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Classification of Coal Seams for Coal and Gas Outburst Proneness in the Zonguldak Coal Basın, Turkey

Olgun Esen
Istanbul Technical University

Samet Can Ozer
Istanbul Technical University

Abdullah Fisne
Istanbul Technical University

CLASSIFICATION OF COAL SEAMS FOR COAL AND GAS OUTBURST PRONENESS IN THE ZONGULDAK COAL BASIN, TURKEY

Olgun Esen, Samet Can Ozer and Abdullah Fisne

ABSTRACT: Coal and gas outbursts can be defined as a sudden release of coal and rock accompanied by large quantities of gas into the working face or other mine workings. It has been a major geological hazard to underground coal mining for over 150 years, and continues to cause serious problems all over the world. The outburst events have appeared rarely in metal mines and have generally occurred in salt and coal mines especially bituminous coal mines. Coal outbursts have occurred in at least 18 nations including Turkey. The most important factors that influence the occurrence of outbursts are gassiness of the coal seam and the desorption rate of the gas in the seam and or part of the coal seam. It is necessary to investigate these factors separately to predict the outburst prone zones. The aim of this study is to determine the outburst prone zones in the Zonguldak Coal Basin. In order to determine the outburst proneness of the coal seams, coal samples were taken from Kozlu and Karadon Collieries. 19 coal samples were taken from underground working areas, from 7 different coal seams, at different depths and with variable borehole lengths. Gas content of the coal seams was measured with US Bureau of Mines (USBM) Direct Method. Desorption rate of the gas in coal was investigated and a threshold limit determined for the study area. According to the experimental results, the coal seams have been classified with regard to outburst prone zones.

INTRODUCTION

Instantaneous coal and gas outbursts in underground coal mines are violent and spontaneous ejections of coal and gas from the working coalface. In the process, a large amount of coal and gas (CH_4 gas, CO_2 gas, or both) is expelled violently, and coal is pulverized. These violent outbursts are major disasters in coal mines (Guan, *et al.*, 2009). There are known cases of gas and coal outbursts resulting from the disintegration of the immediate roof or floor rock of the worked coal seam. One of the causes of difficulties connected with the definition of an outburst is the lack of distinction between the quasi-static and the dynamic phenomena induced by mining (Lama and Bodziony, 1998). Gases associated with coal seams are formed as a result of the coalification process. Coal seams contain a mixture of gases in which methane makes up 80 – 90 % (Creedy, 1991) and varies from 0 to > 25 m^3/ton (Noack, 1998). Outbursts of gas, coal and rock is a worldwide phenomenon. Perhaps over 30,000 outbursts have occurred in the world coal mining industry. Most of the outbursts, almost one third of the total, have occurred in China followed by CIS countries leading the world in the frequency of occurrence of outbursts. The most important factors that influence the occurrence of outbursts are: 1) Gassiness of the coal seam, 2) tectonics, 3) properties of the coal and rock and 4) vertical and lateral stresses occurring in the seam and/or rock or part of the coal seam (Lama and Bodziony, 1998). The techniques of prediction may be applied to control and prevent underground coal-mine outbursts. For example measurements of gas content and pressure from drill holes on the surface and subsurface permits determination of threshold conditions for outburst occurrence (Zhang, 1995). These measurements provide information on the irregular distribution of gas and changes in gas trends allowing the emplacement of methods to control and prevent coal-mine outbursts (Flores, 1998).

In Turkey, the first recorded instantaneous outburst of coal and gas was at Kozlu Colliery in the Zonguldak Coal Basin in 1962. Unfortunately, not enough official data was collected for this event. The second outburst was also occurred at Kozlu colliery in 1969. There have been 90 gas and coal outbursts in Zonguldak Coal Basin between the years of 1969 and 2013 resulting in 374 fatalities. The disastrous outburst resulted to 263 deaths in Kozlu Colliery at depths of between -560 and -485 longwall panel in 1992.

The objective of this study is to investigate the relationship between the outbursts events and gas content of the coal seams and the desorption rate of gas in coal. In addition the risk indices were used

Istanbul Technical University, Faculty of Mines, Department of Mining Engineering, Maslak / Istanbul, TURKEY, Tel: +90 212 285 7364

for determining the outburst prone zones in the Zonguldak Coal Basin. These risk indices were used to classify the coal seams about their proneness to outbursts.

Description of the Zonguldak Coal Basin

Zonguldak Coal Basin, located on the Black Sea coast is the only bituminous coal basin of Turkey (Figure 1). Mining activities in the basin started in 1848 and have been carried out in the region for over 160 years. Several national and international companies operated various coal mines in the basin. In 1938, the basin was acquired by Eregli Coal Enterprise (EKI) which operated these mines until 1983, when the Turkish Hardcoal Enterprise (TTK) was founded (Okten, *et al*., 1995; Cakir and Baris, 2009). Since then the mines in the basin have been operated by TTK. This State owned agency occupies an area of 6885 km^2.

Zonguldak Coal Basin is the main part of the Upper Carboniferous bituminous coal basin of Turkey. Much of the bituminous coal mining has thus been concentrated in the Zonguldak Basin (Karayigit, 2001). The coal seams are located in a Carboniferous deltaic sequence of Westphalian-A age. The coal field has been disturbed by tectonic activity, first by Hercynian and later by Alpine orogenesis resulting in folding and faulting of strata (Okten, *et al.*, 1995). The Carboniferous coal-bearing sequence of the Zonguldak basin contains the Namurien Alacaağzı Formation, Westphalian-A Kozlu Formation and Westphalian B-D Karadon Formation (Gurdal and Yalcin, 2000).

The estimated coal reserve, down to 1,200 m under sea level, is about 1.32x10^9 tons of coal in this basin (Karayigit, *et al.*, 1998). The coal has been produced by five collieries, namely, Armutcuk, Kozlu, Uzulmez, Karadon and Amasra from west to east. The saleable production in 2011 is about 1.6 mt using a labor force of workers of 10 709 of which 8 629 were underground.

The average gas content of the coals in the Zonguldak Basin isabout 12 m^3/ton according to the laboratory measurements on coal samples contained in canisters, while the measurements in coal mines have shown that the gas contents of the coals in the basin are between 1 and 14 m^3/ton (Karacan and Okandan, 2000).

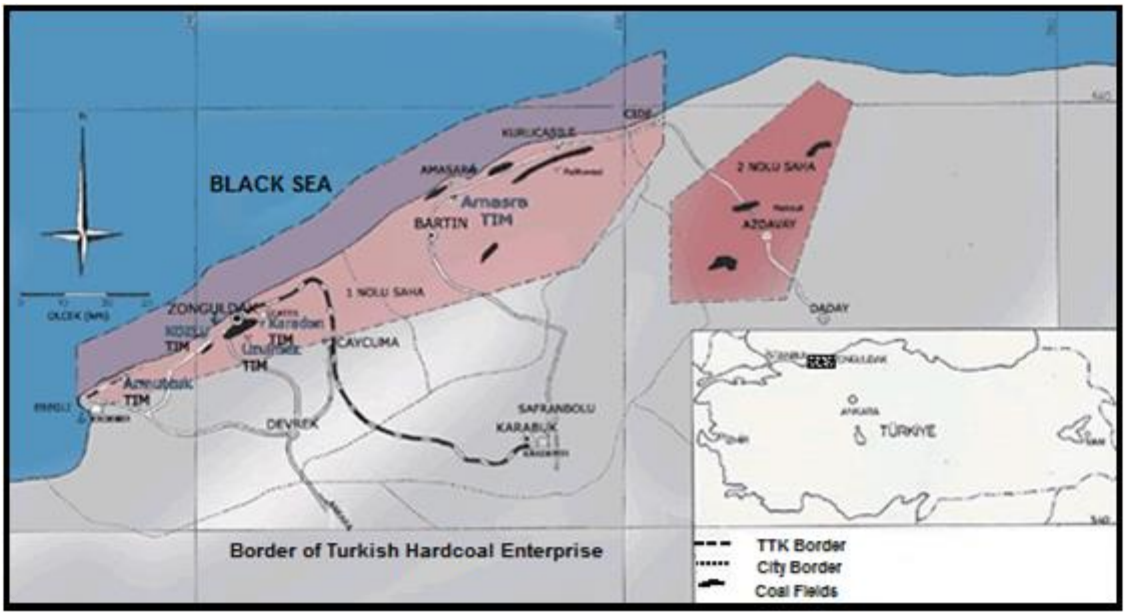

Figure 1 - Location of the Zonguldak Coal Basin

Experimental study

In this study, the coal seams were classified for outburst proneness using gas content and gas desorption rate properties. This classification is aimed to determine outburst prone areas in Kozlu and Karadon Collieries and to protect the working areas of the coal seams.

Coal and gas outbursts are the most important events in underground coal mining operations. Factors influencing the gas and coal outbursts are; structure properties of the coal (the friability of the coal and the coalification process), the gas desorption rate, gas content of the coal seam and the rock pressure. These are the most important factors to predict the outburst prone zones. In this study, the outburst prone zones in Kozlu and Karadon Collieries will be determined and classified with risk indices.

Investigation of gassiness of the coal seams

The most commonly used gas content determination methods subdivide the total gas content of a coal sample into three parts: lost, desorbed and residual gas. The *lost gas* is that portion of the total gas that escapes from the sample during its collection and retrieval prior to being sealed into an airtight desorption canister. Some portion of this free gas will escape during sample retrieval and will not be accounted for by lost gas estimation methodologies based on diffusion of desorbed gas. Once a coal sample is sealed in the desorption canister, the desorbing gas accumulates and can be measured directly, commonly by some variation of the water displacement method. The volume of gas desorbing from a coal sample gradually declines with time. Desorption measurements for the extended desorption techniques are terminated at some point when an arbitrary low desorption rate is reached. This rate may be reached in a matter of days for very friable samples or can take months for some blocky coals. Generally, when the desorption rate reaches an established termination point, some volume of gas remains in the sample. Traditionally, this *residual gas* has been thought of as gas that is 'trapped' within the coal structure due to slow diffusion rates (Diamond and Schatzel, 1998). 19 coal samples were taken from seven different coal seams from different borehole lengths as both Karadon and Kozlu Collieries are at different depths.

The desorbed gas (Q_d) was measured by the experimental apparatus that is shown in Figure 2, which was designed according to USBM Direct Method. The samples were sealed into the canisters then taken to TTK (Türkiye Taskomürü Kurumu, Turkish Hard Coal Enterprises) Gas and Dust Laboratory at the Research and Development Department. The measurements were recorded every 15 minutes in the first day. The measurements have taken 4 – 8 days. Furthermore the dimension of canisters is 10 cm wide and 40 cm high and has 3140 cm^3 inner volume.

Figure 2 - The canisters and the USBM direct method design

The lost gas (Q_l) was calculated from the graph that are generated by the desorption values. The graph consists of the desorption values which are plotted against to the square root of desorption time as is shown in Figure 3. The most important thing when measuring the lost gas, the coal samples have to be sealed as quickly as possible into the canisters.

A sealed crusher mill was used to measure the residual gas (Q_r). The crusher mill's inner volume is 3685 cm^3 and there were 12 balls to grind the coal samples. At the point when the periodic measurement of desorbed gas is discontinued; the residual gas, which were trapped in coal sample's micro and macro cracks, is measured by crushing the sample to a powder (- 200 mesh). The recommended procedure for determining the residual gas requires the transfer of all or a portion of the desorbed coal sample to a desorption ball mill canister for crushing on a roller mill (Diamond and Levine, 1981) to measure the gas. The volume of gas released was measured in the same way as that shown in Figure 2 with a water displacement apparatus. The Figure 4 shows the mill and the experimental design.

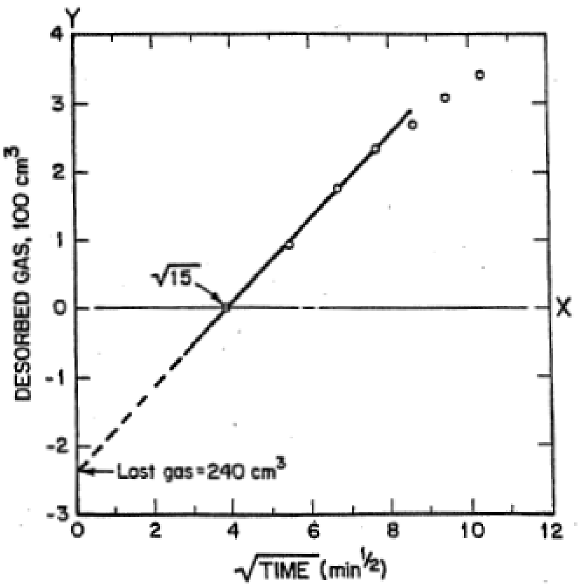

Figure 3 - Measurement of lost gas from the plotted graph

Figure 4 - The mill and the experimental design

Finally all direct gas measurements were continued with the calculation of total gas contents of coal samples. The total gas is calculated with the equation 1 given below (Diamond and Schatzel 1998);

$$Q_t = \frac{(Q_l + Q_d)}{M_t} + \frac{Q_r}{M_c} \quad (1)$$

Where M_t is the total air-dried mass (weight) of the sample and M_c the air-dried mass (weight) of the sample crushed to a powder in the ball mill. The value Q_t called *total gas*, is calculated in cm^3/g, but is commonly converted to ft^3/short t (= cm^3/g x 32) in the United States for ease in making gas resource calculations.

Investigation of desorption rate of gas in coal seams

For the occurrence of gas and coal outburst events, it is necessary for the coal and the rock material have to desorb with high velocity into the working area after the sorption / desorption stability is disrupted. Due to this reason, investigation of desorption rate of gas in coal is being important while researching the proneness of coal seams to gas and coal outburst events. In this study, desorption rates are basically measured according to decrease of the pressure at a certain time owing to adsorption of high pressured gas. Desorption rate measurement experimental apparatus is shown in Figure 5.

For determining the $\Delta P_{express}$ index a coal sample of about 70 g in the range of 0.25–0.5 mm for bituminous (2–3 mm for anthracite) is enclosed in a chamber. The sample is evacuated for 2 min and then methane is allowed to enter into it to raise the gas pressure to 0.2 MPa as quickly as possible. The gas flow into the chamber is closed. The chamber is immediately connected to a manometer and the change in pressure after 1 min is read, which gives the $\Delta P_{express}$ index (Paul, 1977; Lama and Bodziony, 1998). However nitrous gas (N_2O) was used in this study because of safety measures.

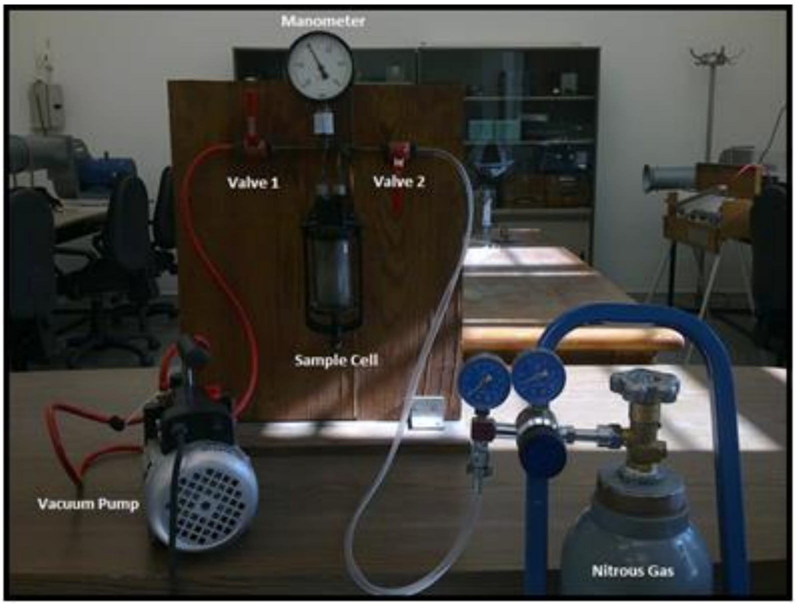

Figure 5 - Desorption experiment measurement design

Results and discussions

In underground coal mining, coal and gas outburst events have an important role which result in such dangerous risks for both workers and working areas. Due to this fact the prediction of outburst prone zones in an underground coal mine is more important. For this reason, many methods have been developed and investigated concerning factors influencing coal and gas outbursts.

19 coal samples were taken from both TTK Kozlu and Karadon Collieries where the most coal and gas outbursts events have been occurred in Turkey. The borehole lengths are varied between 4 m and 18 m and the diameters are constant at 42 mm. Coal samples were taken from these boreholes as drill cuttings, at different depths and from seven different coal seams. 12 coal samples out of 19 are from Kozlu Colliery and the other seven coal samples are from Karadon Colliery.

Gas content measurements of coal seams

The amount of gas content of the coal seams has an important role in the occurrence of coal and gas outbursts. As is shown in Table 1; 12 coal samples which were taken from Kozlu Colliery, have gas content values varying between 3.8 – 16.9 m^3/t and 7 coal samples that were taken from Karadon Colliery, have gas content values varying between 3.0 – 15.5 m^3/t.

Investigations in many countries have shown that the coal and gas outbursts occurred in coal seams which have 9 m^3/t gas content or higher. These coal seams are described that outburst prone areas (Paul, 1977; Okten, 1983). In this study, as a gas content threshold value 9 m^3/t gas content or higher was used to classify the outburst proneness of the coal seams in both Kozlu and Karadon Collieries of the Zonguldak Coal Basin.

The comparisons of the gas content values of coal seams with the threshold limit value of 9 m^3/t are shown in Figure 6.

$\Delta P_{express}$ Index measurements of coal seams

Measuring the $\Delta P_{express}$ Index values there are 3 experiments for each 70 g. coal sample. The results were calculated as an average value, were determined $\Delta P_{express}$ Index value as bar. The results are shown in Table 2 which were taken from Kozlu and Karadon Collieries at different depths and 7 different coal seams.

As it is shown in Table 2; 12 coal samples which were taken from Kozlu Colliery, have gas content values that varied between 0.40 and 0.72 bar and 7 coal samples that were taken from Karadon Colliery, have gas content values that varied between 0.34 and 0.68 bar.

From this point; it's required to compare the results as proneness. Due to the fact that, the threshold limit was determined for the coal basin and 3 coal samples were taken from areas where outbursts occurred on different years in Zonguldak Coal Basin. Measurement results for determining the threshold limit are shown in Table 3.

As it is seen on Table 3; $\Delta P_{express}$ values of coal samples which were taken from areas where outburst occurred are lower than 0.43 bar. Depending on this result, in the Zonguldak Coal Basin, for the Karadon and Kozlu Collieries; the coal seams are described as outburst prone areas which are closer to 0.43 bar or lower than this value, was determined as threshold value (Esen, 2013).

The comparisons of $\Delta P_{express}$ Index values of coal seams with the threshold limit value of 0.43 m^3/t are shown in Figure 7.

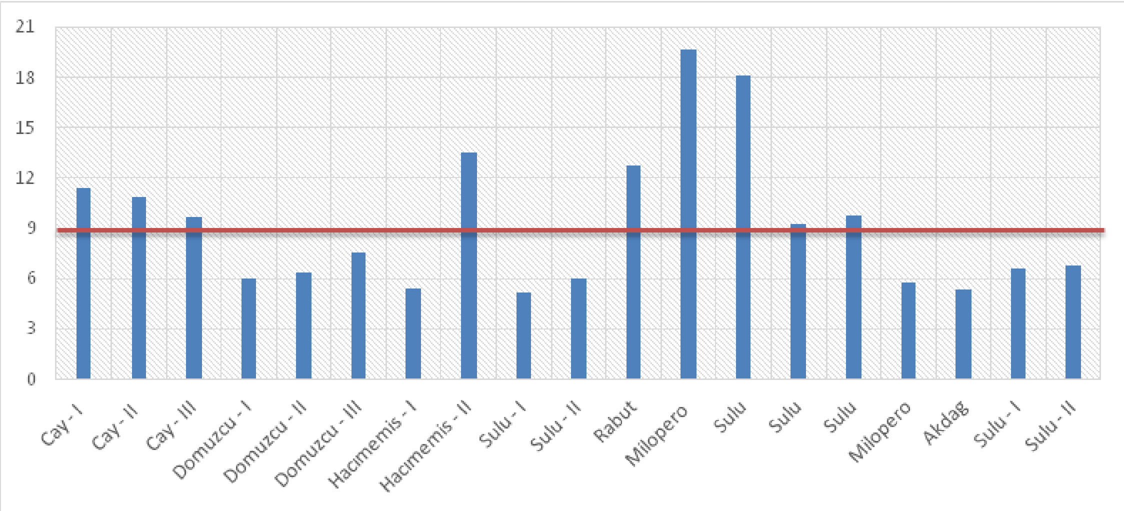

Figure 6 - Gas content values compared with threshold limit

Table 1 - Results of gas content measurements of the coal seams

Sample No.	Colliery	Name of Seam	Working Area	Depth (m)	Lost Gas (m^3/t)	Desorbed Gas (m^3/t)	Residual Gas (m^3/t)	Total Gas Content (m^3/t) (ar)
1	Kozlu	Cay - I	Gateway	-582	2.31	4.07	0.53	6.9
2	Kozlu	Cay - II	Gateway	-579	2.09	4.80	0.78	7.7
3	Kozlu	Cay - III	Gateway	-510	1.72	5.86	0.67	8.3
4	Kozlu	Domuzcu - I	Gateway	-437	1.94	2.34	0.20	4.5
5	Kozlu	Domuzcu - II	Gateway	-437	2.54	3.08	0.29	5.9
6	Kozlu	Domuzcu - III	Gateway	-437	3.28	3.40	0.18	6.9
7	Kozlu	Hacımemis - I	Gateway	-547	0.88	4.01	0.17	5.1
8	Kozlu	Hacımemis - II	Gateway	-547	1.82	6.52	0.27	8.6
9	Kozlu	Sulu - I	Gateway	-560	0.98	2.67	0.16	3.8
10	Kozlu	Sulu - II	Gateway	-560	1.71	3.49	0.22	5.4
11	Kozlu	Rabut	Gateway	-485	2.28	8.76	0.66	11.7
12	Kozlu	Milopero	Raise	-547	1.36	14.49	1.06	16.9
13	Gelik	Sulu	Gateway	-260	2.71	12.04	0.78	15.5
14	Gelik	Sulu	Gateway	-360	1.64	2.48	0.18	4.3
15	Gelik	Sulu	Raise	-360	2.09	6.25	0.71	9.1
16	Gelik	Milopero	Gateway	-360	0.89	2.17	0.23	3.3
17	Kilimli	Akdag	Raise	-460	0.95	1.71	0.32	3.0
18	Kilimli	Sulu - I	Gateway	-360	1.58	3.74	0.40	5.7
19	Kilimli	Sulu - II	Gateway	-360	1.53	3.27	0.30	5.1

Table 2- Results of $\Delta P_{express}$ Index values of the coal seams

Sample No.	Colliery	Name of Seam	Working Area	Depth (m)	Measurements			ΔP_{exp} Index (bar)	Standard Deviation
					1	2	3		
1	Kozlu	Cay - I	Gateway	-582	0.68	0.680	-	0.68	0.002
2	Kozlu	Cay - II	Gateway	-579	0.62	0.630	0.643	0.63	0.01
3	Kozlu	Cay - III	Gateway	-510	0.4	0.397	-	0.4	0.002
4	Kozlu	Domuzcu - I	Gateway	-437	0.72	0.720	-	0.72	0.002
5	Kozlu	Domuzcu - II	Gateway	-437	0.583	-	-	0.58	-
6	Kozlu	Domuzcu - III	Gateway	-437	0.483	-	-	0.48	-
7	Kozlu	Hacımemis - I	Gateway	-547	0.480	0.523	0.523	0.51	0.02
8	Kozlu	Hacımemis - II	Gateway	-547	0.467	0.433	0.403	0.43	0.026
9	Kozlu	Sulu - I	Gateway	-560	0.635	0.573	0.670	0.63	0.04
10	Kozlu	Sulu - II	Gateway	-560	0.503	0.480	0.487	0.49	0.01
11	Kozlu	Rabut	Gateway	-485	0.300	0.520	0.500	0.44	0.122
12	Kozlu	Milopero	Raise	-547	0.417	0.41	0.423	0.42	0.005
13	Gelik	Sulu	Gateway	-260	0.332	0.364	0.335	0.34	0.014
14	Gelik	Sulu	Gateway	-360	0.533	0.55	-	0.54	0.008
15	Gelik	Sulu	Raise	-360	0.390	0.45	0.45	0.43	0.035
16	Gelik	Milopero	Gateway	-360	0.487	0.52	0.533	0.51	0.02
17	Kilimli	Akdag	Raise	-460	0.620	0.607	0.61	0.61	0.006
18	Kilimli	Sulu - I	Gateway	-360	0.570	0.527	0.557	0.55	0.01
19	Kilimli	Sulu - II	Gateway	-360	0.673	0.697	0.683	0.68	0.018

Table 3 - Results of ΔP_{exp} index values of the areas where outbursts occurred

Sample No.	Outburst Event Date	Place of Coal and Gas Outburst Event	Depth (m)	No. of Samples	Measurements		
					Avg (bar)	St.Dev.	Range
1	17.05.2010	-540/51506 Karadon New Shaft - Drift	-540	3	0.40	0.009	0.39-0.41
2	31.03.2011	-360/41406 Gelik Acilik Seam - Gateway	-360	3	0.43	0.013	0.41-0.44
3	11.04.2012	-460/42504 Karadon Acilik Seam - Gateway	-460	3	0.41	0.019	0.39-0.43

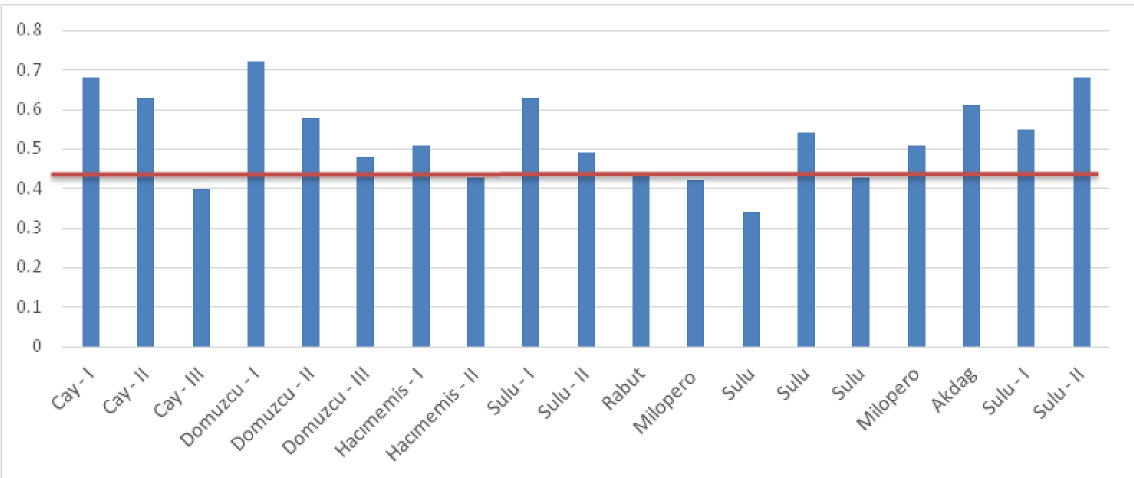

Figure 7 - $\Delta P_{express}$ values compared with threshold limit

CONCLUSIONS

According to the results, the coal seams were classified for coal and gas outbursts to give information about the Zonguldak Coal Basin. Coal seam gas contents in Kozlu Colliery varied between 3.8 m^3/t and 16.9 m^3/t for 12 coal samples and in Karadon Colliery it varied between 3.0 m^3/t and 15.5 m^3/t for 7 coal samples. These gas content value results are on original coal basis. The 9 m^3/t threshold limit value was considered to compare the gas content values to classify the coal seams for their outburst proneness on the received (original coal) basis. According to the results in Kozlu Colliery -480 Rabut Seam (Sample 11), -560 Milopero Seam (Sample 12); in Karadon Colliery -260 Sulu Seam (Sample 13), -360 Sulu Seam (Sample 15) it can be said that these coal seams are explained as outburst prone zones. In addition it can be also described as outburst prone zones which are closer to the threshold limit, -560 Hacımemis Seam (Sample 8) and -485 Cay Seam (Sample 3), with respectively 8.6 m^3/t and 8.3 m^3/t.

The desorption rate of the coal seams, in other words the $\Delta P_{express}$ Index values in Kozlu Colliery changes between 0.40 and 0.72 bar for 12 coal samples and in Karadon Colliery changes between 0.34 and 0.68 bar. In past studies on the Zonguldak coal basin, no threshold value was determined. Due to this, anew threshold value for Kozlu and Karadon Collieries' formations was determined in terms of $\Delta P_{express}$ Index research. For determining the threshold value, coal samples were taken from outbursts area, which occurred which were experienced in the years between 2010 and 2012.

Then bycomparing these study values and the samples which were taken from outburst experienced areas, it can be said for -485 Cay Seam (Sample 3), -560 Hacimemis Seam (Sample 8), -480 Rabut Seam (Sample 11), -560 Milopero Seam (Sample 12), -260 Sulu Seam (Sample 13) and -360 Sulu seam (Sample 15), these coal seams are described as outburst prone seams.

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