Thermal behaviour and microanalysis of coal subbituminous

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Abstract. Differential scanning calorimetry (DSC) and X-ray powder diffraction (XRD) is used to study the thermal behaviour of sub-bituminous coal. The DSC experiment was performed in air atmosphere up to 125 °C at a heating rate of 25 °C min⁻¹. The DSC curve showed that the distinct transitional stages in the coal samples studied. Thermal heating temperature intervals, peak and dissociation energy of the coal samples were also determined. The XRD analysis was used to evaluate the diffraction pattern and crystal structure of the compounds in the coal sample at various temperatures (25-350 °C). The XRD analysis of various temperatures obtained compounds from the coal sample, dominated by quartz (SiO₂) and corundum (Al₂O₃). The increase in temperature of the thermal treatment showed a better crystal formation.

1. Introduction
Coal is physically heterogeneous and chemically complex consisting organic and inorganic components, which contains the types of mineral, bound in it, which are Carbon (C), Oxygen (O), Silicon (Si), Aluminium (Al), Magnesium (Mg) and Calcium (Ca). The mineral as impurities must be taken into account because of the higher the content, the lower the carbon content, causing the lower the heat value of the coal. One of the important factors in the use of coal for an industry is its mineral properties in the combustion processes. Minerals impurities are the main source of the elements that formed ash when coal is burned. The main supplement of coal-fired residue is elements in concentrations of 0.02% to over 0.5% in coal, and usually includes aluminium, calcium, iron, and silicon [1].

The need to understand the implications of coal-based properties due to their use as a fuel has led to the development of advanced techniques to characterize their heterogeneity. The use of coal as fuel demands an understanding of the implications of nature to characterize its heterogeneity. It takes a multidimensional approach to characterize the heterogeneity of coal properties. The type of applications, the ash problem, and the thermal behaviour of the burning process also affects the characterization approach [2].

2. Materials and methods

2.1. Materials
The coal was obtained from PT. Tambang Bukit Tambi, Jambi Province Indonesia. First, it was ground using a grinder FIRTSCHE Pulveisette-16, followed by sieving using shaker by Changsha Kaiyuan Instruments (60 Mesh, 100 Mesh and 150 Mesh) and Electrolab sieve shaker EMS-8.
2.2. Coal characterization
The coal samples were characterized by using SEM-EDX and Calorimeter Bomb. The Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectrometry were used to observe the morphology and to conduct the elemental mapping of the samples. The SEM-EDX used was software from Particle Metric PhenomProX and the electron optical magnification range 80-130.000x, a resolution higher than 10 nm, acceleration voltages about 5-15 kV. The PhenomproX with Energy Dispersive X-ray Spectroscopy (EDS) detector. The calorimeter analysis was using Calorimeter Bomb, type SE-C5500 Automatic Calorimeter AXT.

2.3. Thermal heating treatment
The thermal treatment on the samples were conducted using an oven CKiC 5E-DHG, Muffle Furnace Changsha Kaiyuan Instruments, hotplate Boeco MSH-420 with temperature variations of 25, 150, 250, 300, and 350 °C for 2 hours. The samples were then analysed by several instruments including proximate analysis, structural analysis using XRD, and determine the dissociation energy using Differential Scanning Calorimetry (DSC).

The proximate analysis procedure performed refers to the ASTM standard method, for the determination of the water content of ASTM D3173, for ASTM D3174 ash determination and for the determination of ASTM D3175 volatile matter.

To determine the crystal structure was using an X-Ray Diffraction (XRD) PAN analytical Xpert3 powder goniometer PW3050/60 type of Bragg-Brentano at the Faculty of Science and Technology at Jambi University. Data diffraction of XRD is collected using a target atom Cu (1.54 Å) at 40 kV and 30 mA at range 2θ 15°-70°, step 0.040 and measurement time of 0.5 s per step.

The dissociation energy was determined by using PerkinElmer DSC4000. The heat rate used was 50°C min⁻¹ at 25-350 °C. The sample weight of 0.053 grams corresponded to the aluminium pot as the sample site and the carrier gas flow rate (N₂) of 20 ml min⁻¹.

3. Results and discussion
3.1. Coal characterization
3.1.1. The SEM-EDX analysis
The SEM-EDX analysis was used to evaluate the morphology and the components contained in the coal sample. The SEM-EDX result is presented in Figure 1. The darker part of the coal particle corresponds to a higher hydrogen content, the shiny part corresponds to a higher carbon content, where some very bright parts may also correspond to mineral grains in coal particles [2]. The image also shows clearly separate mineralized structures with irregular morphological forms. This indicated that the minerals contained in coal were in the form of crystal structures, where the crystal structure has a fixed structure because the atoms were arranged regularly in a pattern that repeats periodically over an infinite long-range.

Figure 1. SEM-EDS analysis of the coal
From the EDX results, the dominating elements were C and O with the percentage of 56.13% and 35.13%. Sub-bituminous coal has a carbon value of 50-70% [1] and oxygen contained in coal with a content of 20-30% w/w derived from a variety of accumulating plant material or derived from oxygen inclusions that occur when contact of the source layer with oxygen in open air or water at the time of sedimentation. Besides C and O elements, it also found other elements, which are Si, Fe, Al, Ca and Mg with a percentage of 10.97%, 2.21%, 0.49%, 0.7%, and 0.43%, respectively. Silicon was one of the macro elements in coal with 2.82% concentration in coal of anthracite level and 10.38% for sub-bituminous level [3]. The potential of mineral content from this coal sample was SiO$_2$, Al$_2$O$_3$, MgO, CaCO$_3$ and Fe$_2$O$_3$.

3.1.2. The calorimeter analysis

The result of coal calorific value analysis was 4905.6 Cal g$^{-1}$, this heat value indicated that the sample was categorized as sub-bituminous coal type (low-calorie coal). In the previous research, the value of calories for coal with sub-bituminous rank was 5793.2 and 5706 Cal g$^{-1}$, which was classified as sub-bituminous coal type. General coal in Indonesia, especially Sumatra can be categorized in the type of young coal or low-calorie that has a calorific value between 3500-6100 Cal g$^{-1}$. For the sub-bituminous grades of coal, the heating value obtained in this study was low, this low calorific value may be due to the oxidation process with air to the coal sample at the time of storage of the sample prior to the analysis. The low calorific value in coal was caused by the high level of ash that is impurities inside the coal, thus causing the caloric value to decrease.

3.2. The thermal heating treatment

3.2.1. Proximate analysis

Proximate analysis of coal is one of the first important variables to determine the quality and the initial identifier of the type of coal used. The proximate analysis results are presented in Table 1.

| Parameter         | Temperature (°C) |
|-------------------|------------------|
|                   | 25              | 150             | 200              | 250              | 300              | 350              |
| Inherent Moisture (%) | 3.07          | 0.79            | 0.42             | 0                | 0                | 0                |
| Volatile Matter (%)     | 20.7           | 10.8            | 5.51             | 3.81             | 2.2              | 1                |
| Ash (%)              | 19.2           | 86.2            | 91.9             | 94.2             | 97.1             | 98.6             |
| Fixed Carbon (%)      | 56.9           | 2.21            | 2.17             | 1.18             | 0.69             | 0.39             |

The moisture content in coal consists of several different forms of condensed water (surface free water), water bound to polar groups and cations (water absorbed), and water arising from the chemical decomposition of both organic and inorganic materials [4]. Based on Table 1, moisture content decreases with increasing thermal treatment temperature. The sub-bituminous coal has an inherent moisture of 0.1-1.4% [5].

As is the case with inherent moisture content of coal samples, the higher the temperature the volatile matter in coal decreases. This was because the flying substance is the organic part of the coal that evaporates when heated at a certain temperature. When coal is heated slowly, the volatile matter in coal is decreasing. Coal with bituminous and sub-bituminous grades has a volatile matter content of 15-45% [6].

The analysis of ash content at various temperatures shows that the ash content obtained was higher along with the increase in temperature. Ash is the residue of burning at high temperatures i.e. 950°C where the carbon element will be oxidized and the minerals contained in coal will bind to oxygen to form minerals such as oxides such as SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, CaO and other oxides. The higher ash content was due to the chemical changes in coal occurring in the presence of the filling process, the quantity of ash can be more than, equal to, or less than the amount of mineral material in coal,
depending on the nature of the minerals and the chemical changes occurring in the proliferation process. Various changes that occur include (1) loss of water from silicate minerals, (2) loss of carbon dioxide from carbonate minerals, (3) oxidation of iron oxide pyrite \[6\]. The higher the ash content will be able to degrade the quality of the coal production itself. High ash levels also cause problems in handling and disposing of large amounts of ash produced during the combustion process \[6\]. Sub-bituminous coal has an Ash content of 4-15\% \[6\].

Fixed carbon on coal related to combustion heat. Where the higher the temperature then the carbon content moored in coal will decrease further. This was due to the high ash content contained in the coal sample during the combustion process; the condition will be able to degrade the quality of the coal being analysed. Sub-bituminous coal has a fixed carbon content of 50-70\% \[6\].

From the result of proximate analysis for inherent moisture, volatile matter, ash, and fixed carbon of coal from PT. Bukit Tambi, Jambi Province, Indonesia was categorized into sub-bituminous levels.

3.2.2. The XRD analysis

The result of initial coal characterization using XRD at 25°C (Figure 1 and Table 2) indicated that the XRD spectrum was dominated by Si in Quartz (SiO\(_2\)) form, which was indicated by the presence of some sharp peaks at \(2\theta = 20.9014\) and 26.7465 with d-spacing [Å] 4.25018 and 3.3330 with trigonal crystal system (axis hexagonal) (JCPDS 00-046-1045). As for the Aluminium element identified in the spectra in the form Corundum (Al\(_2\)O\(_3\)). Corundum crystal structure has a characteristic of \(2\theta = 68.4323\), with a d-spacing value of 1.3698 Å and an intensity of 4.36\%. The characteristic of this position is almost in accordance with JCPDS 00-010-0173 standard that Corundum has 20 position characteristics at 68.1980.

Other minerals were calcite (CaCO\(_3\)) with a rhombohedral crystal system found at the peak of 20 39.5245 with d-spacing [Å] 2.28008 (JCPDS 00-05-0586), and hematite (Fe\(_2\)O\(_3\)) minerals with rhombohedral crystals, found at the peak of 20 65.9097 with d-spacing [Å] 1.41605 (based on JCPDS 00-033 -0664). The minerals identified by XRD correspond to the initial characterization results using SEM, where the dominant elements present in the coal content were Si, Al, Fe and Ca elements that were possible in the form of SiO\(_2\), Al\(_2\)O\(_3\), Fe\(_2\)O\(_3\), and CaCO\(_3\).

![Figure 2. XRD Spectra of the coal at 25 °C](image-url)
Table 2. Interpretation data of XRD of the coal at 25 °C

| 2θ [°] | d-spacing [Å] | Mineral          | Intensity (%) |
|--------|----------------|------------------|---------------|
| 20.970 | 4.2363         | Quartz           | 15.5          |
| 26.745 | 3.3315         | Quartz           | 100           |
| 36.643 | 2.4524         | Quartz           | 9.6           |
| 39.553 | 2.2784         | Quartz; Calcite  | 5.09          |
| 40.396 | 2.2328         | Quartz           | 3.57          |
| 42.527 | 2.1257         | Quartz           | 5.67          |
| 45.877 | 1.9784         | Quartz           | 2.96          |
| 50.240 | 1.8145         | Quartz           | 11.8          |
| 54.973 | 1.6689         | Quartz           | 3.96          |
| 60.054 | 1.5393         | Quartz           | 8.8           |
| 64.049 | 1.6706         | Quartz; Hematite | 3.6           |
| 68.432 | 1.3698         | Corundum         | 4.3           |

The XRD analysis of coal at various temperatures was done on temperature variations of 150-350°C with a range of 50 °C to see mineral changes or changes in crystal structure based on the position of 2θ. Changes in the structure of a crystal were strongly influenced by temperature, burning coal at high temperatures below 500 °C increased the crystalline structure of oxide minerals in coal such as SiO₂ [7]. Changes in minerals or changes in the structure of coal crystals by heat treatment are shown in Figure 3. Coal in lignite and sub-bituminous grades have high impurity minerals, the high percentage of ash and impurities is caused by the loss of most of the OH groups in silicates when the coal is isolated at high temperatures, where the XRD results state that SiO₂ minerals have the greatest percentage followed by pyrite, kaolinite, calcite and gypsum [8].

Figure 3 shows the XRD analysis with the temperature variations of 150 to 350 °C. The spectra obtained almost similar to the previous analysis conducted at a temperature of 25 °C (Figure 2), where these peaks show the dominant and consistent peaks of SiO₂ minerals at 350 °C temperature value 2θ = 26.7559 with a 100% intensity detected by JCPDS 00-046-1045 standard. Other mineral peaks also appear as CaCO₃, Fe₂O₃ and Al₂O₃. The shift value 2 on each increase in temperature variation is shown in Table 3.
Table 3. Interpretation data of XRD of coal with thermal heating (150-350 °C)

| Temperature (°C) | 150°C | 200°C | 250°C | 300°C | 350°C |
|-----------------|--------|--------|--------|--------|--------|
| θ [°] | Int (%) | θ [°] | Int (%) | θ [°] | Int (%) | θ [°] | Int (%) | θ [°] | Int (%) |
| 20.89 | 23.2 | 20.91 | 24.5 | 20.95 | 24.8 | 20.99 | 25.2 | 21.00 | 26.1 |
| 26.66 | 100 | 26.67 | 100 | 26.73 | 100 | 26.75 | 100 | 26.76 | 100 |
| 36.57 | 8.28 | 36.58 | 8.9 | 36.63 | 6.2 | 36.66 | 8.9 | 36.68 | 8.5 |
| 39.48 | 6.5 | 39.50 | 5.9 | 39.55 | 5.9 | 39.57 | 4.7 | 39.51 | 4.5 |
| 40.32 | 3.5 | 40.33 | 3.5 | 40.38 | 3.5 | 40.37 | 3.5 | 40.39 | 3.5 |
| 42.47 | 4.8 | 42.49 | 4.8 | 42.52 | 4.8 | 42.55 | 4.8 | 42.58 | 4.8 |
| 50.31 | 5.1 | 50.17 | 5.1 | 50.22 | 5.1 | 50.39 | 5.66 | 50.65 | 5.1 |
| 54.89 | 3.8 | 54.91 | 3.8 | 54.96 | 3.8 | 54.97 | 3.42 | 55.38 | 3.8 |
| 59.98 | 6.8 | 60.0 | 6.8 | 60.04 | 6.8 | 60.05 | 7.03 | 60.19 | 5.11 |
| 60.15 | 4 | 60.17 | 4 | 60.17 | 4 | 60.17 | 3.29 | 60.23 | 4 |
| 64.07 | 1.14 | 64.13 | 1.21 | 64.11 | 1 | 64.12 | 1 | 64.07 | 1 |
| 67.75 | 4.7 | 67.77 | 4.8 | 67.81 | 4.31 | 67.83 | 4.92 | 67.98 | 4.98 |
| 68.15 | 4.82 | 68.17 | 5.72 | 68.21 | 5.9 | 68.24 | 6.3 | 68.21 | 6.5 |

Based on Table 3, the increasing temperature used in the thermal process caused an increase in the value of θ, especially for SiO$_2$ which was in the range of 26.6609 with intensity 100%. The XRD analysis was consistent with the results of the proximate analysis, i.e. the higher temperature used in coal combustion was resulting the higher ash content and the lower the carbon fixed of the coal. It was caused by the high levels of silica formed. The analysis of coal samples using temperature variations of 50 to 1200 °C for ± 2 hours using SEM and XRD was dominated by SiO$_2$ minerals [9].

The shift in the values of θ were due to an increase in the energy that allows the atoms to vibrate at a greater distance between atoms that occurs in a heated material. When an atom has enough energy to break its bond, there will be a diffusion process where the atoms will jump to a new position. The higher energy (temperature) given to a material causes the larger spacing between the atoms and affect the phase and structure of the material. The phase changes and mineral structure of SiO$_2$ can also be seen from the crystal size, which can be known from the Scherer equation (D), where the higher temperature used the larger the crystal size. The comparison of crystal size formed by temperature variation in the thermal process is shown in Table 4.

Table 4. Size of SiO$_2$ crystals at various temperatures

| Temperature (°C) | θ | d-spacing [Å] | D (nm) | Intensity (%) |
|-----------------|---|--------------|-------|--------------|
| 150 | 26.6609 | 3.34366 | 10.37 | 100 |
| 200 | 26.6726 | 3.34222 | 10.65 | 100 |
| 250 | 26.7312 | 3.33502 | 14.63 | 100 |
| 300 | 26.7503 | 3.33269 | 14.88 | 100 |
| 350 | 26.7559 | 3.33206 | 15.79 | 100 |

Silica (SiO$_2$) is the simplest silicate material having three crystalline forms: quartz, cristobalite and tridymite. Based on the JCPDS 00-046-1045 standard, the SiO$_2$ crystalline phase was obtained in XRD analysis results in crystals of quartz. The quartz form of SiO$_2$ can be distinguished into 2, i.e. α-quartz and β-quartz. The difference between the two is in the crystal system and the value of its space group, where the quartz has a trigonal crystal system (a hexagonal shaft) and has a space value of P3121 and
P3221 where the quartz has a hexagonal crystalline system and has the value of space group P6222 and P6422.

In the results of the XRD analysis, the data obtained according to JCPDS 00-046-1045 standard shows that the value of space group owned for quartz mineral in this research is P3221 with trigonal crystal system (hexagonal shaft), it was identified that quartz mineral (SiO$_2$) obtained on the results of XRD analysis was classified in a α-quartz crystalline structure. The β-quartz was not formed in this study was due to the thermal treatment used in the low-temperature range of 150-350 °C so that SiO$_2$ atoms will be difficult to move for greater inter-atomic spacing positions. The crystalline-quartz system has a smaller atomic spacing than the quartz-crystalline system. The thermal treatment of SiO$_2$ at < 570°C low quartz temperature with a crystalline α-trigonal structure (hexagonal shaft) and for temperature 570-870 °C formed high quartz having a crystal β-hexagonal structure [10]. The SiO$_2$ crystal parameters were obtained from XRD analysis in this study are shown in Table 5 and the crystal structure in Figure 4.

**Table 5. The parameter of SiO$_2$ crystal system**

| Parameters       | Quartz        |
|------------------|---------------|
| Formula          | SiO$_2$       |
| Crystal structure| Trigonal      |
| Space group      | P 3221        |
| No space group   | 154           |
| a (Å)            | 4.9134        |
| b (Å)            | 4.9134        |
| c (Å)            | 5.4052        |
| Alpha (°)        | 90.0000       |
| Beta (°)         | 90.0000       |
| Gamma (°)        | 120.0000      |
| h k l            | 1 0 1         |
| d-spacing (Å)    | 3.34347       |

**Figure 4.** The crystalline α-quartz structure of the trigonal system (hexagonal shaft).
3.2.3. The DSC analysis

The DSC curve of the sample is presented in Figure 4. In this study, DSC curve shows two endothermic peaks, namely at 145 and 320 °C. The first endothermic peak at 145 °C, which was caused by the hydrolysis reaction occurring to water from coal. Within the temperature range of 100-200°C, there was a release of a chemical combination of water, followed by the release of compounds of light molecular weight that were weakly bound to the carbon group in the coal. At temperatures below 200°C coal undergo an initial decomposition stage where coal loses maximum water [11][12]. At higher temperature, the breakdown of coal chemical bonds began to occur and results in the formation of tar and light hydrocarbons. At higher temperatures, the breakdown of coal chemical bonds began to occur and results in the formation of tar and light hydrocarbons.

The percent of the sample weight lost during the DSC analysis was 1.5%. The mass loss occurs due to the release of moisture (H\textsubscript{2}O) in coal. In the first stage, the release of a chemical combination of water or hydrolysis was the breaking process of the H\textsubscript{2}O bond due to the heating process. This corresponded to the results of the analysis of proximate analysis on the determination of moisture content that was influenced by temperature rise. These results indicated a decrease in water content along with rising temperatures; this was due to the evaporation process. On thermal heating, low rank coal would experience shrinkage during the thermal heating process, causing moisture to escape from the pores of the coal particles at 100-110 °C, the collapse of the pore structure in the coal due to moisture loss and evaporation [4]. After the heating process, the moisture on the coal would become steam and attempt to exit the gap or cavity between coal particles into the air [13]. Thermal analysis of bituminous coal using PerkinElmer DSC7 with 50°C ≤ T ≤ 200 °C shows endothermic curve followed by the evaporative process of H\textsubscript{2}O bonding [14]. The thermal analysis of coal by DSC and Thermogravimetric explained that in the temperature range 75-118°C is the process of loss of water molecules with endothermic peaks in regions 50 to 150 °C [15].

![Figure 5. DSC curve of sub-bituminous coal.](image)

The second endothermic peak was found at 320 °C, this stage is called the active thermal decomposition stage. At this stage, the decomposition temperature can be used as a determinant of the degree of quality of coal. After losing water, at 200-400 °C, coal began to lose particle mass from the decomposition of phenol structure and carbon oxidation of carboxylate and carbonyl group [12]. At temperature 200-350 °C, sixth coal as research sample started experiencing pyrolysis reaction that is decomposed phenol and carbon oxide structures of carboxylates and carbonyl groups, which are represented by a short endothermic peak on the DSC curve [16].
The DSC curve also provides information about glass transition. The glass transition is a reversible transition from solid to amorphous material. The amorphous structure also represents the outside of a combustion product. This amorphous structure usually involves a major constituent element in chemical reactions associated with burning ash. At the beginning of the active thermal decomposition, the decomposition of compounds containing carbon, hydrogen, oxygen, and the release of volatile matter such as CO₂ (carbon dioxide) and CH₃ (methane) will begin to form pre-plastic phase (150-400 °C) [17].

The determination of an amorphous phase of a sample was also influenced by the heat capacity (Cp) and temperature, called glass transition temperature (Tg). In the glass transition (Tg), the solid will acquire sufficient mobility to convert the solid phase to the plastic phase. It can be observed that the inflexion point of the endothermic peak indicates the glass transition temperature in each sample used, and the glass transition temperature of each sample will vary within the range of temperatures used during the analysis.

The endothermic peak indicated that the thermal analysis performed on coal at a temperature of 100 to 350 °C is an endothermic reaction. The results of the DSC curve of the coal using the heating range of 20 and 50 °C min⁻¹ also found an endothermic peak that was at 140 and 330 °C, while with 100 °C min⁻¹, heat flow emerging exothermic peak and in the temperature range 425-450 °C [16]. The endothermic peak indicated the glass transition temperature of the coal sample [18]. On the DSC samples of bituminous coal samples also appear of weak endothermic curves of glass transition at a temperature of 90 – 180 °C that can be associated with evaporation of water, and water binds to hydrogen [14].

The presence of sharp endothermic peaks displayed on the DSC curve can be used to determine dissociation energy. The dissociation energy is a measure of the heat changes that occur at the breaking of the bonds expressed by the value of the enthalpy value (ΔH). In the dissociation energy can also be determined energy changes that occur during the reaction called the change in free energy Gibbs (ΔG). One aspect that is associated with the energy of a reaction is entropy (ΔS) which shows the degree of irregularity in a system, some of these energy determination parameters can be calculated using known Tm (onset), Tm (peak), and heat capacity (ΔCp) of the peak slope on the DSC curve. The parameters that can be determined from the endothermic peak slope shown from the DSC analysis can be seen in Table 6.

| Heat flow (°C min⁻¹) | Tg (°C) | Tm onset (°C) | Tm peak (°C) | Enthalpy (ΔH, Jg⁻¹) | Entropy (ΔS, Jg⁻¹K⁻¹) | Gibbs Energy (ΔG) |
|---------------------|---------|---------------|--------------|---------------------|------------------------|------------------|
| 50                  | 91.63   | 91.7          | 145.4        | 617.1               | 1.147                  | 0                |
|                     |         | 305.1         | 320.7        | 55.8                | 0.094                  | 0                |

The value of the dissociation energy is the number of enthalpy changes (ΔH) required for the breaking of the bond, where the positive value indicates that when the bond breaking process occurs the heat absorption process, called the endothermic reaction. The value of enthalpy (ΔH) at a peak value of 145.4°C is 617.1 Jg⁻¹. This high enthalpy value may explain that the energy required for the change is considerable. It can also be seen from the wide endothermic peak, seen in the temperature range 91.7-178.4°C. The release of moisture content in sub-bituminous coal is considerable, i.e., it can be seen from the amount of energy required for the process at 96.8 °C which has a wider and sharper peak than coal with anthracite and bituminous species that have shorter and smaller peaks.

The sharp endothermic peak at Tm peak 320.7 °C was the peak of active thermal decomposition that can determine the degree of quality of the coal. At this temperature occurred the release of phenol compounds and the oxidation of carboxylic acids and carbonyl groups. This corresponded to the results of the analysis of the volatile matter, where the higher the temperature will cause the level of volatile matter decreases. In this study, the active thermal decomposition peak was in the 300-340 °C.

\[ \text{Heat flow (°C min}^{-1}\text{)} \quad \text{Tg (°C)} \quad \text{Tm onset (°C)} \quad \text{Tm peak (°C)} \quad \text{Enthalpy (ΔH, Jg}^{-1}\text{)} \quad \text{Entropy (ΔS, Jg}^{-1}\text{K}^{-1}\text{)} \quad \text{Gibbs Energy (ΔG)} \]

\[ \begin{array}{cccccc}
50 & 91.63 & 91.7 & 145.4 & 617.1 & 1.147 & 0 \\
 & 305.1 & 320.7 & 55.8 & 0.094 & 0 & \\
\end{array} \]
temperature range, this temperature range may indicate that the coal sample used is included in the oxidized sub-bituminous coal level, the occurrence of this oxidation may be caused by coal that has reacted with oxygen in a period of time.

4. Conclusion
The characterization of coal PT. Tambang Bukit Tambi, Indonesia with temperature variation i.e. moisture content, volatile matter and fixed carbon have decreased with the increase of temperature, otherwise the higher ash content. This is due to the oxidation of carbon and other elements in coal and binds to oxygen to form oxide minerals.

The dominant mineral elements of C, O and Si with amorphous dominating structures were shown in the XRD results at various temperatures, the presence of this amorphous structure is amplified by the DSC results showing the two peaks of the endothermic curves of glass transition at 145 and 320 °C. The XRD analysis of various temperatures obtained compounds from the coal sample, dominated by quartz (SiO$_2$) and corundum (Al$_2$O$_3$). The existence of two endothermic curves of the glass transition in DSC analysis can determine dissociation energy value ($\Delta$H) of coal, which is 617.1 Jg$^{-1}$ and 55.8 Jg$^{-1}$.

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