THE PITTSBURGH GEOLOGICAL SOCIETY

CONCENTRATED CARBON DIOXIDE IN WESTERN PENNSYLVANIA

Civilization exists by geological consent, subject to change without notice.
Will Durant

CO_2 Concentration	Symptoms
2%	50% increase in breathing rate Prolonged exposure can cause headaches
3-6%	Headaches, shortness of breath
6-10%	Headaches, shortness of breath, tremors, visual impairment, unconsciousness
>10%	Unconsciousness (potentially without warning)

Figure 1. Common symptoms associated with exposure to various concentrations of CO_2.

When you think of air, you generally think about a single element – oxygen, the stuff we need to breathe and carry on with our lives. But air is actually a mixture of numerous elements and chemical compounds, some of which occur naturally and others of which are man-made. One such compound that is both natural and man-made is the gas carbon dioxide, or CO_2.

CO_2 is essential to life on Earth, but for humans and other animals too much of a good thing is dangerous. Too much CO_2 in the air we breathe can be suffocating; too much in the atmosphere above us can enhance the greenhouse effect.

CO_2 recently has become a problem in western Pennsylvania as some families are finding high levels of the gas in their homes. Although CO_2 contamination in buildings is not a new problem, it appears to be increasing as a result of the development of former coal mining areas for new housing.

CARBON DIOXIDE FACTS

Carbon dioxide is a nonflammable, colorless, and odorless gas. Under the right conditions of temperature and pressure, it can occur as a liquid or a solid (dry ice). It is approximately 1½ times heavier than air. Air is a mixture of many gases, the principal ones being nitrogen (78.1%), oxygen (20.9%), argon (0.93%), carbon dioxide (0.035%), and water vapor (between 0 and 4% depending on humidity). Trace amounts of ammonia, carbon monoxide, helium, hydrogen, krypton, methane, neon, nitrous oxides, ozone, sulfur dioxide, and xenon also occur in our air. Although CO_2 makes up only 0.035% of the air we inhale, the air we exhale contains about 3 to 4% CO_2.

CO_2 occurs naturally in both the atmosphere and in the ground. It gets into the atmosphere naturally through volcanic activity, forest fires, and plant and animal respiration, but human activities such as manufacturing and burning fossil fuels also contribute to atmospheric CO_2. It occurs naturally in shallow soils from respiration by plants and microbes, but it is especially abundant in the earth's mantle, dwarfing the total CO_2 in the atmosphere. It is expelled into the atmosphere in great quantities by volcanic activity and other geothermal events. CO_2 also occurs in landfills, coal mines, and some oil and gas reservoirs through bacterial decomposition of organic matter.

CO_2 can be dangerous in concentrations higher than 0.035% (see below), but it is also essential for everyday life. Plants breathe in CO_2 during the day, converting the carbon to organic materials required for them to live, and exhaling oxygen that other living things need. CO_2 also controls all animal, including human, respiration. It has practical value for many day-to-day human applications and manufacturing processes, such as plastics, rubber, electronics, fire extinguishers, refrigeration, carbonated beverages, and propellants (replacing less desirable freon gas). CO_2 is also used to enhance the recovery of oil and natural gas from producing wells.

SOME DANGERS

CO_2 is hazardous in quantities greater than 0.035% of normal air. Government and industrial standards limit the amount of CO_2 a person can be exposed to during standard working periods. For example, the time-weighted average concentration limit for an 8-hour workday and a 40-hour work-week is 9 grams per cubic meter (g/m^3) or 5,000 parts per million (ppm), which equals 0.5% CO_2. What this means is that nearly all workers may be exposed day after day for a normal 8-hour/day workweek to a concentration of 0.5% CO_2 without adverse effect. Anything more than that could cause severe problems. Similarly, a short-term exposure of more than 15 minutes cannot exceed 27 g/m^3 or 15,000 ppm, which equals 1.5% CO_2.

Symptoms of CO_2 exposure vary. CO_2 concentrations exceeding 1.5% can produce hyperventilation and headache. Prolonged exposure to high concentrations can result in death from asphyxiation. Figure 1 identifies the most common symptoms of CO_2 poisoning at different concentrations.

CO_2 AND COAL MINING

CO_2, methane, and other gases are integral parts of coal, adhering to the surface of the coal in microscopic pores and along fracture surfaces. Mining frees these gases from the coal where they can concentrate in dangerous amounts, especially in underground mines. Miners call CO_2 "blackdamp" or "chokedamp" because of its suffocating effect ("damp" is a mining term for a dangerous gas).

CO_2 has become a growing problem in western Pennsylvania due to the adverse side effect of an otherwise positive environmental issue – the reclamation of abandoned coal mines. When abandoned mines are reclaimed, the operator (or the State, in the case of old abandoned mines) fills in the old mine and returns the landscape to something approaching its original configuration. Mine waste generally is treated and buried beneath fill and top soil to minimize the adverse effect of exposing contaminating waste materials to the air and water. In coal containing significant amounts of sulfur minerals such as pyrite, groundwater flowing through the coal typically reacts with the pyrite to form sulfuric acid and "yellowboy", the iron-rich material that stains local streams bright orange (Figure 2). This acidic mine water is a major problem in western Pennsylvania — it should be neutralized before being released to streams and groundwater aquifers. This is done through the addition of

$$4\,FeS_2 + 15\,O_2 + 14\,H_2O \rightarrow 4\,Fe(OH)_3 + 8\,H_2SO_4$$

(Pyrite + oxygen + water → "yellowboy" + sulfuric acid)

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$$

(Sulfuric acid + lime → gypsum + water + carbon dioxide)

Figure 2. Some typical chemical reactions producing CO_2 in coal strip mines. Top – Pyrite, a common mineral in coal, reacts with groundwater to produce iron hydroxide ("yellowboy" that colors local streams bright orange) and sulfuric acid. Bottom - Sulfuric acid reacts with calcium carbonate in bedrock and/or limestone used to neutralize the acid mine drainage to form gypsum, water, and CO_2.

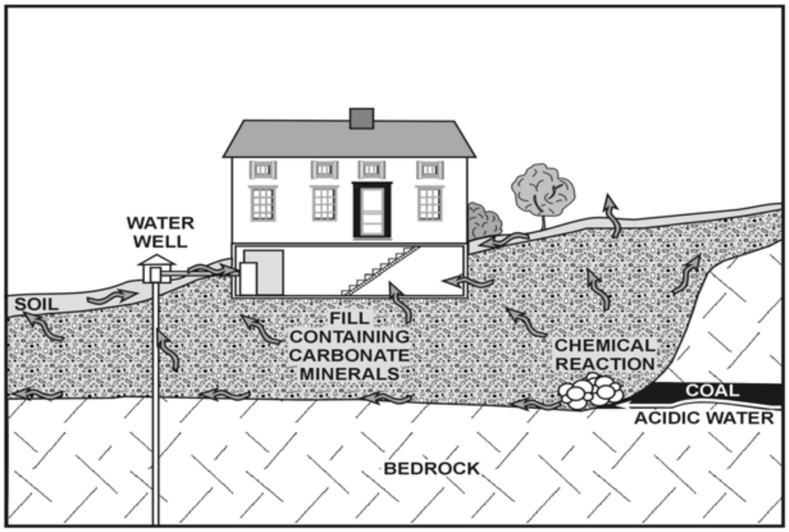

Figure 3. The most common source of CO_2 (gray arrows) in houses built on abandoned mines and some of the many ways it can enter a building.

alkaline materials to the water to raise the water's pH value close to 7.0 (chemically neutral).

Limestone and other rocks containing carbonate minerals such as calcite (calcium carbonate – $CaCO_3$) are the primary alkaline materials added to soils, mine tailings, and waste rock to neutralize acid. Rocks and compounds containing silica minerals, natural oxides, hydroxides, and phosphates can be used also, but carbonate minerals commonly are added to the mix to increase their acid-neutralizing capabilities. CO_2 is one of the products of this process (Figure 2).

But even in mines that have been reclaimed without treatment, CO_2 can be released by reaction of the acid with carbonate minerals occurring naturally in the fill material (such as calcite-cemented sandstone). It can also occur as a result of microbial respiration in organic-rich mine spoil (e.g. plant debris).

Thus, CO_2 can get into soils and shallow rock formations where it can migrate from place to place through rock fractures and permeable soil layers (Figure 3).

CO_2 PROBLEMS

CO_2 would not be a major problem in western Pennsylvania except for one thing – the desire for new housing. Everyone wants to live the American dream of owning a new home, so developers and construction companies are in great demand to develop just about any available piece of land. This has come to include reclaimed strip mines in which acid mine drainage is reacting with carbonate minerals to release CO_2 into the soil or bedrock.

Changes in barometric pressure drive gases, such as air, from higher to lower pressure areas (that's where wind comes from). When barometric pressure falls, soil gases can migrate outward from the ground into the atmosphere. They can also migrate into buildings through cracks, gaps, or construction joints in floors and walls and around water, gas, and sewer lines (Figure 3). Movement and concentration of CO_2 in buildings also fluctuates with changes in interior pressures.

Because CO_2 is odorless and colorless, families living in homes affected by high concentrations typically aren't aware of the problem immediately. They often learn of the problem only as a result of physical ailments (labored breathing, headaches, exhaustion) and/or trouble starting or maintaining a flame (striking a match or keeping a pilot light burning). When anything like these symptoms occur, they should be taken seriously. But don't assume immediately that CO_2 is the culprit, because other gases can cause similar problems. The building needs to be screened for indoor-air quality using portable meters properly calibrated and equipped with oxygen, carbon monoxide, and CO_2 sensors. The meters should be equipped with flame ionization detectors in case hydrocarbon gases also are suspected. Finally, sampling the air for laboratory analysis will precisely determine which compounds are present and in what concentrations.

WHAT CAN YOU DO?

The best short-term remedy for stopping CO_2 migration into buildings is to fill cracks, joints, and gaps in walls, floors, suspended floors, and around service lines with an impermeable seal such as radon-resistant caulk or hydraulic cement.

A reverse radon system (Figure 4) is, at this time, the most effective long-term strategy for eliminating CO_2 problems. Standard radon systems, which draw air from under the basement slab and vent the gas to the outside, work well in reducing small (a few parts per million) CO_2 concentrations, but they tend to draw gases into the building. Therefore, with higher concentrations of CO_2 they will be ineffective at best, and could help increase the problem. A reverse radon system takes outside fresh air and forces it under the basement slab. This increases the air pressure around a building foundation and drives the CO_2 away from the building.

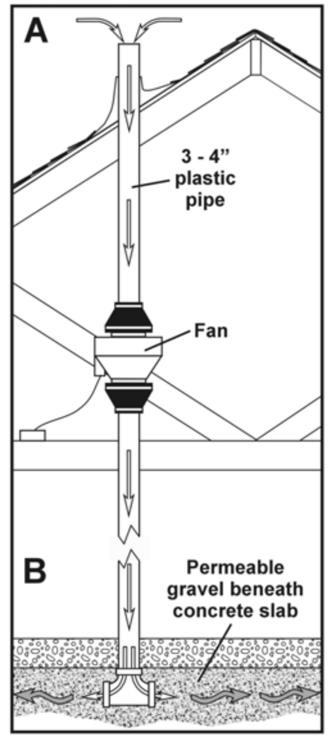

Figure 4. Reverse radon system. Air (white arrows) is pumped into a pipe at the top of a building (A) and forced into the soil beneath the basement foundation (B).

As with a standard radon system, a reverse radon system should be designed and installed by a qualified technician. Information on radon control systems and their construction requirements can be found in the International Building Code, Appendix F. These same requirements can be used to correct CO_2 problems in houses simply by reversing the ventilation process. In addition, wall-mounted continuous CO_2 monitors should be installed, particularly in basements, to check both CO_2 concentrations in the building and the long-term effectiveness of the ventilation system.

CO_2 problems generally are not covered by home-owners' insurance. Contact your insurance agent for complete details. Western Pennsylvania residents wishing to determine if their property lies on a reclaimed strip mine, or above an active or abandoned underground coal mine, should call the nearest District Mining Office of the Pennsylvania Department of Environmental Protection (DEP) and request assistance. The DEP Bureau of Radiation Protection can also provide free literature on protecting houses and other buildings from radon for those homeowners interested in installing reverse radon systems. Call 412-442-4000 to request a copy.

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