Dean&Francis
ISSN 2959-6157

Sulfur Dioxide in the Atmosphere Dangers and Current Mitigation Strategies

Cui He[1, *]

[1] New Oriental Academy, Beijing, China
*Corresponding author: cuihe200751@outlook.com

Abstract:
Sulfur dioxide (SO_2), which is mainly produced by the combustion of fossil fuels, is one of the main causes of air quality deterioration on a global scale. Although its emissions have been significantly reduced in developed countries through the implementation of advanced desulfurization technologies and stringent environmental regulations, SO_2 emissions are still a major challenge in many developing countries. In this study, the CAS methodology was used to comprehensively analyze the major sources of SO_2, its hazards to human health and the environment, and the current management technologies and policies. It was found that the main sources of SO_2 include fossil fuel combustion, ore smelting, and other industrial processes. The environmental impacts of SO_2 include the generation of acid rain and the formation of fine particulate matter (PM2.5), while the direct impacts on human health include respiratory diseases and cardiovascular problems. Existing treatment technologies such as flue gas desulphurization (FGD) are effective in reducing emissions, but costs and technology applicability vary widely between countries. This paper also explores future directions for SO_2 management, including the need for technological innovation and policy adjustments. The findings are important for the development of more targeted and cost-effective global SO_2 reduction strategies.

Keywords: fossil fuels; sulfur dioxide; SO_2 abatement.

1. Introduction

Sulfur dioxide (SO_2) in the atmosphere mainly originates from the combustion of fossil fuels, especially coal and oil. Since the industrial revolution, with the growth of energy demand, SO_2 emissions have increased significantly and become one of the major causes of global air pollution. Although SO_2 emissions have been reduced in some developed countries in recent years with the promotion of renewable energy and the strengthening of environmental regulations, SO_2 emissions are still a serious problem in many developing countries. The study of the hazards of SO_2 and its management is of great significance for improving global air quality and realizing the goal of sustainable development.SO_2, which mainly comes from the combustion of fossil fuels, smelting

ISSN 2959-6157

of ores, and some industrial processes, is a major precursor of acid rain, and is capable of forming fine particulate matter (PM2.5), which has far-reaching impacts on air quality and climate change. Globally, SO_2 emissions vary significantly between regions. For example, European and American countries have significantly reduced SO_2 emissions through the implementation of stringent emission standards and the application of advanced desulfurization technologies. However, many developing countries continue to increase SO_2 emissions due to accelerated industrialization and a lack of environmental protection measures, which has led to serious air pollution problems in these countries.SO_2 is a potent irritant gas, and short-term exposures can lead to respiratory problems such as coughing, asthma, and bronchitis, while long-term exposures may cause chronic respiratory and cardiovascular diseases. In particular, the elderly, children and people with respiratory diseases are more sensitive to SO_2.SO_2 emissions not only have a direct impact on air quality, but also react with atmospheric moisture to form sulfuric acid, leading to acid rain. The effects of acid rain on ecosystems are widespread and far-reaching, and can lead to soil acidification, acidification of lakes and rivers, which disrupts the ecological balance and affects the growth of plants and aquatic organisms [1].

Among the current technological solutions, flue gas desulfurization (FGD) technology is the main means of controlling SO_2 emissions [2]. This technology reduces emissions by converting SO_2 in flue gas to harmless calcium sulfate through the use of absorbents such as limestone and gypsum. In addition, fuel desulfurization and pre-combustion desulfurization are also effective control measures. Many countries have developed and implemented stringent SO_2 emission standards. For example, the Clean Air Act in the United States has significantly reduced SO_2 emissions, and the Air Pollutant Emissions Directive in Europe has been effective in controlling emissions from industries and power plants. However, in some developing countries, policies are not sufficiently implemented and regulated, and there are still major governance challenges. Although existing technologies and policies have controlled SO_2 emissions to a certain extent, there are still some challenges, such as high treatment costs, limited technology application, and inconsistent emission standards. Future research may need to focus more on the development of low-cost and efficient desulfurization technologies, as well as transnational cooperation to promote globally harmonized SO_2 emission standards [3].

2. Main Sources of Sulfur Dioxide

Sulfur dioxide (SO_2) emission sources are categorized into natural and anthropogenic sources. Anthropogenic sources predominate, especially in countries and regions that are highly industrialized and urbanized. A major source of SO_2 is industry, especially heavy industry and metallurgy. For example, during metal smelting and ore processing, large amounts of SO_2 are emitted into the atmosphere through the combustion of sulfide ores. According to the analysis in "The atmosphere of io: abundances and sources of sulfur dioxide and atomic hydrogen", the metal processing industry, especially the smelting of copper, lead and zinc, is one of the significant contributors to global SO_2 emissions. The metalworking industry, particularly copper, lead and zinc smelting, is one of the significant contributors to global SO In addition, petroleum refineries and chemical plants are major industrial sources of SO_2. Globally, the combustion of coal and petroleum products is the largest source of SO_2 emissions. The fuels used in electricity production and home heating systems contain a high percentage of sulfur, which is oxidized to SO_2 and released into the atmosphere during combustion [4]. It is noted that SO_2 emissions are particularly severe in urban areas due to the concentration of transportation and power plants, especially in countries where coal is used as an energy source. especially in countries that use coal as an energy source [5]. Although human activities are the main source of SO_2 emissions, natural sources also contribute to global SO_2 concentrations. Large amounts of SO_2 released during volcanic eruptions can affect air quality locally or even globally. "Integration of satellite monitoring and mathematical modeling in analyzing the nature of elevated sulfur dioxide concentrations in the surface air of northern Finland" emphasizes that although the contribution of natural sources is relatively small, in some regions, such as volcanically active areas like Iceland, their impact cannot be ignored [6].

In many developing countries, rapid industrialization has led to a significant increase in SO_2 emissions. "Emission factors of black carbon and co-pollutants from diesel vehicles in Mexico City" states that, although global SO_2 emissions have decreased in some regions, the lack of effective management technologies and policies, SO_2 emissions are still growing in many developing countries [7]. This phenomenon is particularly prominent in parts of Africa and Asia

3. Major hazards of sulfur dioxide

Sulfur dioxide (SO_2) is a highly reactive gas produced primarily through the combustion of sulfur-containing fossil fuels. It has significant negative impacts on both the environment and human health and has caused several problems worldwide.

3.1 Hazards to human health

The effects of SO_2 on human health are particularly significant, especially on the respiratory system. Short-term exposure to high concentrations of SO_2 can cause acute respiratory illnesses, including symptoms such as coughing, asthma and bronchitis. Long-term exposure can lead to chronic lung and cardiovascular diseases, especially in children, the elderly and people with respiratory problems. According to the analysis in "Hurt-term exposure to sulfur dioxide and daily mortality in 17 Chinese cities: the China air pollution and health effects study (capes)", Sulfur dioxide (SOD) is a major cause of chronic lung and cardiovascular diseases. "SO_2 exposure can significantly increase the incidence of respiratory diseases, especially in high-risk groups [8]. The World Health Organization (WHO) has also classified SO_2 as one of the major air pollutants and it poses a serious threat to global public health.

3.2 Hazards to plants and ecosystems

SO_2 not only affects human health, but also causes great damage to plants and ecosystems. SO_2 in the atmosphere can react with water molecules to form sulfuric acid (H_2SO_4), which leads to the formation of acid rain. Acid rain causes acidification of soil and water bodies, disrupting the balance of ecosystems and affecting the normal growth process of plants, especially on crops and forest plants. "The impact of trading on the costs and benefits of the acid rain program" states that acid rain has had the most significant impact on forests and lakes in North America and Europe, and that the habitats of many aquatic organisms have been acidified [9]. Long-term effects of acid rain also include the loss of nutrients from the soil, leading to reduced crop yields and forest degradation.

3.3 Impacts on air and environmental quality

The impact of SO_2 on air quality is mainly reflected in its role as a precursor substance for acid rain and its reaction with other chemicals in the atmosphere to form particulate matter (PM2.5). This particulate matter not only affects air quality, but also further affects human health. According to "Environmental monitoring and analysis on air pollution issue in China", long-term accumulation of SO_2 in urban air may lead to an increase in the concentration of particulate matter, which may exacerbate air pollution [10]. Especially during the winter heating season, the increase in SO_2 emissions leads to a surge in particulate matter concentrations, which seriously affects atmospheric visibility and air quality.

4. Sulfur dioxide control measures

Emissions of sulfur dioxide (SO_2) pose a serious threat to global air quality and health, and as a result, countries have adopted a variety of technologies and policy measures to control and reduce SO_2 emissions. The following section describes the major control technologies, existing policy measures, and possible directions for future improvements.

Currently, the main SO_2 control technology widely used around the world is flue gas desulphurization (FGD) technology reduces SO_2 emissions by reacting SO_2 in the flue gas with an absorbent (e.g., limestone or gypsum), which is converted into a harmless by-product. This technology is widely used in power plants, industrial boilers, and refineries, and is considered one of the most mature means of SO_2 control. "Amine functionalized metal-organic frameworks for carbon dioxide capture states that wet FGD technology has become the technology of choice in many developed countries due to its high desulfurization efficiency [11]. However, dry and semi-dry FGD technologies have been more widely used in developing countries in recent years due to their lower cost and wide applicability. In addition to traditional FGD technologies, some emerging technologies are gradually being developed and applied in recent years. These technologies have the potential to improve the efficiency of desulphurization and reduce costs. Adsorption desulfurization (AD) is a technology that removes SO_2 from flue gas by adsorption materials (e.g., activated carbon or molecular sieves), which not only captures SO_2 efficiently, but also reduces the operating cost by regenerating the adsorption materials. The application of nanotechnology increases the surface area of the adsorbent material and significantly improves its performance. The application of nanotechnology increases the surface area of the adsorbent material, which significantly improves the adsorption efficiency [12]. In addition, biological desulfurization (BDS) technology has been gradually developed. This technology utilizes microorganisms to convert SO_2 in flue gas into harmless sulfates and sulfides, which is green and particularly suitable for small-scale industries and special environments. This type of technology is currently in the experimental stage, but preliminary studies have been conducted to show that it has great potential to improve the efficiency of desulfurization and reduce the secondary pollution of the environment.

In addition to technical means, policies and regulations are also important ways to control SO_2 emissions. Many developed countries have effectively controlled SO_2 emissions through the implementation of strict emission standards, laws and regulations. For example, the Clean

ISSN 2959-6157

Air Act (CAA) in the United States has achieved significant emission reductions by limiting SO_2 emissions from power plants and industries [13]. In Europe, the European Union (EU), through the Industrial Emissions Directive (IED), requires member states' industrial and power generation sectors to adopt best available techniques (BAT) to reduce SO_2 emissions [14]. However, in many developing countries, SO_2 management still faces great challenges due to technological and financial constraints. Although some developing countries have begun to adopt internationally proven technologies, the scope and effectiveness of their application are still limited, and that future policies should place greater emphasis on international cooperation and technology transfer in order to promote the environmental protection and governance capacity of these countries [15].

Although existing technologies have significantly reduced SO_2 emissions, future research should focus more on how to further reduce costs and improve efficiency.

5. Research prospect for Sulfur Dioxide

Despite the global success of existing governance technologies and policies, the problem of sulfur dioxide (SO_2) emissions still has many challenges, especially in developing countries. In the future, SO_2 governance will enter a new phase with technological progress and deepening global cooperation. Below are a few prospects for SO_2 emission reduction:

Future SO_2 management will rely on more efficient and cost-effective technological innovations. For example, while current flue gas desulfurization (FGD) technologies are effective in treating large volumes of industrial emissions, their high operating costs and resource consumption limit their widespread use in some regions. Emerging nanotechnology and biotechnology are expected to solve this problem. The surface area and reactivity of nanomaterials can greatly improve adsorption efficiency and reduce treatment costs. In addition, bio desulfurization technology shows great potential in reducing secondary pollution of the environment, and it provides a green solution by using microorganisms to convert SO_2 into harmless compounds [16].

The future control of SO_2 emissions will not only rely on technology alone but will also involve the widespread application of intelligent monitoring and automated management systems. Through big data analytics and IoT technologies, the industrial sector can monitor SO_2 emissions in real time and automatically adjust the operating parameters of emission control equipment. Such an intelligent system will not only improve the efficiency of governance, but also provide early warning when problems occur, reducing delays in human intervention.

In terms of policy, future SO_2 reduction will rely more on international cooperation and global policy coordination. Although developed countries have achieved remarkable results in SO_2 emission reduction, many developing countries still face great challenges due to limitations in technology, finance, and management experience. International cooperation, especially through technology transfer and financial support, will play a key role in the future global governance of SO_2. For example, Ma et al. [18] states that developing countries should improve the effectiveness of governance by introducing advanced desulfurization technologies and formulating policies accordingly to their specific economic and environmental conditions. International environmental organizations, intergovernmental cooperation, and the participation of multinational corporations will be key to the success of future SO_2 governance. Globally, laws and regulations will continue to play an important role. For example, environmental regulations in many countries and regions continue to strengthen, forcing companies to adopt stricter emission standards. Future policy trends will not only continue to strengthen emissions standards but may also incentivize the development of low-carbon, green energy technologies and projects. Carbon markets and emissions trading mechanisms are also likely to play an important role in future SO_2 reductions, especially for developing countries, and could be an effective way to promote the adoption of cleaner technologies.

Future SO_2 management needs to rely not only on technologies and policies, but also on active public participation. Increasing public awareness of environmental protection, especially of the dangers of air pollution, can promote more effective policy implementation and public monitoring. At the same time, data collection with public participation (e.g., use of air quality monitoring equipment) will help policy makers understand and respond to air quality issues more precisely.

6. Conclusion

This paper has explored in detail the sources of sulfur dioxide (SO_2), its environmental and health hazards, and the existing and future technologies to combat it. The analysis reveals that industrial processes and combustion of fossil fuels are still the major sources of SO_2 emissions globally, especially in developing countries, where the problem is more prominent.SO_2 not only has serious impacts on air quality, but also triggers acid rain, which poses a long-term hazard to ecosystems and human health.

Although existing technologies such as flue gas desulphurization (FGD) have achieved some success in controlling SO_2 emissions, there is still much room for improvement in terms of technology cost, efficiency and application scope. Future governance will rely more on emerging technological innovations such as nanomaterials and biotechnology, while global cooperation, policy support and public participation will also play an important role in SO_2 emission reduction.

To achieve greater control of SO_2 emissions, future research and policies should focus on improving the economics and efficiency of treatment technologies, especially in resource-limited developing countries. Through multiple efforts, the world is expected to achieve more effective and sustainable SO_2 emission control in the future.

References

[1] Sepehrian M, Anbia M, Hedayatzadeh M H, et al. SO2 dry-based catalytic removal from flue gas leading to elemental sulfur production: A comprehensive review[J]. Process Safety and Environmental Protection, 2023.

[2] Yazdanbakhsh F, Alizadehgiashi M, Bläsing M, et al. Cu–Cr–O Functionalized ETS-2 Nanoparticles for Hot Gas Desulfurization[J]. Journal of Nanoscience and Nanotechnology, 2016, 16(1): 878-884..

[3] Kumar L, Jana S K. Advances in absorbents and techniques used in wet and dry FGD: a critical review[J]. Reviews in Chemical Engineering, 2022, 38(7): 843-880.

[4] Strobel D F, Wolven B C. The atmosphere of Io: Abundances and sources of sulfur dioxide and atomic hydrogen[J]. Astrophysics and Space Science, 2001, 277: 271-287.

[5] Jonidi Jafari A, Charkhloo E, Pasalari H. Urban air pollution control policies and strategies: a systematic review[J]. Journal of Environmental Health Science and Engineering, 2021, 19: 1911-1940.

[6] Dryukova E D, Nerobelov G M, Sedeeva M S, et al. Integration of Satellite Monitoring and Mathematical Modeling in Analyzing the Nature of Elevated Sulfur Dioxide Concentrations in the Surface Air of Northern Finland[J]. Izvestiya, Atmospheric and Oceanic Physics, 2023, 59(4): 390-399.

[7] Zavala M, Molina L T, Yacovitch T I, et al. Emission factors of black carbon and co-pollutants from diesel vehicles in Mexico City[J]. Atmospheric Chemistry and Physics, 2017, 17(24): 15293-15305.

[8] Chen R, Huang W, Wong C M, et al. Short-term exposure to sulfur dioxide and daily mortality in 17 Chinese cities: the China air pollution and health effects study (CAPES)[J]. Environmental research, 2012, 118: 101-106.

[9] Chan H R, Chupp B A, Cropper M L, et al. The impact of trading on the costs and benefits of the Acid Rain Program[J]. Journal of Environmental Economics and Management, 2018, 88: 180-209.

[10] Zykov V N, Kurbatova A I, Chernyh N A, et al. Environmental Monitoring and Analysis on air pollution issue in China[J]. Advanced Materials Research, 2015, 1073: 588-591.

[11] Patzschke C. Amine functionalised metal-organic frameworks for carbon dioxide capture[D]. Monash University, 2014.