EVALUATION OF SELECTED HIGH RANK COAL IN KUTAI BASIN, EAST KALIMANTAN RELATING TO ITS COKING PROPERTIES

EVALUASI BEBERAPA BATUBARA PERINGKAT TINGGI DI CEKUNGAN KUTAI, KALIMANTAN TIMUR BERKAITAN DENGAN SIFAT KOKASNYA

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ABSTRACT

Abundant coal seams of Miocene age with thickness of up to 4.7 metres occur in Kutai Basin, East Kalimantan. Selected coals are analyzed in order to evaluate its coking properties. The coals have bituminous in rank with calorific value of 5,582-8,357 kg/kcal (adb) and vitrinite reflectance of 0.57-0.97%. These selected high rank coals are normally concentrated in high gradient temperature zone or proximity to intrusive body. Vitrinite reflectances of these coals are lower than those of Australian coking coals (1.04-1.06%), but higher than of Indonesian normal coalification coals. Vitrinite is the dominant maceral in coals from Kutai Basin (73-96%), while inertinite and liptinite are only present in small amount, i.e. trace-10.2% and trace-8.2%, respectively. In contrast, vitrinite is lower and inertinite is higher in Australian coking coals, i.e. 64.8- 79.0% and 18.4-31.6%, respectively. Generally, crucible swelling number of Kutai Basin coals is lower than of Australian coking coals. Based on its vitrinite reflectance and calorific values, some of selected high rank coals from Kutai Basin have developed semi coking properties. The enhancement of rank is probably due to the effect of igneous intrusions or high gradient temperature. However, vitrinite content of the coals is higher than of coking coal range. Crucible swelling number of the coal is also too low, except for sample EK 1 and EK 2 which have CSN too much of 6 and 4, respectively. Therefore, the coals are not categorized as prime coking coal, but they can be blended with bituminous inertinite rich coals to make metallurgical coke for blast furnace.

Keywords: coking coal, maceral, vitrinite reflectance, crucible swelling number

SARI

Lapisan batubara Miosen dengan ketebalan mencapai 4,7 meter terdapat di Cekungan Kutai, Kalimantan Timur. Sebagian lapisan batubara tersebut dianalisis untuk dievaluasi sifat kokasnya. Batubara ini berperingkat bituminus dengan nilai kalori 5.582 kg/kkal (adb)-8.357 kg/kkal (adb) dan nilai reflektansi vitrinit 0,57%-0,97%. Batubara berperingkat tinggi ini secara normal terkonsentrasi dalam zona temperatur gradien tinggi atau terletak dekat dengan tubuh intrusi. Reflektansi vitrinit batubara ini bernilai lebih rendah apabila dibandingkan dengan batubara kokas Australia (1,04%-1,06%); namun, lebih tinggi dibandingkan dengan batubara yang mengalami pembatubaraan normal di Indonesia. Vitrinit merupakan maseral dominan dalam batubara Cekungan Kutai (73%-96%). Sementara itu, inertinit dan liptinit ditemukan dalam jumlah kecil, yakni masing-masing 0-10,2% dan 0-8,2%. Secara kontras, vitrinit lebih rendah dan inertinit lebih tinggi pada batubara kokas Australia, yakni masing-masing 64,8-79,0% dan 18,4-31,6%. Secara umum, crucible swelling number batubara Cekungan Kutai lebih rendah daripada batubara kokas Australia. Berdasarkan pada nilai reflektansi vitrinit dan nilai kalori, beberapa batubara peringkat tinggi Cekungan Kutai memiliki sifat semikokas. Peningkatan peringkat ini kemungkinan disebabkan oleh efek intrusi batuan beku atau gradien temperatur tinggi. Sekalipun demikian, kandungan vitrinit batubara

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ini lebih tinggi dibandingkan dengan kisaran batubara kokasnya. Crucible swelling number batubara ini terlalu rendah, kecuali untuk percontoh EK1 dan EK2 yang memiliki crucible swelling number, masing-masing 6 dan 4. Jadi, batubara ini tidak bisa dikategorikan sebagai batubara kokas utama, namun batubara ini bisa dicampur dengan batubara bituminus kaya akan inertinit dalam pembuatan kokas metalurgis untuk tanur tinggi.

Kata kunci: batubara kokas, maseral, reflektansi vitrinit, nilai muai bebas

INTRODUCTION

Currently, Indonesian coal resources are reported to amount of 120.53 billion tonnes of which 31.36 billion tonnes are classified as coal reserves (Badan Geologi, 2013; Directorate General of Mineral and Coal, 2014). The coal reserves are roughly 0.6% of total proven global coal reserves to make Indonesia currently ranks 13th. The coals are distributed mostly in the island of Kalimantan (49%) and Sumatera (51.5%). Regarding coal production, Indonesia is one of the world's largest producers and exporters of thermal coal. In 2014, the coal production increased sharply to 430 billion tonnes (Directorate General of Mineral and Coal, 2014) compared to only 55 million tonnes in 1997 or 217 million tonnes in 2007. The coal production is mostly derived from East and South Kalimantan coalfields, encounting 90% of national coal production. Unfortunately, only about 25% of the coal production is utilized in domestic usage, particularly for power plant and the rest is allocated for export. In order to optimize the use of coal in domestic, the Indonesian Government encourages technology providers, including coke manufacturers to develop their technologies in this country.

Based on age and quality, two main groups of economic Tertiary Indonesian coal deposits are recognized, they are Palaeogene (Eocene and Oligocene) and Neogene (Miocene, Pliocene and Pleistocene) coals. The Eocene and Miocene coals show some differences in coal geometry and quality including both chemical and physical characteristics. However, the Eocene and Miocene coals have the greatest potential for development. The coals are dominated by low rank coal, i.e. subbituminous and lignite in rank that known as steam or thermal coal. This coal is primarily used for power generation, where its use to produce steam and to drive turbine for electricity generation. High rank coal, approximately 20% of the total national resources, is normally located in older formation (Palaeogene) or in the vicinity of igneous intrusion, for instance in Bukit Asam – South Sumatera, East Kalimantan and Central Kalimantan (Daulay and Cook, 1988; Daulay et.al., 2010). However, vitrinite reflectances of heat affected coals from Bukit Asam are much higher than of heat affected coal from East and South Kalimantan. Generally, Indonesian coal has an advantage in term of impurities since it has a very low ash and sulphur contents, average of <10% and <1%, respectively, making it one of the cleanest coals in the world. Kalimantan has higher quality coal resources compared with Sumatera coal.

Understanding the quality of Indonesian coal is essential to maximizing its value in the market. Some of the Indonesian high rank coals are reported as coking or semicoking coals, mostly located in East and Central Kalimantan. There is no natural coking coal reported from Bukit Asam coalfields, this is most probably due to short time of heating process (Daulay and Cook, 1988). With the expensive coking coal price and the limitation of the reserves, many exploration activities in the country are carried out by coal companies to discover coking coal reserves that will be used in blast furnace for steel production. However, there are only a few coking coal projects that are already in production stage, and reported to produce approximately 5 million tonnes per year although some new mines in Kalimantan are expected to start significant production rate soon. Most of this production is allocated for export. Coking coal production will support the government policy to develop new iron ore and steel projects in the country. The question now and need to be clarified what is the quality of the Indonesian coking coal.

Daulay (1994; 1998) also noted that there are some coals in Indonesia that have coke properties based on their physical characteristics, i.e. coal which has high calorific value and vitrinite reflectance. But these coals normally contain high vitrinite contents, up to 90% and low free swelling index (FSI) or crucible swelling number (CSN). Therefore, the purpose of the present study is to analyze the characteristics of selected high rank coals from Kutai Basin, East Kalimantan in order to determine coking properties of the coal. Understanding the coals from analysis to end use is crucial to maximizing sale value and utilization of the coal.

Kutai Basin Coal Formation

The origin of the Tertiary basins along eastern part of Kalimantan contributed greatly to the evolution of ideas on the tectonic history of the Kalimantan island. A mid-Tertiary spreading centre existed in the Makassar Strait (Van Bemmelen, 1949; Katili, 1989). The most important sedimentary coal basins in Kalimantan or Indonesia in general are Palaeogene intermontane and continental margin basins, and Neogene back deep, deltaic and continental margin basins (Koesoemadinata, 1978; Widodo, et.al, 2010; Satyana, et.al, 1999). The Neogene coal seams are typically thicker (up to 30 metres) and more homogeneous in lateral extent than of Palaeogene coal seams.

Four main Tertiary sedimentary basins, and associated coal deposits, are recognised along the east coast of Kalimantan, they are from north to south the Tarakan, Kutai, Barito and Asem Asem Basins. The four basins initially developed as a single large depocentre during the Early Tertiary, only becoming separated by uplifted zones (such as the Mangkalihat Ridge and The Semporna, Kuching, Laut and Meratus Highs) in the later stages of basin development, that is, during the Late Miocene orogenic activity (Sikumbang, 1986). The Tertiary sequences overlie strongly-deformed Cretaceous rocks consisting of an ophiolite complex, metamorphic and volcanic rocks. Marine sedimentary rocks in this area underlie the Tertiary coal deposits.

Coal seams occur in the Kutai Basin, both in narrow steeply-dipping anticlinal and fault zones and in intervening syncline areas with shallow dips. No major structural dislocations are recognised within the coal deposits. However, some of the seams have splits, wash-outs, wedge-outs or discontinuities. Splitting is probably resulted from channel activity associated with peat accumulation whereas discontinuities may have been caused by rapid lateral lithofacies changes (Koesoemadinata, 1978). Variations in seam thickness probably due to seam wash-outs or associated with fold axes or faults. This is reflecting differential subsidence of the basement during peat deposion.

Selected high rank coals used in this study are collected from Kutai Basin. Coal seams in this basin deposited during the Early Miocene Pemaluan and Pulubalang Formations and the Miocene-Pliocene Balikpapan and Kampungbaru Formations. These coal-bearing sequences have been folded into north-northeast trending anticlines and synclines. The Mahakam coal deposits are located in the Semalis, Busang and Gitas anticlinal zones, south of the Mahakam River. Coal deposits in the Sangatta area occur in the Miocene Pulubalang and Balikpapan Formations. The prospective seams are concentrated in the Pinang Dome area which has been postulated as being of diapiric mudstone origin (Rose and Hartono, 1978). Local tectonic activity may have affected the coal rank (Daulay, 1994; Moore and Friederich, 2010). This phenomena is also identified in many places in the world (Singh et al., 2007; 2008; Sarana and Kar, 2011).

Coking Coal

In general terms, based on the rank, coal can be classified as either thermal coal or metallurgical coal. Thermal or steam coal is lower in carbon content and calorific value, higher in moisture content, is the world’s most abundant coal, including Indonesia and is primarily used to produce energy or electricity. Metallurgical coal or also known as coking coal is less abundant than thermal coal and is used to create coke, one of the key inputs for the production of steel. In general, there are several types of coking coals, they are premium coking coal, standard coking coal, semi coking coal and volatile pulverised coal injection (PCI).

Coke is produced by heating coking coal to about 1100°C in the absence of oxygen in a coke oven to remove the impurities (Diez, et.al, 2002). The process of melting coal in the absence of oxygen to remove impurities is called pyrolysis. As the temperature of the coal increases, it becomes plastic, fusing together before resolidifying into coke particles. This is known as the caking process. When making steel, two of the key raw ingredients are iron ore and coke. Coke which is a porous, hard black rock of concentrated carbon is used to convert the iron ore into molten iron.

The quality of coke is determined by the qualities of the coking coals as well as the coke plant operating conditions. Coke quality is largely influenced by coal rank indicated vitrinite reflectance and calorific value, maceral composition, mineral content and the ability to soften when heated, become plastic, and resolidify into a coherent mass. High and medium volatile bituminous rank coals that possess these properties are called coking coals.

METHODOLOGY

Six (6) high rank coal samples have been collected from selected locations in Kutai Basin (EK 1 – EK 6), East Kalimantan. The coal seams occurred in Early Miocene Pulubalang Formation. These coal-bearing sequences have been folded into north-northeast trending anticlines and synclines (Moss and Chambers, 1999). The thicknesses of the seams vary from a few centimetres to 4.7 metres with dips ranging from 5° to 20°. In addition, 2 (two) coking coals from Australia were analysed for comparison. One (1) sample was collected from stockfile of PT Indoferro (AU 1) and the other was from PT Krakatau Posco (AU 2), both are located in Cilegon, Serang.

All coal samples were analyzed for proximate analyses (moisture, ash, volatile matter and fixed carbon), and miscellanous analyses including spesific energy (calorific value) and CSN following ASTM International standard (ASTM, 2009). The result was then evaluated together with petrographic data, both maceral composition and vitinite reflectance.

Petrography of coal is assessed in terms of macerals (vitrinite, inertinite and liptinite) and mineral content. Maceral analysis followed Australian Standard AS 2856.3-2000 (Australian Standard, 2000) and ISO standard 7404-3 (ISO, 2009a). Maceral analysis was performed by counting at least 500 points on each particulate pellet. Vitrinite reflectance was determined using Australian Standard AS 2856.2-1998 (Australian Standard, 1998) and ISO standard 7404-5 (ISO, 2009b). For vitrinite reflectance, 50 measurements were made on each of two particulate pellets per sample. Both analyses were performed on an orthoplan microscope with a MPV2 photomultiplier unit and a 32× oil immersion objective and a Leica DM2500 point counter. Maceral analysis was conducted both in white and fluorescent light, the latter to better distinguish macerals of the liptinite group.

RESULTS AND DISCUSSION

Proximate analysis, calorific value and CSN of selected high rank coals from Kutai Basin and Australian coking coals are presented in Table 1. Calorific value coals from Kutai Basin ranges from 5,582 kg/kcal (adb) to 8,357 kg/kcal (adb). The low calorific value of sample EK 2 reflects the high ash content of the coal (28.1%). The calorific value of the Kutai Basin coals is anomalous high which diverge markedly from the other normal coalification of Miocene coals, i.e. average <5.500 kg/kcal (adb) in Indonesian coal basins (Daulay and Cook, 1988, Prakash, et.al, 2010). The high calorific value of the coals definitely appear not to be age and stratigraphic position, this is more a function of the increase geothermal gradient caused by local instrusions. Whenever the sediments, particularly coal, come in close contact with the igneous bodies, sudden changes in the rank and nature of organic matter have been observed (Daulay and Cook, 1988; Santoso and Daulay, 2009). The same phenomena is also reported by Moore, et.al. (2014) in Pinang area of Kutai Basin where the coal beds in the proximity have been thermally altered due to higher heat flow found in this area. Early study, Moore and Nas (2013) indicated an intrusive heat source at some depth

Table 1. Proximate analysis, calorific value and CSN of the coal samples

No	Sample Number	Parametres					
		Inherent Moisture,%	Ash, %	Volatile Matter, %	Fixed Carbon, %	Calorific Value, kg/kcal (adb)	CSN
1	EK 1	1.7	9.8	35.0	53.5	7,636	6
2	EK 2	1.6	28.1	26.4	43.9	5,582	1.5
3	EK 3	2.2	0.1	44.7	53.0	7,991	2
4	EK 4	1.8	5.2	42.3	50.7	8,357	3
5	EK 5	1.8	6.7	42.1	49.4	7,576	3
6	EK 6	1.7	8.8	27.4	62.1	7,553	4
7	AU 1	1.3	10.0	22.4	66.2	6,528	4.5
8	AU 2	1.2	9.2	24.7	66.1	7,504	6

EK = Sample from Kutai Basin AU = Sample from Australia in this area. Simplicitically, in any sedimentary basin, the rank of coal beds will follow Hilt's Law; that is, the deeper the coal bed, the higher the rank (Thomas, 2007).

Inherent moisture of coal from Kutai Basin ranges between 1.6% and 2.2%. Volatile matter and fixed carbon contents of the coal vary from 26.4% to 44.7% and 43.9% to 62.1%, respectively. Volatile matter and fixed carbon contents of the coal show an inverse relationship with each other as the rank of the coal increases the fixed carbon content becomes higher. CSN of Kutai Basin coals varies 1.5 - 6 and this value is much higher than coals of normal coalification in Indonesian coal basins, both Eocene and Miocene ages (Daulay and Cook, 1988; Daulay, 1994).

Compared with Australian coking coals, Kutai Basin coals have higher inherent moisture and volatile matter contents and this mainly rank dependent. Fixed carbon of Australian coking coals (66.1% - 66.2%) is higher than of Kutai Basin coals, except for sample number EK 6 (62.1%) that has relatively same fixed carbon content with Australian coking coals. In terms of CSN, the value for Australian coal (4.5 – 6) is higher compared with Kutai Basin coals, except for sample number EK 1 (6) and EK 6 (4) which have relatively same CSN value with Australian coking coals. Ash content of the Australian coking coals is relatively higher than that of Kutai Basin coal, except for the sample number EK 2 which has 28.1% ash content.

Table 2 shows petrogaphic analysis including vitrinite reflectance of selected high rank coals from Kutai Basin and two coking coals from Australia. Vitrite is the dominant microlithotype with lesser clarite and duroclarite in some coal samples. Vitrinite is dominant maceral in all samples from Kutai Basin, varies between 73% and 96%. In general, this range represents for vitrinite content of the Indonesian coals (Daulay, 1994; Santoso, 2015). The high vitrinite content in the sample EK 6 probably is due to its high rank and therefore the identification of other macerals is difficult. This coal most probably occur close toward the intrusive body.

Most of the vitrinite occurs as detrovitrinite (Figure 2) and telovitrinite with gelovitrinite as a minor component. Liptinite content consists mainly of resinite and sporinite ranging from trace to 8.2%. Cutinite and alginate are present in some samples. The fluorescence of the liptinite ranges from yellow to dull orange (Figures 3 and 4). This colour indicates that the coal is high rank. Inertinite, comprises predominantly semifusinite, fusinite and sclerotinite, varies from trace to 10.2%. Sclerotinite, consisting of unibicular and bicular teleutospores is present is some coal samples. In some occasion, the hole of sclerotinite is filled by resin and mineral, mostly clay and silica. The Kutai Basin coals contain low to medium mineral matter (1.4% - 17.4%), consisting clay and pyrite. Some of pyrite show framboidal structure (Figure 5) indicating marine influence depositional environment.

Vitrinite reflectance of Kutai Basin coals ranges from 0.57% to 0.97%. These coals can be classified as bituminous rank. The higher vitrinite reflectance of the coal in sample EK 6 (0.97%) is assumed that position of the sample is the

Table 2. Petrographic analysis of the coal samples

No	Sample Number	Maceral, %				Rvmax, %
		Vitrinite	Liptinite	Inertinite	Mineral Matter	
1	EK 1	80.8	trace	1.8	17.4	0.68
2	EK 2	80.1	0.4	2.8	15.8	0.84
3	EK 3	83.0	8.2	7.4	1.4	0.73
4	EK 4	75.0	4.8	10.2	10.0	0.57
5	EK 5	73.0	5.0	8.4	13.6	0.65
6	EK 6	96.0	trace	trace	4.0	0.97
7	AU 1	64.8	0.6	31.6	3.0	1.04
8	AU 2	79.0	1.0	18.4	1.6	1.06

EK = Sample from Kutai Basin; AU = Sample from Australia; Rvmax = Vitrinite Reflectance

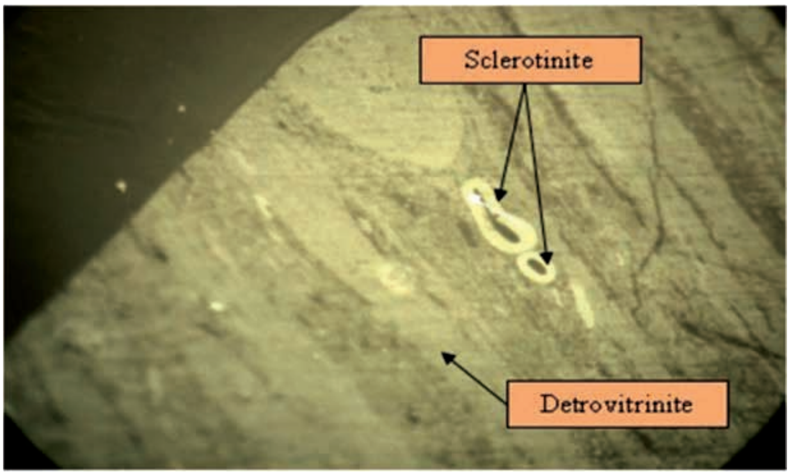

Figure 2. Vitrinite (detrovitrinite) associated with sclerotinite. Sample EK 3, Rvmax 0.73%, 500 x, reflected white light.

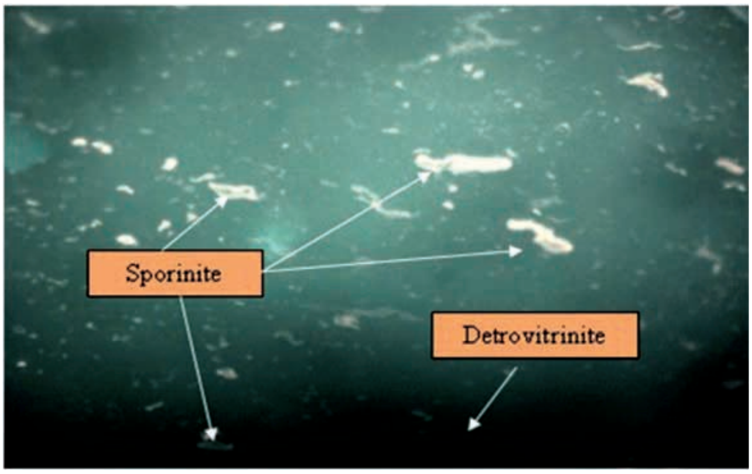

Figure 3. Sporinite associated with detrovitrinite. Sample EK 4, Rvmax 0.57%, 500 x, fluorescence mode.

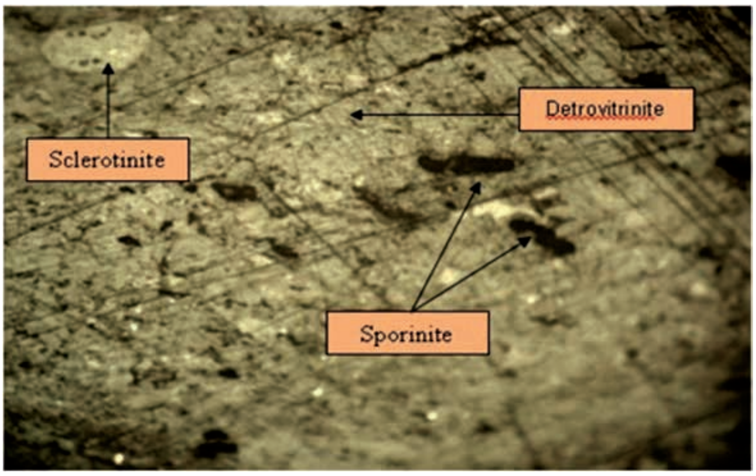

Figure 4. As for Figure 3, but in reflected white light

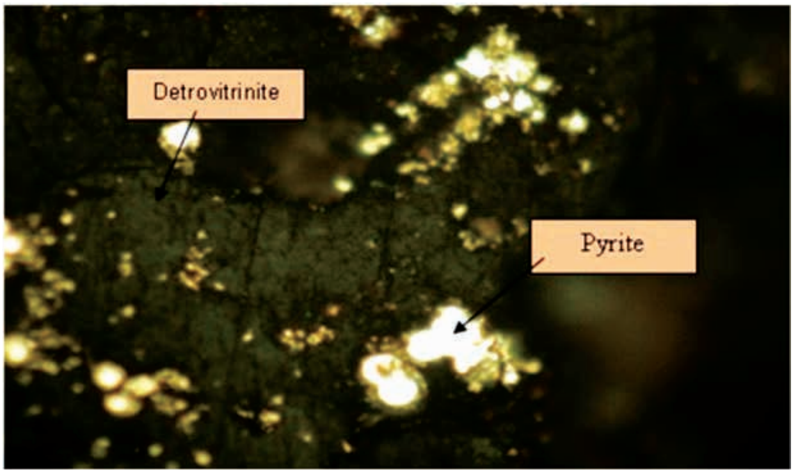

Figure 5. Framboidal pyrite associated with vitrinite. Sample EK 5, Rvmax 0.65%, 500 x, reflected white light.

closest to the body of igneous intrusion with high geothermal gradient, probably up to 50 °C/km (Moore, et.al., 2014).

Compared with Kutai Basin, vitrinite and liptinite contents of Australian coking coal are relatively lower, i.e. 64.8% - 79.0% and 0.6% - 1.0%, respectively. Inertinite content and vitrinite reflectance of the Australian coking coals are much higher than those of Kutai Basin coals, i.e. 18.4% - 31.6% and 1.04% - 1.06%, respectively. Mineral matter is lower in Australian coking coals (1.6% - 3.0%). Figures 6 and 7 show typical inertinite (mostly fusinite and semifusinite) rich coal of Australian coking coals.

In relation to metallurgical coke making, some important technological properties of coal include petrographic data (coal rank, coal type and mineral matter) as well as proximate analyses (volatile matter, moisture) and several miscellanous analyses, mainly calorific value and CSN. Metallurgical coke is made from coking coal. Normal coking coal can be originated during the process of coalification where heat is normally available to the sediments by the depth of burial and then the effect of temperature on rank of coal is gradual and is also related to the duration of burial. Natural coke can be formed under in-situ conditions due to intense magmatic induced heat and overbur-

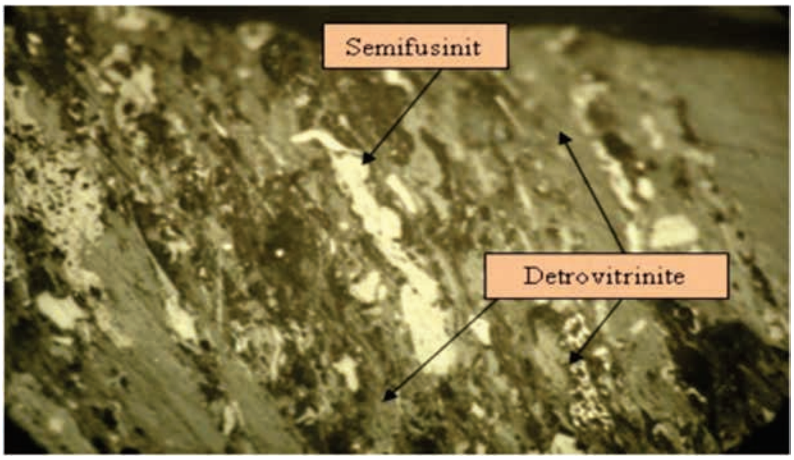

Figure 6. Inertinite rich coal associated with vitrinite (detrovitrinite). Sample AU 1, Rvmax 1.04%, 500 x, reflected white light.

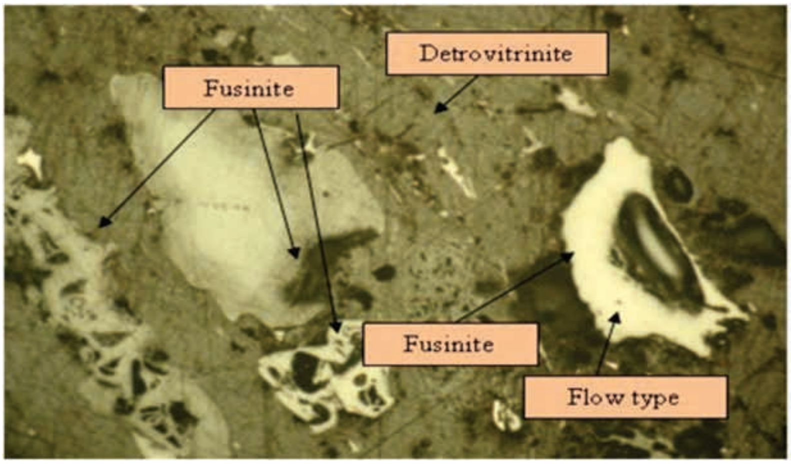

Figure 7. Fusinite associated with detrovitrinite. Sample AU 2, Rvmax 1.06%, 500 x, reflected white light.

den pressure. Natural coke is characterized by the presence of low volatile matter and high ash contents (Singh et al., 2007; 2008).

Pareek (1986) identifies 3 (three) groups of coal based on vitrinite reflectance value; they are non coking coal (< 0.70%), semi coking coal (0.70% - 0.85%) and coking coal (>0.85% - 1.50%). Coal with >1.50% vitrinite reflectance is known as non coking coal because it will be melted when the coal is carbonized. Microlithotypes of the coking coal are normally vitrinertite and duroclarite. Therefore, general characteristics of coking coals that could be processed to make metallurgical coke for blast furnace are as follows:

- vitrinite reflectance : >0.85% - 1.50%,
- vitrinite : 40% - 60%,
- inertinite : 20% - 45%,
- liptinite : <10%,
- mineral matter : <10%,
- volatile matter : <25%, and
- CSN : 4 – 7.

Based on the above coking coal parameters, it can be identified that selected Kutai Basin high rank coals are non prime coking coal. According to vitrinite reflectance, four (4) coal samples have value of 0.57% - 0.68% and these are far below coking coal range. One (1) coal sample has vitrinite reflectance of 0.84%, and this is classified as semi coking coal. Sample EK 6 which has vitrinite reflectance of 0.97% can be identified as coking coal. However, maceral or microlithotype composition of the Kutai Basin coals prevents the formation of good quality coke. Maceral composition of the coals is not balance between vitrinite and inertinite content. Most of the coals are represent vitrite and clarite microlithotypes. Vitrinite content of the coal (75% - 96%) is far higher than of coking coal range. Conversely, inertinite content of the coal (trace – 10.2%) is much lower than of coking coal range. Although inertinite content determine as inert component, Daulay (1994) identified that reflectance of inertinite content, especially semufusinite from eastern part of Kalimantan is low and it will melt or undergous partial or complete fusion during coking process. This type of inertnite is categorized to be reactive. Liptinite and mineral matter contents of the coal, however match with coking coal range. Volatile matter of the Kutai Basin coal is lower than of coking coal range. Finally CSN of the coal is much lower than of coking coal range, except for samples EK 1 and EK 6.

From the above information, it can be concluded that selected high rank coals from Kutai Basin are classified as semi coking coal that could not be used as a single raw material for making metallurgical coke. However, these coals can be blended with high inertinite coking coal to produce coke for blast furnace or upgraded for instance using steam treatment (Shui, et.al., 2011).

CONCLUSIONS

Selected high rank coals from Kutai Basin occur in the high geothermal gradient or close to intrusive body, therefore the coals have high calorific value, fixed carbon and vitrinite reflectance. The coals have high vitrinite content, but low inertinite and liptinite content. Some of the coals have medium

CSN. These coals have been collected and analyzed to determine their coking properties. The properties of the coals are compared with the properties of two coking coals from Australia.

Based on the analysis of selected high rank coals from Kutai Basin, it is concluded that the coal is not prime coking coals due to lack of coking properties of some parameters that normally used to measure coals as raw material to make coke for steel making in blast furnaces. The mention properties including too high vitrinite content, low vitrinite reflectance value and low CSN of the coals. However, the coal that can be categorized as low quality coking coal or semi coking coal can be used as raw material for making metallurgical coke after blending with prime coking coal, particularly with high inertinite content (>60%), high vitrinite reflectance (1.3% - 1.5%) and high CSN (6 - 8) value. In this case, the Kutai Basin semi coking coals can contribute at least 25%.

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