

## **Mine Gases, Detection and Monitoring**

### **Chapter 3**

**pp. 29 - 55**

## **Contaminants**

- **Nonparticulate (gases and vapors)**
- **Particulate (liquids and solids)**
- **Liquid particulates (mists, fogs)**
- **Solid contaminants (dust, fumes, smoke, organisms)**
- **Most common: gases and dusts**

## **Threshold Limit Values**

- **Recommended by ACGIH**
- **Limits on airborne concentrations**
- **Workers can normally be exposed and not suffer adverse effects**
- **Wide variation in individual susceptibility => discomfort or more serious effects**

## **Threshold Limit Values**

- **Based on available information from industrial experience and experimental human and animal studies, or combination of three**
- **May be designed to protect from impairment of health, reasonable freedom from irritation, narcosis, nuisance, or stress**

## **Threshold Limit Values**

- **Health impairment: shortened life expectancy, compromise of physiological function, reduce resistance to other agents, increase chance of disease, or adverse effect on developmental processes**
- **Three values are defined, but not necessarily for all agents**

## **Threshold Limit Values**

- **TLV-TWA: time-weighted average concentration, generally over an 8-h workday or 40-h week (one generally referred to by TLV)**
- **TLV-STEL: max. concentration for exposures up to 15 min without suffering from irritation, chronic or irreversible tissue change, or narcosis of sufficient degree to increase accident proneness, impair self-rescue, or materially reduce work efficiency**
- **TLV-C: concentration that should not be exceeded even instantaneously (very dangerous)**

## Threshold Limit Values

- ACGIH makes recommendations for practice in industrial hygiene, as guidelines for protection
- MSHA incorporated the 1972 ACGIH recommendations into the Mine Act, making them law

## Mine Gases

Know properties of mine gases in chart on pp. 32-33 in textbook

## Mine Gases - Oxygen

- Obviously most important gas; amount needed by a human depends on physical activity (respiratory rate)
- Level inhaled >> than amount consumed
- Exhaled air  $\approx$  16% oxygen
- Mine Act requires at least 19.5% in air
- Must consider both O<sub>2</sub> and CO<sub>2</sub> in determining amount of air needed to satisfy respiratory needs

## Mine Gases - Oxygen

- Mine Act also requires not more than 0.5% carbon dioxide
- Respiratory quotient gives ratio of CO<sub>2</sub> expelled to the O<sub>2</sub> consumed
- Respiratory requirements for different levels of activity are given in Table 3.2 on p. 34 of your book; you should learn these for design purposes, especially for low-quantity drifts, tunnels, entries, etc.

## Respiratory Requirements

Activity Level	Resp. Rate breaths/min	Inhaled air, in <sup>3</sup>	Inhaled air, in <sup>3</sup> /min	O <sub>2</sub> Used cfm	Resp. Quotient
At rest	12-18	23-43	300-800	0.01	0.75
Moderate	30	90-120	2800-3600	0.07	0.9
Very vigorous	40	150	6000	0.10	1.0

## Oxygen Depletion

- Environment is oxygen deficient technically at < 19.5%
- Oxygen is depleted when diluted by other gases, by high-temperature oxidation (IC engines), and by low-temperature oxidation (wood and minerals)
- Other gases often liberated (CO, CO<sub>2</sub>)

## Oxygen Depletion Effects

- 17% O<sub>2</sub>: faster, deeper breathing
- 15% O<sub>2</sub>: dizziness, buzzing in ears, rapid heartbeat
- 13% O<sub>2</sub>: possible loss of consciousness with prolonged exposure
- 9% O<sub>2</sub>: fainting, unconsciousness
- 7% O<sub>2</sub>: life endangerment
- 6% O<sub>2</sub>: convulsive movements, death

## Carbon Dioxide

- Colorless, odorless, noncombustible; possible acid taste in high concentration
- Heavier than air
- Found often in abandoned and unventilated areas
- Sources: rock strata, oxidation, fires, explosions, blasting, exhaled air

## Carbon Dioxide

- Increased concentrations => increased lung ventilation
- If > 0.5% => breathe a little deeper and faster
- If > 3% => lung ventilation doubled
- If > 5% => 300% increase in resp. rate
- If > 10% => tolerate only a few minutes

## Carbon Dioxide

- If > 18% => death occurs rapidly
- Mixture in air called “blackdamp”
- Generally, the quantity of air required for respiratory requirements is quite small compared to the quantity required to keep CO<sub>2</sub> levels below 0.5% throughout a mine
- See Example 3.1, p. 35 in your book

## Carbon Monoxide

- Colorless, odorless, tasteless, toxic and flammable
- Produced by incomplete combustion of carbonaceous material
- Poisonous at very low concentrations (TLV-TWA @ 0.0025%, TLV-STEL @ 0.04%)
- Explosive range: 12.5-74%
- Slightly lighter than air

## Carbon Monoxide

- Sources: fires, explosions, blasting, frictional heating (before burning), low-temperature oxidation, and internal combustion engines
- Acts as asphyxiant by displacing oxygen in hemoglobin; blood cells have affinity > 3000 times that for oxygen
- Blood saturation level (percentage of COHb or carboxyhemoglobin) used to characterize toxic effect

## Carbon Monoxide

- At levels as low as 5% COHb, the first effects of carbon monoxide poisoning appear
- COHb level dependent on CO concentration, length of exposure, and level of activity
- At blood saturation levels of 70% COHb and above, the amount of oxygen in the blood is insufficient to sustain life
- See Table 3.4 (p. 42 in your book) for symptoms at various blood saturation levels

## Carbon Monoxide

- See Fig. 3.3 in your book for the relationship between blood saturation level and duration of exposure to various concentrations
- Fig. 3.4 shows the toxicity of CO as a function of the concentration and exposure time
- Current TLV-TWA is 50 ppm (0.005%)
- Sometimes called “whitedamp”

## Hydrogen Sulfide

- Colorless, explosive and toxic (Table 3.5)
- Formed by decomposition of sulfur compounds
- Low concentrations found from heated gobs or from water seeping in strata
- Large concentrations occur in natural gas and oil fields, and in some sulfur and gypsum mines

## Hydrogen Sulfide

- Quite soluble in water; travels via groundwater
- Slightly heavier than air
- Explosive range: 4-44%
- TLV-TWA @ 10 ppm
- TLV-STEL @ 15 ppm
- Rotten-egg smell; olfactory nerves paralyzed
- Generally called “stinkdamp”

## Sulfur Dioxide

- Colorless, nonflammable, toxic (Table 3.6)
- Formed when sulfur or sulfur compounds are burned, during blasting of sulfur ores, during fires involving sulfur compounds, and from internal combustion engines
- Significantly heavier than air
- Irritating to eyes, nose, throat in very low concentrations (20 ppm)
- TLV-TWA @ 5 ppm; TLV-STEL @ 5 ppm

## Oxides of Nitrogen

- Most common: nitric oxide and nitrogen dioxide; red-brown color, bitter taste
- Formed by blasting and from IC engines
- NO is rapidly oxidized (seldom found)
- Accepted TLV-TWA and TLV-STEL for NO<sub>2</sub> is 5 ppm
- Reacts with moisture to form nitrous and nitric acid; small quantities may cause death by reacting with water in lungs

## Oxides of Nitrogen

- 3 ppm => current recommended TLV-TWA
- 60 ppm => least amount causing immediate throat irritation
- 100 ppm => least amount causing coughing
- 100-500 ppm => dangerous even for short exposure
- 200-700 ppm => rapidly fatal

## Hydrogen

- Colorless, odorless, tasteless, nontoxic and explosive
- Sources: charging of batteries, action of water or steam on hot materials, action of acid on metals
- Explosive range: 4-74%
- Can explode when oxygen content is as low as 5% (methane requires at least 12%)

## Radon & Products

- Gas, chemically inert, radioactive product of disintegrating radium
- Found primarily in uranium mines; present in trace amounts in other types; diffuses from rock strata
- Radioactive decay process continues after diffusion

## Uranium Disintegration Process

<u>Common Name Or Symbol</u>	<u>Isotope</u>	<u>Type Radiation</u>	<u>Half-life</u>
Uranium	U (238, 92)	Alpha	4.49 x 10 <sup>9</sup> yr
UX <sub>1</sub>	Thorium (234, 90)	Beta	24.1 days
UX <sub>2</sub>	Protactinium (234, 91)	Beta	1.17 min
Uranium-234 Ionium	U (234, 92)	Alpha	2.48 x 10 <sup>5</sup> yr
Radium	Thorium (230, 90)	Alpha	8 x 10 <sup>4</sup> yr
	Radium (226, 88)	Alpha	1622 yr
Radon	Rn (222, 86)	Alpha	3.825 days

## Uranium Disintegration Process

<u>Common Name Or Symbol</u>	<u>Isotope</u>	<u>Type Radiation</u>	<u>Half-life</u>
Radium A	Polonium (218, 84)	Alpha	3.05 min
Radium B	Pb (214, 82)	→ -	26.8 min
Radium C	Bismuth (214, 83)	→ -	19.7 min
Radium C'	Polonium (214, 84)	Alpha	2.73 x 10 <sup>-6</sup> min
Radium D	Pb (210, 82)	→ -	22 yr
Radium E	Bismuth (210, 83)	-	5.02 days
Radium F	Polonium (210, 84)	Alpha	138.3 days
Radium G	Pb (206, 82)	none	Stable

## Radon & Products

- During decay, individual members in the series are decaying and being formed at the same time
- At some point in time, equilibrium is reached, and the quantity of each member in the series remains constant
- About 3 h is required for the products through radium C' to reach equilibrium from a given quantity of radon

### **Radon & Products**

- Products formed by decay of radon are called radon daughters
- Radon daughters have relatively short half-lives
- Short-lived alpha-particle emitters are of prime concern to ventilation engineer
- During the decay process, alpha energy reaches ~ 50% of maximum in ~ 40 min
- Thus, we must ensure that poorly ventilated areas do not exist

### **Radon & Products**

- Because it is a gas and has a long half-life, inhaled radon is exhaled before large amounts of alpha particles are emitted
- The daughters, solid particles, attach themselves to dust and tend to be deposited and concentrated in the respiratory system
- Exposure to excessive concentrations of radon and radon daughters has been linked with a high incidence of lung cancer

### **Radon & Products**

- Maximum exposure limit for radon daughters is 1.0 working level (WL), with a yearly cumulative exposure of 4 working-level months (WLMs)
- Working level – concentration of short-lived radon-daughter products in a liter of air that will yield  $1.3 \times 10^5$  million electron volts (MeV) of alpha energy in decaying through radium C'

### **Radon & Products**

- WLM is a cumulative measure of exposure that is calculated by multiplying the average working level of exposure during a given time period by the time of exposure and dividing by 173 (the number of working-level hours per working-level month)
- See Example 3.2 on pp. 47-48 in your book

### **Methane**

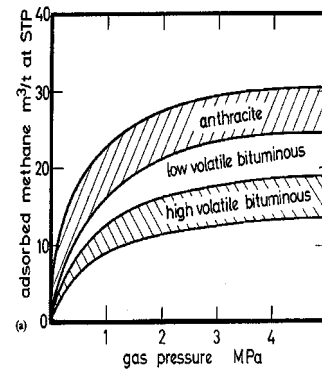
- Most common contaminant in coal mines
- Found in trona mines; sometimes in potash, limestone, oil shale and salt mines
- Small amounts in copper, tungsten, iron, gypsum, marble, gold and silver mines

### **Methane**

- Colorless, odorless, tasteless, nontoxic, and highly flammable
- Much lighter than air, thus found in high areas of mines and at roof
- Amount of gas retained per ton of coal formed is called seam gas content
- Popular index of seam gas content is specific methane emission, which is the volume of methane emitted per ton of coal produced

## Methane

- Although there is a good correlation between specific methane emission and seam gas content, the total flow of methane in a specific mine depends on many diverse factors and there is no simple generalization
- Several direct and indirect methods exist to measure seam gas content

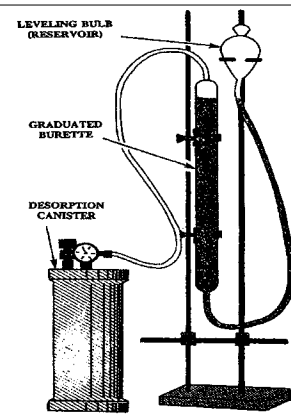


Gas Content Will Increase with Coal Rank

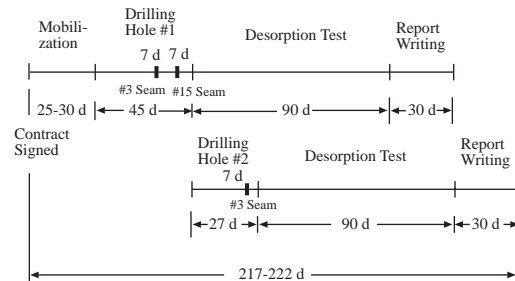
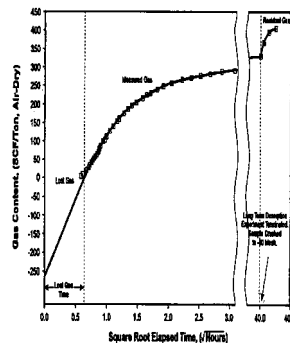
## A Direct Method

- Linear relationship between amount of gas and the square root of time of desorption
- Freshly cored sample placed in airtight container and desorbed for several weeks until the desorption rate is insignificantly small
- Residual gas in sample is determined by crushing it to < 200 mesh

- Core or cuttings are placed in canisters
- Simulate reservoir conditions
- Monitor gas production from core/cuttings



- Cumulative gas is plotted to determine lost, desorbed, and total gas content
- Quantifies source of gas
- Determine diffusion rate



### A Direct Method

- Amount of gas lost in the coring operation is obtained graphically by estimating the time between penetrating the coal seam and placing the cored sample in the container
- The sum of the lost gas, desorbed gas, and residual gas is the gas content for the weight of the sample

### A Few Terms

- Sorption – the process by which a gas is held on a microporous substance in a condensed or liquid-like phase (gas storage on coal is a physical sorption process – also a reversible process)
- Adsorption – increasing sorption due to increasing free gas pressure
- Desorption – opposite of adsorption

### A Indirect Method

Most gas contained in coal is adsorbed on the coal matrix; for idealized monolayer adsorption of methane on coal matrix:

$$Y = \frac{Y_c B p}{1 + B p} \quad (\text{Eq. 3.3; Langmuir Eq.})$$

where  $Y$  – volume of gas adsorbed on matrix,  $\text{ft}^3$   
 $Y_c$  – volume required to cover and saturate the surface completely,  $\text{ft}^3$   
 $B$  – characteristic constant of the coal seam in  $\text{atm}^{-1}$   
 $p$  – reservoir pressure in atm

### A Indirect Method

- Pressure of gas in seam is linearly related to depth, with a gradient of 0.333 psi/ft
- Pressure of gas correlated with rank of coal
- Maximum pressure observed in an anthracite seam was 711 psi
- In a steam-coal seam it was 232 psi
- Valid for U.S. coals (Fig. 3.1, p. 38 in text)

### An Indirect Method

Substituting the depth of a coal seam,  $d$ , in Eq. 3.3 gives:

$$Y = \frac{Y_c b d}{1 + b d} \quad (\text{Eq. 3.4})$$

where  $d$  – depth in ft  
 $b$  – modified seam characteristic

### Methane

- Gas contents, composition and calorific values for five U.S. coal seams given in Table 3.3 on p. 39 of your book
- Amount of gas in coalbed depends on temperature, pressure, degree of fracturing, and permeability of the coal and the surrounding strata
- Gas can exist as free gas in cracks and fissures as well as in adsorbed state
- Gas is released upon reduction of pressure (mining)



## Methane

- Rate of methane liberation is highly variable among coalbeds; up to 2-4 cfm per ft<sup>2</sup> of fresh coal face initially; gradually diminishing; even stopping if adjacent mining passes by a face
- Wide variability in instantaneous rate of methane emission at a face; steady rate from 40 to 400 cfm at highly gassy mines

## Methane

- Example: ~ 700 billion ft<sup>3</sup> contained in Mary Lee seam, AL; at current depth, ~ 400 ft<sup>3</sup>/ton  
Actual gas liberation usually 6-9 times this potential (adjacent strata, outby pillars, etc.)
- Mine Act classifies all coal mines as “gassy”
- Classification criteria for noncoal mines is in 30CFR Part 57, Subpart T
- A minimum detection of 0.25% places a noncoal mine in category I.A
- Fig. 3.2, p. 39 of text, gives explosibility diagram, mapping methane vs. oxygen

## Methane Emission Models

- Rate of emission influenced by Fick’s and Darcy’s laws
- For math analysis, coal seam assumed to be composed of small spheres, at the surface of which diffusion occurs
- Fick’s law describes diffusion from “spheres” along the concentration gradient

## Methane Emission Models

Fick’s law:

$$\frac{\partial C}{\partial \tau} = D \left[ \frac{\partial^2 C}{\partial r^2} + \frac{2\partial C}{r\partial r} \right] \quad (\text{Eq. 3.5})$$

where  $r$  – radial coordinate, ft  
 $\tau$  – time, seconds  
 $C$  – concentration of methane in coal ft<sup>3</sup>/ft<sup>3</sup>  
 $D$  – coefficient of diffusion, ft<sup>2</sup>/s

Solutions for this equation for various initial and boundary conditions are generally available

## Methane Emission Models

- The size of the hypothetical sphere where diffusion takes place is important; it determines the degree of fragmentation of the coal seam
- Combining the radius of the sphere  $a$  with the coefficient of diffusion  $D$ , a new diffusion parameter  $D/a^2$  is developed that determines both the rate at which a coal seam will diffuse methane and the fraction of seam gas content that can be drained in a given time

## Methane Emission Models

Darcy’s law describes gas transport through the fracture system in the coal where the driving force is the pressure gradient

Linear case, homogeneous medium, laminar flow, for low pressures:

$$\frac{\partial^2 p^2}{\partial x^2} = \frac{\mu\phi}{kp} \frac{\partial p^2}{\partial \tau} \quad (\text{Eq. 3.6})$$

where  $p$  – gas pressure, atm  
 $x$  – distance into coalbed from face, ft  
 $\mu$  – absolute viscosity of methane, lb mass/ft.s  
 $k$  – permeability of coal in millidarcies  
 $\phi$  – pseudoporosity

### Methane Emission Models

Pseudoporosity – ratio of the volume of gas adsorbed on the coal surface per atmosphere per volume of coal

Equations clearly indicate that the net rate of emission under idealized conditions is controlled by:

- \* diffusivity (coefficient of diffusion)
- \* reservoir pressure
- \* permeability
- \* seam gas content

### Methane Emission Models

The slower process, upon application of the two equations, will determine the net rate of methane emission

Example:

Typical value of  $D/a^2$  for the Pocahontas No. 3 seam is  $1 \times 10^{-6} \text{ s}^{-1}$ ; 100 times the value for the Pittsburgh seam

Typical permeability for the Pittsburgh seam is 10 millidarcies; 10 times higher than for the Pocahontas No. 3 seam

### Methane Emission Models

Example:

These figures explain why the flow from horizontal holes in the Pittsburgh seam is 140-280 ft/day.ft compared to on 32-75 for holes in the Pocahontas No. 3 seam, even though the seam gas content and reservoir pressure are much higher for the latter seam

It appears that the rate of emission for the Pittsburgh seam is controlled by the diffusivity, while permeability governs the flow in the Pocahontas No. 3 seam

### Gas Detection Methods

- Types of instrumentation:
  - \* handheld detectors
  - \* machine-mounted monitors
  - \* area monitors
  - \* personal dosimeters
- Detection methods:
  - \* catalytic-oxidation detectors
  - \* electrochemical sensors
  - \* optical detectors
  - \* electrical conductivity
  - \* stain tubes

### Gas Detection Methods

- The functionality of each type is explained in pp. 48-49 of your book
- Handheld detectors are the most commonly used; for coal mines, they are permissible
- Safety lamp is used only for detection of oxygen deficiency now (some mines)
- Watch out for gases than give inflated or deflated readings for target gas (e.g., H<sub>2</sub>, CO, ethane, propane, low O<sub>2</sub> for methane)

### Gas Detection Methods

- See Table 3.10 on p. 54 of your book for detection methods for various gases
- Monitoring – continuous or cyclic measurement of a gas
- Two types: machine-mounted, area
- Machine-mounted methane monitors are required in coal mines inby last open X-cut (warning @ 1%; kill power @ 2%)
- Continuous area monitors coupled with data information/analysis system

### **Gas Detection Methods**

- **Finally, sometimes a more exact analysis of gases in the mine environment are needed**
- **Grab samples are often taken in suitable containers**
- **Can also be used at boreholes or tubes going into inaccessible areas**
- **Gas chromatography primarily used**