Research on the Effects of Acid Rain and Improvement Measures

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Abstract. With the continuous development of industrial production, transportation and people's life all over the world, acid rain has become one of the major problems that seriously threaten the world environment. In this paper, the causes of acid rain, the effects of acid rain and the measures to control acid rain are studied. The influencing factors and forming process of acid rain were further expounded. Acid rain also affects buildings, animals, plants and humans to varying degrees - acid rain can cause different degrees of corrosion to buildings; Affecting the reproductive system of aquatic plants and causing egg defects in birds; It affects plant structure, physiological function and living environment. Therefore, in order to deal with acid rain, countries have implemented corresponding measures. This paper mainly introduces the Acid Rain Program (ARP) of the United States and the tax policy of Sweden. The treatment of acid rain is definitely not a simple thing, and people need to further explore more efficient and concise methods in the future. The purpose of this study is to clarify the serious impact of acid rain on society, economy and human life, and to arouse people's attention to acid rain and environmental protection.

Keywords: Acid rain, causes, process, natural and artificial emissions, measures.

1. Introduction

With the continuous development of industrial production, transportation and civil life in various countries around the world, acid rain has become one of the many major problems that seriously threaten the world environment. The first countries to experience acid rain were northern and central Europe, and acid rain was mainly sulfur dioxide and nitrogen oxides in the air. The term "acid rain" was first used in 1872 by British chemist Smith, who noticed that London's rain was noticeably acidic. Smith theorized that this was due to the emission of acidic compounds from burning fuel. In 1960, Swedish soil scientist Auden made the startling discovery that acid rain is a significant source of pollution in Europe, and that when precipitation and surface water become more acidic, slower forest growth, an increase in plant illnesses, and faster material deterioration follow. Since the Swedish government established a scientific team and submitted a report to the United Nations Human Environment Assembly in 1972 titled “Air pollution across national borders - the impact of sulfur in the atmosphere and precipitation on the environment”, acid rain has been a significant area of environmental research around the world [1]. This article analyzes the impact of acid rain and the treatment measures from many aspects, and hopes that all countries in the world can work together to make a contribution to the control of acid rain and protect our homes.

According to our survey, many people have written a lot of review literature on the impact or treatment of acid rain, but almost all of them are specific analyses of a single impact, and have not been explained and evaluated from multiple aspects. This paper analyzes the causes, impacts and treatment measures of acid rain from multiple perspectives, and considers all aspects in detail. At present, no most effective treatment measures for acid rain have been found, and in the future, it can be analyzed and experimentally investigated according to the cause and process of acid rain formation.

This paper analyzes the impact of acid rain from multiple aspects and proposes some corresponding improvement measures. First, briefly explain the history of the discovery of acid rain and analyze what acid rain is. Secondly, the formation process of acid rain and the formation of acid rain caused by natural or man-made causes are analyzed. Next, the impact of acid rain is analyzed

from four aspects: architecture, animals, plants, and humans. Then, some measures to deal with and prevent acid rain are proposed from both policy and technical aspects. Finally, the full text is summarized.

2. Causes and Processes of Acid Rain Formation

2.1. Causes

2.1.1 Natural emissions

There are some natural emissions that can cause acid rain to form, like organisms, volcanic eruptions, forest fires and lightning. Certain organisms in the soil, such as dead animals, can decompose certain sulfides under the action of bacteria, which are then converted into sulfur dioxide. Land plants absorb SO_2 from the atmosphere. Land and marine plants absorb sulfur from soil and water. The absorbed sulfur constitutes the organism of the plant itself. Plant residues are decomposed by microorganisms, and sulfur escapes into the atmosphere as H_2S. Onshore volcanic eruptions release sulfur from the Earth's crust and magma into the atmosphere in the form of H_2S, sulfates and SO_2. The sulfur emitted by submarine volcanic eruptions is partly dissolved in seawater and partly escaped into the atmosphere as gaseous sulfides. Some organic matter in land and sea releases H_2S to the atmosphere due to microbial decomposition, and its emissions vary with the season, with warm seasons being higher than cold seasons. Ocean wave splashes bring sulfur into the atmosphere as sulfate aerosols. Forest fires caused by lightning and dry heat are also a natural source of sulfur oxide emissions, as trees also contain trace amounts of sulfur. As a strong source of release of volatile sulfur-containing gases, biomass combustion is regional and short-term. During combustion, about 50% of the sulfur is released into the atmosphere, while the rest is retained in the ash. Strongly energetic high-altitude rain cloud lightning has the capacity to partially mix the nitrogen and oxygen in the atmosphere to produce nitric oxide, which is then oxidized to nitrogen dioxide in the troposphere. Nitric oxide and nitrogen dioxide together make up nitrogen oxides, which combine with airborne water vapor to produce nitric acid.

2.1.2 Artificial emissions

There are also some artificial emissions that will lead to acid rain, such as combustion, smelting, and transportation. Additionally, the high temperature during coal burning causes nitrogen and oxygen in the air to mix to form nitric oxide, which is then transformed into nitrogen dioxide, resulting in acid rain. Coal contains sulfur, and a significant amount of sulfur dioxide is produced during combustion. Large amounts of sulfur dioxide gas also escape during the reduction of ore to metal. H_2S released by petroleum refining quickly oxidizes to SO_2 in the atmosphere. These activities have led to a significant increase in atmospheric SO_2 concentrations in cities and mining areas, with harmful effects on people and animals. For example, car exhaust, in the engine, the piston frequently sparks, like lightning in the sky, nitrogen becomes nitrogen dioxide.

2.2. Processes

The formation of acid rain is divided into three steps which are as follows. First, the atmospheric pollutants are emitted. The main source of acid rain in the atmosphere is exhaust gases emitted by industry and transportation, including atmospheric pollutants such as sulfur dioxide and nitrogen oxides, which gradually accumulate in the atmosphere. Then after the emitted acid gas such as SO_2 enters the atmosphere, it causes SO_2 enrichment in local areas, which is dissolved in water in the process of hydrocondensation to form sulfurous acid (equation (1)), and then generated sulfuric acid by the catalysis of some pollutants and the oxidation of oxidants (equation (2)). Later, atmospheric circulation: acidic substances will be transmitted with the atmospheric circulation, reach the clouds, fog, rain and other water molecules in the atmosphere, and combine with hydrogen ions in the water molecules to produce acid rain. These acids can also form fine particles in the air, such as sulfuric acid mist, nitric acid mist, etc. In short, the formation process of acid rain mainly includes the

emission of atmospheric pollutants, chemical reactions in the atmosphere and atmospheric circulation. In this process, atmospheric pollutants such as sulfur dioxide and nitrogen oxides are the main components of acid rain, which eventually form by interacting with other chemicals in the atmosphere [2].

$$SO_2+H_2O=H_2SO_3 \quad (1)$$

$$2H_2SO_3+O_2=2H_2SO_4 \quad (2)$$

3. Effects of acid rain

3.1. Buildings

3.1.1 Destruction of marble buildings

Due to their weak acid resistance and susceptibility to corrosion and discoloration from acid rain, many historical structures and works of art built of marble and limestone should be avoided. Marble buildings are most concerned when acid rain occurs because the calcium carbonate in marble will chemically react with acid rain containing sulfur dioxide to produce calcium sulfate. Part of the calcium sulfate will enter the gap between the marble granules, get deposited on the surface of the marble as crusts, and then slowly fall off. Sandstone is more tolerant of acid rain, however with time, surface deposits deteriorate [3].

3.1.2 Erosion of metal buildings

Along with marble structures, acid rain also enjoys eroding bronze artworks displayed outdoors and buildings with gilded roofs. When metal-containing structures and works of art are exposed to acid rain, oxygen can easily access electrons on the metal surface and a chemical reaction takes place. As a result, the metal surface is continuously oxidized and gradually corrodes. According to a study published in the Journal of Water, Air and Soil Pollution of the University of Hong Kong, red brass, mild steel, galvanized steel, and stainless steel 304 can all corrode when exposed to artificial acid rain with a pH of 3.5. However, all four metals corroded more quickly as the acid rain produced by the researchers become stronger.

3.1.3 Destroy monument statues

Because they are built of limestone, historical statues, monuments, and tombstones are susceptible to acid rain (Fig. 1). The sculptures' details may fade over time after being exposed to acid rain, gradually transforming them into featureless blobs. Monumental damage is occurring more quickly in regions with heavy acid rain [4]. Due to acid rain, the goddess statue from the Parthenon temple in Greece gradually grew ragged and unclean. Many monuments in ancient Greece and ancient Rome used marble as a building material, and its main component was calcium carbonate, and when acid rain fell, its surface calcium carbonate became calcium sulfate or calcium nitrate, brittleness and peeling. More than 50 years ago, the reliefs on the steps of the Taihe Hall of the Forbidden City in Beijing and its stone pillars, with clear patterns, are now blurred, and some even lose their shape [5].

Figure 1. Acid rain eroded buildings. https://cn.bing.com/images/search?view=detail

3.2. Influencing Factors

3.2.1 Aquatic life

Water with low pH can cause damage to the gills of fish and embryo death. When fish are subjected to acid rain, their mineral levels become disordered, which has an impact on their reproductive system and prevents females from ovulating. The mucus on the gills of some fish can become extremely sticky and eventually clump together when they are in water with a very acidic pH, making it impossible for them to receive oxygen from the water. Additionally, when the amount of carbon dioxide in acidic water rises, so does the amount of carbon dioxide in blood; As a result, the oxygen consumption of animal species increases and the growth rate decreases. In addition, due to the increase in carbon dioxide, bones decalcify, resulting in deformities in animals. In the acidic water body, the growth of fish will be affected, increase the number of plankton in the water, bring nutrients to the fish, consume oxygen in the water, reduce the content of dissolved oxygen in the water, and affect the growth of fish, even death. At the same time, the decrease of pH value in the water body will increase the type and number of microorganisms in the water body, and some pathogenic microorganisms are more likely to make fish sick and affect fish growth [6].

3.2.2 Bird life

Bird life is one of the less evident effects of acid rain. A study by Miyoko Chu and Stefan Hames of the Cornell Lab of Ornithology found a connection between acid rain and the fall in wood thrush populations. Female birds depend on calcium-rich meals like snails because they need extra calcium to harden their eggs. Acid rain causes snail populations to decline, which causes bird egg deformities. Similar incidents were reported in the Netherlands by both the Cornell Lab and Wolosz, and it's possible that acid rain-induced eggshell flaws are the main reason for some regions' loss of avian biodiversity.

3.2.3 Other Animals

Other creatures that rely on other animals for food, including fish, are indirectly impacted by acid rain, including mammals. According to the Environmental Protection Agency (EPA), acid rain reduces species' population sizes and occasionally results in their extinction, which lowers biodiversity. The rest of the food chain is impacted when one link in the chain is disturbed. Other species that depend on those animals as food sources are harmed by the loss of biodiversity.

3.3. Plants

3.3.1 Direct impact

Numerous studies have demonstrated that many plants, including rice and pine trees, will develop necrotic patches on their leaf surfaces as long as the pH of water is below 3. The leaves' surface pores and stoma have been harmed, which will harm their photosynthesis and secretion. Additionally, the acid water consumes the plant's vital calcium, magnesium, and other bodily components, causing the plant to gradually weaken until it dies [7-9].

3.3.2 Indirect effect

The soil degradation, which is dissolved in rain, fog, or dust to create dry settlement of pollutants, combines and neutralizes soil calcium, magnesium, sodium, and other metal ions, is the indirect cause. Usually, the substrate underneath the surface can replace these metal ions. When this supply runs out, however, soil acidification will significantly reduce the metal ions that are crucial for plant growth, the soil's quality will decline, the trees won't have enough food to grow, and their growth will eventually weaken and stop. Some trees' leaves become yellow because there is not enough magnesium available to build the chlorophyll core, causing chlorophyll to not develop [10].

3.3.3 Others

Metals like lead, which are detrimental to plants, dissolve from the soil when acidity rises. Usually, aluminum is coupled with other elements or found in the soil as insoluble stable compounds. But when acid rain lowers the pH of the soil, this binding is compromised, aluminum ions are washed out of the ground, calcium and phosphorus absorption in the tips of roots is hampered, and plants are unable to absorb nutrients. Additionally, soil animals and bacteria are negatively impacted by aluminum ions. As a result, organic matter cannot be broken down and the plant's supply of nutrients is interrupted.

3.4. Humans

Acid rain's negative effects on the environment and public health are receiving increasing attention on a global scale. General consensus is that sulfur oxides, nitrogen oxides, and carbon oxides released into the atmosphere by unnatural and artificial sources of pollution may be transformed into different acids, and these acids, when they come into contact with rain, can create acid rain. Human health is primarily impacted by acid rain in two ways. First, during the early stages of acid rain precipitation, the human body comes into direct contact with the acidic elements in the air and inhales sulfur and nitrogen oxides through the respiratory tract, causing both immediate and long-term harm to the respiratory system. Dissolution, transfer and transformation of toxic metals (mainly mercury, lead and cadmium) in surface soils and water as a result of late-settling acid rain. This also increases human exposure to toxic metals, which can have indirect effects on human health. Heavy metals are primarily ingested by the general population through food and water. For instance, methyl mercury is primarily ingested by people through fish, which gradually accumulates methyl mercury in the body. Excessive exposure to lead has toxic effects on heme biosynthesis, erythrocyte development, the central nervous system, and the peripheral nervous system. Methyl mercury's effects on the human body are mostly nervous system damage, with the afflicted areas connected to sensory, visual, and hearing functions. While long-term oral exposure to cadmium at low concentrations is mostly linked to kidney impairment, inhaling cadmium is known to cause lung and lung cancer [11].

4. Prevention and Management Measures of Acid Rain

4.1. Policy

4.1.1 United states

The principal contributors of acid rain, SO_2 and nitrogen oxides (NO_x), are mandated to be greatly reduced by the power sector under the Acid Rain Program (ARP), which was established under Title IV-Acid Deposition Control. The total amount of SO_2 that electric generating units (EGUs) in the contiguous United States may emit is permanently capped by the SO_2 program. After a gradual implementation of the program, the final SO_2 cap for 2010 was set at 8.95 million tons, or almost half of the emissions from the power industry in 1980. A program that only applies to a portion of coal-fired EGUs and is more akin to a conventional, rate-based regulatory regime is used to accomplish NO_x reductions under the ARP. The ARP has significantly reduced emissions since it started in 1995.

The ARP established a trading system for permits that uses market-based incentives to drive down pollution. It was the country's first comprehensive cap and trade scheme. It has been shown that reducing emissions through the use of a market-based system is a very effective strategy to reduce emissions, meet environmental goals, and improve human health. Regulated sources are allowed to select the emission reduction method that will result in the greatest financial savings [12].

4.1.2 Sweden

All nations are paying attention to acid rain since it is a severe environmental issue brought on by air pollutants. Sweden places a high value on acid rain control as a nation that is more severely harmed by it. After adopting direct control measures like laws, regulations, and administrative directives to limit the release of air pollution, Sweden turned to economic measures like taxes and had impressive results.

The sulfur dioxide tax and the nitrogen oxide tax were two of the "green taxes" established by Sweden as part of a significant tax overhaul in the early 1990s.

The Swedish government started implementing a sulfur dioxide tax in 1991 in response to the country's growing sulfur dioxide pollution problem. The SO_2 tax in Sweden is an indirect environmental tax because it taxes the inputs burned to produce SO_2 rather than the SO_2 itself. Since monitoring its inputs is simple, a tax like this is intended to offset for the significant monitoring expenses of directly taxing SO_2 emissions. Sulfur dioxide emissions can be decreased, atmospheric environmental quality can be enhanced, and soil acidification can be lessened in this way at a lower cost of taxes. Companies who lower their sulfur dioxide emissions are given tax breaks by the government. The amount of the rebates is based on how much sulfur dioxide is reduced; the more sulfur dioxide is reduced, the bigger the rebate.

One of the few nations in the world with a tax on nitrogen oxide is Sweden. Sweden passed a nitrogen oxide tax in 1990 and put it into effect in 1992 in order to manage nitrogen oxide emissions and reach the environmental aim of lowering nitrogen oxide emissions by 30% from levels in 1985. The nitrogen oxide tax in Sweden is a direct environmental tax that levies a fee on nitrogen oxide emissions, using such emissions as the foundation for taxation. Sweden also has a tax rebate system for the nitrogen oxide tax, and the money from that tax is given back to the company based on how much nitrogen oxide is emitted per unit of energy [13].

4.2. Technology

Many principal actions of lowering sulfur dioxide emissions globally can be implemented. These technologies include, but are not limited to, technology for desulfurizing raw coal (which can get rid of 40% to 60% of the inorganic sulfur in coal); giving low-sulfur fuels first preference (such as low-sulfur coal and low-sulfur natural gas); enhancing coal combustion technology and lowering sulfur dioxide and nitrogen oxide emissions from coal combustion (Liquefied coal technology, for instance, is one of the new technologies that nations have embraced. Adding limestone and dolomite, reacting with sulfur dioxide, and producing calcium sulfate with ash output are its principal uses.); creating

new forms of energy (including combustible ice, solar, wind, and nuclear energy); using biological control.

Biological control, to be specific, is a novel way: At the 1993 International Cooperation Conference on the Application of Environmentally Sound Biotechnology, held in India, experts proposed strategies for using biotechnology to prevent, halt, and reverse environmental degradation, improve the sustainable exploitation and use of natural resources, and uphold ecological balance and environmental integrity. Thiobacillus ferrooxidans and thiobacillus oxidans are the bacteria that scientists have discovered the capable of removing sulfur from pyrite. Using microbial adhesive sulfur, a Japanese partnership known as the Central Research Institute of Electric Power has just created a novel method that can remove 70% of inorganic sulfur and reduce dust by 60%. This method is especially ideal for developing nations that cannot afford to purchase pricey desulfurization equipment since its basic operating principles are straightforward and the equipment is inexpensive. Because biotechnology desulfurization complies with the "source control" and "cleaner production" tenets, it is a very promising governance strategy that is receiving increasing attention from nations throughout the world.

5. Conclusion

Acid rain has become one of the important problems affecting the global environment and human concern. The influencing factors, forming process, influence and control measures of acid rain are discussed in this paper. The research shows that the factors affecting the formation of acid rain are mainly divided into natural factors and human activity factors. If emissions from these factors (acid gas) are released into the atmosphere, the acid gas combines with water in the cloud to form acid rain. The effects of acid rain cannot be underestimated. Acid rain can cause varying degrees of corrosion to buildings and sculptures made of marble, metal and limestone, while acid rain causes changes in the pH of the environment, which can affect the survival of animals, plants and humans. In order to deal with acid rain, various countries have developed corresponding prevention and management measures. This paper discusses the ARP of the United States and the tax policy of Sweden. In addition, the main ways to reduce the emission of sulfur dioxide, a gas that affects the formation of acid rain, are introduced. The prevention and control of acid rain is a long-term task that needs people's continuous attention. This paper mainly clarifies the cause, process and influence of acid rain and analyzes some control measures, aiming at alerting people to the necessity of preventing and controlling acid rain and the urgency of protecting the environment.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Acid rain formation. 2023, https://www.sohu.com/a/673048106_121106854.

[2] The formation of acid rain. https://zhidao.baidu.com/question/98007499.html#:~:text.

[3] Effects of acid rain on buildings. https://zhidao.baidu.com/question/1888856708616879708.html.

[4] Blaettler K., The Effects of Acid Rain on Monuments, 2019, https://sciencing.com/facts-5651871-effects-acid-rain-monuments.html.

[5] Acid rain - Effects on human-made structures. In Encyclopædia Britannica, 2019, https://www.britannica.com/science/acid-rain/Effects-on-human-made-structures.

[6] McGann C., What Is the Effect of PH on Living Organisms? 2018, https://sciencing.com/effect-ph-living-organisms-6723807.html.

[7] Fu X.P., Tian D.L., Research Progress of the Effect of Acid Rain on Plant. Journal of Northwest Forestry University, 2006, 21(4): 23-27. (In Chinese)

[8] Lv J.L., Li S.Y., Huang S.B., Effects of Simulated Acid Rain on Leaves and Fruits of Peach and Pear. Journal of Zhejiang A & F University, 1998, 24(6): 603-607. (In Chinese)

[9] Wang W., Observation of Microscopic and Submicroscopic Structures and Determination of Some Physiological Indexes of Green Vegetables Treated with Simulated Acid Rain. Environmental Science, 1988, 9(3): 12-17. (In Chinese)

[10] Wu L.Y., Effects of Acid Rain on Plant and Soil Ecosystems. Environmental Information Science, 1984, 13(4). (In Chinese)

[11] Chen Y.L., Potential Harm of Acid Rain to Human Health. Journal of Environment and Health, 1990, 7(2): 3. (In Chinese)

[12] United States Environmental Protection Agency. Acid Rain Program. 2023, https://www.epa.gov.

[13] Wang X.L., Tax Policy on Acid Rain Control in Sweden. Urban Problem, 2002, 6: 3. (In Chinese)