

## CHAPTER 15: AIR POLLUTION

### Outline

#### 19-1 Structure and science of the atmosphere

- A. The atmosphere consists of several layers with different temperatures, pressures, and composition
  1. The atmosphere is a thin layer of gases divided into several spherical sublayers.
  2. Density and atmospheric pressure vary throughout the atmosphere due to gravitational forces that pull the gas molecules toward the earth's surface. Air at sea level has a higher density than air at the top of a mountain.
  3. Atmospheric pressure is a measure of the mass per unit of air. It decreases with altitude.
- B. About 75-80% of the earth's air mass is found in the troposphere, the atmospheric layer closest to the earth's surface.
  1. This layer extends about 11 miles above sea level at the equator and about 5 mile above the poles.
  2. About 99% of the volume of air is made up of nitrogen (78%) and oxygen (21%) with the rest consisting of water vapor, argon, carbon dioxide and traces of several other gases.
  3. This layer is also responsible for short-term weather and long-term climate.
- C. The stratosphere is the second layer of the atmosphere and extends from 11-30 miles above the earth's surface.
  1. The concentration of ozone in this layer is much higher than in the troposphere.
  2. Ozone is produced when oxygen molecules interact with ultraviolet radiation ( $3 \text{ O}_2 + \text{UV} \rightarrow 2 \text{ O}_3$ ). This "global sunscreen" keeps about 95% of the sun's harmful UV radiation from reaching the earth's surface.
  3. This ozone layer protects us from sunburn, cataracts, cancer of skin and eye and damage to our immune system.
  4. There is evidence of a decrease in "good" ozone in the stratosphere and increase in "bad" ozone in the troposphere.

#### 19-2 Air Pollution

- A. Air pollutants come mostly from natural sources and from burning fossil fuels.
- B. Primary pollutants are pollutants emitted into the air. They can react with one another and/or with air to form secondary pollutants.
- C. Major air pollutants include carbon oxides, nitrogen oxides, suspended particulate matter, volatile organic compounds, and ozone.

#### 19-3 Urban Outdoor Air Pollution

- A. Outdoor air pollution comes mostly from natural sources and burning fossil fuels in vehicles and power and industrial plants.
  1. Chemicals in the atmosphere in concentrations high enough to affect climate, materials, and health are what constitute air pollution.
  2. Natural sources of air pollution such as dust particles, organic chemicals released by plant decay; forest fires, etc. rarely reach harmful levels.
  3. Increased use of fossil fuels has greatly increased the amount of air pollution, especially in urban areas where people, cars and industry are concentrated.
  4. Outdoor air pollutants are classified into two categories: primary pollutants that enter directly into the troposphere (soot, carbon monoxide), and secondary pollutants that may form when primary pollutants interact with one another or with the air to form new pollutants.
  5. Cities generally have higher pollution levels than rural areas. Winds can carry these pollutants away from their source to other areas.
  6. Indoor air pollutants come from infiltration of outside air, chemicals used or produced inside buildings.
  7. Air pollution is classified as a high-risk human health problem.
  8. Most people exposed to poor air live in developing countries.
  9. Six conventional air pollutants have maximum standards of allowable concentrations set by governments of developed countries (see Table 20-2).
- B. Photochemical smog is formed by the reaction of nitrogen oxides and volatile hydrocarbons under the influence of sunlight.
  1. A photochemical reaction is any chemical reaction activated by light.

2. Photochemical smog contains more than 100 primary and secondary pollutants.
  3. Nitrogen dioxide found in photochemical smog is a yellow-brown gas with a noxious odor and causes a brownish haze to form.
  4. Some NO<sub>2</sub> reacts with hydrocarbons to produce a mixture of ozone, nitric acid, aldehydes, peroxyacyl nitrates (PANs) and other pollutants.
  5. These substances are photochemical oxidants and can irritate the respiratory tract, damage crops and trees.
  6. Photochemical smog is more common in cities in warm, dry, sunny areas.
- C. Industrial smog is a mixture of sulfur dioxide, droplets of sulfuric acid, and a variety of suspended solid particles emitted by burning coal and oil.
1. When coal is burned it is converted to carbon dioxide and carbon monoxide and unburned carbon particles (soot).
  2. Coal and oil also contain sulfur that is then converted to sulfur dioxide.
  3. Reactions with water vapor changes sulfur dioxide to sulfuric acid in several steps. These droplets can then react with ammonia in the atmosphere to form ammonium sulfate. These various components give the air a gray color.
  4. Most countries have adopted pollution controls, but several countries with industrialized urban areas have serious smog problems.
  5. China has a serious gray-smog problem in many areas and many people die prematurely from this.
- A. Outdoor air pollution can be reduced by precipitation, sea spray, and winds and increased by urban buildings, mountains, and high temperatures.
1. Three natural factors help reduce outdoor air pollution: rain and snow, salty sea spray, and winds. Each of these factors helps remove pollutants, but they are then deposited elsewhere.
  2. Four factors can increase outdoor air pollution: urban buildings, hills and mountains, high temperatures, and the grasshopper effect where volatile compounds are carried from tropical or temperate areas to the poles.
- B. A layer of warm air sitting on top of a layer of cool air near the ground can prevent outdoor pollutants from rising and dispersing.
1. Turbulence, caused by the mixing of warm and cold air disperses air pollutants.
  2. A temperature inversion, where a layer of warm air sits over a layer of cold air prevents the mixing and dense, colder air becomes stagnant and accumulates more pollutants.
  3. Two areas are particularly susceptible to inversions:
    - a. a city located in a valley surrounded by mountains that experiences cloudy, cold weather part of the year
    - b. a sunny climate, light winds, mountains on three sides and several million people and vehicles (Los Angeles basin).
- C. Much of Southeastern Asia has a huge brown cloud of industrial smog from coal burning.
1. The rapid industrialization of China and India is repeating what had existed in Europe and the U.S. as part of the industrial revolution during the 19<sup>th</sup> and early 20<sup>th</sup> century.
  2. Solar energy reaching the earth is reduced 2-15% in some areas.
  3. Rice crops may be reduced 3-10% by this in India's winter harvests.
  4. Crops, trees and life in lakes are being damaged.
  5. This may also be an important contributor to premature deaths from respiratory diseases.
  6. This huge brown cloud also seems to be causing changes in regional climate, warming some areas and cooling others. There are also shifting rainfall patterns.
  7. The good news is that this problem can be greatly reduced by setting standards for coal-burning industries, changing to cleaner burning gas, using catalytic converters on cars. China has begun to do this, as has Delhi, India.

#### 19-4 Acid Deposition

- A. Sulfur dioxide, nitrogen oxides, and particulates react in the atmosphere to produce acidic chemicals that travel long distances before coming back to earth.
1. Tall smokestacks reduce local pollution, but can increase regional pollution.
  2. Acidic particles remain in the atmosphere for 2-14 days, depending on the prevailing winds, precipitation, and other weather patterns.

3. The acidic substances return to earth in one of two forms:
    - a. wet deposition as acidic rain, snow, fog, and could vapor with a pH less than 5.6.
    - b. dry deposition as acidic particles
  4. Acid deposition is a problem in areas downwind from coal-burning facilities and urban areas.
  5. Some areas have basic compounds in the soil that act to buffer or neutralize some acidic deposits.
  6. Many acid-producing chemicals generated in one country end up in other countries due to prevailing winds.
- B. Acid deposition can cause or worsen respiratory disease, attack metallic and stone objects, decrease atmospheric visibility, and kill fish.
1. Large amount of money are spent each year to clean and repair monuments and statues damages by acid deposition.
  2. Acid deposition also decreases atmospheric visibility.
  3. Acidified lakes have fish kill and aluminum ions are released into the water by the lower pH (4.5 or less).
  4. Many lakes in northern Europe and the eastern U.S. have few, if any, fish due to decreased pH.
- C. Acid deposition can deplete some soil nutrients, release toxic ions into soil, and weaken plants that become susceptible to other stresses.
1. Effect of acid deposition on plants is caused partly by chemical interaction in the soils.
  2. There may be an initial growth stimulus from added nitrogen and sulfur, but continued deposition leaches essential magnesium and calcium salts from the soil and lowers plant productivity.
  3. Herbivores that eat these plants can also develop calcium deficiencies.
  4. Synergistic effects may occur when the plants are exposed to several pollutants simultaneously.
  5. Acid can also dissolve aluminum, cadmium, and mercury ions from the soil. These ions are toxic to plants and animals.
  6. Acid loving mosses may be stimulated to grow and harm trees by holding quantities of water and killing mycorrhizal fungi needed by the trees.
  7. Weakened trees are more susceptible to diseases.
  8. The mountaintop trees are those that are most harmed by acidic rain because they are also growing in thin soils.
- D. Progress has been made in reducing acid deposition in the U.S., but there is a long way to go.
1. The 1990 amendments to the Clean Air Act have lead to significant reductions in SO<sub>2</sub> and NO<sub>x</sub> emissions from coal-fired power and industrial plants.
  2. Acid deposition has accelerated leaching of ions such as calcium and magnesium from soils in some areas, which could lead to a decrease in tree growth.
  3. Acid deposition has also increased concentrations of toxic forms of aluminum in some soil and in lakes and streams.
  4. It is predicted that an additional 80% reduction in SO<sub>2</sub> emissions would be needed to allow northeastern streams and lakes to recover from the effects of acid deposition.
- E. A number of prevention and control methods can reduce acid deposition, but they are politically difficult to implement.
1. The best approaches are those that reduce or eliminate emissions of SO<sub>2</sub>, NO<sub>x</sub> and particulates.
  2. Use of low sulfur coal is both good and bad, it lowers the amount of SO<sub>2</sub> released but because more must be burned to generate the same amount of electricity, it emits more mercury, CO<sub>2</sub>, and radioactive particles.
  3. Controlling acid deposition is a politically controversial issue.
  4. Inclusion of environmental and health costs to the current cost of coal would give a more realistic picture.
  5. Approaches to neutralize acid lakes include adding limestone or lime to the water or soil or adding a small amount of phosphate fertilizer, this approach is being evaluated.

#### 19-5 Indoor Air Pollution

- A. Indoor air pollution is usually a much greater threat to human health than outdoor air pollution.
1. EPA studies have shown that:
    - a. Levels of 11 common pollutants are 2-5 times greater inside homes and commercial buildings than outside.

- b. Inside cars in traffic-clogged areas the pollution may be 18 times higher than outside.
- c. Health risks are magnified because people usually spend 70-98% of their time indoors or in vehicles.
- 2. Sick-building syndrome has been linked to various air pollutants, and new buildings are apt to be more prone to this than old building due to less air exchange.
- 3. The EPA lists the four most dangerous indoor air pollutants in developed countries as cigarette smoke, formaldehyde, radioactive radon-222 gas, and very small fine and ultrafine particles.
- 4. In developing countries as many as 2.8 million people die prematurely each year from breathing elevated levels of indoor smoke and particulates.
- B. Formaldehyde is the chemical that causes most people in developed countries difficulty. It is used to manufacture common household materials.
- C. Radon-222 gas is found in some soils and rocks and can seep into some homes and increase the risk of lung cancer.
  - 1. Radon is produced by the radioactive decay of uranium-238.
  - 2. Radon gas tends to be pulled into homes because of the slightly lower atmospheric pressure inside most homes.
  - 3. Radon is thought to be the second leading cause of lung cancer deaths each year in the U.S.
  - 4. The EPA and the Surgeon General's Office recommended that everyone living in a detached home, a townhouse or the first 3 levels of an apartment building test for radon.
  - 5. Remedies include sealing cracks in foundation and walls, increase ventilation and use a fan for cross ventilation.

#### 19-6 Health Effects of Air Pollution

- A. The respiratory system has several ways to help protect you from air pollution.
  - 1. Hairs in the nose filter out large particles. Sticky mucus lines the respiratory trap to capture smaller particles and some dissolved gases.
  - 2. Sneezing and coughing expel contaminated air and mucus.
  - 3. Prolonged or acute exposure to air pollutants can overload or break down the natural defenses.
  - 4. Several respiratory diseases can develop such as asthma, lung cancer, chronic bronchitis and emphysema.
  - 5. People with respiratory diseases, older adults, infants, pregnant women, and people with heart disease are especially vulnerable to air pollution
- B. Each year, air pollution kills about 3 million people, mostly from indoor air pollution in developing countries.
  - 1. Air pollution deaths in the U.S. range from 150,000 to 350,000 people per year.
  - 2. A large diesel-powered bulldozer produces as much air pollution as 26 cars.
  - 3. The EPA proposed emission standards for diesel-powered vehicles that go into effect in 2007 with full compliance by 2012. It is thought that this will reduce diesel-fuel emissions by 90%.

#### 19-7 Preventing and Reducing Air Pollution

- A. Clean Air Acts in the United States have greatly reduced outdoor air pollution from six major pollutants.
  - 1. The U.S. Congress passed Clean Air Acts in 1970, 1977, and 1990.
  - 2. National air quality standards (NAAQS) were established for six outdoor criteria pollutants.
  - 3. Two limits were established: a primary standard is set to protect human health and a secondary standard is set to prevent environmental and property damage.
  - 4. EPA has established national emission standards for 188 hazardous air pollutants (HAPs) that may cause serious health and ecological effects. These include neurotoxins, carcinogens, mutagens, teratogens, and others.
  - 5. Good news is that the six criteria air pollutants decreased 48% between 1983 and 2002 even with increased energy consumption, miles traveled and population increase.
  - 6. Between 1983 and 2002, emissions from the six major air pollutants decreased: 93% for lead, 41% for carbon monoxide, 40% for volatile organic compounds, 34% for suspended particulate matter, 33% for sulfur dioxide, and 15% for NOx.
  - 7. Release of two HAPs – mercury and dioxins has increased in recent years. These are toxic at very low levels. EPA estimates that about 100 million Americans live in areas where the risk of cancer from HAPs is 10 times higher than the accepted standard.

8. Smog levels did not drop any between 1993 and 2003 after dropping in the 1980s.
- B. Outdoor air pollution in the U.S. has been reduced since 1970.
1. U.S. citizens insisted that laws be passed and enforced to improve air quality, and the country was affluent enough to afford the controls and improvements.
  2. One deficiency in the Clean Air Act is that we rely more on cleanup rather than prevention.
  3. Another deficiency is that Congress has not increased fuel-efficiency standards for cars, etc.
  4. Inefficient two-cycle engines have been inadequately regulated regarding emissions.
  5. Oceangoing ships have little or no air pollution regulations.
  6. The Clean Air Acts have not done much to reduce greenhouse gas emissions.
  7. There has been little done to deal seriously with indoor air pollution that is considered the most serious problem in terms of poorer health, premature deaths, and economic losses from lost work time.
  8. Better enforcement of these Acts is also needed. Company executives claim that improvements would cost too much, but these estimates are often too high and implementation has helped to increase economic growth and create jobs.
- C. Allowing producers of air pollutants to buy and sell government air pollution allotments in the marketplace can help reduce emissions.
1. The Clean Air Act of 1990 allows an emissions trading policy that permits companies to buy and sell SO<sub>2</sub> pollution rights.
  2. This cap-and-trade approach may be an improvement over command-and-control as long as it reduces SO<sub>2</sub> emissions. The cap would gradually be lowered.
  3. These pollution credits may be purchased by anyone and then not used if they so desire.
  4. This method allows “hot spots” to continue to exist. Spot monitoring to check for emissions should be done.
  5. Between 1980 and 2002 this scheme reduced SO<sub>2</sub> emissions by 40% in the U.S.
  6. Emissions trading has been expanded to include NO<sub>x</sub>, particulate emissions, and volatile organic compounds, and for the combined emissions of SO<sub>2</sub>, NO<sub>x</sub>, and mercury from coal-burning power plants.
  7. The Clear Skies initiative of 2001 has been criticized as a way for the big polluters to continue polluting.
  8. This plan is not a good one for reducing toxic mercury in the environment.
  9. In 2002 the EPA reported that the largest and oldest cap-and-trade program produced less emissions reductions than projected or that could be expected. There were accounting abuses.
- D. Plants already in existence in 1970 were not required to meet the new Clean Air Act standards.
1. A 1977 rule in the Clean Air Act (New Source Review) requires older plants to upgrade pollution control equipment when they expand or modernize the facilities.
  2. This has been circumvented by calling these expansions maintenance.
  3. In 2002 the Bush administration eased the New Resource Review restrictions for older facilities.
  4. In 2003 the National Academy of Public Administration advised Congress to give the dirtiest coal-fired power and industrial plants a 10-year deadline to install the most modern pollution controls or shut down.
- E. There are a number of ways to prevent and control air pollution from motor vehicles.
1. Get older, more polluting vehicles off the road.
  2. In 2003 a new process for removal of pollutants from fuels of vehicles. It is a class of chemicals called zeolites and uses an adsorption process that is more efficient than catalytic converters.
  3. Hybrid-electric vehicles and zero-emission vehicles should reduce emissions over the next 10-20 years.
  4. Developing countries are increasing their air pollution with more vehicles on the road that are over 10 years old and are without pollution controls.
- F. There is controversy over reducing emissions of ultrafine particles that pose a serious threat to human health.
1. Fine particles (less than 10 microns) and ultrafine particles (less than 2.5 microns) are generally not captured by most air pollution control equipment.
  2. These particles penetrate the natural defenses of the respiratory system.

3. These particles are estimated to kill 65,000-200,000 Americans/year. This number is even higher in developing countries (300,000-700,000).
  4. Costs to implement stricter standards are estimated at \$7 billion/year with health and other benefits of \$120 billion/year.
- G. Indoor air pollution is a greater threat to human health, but little effort has been spent on reducing it.
1. Figure 20-20 suggests several ways to reduce indoor air pollution.
  2. In developing countries indoor air pollution can be reduced by use of clay or metal stoves and venting to the outside, and by use of solar cookers in sunny areas. This would also reduce deforestation.
- H. There is a need to focus on preventing air pollution of all types in developing countries.
1. At present there is an output approach to controlling pollution.
  2. We need to shift focus to preventing air pollution.
  3. Figure 20-21 shows ways to prevent air pollution over the next 30-40 years.
  4. Figure 20-22 lists ways to reduce your exposure to indoor air pollution.

### **Summary**

1. The layers of the atmosphere are the troposphere, stratosphere, mesosphere, and thermosphere.
2. Major classes of air pollutants include carbon, sulfur, and nitrogen oxides, volatile organic compounds, suspended particulate matter, photochemical oxidants, radioactive substances, and hazardous chemicals that can cause health problems. Primary sources of these pollutants include cars, industry, and natural phenomena such as volcanic eruptions.
3. The two types of smog are the photochemical and the industrial or gray-air smog.
4. Acid deposition includes wet deposition of acidic rain, snow, fog, and cloud vapor with pH less than 5.6, and dry deposition of acidic particles. The solution to this problem is prevention that reduces emissions of acidic nitrogen and sulfur oxides, and particulates.
5. Harmful effects of air pollution include various respiratory diseases, premature deaths, damage to plants, and materials such as buildings, cars, statues, etc.
6. We can reduce air pollution through prevention and cleanup, including low sulfur coal, shifting to less polluting fuels, removal of pollutants after combustion, use of mass transit or alternative transportation, improving fuel efficiency, and tax incentives.