MINE ATMOSPHERE MONITORING SYSTEMS

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ABSTRACT

Mine Atmosphere Monitoring Systems (MAMS) are intended to monitor continuously the mine air at fixed locations in order to detect the presence of contaminants (such as CO or smoke from a fire), the levels of methane and oxygen, and the velocity of airflow. Further, MAMS are intended to alert mine personnel of a potentially hazardous situation in a time frame sufficient to safely evacuate personnel and/or initiate and execute proper corrective procedures. MAMS are intended to augment, not to replace, conventional methods for underground hazard protection,thus increasing the level of safety in underground mines.

In order to perform their intended functions, MAMS must be highly reliable and designed properly. Reliability is a function of the electronic components that are used to fabricate the system and subsequent calibration and maintenance of these components. In general, reliability of MAMS is independent of the mines in which they are installed and used. Design, on the other hand, can be very dependent upon the mine in which the system is to be used. Proper design of MAMS include the selection of appropriate monitoring locations and placement of transducers which can depend upon the layout of an underground mine.

It is the intent of this paper to discuss both the reliability and design aspects of MAMS in order to provide better understanding of these systems, their capabilities, and their limitations. Particular emphasis will be placed upon the use of these systems for automatic fire detection.

INTRODUCTION

The life-blood of any underground mine is its ventilation system. As large volumes of fresh air are coursed throughout the underground workings, breathable, life-sustaining atmospheres are maintained, providing a healthy working environment. As the air sweeps across a working face, deadly methane is diluted to safe levels, along with the ever-present dust that can rob an underground worker from enjoying the benefits of a longer life. Within the past few years, a technology has evolved to continuously monitor this precious air in order to make certain that it

remains as contaminant free as possible --and, in the event that an incident occurs which results in contamination of the ventilating air, to alert mine personnel of the situation as quickly as possible so that emergency procedures can be initiated.

This report discusses the evolving technology of Mine Atmosphere Monitoring Systems, including the rationale behind its development and the safety benefits it can provide when installed and used properly. The report discusses, in a general sense, the components used to fabricate a system and offers some insight into how to design such systems in order to provide for optimum hazard recognition.

The "Why" of MAMS

Historically, underground mines have relied on various types of "monitors" to keep abreast of the quality of mine air. Some of these monitors have been of the human variety, where a person's keen sense of smell and sight are often used to great advantage to detect the odors given off from smoldering or burning coal, or to discern the barely visible wisps of smoke travelling down an entry. The flame safety lamp is another good example of a contaminant monitor. When exposed to an oxygen-depleted atmosphere, the flame begins to die out, or when exposed to excessive methane levels, the flame lengthens.

As time progressed, hand-held methane sensors began to replace the safety lamp as an indicator of excessive methane. Hand-held velocimeters were used to measure ventilation air velocity. Respirable dust samplers were attached to miners' belts to measure their exposure during a working shift. The list goes on. All of these devices have gradually gained acceptance for use underground and they represent significant improvements in our ability to monitor mine air in order to maintain its ability to support life.

But these advances, as great as they may be, have a common thread, namely, that they require the presence of someone to use them. But what happens when someone is not there at the moment a hazard occurs? As mining technology has advanced during the eighties and will continue to advance into the next decade, the physical size of our mines is increasing. Twenty or thirty years ago, when someone "walked the belt" to check for hazardous conditions, the inspection took only a half hour or so; today, especially in some of our larger mines, the same type of inspection takes considerably longer.

MAMS are intended to add to the safety of miners by continuously monitoring the mine air and providing information to miners as to its quality and its quantity so that rapid, reliable warning of a developing hazard can be given. Such a system, when designed, installed, and maintained properly "acts" like a continuous inspector, always vigilant to the occurrence of some unforeseen, developing hazard. By distributing transducers throughout a mine in some well-planned, logical fashion, early detection of excessive methane, CO or smoke from fires, oxygen-depleted areas, and/or abrupt changes in airflow can be detected automatically with subsequent, appropriate warnings given.

This is not to say that a person's nose could not have smelled the characteristic odor from a smoldering coal fire before a CO or smoke sensor issued an alarm, but rather, if no one's nose was there to smell the odor, what would have happened? Does one wait until the returns have been inspected to find that a roof fall has occurred and that methane is above an acceptable level? It is questions such as

these that have prompted the development of MAMS technology, that is, the necessity of knowing when a hazard occurs independent of required, periodic examinations so that proper emergency responses can be initiated at the earliest possible times. The potential of MAMS to augment the degree of safety in our underground mines is great. This technology needs to advance, and in the process of advancing to educate mine personnel not only about its potential but also about its limitations, so that, in time, such technology gains credibility and acceptance.

The "What" of MAMS

MAMS cannot replace all of a person's abilities to locate and define all hazards, nor is it the intent of MAMS to do so. With this in mind, it becomes immediately obvious that such systems can perform a limited number of functions and therefore have limited capabilities. However, the capabilities of such systems, even if limited, need to be exploited. To do this, cause and effect relationships between measurable quantities which MAMS can detect and the nature of the occurrence producing these measurable quantities need to be defined and understood.

In general, MAMS are currently limited to the detection and measurement of the following quantities:

1. Carbon monoxide (CO) or smoke
2. Methane
3. Oxygen
4. Air velocity

The detection of low levels of CO or smoke is intended to provide for early warning of a developing fire, either in its incipient, smoldering stages or its very early flaming stages. To most users, this is obvious. However, a crucial point about such sensors should be made-namely, that they measure CO or smoke levels independent of the source of the CO or smoke. What this means is that such sensors have no capability of determining whether the CO that they are measuring is coming from a fire or from some non-fire related activity, such as welding or from the use of diesel-powered equipment. Routine activities such as these can sometimes produce a sensor alarm but it should be clarified that when such alarms do occur, this is a clear signal that the sensor is really doing its job, rather than a signal that the sensor has failed.

Methane sensors are designed to detect the presence of excessive methane accumulations. Methane buildups can result from outbursts, mining into large pockets of methane in the coal seam, inadequate ventilation of the working face, or ventilation reductions due to falls of roof or rib.

Oxygen sensors are designed to detect the presence of an atmosphere which has insufficient oxygen to support life. Oxygen-depleted atmospheres most often occur in caved or gob areas, but can also occur in active workings which are weakly ventilated. In some applications methane and oxygen sensors are used together to detect potentially explosive atmospheres.

Air velocity sensors are used to monitor the air velocity in entries which may be crucial to a mine's operation, such as a belt or track entry, or within an entry where contaminant-free air is crucial to the safety of miners, such as an escapeway. Typically, when the air velocity is reduced to some minimal level within a given entry, an alarm is given. Most unexpected velocity reductions are due to falls of roof or rib which increase the resistance to flow. Other causes would be stoppage of a ventilation fan, but this condition is usually detectable at the fan itself.

With the exception of oxygen-depleted atmospheres, the three other hazards of fire, excessive methane, and airflow reductions are hazards that can develop almost instantaneously, or over a short period of time. To rely solely upon periodic inspections, spaced at finite intervals, often of a few hours duration or longer, when there exists technology for essentially continuous inspection would appear to be an error in judgment - especially when the potential consequences of injury and loss of life are evident.

However, as with any developing technology, there exist negative aspects as well as positive aspects. For the most part, the positive aspects of these systems are addressed above. On the negative side, the systems currently in use are not inexpensive, both from the standpoint of initial capital investment and the standpoint of system operation and maintenance. The costs of system components, installation of the system, and subsequent use and maintenance of the system may often be substantial enough that smaller mines cannot afford the technology, although there does exist a cost-effective alternative using pneumatic sampling systems. Even for mines that are able to commit themselves to the use of such systems, complaints of reliability are often voiced, although system reliability has greatly improved in the last few years. Often, complaints of systems that fail to work as expected are due to inadequate or improper placement of sensors. For instance, placing a CO or smoke sensor in a dead-ended crosscut and calling it proper placement is not much different than trying to measure air velocity by installing a velocimeter in the same location.

In other cases, system failure can sometimes be due to the lack of commitment by mine operators to follow guidelines for routine maintenance and calibration. Allowing an uncalibrated or nonfunctional sensor to remain in place and calling it a fire sensor is like blindfolding a miner, putting a clothespin on his/her nose and asking him/her to do a preshift examination.

Some complaints are more reasonable, such as the sensitivity some CO sensors exhibit to other gases such as hydrogen, a gas generated during recharging of some batteries, or the non-linear behavior of methane sensors to concentrations in excess of 5%.

Most, if not all, of these problems are currently being addressed and there exist promising solutions in many of these problem areas.

The "How" of MAMS

The previous sections have outlined the rationale for using these systems and presented a general discussion of what such systems can be expected to provide in terms of safety. All of these factors, combined with the needs of a particular mine, provide the basis for deciding whether or not to make a commitment to purchase, install, and use such a system. Once a decision is made to go forward, what are the mechanics of the system itself?

In very general terms, MAMS can be subdivided into three basic sections. The first section is comprised of the transducers (or sensors) that are distributed throughout the mine, or that section of a mine in which the system is to be used. The types of sensors to be used are dictated by the needs of a particular mine. If the system is to be used only for fire detection purposes, then the only sensors necessary would be CO or smoke sensors. If a mine has methane problems, then a combined system using both fire sensors and methane sensors is in order. If airflow is

critical in certain areas, then velocimeters are added to the system. Finally, if O_2 depletion is critical in some areas, then O_2 sensors could be added to the system. The final set of transducers could be any one or any combination of the above, depending upon a particular mine's needs, the rationale for the system, and the regulatory requirements for use of such systems. Depending upon the areas in which the sensors are to be used, some may have to be permissible.

The second section of MAMS is the outstation. In a typical system, all transducers are electrically wired to the outstation,where power for the transducers is provided and signals from each transducer accepted. Transducers are individually connected to the outstations with separate wiring,or, all the transducers are connected along one set of wires to the outstation (a multiplex system). Once the outstation receives a transducer signal, it is transmitted electrically to an above ground control station, which is the third section of the system. Communication between the control center and the outstation allows one to set alarms and other system functions, such as transducer failure alerts. At the control center,readings from all sensors can be printed out on a periodic basis. This capability is important if trending of the transducer data is necessary. Some systems come with graphics capabilities which can greatly simplify record-keeping and data analysis. Often, such records allow one to reconstruct the time history of some accident or other occurrence. Most systems, at the very minimum, print out all sensor alarms and malfunction conditions.

The type of system just described is the basic system available today for mine monitoring. The complexity of the system depends upon the number of transducers required, whether the transducers must be explosion-proof or intrinsically safe, the size of the mine and other factors. Most control centers can process inputs from a few to several outstations and most outstations are capable of providing power to and accepting signals from a hundred or so transducers.

At a cost of about $1,000 or more per transducer, it becomes clear that the cost of the system increases substantially both with the number of monitoring locations and the number of transducers installed at each location. Once installed, regular maintenance and calibration of the transducers is required, and the larger the number of transducers, the more time required to perform these functions. The purchase, installation, use, and maintenance of MAMS require a significant commitment by mine personnel in both time and monies.

For many mines, the resources do not exist to make this commitment. Fortunately, there does exist an alternative to the system described above which allows for continuous monitoring for CO, smoke, CH_4 and O_2 and at a reduced cost. The alternative is a pneumatic sampling system (1,2,3) which utilizes polyethylene tubing and teflon-lined diaphragm pumps to pull gas samples from remote monitoring locations to a central station where the samples of gas are analyzed for the contaminants of interest. The simplicity of the system means that all transducers can be located in one convenient location, thus streamlining the procedures for maintenance and calibration. In addition only passive, non-electrical tubing extends from the central analysis station to the desired monitoring location, thus eliminating permissibility constraints. For a simple system which monitors only one contaminant, such as CO or smoke, the initial cost is considerably less than the initial cost for the conventional,

fixed-point transducer monitoring system because only one transducer is required to monitor several locations. However, the pneumatic system is not marketed commercially for use underground although all components necessary to implement such a system are readily available.

Fire Detection. Fires represent a major hazard in underground mines. They can be detected in their earliest stages of development by CO or smoke sensors. Of these two types of sensors, CO sensors have found the greatest usage in underground usage in underground mines. However, all of the data available indicate that smoke sensors are more sensitive than CO sensors and, in general, will provide for earlier warnings. Unfortunately, it is only recently that intensive underground testing of smoke sensors began in order to determine their reliability. The smoke sensor's greater sensitivity is due to two factors:

First, on a mass basis, they are inherently more sensitive. A smoke sensor will alarm at smoke levels of ~ 1 or 2 mg/m^3 of smoke, which corresponds to a smoke optical density of ~ 0.05 m^{-1}. On a mass basis, 1 ppm of CO equals 1.25 mg/m^3, so that at an alarm level of 10 ppm CO, the mass level is 12.5 mg/m^3. This is not to say that CO sensors cannot measure 1 or 2 ppm of CO. Indeed they can, but most mines have CO background levels of 2 to 5 ppm, so that to reduce false alarms, the CO alarm level must be set above this range.

Second the production of CO requires that a chemical reaction take place between the carbon in the fuel and the oxygen in the air. This implies that the rate at which CO is produced depends upon the amount of carbon in the fuel and, further, that sufficient heat be available to sustain the rate of formation of CO. Smoke, on the other hand, is produced by thermal processes during the incipient, smoldering stages of a fire and as soot particles in flames. Neither of these processes is chemically dependent. In due course, it should be expected that smoke sensors will be used extensively in underground mines. Regardless of whether a CO or smoke sensor is used, the manner in which they would be deployed is the same.

There is the question of spacing of fire sensors in entries, and, in particular, belt entries. The times at which CO or smoke arrives at a sensor location depends upon the ventilation air velocity. The lower the velocity, the more time it takes, and the higher the velocity, the less time it takes. At high ventilation rates, CO and smoke are also more severly diluted than at low ventilation rates. As a result, a larger fire is needed to produce sufficient CO or smoke to cause an alarm at a higher velocity than at a lower velocity. Dilution is a fact, and the fact is that, at higher air velocity, it will take a larger fire to produce the levels of CO or smoke produced by a smaller fire at a lower velocity.

However, all of the data available indicates that at higher airflows it also takes a larger fire to produce the same hazard at that which would result from a smaller fire at a lower velocity. A simple example will serve to illustrate this point.

Assume that in an entry that measures 6′ x 20′ the air velocity is 150 feet per minute. A fire produces CO at a rate which is proportional to the fire intensity and which is subsequently diluted by the airflow. Assume that the fire hazard is defined as that size of fire necessary to produce 200 ppm of CO. At the 150 ft/min velocity, 10 ppm of CO is produced when the fire intensity is about 1300 BTU/min, 200 ppm of CO is produced at a fire intensity of

about 27,000 BTU/min. Now, assume that the air velocity is 600 feet per minute. Ten ppm of CO is produced at a fire intensity of about 5,200 BTU/min.,but it takes almost 108,000 BTU/min.of fire intensity to produce 200 ppm. Consequently, even through it takes a larger fire to produce 10 ppm CO at the higher velocity, it also takes a much larger fire to produce the hazard level of 200 ppm of CO.

This example clearly indicates that in order to properly use fire sensors, the times to alarm must be tendered by some time to reach a defined hazard, such as the 200 ppm CO level given in the above example. The time between alarm and hazard represents the time that is available to react to the fire, either in terms of evacuation or control/extinguishment efforts.

If the rates of growth of typical fires are known, then the times to reach sensor alarm and the times to reach some defined hazard may be calculated and the reaction time determined. All of the data available indicates that,for air velocities of less than about 300 to 400 ft./min. the fire intensity increases at a rate which is proportional to the velocity of air. In the worst case, these rates have been found to vary with the square of the velocity. Above velocities of 300 to 400 ft./min. fire intensities will also increase but at a reduced rate which is not proportional to velocity.

For a fire in a belt entry, the relative time from the time at which 10 ppm of CO is produced until the time at which the fire is large enough to begin spreading along the belt is typically on the order of 10 to 20 minutes,independent of the air velocity. At low velocities it takes longer for the CO to reach a sensor than it does at higher velocities. This, in effect, means that most of the 10 to 20 minutes could be used just for the CO to reach a sensor. As a result, it would appear that at lower velocities, sensors need to be spaced closer together, so that more of the time can be used to react to the fire.

However, the spacings and times depend strongly upon how one defines the hazard. Belt flame spread is one hazard example. One could just as easily define the hazard as some high level of smoke or CO, or it could be the size of fire that results in fuel-rich burning,where the levels of CO can increase dramatically.

The study of fires, fire growth rates, and the hazards they present are subjects of on,going research. It suffices to say that detection should be as rapid as possible so that most of the time available can be used to respond to the fire.

Before concluding the discussion of fire detection, it should be mentioned that placement of sensors near the roof of an entry can often be crucial to the early detection of a fire. The CO and smoke from a fire rise due to buoyancy, especially near the fire, so that most of the CO and smoke exists in a stratified layer near the roof. As the CO and smoke flow down the entry, this layer dissipates due to mixing. Stratification is especially significant at the lower air flows (<200 or 300 ft./min.) Because of this effect, it is generally recommended that fire sensors be located near the roof at a distance from the roof no greater than about 25% of the total entry height.

CONCLUSIONS/SUMMARY

Mine Atmosphere Monitoring Systems (MAMS) offer significant potential for increasing safety in underground mines. Improvements in sensor sensitivity, sensor reliability and system reliability are continuously being made. For

many applications, pneumatic monitoring systems may be a cost-effective solution for monitoring of a mine's atmosphere. In the area of fire detection, smoke sensors offer the greatest potential for early warning. Spacing and location of sensors can be critical in many applications. Research into defining and modeling typical fire scenarios shows significant promise for developing strategies for optimizing spacing and for determining the significant hazards associated with fires.

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