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RESEARCH ARTICLE

The Role of Inertinite Characteristics and Coal Porosity of Seam A-1 of The Muara Enim Formation in West Merapi, Lahat, South Sumatera, Indonesia

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Abstract

Coal contains a complex network of nano-, meso-, and a macro-pore can store fluids and allow fluids to flow through it. Nanoporosity in coal is primarily a result of molecules that have aromatic molecular structures and have been preserved in coal. Most adsorbate compounds, including gases, are stored here. The study area is located in South Sumatera, West Merapi Area, Lahat Regency. Geologically, the area in South Sumatra Basin belongs to the Middle-Late Miocene Muara Enim Formation. Using the ply-by-ply method, coal samples were taken directly from Seam-A in the coal mine walls outcrop, based on macroscopically determinable lithotype information. During laboratory analyses, coal is microscopically analyzed to determine the amount of porosity, permeability, and vitrinite reflectance. The purpose of this study is to investigate the change in composition and characteristics of inertinite macerals when the porosity value is varied.. Vitrinite content is between 91.00-92.80 %; liptinite 0.90-3.40%; inertinite 3.70-4.80%; mineral matter 0.7%-1.8%. Withh a vitrinite reflectance average of 0.34-0.36%, the variation in composition is an indication of changes in plant communities or coal facies. It is generally classified as sub-bituminous coal (ASTM). Porosity value of seam A upper is 1.9% and seam A lower 1.51%, permeability value seam A upper is 70.1 mD and seam A lower 27.1%. Composition of mineral matter in seam A upper is 0.8% and seam A lower 1.7%. The increasing number of inertinite pore is followed by lower porosity value. The inertinite maceral is predominantly aromatic with a high level of cross-linking, and exhibits a high level of aromatization and condensation. They have the highest carbon and the lowest oxygen hydrogen content. A coal maceral's porosity is composed of void spaces, such as open cell lumens preserved in semifusinite and sclerotinite. The porosity of cleats is the percentage of volume in relation to volume of coal, and the porosity of permeability. In coal, semifusinite has extensive interconnected pores that can form significant conduits for fluid flow.

Keywords: inertinite, porosity, mineral matter, permeability, fluid flow, vitrinite reflectance

1. Introduction

1.1 Sub Introduction

Considering coalbed methane plays typically span large areas of sedimentary basins, as well as the fact that the gas is mainly stored in an adsorbed state rather than free, coal is classified as a continuous-type, unconventional gas reservoir. Even though it is commonly believed that coal reservoirs are continuous, the properties of coal reservoirs are extremely heterogeneous. In fact, geologic factors can influence storage capacity, hydrocarbon content and production (Isabel, 2012). The geological factors influencing commercial hydrocarbon production in sedimentary basins vary considerably.

The researched area is part of the Muara Enim Formation. According to (Ginger and Fielding, 2011), this formation is a filler in the Middle-Late Miocene South Sumatra Basin which is composed of. carbonaceous, lenticular, laminated claystone, tuff sandstone, and coal interbedded. There are two coal seams, Petai, and Merapi, in the Muara Enim Sandstone Unit, and two coal seams in the Muara Enim Claystone Unit, Mangus, which will be the research target in the Seam-A and Suban part of Seam-B. Coal is classified as sub-bituminous (Koesoemadinata, 2002).

The coal contains a complex network of nanopores (<nm), mesopores (2-50 nm), and macropores (>50 nm) that enclose fluid, through which it can be transported and stored. As stated earlier, the large majority of adsorption compounds, including gases, is stored in coal's nanoporosity, which is apparently caused by the aromatic moleculer structure of its biopolymers. (Isabel, 2012). Macerals of inertinite have a high aromatization and condensation rate and are formed from mainly aromatic structures with a high degree of crosslinking. There is also porosity in coal macerals such as open cell lumens preserved in fusinite that can contribute to porosity. The macropores associated with primary coal fabric are largely not interconnected, therefore, it does not appear that they play an important role in coal bed methane production. Nevertheless, semifusinite can contain considerable porosity and act as an important conduit for coal fluid flow. (Isabel, 2012);(Diessel *et al.*, 1992) (Hodot, B.B., 1996) Hodot, (1966) classified coal pores into macropores (pores larger than 1,000 nm), mesopores (pores of 100 to 1,000 nm), transition pores (10 to 100 nm), and micropores (10 nm or smaller). There are various porous structures in a matrix with irregular surfaces and irregular structures. Porosity of coal beds is also affected by chemical structure, composition, and characteristics (Mastalerz et al., 2008; (Rahmad, Kusumayudha *et al.*, 2018). In addition, the rank of coal also affects porosity (Rahmad, Raharjo and Rahmanda, 2020). Based on their size, there are four types of pores in the matrix: macro, meso, transition, and micropores. It appears that macropores are found in low-grade coals, while the others are found in high-grade coals, according to Rahmad, Kusumayudha *et al.*, 2018.

The porosity of the coal will be affected by changes in the pore structure of the inertinite maceral. The more inertinite maceral in the coal, the greater the porosity of the coal, and vice versa (Raharjo, 2018).

Inertinite maceral shows regular and irregular pore structures (size, shape, and distribution). As the pore structure in inertinite is irregular, it affects the porosity value in coal.

Through petrographic observations of inertinite maceral coal, it can be seen whether the pore structure of the coal is regular or irregular. This can be used to determine whether the porosity of the coal is large or small.

The vitrinite reflectance (Rv) is one of parameter to determine of coal rank or maturity especially in thick Muara Enim Fomration's coal (Stach, 1982) One parameter to determine the composition of coal microscopy is from the aspect of coal type, which relates to coal-forming plant species and in its development will be influenced by biochemical processes during the peat process and the potential of coal methane gas resources in Keban Area, Lahat South Sumatera (Figure 1). An objective of this study is to determine the composition and characteristics of inertinite macerals as porosity changes.

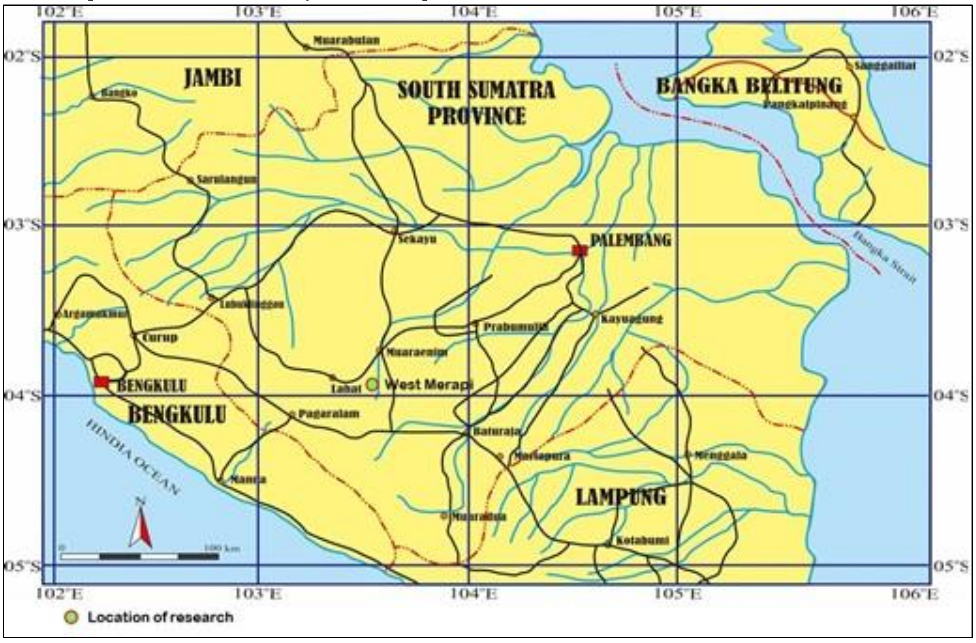

Fig 1. Location of the research, West Merapi, Lahat, South Sumatera

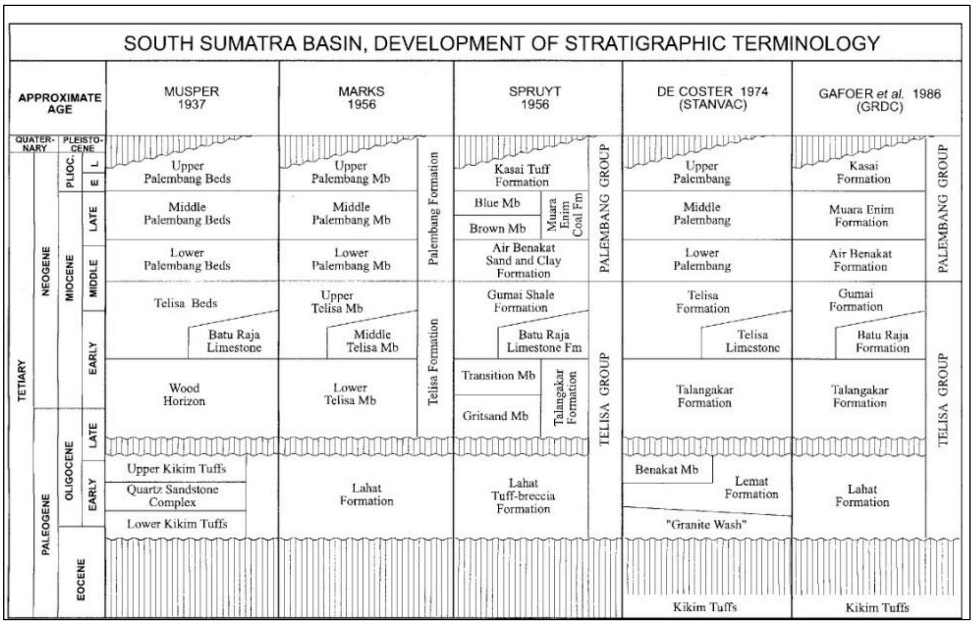

Fig 2. Regional Stratigraphy (de Coster, 1974 ; Ginger and Fielding, 2005).

2. Geological Setting

The South Sumatera Basin is one of back arc basin in Sumatera Island that was forming by tectonic activity of Indo Australian Plate and Eurasian Plate since Cenozoic to recent. Cretaceous-Eocene orogeny was resulting graben and half graben where filled up with terrestrial, volcaniclastic and deltaic sediment. On the Early Neogene was going to the transgresive system sediment such as Carbonate and marine clastics. The end of Neogene regressive system was very dominant producing fluvial to deltaic sediment. In this period was the beginning of high tectonic activity which produce a structural inversion and folding (Darman, H., Sidi, H.F., 2000) (Bemmelen, 1969) Within this basin area, 330510 km2, there is a tertiary sandstone outcrop called Barisan Hill in the southwest, as well as a shelf (Sunda Shield) to the east, a mountain range to the west, and the Lampung highlands in the southeast (A. J. Barber, M. J. Crow, 1974).

As mentioned previously, Syn Orogenic/Inversion Megasequence tectonics dominate the area under study, which according to (Ginger and Fielding, 2011) has resulted in several structural traps for hydrocarbons in the South Sumatra Basin. It is an east-west oriented anticline that dominates the Muara Tiga Besar area. A similar slope of the layer is observed in the studied area to that of the northern limb of the anticline (homocline).

Studies were conducted in a part of the Muara Enim Formation, an infill formation that lies within the South Sumatra Basin. The formation dates back to the middle-late Miocene, say (Ginger and Fielding, 2011). A period of increased volcanic activity occurred during the Late Miocene in the Bukit Barisan Mountains. Fluvial-deltaic environments deposit the vast majority of sediment material.

Generally, the South Sumatra Basin stratigraphy can be viewed as consisting of one megacycle, which includes transgression followed by regression. During the transgressive phase, the Talang Akar, Baturaja, and Gumai formations were deposited. While the Air Benakat, Muara Enim, and Kasai Formations were deposited during the regressive (Air Benakat, Muara Enim, and Kasai Formations), the Lemat and older Lemat Formations were deposited before the main transgressive. (Ginger and Fielding, 2011); (Figure 2).

The studied area consists of Muara Enim Sandstone Unit and Muara Enim Claystone Unit with their respective lithologies: carbon laminated, glauconitic sandstone, and coal interbedded. Material in the claystone unit consists of lenticular claystone, tuf sandstone, and carbon laminated claystone. As shown in Figure 3, The Muara Enim Sandstone Unit consists of coal seam C (Petai) and seam D (Merapi), the Muara Enim Claystone Unit contains coal seam A-1 (Mangus, which is the target of the research) and B (Suban). The rank of coal in the studied area are subbituminous-high volatile bituminous (Koesoemadinata, 2002);(Diessel *et al.*, 1992) ; (Diessel *et al.*, 1992).

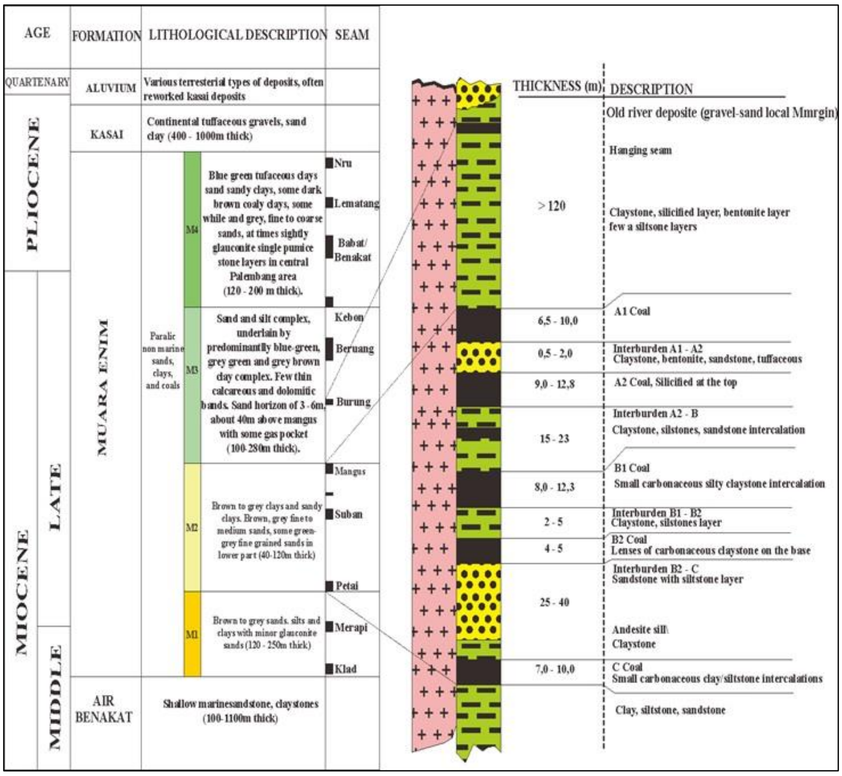

Fig 3. The stratigraphy and Coal Formations of Muara Enim (Shell Mijnbouw, 1978)

3. Sample And Methods

A study of coal mining was conducted in the Lahat region and its surrounding areas. Field methods include observation of coal seams, sampling for gasification development planning, and collecting infrastructure data. In Muara Enim Formation, seam Mangus Seam A-1 (10 meters) is the target coal seam. (Figure 4).

The coal samples were taken from the coal mine walls at Seam-A by the ply-by-ply method and based on the appearance of the lithotype macroscopically. Each sample is then reduced in size, and a composite is divided into two for archive purposes and laboratory analysis.

Laboratories perform the following analyses:

A. Coal porosity analysis, coal that has been cut into a beam shape is used to measure the porosity. The diameter of the beam is 2.5 cm and its height is 2 cm. In the following step, for one hour we put the dry sample into a vacuum desiccator and saturated it with kerosene.

B. An examination of coal microscopically to reveal maceral, vitrinite reflectances and mineral matter. During the polishing procedure, coal samples carried out from the mining wall outcrop. In order to prepare them, a variety of materials and tools need to be used, including:

(1) Coal samples (2) Pounder Tool (3) Resin/ transoptic powder (4) Sieve sizes 16, 20 and 65 mesh (5) Thermometers, and presses and print polished briquettes (6) Grinding-polish machine (7) Alumina oxide in sizes of 0.3, 0.05, and 0.01 microns; and 800 and 1000 mesh silicon carbide (8) Objective glass and night candles.

Fig 4. Coal sampling of Seam A-1

To obtain enough samples for analysis, the coal samples are quartered and concentrated from drill cores. Afterward, manual crushing of the coal samples was followed by sieving with mesh number 16 and 20. That grain size fractions of coal were used for petrographic analysis.

Coal fractions with an average size of -16 mesh + 20 mesh are mixed 1:1 with resin/ transoptic powder. A 200oC heat is then applied to the mixture in the mold. The mold is then pressed to 2000 psi after reaching 200^{o}C and the heater is turned off. Once the briquette reaches room temperature, it can be removed. As a next step, briquette polishing begins with a cutting tool (grinder-polisher) followed by smoothing with silicon carbide sizes of mesh 800 and 1,000. After that, polish with 0.3 microns, 0.05 microns, and finally 0.1 microns alumina oxide on silk or silk fabric. Using the night candle holder, the polishing incisions are placed on the preparatory glass, followed by leveling.

Polishing incisions are analyzed under a reflectance microscope both qualitatively as well as quantitatively to determine the mineral content and minerals in coal. An investigation using reflected light and examining 500 points under 200-fold magnification. Researchers conducted the analysis at the R&D Center for Mineral and Coal Technology in Bandung, Indonesia, under Spectrophotometer Polarization with Fluorescence with Microscope, type: MPM100, brand: Zeiss, is used in the coal mining classification (2856-1986., 1986)

4. Results And Discussion

Five coal samples from West Merapi were analyzed to determine the composition of the Seam A-1 coal: A-1(1), A-1 (2), A-1 (2), A-1 (3), A-1 (4), A-1 (5) (Tables 1 and 2) is vitrinite between 91.0% 92.8% ; liptinite 0.9% -3.4% ; inertinite 3.7%-4.8%. and mineral matter 0.7%-1.8% with vitrinite reflectance value 0.34%-0.36% (Rv random) which interpreted as lignite.

There are several microscopic features of the maceral group of vitrinite, including telovitrinite that is light to dark gray, light layers consisting of telocollinite, which no longer acts as a matrix for showing wood fiber structure, and Detrovitrinite by an average of 55.1% trapped within inertinite, liptinite, and mineral matter. In the subgroup maceral detrovitrinite, desmocollinite, dominates the larger percentage of macerals. Approximately 7,8% of densinite is found in a fine sized mix of vitrinite fractions, more tightly and homogeneously distributed than attrinite. In general, gelovitrinite tends to be homogeneous, round-oval in shape, and generally isolated inside desmocollinite. Only gelovitrinite maceral corpogelinite is found in the gelovitrinite subgroup (Figure 5).

Fig 5. Coal Microscopic of Seam A-1

Table 1. Macerals and mineral matter composition and reflectance vitrinite value of Seam A-1.

No.	Area	Age	Formation	Sample No.	LITHOTYPE	MACERALANALYSIS																												Rv random
						MACERAL GROUP (% Vol.)																									MINERAL MATTER (% Vol.)			
						VITRINITE(HUMMINITE)										LIPTINITE(EXINITE)									INERTINITE									
						Telovitrinite (Humotelinite)				Detrovitrinite (Humodetrinite)			Gelovitrinite (Humocolinite)												Telo-Inertinite			Detro-Inertinite		Gelo-Inertinite				
						Textinite	Texto-ulminite	E-ulminite	Telocollinite	Attrinite	Densinite	Desmocollinite	Corpogelinite	Porigelinite	Eugelinite	Sporinite	Cutinite	Resinite	Liptoderinite	Alginite	Suberinite	Flourinite	Exsudatinite	Bituminite	Fusinite	Semifusinite	Sclerotinite	Inertodetrinite	Micrinite	Macrinite	Oxide	Pyrite	Clay	
1	Lahat	Middle - Late Miocene	Muara Enim	**A-1 (1) TOP**	Coal, black, dull, spotly vitreous, blackish scratched , blocky	**91.0**										**3.4**									**4.8**						**0.8**			**0.34**
						1.7	2.1	-	80.9	2.4	3.1	-	0.8	-	-	0.3	2.6	-	0.5	-	-	-	-	-	1.7	1.0	1.1	1.0	-	-	-	0.8		
2				**A-1 (2)**	Coal, dark browish black-black, dull, rarely vitreous streaks, blackish	**92.0**										**2.1**									**4.1**						**1.8**			**0.35**
						1.9	2.3	-	80.4	2.6	3.6	-	1.2	-	-	-	1.4	-	0.7	-	-	-	-	-	1.3	1.4	0.8	0.6	-	-	-	1.8	-	
3				**A-1 (3)**	Coal, black, dull, rarely vitreous streaks, blackish scratched,	**91.9**										**2.6**									**3.9**						**1.6**			**0.35**
						1.8	2.7	-	81.0	2.3	3.2	-	0.9	-	-	0.2	0.8	-	0.4	-	1.2	-	-	-	1.8	1.2	0.6	0.3	-	-	0.2	1.4		
4				**A-1 (4)**	Coal, dark brownish black-black, dull, blackish scratched, blocky	**92.7**										**2.8**									**3.8**						**0.7**			**0.36**
						2.3	2.8	-	65.0	4.6	14.2	-	3.8	-	-	-	2.3	-	0.5	-	-	-	-	-	1.4	1.8	0.3	0.3	-	-	-	0.7	-	
1				**A-1 (5) BOTTOM**	Coal, dark brownish black-black, dull, blackish scratched, blocky	**93.7**										**0.9**									**3.7**						**1.7**			**0.36**
						1.9	1.4	-	70.9	8.8	9.2	-	1.5	-	-	-	0.6	-	0.3	-	-	-	-	-	2.0	0.7	0.8	0.2	-	-	-	1.7	-	

Fig 5. Coal Microscopic of Seam A-1

Table 2. Macerals composition, porosity and permeability of Seam A-1

No	Sampel	Rv random	Maceral Group (% Vol)			Mineral Matter (% Vol.)	Porosity	Permeability		Sample Photo
			Vitrinite	Liptinite	Internite		%	mD	Darcy	
1	A- (1) TOP	0.34	91.0	3.4	4.8	0.8	1.9	70.1	0.07	
2	A-1 (4)	0.35	92.0	2.1	4.1	1.8	1.85	41.4	0.04	
3	A-1 (3)	0.35	91.9	2.6	3.9	1.6	1.75	17.7	0.18	
4	A-1 (2)	0.36	92.7	2.8	4.1	0.7	1.55	48.6	0.49	
5	A-1 (1) BOTTOM	0.36	93.7	0.9	4.8	1.7	1.51	27.1	0.27	

The inertinite maceral group of Seam A composed by Telo-inertinite and Detro-inertinite. There is only maceral inertodetrinite in macro-Detro-inertinite. Compared with semifusinite, There is a major difference between maceral teleo-inertinite and maceral fusinite, in that the former has a higher relief and thinner cell walls. Furthermore, the structure appears clearer than semifusinite. Over 5% of all samples are composed of sclerotinite maceral (Figure 5). The maceral sclerotintes have oval or circular forms with high reflective properties, and they are believed to come from a fungus that contains black melanin known as mycelia.

Mineral matter analysis shows that the coal seam from the seam-A contains pyrite that present mostly as fine crystals within the dense macerals (Table 1; Figure 5).

Porosity and permeability values of Seam-A coal in East Merapi of 5 coal samples (Table 2) are: A-1(1), A-1 (2), A-1 (2), A-1 (3), A-1 (4), A-1 (5) show the porosity between 1.52%-1.9 % and the permeability 17.7-70.1 mD.

The comparison between the inertinite content and the porosity value shows that the incrasing inertinite parallelly to porosity while the permeability value tends to increase (Table 2).

In coal, fluids can be stored and can flow through a complex network of nanoporous (*nm), mesoporous (2-4 nm), and macroporous (>50 nm) spaces. It appears that aromatic molecular structures of biopolymers are the major source of nanoporosity in coal, and as mentioned earlier, this is where the vast majority of adsorbed compounds are stored, including the gases. The flow within the polymeric network is controlled primarily by diffusion rather than by Darcy flow, and the direction of flow within the nanostructure is determined by fluid concentration gradients rather than by pressure gradients.(Bustin, R. M. and Clarkson, C. R., 1999); (Pone, Halleck and Mathews, 2009) speculated that mesopores might provide space for multilayer adsorption in coal, but in reality we know less about their structure and origin.

As pore sizes increase, Darcian flow becomes more significant, and coal can contain macroporosities exceeding 5% at standard pressure (Isabel, 2012); (Mazumder *et al.*, 2006). In coal macerals, void spaces are found in the form of open cell lumens preserved in pyrofussite. Coalbed methane production appears to be limited to a few macropores associated with the primary coal fabric.

However, semifusinite may have considerable porosity and may form important conduits for fluid flow. The interconnected macropore space in coal is largely defined by natural fractures, particularly cleat systems, and is therefore of primary importance to reservoir properties. The coal cleat system consists of face cleats and butt cleats, which are orthogonal fracture systems with close spacing (cm to mm scale), analogous to joints in other rock types. (Figures 6 and 7).

The pores structure of coal, such as pore size, pore shape, pore distribution and interconnection between pores, can determine the porosity and permeability of coal, which is influenced by the type of coal and rank of the coal (Zhang *et al.*, 2014) The matrix structure related to the abundance of pore volume, like micropores, mesoporous and macropores, is a function of coal organic matter and vitrinite reflectance (Laubach, 1998); (Bustin, R. M. and Clarkson, C. R., 1999); (Pone, Halleck and Mathews, 2009) ; (Harpalani, S., Schraufnagel, R.A., 1990); (Harpalani, S., Chen, G., 1995)

Understanding the composition of maceral is important in understanding the properties of coal pores, porosity, and coal permeability when coal rank is stable or changes regularly (Zhang *et al.*, 2014) The composition of inertinite maceral contains more mesoporous (Clarkon & Bustin, 1996), in samples A-1 (1) and A-1 (2) as in Figure 5 that show the presence of pores in inertinite maceral which are different, especially in shape, pore size and pore distribution, in sample A-1 (1) the number of pores in inertinite is less than that in sample A-1 (2).

Fig 6. Cleat system of Seam A-1

Fig. 7. The Gases bubble on permeability by cleat system of Seam A-1

According (Bustin, R. M. and Clarkson, C. R., 1999); the increase in vitrinite reflectance will cause the number of mesoporous and micropores develop as a result of the smaller porosity. The increase in vitrinite reflectance will affect the porosity of the coal, the coal sample A-1 (1) Top Rv random = 0.34% has a porosity of 1.9% and sample A-1 (2) Rv random = 0.35%, the porosity decrease to 1.85% (Table 2). This is due to the coal processes and combined with the continuous physical compaction will decrease the coal porosity.

Permeability data from both samples show that sample A-1 (1) has permeability 70.1 mD, while sample A-1 (2) has permeability 27.1 mD. This permeability change is due to the fact that the two samples have different mineral matter, in sample A-1 (1) has mineral matter = 0.8% while sample A-1 (2) is 1.7%. Mineral matter will fill the pores in coal, the more mineral matter, the flow of fluid and gas will be obstructed.

Conclusion

- The increasing inertinite content is followed by the higher porosity value
- Porosity consists of void spaces in coal macrocrystalline materials, which can be preserved in the intracellular space in inertinite (semifusinite and sclerotinite)
- Semifusinite has considerable pores that can conduct fluids, which can be important for coal fluid flow
- The increase of vitrinite reflectance causes the porosity decrease, because the pores in inertinite is developed into mesoporous and micropores
- The increase in mineral matter causes permeability decrease due to mineral matter filling the pores, which will inhibit the flow rate of fluids or gases.

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