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By Maulana Yusuf

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The Role of Organic Sulfur in the Formation of Methane Emissions on the Spontaneous Combustion of Coal

Maulana Yusuf[1*]

[1] Mining Engineering Department, Faculty of Engineering Sriwijaya University, Jalan Raya Palembang Prabumulih Indralaya, South Sumatra, 30862, Indonesia

* E-mail: maulanayusuf@ft.unsri.ac.id

ABSTRACT

Spontaneous combustion of coal is a phenomenon that often occurs in open coal mining activities, especially strip mining and open pit mining systems which are detrimental to mining companies, the economy, the environment, and society. This phenomenon causes coal mining activities to contribute to CH_4 gas emissions in global warming by 11% of total global emission. The purpose of this study was to analyze the role of organic sulfur in the formation of CH_4 gas emissions in the spontaneous combustion of coal in the TAL area. The approach is based on a literature review and field survey. The literature review was intended to examine the influence of geological factors, maceral analysis, and depositional environment on the rank and form of coal sulfur, while the field survey was conducted by measuring CH_4 gas emissions in 36 samples of spontaneous combustion hotspots. Literature review shows that coal in the TAL area belongs to low rank (sub-bituminous/sub-bituminous B) which has high organic sulfur content in the form of thiother bonds (C-S), especially carbon disulfide (CS_2). The average CH_4 emission measurement in the field is 6,989 mg/m^3, which is still within the limits set by other researchers, between 3,700–34,098 mg/m^3. The role of organic sulfur from C–S bonds especially CS_2 in the formation of CH_4 gas emissions, is very dominant at 93.10% or 6,507 mg/m3 of the total coal sulfur in the TAL area. The emission of CH_4 gas in the spontaneous combustion of coal is strongly influenced by geological factors, maceral analysis, and the depositional environment related to the rank and form of coal sulfur. Further, detailed, and comprehensive research on the form of organic sulfur needs to be carried out to mitigate CH_4 gas emissions in the spontaneous combustion of coal in the TAL area.

Keywords: spontaneous combustion of coal, hotspot, emissions of CH_4 gas, organic sulfur, thiother bond.

INTRODUCTION

The phenomenon of spontaneous combustion of coal has long been the concern of various experts because it is very detrimental to mining companies, the economy, the environment and society [Gorka, et al., 2022; Onifade & Genc, 2018; Onifade & Genc, 2019; Phenrat, 2020; Umar, et al., 2012; Zhu et al., 2018]. Spontaneous combustion occurs due to oxidation of coal at low temperatures, exothermal reactions, adiabatic processes, and long-term accumulation of coal causing self-heating to spontaneous combustion, which includes the following processes: latent stage, heat accumulation stage, evaporation stage, active stage, and hypoxic stage.

The stages of spontaneous combustion greatly affect the formation of gas emissions produced, especially greenhouse gases [Ahamed, et al., 2016; Hongqing, et al., 2017; Onifade & Genc, 2019; Ozdeniz, et al., 2014; Sloss, 2013; Wang & Chen, 2015; Zhu, et al., 2018]. Spontaneous combustion often occurs in various open pit mines in the world including Indonesia, especially low rank coal such as: lignite and sub-bituminous [Patnaik, et al., 2017; Wang, et al., 2003; Zhafira, et al., 2018]. Cases of spontaneous combustion have occurred in coal mining areas, especially low rank coal [Jia, et al, 2021; Pone, et al., 2007; Qi, et al., 2021; Singh, 2013; Wan-Xing, et al., 2011; Zhu, et al., 2022].

Spontaneous combustion of coal is strongly influenced by intrinsic and extrinsic factors. Intrinsic factors include: moisture content, volatile matter, ash/mineral matter, coal rank, sulfur content, heat due to soil movement, particle size, porosity, weathering, bacteria, temperature, ventilation, petrography, thermal conductivity, pyrite mineral content, and geology. While the extrinsic factors include: the condition of the pillars and roof in underground mines, ventilation systems and airflow rates, waste materials in the mine area, mining methods, work on coal seams, heat from the engine, and work outside the mine area [Lang & Fu-bao, 2010; Mirdha, 2012; Onifade & Genc, 2018; Onifade & Genc, 2019; Onifade & Genc, 2020; Singh, 2013; Zhao, et al., 2021]. Research on the two factors above has been carried out by many researchers from various disciplines in order to reduce or even avoid spontaneous combustion of coal in the mining area.

This research was conducted based on two approaches, namely: a literature review and a field survey. The literature review analyzes geological factors, maceral analysis, depositional environment related to the rank and form of sulfur, and the influence of sulfur in spontaneous combustion of coal. The rank and form of sulfur will greatly affect the formation of CH_4 gas emissions in spontaneous combustion of coal [Damayanti & Khaerunissa, 2018; Deng, et al., 2015; Gao, et al., 2022; Wang & Chen, 2015]. Research on the effect of sulfur on CH_4 gas emissions in spontaneous combustion of coal is mostly carried out in the form of inorganic sulfur, especially pyrite and sulfate minerals rather than organic sulfur [Gao, et al., 2022]. While field surveys were carried out by measuring CH_4 gas emissions at spontaneous combustion hotspots in the TAL area using a modified static closed chamber technique connected to a multigas detector [Dong, et al., 2007; Minamikawa, et al., 2015; Pihlatie, et al., 2013; Sudramanian & Pazhanivelan, 2019].

One of the effects of spontaneous combustion of coal is the emission of greenhouse gases, such as: CO_2 and CH_4 gases which are exposed to the air which greatly affect global warming. CH_4 gas is one of the greenhouse gases whose global warming potential is 28–36 times that of CO_2 gas over a 100 year period [Aldhafeeri, et al., 2020; Kholod, et al., 2020; Wu and Mu, 2019]. Research on the concentration of CH_4 gas emissions in coal mining activities in the field shows quite large results ranging from 3,700–34,098 mg/m^3 [Fabianska, et al., 2019; Gorka, et al., 2022]. Coal mining activities contribute 11% of CH_4 gas emissions to global warming [Kholod, et al., 2020]. The increase in the concentration of global CH_4 gas emissions is closely related to increasing global climate change, it is predicted that global temperatures will increase in the range of 1.8–4.0 °C or an average of 3.0 °C [Rahman, 2018]. The Paris Agreement in 2015 has limited global temperature increases to between 1.5–2 °C [Lamb, et al., 2021]. CH_4 gas emission in spontaneous combustion of coal is a serious concern for mining companies, environment and mining experts in order to mitigate this gas emission.

Data collection of CH_4 gas emissions on spontaneous combustion of coal in the field can be grouped into three methods, namely: measurement of point sources, measurements of coal piles, and measurements of ambient air. Point source measurements are mainly carried out at coal vents and crevices using sample grabs, optical techniques, and remote sensing. Sampling was carried out using glass and plastic or stainless steel tubes which were then subjected to laboratory tests [O'Keefe, et al., 2011 in Sloss, 2013]. Measurements on coal piles are carried out using a chamber that is placed on a pile of spontaneous combustion of coal, especially using a closed dynamic chamber [Engle, et al., 2012 in Sloss, 2013; Carras, et al., 2009 in Sloss, 2013; Cook & Lloyd, 2012 in Sloss, 2013; Lilley, et al., 2012]. Measurement of ambient air around spontaneous combustion of coal is very difficult to do, especially for equipment mobilization and requires very expensive operational costs [Carras, et al., 2005 in Sloss, 2013].

The conditions of the research field in the TAL area are difficult with steep topography and spontaneous combustion hotspots located spread out, so the measurement of CH_4 gas emissions is efficient and effective using closed static chambers [Engle, et al., 2012 in Sloss, 2013; Carras, et al., 2009 in Sloss, 2013; Cook and Lloyd, 2012 in Sloss, 2013]. Research on spontaneous combustion of coal in the TAL area uses a closed static chamber modification with considerations of shape, size, material, simple operation, relatively cheap, and the technology is very easy to adopt while the disadvantage is that after the chamber is placed above the hotspot there will be different conditions inside and outside the chamber. These conditions cause the concentration of CH_4 gas emissions in the chamber to increase with time [Heinemeyer & McNamara, 2011; Pihlatie, et al., 2013].

This study aims to analyze the role of organic sulfur in the formation of CH_4 gas emissions at coal spontaneous combustion hotspots which are scattered in the TAL area using a closed static chamber method as a gas trap and a multigas detector as a tool to measure CH_4 gas emission.

METHODS

The research approach is carried out by connecting literature reviews with field surveys [Taherdoost, 2022]. Both approaches will be able to answer the research objectives stated above. The literature review discusses the relationship between geological factors, maceral analysis, depositional environment related to the rank and form of coal sulfur, and the effect of sulfur on spontaneous combustion of coal related to the form of organic sulfur which affects the formation of CH_4 gas emissions in spontaneous combustion of coal. A field survey was conducted to measure the average concentration of CH_4 gas emissions at coal spontaneous combustion hotspots in the TAL area using a closed static chamber connected to a multigas detector.

Location and research design

The research location in the TAL area is one of PT. Bukit Asam (Persero) Tbk with an area of 7,261 ha with coordinates 103° 45' – 103° 50' East Longitude and 3° 42' 30'' – 4° 47' 30'' South Latitude. The research area is located in the mine front area with an area of approximately 10 ha. Coal mining in the TAL area uses an open pit mining method with an open pit mining system which produces low rank coal, such as: sub-bituminous and high rank coal, such as: bituminous and anthracite [Jati, et al., 2020; Miller, et al., 2019; Nafian & Rizal, 2021].

Measurement of CH_4 gas emissions was carried out at various coal spontaneous combustion hotspots spread across the TAL area, especially the mine front. Measurements are made only on spontaneous combustion hotpots that have taken place in the form of indications of the presence of smoke and hotspots and do not consider the initial process. Scheme for measuring CH_4 gas emissions in spontaneous combustion of coal in the TAL area can be seen in Figure 1.

Closed static chamber modification

The shape, size, and material of the closed static chamber are adjusted to the dimensions of the spontaneous combustion hotspots in the cubical TAL area with dimensions of 50×50×50 cm and 0.5 mm thick. The material used is stainless steel and is resistant to temperatures > 100 °C. The upper center of the chamber is equipped with a small pipe 2 cm long and 2 mm in diameter which functions as a place for gas emissions to the multigas detector which is connected to a plastic pipe. The chamber body is covered with fiber to prevent heat from entering and leaving (adiabatic process). Closed static chamber modifications can be applied to various ecosystems and measure low concentrations of CH_4 gas emissions [Chaichana, et al., 2018; Heinemeyer & McNamara, 2011].

MULTIGAS DETECTOR CALIBRATION

An important preparation before measuring CH_4 gas emissions is equipment calibration in

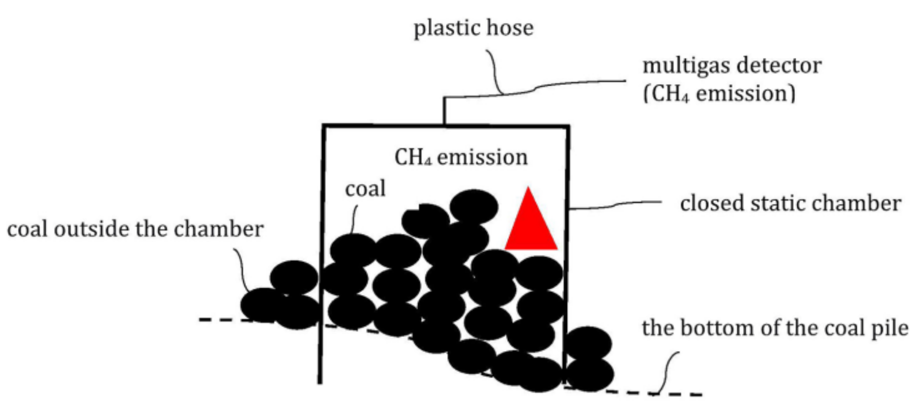

Figure 1. Scheme for measuring CH_4 gas emissions in spontaneous combustion of coal in the TAL area

the form of a multigas detector. Measurement of CH_4 gas emissions in the field encounters many obstacles, especially field conditions with steep topography, spontaneous combustion temperatures >100 °C, scattered spontaneous combustion hotspots, slow survey equipment mobilization, and examination of CH_4 gas emission data in the laboratory is very difficult, time consuming, and expensive. One of the ways to calibrate a multigas detector is to do it directly in the field outside the spontaneous combustion area. Calibration is carried out before taking measurements, the initial conditions are determined in the form of O_2 percentage, temperature, time, and CH_4 gas emissions under normal conditions (ambient) using the calibration on the equipment according to the rules recommended by the multigas detector manufacturer or the equipment manual based on MSA Altair 4X Multigas Detector Bump Test Procedure. Measurement of CH_4 gas emissions using a multigas detector is carried out if the initial conditions are in accorandce with the equipment and manual calibration instructions [Beswick-Honn, et al., 2017; Dong, et al., 2017; Wilkinson, et al., 2018].

CH_4 gas emission measurement

Measurement of CH_4 gas emissions in the field was carried out based on samples of coal spontaneous combustion hotspots which were dominantly scattered in the mine fronts of the MT4 and Murman locations in the TAL area. Data from measurements of CH_4 gas emissions at coal spontaneous combustion hotspots at the two locations using a chamber connected to a multigas detector obtained a total of 36 data (Table 1).

Data normality test

Measurement of the concentration of CH_4 gas emissions in coal spontaneous combustion hotspot samples in the TAL area obtained 36 data and it is necessary to carry out a normality test to see whether the data is normally distributed. Normally distributed data is needed for further analysis, such as: regression and determining the average CH_4 gas emission from a sample. The data normality test uses the Shapira-Wilk method because the amount of data is $n \leq 50$ [Kwak & Park, 2019; Hanuz, et al., 2016; Tomsik, 2019]. The normality test of CH_4 gas emissions on 36 data with a confidence level of $p = 0.05$ shows that the data is normally distributed where $W_{count} = 0.938 > W_{table} = 0.935$.

RESULTS AND DISCUSSION

Measurements on spontaneous combustion of coal hotspots in the TAL area of 36 data obtained an average CH_4 gas emission of 10,654 ppm or 6,989 mg/m³ (CH_4 = 16.04 g/mol). If these data are compared with previous studies conducted using other methods and locations with values between 3,700–34,098 mg/m³ [Fabianska, et al., 2019; Gorka, et al., 2022], the results of measuring CH_4 gas emissions are still within these value limits. CH_4 gas emissions obtained from the results of field measurements are relatively large when multiplied by the global warming potential of 28–36 times that of CO_2 gas [Aldhafeeri, et al., 2020; Kholod, et al., 2020; Wu & Mu, 2019] of 251,619 mg/m³ CO_2-eq.

Analysis of rank and form of coal sulfur

The rank and form of coal sulfur is largely determined by the coalification process (geological factors) in certain depositional environments [Amijaya, 2005; Marwanza, et al., 2021; Maulana & Anggara, 2020; Sahay, 2010; Daulay & Santoso, 2008; Zamroni, et al., 2020]. The location of the Tanjung Enim TAL area including the South Sumatra Basin is one of the most important basins producing low rank coal in Indonesia, such as: lignite and sub-bituminous. Local intrusion of andesitic igneous rocks at the study site produces high rank coal, such as: bituminous and anthracite [Amijaya, 2005]. The uniqueness of the TAL area is the variety of coal formed from low rank to high rank which is different from other company's site, such as: Muara Tiga Besar, Banko Barat, Banko Tengah, and other areas. The varying rank of coal causes relatively different physical and chemical properties of coal.

Previous research in the TAL area was dominated by low rank coal, namely sub-bituminous and relatively few high rank coal, such as: low volatile bituminous and medium volatile bituminous [Santoso, 2017]. Maceral analysis shows that the low rank coal formed is dominated by huminite (34.6–94.6 vol.%), slightly sulfide minerals (0–2 vol.%), and kaolinite. The high rank coal that is formed is dominated by vitrinite (82.4–93.8 vol.%), a little illite, and rectorite

Table 1. Data from measurement of CH_4 gas emission in the TAL area

Sample	UTM coordinates	CH_4 gas emissions	
		(mg/m³)	Location
1	0363158 and 9586555	1 968	Front MT4
2	0363006 and 9586242	6 331	Front MT4
3	0363202 and 9586245	8 856	Front MT4
4	0362987 and 9586270	1 968	Front MT4
5	0365123 and 9586047	6 364	Front MT4
6	0365126 and 9586049	5 019	Front MT4
7	0365121 and 9586042	12 661	Front MT4
8	0365125 and 9586040	11 809	Front MT4
9	0365123 and 9586045	6 232	Front MT4
10	0365054 and 9586864	2 099	Front MT4
11	0365057 and 9586861	2 952	Front MT4
12	0365059 and 9586867	656	Front MT4
13	0365058 and 9586868	5 576	Front MT4
14	0363033 and 9586298	3 608	Front MT4
15	0364769 and 9585790	3 772	Front MT4
16	0363015 and 9586746	7 544	Front MT4
17	0363017 and 9586280	1 640	Front MT4
18	0362816 and 9586283	6 888	Front MT4
19	0364949 and 9586594	4 428	Front MT4
20	0365070 and 9586988	4 592	Front MT4
21	0365070 and 9586988	6 429	Front MT4
22	0365375 and 9586018	9 512	Front Murman
23	0363136 and 9586393	13 121	Front MT4
24	0363301 and 9586909	9 841	Front MT4
25	0363040 and 9586094	7 216	Front MT4
26	0363031 and 9586257	15 417	Front MT4
27	0363029 and 9586258	13 121	Front MT4
28	0363038 and 9586253	10 169	Front MT4
29	0363019 and 9586264	14 761	Front MT4
30	0364902 and 9586041	1 312	Front Murman
31	0363006 and 9586242	4 920	Front MT4
32	0363006 and 9586242	5 740	Front MT4
33	0362954 and 9586265	5 904	Front MT4
34	0363006 and 9586242	7 872	Front MT4
35	0363006 and 9586242	6 560	Front MT4
36	0363041 and 9586261	14 761	Front MT4
The average CH_4 gas emission		6 989	

Table 2. Form of coal sulfur

No	Coal rank	Sulfur form (%)				Description
		S_T	S_O	S_P	S_S	
1	Sub-bituminous	0.29	0.27	0.01	0.01	Coal from the field
2	Bituminous	2.45	1.50	0.85	0.10	Coal blending
Percentage of sub-bituminous coal sulfur forms		100.00	93.10	3.45	3.45	

Note: S_T – total sulfur; S_O – organic sulfur; S_P – pyrite sulfur; S_S – sulfate sulfur.

while the most common minerals found are carbonate, pyrite, and marcasite [Amijaya, 2005]. The proximate and ultimate tests show that the coal in the TAL area includes low rank sub-bituminous coal (sub-bituminous B) with a calorific value of 5,617–6,992 kcal/kg while a low total sulfur value between 0.48–0.67% below 1% [Arisanti, et al., 2018; Belkin, et al., 2009; Sari, et al., 2017]. The literature review that has been carried out shows that the coal in the TAL area is dominated by sub-bituminous coal which belongs to sub-bituminous B with low total sulfur below 1% [Sari, et al., 2017; Schweinfurth, 2009].

The form of coal sulfur can be divided into two groups, namely: inorganic sulfur and organic sulfur. Inorganic sulfur consists of the pyrite and sulfate mineral which is dominated by the pyrite mineral. Inorganic sulfur can be easily removed through the washing process. While organic sulfur can be divided into two groups, namely: organic sulfur in micro molecules containing sulfur which is easily separated using organic solutions and organic sulfur in macro molecules forming thiother bonds (C-S) which are difficult to separate from the coal structure. Organic sulfur found in the coal structure consists of mercaptans, disulfides, thiothers, sulfoxides, sulfones, thiophenes, sulfonates [Gao, et al., 2022; Zhang, et al., 2016].

Total coal sulfur can be grouped into three forms, namely: organic sulfur, pyrite sulfur, and sulfate sulfur where pyrite sulfur and sulfate sulfur are included in inorganic sulfur. The next study will be carried out to analyze the total sulfur forming components in the TAL area in the form of organic sulfur, pyrite sulfur, and sulfate sulfur. Coal in the TAL area includes sub-bituminous coal (sub-bituminous B) with a calorific value between 5,617–6,992 kcal/kg with total sulfur between 0.48–0.67% [Arisanti, et al., 2018].

Research on organic sulfur, pyrite sulfur, and sulfate sulfur shows that in PT. Bukit Asam (Persero) Tbk mining area is dominated by organic sulfur, especially sub-bituminous coal [Belkin, et al., 2009]. The forms of organic sulfur, pyrite sulfur, and sulfate sulfur in the TAL area which consist of low rank coal (coal from the field) and high rank coal (coal blending) show that the form of coal sulfur is dominated by organic sulfur, pyrite sulfur, and sulfate sulfur respectively with different percentages (Table 2).

Sub-bituminous coal sulfur (sub-bituminous B) in the TAL area shows low total sulfur < 5% which indicates relatively low pyrite sulfur and sulfate sulfur not affected by the influence of sea water and is dominated by organic sulfur. Conversely, high total coal sulfur > 5% is influenced by sea water and is dominated by high sulfur pyrite and sulfate sulfur [Purnama, et al., 2018]. Analysis of rank and total coal sulfur in the TAL area shows that it is dominated by sub-bituminous (sub-bituminous B) with total sulfur content in the form of organic sulfur.

Analysis of organic sulfur on CH_4 gas emissions

Analysis of the rank and form of sulfur that has been carried out based on a literature review shows that the rank of coal in the TAL area is dominated by sub-bituminous (sub-bituminous B) with a very high organic sulfur form (93.10%) compared to pyrite sulfur (3.45%). Organic sulfur consists of two groups, namely: organic sulfur in the form of micro-molecule containing sulfur which is easily separated using organic solutions and organic sulfur in the form of macro molecules in C-S bonds which are difficult to separate from the coal structure. Coal organic sulfur in the form of macro molecules if spontaneous combustion of coal occurs will cause emissions of gases that are exposed to the air, such as CO, CO_2, H_20, and CH_4 [Zhang, et al., 2018; Wojtacha-Rychter & Smolinski, 2020]. The spontaneous combustion oxidation process of coal occurring at low temperatures can be detected early by measuring CO gas [Liu, et al., 2020]. High organic sulfur forms are found in the coal structure consisting of thiol (SH), thiother (C-S), sulfone (SO_2-C), and thiophene (CH-S) bonds which greatly affect the occurrence of further reactions in self-burning coal [Borah, et al., 2001; Gao, et al., 2022; Zhang, et al., 2016].

Very little research has been done on the role of organic sulfur in the process of spontaneous combustion, which has been demonstrated through field and laboratory research, especially in the formation of CO and CO_2 emissions. Most of the approaches taken to the role of organic sulfur in coal spontaneous combustion are mostly in the form of thiophenol and thiophene sulfur reactions with O_2 [Borah, et al., 2001; Zhang, et al., 2016; Gao, et al., 2022].

A literature review on geological factors, maceral analysis, depositional environment, and the role of sulfur in spontaneous combustion as described above shows that the coal in the TAL area contains organic sulfur and small amounts of pyrite sulfur and sulfate sulfur. The effect of pyrite sulfur and sulfate sulfur on the coal in the TAL area indicates a relatively small role in the spontaneous combustion process, especially the latent or incubation stage, the heat accumulation (oxidation) stage, and the evaporation stage. The content of organic sulfur in the TAL area is included in thiother sulfur (C-S) especially carbon disulfide (CS_2) because the rank of sub-bituminous/sub-bituminous B coal is almost close to bituminous coal. The content of elements C, H, O, and S in sub-bituminous coal in the TAL area causes spontaneous combustion to be greatly influenced by the presence of organic sulfur in the form of thiother bonds (C-S) in the form of CS_2. Self-heating and oxidation of coal with CS_2 at low temperatures will form COS and SO. The CS_2 oxidation reaction can be written [Glarborg, et al., 2014; Hosseini, et al., 2010; Rich & Patel, 2015; Zeng, et al., 2019]:

$$CS_2 + O_2 \rightarrow COS + SO \quad (1)$$

$$COS + O_2 \rightarrow CO + SO_2 \quad (2)$$

$$CS_2 + H_2O \rightarrow COS + H_2S \quad (3)$$

$$COS + H_2O \rightarrow H_2S + CO_2 \quad (4)$$

$$CS_2 + 3O_2 \rightarrow 2SO_2 + CO_2 \quad (5)$$

$$H_2S \rightarrow 1/2S_2 + H_2 \quad (6)$$

The sub-bituminous coal found in the TAL area has the characteristics of high organic sulfur (S), high water content (H), relatively high coal carbon (C) because it is close to bituminous coal, oxygen (O) is relatively available, self-heating and oxidation at spontaneous combustion can occur as in reactions 1–6. Early indications of self-heating and oxidation processes in coal spontaneous combustion are exposure to CO gas followed by CO_2, SO, SO_2, H_2 and H_2S. Reactions 1–6 show that organic sulfur, especially thiother bonds (C-S) in the form of CS_2 is one of the main causes of coal spontaneous combustion in the TAL area.

The formation of CH_4 gas emissions occurs after the formation of CO and H_2 gases originating from CS_2 bonds with the following reactions [Bogdan, et al., 2019; Hosseini, et al., 2010; Sudarmanian & Pazhanivelan, 2019]:

$$CS_2 + 4H_2 \rightarrow CH_4 + 2H_2S \quad (7)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (8)$$

The process of forming CH_4 gas emissions from organic sulfur in coal spontaneous combustion takes place at low temperatures. The contribution of organic sulfur, especially thiother bonds (C-S) in the form of CS_2, is very dominant at 93.10% of the total coal sulfur in the TAL area. The average concentration of CH_4 gas emissions from the measurement results is 6,989 mg/m^3 where the role of organic sulfur is very dominant at 93.10% or 6,507 mg/m^3. The role of sulfur in the formation of CH_4 gas emissions in coal spontaneous combustion begins to occur during the oxidation process which is largely determined by the form of sulfur in the mine area. Geological factors, maceral analysis, and depositional environment are very influential in the formation of the rank and form of sulfur in coal.

CONCLUSIONS

The form of organic sulfur in the TAL area is strongly influenced by geological factors, maceral analysis, and depositional environment, especially in the process of coal coalification related to the rank and form of coal sulfur. CH_4 gas emissions that occur in spontaneous combustion of coal hotspots in the TAL area are initiated by an oxidation process and are strongly influenced by organic sulfur, especially thiother (C-S) bonds in the form of CS_2 of 93.10% or 6,507 mg/m^3. Further, detailed and comprehensive research to determine the role of organic sulfur in coal spontaneous combustion is needed, especially proximate, ultimate and maceral analysis to ascertain the form of organic sulfur that occurs in the TAL area or other mining areas in Indonesia.

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