SNC2D **NAME:** _____

CASE STUDY

Combustion Reactions and the Environment

Many types of chemical reactions affect our lives. Chemical reactions allow drain cleaners (sodium hydroxide) to clear clogged pipes, create nitrogen gas to inflate car air bags in an accident and provide energy for the cells in our brain while we read this paper. However, one type of reaction has been uniquely important to human society. Combustion reactions have been essential to human development but also threaten the world we inhabit.

The Importance Combustion Reaction

Combustion reactions involve the reaction of elements or compounds to form oxides. The most important combustion reactions use organic compounds as a fuel:

Reaction 1: organic compound + oxygen ⟶ carbon dioxide + water

These reactions are known as **exothermic** reactions since they release energy to the surroundings. Combustion reactions using wood as a fuel were used by early humans to provide warmth and light. As technology progressed, other fuels such as a carbon-based mineral called coal and and whale oil were used to provide energy. In the 1850's, whale populations were declining due to hunting for oil and a substitute was needed. Using a process called fractional distillation, petroleum (crude oil) could be broken down into useful fuels such as kerosene, gasoline and diesel fuel. These molecular compounds are known as hydrocarbons and have a general formula C_xH_y. Together with coal, hydrocarbons provided a cheap and abundant source of energy just as the world was entering the industrial revolution. Although hydrocarbons have many uses such as the production of chemicals and plastics, the majority of global consumption is used for fuel for transportation, heating and electricity production.

Since the 1850's, society's dependence on petroleum has steadily increased and this trend continues to the present day. As shown in Figure 1, world oil consumption has increased from approximately 31 million barrels per day in 1965 to almost 84 million barrels per day in 2009. Growth in the population and wealth of industrialized countries such as the Canada, the United States, Germany and Japan produced some of the growth. More countries have also entered the industrial stage of their development, greatly increasing their consumption of petroleum. In addition to liquid petroleum products, natural gas consisting of smaller hydrocarbons like methane has become an important source of energy for home heating and in the production of electricity.

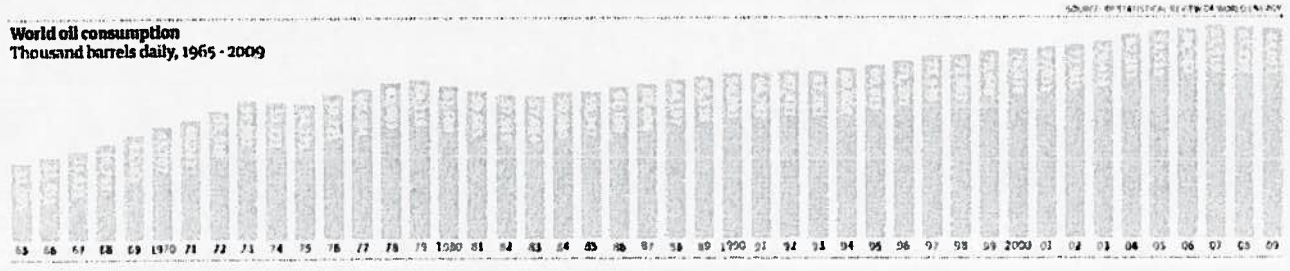

Figure 1: World Oil Consumption, 1965-2009. [1]

Problems with Combustion Reactions

1. Incomplete Combustion

One environmental problem associated with combustion results from a type of reaction called incomplete combustion. Reaction 1 shows the general equation for complete combustion, where the only two products are carbon dioxide and water. When fuels burn in a typical car engine, however, other products can be formed. Carbon (soot) and a poisonous gas, known as carbon monoxide, can be produced along with carbon dioxide and water. Carbon can enter the lungs and cause tissue damage if the exposure is severe. A more deadly killer, however, is the carbon monoxide.

Carbon monoxide is a colourless, odourless gas that can seep into homes from a faulty furnace, fireplace, or vehicle running in a garage. The gas kills by binding to proteins in the blood, preventing the transfer of oxygen from the blood to cells, thereby killing them. Most homes now contain a carbon monoxide gas detector to warn residents of the presence of this gas. To reduce the release of carbon monoxide from automobiles, car exhaust systems now contain a device known as a catalytic converter. This device contains the catalyst platinum. This metal acts to speed up the formation of carbon dioxide through the reaction of carbon monoxide and oxygen:

Reaction 2: carbon monoxide + oxygen $\xrightarrow{\text{Pt catalyst}}$ carbon dioxide

Catalytic converters greatly reduced the pollution released from automobiles when they were introduced in the 1970's.

2. Acid Precipitation

Another serious environmental problem related to combustion is acid precipitation (rain, snow). Natural rain is always slightly acidic (pH 5.6) due to the natural presence of carbon dioxide in the air, which produces carbonic acid:

Reaction 3: carbon dioxide + water $\longrightarrow$ carbonic acid

Air pollution can cause rainwater to become much more acidic than normal, as low as pH 2 (similar to vinegar). Car engines contribute to the problem of acid rain. Some fuels contain a significant amount of sulfur. This sulfur can undergo combustion in a car engine to form sulfur dioxide and sulfur trioxide gases.

Reaction 4: sulfur + oxygen $\longrightarrow$ sulfur trioxide

In the air, this non-metal oxide can react with water droplets in clouds:

Reaction 5: sulfur trioxide + water $\longrightarrow$ sulfuric acid

This reaction produces sulfuric acid and can make the water droplets much more acidic.

Due to the high temperature of the car engine, nitrogen can react with oxygen to produce a gas called nitrogen dioxide (NO_2). This gas can react with water droplets in the air to produce nitric acid (HNO_3). Other sources of these gases that cause acid rain are metal refining, coal-fired electrical generating plants, steel production, fertilizer production and paper manufacturing. Once in the

atmosphere, acids move through the water cycle and return to the earth as acid precipitation (rain or snow) (Figure 2).

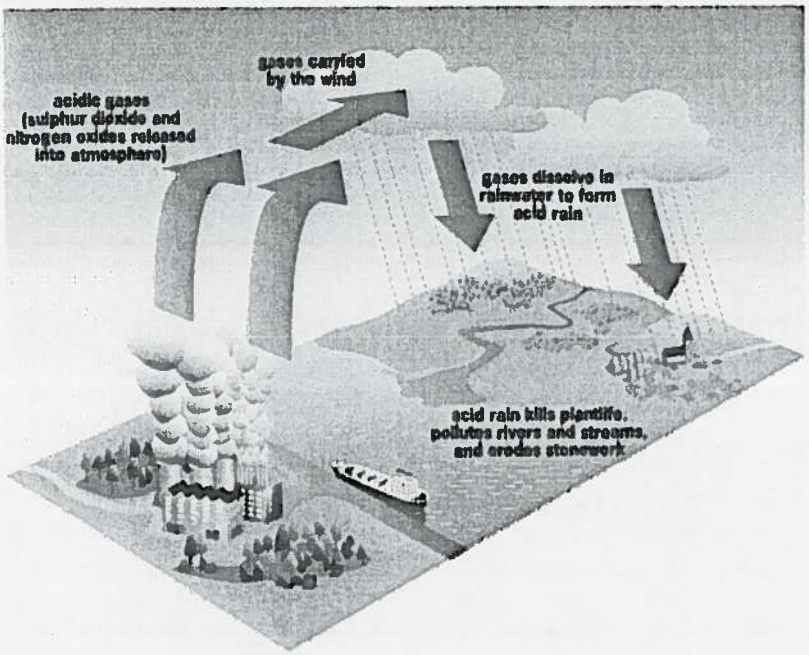

Figure 2: Acid precipitation in the water cycle. [2]

Acid precipitation has many effects. In cities, the acid rain reacts with building materials such as marble, which is composed of calcium carbonate. Although this may seem beneficial at first since the acid is neutralized, the reaction in fact erodes buildings or monuments. Many statues and historic buildings in Europe have been damaged this way. Figure 3 shows a statue that has been damaged by acid. Acids also react with metals such as iron and can corrode the reinforcing rods in structures such as bridges, contributing to their collapse.

Acid rain also affects natural ecosystems. On land, acid rain can decrease the pH of soil, causing trees and other plants to die off. This can have a domino effect in the ecosystem, reducing the population of many other species. The water in freshwater lakes and streams also becomes more acidic due to acid rain. This can cause fish and other aquatic organisms to die off.

In some damaged lakes, a basic chemical called calcium hydroxide has been added to raise the pH of lakes by neutralizing the excess nitric (HNO_3) or sulfuric acid (H_2SO_4). This chemical has been widely used to control the acidity in foods such as orange juice. Although this process has been tried experimentally on some lakes and does work, it is too expensive to be a practical long-term solution to the problem of acid rain.

Figure 3: Acid damage to a statue. [3]

3. Climate Change

Perhaps the best known environmental problem associated with combustion is the potential impact this reaction is having on the Earth's climate. Although carbon dioxide gas is a tiny component of the atmosphere (less than 0.04%), scientists agree that the amount of carbon dioxide in the atmosphere is increasing due to combustion of wood, coal, natural gas and petroleum. Carbon dioxide is one of a group of atmospheric gases that can trap and retain heat in the atmosphere. Therefore, changes in the level of carbon dioxide could potentially change the balance of energy on our planet and have drastic effects on climate. Human impact on climate will be a major topic of the next unit in this course.

Alternatives to Combustion

Combustion reactions have provided our society with a cheap and convenient source of energy. As the world's supply of natural gas and petroleum is used up and we become aware of the problems associated with this reaction, alternative fuels are being sought. These include renewable fuels such as ethanol and hydrogen. Ethanol is a liquid fuel produced using sugar from corn or sugarcane. It can be burned in modified car engines but is not made from fossil fuels. Hydrogen gas can be produced from the decomposition of water. When this reaction is reversed, the reaction can be used to produce energy:

Reaction 6: hydrogen + oxygen $\longrightarrow$ water

Until alternatives are available, however, the simplest action that all citizens can take is to reduce their reliance on combustion in their everyday life. Simple actions such as using less electricity or walking to school have a very small individual impact. However, when multiplied by the thousands of people taking action, these small acts can have a significant effect.

Questions:

Answer these questions on a separate sheet. Use full sentences where appropriate.

1. Describe three ways that combustion reactions affect your daily life. [3 A]
2. Gasoline contains a mixture of hydrocarbons including heptane (C_7H_{16}).
   a) Write a word equation for the combustion of heptane. [2 K]
   b) Write the balanced chemical equation for the combustion of heptane. [2 K]
3. a) Why is incomplete combustion a problem? [1 A]
   b) Write a word equation to describe an incomplete combustion reaction involving heptane. [2 K]
4. Platinum acts as a catalyst to speed up Reaction 2 between carbon monoxide and oxygen.
   a) Write a balanced chemical equation for this reaction. [2 K]
   b) What type of reaction is this classified as? [1 K]
5. a) Describe 2 ways that acid precipitation can affect natural ecosystems. [2 A]
   b) Describe 2 social or economic effects of acid precipitation. [2 A]
6. a) What compound are scientists using to restore acidic lakes? [1 K]
   b) Write a word equation for the reaction of this compound with sulfuric acid. [2 K]
   c) Write a balanced chemical equation for this reaction. [2 K]
   d) Why is the use of this compound not the final answer to the problem of acid rain? [1 A]
7. This case study presented some suggestions on how individuals can reduce their contribution to the problems associated with combustion. Identify three **specific** ways (*besides the ones mentioned in the case study*) that an individual can reduce their contribution to the problem. [3 A]

References:

1. BP Energy Statistics. The Guardian. (http://www.guardian.co.uk/news/datablog/2010/jun/09/bp-energy-statistics-consumption-reserves-energy?INTCMP=SRCH#data) Accessed Feb. 27, 2010.
2. Good for You. (http://www.goodforyou.com.sg/wordpress/images/p0013033-acid-rain.gif) Accessed Dec. 7, 2009.
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Application	Knowledge
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