Methane Mitigation

Chemistry Extension

Goal: Introduce students to the characteristics and potential recycling of "Garbage" gas.

Objectives: Students will…
- Create methane gas through a chemical reaction
- Observe the combustibility of methane through a chemical reaction

Materials (for a class of 30):
- 2 pieces latex tubing, 1/8-inch (3.175 mm) ID, 5 cm lengths (fits over plastic tubing)
- 2- 18 x 150 mm test tubes or larger
- Two-hole #1 stopper fitted with two short length (2 cm) of glass or plastic tubing
- 60ml plastic syringes with Latex LuerLOK syringe end caps
- 1 can of silicon spray
- Ring stand with suitable clamp to hold test tube and syringes
- Small Bunsen burner
- Matches or a lighter
- Sodium hydroxide, NaOH or soda lime
- Sodium acetate, $NaC_2H_3O_2$
- 1-250 ml beaker or 9-ounce plastic cup
- Test tube clamp
- 30 copies of Methane Mitigation-Student Sheet

**Note: Here we describe the preparation of methane. Laboratories equipped with natural gas (not LP gas) may use that gas for the experiments suggested below.*

Time Required: 45-60 minute period

Standards Met: S1, S2, S6

Procedure:

PREP
- Prepare one lab set-up per group with materials listed above.
- Review procedure in It's a Gas! for preparing methane.

IN CLASS
- Divide students into groups of 4.
- Explain that they will be creating methane gas through a chemical reaction (see teacher background information). They will look at the combustibility of methane in this lab.
- Be sure to review safety procedures with students prior to lab.
- Review It's a Gas! procedures for producing methane with students.
- Produce methane as students did in It's a Gas!
- Hand out Methane Mitigation-Lab Procedure, review and allow time to complete the lab.

- Review clean up procedure with students and give them time to complete a thorough clean up of their lab stations.
- Hand out Methane Mitigation-Student Sheet and review answers if time allows.

Assessment:
- Completed lab procedures
- Completed Methane Mitigation-Student Sheet

Methane Mitigation-
Background Information

Methane is a colorless, odorless gas with a wide distribution in nature. It is the principal component of natural gas, a mixture containing about 75% CH_4, 15% ethane (C_2H_6), and 5% other hydrocarbons, such as propane (C_3H_8) and butane (C_4H_{10}). The "firedamp" of coal mines is chiefly methane. Anaerobic bacterial decomposition of plant and animal matter, such as occurs under water, produces marsh gas, which is also methane.

At room temperature, methane is a gas less dense than air. It melts at –183°C and boils at –164°C. It is not very soluble in water. Methane is combustible, and mixtures of about 5 to 15 percent in air are explosive. Methane is not toxic when inhaled, but it can produce suffocation by reducing the concentration of oxygen inhaled. A trace amount of smelly organic sulfur compounds (*tertiary*-butyl mercaptan, (CH_3) 3CSH and dimethyl sulfide, $CH_3–S–CH_3$) is added to give commercial natural gas a detectable odor. This is done to make gas leaks readily detectible. An undetected gas leak could result in an explosion or asphyxiation. (The attached scratch-and-sniff sheet from Madison Gas & Electric Company is for your use outside of class.)

Methane is synthesized commercially by the distillation of bituminous coal and by heating a mixture of carbon and hydrogen. It can be produced in the laboratory by heating sodium acetate with sodium hydroxide and by the reaction of aluminum carbide (Al_4C_3) with water.

In the chemical industry, methane is a raw material for the manufacture of methanol (CH_3OH), formaldehyde (CH_2O), nitromethane (CH_3NO_2), chloroform (CH_3Cl), carbon tetrachloride (CCl_4), and some freons (compounds containing carbon and fluorine, and perhaps chlorine and hydrogen). The reactions of methane with chlorine and fluorine are triggered by light. When exposed to bright visible light, mixtures of methane with chlorine or fluorine react explosively.

The principal use of methane is as a fuel. The combustion of methane is highly exothermic.

CH_4 (g) + 2 O_2 (g) CO_2 (g) + 2 H_2O (l) H = –891 kJ

The energy released by the combustion of methane, in the form of natural gas, is used directly to heat homes and commercial buildings. It is also used in the generation of electric power. During the past decade natural gas accounted for about 1/5 of the total energy consumption worldwide, and about 1/3 in the United States. The cost of natural gas to Wisconsin consumers is regulated by the State Public Service Commission. Madison Gas Electric Company currently charges its residential consumers about $0.66 per 100 cubic feet.

Natural gas occurs in reservoirs beneath the surface of the earth. It is often found in conjunction with petroleum deposits. Before it is distributed, natural gas usually undergoes some sort of processing. Usually, the heavier hydrocarbons (propane and butane) are removed and marketed separately. Non-hydrocarbon gases, such as hydrogen sulfide, must also be removed. The cleaned gas is then distributed throughout the country through thousands of miles of pipeline. Local utility companies add an odorant before delivering the gas to their customers.

Some methane is manufactured by the distillation of coal. Coal is a combustible rock formed from the remains of decayed vegetation. It is the only rock containing significant amounts of carbon. The elemental composition of coal varies between 60% and 95% carbon. Coal also contains hydrogen and oxygen, with small concentrations of nitrogen, chlorine, sulfur, and several metals. Coals are classified by the amount of volatile material they contain, that is, by how much of the mass is vaporized when the coal is heated to about 900°C in the absence of air. Coal that contains more than 15% volatile material is called bituminous coal. Substances released from bituminous coal when it is distilled, in addition to methane, include water, carbon dioxide, ammonia, benzene, toluene, naphthalene, and anthracene. In addition, the distillation also yields oils, tars, and sulfur-containing products. The non-volatile component of coal, which remains after distillation, is coke. Coke is almost pure carbon and is an excellent fuel. However, it may contain metals, such as arsenic and lead that can be serious pollutants if the combustion products are released into the atmosphere Municipal solid waste landfills are the largest human-generated source of methane emissions in the United States, releasing an estimated 55 MMTCE to the atmosphere in 2001 alone. Given that all landfills generate methane, it makes sense to use the gas for the beneficial purpose of energy generation rather than emitting it to the atmosphere. Landfill gas (LFG) is created as solid waste decomposes in a landfill. This gas consists of about 50 percent methane (CH_4), the primary component of natural gas, about 50 percent carbon dioxide (CO_2), and a small amount of non-methane organic compounds. Methane is a very potent greenhouse gas that is a key contributor to global climate change (over 21 times stronger than CO_2). Methane also has a short (10-year) atmospheric life. Because methane is both potent and short-lived, reducing methane emissions from MSW landfills is one of the best ways to achieve a near-term beneficial impact in mitigating global climate change.

One way to reduce the emission of methane gas into the atmosphere is to trap it for energy use. It is estimated that a LFG project will capture roughly 60-90% of the methane emitted from the landfill, depending on system design and effectiveness. The captured methane is destroyed (converted to water and the much less potent CO_2) when the gas is burned to produce electricity. Carbon Dioxide emissions from landfills are not considered to contribute to global climate change because the carbon was contained in recently living biomass. The same CO_2 would be emitted as a result of the natural decomposition of the organic waste materials outside the landfill environment The greenhouse gas reduction benefits of a typical 4 megawatt LFG project equate to planting over 60,000 acres of forest per year or removing the annual carbon dioxide emissions from over 45,000 cars. This amount of energy would also offset the use of 1,000 railcars of coal or prevent the use of almost 500,000 barrels of oil.

Indirectly reduces air pollution by offsetting the use of non-renewable resources

Producing energy from LFG avoids the need to use non-renewable resources such as coal, oil, or natural gas to produce the same amount of energy. This can avoid gas end-user and power plant emissions of CO_2 and criteria pollutants such as sulfur dioxide (which is a major contributor to acid rain), particulate matter (a respiratory health concern), nitrogen oxides (NOx), and trace hazardous air pollutants.

It should be noted that LFG electricity generation devices, like all combustion devices, generate some emissions of NOx, which can contribute to local ozone and smog formation. Depending on the fuels and technologies used by the power plant and the landfill project, the NOx emission reductions from the power plant may not completely offset the NOx emitted from the LFG electricity project. However, the overall environmental improvement from landfill gas electricity generation projects is significant because of the large methane reductions, hazardous air pollutant reductions, and avoidance of the use of limited non-renewable resources such as coal and oil that are more polluting than LFG.

Other local benefits

Collecting landfill gas to produce electricity improves the air quality of the surrounding community by reducing landfill odors. Burning LFG to produce electricity also destroys most of the non-methane organic compounds that are present at low concentrations in uncontrolled LFG, thereby reducing possible health risks from these compounds. Gas collection can also improve safety by reducing explosion hazards from gas accumulation in structures on or near the landfill. Generating electricity from existing MSW landfills is also a relatively cost-effective way to provide new renewable energy generation capacity to supply community power needs, and can create jobs that help build the local economy.

Benefits the local economy

Landfill gas projects generate revenue from the sale of the gas. Landfill gas use can also create jobs associated with the design, construction, and operation of energy recovery systems. Landfill gas projects involve engineers, construction firms, equipment vendors, and utilities or end-users of the power produced. Much of this cost is spent locally for drilling, piping, construction, and operational personnel, helping communities to realize economic benefits from increased employment and local sales. Businesses are also realizing the cost savings associated with using LFG as a replacement for more expensive fossil fuels, such as natural gas. Some companies will save millions of dollars over the life of their LFG energy projects. By linking communities with innovative ways to deal with their LFG, LMOP helps communities enjoy increased environmental protection, better waste management, and responsible community planning. For example, the Ecology Club at Pattonville High School in Maryland Heights, Missouri, came up with the idea to use gas from the nearby landfill to heat their school. The school paid $175,000 to run a 3,600-foot pipeline between the landfill and the school's two basement boilers. In turn, the landfill owner donated the methane to the school as a way of "giving back to the community." The school anticipates that it will save $40,000 a year, and recapture its investment within five years.

Reduces Environmental Compliance Costs

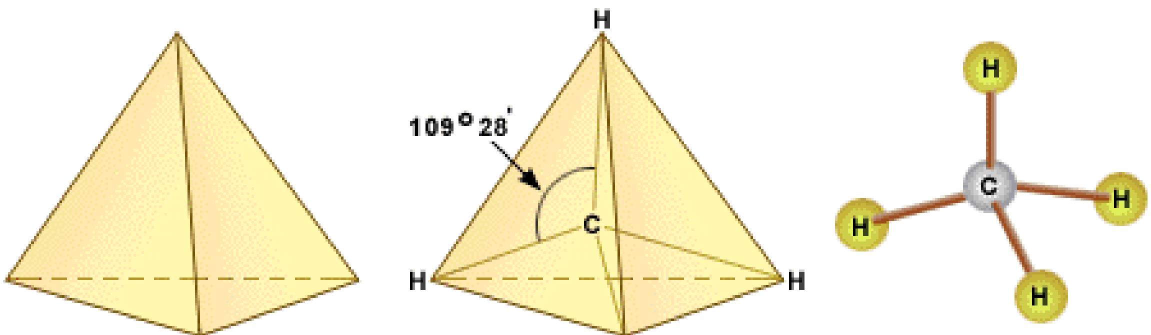
Current EPA regulations under the Clean Air Act require many larger landfills to collect and combust LFG. There are several compliance options, including flaring the gas, or installing an LFG use system. Only LFG energy recovery offers communities and landfill owners the opportunity to reduce the costs associated with regulatory compliance by turning pollution into a valuable community resource.

In the following lab activities you will synthesize methane gas and observe its combustion characteristics.

General Safety Precautions

Always wear safety glasses. Methane is relatively non-toxic; it is a simple asphyxiant. It is flammable in air and forms explosive mixtures with air.

Methane



A tetrahedron | Three-dimensional structure of a methane molecule | A model of methane molecule

Methane (CH_4) occurs as a natural gas in the underground petroleum wells deep inside the earth. Methane gas is also known as marsh gas as it is emitted by bacterial decomposition of dead plants and animals. Methane is found in coal mine gases, gobar gas, sewage gas and bio-gas.

Methane Mitigation–Teacher Answer Key

Name: ______________________________________ Date: _____________________

1. Where did the methane gas come from that you collected?

    The methane gas was the product of a chemical reaction between sodium acetate and soda lime when it was heated.

2. How is methane gas produced in a landfill?

    Methane gas is produced in a landfill by the decomposition of organic material.

3. List at least two characteristics of methane gas.

    Methane gas is lighter (less dense) than air.
    Methane gas is combustible.

4. How would collecting methane gas from landfills and then using it for energy production help reduce global climate change?

    Methane gas is a potent greenhouse gas. By not allowing methane gas to escape into the atmosphere, we can potentially reduce the affect of global climate change.

Methane Mitigation-Lab Procedure

The experiment below involves the combustion of methane. The reaction is:

CH_4 (g) + 2 O_2 (g) -----> CO_2 (g) + 2 H_2O (g) ΔH = -802.3 kJ

Materials:

- Methane produced from It's a Gas! experiment
  - Large test tube fill with methane from above
  - 1 -- 250-mL beaker or 9-ounce plastic cup
  - Candle in holder
  - Matches or lighter
  - 1 test tube clamp

Procedure:

- Be sure to wear your safety goggles and follow all safety procedures.
- Follow procedures from It's a Gas! to produce the methane needed for this experiment.
  - Use one stoppered test tube of methane from your It's a Gas! experiment.
  - Darken the room.
  - Remove the stopper from the test tube and hold the test tube with its mouth directed downward.
  - Bring a burning candle up to the mouth of the test tube and the gas will begin to burn. In order to maintain the flame and burn all of the gas, the test tube must be rotated to a 45° angle position with open end up so that the lighter-than-air methane can leave the test tube. The gas will burn down the test tube in the form of a narrow, bright blue disk that produces condensation on the glass just above the flame. It takes approximately 15 seconds for the burning disk of methane to burn to the bottom of the tube. Caution: The test tube will become hot, so use a test tube clamp.
  - Record your observations below.

- Follow the instructions from your instructor for clean-up and disposal of materials then complete Methane Mitigation-Student Sheet.

Methane Mitigation–Student Sheet

Name: ______________________________________ Date: _____________________

1. Where did the methane gas come from that you collected?

2. How is methane gas produced in a landfill?

3. List at least two characteristics of methane gas.

4. How would collecting methane gas from landfills and then using it for energy production help reduce global climate change?