Petroleum and Coal

Article **Open Access**

The Coking Properties Quality Prediction of Coal from Steenkool Formation in Bintuni Basin, West Papua, Indonesia

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Received June 7, 2019; Accepted September 29, 2020

Abstract

The Pliocene coals from the Steenkool Formation in Bintuni Basin, West Papua were selected and analyzed using proximate, ultimate, and rheological methods to evaluate their coking properties. This study revealed that all coal samples were high-volatile bituminous. The Horna Block coal samples have an average of Simoni's G-value of 0.95; Free Swelling Index of 5.0 and maximum fluidity 18,33 ddpm, therefore that coal samples are classified as a low-plasticity and moderately-coking grade. Although the Menci and Disihu blocks have a similar G value as the coal in Horna Block (i.e. 0.94 -0.96); but because of the low Free Swelling Index value of around 1-3 so it is categorized as weak-coking grade. The CSR and CRI show that all coal samples are meet with the Blast Furnace standards in several countries.

***Keywords**: Coking coal; Steenkool formation; Proximate analysis; Rheology.*

1. Introduction

The Bintuni Basin is one of the sedimentation basins located in West Papua Province, the Indonesian Archipelago which is rich in coal and oil and gas resources. The largest gas project in the Bintuni Basin was developed in the Tangguh area. The Tangguh LNG Project is being developed by BP, and comprises six offshore and onshore gas fields with a total estimated (proven, probable, and possible) reserve of generally 'dry gas' at 24 trillion cubic feet (TCF). The coal found abundantly in the northern part of the Bintuni basin. The main exposed stratum is the Tertiary Pliocene Steenkool Formation. The rock group is a coal-bearing rock group, and the main lithology is sandstone, siltstone, mudstone, and coal seam. However, information about the quality and quantity of coal has not been widely published.

Based on the coal formation process, coal is classified into peat, lignite, sub-bituminous and bituminous to anthracite [1]. Whereas in the industrial sector, coal terminology is based on the type of utilization of coal which depends on the attributes possessed by coal, such as coal caking and non-caking coal.

Non-caking coal is often referred to as thermal coal, also known as steaming coal, which is coal that is usually burned to drive electricity-generating turbines both for meeting public and industrial energy needs (such as the ceramic industry, paper manufacturing, cement industry). While caking coal is categorized as cooking coal, or often also called metallurgical coal; is coal used in the process of making coke which is used in the steel and iron making industry. However, not all coal can function as coking coal; coal can turn into coke only if it is softened into a plastic mass on carbonization, followed by decomposition, swelling, and evolution of gases and finally resolidification while gas is still being developed [2].

Increased demand for coke coal quality by blast furnace operators and increased use of PCI (pulverized coal injection) in the world related to the construction of several blast furnaces for steel processing, which of course requires coal as a paired source in blast furnace technology with pulverized coal injected at the tuyeres and coke as a permeable support. Has led to more intensive research and development in the case of coking coal, especially an understanding of coal quality for the quality of coke making. The Indonesian archipelago has a lot of coal resources but is limited to cooking coal. Some cooking coal in Indonesia is spread in East Kalimantan in the Pulobalang Formation [3-4], while in Central Kalimantan it is identified in the Batu Ayau Formation [5]. The more intensive research and development in the case of coking coal, especially an understanding of coal quality for the quality of coke making in Indonesia, especially in the Bintuni Basin, is very important to do.

The purpose of coal research of Steenkool Formation in Bintuni Basin, West Papua evaluates the coal proximate, ultimate, and rheology tests about their coking properties (fluidity/plastic properties) in accessing the suitability for metallurgical coke production.

2. Material and methods

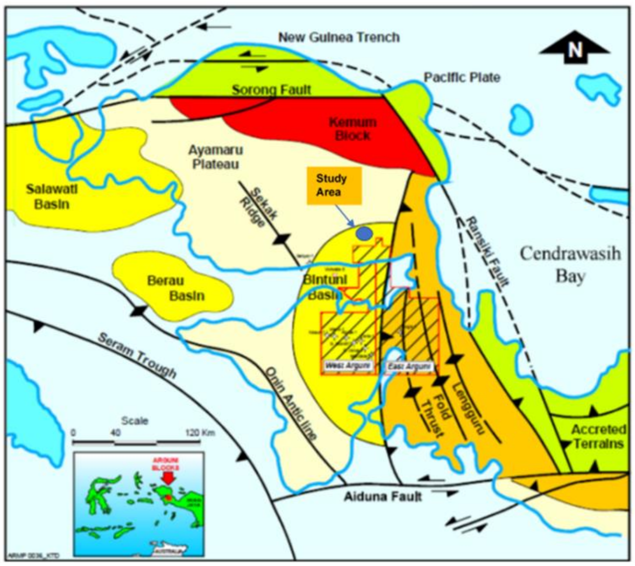

Figure 1. Map of study area in Isim District, West Papua Province, Bintuni Basin

Three coal sampling locations were conducted at Disihu Block, Horna Block and Menci Block, which located in Isim District, West Papua (Fig. 1).

The coal thicknesses ranging from 0.6–3.10 meters. The method of coal sampling is a channel ply sampling/ply by ply. The samples can be taken channel sampling per seam thickness (layer) or ply per ply (if there are parting insertions) [6].

Before being analyzed the coals have to dry to expel moisture and ground into a fine material. Then a fine powder is filtered using a filter size of 0.0250 cm and 0.0425 cm. The airtight plastic bag used for storing a fine powder before a proximate, an ultimate, and a rheology measurement were performed.

2.1. Analysis of proximate and ultimate analysis

The American Society for Testing and Material Standards (ASTM) is used as a reference in the proximate analysis of coal samples [7]; the test was measured moisture, volatile material, fixed carbon, and ash within the sample and was reported as a percentage of the weight of the sample used. ASTM D3173 is used for moisture (IM). To determine a volatile matter (VM) is used the ASTM D3175. The ASTM D3172 is used to measure fixed carbon (FC). For ash and total Sulphur determined by ASTM D3174 and ASTM D4239, respectively.

The ultimate analysis is done to determine the chemical elements in coal; such as carbon (C), hydrogen (H), oxygen (O), sulfur (S), and other elements in coal samples. These variables are measured in percent by weight (% by weight) and are calculated on the basis described as air-dried base. The ASTM D5373 is used to identify a carbon. To determine a hydrogen is used ASTM D5373. For nitrogen identified by ASTM D5373. The ASTM D5142-02 is used to measure a Sulphur. To determined oxygen content is used ASTM D3176

2.2. Ash analysis

To determine the level of basicity index (BI), the component analysis is carried out in ash. The ash composition of coal: SiO_2, Al_2O_3, Na_2O, K_2O, CaO, MgO, total Fe as Fe_2O_3, P_2O_5, MnO, TiO_2. The ash chemical components were determined according to the ASTM D6349-13.

2.3. Rheology analysis

The three tests that measure rheological properties are the free swelling index (FSI), Gieseler plastometry (measured the fluidity) and, Ruhr dilatometry (measure the dilatation).

2.3.1. Free swelling index determination

Modified an ASTM D720-67 procedure was used conducted a free swelling index [8]. This test is one of the tests that is often used to find out the potential of coal in the formation of coke. This test also makes it possible to find out its potential quickly. However, this test cannot describe coal as having good or bad potential for coke formation This experiment used a coal sample of 1 gram of coal which was heated in covered silica crucible at a temperature range of 800°C and 820+ 10°C in 1 minute and 820+ 50^{0}C in 1 minute. The value of FSI is obtained by comparing the button coke formed in the crucible with a chart of standard profiles. The FSI value between 1 and 9 in increments of 0.5.

2.3.2. Gieseler plastometry

The Gieseler plastometry test is performed to determine the degree of formation of the coal plasticity phase and what is the maximum temperature of fluidity reached [9-10]. A total of 5 grams of freshly ground coal (< 0,0425 cm) were put into the crucible by pressing using a ballast 1 kg weight ten times. The initial temperature of the test is 350^{o}C with an increase in heating temperature of 3^{o}C per minute. With a constant torque the stirrer will stir the coal. The stirring movement is seen on the dial and measured in dial division per minute (ddpm). When the coal component (coal maceral) begins to enter the plastic zone, due to it experiences less friction when the coal becomes more liquid, the ddpm value will start to increase. When the dial reads read 1 ddpm indicate the initial temperature of softening (^{0}C) was start reading and at a times the reading reaches the maximum value, the temperature read is recorded as the maximum temperature of fluidity (°C). The zero-reading indicated that the measured temperature is the solidification temperature (^{0}C). The plastic range is defined as the difference between the compaction temperature and the initial softening temperature. The maximum speed of the stirrer movement is referred to as maximum fluidity, which the unit measurement is ddpm. The ratio between temperature range and log maximum fluidity is called the Gieseler ratio.

2.3.3. Ruhr dilatometry

In this test, freshly ground coal with a size of 0.0425 cm is moistened and formed into a pencil with a length of 6 cm. Next, a coal pencil is placed in a tub where just above it is placed a sliding-fit steel rod. In a special furnace is placed a tub that is heated at a temperature of 300^{0}C with an increase of 3^{0}C per minute. The dilatometer data point, i. e, softening temperature (^{0}C), maximum dilatation temperature (^{0}C), contraction (%), and dilatation (%) were used to calculate the cooking capacity (G-value).

$$G = \frac{E+V}{2} x \frac{c+d}{V\,x\,c + E\,x\,d} \qquad (1)$$

where: G-cooking capacity; E-softening temperature; V- Maximum dilatation temperature; c- contraction; d -dilatation.

3. Result and discussion

3.1. Proximate analysis

The coals show low moisture content (< 3%), high volatile matter (>40%), high fixed carbon, low ash content (below 10%) and higher calorific values ranging from 7,208 cal/g to 7,930 cal/g. All the coals were classified as the high volatile bituminous coal. The result proximate analysis was tabulated in Table 1.

Table 1. Data from proximate analysis

Location/Sample No		Parameter			
		Moisture (adb)	Ash (adb)	Volatile matter	Fixed carbon
Horna	D1	2.3	1.1	44.2	52.4
	D2	2.4	1.2	44.1	52.3
	D052	1.9	1.4	45.2	51.5
Menci	D96	1.9	4.2	45.9	47.5
	D211	2.6	6.3	44.7	46.4
Disihu	D22	2.1	1.7	47.2	49.0
	D122	2.8	7.2	44.7	45.3

One of the parameters that must be known in determining the quality of coal for the formation of coke is to measure the moisture content. A large moisture level will form coal particle agglomeration that make pseudo-particles. So, the compacting effect will appear, make a decrease in space between particles and an increase in density. A high moisture content is not useful because it increases operational costs in removing impurities from the furnace and decreasing system capacity [11-12]. For good coking coal, the moisture content should be between 1% and 6% but most of the adequate content is in the range of 3-4%. Based on the moisture content, the coal samples were in value for good coking coal.

The high ash content in coal is disadvantageous because of the negative effect in the form of decreased Blast Furnace efficiency due to the amount of slag that has accumulated in Blast Furnace [13-14]. The good coke quality which indicated by a high CSR and low CRI value is related with lower ash content (<10%). The decreasing coke productivity in the blast furnace is correlated with increased ash in coals. All coal samples in this research area were categorized under low ash content (1.1%–7.2%); therefore, these coal samples have good potential for coke-making.

The performance of the blast furnace is also influenced by the presence of volatile matter (VM) in the coal [15]. The high pressure during the carbonization process due to the high content of VM (> 30.30%.), the Blast Furnace should be broken especially in the walls. The best coals for coke making have VM in the range of 27.70% to 30.30% air-dried base (adb). Therefore, all coal samples with a volatile matter content in the range of 44.19%–47.2% are included in the range that is not acceptable for making good metallurgical coke. However, with special treatment, such as the size of coal made smaller (< 0.5 mm), it will cause increased dilatation followed by the release of volatile matter from the matrix [16].

For good coke-making, the coal must have high carbon content, which is expressed in fixed carbon (FC). All coal samples had a high FC content in the range of 46.4% to 52.4% (Fig. 2). The Horna Block coal samples had the highest value (52.4%) with more carbon for coke formation followed by the Disihu Block (49.0%) and Menci Block coal samples (47.5%).

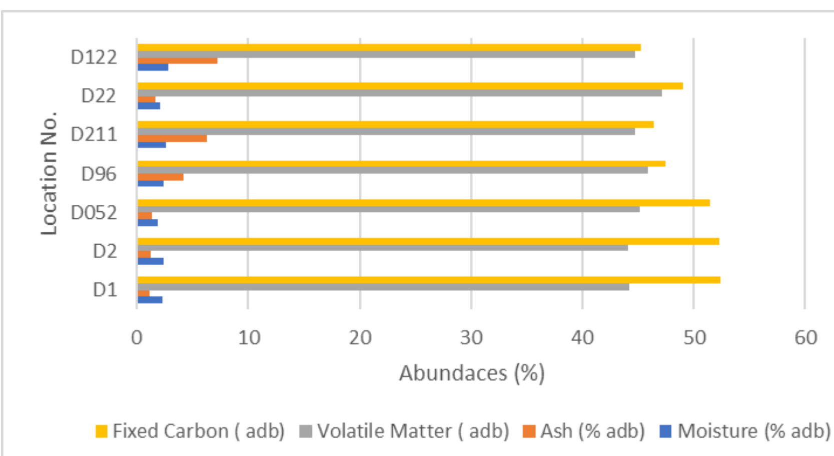

Figure 2. Graph of proximate analyses

3.2. Ultimate analysis

The result of ultimate analysis is demonstrated in Table 2

Table 2. Data from Ultimate Analysis

Location/No.		Elemental Elements (%)				
		Hydrogen	Oxygen	Nitrogen	Carbon	Sulfur
Horna	D1	5.91	7.53	2.20	82.5	0.80
	D2	5.96	7.08	2.19	82.8	0.81
	D052	5.90	8.37	2.08	81.1	1.17
Menci	D96	5.72	10.02	2.02	77.5	0.72
	D211	5.51	10.45	2.04	75.1	0.62
Disihu	D22	5.83	12.68	1.94	77.63	0.22
	D122	6.06	12.13	1.92	72.22	0.47

The percentage of hydrogen element in coal deposits in the three locations shows that there is no big difference, either between samples in one block or between blocks; as follows Horna Block 5.91% and 5.96%; 5.90%, Menci block 5.72% and 5.51% and Disihu Block 5.83% and 6.06. Similarly, there was no significant difference in the carbon content of coal samples in all blocks in the Isim District. The highest carbon content was found in the Horna Block, while the lowest was found in the Disihu Block (D122). The sulfur in Disihu Block of 0.22% and 0.47% and the Menci coal samples had a value of 0.72%–0.72%, whereas the Horna Block samples more higher contents (0.80%–1.17%) comparing the two locations. The oxygen contents of the coal samples were in the range of 7.08% to 12.68%. The high oxygen content of 12.683% (D22) was found in Disihu Block. In Menci Block and Horna Block samples were smaller as 10.45 % (D211) and 7.53 % (D1), respectively. The lowest value of nitrogen was identified in Disihu Block (1.92 %), while the highest nitrogen content of 2.20 % was detected in the Horna Block. The ultimate analysis of all coal samples shows that all samples contain large amounts of carbon, while other elements such as hydrogen, nitrogen, oxygen, and sulfur are found in smaller amounts. This research found that the content of elemental carbon is quite large in all samples but is in a short-range (Fig. 2).

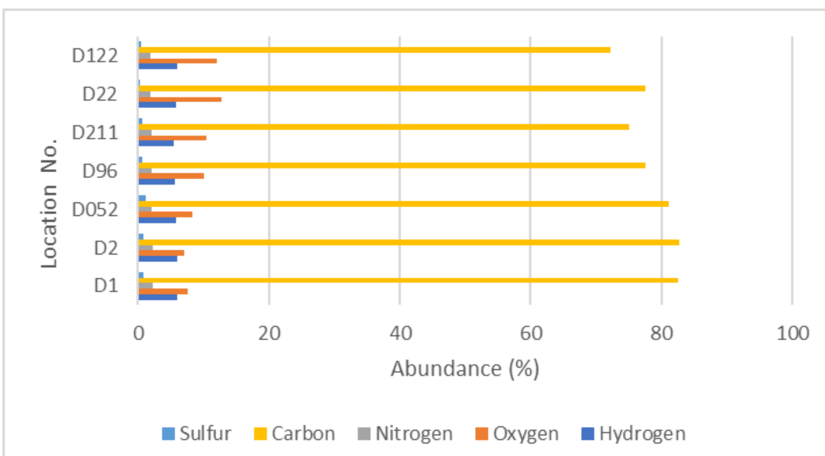

Figure 3. Graph of elemental content of elements in coal

The high carbon content is related to the high volatile matter content [17] as shown in Table 1. Ultimate analysis indicates that all coal samples are categorized as flame coal with good grade characterized by low sulfur content, and can be used for coke making technology [18].

3.3. Ash chemical component analysis

The results of the ash chemical component analysis of all coal samples are shown in Table 3.

Table 3. Data from ash chemical component analysis

Ash	Horna Block			Menci Block		Tisihu Block	
	D1	D2	D052	D96	D211	D22	D122
SiO_2	25.61	27.57	32.17	25.65	40.45	48.46	46.59
Al_2O_3	11.67	10.25	12.81	14.86	20.15	23.43	26.14
Fe_2O_3	29.13	30.19	30.57	15.73	9.8	14.86	7.85
TiO_2	0.62	0.59	0.57	0.57	0.73	0.38	0.79
CaO	7.99	7.66	4.66	10.17	6.13	5.02	3.96
MgO	9.59	8.88	8.09	11.26	7.24	2.18	4.76
K_2O	0.32	0.26	1.17	0.74	2.79	0.55	1.79
Na_2O	0.89	0.87	0.84	0.97	1.64	0.42	0.35
P_2O_5	0.04	0.04	0.05	0.43	0.06	0.11	0.44

The result of the chemical composition of the ash to obtain coke with the specified Coke Reactive Index (CRI) and CSR (coke strength after reaction with CO_2). The better quality of coke is requirement low CRI and high CSR index. The ash basicity index employed in formula 2 may be denoted by B_b

$$Bb=Na_2O+K_2O+CaO+MgO+Fe_2O_3/(SiO_2+Al_2O_3) \quad (2)$$

$$CRIp=13.4-0.45\ (Bb)^2+9.35\ (Bb) \quad (3)$$

$$CSRp=94.23-1.275\ CRIp$$

where: B_b-basicity index; CRI_p- predicting CRI; CRS_p - predicting CSR.

Table 4 shows coke quality parameters CRI and CSR, calculated by using basicity index (BI) model, and according to formulas (2) and (3). All coal samples analyzed show low CRI_P (15.78 - 24.51) values and high CRS_P values (62.77- 74.12).

Table 4. Predicting value of CRI and CRS of coal

Location/Sample No.		Parameter		
		Bb	CRI_P	CSR_P
Horna	D1	1.29	24.68	62.77
	D2	1.27	24.51	62.98
	D052	1.01	22.37	65.71
Menci	D96	0.96	21.96	66.23
	D211	0.46	17.57	71.83
Disihu	D22	0.32	16.35	73.38
	D122	0.26	15.78	74.12
Average			20.46	68.15

3.4. Rheology properties

The results of the FSI, dilatometric properties, and Gieseler test of all coal samples are shown in Table 5. All coal samples from the Horna Block had the highest FSI of 5.5 followed by coal samples from Menci Block and Disihu Block with 3.0 and 2.5, respectively. Based on the British Standard Swelling Number (BSS No.), the Horna Block coal samples are classified as coal of moderate caking power, while the Menci Block and Disihu Block coal samples are classified as coals of weak caking power.

Table 5. Data from rheology test

Parameter	Horna Block			Menci Block		Disihu Block	
	D1	D2	D052	D96	D211	D22	D122
FSI	5.5	5.5	5.5	3.0	1.5	3.0	2.5
ST (^{0}C)	358	369	352	368	376	368	376
MCT (^{0}C)	408	405	402	439	500	429	446
MDT (^{0}C)	440	440	436	438	440	18	1
C (%)	20	25	15	18	28	21	16
T (%)	19	32	28	19	36	17	27
G	0.90	0.95	0.99	0.93	0.96	0.93	0.99
D (%)	-1	7	13	1	8	-4	11
IST (^{0}C)	392	387	304	403	406	456	454

Parameter	Horna Block			Menci Block		Disihu Block	
	D1	D2	D052	D96	D211	D22	D122
MFT (^{0}C)	428	426	432	427	413	459	457
ST	449	449	466	446	436	468	465
MF	13	20	22	2	2	4	4
PR	57	62	162	43	30	12	11
GR	51.17	47.65	113.23	142.84	99.65	19.93	18.27

Remarks:

FSI : Free Swelling Index
ST : Softening Temperature
MCT : Max. Contraction Temperature
C : Contraction
D : Dilatation
G : Cookability Factor
IST : Initial softening Temperature
MFT : Max. Fluidity Temperature
ST : Solidification Temperature
MF : Fluidity Temperature
PR : Plastic Range
GR : Gieseler Ratio

The Gieseler plastometric test was shown in Table 5. The rheological characteristic values such as the initial softening, maximum fluid, and re-solidification temperature that have been measured. The Horna coal samples have an average of the initial softening temperature is 361°C, a maximum fluidity between 13 to 22 ddpm and the average of solidified temperature of 451°C. The temperature range between was 57°C to 152°C. The Menci Block coal samples had low maximum fluidity with an average 2 ddpm, range is 30°C and 40°C, the average of maximum fluidity in Disihu is 4 ddpm with plastic range 11°C and 12°C. An adequate range for proper operation of a blast furnace is 750-1,000 ddpm.

To assess the cookability of the coal, the dilatometric test was conducted. This test is used in calculating the cookability factor G-value of Simonis. Referring to the results of the dilatation test, the G-value of each location can be determined; the average G-value for the Horna Block, Menci, and Disihu 0.95, 0.84, 0.96, respectively Based on Simon's G-range, the values between 0.90–0.99 are classified as medium to strongly coking coals.

3.5. Discussion

The parameters of proximate and ultimate analysis, show that all coal samples were suitable used for coke making technology, except the volatile matter (VM). In this study, all coal samples have VM more than 45% daf. The best coals for coke making have 24–26% dry ash free (daf) volatile matter [19]. The high VM content will produce low maximum fluidity as indicated in the coal samples from this area which in the range of 2-22 ddpm. The Lower fluidity produces weaker bonding during carbonization, making coke susceptibility to damage during transport.

Based on Simon's G-range, the values between 0.90–0.99 are classified as medium and strongly cooking coals. The coals can be classified as a medium-cooking class. This is also supported by an intermediate FSI value (5.5). It was observed from the various coals tested, that total dilatation values are moderate (17-36%). In the steel industry, the required physical properties of blast furnace coke (Table 6) are the same; namely CRI (coke reactivity index) and CSR (coke strength after reaction with CO_2) [20].

Table 6. The coke reactivity index (CRI) and coke strength after reaction with CO_2 (CSR) from several blast furnace in some country

	European Range [20])	Australian Range [21])	American Range [22])	Japan Range [23])	China Range [24]
CRI	20 -30	17.7	23	< 35	23-24
CSR	> 60	74.1	61	50 - 65	79-71

This study shows that there are differences between various parameters measured in determining coal quality as coke making, however, based on the CSR and CRI in all coals show low CRI values (15.78 – 24.68%) and high CSR values (62.77- 74.12%); indicates that coals in the research area has the potential to be used as a coke-making material as the CRI and CSR parameter value which required in several blasts furnace in various places in the world (Table 6).

4. Conclusion

Although the proximate, ultimate, ash analysis, rheology's parameter, indicated that all coal samples have low-moderate potential to use as making coke. It also supported by the value of CRS and CSR which meets with the Blast Furnace standard criteria in several countries (low CRI and high CSR). Due to low fluidity the coal from Bintuni Basin can't used in coke making alone. To improve the quality of coal in the research area for use in the steel industry, the coal must be blended with other coal with high fluidity, which can make the interaction between coal particle to be strength.

Acknowledgments

The authors are grateful to the funding from the University Padjadjaran Research Programme of the Academic Leadership Grant (ALG) of the year 2018. The authors also would like to acknowledge the Dean of the Faculty of Geology for their support to establish this article.

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