency of bituminous ash was based on base to acid ratio of the ash compositions and then multiplied to the sulfur content.

The slagging index of all blended coals was obtained less than 0.6. This value was categorized as a low slagging tendency.

Fouling Tendency of Blended Coal

The calculation of the fouling index (R_f) of bituminous ash type was obtained through the base to acid ratio and sodium and potassium contents (Eq. 3).

Referring to Table 19, the fouling index of PP coal at the ratio of 75:25 was obtained 0.13 and categorized as low fouling tendency (according to Table 11). While fouling index of the blended PS and PM coals were obtained in the value of 0.2-0.4 and classified as a medium fouling tendency, while PM coal at the ratio of 25:75 was obtained 1.05 and classified as a high fouling tendency.

The fouling tendency classification of lignite coal ash is shown in Table 20. Refer to Table 12, the blended ratio of PP coal at 25:75 and 50:50 were categorized as low–medium fouling tendency.

Table 17. The slagging tendency of blended coal (as lignite)

Sample codes	Ratio	HT		IT		R_s*	Slagging classification of samples
		(°C)	(°F)	(°C)	(°F)		
PP	25 : 75	1,284	2,343	1,208	2,206	2,233	High
	50 : 50	1,340	2,444	1,274	2,325	2,348	Medium

Table 18. Slagging tendency coal ash type of bituminous

Sample codes	Ratio	Base Fe_2O_3+CaO+ MgO+Na_2O+K_2O (%)	Acid SiO_2+Al_2O_3 +TiO_2 (%)	Sulfur	Slagging index	Slagging classification
PP	75 : 25	19.25	75.98	0.28	0,07	Low
PS	25 : 75	22.28	66.96	0.40	0.13	Low
	50 : 50	18.82	73.58	0.36	0.09	Low
	75 : 25	16.94	76.7	0.33	0.07	Low
PM	25 : 75	34.79	56.38	0.28	0.17	Low
	50 : 50	25.6	67.67	0.28	0.11	Low
	75 : 25	19.96	73.76	0.29	0.08	Low

Table 19. Fouling index bituminous ash type of blended coal

Sample code	Ratio	Base compound (%)					Acid compound (%)			Fouling index R_f
		CaO	MgO	Fe_2O_3	Na_2O	K_2O	Al_2O_3	SiO_2	TiO_2	
PP	75 : 25	6.31	1.53	10.88	0.30	0.23	33.40	41.20	1.38	0.13
PS	25 : 75	7.46	2.27	11.67	0.57	0.31	27.76	38.00	1.20	0.29
	50 : 50	5.22	1.63	11.15	0.55	0.27	30.0	41.40	1.28	0.21
	75 : 25	4.35	1.21	10.97	0.19	0.22	32.30	43.00	1.41	0.15
PM	25 : 75	10.63	4.52	17.94	1.36	0.34	16.98	38.50	0.90	1.05
	50 : 50	7.28	2.67	14.70	0.70	0.25	25.20	41.40	1.07	0.36
	75 : 25	5.04	1.65	12.42	0.62	0.23	29.33	43.10	1.33	0.23

Table 20. Fouling index lignite of blended coal

Samplecodes	Ratio	CaO (%)	MgO (%)	Fe_2O_3 (%)	Total amount (%)	Classification
PP	25 : 75	15.84	3.29	10.18	29.31	Low-medium
	50 : 50	10.20	2.23	10.79	23.22	Low-medium

CONCLUSIONS

Coal blending is an effective way to organize and control coal ash fusibility in terms of meeting the requirements of coal during combustion. The results indicate—that Pendopo coal ash was classified as bituminous ash, while the ash type of Palangkaraya, Samarinda and Muara Enim coals were classified as the lignite. Slagging and fouling index calculation showed that the best composition happened in the blended of Pendopo and Palangkaraya coals with the ratio of 25:75 and 50:50.

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