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AN INVESTIGATION OF THE COAL SEAM GAS CONTENT AND COMPOSITION IN SOMA COAL BASIN, TURKEY

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ABSTRACT: The Miocene Soma Basin in Turkey is estimated to contain at least one billion tons of lignite and about half of this reserve is present at depths greater than 600 m. In the Soma Basin, Turkish Coal Enterprises (TKI) has conducted open cut coal mining and underground coal mining activities for several decades in the Northern and Central part of the basin. It is known from the mining operations that the Soma coal basin has considerably gassy coal seams, but until now there isn't any sufficient scientific and technical research about gas content and composition of coal seams in the basin. Recently, coal exploration activities have been extended to the Southern part of the basin by means of exploratory drilling**.** In this context, 49 coal core samples were collected and were analysed in terms of gas content and composition. The gas content measurements indicate that as much as 4.2 m^3/t coal is present in the coal recovered from 1010.50 to 1010.90 m below the surface. The composition of the gas is dominantly methane with more than 80 %. Considering the chemical composition of the gas and gas indices, the source of the coal gas is biogenic probably generated by bacteria that are introduced to the coal seam by fresh water following mainly the normal faults bordering the graben structure. The possibility of coalbed methane potential of the basin is also investigated with regard to preliminary gas content data.

INTRODUCTION

Methane emission continues to cause serious problems during subsurface coal mining operations. These problems can be described as dangerous methane emissions that result in explosions, coal and gas outbursts, firedamp etc. However, methane can be removed from an underground mine by an efficient mine ventilation design. At high methane concentrations in workplaces, a methane drainage system might be used. Both of these applications can only be predicted by measuring the gas content of a coal seam.

Knowledge of the gas content of a given coal seam is most important for assessing the potential danger of methane emission during mining operations (Yalcin and Durucan, 1991). In order to evaluate the potential gas problems of a new mine or unmined areas of an underground mine, gas content measurements are the most important step for mining operations (Diamond and Schatzel, 1998). During the phase of an underground mine development, gas content measurements can be achieved from surface exploration drillings (Diamond, 1979; Diamond and Schatzel, 1998). An early assessment of the potential for methane emission problems provides the greatest amount of lead time to incorporate longer term gas drainage techniques into the mine development plan (Diamond, 1994). Once mining is underway, gas content testing can be used periodically to assess gas content conditions ahead of mining. Gas content data are also vital for determination of the commercial potential of a field, and core analyses provide that information. Economic production of coalbed methane depends on the amount of gas content. To understand the gas type that releases from the coal seams and neighboring strata, gas composition measurements should be performed.

In the Soma coal basin, coal seams are known as gassy since TKI operated the coal seams for decades. Because of this, the virgin coal seams, where depths are greater than 600 m,

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must be measured in terms of gas content before the mining operations. This paper involves gas composition analysis and a preliminary gas content study of an underground coalmine that has currently been established in the Eynez part of the Soma coal basin, Manisa Turkey. The purpose of the study is to collect sufficient gas content data from surface drillings and to perform a preliminary gas content assessment. Coalbed methane potential of the area is also investigated.

STUDY AREA

The Soma Basin has the most significant coal deposits in western Turkey. The total coal reserves of the Soma Basin are about 719 Mt; about 10.3 Mt of coal are annually produced by mainly open-pit mines, of which annually 7.7 Mt are used in Soma coal-fired power plants with 990 MW total installed capacity, whereas 772,325 tonnes are used for domestic heating and industrial purposes (TKI-ELI 2016). The annual production capacity of the new mine in the Eynez part of Soma coal basin is planned to be 5 million tons and the infrastructure will be adequate for 8.5 million tons/year capacity. Production is planned to commence in 2018 for the underground mine, which will be the deepest lignite mine in Turkey (Mining Turkey, 2016).

In the Soma coal basin, two common formations exist; the Soma and the Denis Formation. The Soma coal basin extends in a NE–SW direction in an approximately 20-km long and 5-km wide, fault-controlled basin in western Turkey. The major coal-bearing Soma Formation started deposition during the Early to Middle Miocene (Seyitoglu and Scott, 1991; Inci, 2002; Karayigit et al., 2017). A generalized stratigraphic illustration of the Soma coal basin and the location map of the study area are given in Figures 1 and 2 respectively (Karayigit and Whateley, 1997; Inci, 1998a; Karayigit et al., 2017). Paleozoic and Mesozoic basement rocks remained under the influence of Alpine Orogeny and as a result of folding and faulting, especially graben type faultings, they formed basins necessary for the deposition of Miocene deposits. Neogene is represented by Miocene Basement series (composed of pebblestone, sandstone and clay, (M1), Lower Lignite series (KM2), Marl series (M2), Limestone series (M3), Middle Lignite series (KM3) and Pliocene Sandstone-Siltstone-Mottled Clay series (P1), Upper Lignite series (KP1), Clay-Tuff-Marl series (P2ab), Clay-Sandstone-Pebblestone series (P2c) and Silicified-Limestone-Tuff series (P3) from bottom to top respectively.

The study area involves coal seams that are independent from each other due to geological conditions. Eynez part of the Soma coal basin has three coal seams and are named KP1 (upper seam), KM3 (middle seam), and KM2 (main seam). According to mining operations, only the KM2 seam will be mined after termination of exploration drillings. As it is shown in Figure 1, the KM2 coal seam was settled on the M1 formation and the thickness of the KM2 seam ranges between 3.5 and 30 meters. The KM2 seam generally shows hard, massive and bright coal perspective. On the M3 limestone unit, the KM3 seam was settled and it shows a banded, bright black coal perspective. Average thickness of the KM3 coal series varies between 1 and 7 m. P1 series are followed by KP1 coal seam that is called the upper seam. According to Brinkmann et al. (1970), the KP1 coal series make an indicator series, which is important parameter for geologists. Thickness of the KP1 coal seam varies from 0.5 to 4.5 meters and it doesn’t have economical value in terms of the mining industry. Towards thestudy area from the TKI mine, coal depth increases as well. Due to past mining experiences in the mentioned area, it is believed coal seams have regional high gas concentrations. In accordance with the probability of increasing gas content, it is necessary to investigate the gas content of the coal seams in this area.

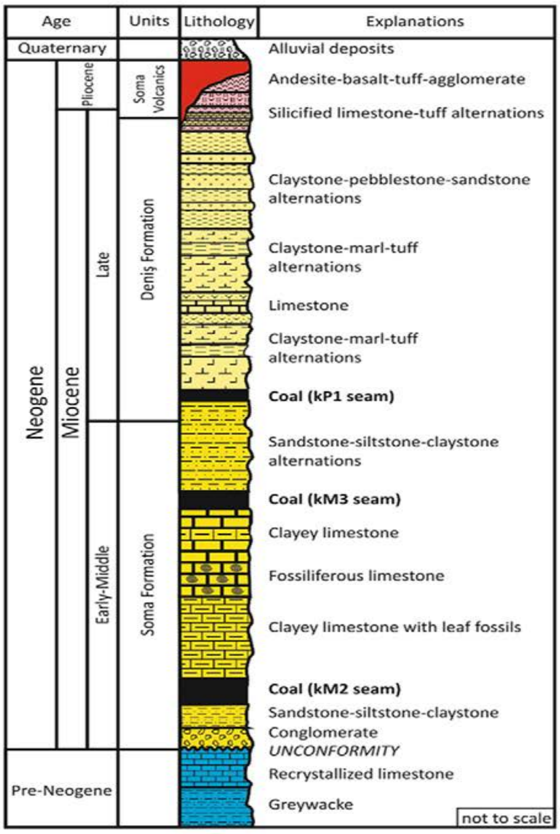

Figure 1: Generlized Stratigraphic illustration of the Soma Basin (from Karayigit et al., 2017).

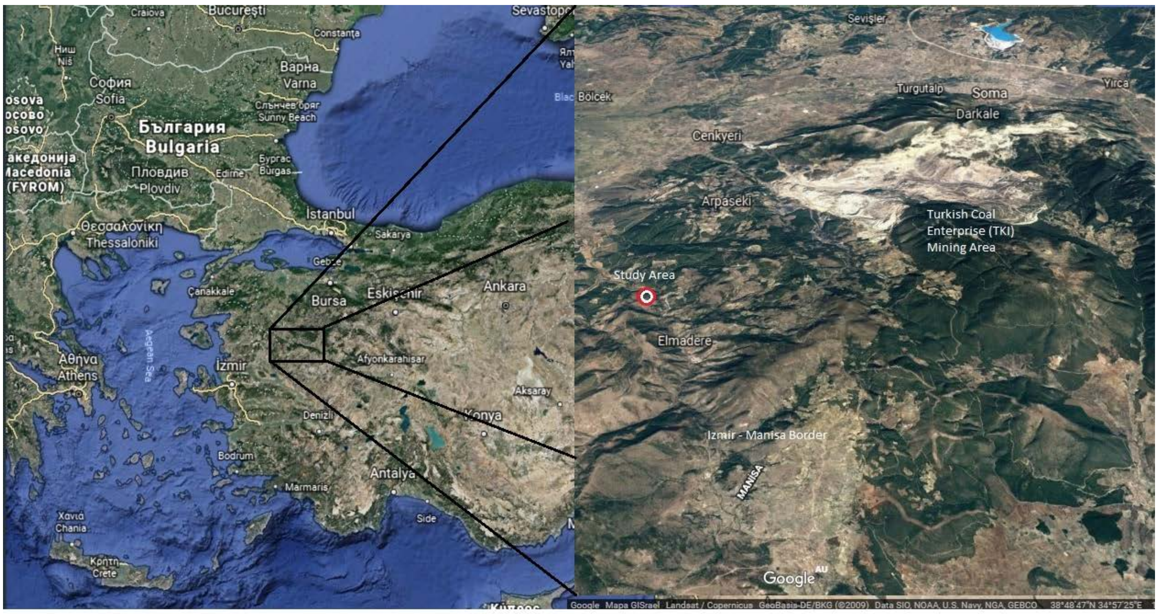

Figure 2: Location map of the study area in the Soma coal basin.

MATERIALS AND METHODS

Coal gas content analyses for 49 samples from 18 wells and coal gas composition analyses for 6 samples (Table 1) were carried out both in the field and at Istanbul Technical University, Faculty of Mines, Mine Ventilation and Safety Laboratory. Coal seam gas content determinations have been based on following the "USBM Gas Content Direct Method" and

ASTM D7569-10 “Standard Practice for Determination of Gas Content of Coal-Direct Desorption Method”. Gas composition analyses have been performed via Gas Chromatography device. Proximate analyses were performed with ASTM Standars that are very useful for classifying the coal seams in terms of their gassiness and their chemical properties.

Gas Content Measurements

Gases associated with coal seams are formed as a result of the coalification process. Coal seams can contain a mixture of gases in which methane makes up 80–90 % (Creedy, 1991) and varies from 0 to 25 m^3/t (Noack 1998). Minor amounts of carbon dioxide, nitrogen, hydrogen sulfide, and sulfur dioxide make up the other components of coal seam gases (Flores 1998). It is necessary to determine the coal seam gas content and its gas composition beforehand to protect the mining workplaces and also to determine the gas potential of the mining area l. A coal seam gas content named as total gas content can be determined by three components. These components are “Lost Gas”, “Desorbed Gas or Measured Gas” and “Residual Gas” which are determined by the rules of USBM Gas Content Direct Method (Bertard et al., 1970; Diamond and Levine, 1981; Diamond et al., 1986; Diamond and Schatzel, 1998).

Table 1: Collected coal samples and their properties.

Well ID	Coal Seam	Depth (m)		Canister No.
		From	To	
PF-27	KM2	1248.20	1248.50	8
	KM2	1249.70	1250.00	4
	KM2	1250.70	1250.90	9
	KM2	1252.00	1252.40	3
	KM2	1255.30	1255.60	7
PF-28	KM2	1007.53	1007.80	1
	KM2	1009.48	1009.70	2
	KM2	1010.50	1010.90	5
PF-29	KM2	717.80	718.20	1
	KM2	718.80	719.10	5
	KM2	722.10	722.50	6
	KM2	719.70	720.00	7
PF-32	KM2	684.50	684.80	8
	KM2	685.50	685.80	1
PF-33	KP1	520.70	521.00	Y10
PF-34	KM2	830.00	830.20	Y4
	KM2	831.30	831.50	Y16
PF-35	KP1	612.10	612.30	Y18
	KP1	614.00	614.20	Y9
	KP1	614.60	614.70	Y14
	KP1	615.80	616.10	Y20
	KM2	753.50	753.80	Y1
	KM2	754.80	755.10	Y2
	KM2	756.80	757.10	Y3
PF-36A	KM2	632.50	632.70	Y5
PF-37	KP1	599.70	600,00	Y17
	KM2	744.40	744.70	Y11
	KM2	744.70	745.00	Y8
	KM2	745.90	746.15	Y10
PF-38	KP1	593.10	593.35	Y8
	KP1	659.40	659.70	Y3
	KM2	794.40	794.65	Y18
	KM2	795.70	795.90	Y16
PF-39	KP1	510.10	510.22	Y13
	KP1	512.15	512.33	Y19
PF-40	KP1	572.60	572.80	Y6
	KM2	710.15	710.35	Y11
PF-41	KP1	665.60	665.80	Y7
	KM2	864.30	864.50	Y6
	KM2	888.85	889.10	Y3
PF-42	KP1	470.00	470.25	Y2
PF-43	KP1	694.35	694.60	Y15
	KM2	910.10	910.30	Y2
PF-44	KM2	859.30	859.50	Y7
PF-48	KM2	1040.95	1041.15	Y19
	KM2	1045.70	1045.90	Y6
KGT-1	KP1	659.60	660.20	Y13
	KP1	677.40	677.70	Y11
	KP1	677,7	678	Y12

Lost gas, which is called Q1, is the important part of the total gas content, which can be estimated only from the initial gas readings of the coal by a plotted graph of desorbed gas. On the other hand, lost gas is the gas that releases from the coal sample during coring until it is sealed into the canister. Coal sample collection and gas desorption tests areperformed during the coring operations and five important times have been recorded for the estimation of lost gas. These lost gas estimation times are; the time of the first penetration of the coal (time coring started), the time that presents the end of coal penetration (time coring ended), after ending the coal penetration the retrieval of core (core-off bottom time), surface arrival time (time core at surface), and the time when the canisters were sealed (time canister closed). These parameters must be recorded on the canister spreadsheet which is indicated by Barker and Dallegge (2005).

Desorbed gas (Q2) can be measured from a coal sample that is sealed in the canister and a graduated cylinder as it is suggested by Diamond and Schatzel, (1998). The initial readings, especially in the first 3 hrs are very important in estimation of lost gas. Desorbed gas readings must be taken every 5, 10 and 15 minutes for the first hour. Then, measurements can continue with increased times of gas readings which is actually depend on the gas desorption rate. Generally, the termination of desorbed gas measurement is when the daily emissions were less than an average of 10 cm^3 of gas desorption per day for one week as suggested by Diamond and Levine (1981). Once a coal sample ceases to release more gas effectively, then the coal sample is removed from the canister for determination of Residual gas (Q3) in the grinder. Following the termination of desorption tests, coal sub-samples were taken into grinder for residual gas measurement. Each coal sample were pulverised under 250 microns (60 mesh). This causes opening of the micropores of the coal matrix which includes the gas molecules at the adsorbed state. Finally, total gas content of each coal samples were determined by the given equation (Diamond and Schatzel, 1998);

$$Q_T = \frac{Q_1 + Q_2}{M_t} + \frac{Q_3}{M_c}$$

In this equation;
M_t = coal mass that is collected in desorption canister (g),
M_c = coal mass that is used in residual gas analyses (g).

Provided coal cores from the wire-line coring were collected and selected macroscopically and sealed in the airtight and stainless steel desorption canisters. The desorption canisters have 7.0 cm inner diameter and 30 cm length (Figure 3). In the coring operation, the diameter of the drilling core was NQ (inner diameter 4.76 cm) and core was sectioned into the desorption canister as closely as possible to minimize the headspace volume. Desorption canisters were also filled with distilled water to remove headspace calculation errors. Both ambient temperature and barometric pressure were also recorded during each gas measurement. The reservoir temperature was measured at the drilling site and selected as 28ºC. All measurements were entered into a canister spreadsheet for determining the coal seam gas content.

Figure 3: A view of desorption canisters in water at 28˚C reservoir temperature.

Gas Composition Measurements

In order to determine chemical composition of coal gas, a gas chromatograph is utilized. Since gas contents of lignite seams are commonly low, it is imperative to apply chromatography techniques. A Gas Chromatography (GC) device can work with gas samples with limited volume. Agilent 7890A model gas chromatography is utilized to analyse chemical compositions of gas. The device includes two detectors at the end of the columns. Flame Ionization Detector (FID) is utilized to detect hydrocarbons in coal gas content and Thermal Conductivity Detector (TCD) is utilized to detect the remaining gas compounds. Air contamination during gas composition measurements is eliminated by normalization calculations, that, equivalent atmospheric nitrogen and carbon dioxide of oxygen is substracted from the results. For determining the composition of coal seam gas in the Soma coal basin, some coal core samples were taken in canisters and the gas volumes were taken into vacutainers during desorbed gas measurements (Figure 4).

Figure 4: Gas sampling at the field using vacutainers.

Proximate Analysis

Proximate analyses were performed for better understanding of a coal seam gas classification at a mining area. It is also required for a gas assessment because coal type should be determined to classify the seams according to their gassiness. Coal cores were divided into sub-samples pulverized for the residual gas measurements. The testing procedure adopted throughout for proximate analysis conformed to the appropriate ASTM Standard for coal analysis and testing (ASTM D2013/D2013M-12; D3173-11; D3174-12; D3175-11). In summary, this procedure involved the drying of a known mass of coal in an oxygen-free oven at 107°C for a period of one hour. After removal from the oven, and subsequent to the sample being placed in a desiccator, the coal was weighed, and the loss of mass ascribed to inherent moisture. Ash content determination was achieved by combusting the coal until a constant mass was attained in an ash furnace. This was achieved by heating the sample to 500°C for 1 hour before increasing the temperature to 750°C, until combustion was complete. Then, coal samples were stored in the furnace for 2 hours at 750°C. The percentage of ash was calculated from the mass of the residue remaining after incineration. The sample was then heated in a cylindrical silica crucible in a muffle furnace at 900°C for seven minutes. The loss of mass recorded during this process equated to the proportion of volatile matter present in the sample. The amount of fixed carbon was not determined directly, but represented the difference between the sums of all other components.

RESULTS AND DISCUSSION

49 coal core samples from 18 different surface exploration drillings were analysed for gas content and gas composition tests. 17 coal samples were taken from KP1 coal seam and 32 coal samples were taken from KM2 coal seam for gas content testing. Gas content (lost, desorbed and residual) and gas the composition of coal samples were determined by measurements in both field and laboratory. The proximate analysis of samples was conducted in the laboratory to classify the coals based on ASTM Standards.

It is known from the basic literature that the gas content of coal seams increase with increase in depth. The gas content, ash content and the moisture content of coal correlated with depth. The relationship between depth and total gas content of coal is shown in Figure 7. Gas content of the coal samples ranged between 0.48 – 4.20 m^3/t on as-received basis, 0.90 – 7.26 m^3/t on dry and ash free basis. The high values of gas contents on a dry and ash free basis might be caused by high values of ash contents in some samples. Although the correlation of gas content on an as-received basis with depth is low, the increasing trend corresponds with the gas content of the coal seams being increased by the increase of depth. The moisture and ash content of the coal seams on an as-received basis varied between 3.00 – 24.56 %, and 2.61 – 61.91 % respectively. Volatile matter of the coal seams are varied between 4.06 – 47.07 % on an as-received basis and 40.74 – 88.54 % on a dry and ash free basis. In this study, moisture content (Figure 8) and the ash content (Figure 9) of the coal seams decreased with increasing depth. According to ASTM standard, coal samples used in this investigation are classified as lignite but much closer to "sub-bituminous coal" due to volatile matter of 80 % of the coal samples being above 50 %. This is caused by high values of ash and moisture content that affects calculation of the volatile matter of coals.

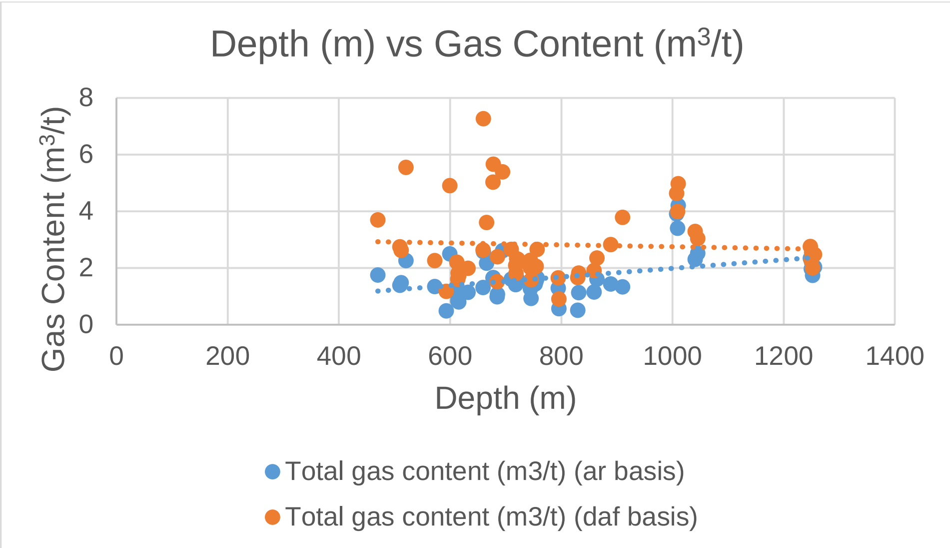

Figure 7: Relationship between coal seam gas content and its change with depth.

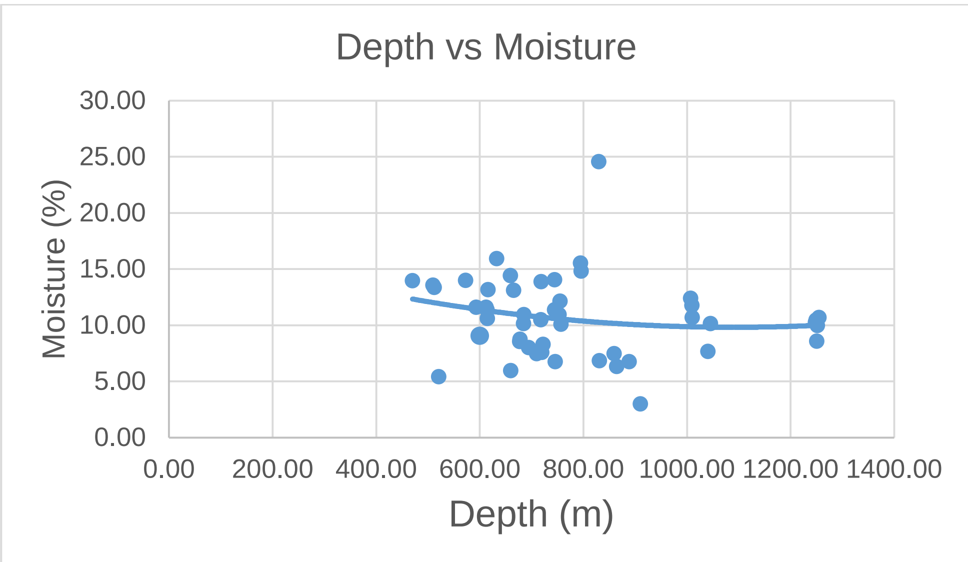

Figure 8: Change of moisture content in coal with increase of depth.

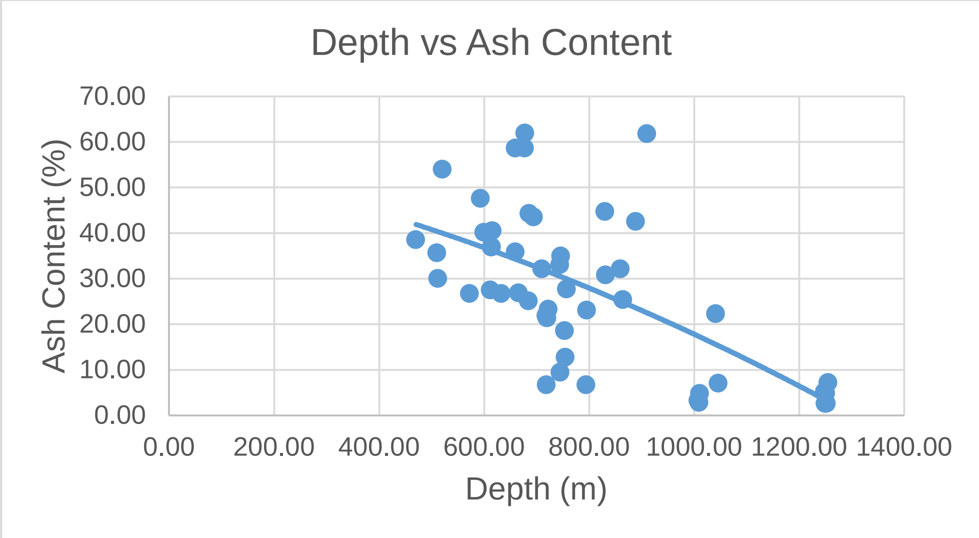

Figure 9: Change of ash content in coal with increase of coal depth.

The results of gas composition of coal are given in Table 4. To perform the gas composition tests, 6 coal samples were taken from the KM2 coal seam due to its economical importance. The results show that methane is the dominating compound in the gas content with relatively lesser variation in other gases. Apart from other factors, gas composition of the seam is favorable for CBM production. The ratio of C1 / (C1+..+C5) is 99.8 % in average with negligible variation suggesting dry CBM (Li, et al., 2015).

Table 4: Results of gas composition measurements of the KM2 coal seam.

Coal Seam	Canister No.	Depth	CO2	He	H_2	N_2	CO	CH_4	C_2H_6	C_2H_2	C_2H_4	C_3H_8	iC_4H_{10}
		(m)	(%)	(ppm)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
KM2	K302	943.45-943.60	0.666	24.7	0	21.259	0.076	77.934	0.061	0	0	0	0
KM2	K303	941.30-941.40	0	0	0	4.05	0.216	95.449	0.147	0.003	0	0.127	0.008
KM2	K304	1201.45-1201.60	3.759	0	0	3.36	0.302	92.333	0.243	0	0.004	0	0
KM2	K305	942.80-942.90	0	0	0	5.058	0.221	94.576	0.133	0.001	0	0	0.011
KM2	K306	946.55-946.70	1.289	0	0	11.235	0.105	87.305	0.066	0	0	0	0
KM2	K307	944.50-944.70	0.686	2.323	0,003	14.448	0.078	84.739	0.046	0	0	0	0
					Average	9.902	0.166	88.723	0.116				
					Variance	6.48	0.085	6.148	0.068				

Thakur (2011) has classified the coal seams that can be divided into three categories according to their gassiness and depth (Table 5). According to classification of Thakur (2011); in the Eynez part of the Soma coal basin, coal seams are classified as “Mildly Gassy” and “Moderately Gassy” in accordance with the average gas content of 1.67 m^3/t and the maximum gas content of 4.20 m^3/t. Furthermore, the maximum gas content value has an evidential point that it is provided from the depths between 1010.50 – 1010.90 meters and from PF-28 exploration well.

Table 5.:Gassiness classification of the coal seams.

Category of Mine	Depth (m)	Gas Content (m^3/t)
Mildly gassy	≤ 200	< 3
Moderately gassy	200 to 500	3 – 10
Very gassy	> 500	10 – 25

Moreover, gas content values were considered while calculating the in-situ gas potential of the mining area. According to the field observation and investigation that *in situ* gas potential for CBM production has been estimated as approximately above the 300 million m^3, which corresponds with a 150 million m^3 coal reserve.

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