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Assessment of an Underground Coal Mine Fire: A Case Study From Zonguldak, Turkey

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ASSESSMENT OF AN UNDERGROUND COAL MINE FIRE: A CASE STUDY FROM ZONGULDAK, TURKEY

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ABSTRACT: This paper aims to evaluate an underground coal-mine fire detected on November, 11th 2007 in Gelik Mine of Karadon Colliery of Turkish Hardcoal Enterprise (TTK), Zonguldak, Turkey. Several techniques were employed by TTK to fight the fire including sealing, filling the mine with water and pumping nitrogen. The mine atmosphere was continuously monitored and gas samples were collected for analysis using a gas chromatograph. In this study, following a description of the fire fighting efforts, the interpretations of well-known fire indices applied to the different stages of the incident were given and attempts were made to compare and to test the reliability of these indices.

INTRODUCTION

Fire in coal mines is a serious problem in Zonguldak Basin and worldwide. Spontaneous combustion is the main reason in most of the mine fires detected within the mines of TTK. Mine fires may lead to loss of life, stopping production, equipment loss and mine closure.

The mine fire to be investigated was detected in Gelik Mine of Karadon Colliery. There were six mine fires in Karadon Colliery due to spontaneous combustion between 1990 and 2000. In advancing longwall mining, coal left in the goaf (gob) and other geological conditions are considered as the main reasons for these fires. Other factors include air passing through the goaf, coal left at the roof or floor of the face, where seam thickness is high and air leakages due to the roof collapse.

This paper aims to evaluate the mine fire which took place at Gelik Mine-Karadon Colliery. Several gas indices were utilized to assess the underground atmospheric conditions as well as the continuity of the fire.

GENERAL INFORMATION ABOUT BASIN, TTK AND GELIK MINE

Zonguldak hardcoal basin in Turkey is the only basin with hardcoal deposits. Mining activities in the basin started in 1848 and several national and international companies operated various coal mines. 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. Since then the mines in the basin have been operated by TTK.

TTK is a government organisation and is the dominant coal producer in the basin. At June 2008, TTK employed 9,857 workers and 1,940 officers, including engineers. Total coal production by TTK in 2007 was 2,423,719 tonnes run-of-mine coal, 1,675,372 of which was saleable. There are five main collieries operated by the organisation, namely, Armutcuk, Kozlu, Uzulmez, Karadon and Amasra collieries. Reserves of these collieries are presented in Table 1.

Gelik mine is one of the two hardcoal mines within Karadon Colliery which is located 12km east of Zonguldak and covers an area of 30 km^2 (Figure 1). Gelik mine employs a total of 1,228 persons; 1,210 are mine workers and 18 are administrative staff, including engineers. The estimated total reserve of the mine is estimated at 175,127,801 tonnes. Coal production is by conventional longwall mining using pick and shovel with timber supports and chain conveyors. There were ten longwall faces, located at -150/-260, -260/-360,-360/-430 and -430/-470 levels. Daily production of the mine was 2,200 tonnes before the fire took place. The information about the active longwalls is presented in Table 2.

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Table 1 - Reserves of five main collieries of TTK (TTK Annual Report, 2007)

	Reserves (tonnes)				
Colliery	**Available**	**Proved**	**Probable**	**Possible**	**Total**
Armutcuk	1,168,000	4,594,324	11,089,144	5,885,637	**23,037,105**
Amasra	233,700	171,873,195	115,052,000	121,535,000	**408,693,895**
Kozlu	3,353,714	68,729,821	40,539,000	47,975,000	**160,597,535**
Uzulmez	2,178,060	137,181,373	94,342,000	74,020,000	**307,721,433**
Karadon	2,924,000	136,905,375	159,162,000	117,034,000	**416,025,375**
Gelik Mine*	1,067,515	54,177,286	65,983,000	53,900,000	175,127,801
Total	**10,157,474**	**519,284,088**	**420,184,144**	**366,449,637**	**1,316,075,343**

* Included in Karadon Colliery reserves.

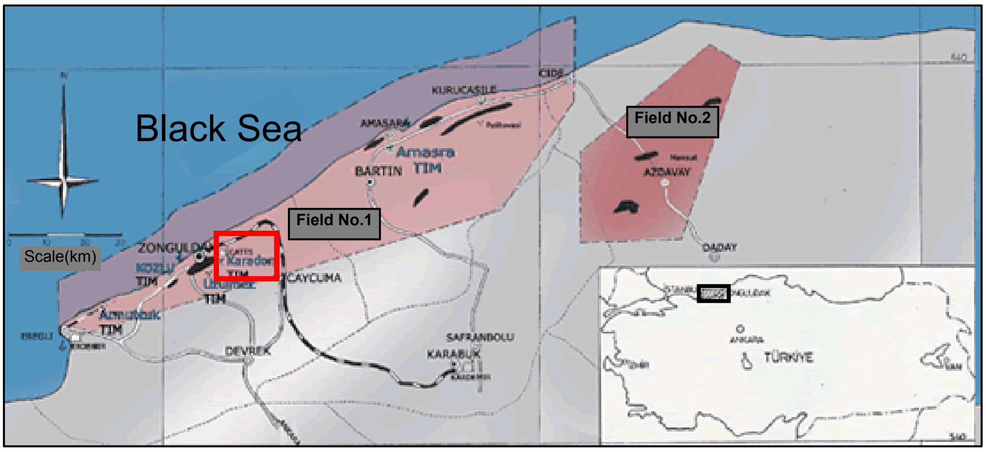

Figure 1 - Location of Zonguldak Basin including the borders of TTK (TTK, 2007)

THE INCIDENT- INITIATION OF FIRE AND FIRST ACTIONS

The first indication of the fire underground was when an underground worker reported smoke and a smoky smell at the end of No.41222 drift (-150/-260) and a smoke concentration at No.41303 drift at 17:00 on Sunday, 11th November, 2007. Afterwards, an investigation team went underground and confirmed a blazing fire on No.41300 drift (-260) at 21:00.

The reason for the initiation of the fire was not known at first. It was thought to be the result of either a spontaneous combustion event or an electrical contact. Though the reason was not exactly known, the mine management's response was to fight the fire by every means possible, which included sealing-off, pumping nitrogen and filling the area with water. This response was likely based on the history and previous experience in the basin, i.e. disasters and explosion risks due to high CH_4 content of the mines in the basin causing the management to panic. However, the mine inspection undertaken after discharging the water and opening the seals showed that the fire had been initiated by an electrical contact.

After the detection of the fire, two teams started to fight the fire with water at two different points at 00:30 on 12th November, 2007. The first team managed to advance to the entrance of No.41306 drift (-260) by extinguishing the fire. However, the team encountered a roof collapse and observed the fire continuing behind the fall at both No.41300 (-260) and No.41306 drifts(-260).Since it was not possible to pass through the collapsed area the first team stopped the fire fighting at 04:00 on 13th November, 2007.

While these events had been taking place the second team working at No.41303 drift (-260) was advancing up to the place where there was once a transformer station, 20 m away from No.41307 drift (-260). However, there was also a roof collapse in this area. Due to intense smoke and CO concentration, up to 2,000 ppm it became impossible to advance further, and a decision was made to pull out of the drift at 06:00 on 13th November, 2007 and seal the mine. The timeline showing the dates of the actions during the fire is presented in Figure 2.

Table 2 - Active longwalls in Gelik mine (TTK, 2008)

Name	Levels and Drift Codes	Production Method[3]	Seam Thickness (m)	Seam Inclination (°)	Average Daily Production[4] (tonne/day)
Acılık[1]	-150 / 41230 -260 / 41307	Advancing Longwall	2.5 - 3.0	25	250 - 300
Sulu[1]	-150 / 41230 -260 / 41307	Retreating Longwall	2.0 - 2.5	35	150 - 200
Sulu[1]	-150 / 41228 -260 / 41306	Retreating Longwall	2.5 - 3.0	35	250 - 300
Cay[1]	-150 / 41306 -260 / 41406	Advancing Longwall	1.0 - 1.5	30	100 - 150
Acilik[1]	-260 / 41307 -360 / 41407	Advancing Longwall	2.0 - 2.5	35	150 - 200
Acilik[2]	-150 / 41227 -260 / 41315	Retreating Longwall	2.5 - 3.0	25	250 - 300
Acilik	-260 / 41315 -360 / 41415	Retreating Longwall	2.5 - 3.0	35	250 - 300
Ozkan	-360 / 41409 -430 / 41509	Retreating Longwall	1.5 - 2.0	20	200 - 250
Nasufoglu	-360 / 41409 -430 / 41509	Advancing Longwall	2.0 - 2.5	20	150 - 200
Sulu	-430 / 41509a -470 / 41409b	Retreating Longwall	2.5 - 3.0	15	200 - 250

1 : Constrained in fire zone.
2 : Transport roadway is closed due to the fire.
3 : Back of the faces is caved.
4 : Changes according to the number of timbers.

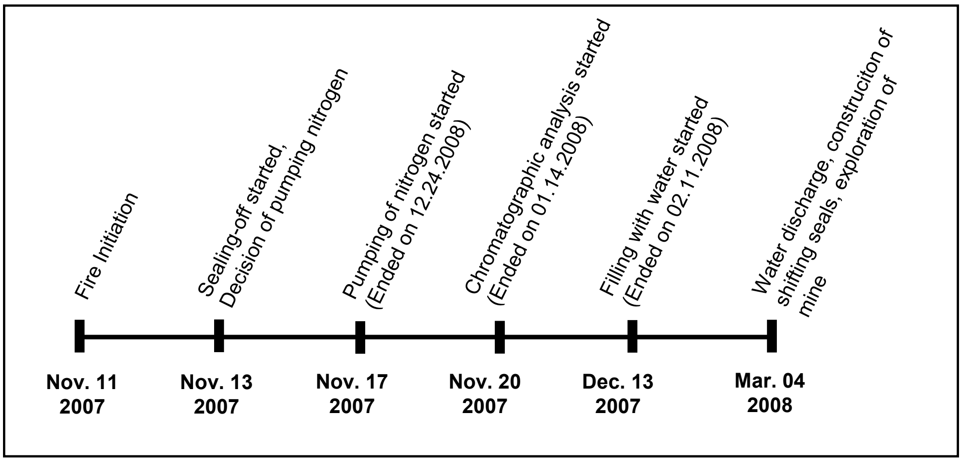

Figure 2 - Timeline of events in Gelik mine fire

The sealing-off operation followed by pumping of nitrogen

The decision was made to erect the first seal at No. 41300 drift (-260) at approximately 11.00 am on Tuesday, 13th November, 2007. A further 19 seals were erected during the period to 05th January, 2008. The location and the details of the 20 seals are illustrated in Figure 3.

The connection of the fire area to the ventilation network was cut and it was thought that no fresh air was able to enter the area following the construction of the first seven seals erected on 13-14th November, 2007. However, on 14th November, gas measurements showed that the seals were not effective, possibly because of leakage (CO: 2500ppm, CH_4:3.6%, CO_2:3.63 and O_2: 14%). Mine management then decided to install additional seals and pump nitrogen into the area in an attempt to control the fire as quickly as possible.

Liquid nitrogen was obtained from nearby nitrogen production facilities and transported in tankers to Cumhuriyet shaft which was operated between the levels +126 and -668. Construction of a nitrogen transportation line was completed on 17th November, 2007 and nitrogen injection to the fire area from No.1 seal commenced by 23.45. Pumping continued for 37 days until 16.30 on 24th December, 2007. During that period, apart from small breaks, there was a 2.5 day delay in pumping nitrogen caused by severe winter conditions which hampered the transport of nitrogen to the mine site. A total of 1056.9 tonnes of nitrogen was pumped into the mine which was transported by 47 tankers whose capacities ranged from 13.1 to 30.2 tonnes.

Filling the fire zone with water

The mine management held a meeting to discuss the fire situation on 13th December, 2007. Although 16 seals had been constructed (3 in -55, 4 in -150, 5 in -260 and 4 in -360 levels, as shown in Figure 3) gas samples taken from the mine since 20th November, 2007 indicated that oxygen concentration were not decreasing (CO: 34ppm, CH_4: 4.3%, CO_2: 2.36%, O_2: 12.62), prompting the mine management to conclude the possibility of air leakage to the fire area. Air leakage was thought to have come from a number of old and abandoned workings close to the fire zone, and affected most of the -55, -160, -260 and -360 levels. Therefore, the mine management decided to fill the mine with water to prevent fresh air entrance to the mine and thus extinguish the fire.

The water filling operation commenced at 20.00 on 13th December, 2007 from the No.1 seal constructed on No.41300 drift (-260) by a 100mm-diameter pipe and No.10 seal constructed on No.41303 drift (-260) by a 50 mm-diameter pipe. The piped water was provided by pumps from the water pools located on the on-setting station which was 220m away from No.1 seal and on the bottom of No.41222 (-150/-260) incline.

Filling operations stopped on 26th December, 2007 at 16.00-24.00 shift. However, analysis of gas samples which were continuously being taken from the fire area indicated that there was an increase in CO concentration. Therefore, water filling operation was resumed on 27th December, 2007 until 3rd January, 2008. At this date no CO was detected in the mine atmosphere so the water filling operation was stopped. On 9th January, 2008 the seals were checked and it was determined that No.4 seal on No. 41303 drift (-260) was full of water but there was no water behind No.1 seal on No.41300 drift (-260). Meanwhile, gas analysis showed that CO concentration had exhibited no change since 3rd December, 2007 which was about 0-1 ppm. Thereupon, the water in No.4 seal was started to be discharged. After this date mine atmosphere was continuously monitored. On 14th January, 2008 gas analysis showed that CO concentration in the mine increased from 2 ppm to 3220 ppm in 17 hours. Thus, mine management realized that there was a heating in the mine again and decided to stop discharging the water from the seal and pump more water into No.1 and No.10 seal. Water pumping continued for 28 days and stopped on 11th February, 2008.

During the 28 day period, actions which were taken by the mine management included:

- Continuously monitoring mine atmosphere by analysing gas samples using a gas chromatograph, 5 times a day
- All seals were checked for leakage and any leaking seals were recoated
- Water level behind the seals was monitored. Leaking seals were recoated
- In the other parts of the mine, old and abandoned panels in particular, air leaks were investigated and caissons were applied to regions where there was air leakage.

Water discharge, construction of shifting seals and exploration of mine

Water discharge commenced on 4th March, 2008 from No.1 seal. Then, No. 4 and No.13 seals were opened and these places were ventilated on 5th March and 6th March, 2008, respectively. Meanwhile, No.1 seal had to be stopped since discharged water obstructed the transportation through -360 trolley drift. Having taken all the necessary precautions No.1 shifting seal was constructed on No.41228 drift and closed.

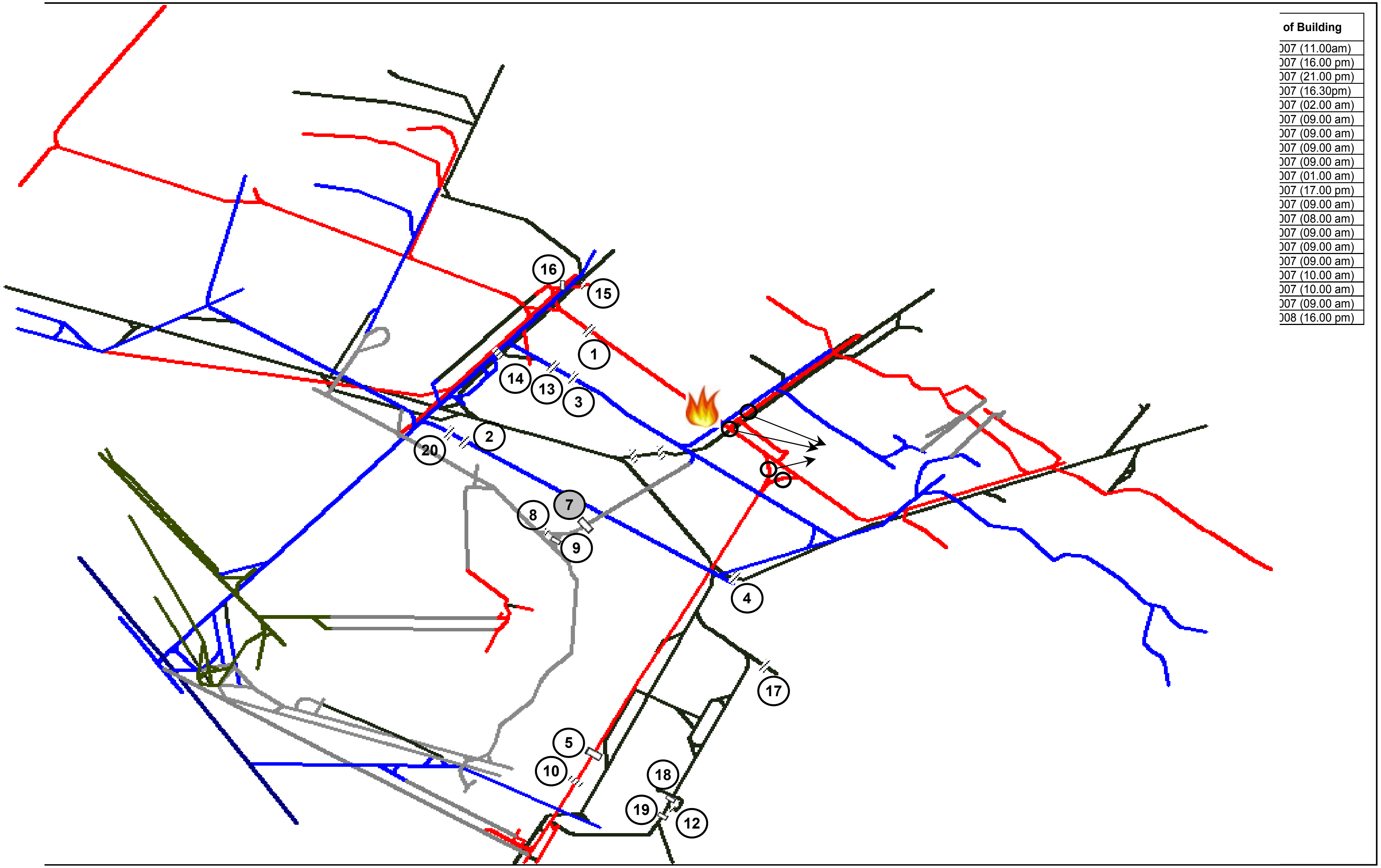

Figure 3 - Mine plan showing the location of the seals

No. 20 and No.2 seals were opened and these places were ventilated on 7th March, 2008. No. 2 shifting seal was constructed on No.41230 drift and closed. Finally, on 9th March, 2008, No.10 and No.5 seals and on 10th March, 2008 No.1 seal were opened and ventilated.

Opening of seals, construction of shifting seals and water discharge operations were performed gradually and in coordination to prevent air from entering the panels which possess spontaneous combustion risks.

An inspection of the mine was undertaken after discharging the water and opening of the seals. During the inspection it was found that:

- There had been two large roof falls in the junction of No.41300, No.41303 and No.41307 drifts. One of them was at the cut-through which connected No.41300 and No.41303 drifts and the other was between No.41300 and No.41307 drifts.
- There were two more collapses, with one at the junction connecting No.41300 and No.41306 drifts and the other 20 m Northeast of No.41306 drift entry.
- The fire had taken place in the region around 20m northwest, 200m northeast and 200m southeast of No.41306 drift. All timber supports, conveyor belts and cables were burnt out.
- No fire indication was observed in roadways connecting No.41303 drift to No.41300 and No.41307 drifts.

MONITORING OF MINE ATMOSPHERE OF GELIK MINE FIRE

Mine atmosphere was continuously monitored during the fire. The first gas samples were taken on 20th November, 2007 from No.7 seal which was the only seal where sampling was possible at that time. Gas sampling continued for 55 days until 14th January, 2008. During this period a total of 435 samples were taken. 118 samples were analysed by gas chromatograph at the Department of Safety and Education of TTK. The rest of the samples were roughly analysed in the laboratories of Gelik Mine. All data obtained from the gas chromatograph analysis were taken into account to validate the scientific approach. Figure 4 shows the trend in the concentrations of CO, CO_2, CH_4 and O_2 during the incident.

Fire gas indices applied to Gelik Mine fire

The mine fire was monitored after sealing to check whether it was being controlled or progressing. Status of mine fires is usually assessed by different indices or ratios, such as production of CO, Graham's ratio, C/H ratio, CO/CO_2 ratio, Willet ratio, Trickett ratio, etc. together with the estimation of temperature of fire area. However in this case, none of the indices or ratios used was capable of giving a precise and certain picture of the status of fire within the sealed area. Therefore, several different indices/ratios should be used together to achieve more precise results. The indices and ratios generally used in Turkish coal mines are briefly discussed below.

Oxygen Consumption

The flaming combustion in a fire is expected to cease when the oxygen concentration is below 12.4%. However, fire can be sustained for a long time even at 1-2% oxygen in the atmosphere. Successful extinguishing of a mine fire can occur if no re-ignition occurs with the introduction of sufficient amount of oxygen to fire zone. However, in most cases as in this present case study, it was extremely difficult to get an accurate oxygen consumption rate since there was some air leakage into the sealed area.

Emission of CO and Graham's ratio

CO is considered to be an effective way of detecting the heat or a fire in a mine. With modern instruments and monitoring techniques it is possible to measure even minute traces of CO emission. If correctly interpreted, the formation rate of CO along with its ratio to the consumption of oxygen, i.e. CO/O_2 deficiency ratio, is a useful guide to assess the extent and course of fire.

Graham (1920) offered a method of calculating the degree of heating by comparing the formation rate of CO or CO_2 with that of the O_2 consumed. He observed the increase in oxygen adsorption in coal with increased temperature. This is known as Graham's ratio whose formula is given by Equation 1 and is still a widely used tool to detect and assess a mine fire. If the value of this ratio is around one it indicates a risky situation and if it is about three then it may indicate that the heating may turn into an extensive fire. In the case of an extensive fire the ratio gives a value higher than seven.

$$GR = \frac{CO}{0.265N_2 - O_2} x100 \qquad (1)$$

Figure 5 and 6 presents the graphical illustration of the variation in O_2 deficiency and Graham's ratio for Gelik mine fire.

Willet's Ratio

Willet (1952) proposed a ratio based on the analysis of samples taken behind sealed off areas in some coal seams in which the CO produced by oxidation did not disappear at all, or disappeared at a very slow rate with the progressive extinction of fire. He used the ratio below to assess the magnitude and extent of the fire along with the analysis of CO. The ratio shows slow decreases during extensive fires.

$$\text{WR} = \frac{\text{CO produced}}{\text{Black damp} + \text{Combustible gas}} \% \qquad (2)$$

Variation in Willet's ratio values for Gelik mine fire is presented in Figure 7.

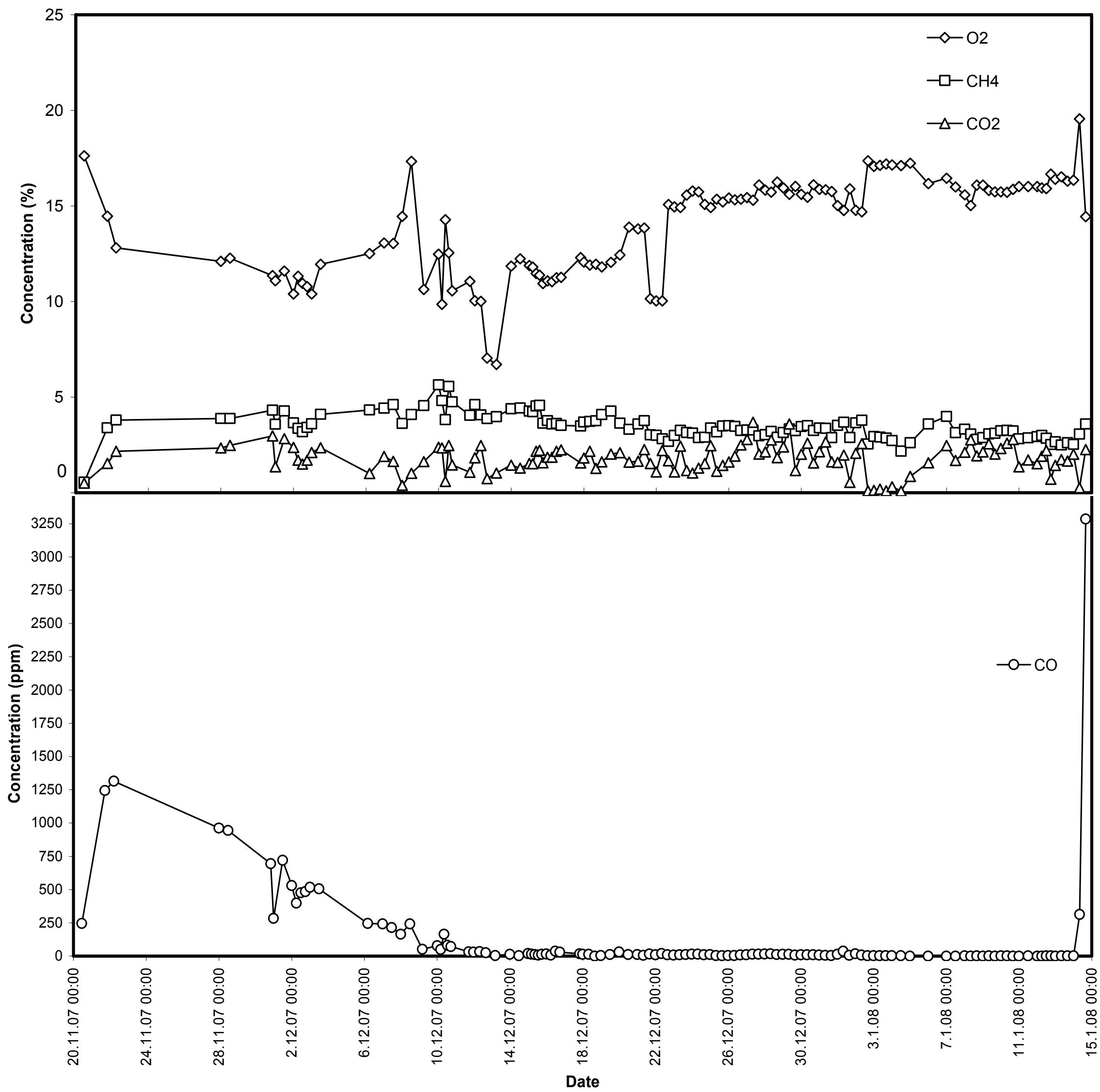

Figure 4b - Variation in the concentrations of CO, CO_2, O_2 and CH_4

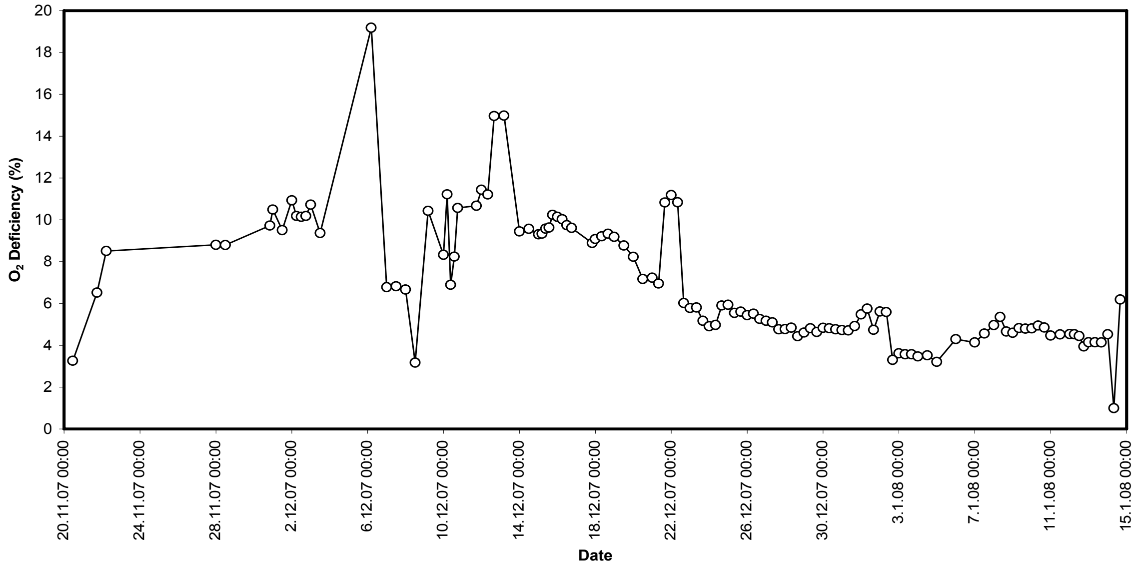

Figure 5 - The variation in O_2 deficiency values for Gelik mine fire incident

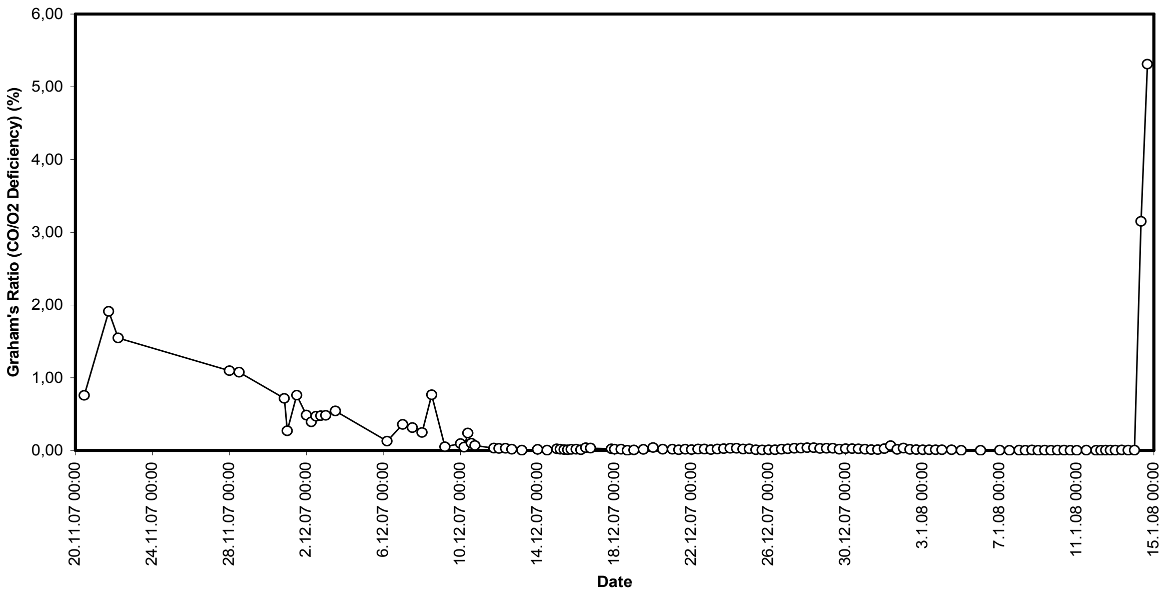

Figure 6 - The variation in Graham's ratio for Gelik mine fire

C/H Ratio

Ghosh and Banerjee (1967) introduced C/H ratio to assess the intensive character of a fire. Assuming coal to be a fuel of the type $C_xH_yO_z$ the following relationship was established:

$$C/H = \frac{6(CO_2 + CO + CH_4 + 2C_2H_4)}{2(0.265N_2 - O_2 - CO_2 + C_2H_4 + CH_4) + H_2 - CO} \quad (3)$$

By combining the above C/H ratio and oxygen consumption rate Ghosh and Banerjee (1967) offered a method to determine and characterise the extent and intensity of a fire in a sealed area (Table 3). Ghosh et al.(1980) also reported a comparison between Graham's Ratio (CO/O_2 deficiency) and C/H ratio of the fire gases in Jharia field (Table 4). The application of C/H ratio used to assess Gelik mine fire is given in Figure 8.

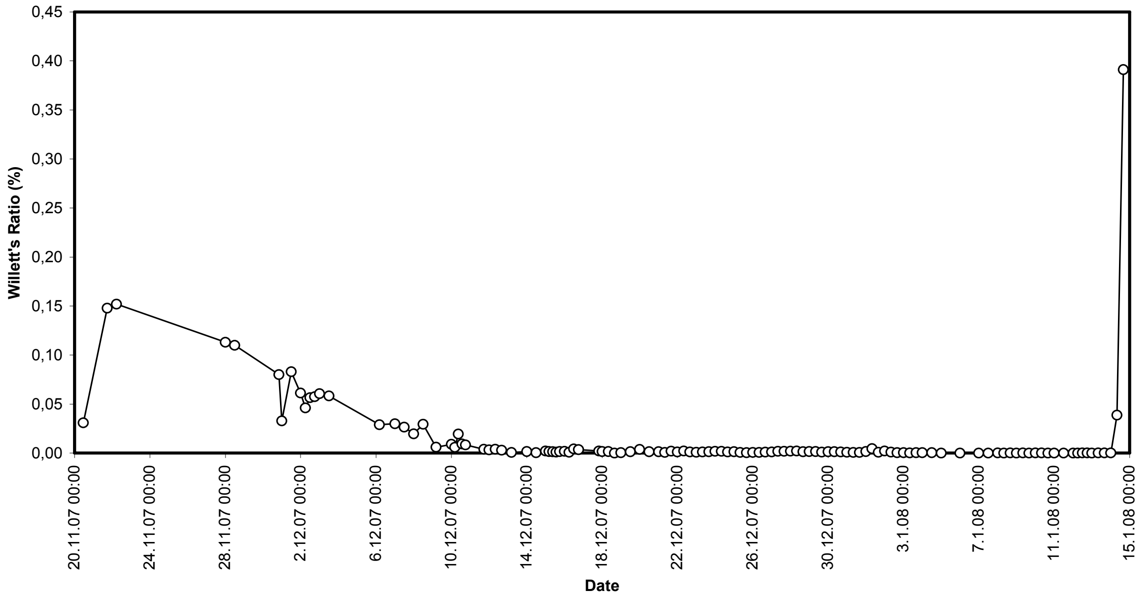

Figure 7 - Variation in Willett's ratio for Gelik mine fire

Table 3 - Application of C/H ratio in the assessment of an underground mine fire

C/H values, from analytical data of fire areas	Rate of oxygen consumption as observed from periodic analysis	Remarks on the nature of fire
1. High and very near to that of coal i.e. nearly 20	(a) Fast	Blazing and extensive burning of coal
	(b) Slow	Blazing but localised burning of coal
2. Appreciably higher than that of coal i.e. more than 20	(a) Fast	Blazing and extensive fire associated with burning of props etc.
	(b) Slow	Blazing fire associated with burning of props etc., but a localised one
3. Appreciably lower than that of coal i.e. much below 10	(a) Fast	Superficial fire but covering an extensive area
	(b) Slow	Superficial fire and a localised one

Table 4 - Comparison between CO/O_2 deficiency and C/H ratio in Jharia field (Ghosh et al., 1980)

Description of fire areas	CO/O_2 Deficiency	C/H Ratio
Fire of recent origin, slight heating noticed, area kept sealed off	0.20-0.90	0.25-0.75
Heating in an advanced stage, area kept sealed off	1.75-3.00	1.01-1.45
An old abandoned long-standing fire, hot fumes observed coming out from overhead surface cracks	0.22-1.16	20 and above

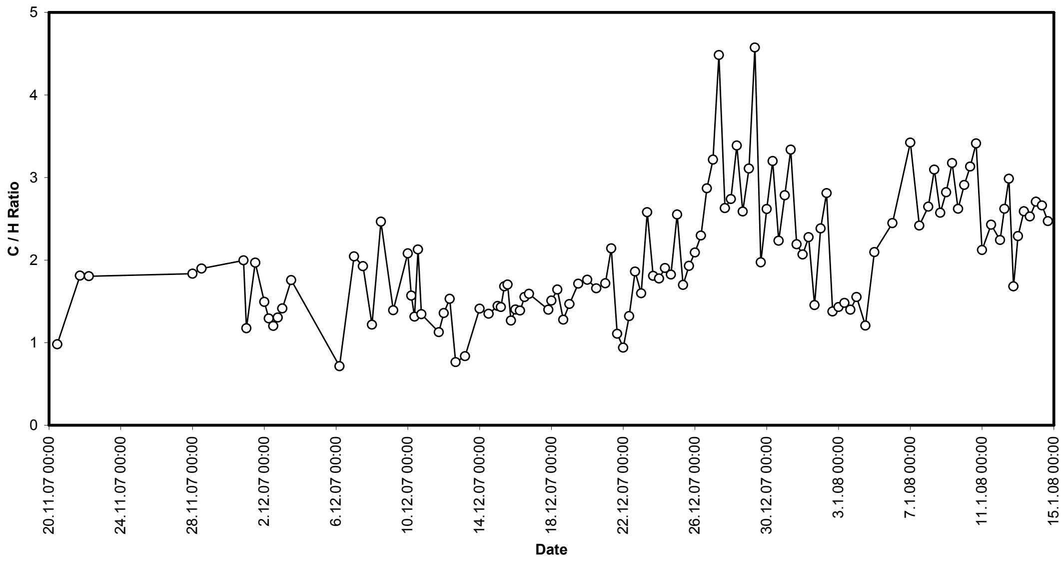

Figure 8 - The variation in C/H ratio for Gelik mine fire

Jones-Trickett Ratio

The Jones-Trickett ratio resulted from numerous examinations of the gases formed as by-products of colliery explosions and mine fires. This ratio can be used to indicate the type of explosion that has occurred in a mine and the level of activity or passivity of a fire behind seals. It was originally developed to help researchers differentiate between gas or coal dust explosions. It has been adopted to mine fire situations. Jones and Trickett (1954) suggested that analysis of the gases in a sealed area may indicate whether methane or coal dust had been involved in an explosion. They treated the combustion of methane and of coal theoretically, in each case deriving a relationship between the amount of oxygen used in the reaction and the amounts of carbon dioxide, carbon monoxide, and hydrogen produced. All these quantities can be determined when a sample of gas is analysed. The relationship for methane is different from that for coal due to the difference in chemical composition; hence, observation of the relationship makes it theoretically possible for the products of a methane explosion to be distinguished from those of a coal dust explosion. The ratio is expressed as:

$$TR = \frac{CO_2 + (3/4)CO - (1/4)H_2}{0.2647N_2 - O_2} \tag{4}$$

The ratio varies with the type of fire, depending on the fuel. If the ratio is less than 0.4, no combustion exists. When the ratio is between 0.4 and 0.5, methane is the fuel. The values between 0.5 and 0.9 indicate that the fuel is coal, oil, conveyor belt, insulation. The value of the ratio between 0.9 and 1.6 implies that wood is burning. Values above 1.6 generally occur in laboratory conditions. Thus, the gas chromatograph or sampling device(s) should be carefully examined if the ratio results above 1.6 during a possible mine fire. Figure 9 shows the trend in the Jones-Trickett ratio for the Gelik mine fire.

RESULTS AND DISCUSSION

The Gelik mine fire is not a spontaneous combustion event but resulted from an electrical contact. TTK applied several fire fighting actions including sealing-off the area, pumping nitrogen and filling the area with water to control the fire as quickly as possible. Seven seals were built initially but the expected decrease in the concentrations of CO and O_2 did not occur, possibly due to leakage. Thus a further 13 seals were constructed to prevent air from entering the fire zone. At the same time nitrogen was pumped to the zone to control the fire. However, the authors expected that this was not going to be effective since the volume of the void into which the nitrogen was being injected was too great. The result was as expected; pumping of nitrogen was not as efficient as the mine management desired. It was also decided to fill the fire zone with water to control the fire.

Continuous sampling from the fire area provided data for examination. The data obtained from the analysis, using a gas chromatograph, was examined and interpreted for different gas indices. CO concentration is generally used in Turkish coal mines to monitor the mine atmosphere during mine fires. Graham's ratio (CO/O_2 deficiency) is another method used to assess the condition of mine fires.

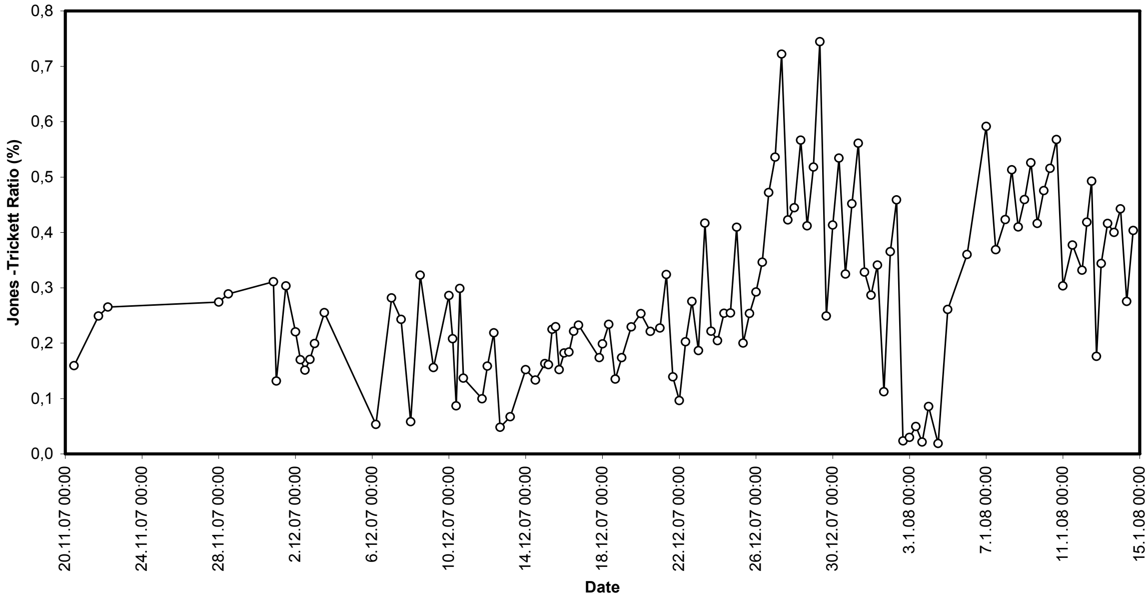

Figure 9 - The variation in Jones-Trickett ratio during Gelik mine fire

In the Gelik mine case, CO concentration at the beginning of the fire was measured as 1,250 ppm and decreased to normal levels (below 50 ppm for Turkish coal mines) after control actions (sealing-off, filling with water and pumping nitrogen) were implemented. However, CO concentration climbed to 3,250 ppm following the opening of the No.1 seal on drift No. 41300 (-260) in 1st January, 2008. As soon as the seal was opened the CO concentration started to increase dramatically and the area was resealed.

Although there was some observed decrease at the beginning of the fire, the oxygen concentration showed an increase in general. It can be considered that the precautions taken to combat the fire were effective at early stages, thus causing a decrease in the oxygen concentration but since there was air leakage into the fire zone it was not possible to reduce the oxygen concentration below 15-16%. It is considered that the air leakage is the result of either unfavourable geological conditions (faults, cracks etc.) or workings of adjacent private mines.

A sharp increase (from normal value to two) in Graham's ratio implied that there was an advanced heating which may turn into an extensive fire. After sealing, filling the fire zone with water and pumping nitrogen Graham's ratio reduced to its normal value indicating heating had cooled down. Nevertheless, after No.1 seal on drift No. 41300 (-260) was opened, there occurred a dramatic increase in Graham's ratio since CO concentration reached to 3,200 ppm on 14th January, 2008.

Willet's ratio followed the same trend as Graham's index showing an increase at the beginning and then reducing, implying that the fire was extinguished but then increasing sharply on 14th January, 2008, as result of the sharp increase in CO concentration.

While the indicators above implied that the fire seemed to be extinguished, the C/H ratio value approaching five suggested that there was possibly a localised, superficial fire behind the seals. This was proved after measuring high CO concentrations as soon as the seal was opened.

The Jones-Trickett ratio suggested that no combustion existed until the date 23rd December, 2007 when the ratio had a value of 0.42. After that time the ratio increased, ranging between 0.5 and 0.9, indicating there was a fire in which coal, oil, conveyor belts and insulation were the fuel. This suggestion proved to be true after a subsequent mine inspection confirmed that coal, conveyor belts and cables had burned.

CONCLUSION

Monitoring of the mine atmosphere is very useful in mine fire incidents. Relating the concentrations of individual gases to time, applying gases to equations, and examining their change over time are tools that have been successfully used to determine if a heating exists and, if so, the extent of the emergency. Hence, fire ratios (indices) play a very important role in assessing the status of a sealed-off mine fire. In this study, concentrations of gases in the mine atmosphere were monitored and several indices were utilized to assess the Gelik mine fire, Zonguldak, Turkey. Although the variation in CO concentration, Graham's ratio (CO/O_2 deficiency) and Willet's ratio indicated that the fire had been extinguished, the variation in O_2 concentration, C/H ratio and the Jones-Trickett ratio suggested that heating and/or the fire was still continuing. Opening of the seal No.1 and the resultant dramatic increase in CO concentration in a short period proved that the fire hadn't been extinguished. Therefore, it is concluded that it would be more precise to evaluate the ratios together instead of treating them alone since the uses of ratios may vary from case to case. Furthermore, attention must be paid to understand the individual fire and/or heating cases and to get more reliable results by carefully assessing different ratios or indicators.

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