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Acid Rain

What is Acid Rain?

The term acid rain, as commonly used, refers to rain, snow, or fog containing a dilute solution of sulfuric acid and nitric acid, formed mainly from pollution associated with fossil fuel combustion. Other terms for this phenomenon are acid precipitation and wet deposition. Wet deposition accounts for about half of all acidic deposition.

Acid precipitation is defined as any precipitation with a pH value of less than 5.6. Pure distilled water, a neutral substance, has a pH of 7. A pH value of less than 7 indicates an acidic material. Normal, unpolluted rain is slightly acidic, with a pH of 5.6 For more about pH, see The pH Scale. Acid deposition also occurs through dry deposition of acidic gases and particles. This material is deposited onto trees, buildings, cars, and homes. Dry-deposited gases and particles can be washed from surfaces by rainstorms. The acidic runoff combines with wet-deposited acid precipitation and further impacts the environment.

Acid deposition readily crosses domestic and international boundaries. The tall chimney stacks used by industry to reduce local effects of pollution promote long-distance transport of the sulfur oxides and nitrogen oxides that cause acid deposition. Air pollutants remain suspended in the atmosphere for up to five days, allowing them to travel great distances before being deposited. Thus, a coal-burning power plant in the Midwest can cause acid deposition along the East Coast of the U.S.

Eastern North America and northern Europe are most known for their acid deposition problems. These forested areas of the globe have humid atmospheres, providing the water content needed to convent sulfur oxides and nitrous oxides to acids. In more arid regions such as the American West, airborne dust originating from alkaline soils provide a natural means of neutralizing sulfur oxides and nitrogen oxides. Acid deposition tends to be minimal in relatively dry areas.

The term acid rain was coined in 1852 by English chemist Robert Angus Smith, who noted a connection between London's air pollution, caused by industrial activity, and its acidic rainfall. Large-scale effects of acid deposition were not recognized until the mid-20th century. Environmental regulations to control industrial emissions of sulfur dioxide, a major source of acid deposition, began in 1990 in the United States.

How is Acid Rain Formed?

The primary cause of "acid rain," more accurately called acid deposition, is air pollution from burning fossil fuels. Fossil fuel use does not directly emit acids into the atmosphere. Instead, it releases large amounts of acid precursors, primarily sulfur oxides (SO_x) and nitrogen oxides (NO_x). When exposed to the atmosphere, these react with water to form sulfuric acid and nitric acid, components of acid deposition.

Sulfur dioxide (SO_2) is emitted through combustion of fossil fuels containing sulfur as an impurity. Coal combustion is by far the major source of sulfur dioxide emitted into the atmosphere. During combustion, sulfur is oxidized to form sulfur dioxide (SO_2). Sulfur dioxide rises into the atmosphere and is oxidized once again in the presence of atmospheric hydroxyl radicals to form sulfur trioxide (SO_3). Sulfur trioxide reacts with atmospheric water droplets to form sulfuric acid (H_2SO_4). Sulfur dioxide emission is the most common contributor to acid deposition, responsible for about 70% of the total. The greatest source of sulfur dioxide is electrical utility plants, which pump approximately 15 million tons of SO_2 into the atmosphere each year, out of the total 22 million tons generated annually by human activities. Other contributors of sulfur dioxide include industrial processes and automobiles and other motor vehicles.

Nitrogen oxides (NO_x) are also formed through fossil fuel use. In contrast to sulfur, nitrogen is not an impurity but rather an integral part of the organic material making up fossil fuels. Fossil fuel combustion releases nitrogen into the atmosphere, usually in the form of nitric oxide (NO). Nitric oxide (NO) is oxidized by atmospheric molecules, such as ozone (O_3) or hydrogen dioxide (HO_2), to form nitrogen dioxide (NO_2). Nitrogen dioxide (NO_2) reacts with OH in the atmosphere to form nitric acid (HNO_3). Nitric acid can also form when nitrogen dioxide (NO_2) reacts with the nitrate radical (NO_3) in the presence of atmospheric water or aldehydes. Nitrogen oxides account for approximately 30% of all acid deposition. Major sources of nitrogen oxide emissions are automobiles and fossil fuel burning power stations.

Nitric acid and sulfuric acid eventually fall back to the Earth's surface as acid deposition. This precipitation can be wet (rain, snow, or fog) or dry (gases or acidic salts).

The pH Scale

The pH scale measures how acidic or basic a substance is. It ranges from 0 to 14. A pH of 7 is neutral. Values less than 7 are acidic, while those greater than 7 are basic. Each whole pH value below 7 is ten times more acidic than the next higher value. For example, a pH of 4 is ten times more acidic than a pH of 5, and 100 times more acidic than a pH of 6.

Pure water is neutral, with a pH of 7.0. When chemicals are mixed with water, the mixture can become either acidic or basic. Alkaline is another word for basic.
Vinegar and lemon juice are acidic, while laundry detergents and ammonia are basic. Mixing acids and bases can cancel out their extreme effects, similar to the way mixing hot and cold water can even out the temperature.

Normal rain is slightly acidic, with a pH of approximately 5.6. Precipitation with pH less than 5.6 is considered acidic. In the year 2000, the most acidic rain falling in the United States had a pH of about 4.3.

Environmental Effects of Acid Rain

Acid rain, more accurately termed acid deposition, has been studied for many years. Numerous environmental effects have been attributed to acid deposition. Perhaps one of the best-known is acidification, a condition in which lakes and streams have a low pH level, resulting in the death of fish and other animal and plant life. Acidification can be chronic, where a given surface water body has a constantly low pH value, or episodic, where pH levels decrease for brief periods due to runoff from melting snow or heavy rain.

U.S. areas prone to chronic acidification include the Adirondacks and Catskill Mountains in New York State, the Appalachians, the upper Midwest, and mountainous areas in the western U.S. One of the most acidic lakes in the U.S. is Little Echo Pond in Franklin, New York, with a pH of

4.2. In the New Jersey Pine Barrens, over 90% of streams are acidic.

Episodic acidification, which can be severe enough to cause fish kills, is common in the mid-Appalachian region, where it affects approximately 30% of sensitive streams, and in the Adirondacks, where 70% of sensitive lakes are at risk.

In eastern Canada, 14,000 lakes are extremely vulnerable to chronic acidification. Acidification also occurs in much of Scandinavia and in parts of the United Kingdom and the Alps.

Forest damage is another environmental effect related to acid deposition. A 1999 survey of European forests showed that one out of every four trees had suffered the loss of 25% or more leaves or needles. Tree damage is believed to have multiple causes, including acidification of soil and high concentrations of ground-level ozone, both side-effects of acidic deposition. In Germany, this phenomenon, first observed in the Black Forest in the 1960s, is termed Waldsterben or tree death. An example is shown in the photo above. Damage was first observed in conifers, then later in deciduous trees, such as oak and beech. By 1990, nearly half the trees in the Black Forest were damaged.

Soils are also affected by acid deposition, particularly in areas with highly siliceous bedrock (granite, gneisses, quartzite, and quartz sandstone). These soils, which are common in eastern North America and Scandinavia, are already somewhat acidic. When acid deposition occurs on acidic soils, important cations including potassium, calcium, magnesium, and sodium are readily leached out, making them unavailable to plants as nutrients. This phenomenon, termed soil depletion, reduces the fertility of the soil. Similarly, in areas with old, highly leached soils, acid deposition depletes the small amounts of cations present, and the soil soon becomes unable to support plant life.

In contrast, soils rich in calcium, potassium, magnesium, and sodium are more resistant to the effects of acid deposition. These soils, common in arid and semi-arid regions such as the Utah desert shown above, are naturally alkaline and have the ability to buffer acid deposition. Much of the western U.S. is at less risk for acid deposition for this reason. The buffering capacity of alkaline soils can, however, be depleted by continuous acid deposition.

Many plants and animals are sensitive to acidification. The vulnerability of fish and other small aquatic organisms is well-established. As acid precipitation flows through soils, aluminum is released. As pH in a lake or stream decreases, aluminum concentration increases. Both low pH and high aluminum concentrations are toxic to fish. Frogs are relatively tolerant of low pH, but the insects upon which they feed are not. Lichens, mosses, and fungi are also particularly sensitive to acid deposition. Human health is indirectly affected by acid deposition through the consumption of toxic metals that entered the food chain during soil acidification.

Acid deposition is well-known for its corrosive effects on buildings and monuments made of sensitive materials such as limestone or sandstone. An example is shown at left. These easily weathered materials are slightly soluble in normal rainwater. In the presence of acid deposition, weathering rates are greatly increased.

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