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# GAS DESORPTION RATE OF COAL SEAMS IN ZONGULDAK COAL BASIN AS AN INDICATOR OF OUTBURST PRONENESS

Olgun Esen<sup>1</sup>, Abdullah Fisne<sup>2</sup>, Gündüz Ökten<sup>3</sup>, Dennis Black<sup>4</sup>

**ABSTRACT:** Outburst is a significant hazard in underground coal mining and may be expressed as a violent ejection of coal and gas from the mining face. Greatest risk of outburst is during initial intersection of an unmined coal seam and during development mining of the coal seam in close proximity to geological disturbances.

Outburst events have been reported during underground mining operations in over 18 countries, including Turkey, for over 150 years. In the Zonguldak Coal Basin, located on the Black Sea coast of North West Turkey, 90 outbursts were recorded over 44 years, between 1969 and 2013, resulting in 374 fatalities.

To protect the mine workings from the outburst hazard, the outburst indicators,  $\Delta P_{0-60}$ ,  $\Delta P_{\text{express}}$  and the  $K_T$  index, have been investigated to evaluate potential application to predict outburst prone areas. The study of 166 coal samples collected from the three (3) coal seams, Acilik, Sulu and Cay seams, mined at Kozlu and Karadon collieries in the Zonguldak Coal Basin, found the results of  $\Delta P_{0-60}$ ,  $\Delta P_{\text{express}}$  and the  $K_T$  index ranged between 2 to 26 mmHg, 0.16 to 0.76 bar, and 0.57 to 0.79 respectively. These results were compared with threshold limit values reported in previous studies to identify areas of potential increased outburst risk.

## INTRODUCTION

An outburst is a sudden release of gas and coal under pressure from a working face area (Black, 2011). Various theories have been presented regarding factors that contribute to the occurrence of coal and gas outbursts. Factors that may affect outburst potential include tensile strength of coal, gas emission rate, gas pressure gradient, moisture content and the magnitude of local stresses (Lama, 1995). Specifically, high levels of seam gas near geological structures have been identified as a major contributing factor in the coal and gas outburst phenomenon (Lama, 1995). In Turkey, methane (CH<sub>4</sub>) is the dominant seam gas and has been associated with past outburst events. Carbon dioxide (CO<sub>2</sub>) and variable concentrations of CH<sub>4</sub> and CO<sub>2</sub>, in combination with the ejection of fine coal particles, have also been released in outburst events reported in Australia, Canada, China, Czech Republic, France, Poland (Beamish and Crosdale, 1998; Lama and Bodziony, 1998; Lama and Saghafi, 2002; Liu et al., 2008; Aziz et al., 2011).

Despite much research, the coal and gas outburst phenomenon is not well understood and many researchers continue to investigate the occurrence mechanism and prediction techniques. In Turkey, coal and gas outburst events were first recognised and reported in 1969 and in the 44 years to 2013, 90 outburst events were recorded, all events occurring in the Karadon and Kozlu collieries located in the Zonguldak Coal Basin. Fisne and Esen (2014) reported the highest number of outbursts occurred during mining of three seams at the two collieries; 20 outburst events in the Acilik seam, 15 outbursts in the Cay seam, and 13 outbursts in the Sulu seam.

The two methods used for outburst prevention in Turkish coalmines are (a) local drilling of boreholes to reduce gas pressure, and (b) protective seam mining. However, further work is needed to identify accurate and reliable methods to locate areas of increased outburst risk, where outburst prevention efforts can be concentrated. Four factors are considered to have the greatest impact on outburst propensity, the most significant being gas content/gas

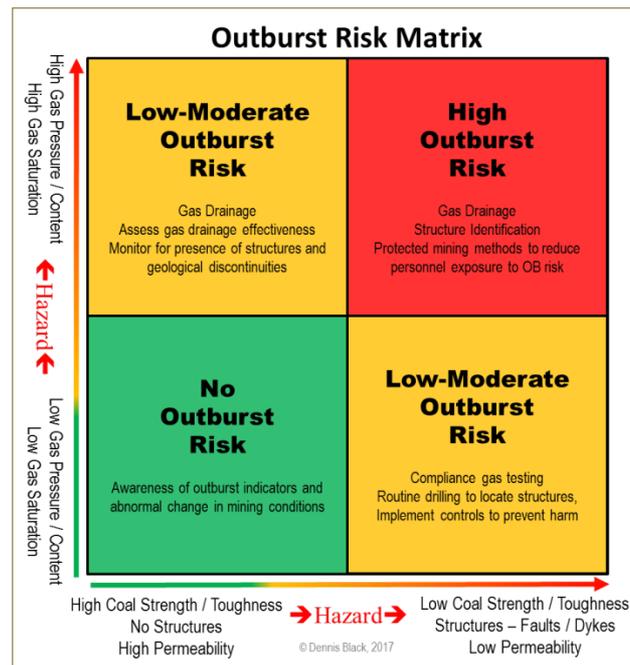
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pressure, have been presented as an outburst risk matrix by Black (2017) and Black *et al.*, 2009 (Figure 1).



**Figure 1: Outburst risk matrix (Black, 2017).**

Bodziony and Lama (1996) described outburst prediction indices, such as  $\Delta P_{0-60}$ ,  $\Delta P_{\text{express}}$ , and the  $K_T$  index, used with varying levels of effectiveness by different countries, to identify areas of increased outburst risk. While these prediction indices, related to initial gas desorption, must be used in conjunction with other parameters such as coal properties, coal seam gas content and stress conditions, to fully assess outburst risk, it is important to recognise and accept the importance of gas desorption rate from coal while investigating the outburst prone coal seams.

In this study,  $\Delta P_{0-60}$ ,  $\Delta P_{\text{express}}$  index, and  $K_T$  index are determined for coal samples collected from the Acilik, Sulu and Cay coal seams in Kozlu and Karadon collieries and the results are assessed to identify potential outburst prone conditions in each seam.

### STUDY AREA

Zonguldak Coal Basin, located on the Black Sea Coast (Figure 2), is the only bituminous coal basin in Turkey. Zonguldak Coal Basin is the main part of the Upper Carboniferous bituminous coal basin, 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 coalfield has a complex and hard geological condition, 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 Alacaagzi Formation, Westphalian-A Kozlu Formation and Westphalian B-D Karadon Formation (Gurdal and Yalcin, 2000).

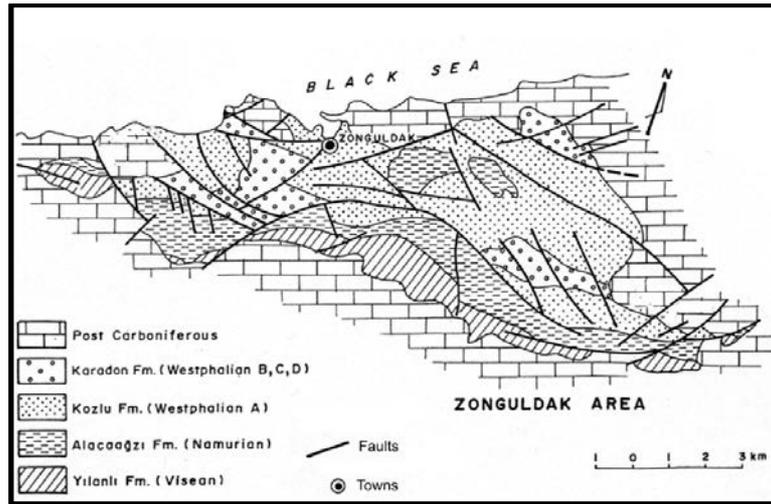


Figure 2: Geological setting of the Zonguldak coal basin (from Hosgormez, 2007).

Mining activities in the basin started in 1848 and have continued in the region for over 160 years. Several national and international companies operate coal mines in the basin. The mining area is 6885 km<sup>2</sup> and mining depth continues to increase. Coal is produced from five collieries, shown in Figure 3, Armutcuk, Kozlu, Uzulmez, Karadon and Amasra that are operated by the Hard Coal Agency of Turkey (TTK). In Kozlu colliery, mine workings have extended out below the Black Sea and have reached depths of 1200 metres. The saleable production is relatively low by Australian standards, totalling 948,573 tonnes in 2015, 908,107 tonnes in 2016, 2017 production year-to-date is approaching 830,000 tonnes. TTK employs 9,000 people and 6,000 of those employees work in the underground mines (TTK Annual Report, 2017). Increasing gas content and high gas concentration in working places has been identified as a contributing factor to reduced coal production from the TTK collieries. While the Acilik, Sulu and Cay seams are recognised as having the highest propensity for coal and gas outbursts, they contain the highest quality coal and are the target for intensive coal production in the basin.

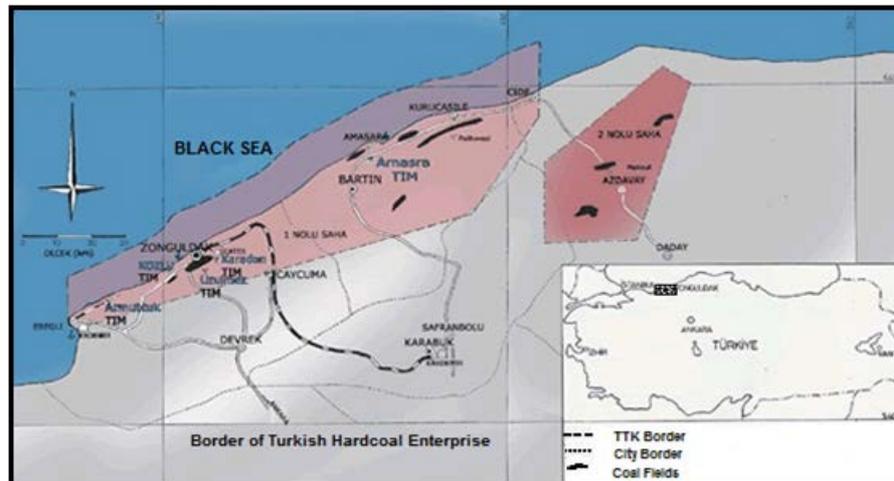


Figure 3: Location of the Zonguldak Coal Basin.

### METHODOLOGY OF GAS DESORPTION RATE INDICES

Gas desorption rate is an important parameter to consider in assessing outburst proneness of the coal seams (Williams, 1997). A variety of sorption/desorption indices have been used in different countries for prediction of coal outburst risk (Lama and Bodziony, 1996). These indices provide a measure of initial gas desorption, typically from small samples of fine coal particles, and the index values must be related to other factors such as structure of coal, gas

content, and stress, to thoroughly assess outburst risk. The following three indices have been investigated:

- $K_T$  index
- $\Delta P_{0-60}$  index; and
- $\Delta P_{\text{express}}$  index.

### $K_T$ index

This index is a measure of the change in desorption rate of a coal sample. Plotting measurements of gas desorption ( $\text{cm}^3/\text{min.kg}$ ) relative to desorption time (min) on a ln-ln scale, the slope of the curve represents the  $K_T$  value. The method of sampling consists of drilling holes and collecting fractions of particles in the range 0.40 to 0.63 mm and the mass of the sample depends upon the capacity of the equipment. Lama and Bodziony (1996) suggest the critical value  $K_T < 0.645 \pm 0.035$  is considered normal and for outburst conditions,  $K_T$  should be at least 0.75. Lama and Bodziony also suggest the critical  $K_T$  value relates to a gas content of  $9.0 \text{ m}^3/\text{t}$ .

Ökten (1983) proposed the  $K_T$  index categories, listed in Table 1, to classify outburst prone coal seams.

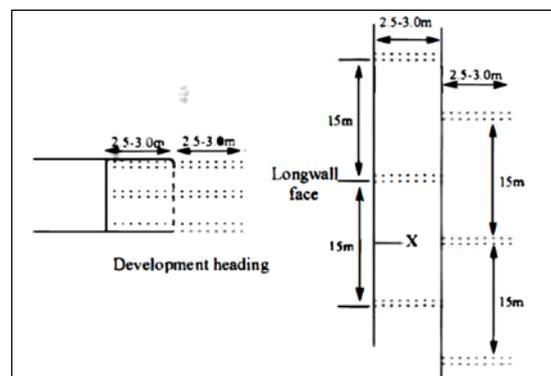
**Table 1:  $K_T$  index classification for coal and gas outbursts.**

Category	$K_T$ Range	Description
1	0.75 to 0.82	Potential of Outburst
2	0.82 to 0.88	Risk of Outburst
3	> 0.88	High Risk of Outburst

### $\Delta P_{0-60}$ index

Lama and Bodziony (1996) referred to work of , Ettinger et al. from 1953, which presented an alternative to measuring gas desorption as a percentage of gas sorbed at 1 atm pressure, which involved measuring gas pressure build up in an enclosed chamber of definite dimensions, expressed as “gas emission index”.

The  $\Delta P_{0-60}$  index, which is a measure of pressure rise in the initial 60 second period has been used to predict outburst prone coal seams in a number of countries (Lama and Bodziony, 1996). The method involves drilling 3.0 metre long holes in advance of development and longwall faces, with boreholes spaced every 15 metres across a longwall face, as shown in Figure 4. Cuttings are collected from the last half metre of each hole, from 2.5 to 3.0 metres, and sieved. In testing bituminous coal, a 3.0-gram sample of 0.25 to 0.50 mm particle size is enclosed in a sealed chamber within 90 seconds of drilling and the change in gas pressure (mmHg) is recorded over a period of 60 seconds.



**Figure 4: Placement of holes for sampling for  $\Delta P_{0-60}$  determination (Lama and Bodziony, 1996).**

The critical value of  $\Delta P_{0-60}$ , above which is considered a sign of imminent outburst risk, is 15 mmHg (~20 mbar) (Lama and Bodziony, 1996). Vandeloise (1964) proposed  $\Delta P_{0-60} = 20$  as the lower limit of outburst danger in Belgian coal whereas in the Cevennes coalfield, the  $\Delta P_{0-60} = 14$  was reported to be the lower limit of outburst danger.

The classification for  $\Delta P_{0-60}$  index values defining outburst risk, presented by Lama and Bodziony (1996), has been listed in Table 2.

**Table 2:  $\Delta P_{0-60}$  index classification for coal and gas outburst**

Category	$\Delta P_{0-60}$ Range (mmHg)	Description
1	0 to 15	Not Prone to Outburst
2	15 to 30	Slightly Suspect
3	30 to 45	Suspect to Outburst
4	45 to 60	Dangerous
5	> 60	Highly Dangerous

Lama and Bodziony (1996) report that the  $\Delta P_{0-60}$  index value measured from testing dull coal is typically higher than from bright coal which they suggest may be due to dull coal having lower diffusivity. The  $\Delta P_{0-60}$  index value is affected by ash content of the coal sample and Lama and Bodziony presented the modified value to account for ash that is given by the equation:

$$\Delta P_{0-60} (afb) = \frac{\Delta P_{0-60}}{1 - Ash\%}$$

#### $\Delta P_{\text{express}}$ index

Paul (1977) modified the  $\Delta P_{0-60}$  index testing method to provide a new index value which was named  $\Delta P_{\text{express}}$ . The method involved in determining the  $\Delta P_{\text{express}}$  index requires a coal sample of about 70 g in the range of 0.25 – 0.5 mm for bituminous coal to be sealed in a chamber. The sample is evacuated for 2 minutes and then methane is allowed into the sealed chamber to raise the pressure to 200 kPa. The chamber is then immediately connected to a manometer and the change in pressure over time is recorded. The gas pressure recorded on the manometer after a period of one (1) minute gives the  $\Delta P_{\text{express}}$  index (Lama and Bodziony, 1996).

Paul (1977) presented data from testing anthracite coal that indicated a correlation between the  $\Delta P_{0-60}$  and  $\Delta P_{\text{express}}$  index values. In that example, the critical value of  $\Delta P_{0-60}$  index, 15 mmHg, was found to correspond to a  $\Delta P_{\text{express}}$  index value equal to 0.45 bar (45 kPa) for anthracite. This threshold limit can be used to compare the coal seams in terms of outburst proneness.

## RESULTS AND DISCUSSION

In this study, coal samples were collected from the Acilik, Sulu and Cay seams. As the majority of outburst events have been recorded in these three coal seams mined in the Zonguldak Basin, it is suggested they represent the greatest outburst risk. The gas desorption rate from each seam has been investigated by measurement of the  $\Delta P_{0-60}$ ,  $\Delta P_{\text{express}}$ , and  $K_T$  indices. According to Okten (1983) and Esen (2013), data from 166 coal samples were combined and compared with their threshold limits to determine outburst propensity. Coal samples were taken only from Kozlu and Karadon Collieries in different mining areas such as from longwall face, raise and gateway. The results of desorption rate measurement are listed in Table 3. Measurement of the  $\Delta P_{0-60}$  and  $\Delta P_{\text{express}}$  index was completed on a total of 118 coal samples and the  $K_T$  index was measured on 48 coal samples. The results obtained from the gas desorption index measurement were found to range between 0.16 to 0.76 bar for  $\Delta P_{\text{express}}$ , 2 to 26 mmHg for  $\Delta P_{0-60}$ , and 0.57 to 0.79 for  $K_T$  index

Table 3: Gas desorption rate data.

Indicator	Number of Samples			Index Range
	Acilik	Sulu	Cay	
$K_T$ index	22	14	12	0.57 – 0.79
$\Delta P_{0-60}$ (mmHg)	22	22	15	2 – 26
$\Delta P_{\text{express}}$ (bar)	22	22	15	0.16 – 0.76

The  $K_T$  index is considered as important in assessing outburst propensity of coal seams in underground coal mining. Testing to determine the  $K_T$  index was completed on 48 coal samples; 22 samples from the Acilik seam, 14 coal samples from the Sulu seam, and 12 samples from the Cay seam. The results of the  $K_T$  index value of each seam and their relationship with  $K_T$  outburst threshold limit were summarised in Figure 5.

From testing, two (2) coal samples were found to have  $K_T$  index values of 0.75 and 0.79, which based on the  $K_T$  index outburst classification, presented in Table 1, suggests the area where those samples were collected from Acilik seam may be potentially outburst prone. In addition, three (3) coal samples are being very much closer to the critical  $K_T$  threshold limit with a value of 0.730, 0.730 and 0.740, which were taken from Acilik seam. Cay and Sulu Seam have lower  $K_T$  index values and have no outburst potential.

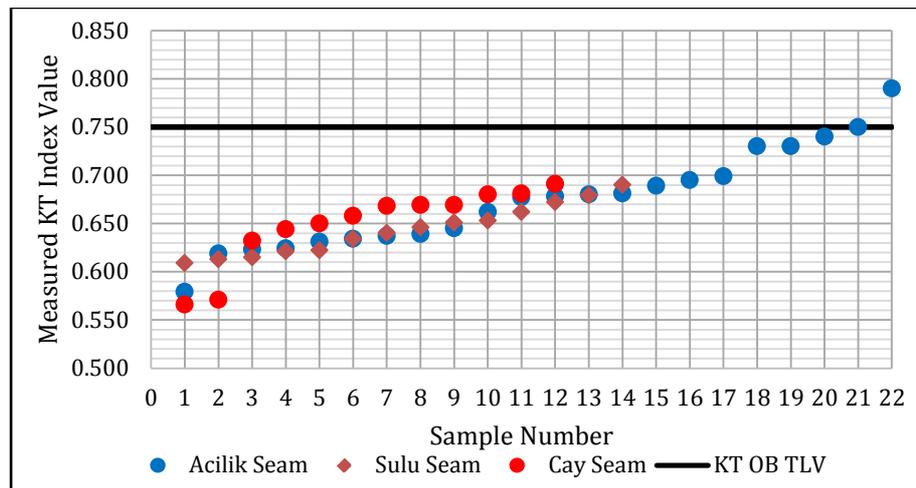
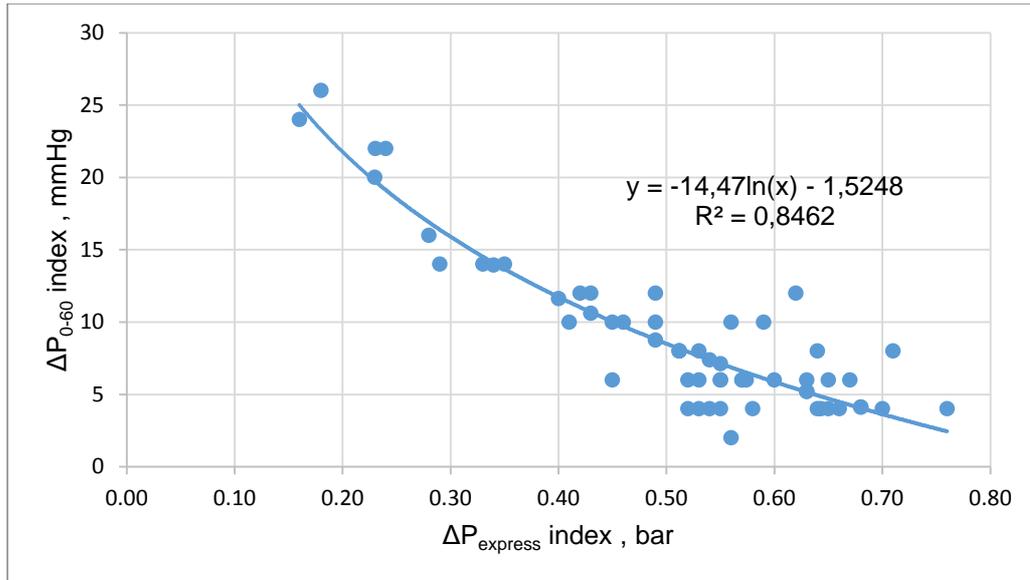


Figure 5: Results of  $K_T$  values of each seam and their relationship with  $K_T$  outburst threshold limit.

The coal being mined in the Zonguldak Coal Basin is bituminous and there is a need to establish a process that can be applied to accurately and reliably describe a threshold limit value to classify outburst prone areas of the coal seams. The data from Esen (2013) and Okten (1983) was combined on the plotted graph (Figure 6). An outburst Threshold Limit Value (TLV) corresponding to the critical value of 15 mmHg for the  $\Delta P_{0-60}$  index, as proposed by Lama and Bodziony, was applied to the index data representing the testing on coal samples from the Acilik, Sulu and Cay seams and the corresponding critical value of  $\Delta P_{\text{express}}$  index was found to be equal to 0.32 bar. It is therefore suggested that the  $\Delta P_{\text{express}}$  index be used as an indicator of outburst risk for mining in Acilik, Sulu and Cay coal seams with a TLV equal to 0.32 bar (35 kPa) established as the critical value.

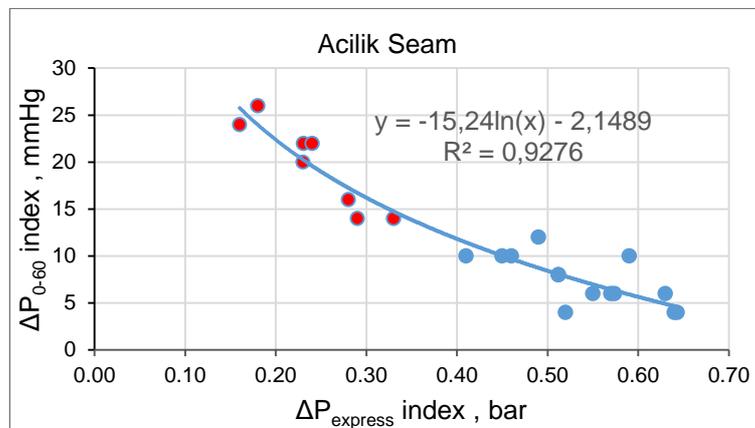


**Figure 6: The relationship between  $\Delta P_{0-60}$  index and  $\Delta P_{express}$  index.**

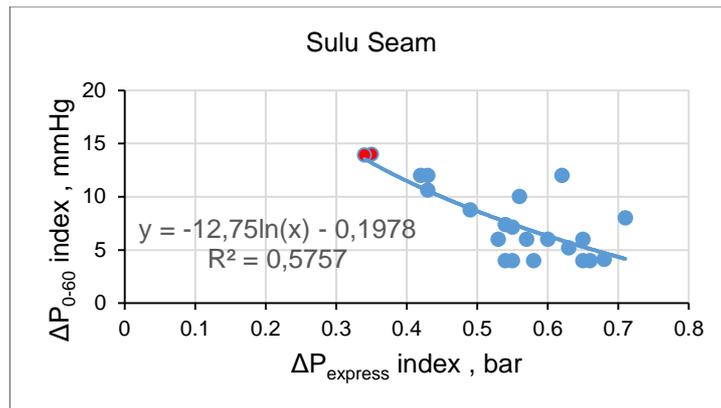
Figure 7, Figure 8 and Figure 9 present the relationship between the  $\Delta P_{0-60}$  index and the  $\Delta P_{express}$  index values determined for the Acilik seam, Sulu seam and Cay seam respectively. From the 22 coal samples tested from the Acilik seam, presented in Figure 5, eight (8) coal samples lie above the proposed TLV. In the outburst history of Karadon and Kozlu collieries, which have experienced most outbursts in the region, the greatest number of outburst events has occurred in the Acilik seam.

The gas emission data indicates higher gas desorption from the Sulu seam relative to the Cay seam. The data collected from testing the 22 samples from the Sulu seam, presented in Figure 7, shows that only two (2) samples were approaching the proposed TLV. The results suggest that in the current mining areas, particularly those areas sampled in the Cay seam, there is presently a low risk of outburst.

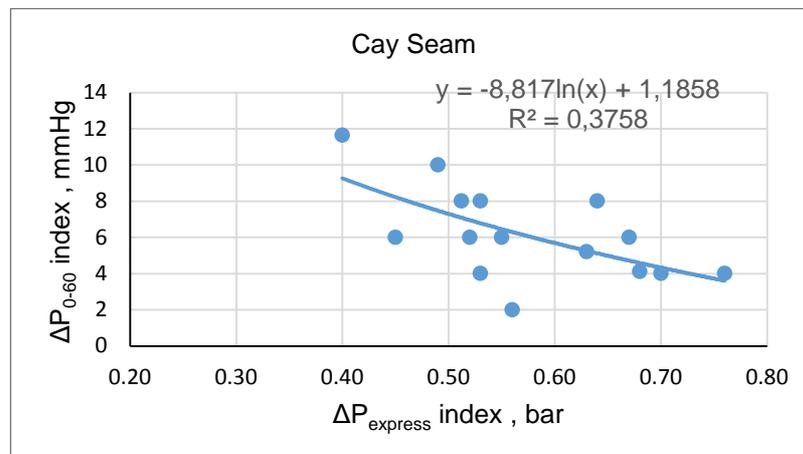
In conclusion, from experience and data collected and presented, the Acilik seam has been confirmed as the most outburst prone coal seam being mined in the Zonguldak Coal Basin. Testing of coal samples from the Sulu seam indicated conditions are approaching potential outburst risk levels. The results of testing coal sample from the Cay seam indicates that present mining areas are at comparatively low risk of outburst.



**Figure 7: The relationship between  $\Delta P_{0-60}$  index and  $\Delta P_{express}$  index for Acilik Seam.**



**Figure 8: The relationship between  $\Delta P_{0-60}$  index and  $\Delta P_{\text{express}}$  index for Sulu Seam**



**Figure 9: The relationship between  $\Delta P_{0-60}$  index and  $\Delta P_{\text{express}}$  index for Cay Seam**

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