CHAPTER 2.—SAMPLING FOR METHANE IN MINES AND TUNNELS

By Fred N. Kissell, Ph.D.[1]

In This Chapter

- ✓ Instruments available to measure methane in mines and tunnels
- ✓ Using a portable detector in both accessible and restricted spaces
- ✓ Machine-mounted monitors: placement and response time
- ✓ Calibration of catalytic detectors for different gases

and

- ✓ Misinterpreting warning signs

This chapter gives guidelines for methane measurement in mines and tunnels. The emphasis is on the measurement procedure and the interpretation of the measurement rather than on the instrument itself.

The failure to properly sample for methane is a major contributing factor to methane explosion risk. Sampling errors are most likely to occur at mines or tunnels where the presence of methane is not suspected or during nonroutine tasks at mines or tunnels known to have gas.

More specific information on methane sampling at continuous miner sections is in Chapter 3. Chapters 4 and 5 discuss sampling at longwall sections, and Chapter 14 discusses sampling at tunnels.

METHANE DETECTORS FOR MINING

Many models of gas detectors are available to measure methane concentrations, as well as most of the other contaminant gases found in mines and tunnels. An example is the iTX Multi-Gas Monitor, a portable gas detector available from Industrial Scientific Corp., Oakdale, PA. This handheld instrument measures several gases simultaneously. The cost (2004) ranges from $1,300 to $2,200, depending on the number of gases measured. Similar instruments are available from other manufacturers.

Most methane detectors used in mining use a catalytic heat of combustion sensor to detect methane and other combustible gases. These have been proven through many years of reliable operation. For detection of methane, proper operation of catalytic heat of combustion sensors

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requires both a methane concentration below 8% and an oxygen content above 10%[2]—requirements that are usually satisfied in mining applications.[3]

Some methane detectors measure the methane concentration by using infrared absorption as an operating method. These detectors (infrared analyzers) can measure accurately without oxygen and in a concentration range up to 100 vol % of methane. However, water vapor and dust can cause operating difficulties. In some mines [Kim 1973], the methane may be accompanied by ethane, which can produce an exaggerated infrared detector response.

A list of approved gas detectors and gas monitors for U.S. mines is available from MSHA's Approval and Certification Center, Triadelphia, WV.

Based on how they are certified by the Mine Safety and Health Administration (MSHA), methane detectors used in mining fall into two categories: portable methane detectors and machine-mounted methane monitors. Portable detectors are designed to be hand-carried, so measurements can be made at any location. They are approved by MSHA under 30 CFR[4] 22. Among other requirements, "indicating detectors" must give indications of gas at 0.25% methane and must have an accuracy of at least 20% over most of the applicable range.

Machine-mounted methane monitors are mounted on certain types of mining machinery and operate continuously. These monitors are certified under 30 CFR 27, which has different requirements than the Part 22 used for portable detectors.[5] The Part 27 requirements include a design that prevents the mining equipment from operating unless the methane monitoring system is functioning, a warning device that activates when the methane concentration is above 1.0%–1.5%, and a means to shut off power[6] to the equipment when the methane concentration is 2.0% and above.[7]

MSHA certification requirements for Part 27 monitors are different from the certification requirements of Part 22 detectors. Because of this, Part 27 monitors cannot be used for tasks requiring the use of Part 22 detectors (such as the 20-min gas check task).

[2]The percentages specified in this chapter are percentages by volume.

[3]When the methane concentration is *over* 8% *or* when the oxygen concentration is *under* 10%, the sensor response declines. As a result, in these circumstances the methane concentration indicated by the instrument will be less, possibly much less, than the true methane concentration. For more specifics on operating conditions, check the documentation that accompanies the instrument.

[4]*Code of Federal Regulations.* See CFR in references.

[5]Thus the distinction between "detectors" and "monitors."

[6]Either electrical or diesel power.

[7]For rapid-excavation machines in tunnels, the Occupational Safety and Health Administration (OSHA) requires electrical power to be shut off at 1.0% and above. See Chapter 14.

USING PORTABLE METHANE DETECTORS

Taking a gas reading with a portable methane detector is a simple matter. Where to measure and how to interpret the reading is not simple. For this reason, the many key points on gas measuring in both “accessible” and “restricted” spaces must be addressed.

Methane measurements in accessible spaces. Accessible spaces are those that can be readily entered by a person making a methane measurement with a handheld portable methane detector. In accessible spaces, most methane measurements should be made as follows:

- Close to the methane source, where higher concentrations are more likely to be encountered.
- Close to the mine roof, where higher concentrations are more likely to be encountered.
- In regions where the dilution of methane is impaired, i.e., those that are poorly ventilated and those where air movement is blocked by equipment.
- While cutting is underway, because the methane release rate is higher as coal or rock is broken and the mining machinery advances.

Fortunately, most places in mines where methane is to be measured are relatively accessible, i.e., the person making the measurement can easily reach the chosen location. The issue is how to choose the best location for measurement.

In making measurements, consideration must always be given to how methane is released and diluted to safe levels. Methane entering a mine or tunnel often enters as a localized source at high concentration. An example is shown in Figure 2–1, which depicts a cloud of methane being diluted into a moving air stream. As shown in the figure, methane enters through a crack in the rock. If no air enters the crack, the methane concentration in the crack can be close to 100%. However, as the methane emerges from the crack, it progressively mixes with and is diluted by the ventilation air. Suppose this progressive dilution reduces the concentration from 100% to 1%, as shown in Figure 2–1. In this case, the instrument reading depends highly on the location of the measurement—a critical concern if one intends to use the reading to assess whether a hazard exists. This problem is handled by requiring methane measurements at a distance of not less than 12 in from the roof, face, ribs, and floor. If there is enough gas coming from the crack (or other source) to exceed statutory limits at a 12-in distance, then a hazardous condition exists.

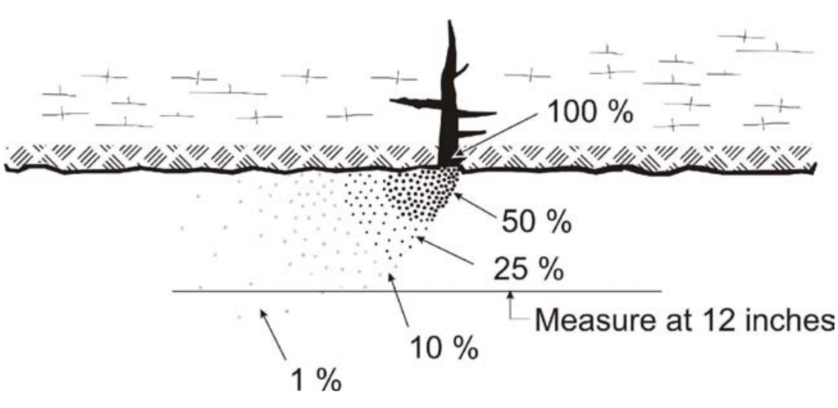

Figure 2–1.—Depiction of methane being diluted into a moving air stream.

In some cases, measurements must be taken at distances less than 12 in. For example, methane is lighter than air, so methane emerging from the roof can form a high-concentration layer along the roof of the mine (or crown of the tunnel). The thickness of such layers can be less than 12 in. Methane layers[8] are more likely to form if the ventilation air velocity measured at the roof is 100 ft/min or less [Raine 1960], if the roof has cavities [Vinson et al. 1978], or if the roof has drillholes that serve as emission sources. Therefore, the degree of hazard resulting from a high-concentration layer of gas must be assessed from measurements of the size of the layer, as well as the location and size of the source. This is why gas readings must be done by a qualified, competent person, as prescribed by MSHA and OSHA regulations.

Methane measurements in restricted spaces. For the purpose of this discussion, a restricted[9] space is one that cannot be readily entered to make a methane measurement. Examples of restricted spaces are a mine shaft that has been capped or a mine entry that has been closed to travel because of hazardous roof. The lack of accessibility often restricts both the ventilation air and the opportunity to make a convenient methane measurement.[10]

When making methane measurements in restricted spaces, simply making a measurement at the *entrance* of the restricted space is not adequate. The measurements must be made deep within and at the top of the restricted space, and also at every location within the restricted space where an ignition source (such as sparks from a torch) may be present.

Restricted-space measurements can be made in two ways. First, the methane detector can be equipped with a remote "sample draw" capability. These use a small pump or hand-squeezed bulb to pull the sample through an extension probe and pass it through the detector. Some methane detectors have an accessory sampling pump that attaches to the detector; others have a built-in pump.

Second, the methane detector can be attached to a cradle at the end of a long handle, which is then extended into the restricted space. This permits a direct reading without aspiration, provided that the instrument has a large LED readout that can be read from a distance.[11]

Remember that gas detectors only sample the air that passes through the instrument.

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[8]For more information on methane layers, see Chapters 1 and 11.
[9]This chapter uses the term "restricted space" because it is a more appropriate distinction for mining applications. The more common "confined space" term is not used because the whole mine can be regarded as a confined space. Further, none of these special terms do a good job of describing measurements at coal mine gobs, a specialized topic not considered in this chapter.
[10]For example, a restricted-space methane explosion occurred in January 2003, killing three workers during a shaft-sinking operation at a coal mine near Cameron, WV. A 7-ft-high "water ring" space had been excavated back into the strata behind the shaft wall. These water rings facilitate water drainage from the exterior side of the shaft lining. Prior to pouring the concrete shaft lining, the water ring space was sealed off with corrugated sheets of steel to prevent it from being filled with concrete. After the concrete had set, the three miners were killed while in the process of opening an access door with an acetylene torch. An investigation by the West Virginia Office of Miner's Health, Safety and Training concluded that "an adequate methane test was not made" [Mills 2003].
[11]See the sections on methane detection in the continuous miner chapter (Chapter 3).

Out-of-range gas concentrations in restricted spaces.[12] Because some restricted spaces have little ventilation, the gas concentrations in these spaces may fall outside of the accurate operating range of catalytic heat of combustion sensors. For accurate operation of these sensors, the concentration of methane must be below 8% *and* the concentration of oxygen must be above 10%. When measuring methane concentrations above 8%, instruments with catalytic heat of combustion sensors can act in a way that is misleading, responding with a rapid upscale reading followed by a declining or erratic reading[13] [CSA 1984]. Such instrument behavior should be a tipoff that very high, potentially explosive methane levels may be present.

Restricted spaces may also lack the 10% oxygen level necessary to ensure the proper operation of catalytic methane detectors. For example, the gas in exploration boreholes often contains little to no oxygen. In such circumstances, if the instrument being used has a second sensor to measure the oxygen level, an oxygen concentration less than the required 10% will be indicated, thereby alerting the user that the methane reading may be incorrect. However, even if the oxygen concentration is less than 10%, valid methane measurements are possible with other kinds of methane detectors. One approach to sampling low-oxygen atmospheres is to use a methane detector that operates by infrared absorption. Another approach is to use a catalytic methane detector that provides dilution sampling. The term “dilution sampling” refers to adding a controlled quantity of ambient air to the sample in order to raise the oxygen content of the sample.[14] For example, if 1 L of sample gas is added to 1 L of ambient air, the oxygen level of the mixture will be adequate to operate a catalytic methane detector, and the true concentration of methane may be obtained by multiplying the detector methane reading by a factor of two.

The bump test. It is a good idea to perform a quick “bump test” on every portable methane detector to ensure that it is working properly. Before every shift, briefly expose the portable detector to a known concentration of methane gas high enough to set off the methane alarm. Note the reading to ensure that it is correct. A bump test is not a calibration, but a quick way to ensure that the most important functions of the instrument are intact.[15]

USING MACHINE-MOUNTED METHANE MONITORS

The disadvantage of portable handheld detectors is that a peak emission can be missed because readings at the appropriate locations are only taken at infrequent intervals. By contrast, machine-mounted monitors operate continuously and can identify emission peaks and automatically shut off electrical equipment when the methane level is excessive.

Machine-mounted methane monitors are usually mounted on mining and tunnel-boring machines. They are designed to have their readout display separated from the sensing head so

[12]This also applies to methane layers.
[13]Some instruments will report this as an out-of-range condition. For more information, consult the operating instructions for the instrument.
[14]Methane gas mixtures with 10% oxygen or less are not combustible, but may become so when mixed with more air. See Chapter 10 on using inert gas to prevent highwall methane explosions.
[15]A similar test is described by the Canadian Standards Association [CSA 1984].

that the readout is visible to the machine operator and the sensing head is placed in a location where methane is most likely to accumulate.

The usefulness of machine-mounted monitors depends on three critical factors: placement of the sensing head in a location where methane accumulates, the response time of the monitor, and whether or not the sensor head is covered by a heavy layer of dust or debris.

Placement of the sensing head where methane accumulates. Proper placement of monitor sensing heads is crucial to the reliable detection of methane levels. Figure 2–2 shows a typical methane profile map measured from experiments at a full-scale simulated continuous miner face [Wallhagen 1977]. A striking feature of such profile maps is the steep gradient in the methane concentration along the length of the machine. Thus, a distance of a foot or two forward or backward in the location of the sensing head will greatly change the indicated methane level. In the instance depicted, the sensing head should be as far forward as possible to measure higher methane levels.[16] Inevitably, some tradeoffs are involved in picking the location, for a sensor head located too far forward will quickly become damaged or clogged with dust.

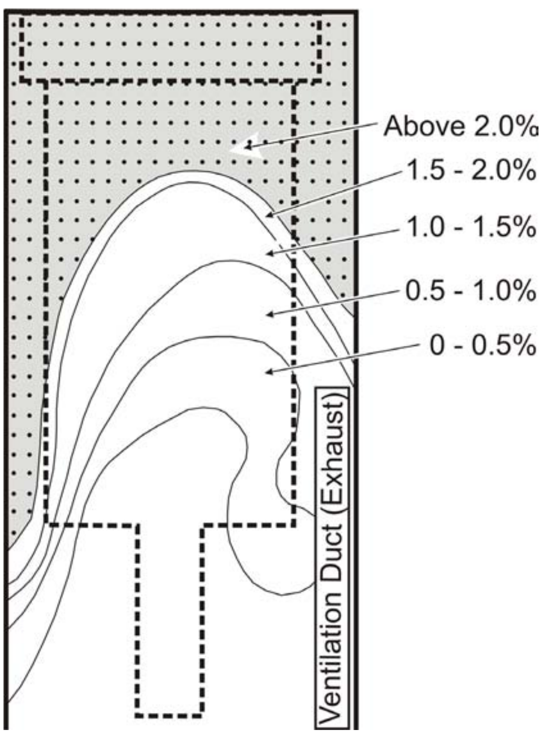

Figure 2–2.—Methane profile map from a simulated continuous miner face.

Response time of the sensor head. It is important that methane monitors have a short response time because the methane concentration can change quickly. With a short response time, the indicated concentration does not lag too far behind the true concentration. Figure 2–3 shows a recorder chart from a machine-mounted monitor at a coal mine working face [Kissell et al. 1974]. The peaks correspond to the cutting cycle of the mining machine, with the methane concentration spiking as the machine cuts into the coal.
A methane monitor with a short response time will follow the spikes, giving warnings at the appropriate time. Taylor et al. [2004] reported on the response time of methane monitors in a test chamber designed to simulate mining conditions, while Taylor et al. [2002] reported on the response time using calibration caps supplied with the instrument.

[16]A typical sensing head location on continuous miners is on the side of the cutter head boom, a foot or two behind the cutter head.

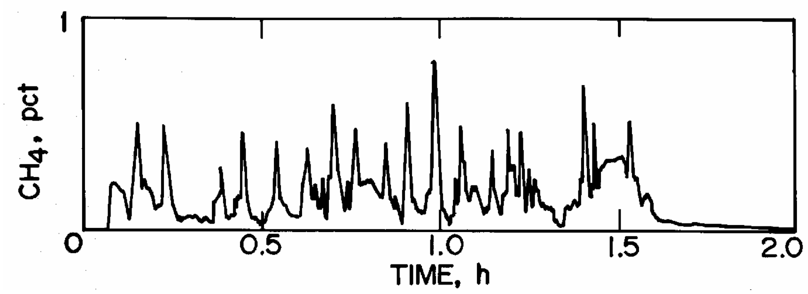

Figure 2–3.—Recorder chart from a machine-mounted methane monitor.

Dust-clogged sensor heads. Machine-mounted methane monitors are usually in locations where dust quickly accumulates on the sensor heads, so some care must be directed toward preventing the sensor heads from getting clogged by heavy dust accumulations or covered with debris. Whether a sensor head is clogged can be assessed during calibration by noting the response of the monitor. All of the monitor manufacturers provide calibration caps that cover the sensing head and allow it to be flooded with calibration gas. When the sensor head is flooded with calibration gas, the instrument reading should be at least 90% of the calibration gas concentration and the response time should be similar to that obtained with a clean head.[17] A lower concentration reading indicates a monitor problem, possibly a dust-clogged sensor head. For this reason, sensor heads in particularly dirty locations should be cleaned and calibrated more frequently.

CALIBRATION OF CATALYTIC INSTRUMENTS FOR DIFFERENT GASES

Methane detectors used in mining must be periodically calibrated with a known concentration of methane-air mixture that is injected into the instrument from a tank containing the gas mixture. However, combustible gases other than methane are sometimes encountered underground, and if the gas being sampled is different from the gas used to calibrate the instrument, the error in the instrument reading can be considerable. For instance, a tunnel being excavated under a leaking gasoline storage tank might contain gasoline vapor. Under these circumstances, a detector calibrated with a methane-air mixture will read low because higher molecular-weight gases (such as those in gasoline vapor) diffuse more slowly into the sensor element. As an example, suppose a methane-calibrated instrument is carried into a tunnel containing only gasoline vapor in the air, and the instrument reads 10% of the lower explosion limit (LEL).[18] In this circumstance, the actual gasoline vapor concentration in air is about 20% of the LEL—twice the indicated reading.

The opposite effect on instrument error can also take place. If the gas detector is calibrated with a higher molecular-weight gas such as pentane, then carried into a tunnel containing only methane, and if it reads 10% of the lower explosive limit (LEL), the actual methane concentration is 5% of the LEL, i.e., half the indicated reading.

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[17]Using calibration caps supplied by the manufacturers, Taylor et al. [2002] measured the 90% response time of three models of methane monitors. They found that the response time depends on a host of extraneous factors, such as the calibration gas flow rate. If a calibration cap is used to assess monitor response time, the best approach is to note the response time of a clean monitor head and then look for corresponding changes as conditions change.

[18]Do not confuse % methane with % of the LEL. The LEL of a mixture of methane and air is 5% methane by volume. Thus, 5% methane by volume is said to be equivalent to 100% of the LEL. It follows that a concentration of 1% of methane by volume in air is 20% of the LEL. Other flammable gases have different LELs. For example, mixtures of propane and air have an LEL of 2.1% propane by volume; therefore 50% of the LEL is 1.05% by volume.

For this reason, when operators are encountering methane, they should calibrate for methane. On the other hand, if higher hydrocarbons are being encountered, operators should calibrate with a higher hydrocarbon, such as pentane or propane.

Calibration-sampling correction value tables for a variety of combustible gases are readily available [Industrial Scientific Corp. 2004]. More information on the response of catalytic sensors to different gases is available from Firth et al. [1973].

MISINTERPRETING WARNING SIGNS

It is not unusual to misinterpret a gas warning sign, especially in underground workings thought to have no gas. A primary reason is that the gas flow varies with the excavation rate. Suppose, for example, a tunnel-boring machine (TBM) begins to cut into an area of gassy ground, releasing methane into the ventilation air. The machine-mounted monitor on the TBM senses this gas and shuts it down. After spending some time tracking down the source of the shutdown and figuring out what to do, a worker begins to hunt for gas with a handheld detector. The worker hunting for gas cannot find much because the emission dropped when the TBM stopped. Thus, everyone concludes that the monitor on the TBM is not working properly. Given two instruments, one with bad news and the other with good news, the tendency is to believe the good news. However, when methane detection and monitoring instruments fail, they rarely give a false alarm or a false high reading; in other words, they rarely indicate gas when there is none. The usual failure mode is to not register gas that is present. Therefore, when any instrument registers gas, it is better to trust the reading and take appropriate precautions.

Operators must be especially cautious when successive methane readings vary more than they normally do. When the airflow is low or when measurements are taken close to the source, the methane will not be well mixed into the air. This could lead to a high reading in one area with a low reading just a few feet away. This incomplete mixing can indicate that the ventilation air is deficient and that even higher concentrations of gas might be found nearby.

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