U. SIVA SANKAR
MD. ABDUL KHADIR
and
K. NAGESWARA RAO

Introduction of tube bundle gas monitoring system at Adriyala longwall project, India

Modern mining methods create a higher risk of spontaneous combustion from fast moving faces and increased ventilation. If spontaneous combustion did occur, the consequences were costly in both lost equipment and lost production. The detection and management of explosive atmospheres in underground coal mines is critical to the safe operation of a mine. Underground coal mines contain potentially explosive gases. But monitoring on its own never prevents a mine fire or puts it out if it starts. What continuous monitoring offers is a means of identifying a problem early and subsequently an opportunity to take appropriate control action. This paper briefs about the tube bundle gas monitoring system and its introduction in Adriyala longwall project of Singareni Collieries Company Limited.

Introduction

Tube bundle gas monitoring systems were developed by the National Coal Board in the United Kingdom (UK) in the late sixties as a means of early detection of spontaneous combustion (Chamberlain et al 1971). In brief, tube bundle systems are comprised hollow tubes run from the surface to the desired monitoring location, through which gas samples are drawn to the surface by way of vacuum pumps as shown in Fig.1. By switching from one tube to another on the surface, the sample from each point in turn can be analysed. All analysis, pumping and switching hardware is located on the surface removing the need for equipment to be approved for use underground. Electrical supply to the system can also be separate from mine power allowing operation during loss of power underground.

Although originally designed for monitoring carbon monoxide, it was identified early in the development of the technology that the system was easily adapted to include analysis of methane, carbon dioxide and oxygen as well; with the comparatively small increase in cost for the enhanced analytical capabilities justified (National Coal Board 1977).

Messrs. U Siva Sankar, Dy. Manager, Adriyala Longwall Project, SCCL, ulimella@gmail.com, Md Abdul Khadir, Colliery Manager, Adriyala Longwall Project, SCCL, abdulkhadir1973@gmail.com and K Nageswara Rao, Project Officer, Adriyala Longwall Project, SCCL, po_alp_rg3@scclmines.com

The samples are analysed sequentially using very accurate and stable infrared and paramagnetic techniques. Tube bundle systems appear to have been used proactively in the United Kingdom, Australia, New Zealand and China.

Typically tube bundle systems integrate data about ventilation rates and barometric pressure with gas concentrations to provide a dynamic, sophisticated and comprehensive picture of the underground mine environment. The capacity to remotely sample (without exposing personnel to risk) and measure these additional components as well as carbon monoxide, and the ability to extract samples for analysis by other techniques such as gas chromatography, has meant that mobile tube bundles find widespread use internationally as a means of gas analysis during or following a major incident at a mine (see for example: Harrison, Bell and Brady 2010; Marx et al 2008; Valoski 2010; Mischo and Weyer 2012).

One of the most commonly cited disadvantages of tube bundle systems is the time taken for the sample to travel through the tube to the surface and be analysed (see for example: National Coal Board 1977; Harrison 1973; Chakravorty and Kolada 1988; Oda et al 1987). The time between the sample entering the tube and being analysed is not just dependent on the travel time through the tube but also on the sampling sequence. Tube bundle systems make use of one analyser or set of analysers to analyse samples from multiple locations, so analysis for each point is not continuous but cyclic. The time from sampling to analysis may vary between ten minutes and hours and is dependent on many factors including length of tube, internal diameter of tube, restrictions (e.g. water condensate) in the tube, number of tubes in the system, sampling sequence, vacuum pressure, volume of plumbing between sample pump and analyser and analyser response time. Much comment has been made that the delay in obtaining results is not significant when considering application of the technique to detection of spontaneous combustion because of the longer time frames associated with the development of spontaneous combustion (e.g. Chamberlain et al 1971; Litton 1983; Hertzberg and Litton 1976).

While tube bundle systems not have a response time

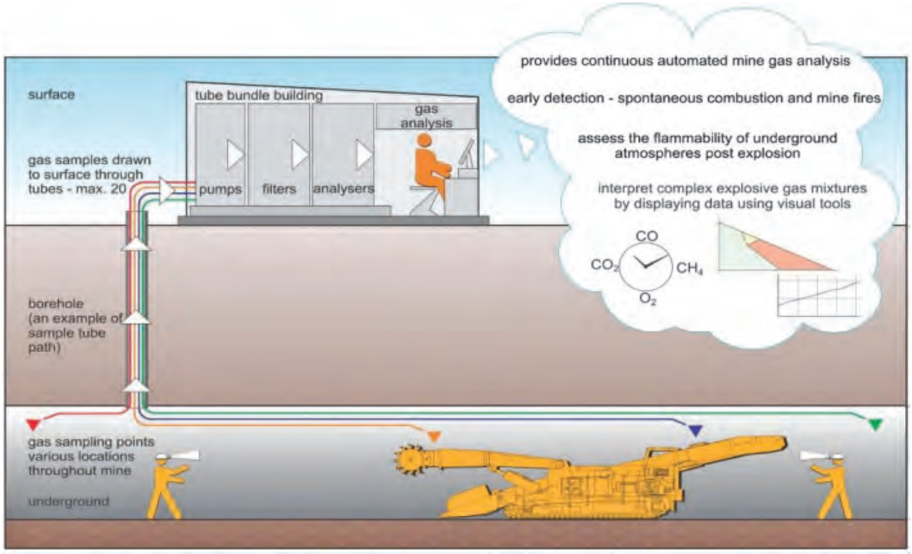

Fig.1 Tube bundle system schematic diagram

indicators of smell and haze were detectable (National Coal Board 1977). The rate of evolution of carbon monoxide had been established as the earliest indicator of incipient spontaneous combustion. But it was quickly identified that extending the analysis to include oxygen, methane and carbon dioxide was worth the additional expense and provided a much better understanding of the variations in the atmosphere of an underground coal mine. Determination of the explosibility in sealed and active gobs is a primary function of tube bundle systems, equally as important as the early detection of spontaneous combustion and fires.

sufficient for detection of electrical fires, belt fires or sudden releases of methane into the general body posing an immediate explosion risk, they do provide a very effective means of determining increasing or decreasing trends of gas concentrations. This in turn provides for the prediction of explosibility status and the development or extinguishment of other fires allowing implementation of appropriate controls. Similar to the onset of spontaneous combustion, the development of explosive atmospheres in sealed areas or active gobs does not generally happen instantaneously, but over a period of time that is suitable for detection and more importantly prediction by tube bundle systems.

Alternative to tube bundle gas monitoring systems

A study of preliminary analysis of technology and techniques that provide an alternative to tube bundle monitoring was conducted. These included manual sampling, open path remote sensing, radon detection and gas chromatography. Real-time gas sensor or telemetric monitoring was identified as the technique most commonly considered (rightly or wrongly) as an alternative to tube bundle monitoring.

Real-time gas sensor monitoring was the system that came closest to tube bundle systems. However, Simtars does not consider real-time gas sensor systems an alternative to tube bundle monitoring, rather it is considered complementary. Both systems have strengths and weaknesses that determine their suitability for addressing specific hazards. Table 1. is a summary of the techniques considered as potential alternatives to tube bundle systems.

Application of tube bundle system

The system was originally developed to continuously monitor the carbon monoxide content of the air passing critical points underground in order to detect spontaneous combustion in its very early stages before, the traditional

Effectiveness as a preventative measure

- Tube bundle systems have a proven track record of averting mine disasters due to gas explosions. Even in situations where explosions were not prevented, lives were saved as the result of timely information provided by tube bundle systems.
- Tube bundle systems currently provide the most effective means of automated sampling of sealed and active gobs providing ongoing trending and determination of explosibility status even when the mine has been evacuated.

Value in post-event situations

- Tube bundle systems remain available after a mine has been evacuated as they operate independently of underground power.
- There are numerous incidents in many countries/ jurisdictions where mines rescue teams have been deployed underground and subsequently killed in an explosion, largely due to an unknown or incomplete knowledge of underground atmospheric conditions. Tube bundle systems can provide a determination of the mine atmosphere following an explosion or fire before the deployment of rescue teams underground.
- The need for post-event gas analysis has often been identified the need for improved survivability of a mine’s existing monitoring system. There are a number of measures that may be utilised during the installation of tube bundle systems that improve the survivability of the underground tubes during an explosion. A key factor is strict adherence to a rigorous installation and maintenance standard.
- Mobile laboratories play an important role in gas analysis in post-event response, but experience indicates they are

best used in conjunction with fixed tube bundle systems to extend their capabilities rather than as an alternative to fixed systems.

Tube bundle system at adriyala longwall project

Adriyala longwall project (ALP) is pioneered in the introduction of latest technologies. ALP successfully commissioned a state of art high capacity longwall introducing 2×1152 tonnes, shield supports with a rated capacity of about 3.0 MTPA. Besides this, there are road headers, bolter miner for trunks and gate roads development respectively. This large underground project is a flag ship project not only for SCCL but also for Indian coal mining industry as a whole.

There are four workable seams in the mine with minimum geological disturbances. The total extractable reserves in the project are 78.597Mt. The mine is accessed with four punch entries and one return air shaft of 7.5m dia with 484m depth from surface. The rated production from the project is 2.817 million tonnes per annum and has planned life of 35 years.

A SICK tube bundle gas monitoring system has been purchased from Safety in Mines Testing and Research Station (Simtars) Australia. Simtars is a professionally independent, functional entity of the Queensland Department of Natural Resources Mines and Energy with extensive experience in the public and private sectors.

SICK is a German based company. The SICK tube bundle systems are installed at the majority of Australian coal mines and SICK have a presence in India to provide assistance with the system and the 6 monthly maintenance on the system. 20 point tube bundle gas monitoring system was introduced in Adriyala longwall project.

Tube bundle systems have been designed to operate 24 hours a day, 365 days per year. The basic principle is based upon running food grade polyethylene tubes from the surface to the required underground monitoring point and drawing gas samples using surface installed purging pumps for analysis on a dedicated four gas analyser. These tubes can be up to 6 km length for ½" tube and 9.5 km for 5/8" tube.

System is of Supervisory, Control and Data Acquisition (SCADA) software and hardware and developed specifically for continuous automated mine gas monitoring, interpretation and decision support system.

The system consisting of Sick Maihak 715 gas analyser configured specifically for the monitoring of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO) and oxygen (O_2) in coal mines. The analyser uses a Multor non-dispersive infra-red (NDIR) bench for measuring CO_2 in the range 0-50% and CH_4 in the range of 0-100%, a Unor NDIR for measuring CO in the range of 0-1000 ppm, and an Oxor P paramagnetic bench for measuring oxygen in the range of 0-25%. This analyser typically has an accuracy range of ±1% full scale for each component measured.

The gas conditioning equipment consists of various flow control components, sample gas cooler, gas selection station, filtration and water removal equipment and presents to the analysers gas samples completely free of water or any particulate matter. To ensure maximum safety, each sample tube is equipped with approved flame traps at both the underground and surface ends of the tube. A flow meter shall

TABLE.1

Issue	Tube bundle systems	Real–time Telemetric	Fibre optic	Borehole monitoring
Commercially available	Yes multiple suppliers	Yes multiple Suppliers	Not for underground coal methane monitoring	Components available not a complete system as such
Proven technology	Yes over 40 years	Yes over 30 years	Only at research and trial stage for underground coal mining,	Used successfully during emergency response to incidents and adhoc basis.
Underground power	Not required	Required	Not required unless coupled to independent sensor technology such as traditional real-time gas sensors.	Not required
Response time/result availability	Delayed by transport of gas from underground to surface for analysis (typically between 15 – 120 mins)	Minimal delay	Minimal delay	Dependent on measurement technique – minimal (sample travel distance ~500m max)
Typical Gases analysed	Carbon monoxide, methane, oxygen carbon dioxide	Carbon monoxide, methane, oxygen carbon dioxide	Methane and possibly carbon dioxide.	Unlimited – dependent on adsorption/ reactivity with sample line.
Analytical range	Covers full expected range for all but carbon monoxide. Current systems often limited to 1000 ppm	Limited, typically only oxygen measures full expected range. Dependent on available sensors but methane typically up to 5%, carbon dioxide 3% and carbon monoxide rarely above 200ppm more often maximum of 50ppm	Methane possible up to 100% (assume carbon dioxide to be the same) Other gases dependent on sensor used but expect same as those for real-time	Unlimited – dependent only on analytical equipment available

(Table 1 contd.)

Quality of results	High – useful for calculation of indicating ratios	Good for identification of problem but not always adequate for calculation of indicating ratios	Very good but for methane only, possible carbon dioxide	Dependent on instrumentation selected.
Implication of sample matrix	None	Requires oxygen for some sensors (electrochemical and pellistor)	None	Dependent on sensors chosen but based on almost unlimited choice could easily be avoided
Restrictions on sample locations	None other than access (really only an issue for inner gob) Response time limits applicability to monitoring for early detection of belt fires but can be of assistance in responding to such fires once developed	Need to access for calibration and maintenance and many require oxygen to function so generally limited to ventilated areas, not suitable for gobs or sealed areas	None other than access (really only an issue for inner gob)	Limited to available boreholes. Will be very dependent on surface access and drilling capabilities and budget
Determination of explosibility	Possible in almost all circumstances, from all areas being monitored, even during incidents generating significant hydrogen and carbon monoxide samples can be collected and analysed by gas chromatography.	Not able to include contribution of hydrogen and carbon monoxide range so low included contribution to explosibility negligible.	Oxygen not measured (unless coupled to realtime sensor) so only methane measured which does not give true determination of explosibility.	Able to cater for all gases –dependent on instrumentation selection.
Maintenance	Intensive	Intensive due to number of sensors and distribution around the mine and problems associated with and conditions exposed to	Negligible	Similar to real-time (dependent on number of locations) but access likely to be easier
Calibration	Can be automated and minimal requirements as one set of analysers for all points	Intensive due to number of sensors and distribution around the mine and problems associated with drift and conditions exposed to	Automatic checks	Similar to real-time (dependent on number of locations) but access likely to be easier
Automated System checks	Most components in modern systems monitored and problems generate alarms	Very limited	Yes	limited
Sample delivery/collection	Yes, samples can be collected from surface for additional analysis	No	No	Yes, samples can be collected from surface for additional analysis
Additional functionality	Limited primarily to gas measurement	Can be used to activate controls such as tripping power. Can include point source temperature and ventilation parameter monitoring. Because data is continuous and real-time data from multiple points can be feed into expert systems and evaluation and assessment of conditions underground made including determination of best route out of mine	There are many opportunities for additional functionality with fibre optics including telemetric applications, temperature measurements and even guidance out of the mine during emergencies	Boreholes provide access to the mine and therefore in addition to monitoring provide facilities/access for communications, cameras, inertisation and remote seals

be provided and visible on the analyser and the analyser generates low flow alarms.

System shall have provision to introduce manually collected gas samples from bags into the analyser for determination of composition, plus the ability to collect samples from any of the sample tubes for additional analysis through the “bag in” and “bag out” arrangement. The schematic line diagram of tube bundle hardware in the analyser room is as shown in Fig.2.

Analyser room is installed on surface near the punch entry-5 (PE5D). A, B and C bundles of 7 core tubes (ID-0.35", OD-0.5") are laid from analyser room to underground along PE-5D up to 61LN/PE5D, PE5R/74LN and PE5R/85L marshalling stations respectively. Individual tubes (ID-0.35", OD-0.5") are laid up to monitoring locations from respective each bundle tubes connected to marshalling stations.

Bundles are supported on gallery side L shaped hooks as well as roof cable brackets. The bundles are attached to the fully tensioned 10 SWG GI catenary wire by cable ties at an interval to prevent sagging. Individual tubes of the bundle as well as the individual tubes are joined with stainless steel or brass connectors and are further taped to ensure no leakage.

The tubes are installed such that, there is the minimum amount of undulation to avoid the settling of water. All tubes are run so that the water runs down dip to the marshalling panels where there are water traps. If single tubes are run down dip, water traps or seal panels are installed at the low point where water accumulates.

Tubes are provided with end of line of filters with flame traps to prevent entering of dust and flame. Flame traps are also provided at the tube end in the analysed room as shown in Fig.3(a) and 3(b).

The monitoring points are selected based on the statutory and other mine requirements for gas monitoring in underground coal mines as shown in Fig.4. The requirements are for methane, carbon monoxide, carbon dioxide and oxygen to be continuously monitored at the following locations:

- the return airway of each ventilation split
- the return airway from each gob area

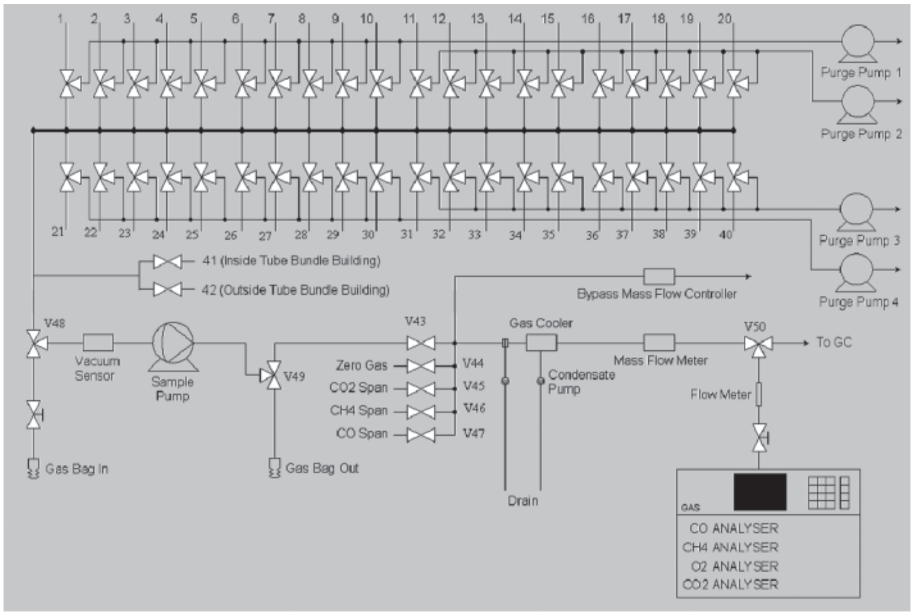

Fig.2 Schematic diagram of tube bundle hardware in analyser room

Fig.3 (a) and (b) end of line filter and flame trap at both ends of the tube

- the return of airway at the upcast shaft
- the return side of each conveyor belt
- the return side of the free steered diesel vehicle's roadways, and
- Isolation stoppings of sealed off area as well as isolation stoppings of panel under extraction.

The gas monitoring system automatically detects or calculates with the help of Segas professional software coupled with SAFEGAS tube bundle control software, the values and trends of:

- gas concentrations
- the ratio of carbon monoxide and oxygen deficiency (Graham's Ratio)
- the ratio of carbon monoxide and carbon dioxide gas explosibility and must:
- automatically activate an alarm if a gas alarm level is exceeded
- record the values and trends
- display the record at the surface of the mine where it can be easily accessed by coal mine workers and in a way that the record can be easily read by the workers
- keep the information on which the values and trends were based at the mine in a way that enables the information to be easily accessed and inspected
- Provide for an alternative electricity supply to ensure the system continues to function if the normal electricity supply fails.

Segas Professional is also the data interpretation tool used for the Simtars supplied gas chromatographs. Segas Professional is closely integrated with Safegas and allows operators to readily convert complex gas data into easily understood graphs and visual interpretive tools in an effortless fashion as shown in Fig.5.

Analyser calibrated at the time of installation and also at intervals of every month. The gases used for calibration are N_2 (Grade 5, 99.999 purity), CO_2 (Grade 4.5, 99.995 purity), CH_4 (Grade 4.5, 99.995 purity) and CO (1000 ppm, balance N_2). Leak test of individual tubes was done for every sampling or monitoring location with the use of CH_4 gas (2.5% CH_4 and balance N_2) injected at tube end to find any leakage of the individual tube and to rectify the same. This should be further done at every month interval or after every shifting or relocating of monitoring point.

Safegas allows four individual alarm thresholds (two levels for high and two levels for low) to be set for each parameter per monitoring location. Any value which equals or exceeds the threshold, in either direction, will trigger Safegas to raise an alarm.

Alarm levels shall be set by establishing what is normal for the sample location. This can be done by reviewing the time graphs for the location and also using statistical analysis of the last month's results for the sample location. The alarm shall be set to represent a variation from normal that is considered unusual and needs investigation. The effects of shot firing as well as presence of diesel vehicles should be taken into consideration while setting alarm levels. The investigation required is identified in the TARP that has been prepared. Consideration shall also be taken of statutory limits when setting alarm levels. Alarm levels shall be reviewed monthly after the monthly ventilation survey, on the introduction of a new tube or after a major ventilation change.

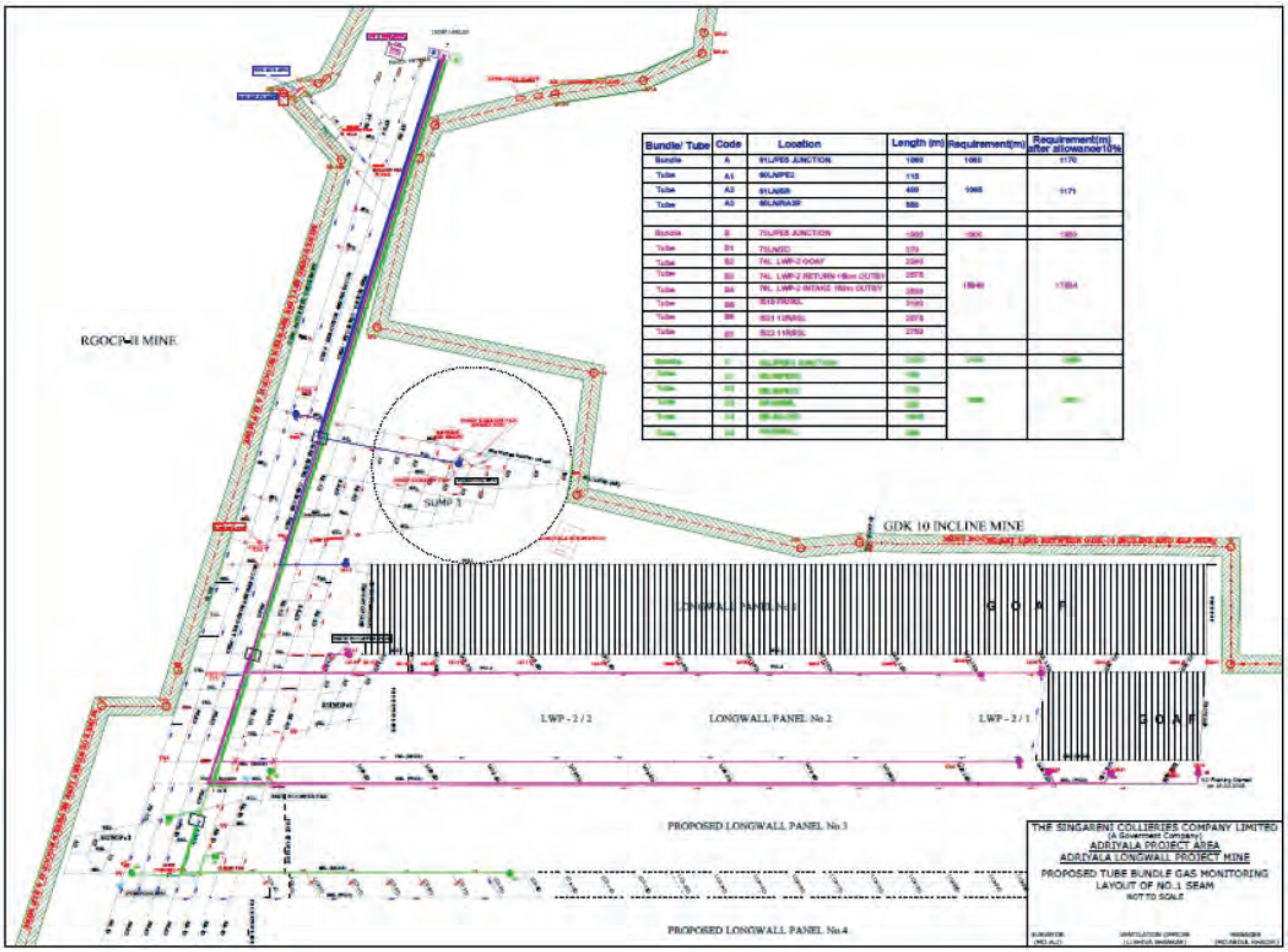

Fig.4 Tube bundle system layout at ALP

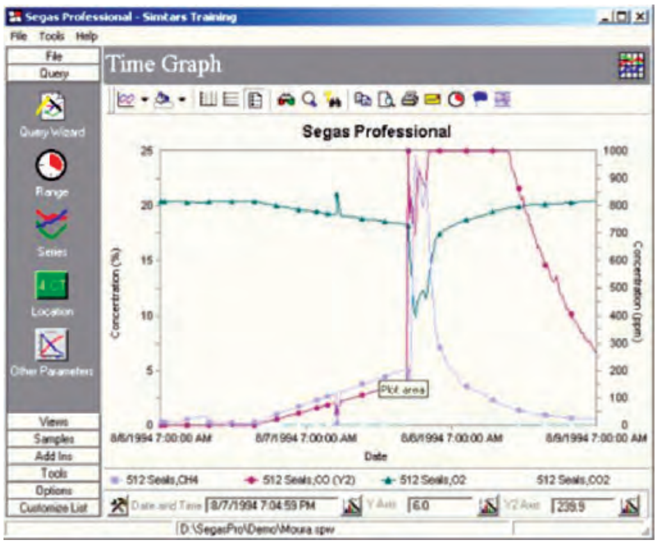

Fig.5 Time graph of respective monitoring location or sampling point

Conclusions

Tube bundle system needs less maintenance and is user friendly. Tube bundle technology coupled with the assignment of proper responsibility and accountability; effective management systems, practices, procedures and support networks; and competent personnel operating the systems can improve safety in underground coal mines. This can be achieved by providing early warning of spontaneous combustion and fires, by providing critical information following a major event and by continuously monitoring during normal mining operations to ensure atmospheres in active working areas, sealed gobs are not explosive. This has the added benefit of less disruption to production by providing the opportunity for early intervention.

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