Quality of coal seam D of Muara Enim Formation, Central Palembang Subbasin

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Abstract. Coal seam D belongs to Muara Enim Formation in Central Palembang Subbasin, South Sumatera Basin, which ages of Middle Miocene to Late Miocene. This study aims to determine the quality of the coal, especially sulphur content and form, ash content and composition, and trace elements of heavy metals. Those are important to know as a reference in suitability in the use of this coal. Methods of analysis is proximate, total of sulphur, form of sulphur, SEM-EDS, ash composition, and trace element. The coal is categorized as low rank coal or lignite with a very low total sulphur max 0.25%, dominated by the organic sulphur formed during the peatification and coalification process (syngenetic). The coal has a safe ash composition. It shows from a very low metal oxide content that causes slagging and fouling at low temperatures process. Likewise, the trace element content of the coal such as chromium (Cr), cadmium (Cd), manganese (Mn), lead (Pb), nickel (Ni) is still far below the threshold for trace element content in coal.

1. Introduction
The characteristics of coal will greatly influence the proper use of coal. The study of coal characteristics is usually carried out along with a petrographic study to observe organic and inorganic components, which emphasizes the systematic method of describing and classifying coal [1], which can interpret coal basins related to the depositional environment, geothermal history, predict the potential for coal utilization, as well as oil and gas exploration [2,3]. The characteristics of coal are determined by several factors, including the forming plants, the depositional environment and the geological structure control. It causes variations in the characteristics of coal from one place to another. One of the characteristic parameters of coal is the sulphur content, which is related to the quality and economic value of coal. This sulphur content value can affect the processing and utilization of the coal. Sulphur is one of the components found in coal, both as organic and inorganic sulphur. Generally, the sulphur component in coal is present as syngenetic sulphur, which is closely related to physical and chemical processes during the peatification stage [4,5]. The distribution pattern of sulphur content in the coal seam can be found with variations both vertically and laterally. This has something to do with the depositional environment and geological conditions [6].

This study aims to determine the quality of the coal, especially sulphur content and form, ash content and composition, and trace elements of heavy metals. Those are important to know as a reference in suitability in the use of this coal.

The study is located in the Sekayu area, Musi Banyuasin Regency (Figure 1). Regionally, the studied area is situated in the Suban Burung Block on the geological map of the Sarolangun sheet.
Based on this geological map, the studied area is in the South Sumatera Basin, which is influenced by tectonic activity of subduction of continental plates between the Eurasian and the Indian Ocean Plates. The sedimentation cycle develops in the basin in a very wide swamp area and coal is formed in a parallic-limnic environment and brackish water [7–9]. The basin is divided into the Jambi Depression in the north, the North Palembang Subbasin, the Central Palembang Subbasin and the South Palembang Subbasin or the Lematang Depression [10]. Sedimentation in the South Sumatra Basin continued during the Tertiary Age accompanied by a decrease in the base of the basin until the thickness of the sediments reached 600 meters. The sedimentation cycle in this basin is divided into 2 phases, namely: 1. The transgressive phase, resulting in the Telisa Group sediment consisting of the following formations: Lahat, Talang Akar, Baturaja and Gumai. The Telisa group was deposited inconsistently on Pre-Tertiary bedrock. 2. Regressive phase, resulting in the Palembang Group sediment consisting of the following formations: Air Benakat, Muara Enim and Kasai. Sedimentation occurring during the Tertiary develop in a semi-closed marine environment. In the transgressive phase the order of the shallow land-transition-sea facies are formed, while in the regressive phase the opposite order is formed, namely shallow sea-transition-land. The stratigraphy of this basin can be recognized as a large cycle consisting of a transgression followed by regression. Tertiary deposits in this basin, from old to young, consist of the following formations: Lahat, Talang Akar, Baturaja, Gumai, Air Benakat. It was concluded that rock and coal deposits belonging to the Muara Enim Formation have a regressive depositional cycle.

**Figure 1.** Location of the studied area (modified from Purnama et al. [11]).

### 2. Materials and methods

Samples of the coal were obtained from drilling exploration results in Underground Coal Gasification (UCG) Project conducted by the Research and Development Center of Mineral and Coal Technology (Puslitbang tekMIRA). Ply-by-ply samples were collected from 4 points (UCGs 7, 9, 11 and 12), while composite samples were collected from 3 points (UCGs 2, 5 and 6). The samples were taken for preparation of resize of the coal to 60#. They were divided to several part to be analyzed such as proximate analysis, sulphur content, sulphur form, ash composition, trace element and Scanning Electron Microscopy-Energy Dispersive Spectroscopy (SEM-EDS). The analytical method was used to find out general quality such as proximate, and calorific value and total sulfur content. This study has detail examining the characteristics and form of sulfur and ash content of metal oxides and metals, so that the quality of coal layer D can be known with certainty.
3. Results and discussion

The coal of the Muara Enim Formation in the Central Palembang Subbasin, precisely in the Sekayu area was formed in fluvial depositional to deltaic environment. The coal specifically located in the Sungai Pinang area was deposited in the deltaic environment. While Surjono and Geger [12] stated that the coal in this area was deposited in upper delta plain to lower delta plain environment. Permana and Panggabean [13] mentioned that the coal with abundant pyrite and minerals was deposited in a brackish environment. Based on their abundance, the minerals in the coal can be divided into primary-, extra-, minor- and trace minerals [14]. The research was conducted on the coal seam D of the Muara Enim Formation, locating in the Central Palembang Subbasin, the Central Miocene to Late Miocene South Sumatera Basin.

From the composite and ply-by-ply quality analysis result such as proximate, calorific value and total sulphur quality, it is concluded that the coal is categorized as a low rank coal (Table 1).

| Analysis                        | Composite (avg) | Ply-by-Ply (avg) |
|---------------------------------|-----------------|------------------|
| Total Moisture (%) (ar)         | 30.75           | 28.15            |
| Ash Content (%) (adb)           | 2.79            | 7.15             |
| Volatile Matter (%) (adb)       | 39.58           | 37.72            |
| Fixed Carbon (%) (adb)          | 41.04           | 39.3             |
| Calorific Value (Cal/g, adb)    | 5,845           | 5,577            |
| Total Sulphur (%) (adb)         | 0.19            | 0.25             |

3.1. Sulphur content and form

Total sulphur content of the coal sample has an average value of 0.19% with a maximum value of 0.26% and a minimum value of 0.08%, while the total sulphur content of the ply-by-ply sample has an average value of 0.25% with a maximum value of 0.89% and a minimum value of 0.19%. From the composition of the form of coal sulphur, it was found that organic sulphur dominates the sulphur content of the coal. An increase in the sulphur form has increased in roof and floor coal, but in total it is still below 1%. In general low sulphur coal (<1%) contains more organic sulphur than pyritic. Anggayana and Widayat [15] firm that organic sulphur abundance in coal is form in diagenesis process and add by reducing sulphate contaminant from the bottom layer of peat. This is inline with the result of sulphur form analysis to the coal, which was dominated by organic sulphur of 0.164%, followed by pyritic sulphur around 0.047% and sulphur sulfate content, which had the lowest value of around 0.017%. The lateral and vertical distribution of the form of sulphur is shown in Figure 2. According to the vertical distribution of sulphur content (ply-by-ply) at several drilling points, it was found that the sulphur content in the top and bottom coals had a relatively higher sulphur content than the coal in the middle. This is probably due to the influence of impurities on the overburden either on the roof or the coal floor.

Anggayana and Widayat [15] also stated that there is a relationship between the depositional environment and the sulphur content in coal in Berau, East Kalimantan. It is showed that coal quality is strongly affected by the environment in which the coal is deposited. The coal seam D was formed in a limnic depositional environment [16].
Figure 2. Vertical distribution of form of sulphur in the coal.
The results of coal cleats mapping on the surface [17], show that the direction of the cleats is north to northeast and south to southwest, with a frequency of 10 to 20 cleats every 2 meters. The qualitative and quantitative distribution of pyritic sulphur on the coal surface can be detected by using SEM-EDS. The results of the qualitative analysis of SEM data show that pyritic sulphur in the form of a fine framboidal size of about 5μm is found around the coal surface or coal cleat area, but it does not fill the cleat (Figure 3). So, it is concluded that the pyritic sulphur present in the content of the coal is formed along with the peatification process and coalification (syngenetic).

![Figure 3. SEM image of micro cleat in the coal.](image-url)
From the SEM analysis data on several samples of the coal, micro-fractures measuring 1-5μm were obtained, with the number of cleats in 1 inch between 1-10 pieces. Therefore, based on diagram Laubach [18], the permeability of the coal is around 0.005-0.5mdarcy (Figure 3). The small cleat fracture in the coal correlates with the lithotype of the coal, which tends to be dull black and rich in inertinite [19]. The cleat condition of the coal is not filled with pyritic sulphur. The form of framboidal pyritic sulphur is spread over the surface of the coal, which indicates that its formation coincides with the coal formation process, the low value of pyritic sulphur compared to the value of organic sulphur indicates that the depositional environment is not affected by sea water conditions or on limnic conditions [20]. Meanwhile, from quantitative analysis (EDS), pyritic sulphur content was detected to occupy the surface area of the coal about 3.39%–4.34% of the area of the EDS mapping on the coal surface (Figure 4).
3.2. *Ash content, composition and trace element*

Ash content of the coal is an inorganic component that does not burn, when coal is burned with abundant oxygen. Results of ash content analysis of composite of the coal sample (UCG 2, 5 and 7) have an average value of 2.79% (adb) or equivalent to 3.3% (db) with minimum value of 1.77% and maximum value of 8.65%, while ash content of the ply-by-ply sample (UCG 7, 9, 11 and 12) has an average value of 7.15% equivalent to 8.5% (db) with minimum value of 1.53% and maximum value is 25.16% (Figure 5). The melting point value of the coal ash sample at UCG 11 was obtained 1,223ºC under reduced conditions, while in oxidation conditions was 1,234ºC.

![Ash Content](image)

**Figure 5.** Ash content of the coal.

Additional analyses such as composition of ash and trace elements of heavy metals were also carried out, as this is related to environmental issues. The chemical composition of the coal ash consists of silicon dioxide (SiO₂), aluminium oxide (Al₂O₃), iron (III) oxide (Fe₂O₃), potassium oxide (K₂O), sodium oxide (Na₂O), calcium oxide (CaO), magnesium oxide (MgO), titanium oxide (TiO₂), manganese oxide (MnO), phosphorus pentoxide (P₂O₅), sulphite (SO₃), hydrogen dioxide (H₂O), LoI. This ash composition shows a very low content, especially in metal oxides that cause slagging, fouling and ash build up at low temperatures, namely Fe₂O₃, CaO, K₂O and Na₂O, which have the content below 0.1%. Thus, the coal is good enough and safe to use (Tables 2 and 3 and Figure 6).

**Table 2.** Chemical composition of the coal ash (sample point UCG 2).

| Component (%) | Sample Point |
|---------------|--------------|
|               | Top | Middle | Bottom | Average |
| SiO₂          | 49  | 56    | 43     | 49     |
| Al₂O₃         | 15  | 15    | 10     | 14     |
| Fe₂O₃         | 23  | 26    | 20     | 23     |
| K₂O           | 0.8 | 1.2   | 1.1    | 1.1    |
| Na₂O          | 7.3 | 8.6   | 12     | 9.1    |
| CaO           | 64  | 62    | 64     | 63     |
| MgO           | 12  | 4.2   | 9.3    | 8.7    |
| TiO₂          | 1.7 | 1.6   | 1.4    | 1.6    |
| MnO           | 0.68| 0.26  | 0.41   | 0.45   |
| P₂O₅          | 0.27| 0.02  | 0      | 0.1    |
| LoI           | 7.1 | 5.7   | 8.8    | 7.2    |
| SO₃           | 28  | 26    | 33     | 29     |
| H₂O           | 4.3 | 3.2   | 3.5    | 3.7    |
Based on the classification of trace elements of heavy metals, the coal is divided into 4 groups, namely Group I: chromium (Cr), cadmium (Cd); Group IIA: manganese (Mn), lead (Pb), nickel (Ni); Group IIB: copper (Cu), zinc (Zn); and Group III: cobalt (Co) [21,22]. Thus, what needs to be considered is the trace elements that are included in Group I and Group IIA. However, the trace element content of dangerous heavy metals in the coal sample is still far below the threshold for trace element content in coal, so it is safe to use (Table 4 and Figure 7).

This study has found that the coal has an appropriate quality as a low rank coal and is safe to use based on proximate, calorific value and total sulphur quality, supported with low ash composition below 0.1% in metal oxides such as Fe₂O₃, CaO, K₂O and Na₂O, which can cause slagging and fouling at low temperatures. This is in line with trace element content in the coal that is far below the threshold. So it is safe to use for power generation.

Table 3. Chemical composition of the coal ash (sample point UCG 6).

| Component (%) | Sample Point |
|---------------|--------------|
|               | Top | Middle | Bottom | Average |
| SiO₂          | 51  | 22    | 11     | 28     |
| Al₂O₃         | 8   | 16    | 1.3    | 8.5    |
| Fe₂O₃         | 28  | 22    | 6.3    | 19     |
| K₂O           | 1   | 0.9   | 0.01   | 0.65   |
| Na₂O          | 8.1 | 10    | 0.82   | 6.3    |
| CaO           | 63  | 67    | 42     | 58     |
| MgO           | 12  | 11    | 1.3    | 7.9    |
| TiO₂          | 1.5 | 1.7   | 0.03   | 1.1    |
| MnO           | 0.4 | 0.24  | 0      | 0.21   |
| P₂O₅          | 0.02| 0     | 0      | 0.01   |
| LoI           | 6.2 | 13    | 0.81   | 6.7    |
| SO₃           | 29  | 20    | 6      | 19     |
| H₂O           | 2   | 4.8   | 0.1    | 2.3    |

Figure 6. The major chemical component in the ash of top, middle and bottom of the coal sample.
Table 4. Trace element of the coal.

| Sampling Point | Cu    | Pb    | Zn    | Co    | Ni    | Mn    | Cr    | Cd    |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| UCG7-1         | 1.3735| 1.5785| 54.8375| 0.6355| 0.943 | 35.6085| 4.756 | 0.164 |
| UCG7-2         | 2.532 | 2.11  | 2.743 | 0.211 | 1.055 | 12.027 | 57.392| 0.211 |
| UCG7-3         | 2.3705| 3.0601| 9.913 | 1.1637| 2.8446| 26.6789| 5.7754| 0.3879|
| UCG7-4         | 0.9765| 0.7285| 3.162 | 0.3255| 0.806 | 10.5865| 1.953 | 0.1705|
| UCG7-5         | 1.1016| 0.765 | 0.4896| 0.4437| 0.5202| 17.901  | 1.1322| 0.1683|
| UCG7-7         | 0.9853| 0.9185| 1.0354| 0.5678| 0.6513| 43.1194| 1.2024| 0.2004|
| UCG 11-2       | 0.9881| 1.0363| 3.1571| 0.4579| 0.7712| 11.1583| 2.5305| 0.1205|
| UCG 11-5       | 0.896 | 1.2096| 3.808 | 0.4928| 0.7616| 11.5584| 7.3024| 0.1344|
| UCG 11-6       | 1.146 | 0.4775| 0.8022| 0.2865| 0.3247| 5.9974 | 2.292 | 0.0955|

Figure 7. Trace element concentration of the coal.

4. Conclusions

The coal seam D of Muara Enim Formation in Central Palembang Subbasin, South Sumatera Basin is low rank coal/lignite coal with calorific value of 5,577 cal/g to 5,845 cal/g, with sulphur content of 0.15% to 0.19%, ash composition that is still below the threshold and low content of heavy metal trace elements. According to those qualities, this coal is very suitable and safe to use as steam coal for power plants. Further research is needed regarding the characteristics of coal in this area to maximize its utilization. In addition, it is also necessary to conduct similar research on coal in other areas to obtain clean and environmentally friendly coal.

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