

Assessment of status and extent of fire in abandoned coalmines – a case study

The problem of fire in abandoned mines is a global challenge to all coal producing countries. The main and immediate concern is to save the vital surface structures like railway lines/roads, bridges, rivers/stream, overhead construction from such fires as well as protecting adjacent underground property of the mine either by isolating or digging out permanently. But the difficulties are being faced, in both the cases of isolation of such fires, due to lack of knowledge of exact location of fire in unapproachable mine as the surface evidence of fires may not be related by straight line paths to the source of combustion.

Authors have identified three zones around fire viz., active fire zone, upstream zone (negative pressure zone) and downstream zone (positive pressure zone) on the basis of some parameters viz temperature, pressure by measurement through boreholes, gas composition, fire index ratio from results of air samples collected through boreholes and application of US Mine Fire Diagnostic (MFD) model. Vector representation of trend of gas composition, borehole wise, was also used in identifying the different zones and their widths. This concept was applied for identifying different zones of fire affected area in one of the mine of Bharat Coking Coal Limited (BCCL) situated in central part of India in state of Jharkhand.

The details of methodology for measurement of parameters considered, particulars of the mine and experimental conditions, results of investigation and steps for calculation of status and extent of fires including rate of progress for some period have been covered in this paper.

Introduction

The problem of fire in abandoned mines is a challenge to all the coal producing countries including India. The cost of tackling [1] such fires are prohibitive because, usually the fires cover a much larger area, many a times they are inaccessible due to lack of accurate mine maps. Fire-spread is faster in mined out coal formation than in inactive

ones in undeveloped areas [2]. The fire advance rate varies from a few inches to a few hundred feet per month - depending on situation and mining conditions. The combustion rate of the fire depends on the rate of oxygen feed to the burning fuel. The fire has a tendency to continue burning for a long time when there is scope of entry of air. It may be from leakages in the stoppings, cracks and fissures in the coal massive created from adjacent workings, and from shallow overburden. Therefore, the main and immediate concern of such fires are to save the vital surface structures like railway lines/roads, bridges, rivers/stream, overhead construction as well as protecting adjacent underground property of the mine. Another difficulty faced in isolation of such fires is determination of exact location of fire in unapproachable mine as the surface evidence [3] of fires may not be related by straight line paths to the source of combustion, since hot gases follow the path of least resistance. Therefore, the heated source of combustion products can be at a distant, laterally and vertically from the surface expression. Prediction of location of fire by any mathematical model may not be accurate, as strata get broken in irregular fashion due to heat load. Methods using remote thermal characteristics or variations in the gross composition of the mine atmosphere have not been routinely successful for locating isolated combustion zones. Infrared photography discriminates temperature variations only within a few centimeters of the surface, usually indicating heated vents and fractures. Again core drilling and near-surface geophysical imaging techniques [4] will produce adequate information on structural features, but are less reliable in indicating combustion areas. The elevated temperatures [5] can alter the mineralogy of iron bearing blocks, but magnetic anomalies are more likely to be associated with areas that have been heated and cooled with active combustion. Similarly, electrical terrain conductivity surveys [6] may indicate water flow in areas where combustion is unlikely. Near surface seismic surveys and ground penetrating radar can indicate subsidence areas and changes in subsurface structure, but these are not necessarily related to combustion.

To locate this type of remote, subsurface fire, it is necessary that [7] it has a measurable characteristic detectable through standardized sampling methods and the

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data interpreted according to an appropriate algorithm. A novel method [8] for determination of location of fire as well as status of heating, envisages drilling of adequate number of boreholes at strategic locations in a fire area from surface and drawing out gas samples. Borehole temperature measurement in the mine void may be more accurate in case of leaky sealed-off area. The result of temperature measurement [9] alongwith gas composition, pressure and pressure behaviour proves to be helpful in locating fire. Assessment of fire area [10] and its division into three zones viz., active fire zone, upstream zone (negative pressure zone) and downstream zone (positive pressure zone). Temperature of environment is above critical temperature of coal, pressure of zone more than atmospheric pressure, oxygen below 2%, may be considered as "fire active zone"

Authors have attempted to identify active fire zone on the basis of temperature, pressure by measurement through boreholes, gas composition, fire index ratio calculated from results of air samples collected through boreholes and US Mine Fire Diagnostic model (MFD) [11]. (Vector representation of trend of gas composition, borehole wise, was also used in identifying the active fire zone and their width. This concept has been applied for identifying active fire zones in fire affected area in one of the mine of Bharat Coking Coal Limited (BCCL).

Case study

East Bhagatdih colliery belonging to Kustore Area of Bharat Coking Coal Limited (BCCL) is situated about 7 km from Dhanbad railway station. The mine is quite old, extensive having 15 numbers of coal seams within leasehold area of 242.92 hectares. The topmost coal seam is XV seam with descending order towards lower seam. The workings have receded to VII/VIII seams after partial extraction of coal from the upper seams. The north-east boundary of the mine, developed along X seam, has been affected by fire of Rajapur

opencast project (ROCP) since long. In the mine X seam (thickness 12.56 m and gradient 1:10) has been developed in two sections viz X (T) and X (B) by bord and pillar method and is standing on pillars. There are also a few sealed-off areas in the seam.

An indication of fire was observed in X (T) seam at the junction of 1R and 1L No. 5 pit on 14th July, 2006. The fire was progressing very fast and within a very short span of time it turned into a blazing fire. The intensity of the fire, from gas analysis results, can be judged by the fact that the Graham's ratio reached a value of 19.0% and the environment of the area between pit no.5, pit no-4 and pit no 10 in X (T) seam was polluted by a high concentration of noxious gases. To save the workings below X seams, fire had to be isolated by erecting stoppings in shaft level around 10 pit. Subsequently, no 5 pit has also been filled with sand. Unfortunately the situation compelled involvement of a large area of about 242.92 hectares for fire to spread and to engulf 6.06 million tonnes of prime colliery coal in X(T) and X(B) seams. The production/workings in the mine has also been suspended owing to the danger of inundation from water logged area at the adjoining boundary of East Bhagatdih and Pure Jharia section of ROCP. There are many important surface structures e.g. R.S.P. College, Raj School, Water Board Colony, Bokapahari Basti, private houses etc. situated over the fire affected area. Therefore, mine management entrusted an assignment to the Central Institute of Mining & Fuel Research erstwhile (CMRI) Dhanbad. To determine extent of fire was one of the objective under scope of work to take corrective measures by the competent authority. The authors carried out investigations and developed a methodology for determination of extent of fire in abandoned mine. In the mine. The upper seams are mainly standing on pillars except few patches where pillars are extracted either by caving or with stowing. The other details of the seams are given in Table 1.

TABLE 1: DETAILS OF COAL SEAMS

Name of seam	Thickness (m)	Depth from surface (m)	Parting (m)	Present status	Balanced / mineable coal (million tonnes)
1. XV Seam	6.7	23.78 - 30.48		Exhausted	
2. XIV Seam	7.9	71.63 - 79.55	41.15	Exhausted	
3. XIII Seam	6.58	80.62	1.07	Jhama (virgin)	
4. XI/XII Seam	13.10	129.54 - 142.64	42.34	Exhausted standing on pillar	0.14
5. X Seam	13.55	171.28 - 181.33	28.64	Standing on pillar	1.81
6. IX Seam	1.21	197.02 - 198.23	12.19	Partially developed	0.15
7. VII/VIII Seam	16.92	229.34 - 246.76	31.61	Standing on pillars and virgin	15.71
8. VI Seam	3.04	274.61 - 277.63	27.93	Virgin	5.71
9. II, III & IV Seam	9.29	325.11 - 334.40	12.02	Virgin	10.00
10. I	2.40	350.11 - 352.92	16.15	Virgin	11.99
11. Zero Seam	3.0	370.13 - 373.13	17.96	Virgin	

The present study is limited to X seam only which is affected with fire. The X seam has been extensively developed contiguously in two section viz, X (T) and X (B). The extent of development is from Rajapur OCP in north, Simlabahal colliery/Bhargora project in south, Khas Jharia/Kujama colliery in East Ena and Kustore in west. The seam is mainly standing on pillars except in few patches where pillars have been extracted either by caving or with stowing. Major portion of the area is stowed except one gallery (inspection gallery) from pit no. 4 to pit no.5, prior to sealing it was used as inspection gallery for inspection of N-E barrier/stopping at 2R/-1L and water dam at shaft level east of no 3 pit/4 rise. This inspection gallery was naturally ventilated through no. 5 and no. 4 pits. Within the area there is also a caved panel between 3R to 6R and -1L to -5L from no.5 pit. The seam is connected with eight shafts which are presently closed.

ABOUT THE FIRE AREA

For ease of investigation, the surface area above X seam, on the basis of location of Dhanbad-Jharia road passing over the seam from north to S-E direction, has been divided into two zones viz. zone A and B. The surface area of zone-A is thickly populated and including many important surface structures viz, RSP College, Raj School, water tank, MADA colony etc.. The area of zone-A lies between a line joining pit no 4, 1 and 2 to extreme end in east direction i.e. ROCP boundary and area of zone-B is the remaining part of the property. Presently, the zone A is affected with fire. In zone-A pit no. 4, 1 and 2 are situated at the west side boundary and is further demarcated by imaginary lines B1, B2, B3 and B4. The extent of line B1 is along Dhanbad-Jharia road passing in north to south direction near no. 4 pit. The extent of line B2 is along approach road connected with D-J Road near

ROCP office to Bokapahari, which is passing almost over the adjoining boundary between ROCP and East Bhagatdih colliery. In N-E portion of the boundary the line B3 starts from no 5 pit to Pure Jharia section of ROCP. The remaining portion of boundary is bonded by line B4 in S-E between East Bhagatdih and Pure Jharia. The details are shown in Fig.1.

Investigation

SELECTION OF LOCATION OF BOREHOLES

Selection of sufficient number of boreholes representing the area of study

Generally following points are taken into consideration while drilling boreholes.

- I. Location of borehole. Borehole should be well connected with underground environment.
- II. Borehole should not be watery.
- III. Diameter of borehole should be sufficient for lowering sampling pipes and temperature probes.
- IV. Borehole should be cased at least up to loose strata.
- V. Borehole should be air leak proof by making concrete platform and proper capping arrangements.

Keeping location of hot spot around borehole no.1, unstowed portion, sealed-off and open areas into consideration, the developed area of X (T) seam was divided into two zones viz, zone-1 and 2 as shown in Fig 2. In same the figure marked area ABCD may be named as zone-1, which is a caved and sealed off panel in west side of borehole no.1. Similarly, marked Area ABEFGH may be named as zone-2 along southwest of borehole no. 1 up to the boundary of RSP College. As per the availability and suitability of space either from surface or underground, location of six boreholes [4 boreholes up to X (T) and 2 boreholes up to X (B) seams] have been selected and drilled. The location of boreholes, depth, diameter and arial distance from borehole no.1 are furnished in Table 2.

The investigation comprising study of pressure behaviour, temperature measurement, collection of gas through different boreholes, have been carried out during the period between July 2006 and April 2007. The methodology adopted for investigation are discussed in brief.

Measurement of temperature through boreholes

The temperature at the bottom of boreholes was measured using maximum type mercury thermometers contained in brass casings, lowered to the bottom of the borehole with the help of winch machine. Thermometer in casing is kept in the borehole for about 30 minutes [10].

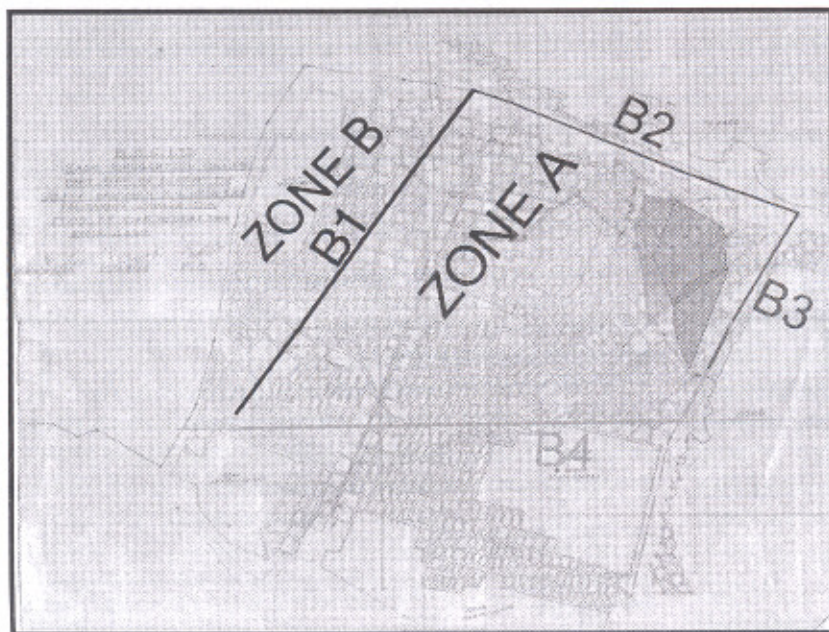


Fig.1 Part plan of X seam showing boundary and active fire zones

TABLE 2: DETAILS OF BOREHOLES

Name of zone	Borehole no.	Sunk up to	Location	Depth (m)	Diameter (mm)	Date of drilling	Arial distance from BH no.1(m)
1.	1	X(T)	-5LW/1R	45	100	July 06	0
2. Zone-1	3	X(T)	-4LW/1R	48	100	July 06	90
3.	2	X(T)	-1LW/1R	46	100	July 06	120
4. Zone-2	4	X(T)	(5PIT)SLW/1R	52	100	Feb. 07	110
5.	5	X(B)	(5PIT)SLW/2R	60	100	Feb. 07	115
6. Zone -2	6	X(T)	(5PIT)SLW/3R	52	100	Feb. 07	120
7.	7	X(B)	(5PIT)SLW/4R	60	100	Feb. 07	125

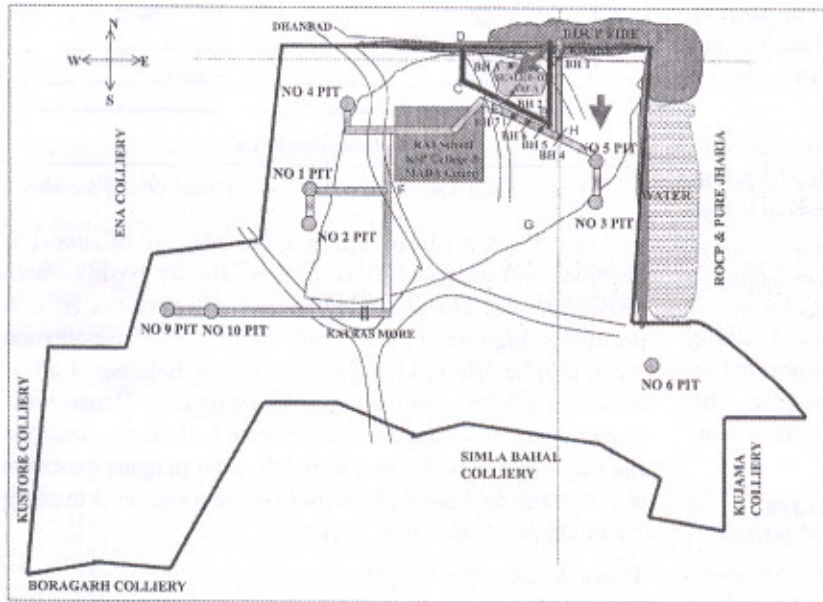


Fig.2 Schematic layout of modified zone of propagation of fire in X seam of East Bhatgadh colliery, BCCL

DISCUSSION OF RESULTS OF INVESTIGATION

Results of pressure behaviour study revealed that:

- Pressure of borehole no.1 is positive round the clock. This may be due to draught created by fire in sufficient magnitude more than the magnitude of diurnal change in barometric pressure. This also indicates poor quality of sealing of X (T) seam developed area.
- Pressure of borehole nos.2 and 3 of zone-1 are negative round the clock. This indicates that zone-1 is under the influence of fire. This may be called as upstream of fire zone.
- Pressure of borehole nos. 4 and 6 of zone-2 varies from negative to positive against atmosphere with time but in opposite phases with diurnal change in barometric pressure. This indicates that zone-2 is also

under influence of fire. This zone sometimes may act as downstream and sometime as upstream.

The results of temperature measurements revealed that:

- Temperature of borehole no. 1 was measured in the range of 115-123°C, which is an indication of active fire.
- Temperature of borehole no. 3 was measured in the range of 54-69°C with rising trend a. This may be due to progress of fire towards the zone.
- Temperature of borehole 2 was almost equal to strata temperature.
- Temperature of boreholes 4, 5, 6 and 7 are almost equal to strata temperature.

The results of analysis of air samples collected from u/g through different boreholes revealed that:

- Value of Grahms ratio indicates active fire around borehole no. 1
- Concentration of CO₂ and O₂ in borehole 6 and 4 indicates that borehole no. 4 is connected with another air leakage path.

Study of pressure behaviour of the area in u/g around borehole

The study of pressure behaviour is helpful in assessment of quality of sealing as well as in identification of different zone around fire. This study was conducted by connecting borehole with a sensitive incline manometer of least count 0.05 mmwg and pressure of boreholes is recorded with time.

Collection of gas samples and analysis

To draw the representative air samples through boreholes, a thickwall polythene tube of 6 mm diameter connected with a cone was slowly lowered to the bottom of the borehole. The mouth of borehole was tightly sealed off to stop mixing of surface air during sampling. The free end of the tube at the surface was connected to an electric power operated air suction pump of capacity 10 liters/min. The pump is allowed to run for more than 30 minutes to purge the system of atmospheric air and fill the sampling bag with air from the sealed area. The sample was analysed in the laboratory using multi gas analyser/gas chromatograph.

- Value of RI index in MFD model of air sample of borehole no. 1 was calculated for the period January-April 2007. The RI values were found in the range of 101 to 129. As per the model this is an indication of active fire.
- Value of RI index in MFD model of air sample of borehole no. 3 (zone-1) was calculated for the period January-April 2007 and found rising from 41.83 to 50.57. As the RI values showed rising trend and have crossed the limiting value of 50. As per the model, value above 50 indicates suspected heating. Hence borehole no. 3 may be considered under influence of fire.
- Value of RI index in MFD model of air sample of borehole no. 4 (zone-2) was calculated for the period 3rd April to 13th April 2007 and the average value were found in the range of 69.26 to 36.42. Hence borehole no. 4 may also be considered under influence of fire.
- The RI value of the sample of borehole no. 2 and 6 in X(T) and BH no. 5 and 7 in X(B) section for period 3rd April to 13th April 2007 were found below 50. This indicates that boreholes nos. 5 and 7 are unaffected by fire.

Diagnosis of the problem

A conceptual model, representing downstream of fire, active fire zone and upstream of fire zone, has been conceived as shown in Fig.3. The same is also marked on the plan. The summary of results of different studies are represented with the conceptual model as under (Fig.3).



Fig.3 Model representing different zone round fire in X (T) section

Calculation of extent of fire

Determination of extent of fire in unapproachable abandoned mine is difficult and is totally a site specific. It depends upon various parameters such as geo-mining conditions, air leakage rate, availability of combustibles etc. An attempt has been made for determination of extent of fire on the basis of gas composition of boreholes. The calculation is based on the following assumption:

1. Pressure in active fire zone starts from zero to maximum positive value
2. Temperature of active fire zone equal or more than 89°C [critical temperature of X{T} seam coal]
3. Plotting of trend of gas concentration of different boreholes at strategic locations and marking of oxygen concentration in active fire zone is less than 2%
4. Index value of US MFD model is 100 or more in active fire zone.

STUDY OF PRESSURE OF BOREHOLES

Average value of the pressure measured through boreholes monthly basis was calculated and incorporated in the model as shown in Fig.4.

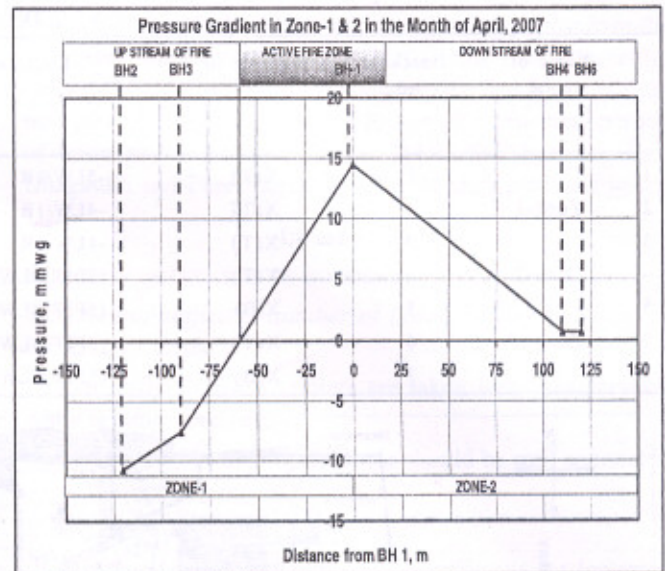


Fig.4 Model representing fire zones on the basis of BH pressure

From Fig.4 it can be inferred that pressure of zone-1 is negative and pressure of zone-2 is slightly positive with respect to atmosphere while pressure of active fire zone is positive in high magnitude. From the results of investigation it can also be inferred that pressure of borehole nos. 4 and 6 are varying from negative to positive with time. Hence zone-2 is acting as downstream and upstream both. In this situation fire may travel in both zones from BH-1. From figure the extent of active fire area would be 68m from borehole no. 1 in zone-1 and in zone-2 not clear.

TEMPERATURE MEASUREMENTS

The results of temperature measurements through boreholes month-wise are incorporated in the conceptual model as shown in Fig.5.

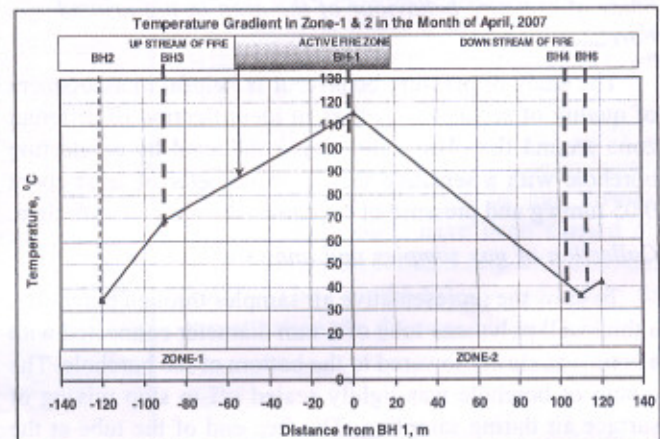


Fig.5 Model representing fire zones on the basis of BH temperature

From Fig 5 it is clear that temperature of BH-3 is rising with time and thus fire is propagating in zone-1. The extent of active fire in zone-1 would be 58m and 38m in zone-2 from borehole no. 1

US MINE FIRE DIAGNOSTIC MODEL

The value of RI from the results analysis of air samples drawn through boreholes for the month of February 2007 and April 2007 was depicted with the model as shown in Fig.6.

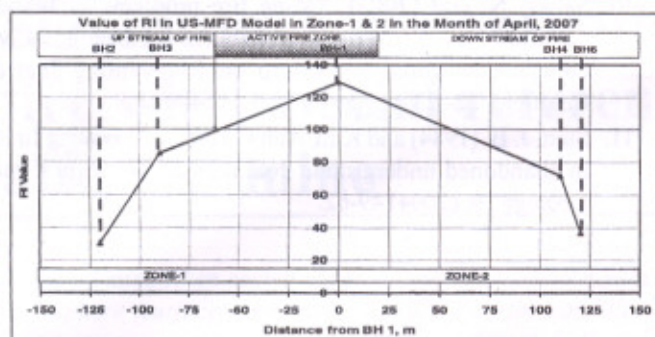


Fig.6 Representing values of RI in different boreholes

This model (Fig.6) indicated that extent of active fire is 62m in zone-1 and 55m in zone-2 from borehole no. 1.

AIR SAMPLE ANALYSIS RESULTS

The results of air sample analysis through boreholes particularly CO₂ and O₂ for the month April 2007 was depicted with the conceptual model as in Fig.7.

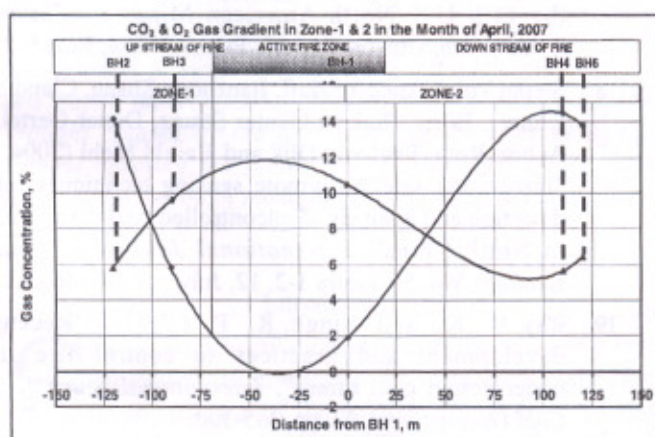


Fig.7 Representing CO₂ and O₂ trend in different boreholes in the month of April 2007

TABLE 3: EXTENT OF FIRE DETERMINED BY STUDIES OF DIFFERENT PARAMETERS

Name of Study	Extent of fire in Zone-1 from BH No.1 in 9 month [m]	Extent of fire in Zone-2 from BH No.1 in 9 month [m]
1 Pressure behaviour	62	—
2 Temperature measurement	58	38
3 US MFD model	62	55
4 Gas trend	68	5
Average	62.5	32.67

It is clear from Fig.7 that the active fire zone has extended 68m in zone-1 and 5m in zone-2 (April 2007).

Hence fire lies in the area between borehole no. 1 (-5LW/

1R) and borehole no. 3 (-4LW/1R) and borehole no. 4 (no. 5 pit SL/1R) are affected with active fire. The area, between borehole no. 3 and borehole no. 2 and borehole no. 4 and borehole no. 6 are downstream sides (oxygen supplying zone) of the fire. The extent of fire calculated from different parameters have been summarized in Table 3.

The fire has extended within the radius of about 62 m in zone-1 and 32 m in zone-2 till April, 2007 and also depicted in Fig.1.

Conclusions

The results of investigation, comprising selection of location of boreholes, study of pressure behaviour of underground environment, measurement of temperature and collection of representative air samples through boreholes and their depiction on a conceptual model of fire area have led to the conclusion that the fire is propagating towards west and south side from borehole no. 1 in X (T) seam and has covered an area about 62 m radius from borehole no. 1. The study was aimed at a very well defined objective, the results of investigation carried out in the mine and critical analysis of the collected data however, have thrown up some findings which may be extremely useful in taking corrective measures against such fires in abandoned mines particularly in Jharia coalfield.

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INVESTIGATION INTO THE EFFECT OF HIGH EXPANSION, HIGH STABILITY FOAMING MATERIAL ON AUTO OXIDATION OF COAL USING THERMO GRAVIMETRIC TECHNIQUE

(Continued from page 405)

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