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Sulphur Dioxide Extraction Process from Flue Gases

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***Abstract**: This paper details the design of a spray tower for wet flue gas desulfurization (FGD), a system aimed at removing sulfur dioxide (SO_2) from flue gas. The design of the scrubber system's essential parts, such as the scrubber thickness, pipe network diameter, energy gain rate, and SO_2 removal efficiency, is the main emphasis of the study. A number of variables, including sorbent particle size and slurry concentration, affect how well SO_2 is removed. The study also shows that the scrubber system is less expensive initially than traditional alternatives and is easy to build. Furthermore, the process produces useful byproducts, especially gypsum, which may be utilized to make wallboard. The creation of these marketable byproducts lessens the difficulties associated with post-operation trash management. It has been demonstrated that magnesium hydroxide ($Mg(OH)_2$) can successfully reduce visual opacity and manage sulfuric acid mist emissions. One of the system's distinguishing features, the procedure produces a high SO_2 removal effectiveness of 99%. Additionally, it achieves a 99.9% reagent usage rate and yields 99% pure gypsum. The suggested method is a great choice for treating flue gas in coal-fired power plants because of these benefits.*

Keywords: Sulphur Dioxide, flue gas, Extraction, Scrubber System's

Introduction

A major global chemical pollutant, sulfur dioxide (SO_2) is released into the environment from numerous sources. These include the burning of fossil fuels (coal, oil, gas), industrial processes like petroleum refining and ore smelting, vehicle emissions, and sulfuric acid manufacturing [1]. Factors such as plant size, type, and sulfur compound conversion efficiency affect how much SO_2 pollution there is. Many people believe that SO_2 is bad for the environment and human health when it is released into the atmosphere. Through chemical interactions with other elements in the atmosphere, it contributes to the production of smog, the loss of the ozone layer, and acid rain. While 1% concentrations may irritate the skin, 20 ppm concentrations may irritate the eyes. Concentrations exceeding 20 ppm can cause coughing, sneezing, and extreme discomfort, however acute sulphur dioxide poisoning is uncommon because of its strong odor and irritating effects [1]. As a result, SO_2 emissions are tightly controlled to keep concentrations below acceptable levels for occupational exposure.

There are three main approaches to reducing pollution from sulfur dioxide. The first is the use of fuels that are naturally low in sulfur. The second strategy concentrates on fuel desulphurization, which is usually accomplished in petroleum via hydrogen processing. Eliminating sulfur compounds from flue gases is the third technique, which is especially important in large combustion systems like power plants. Nowadays, post-combustion desulphurization procedures are given more attention in an effort to reduce SO_2 emissions. Addressing the worldwide issue of acid rain requires the development of economical techniques for extracting SO_2 from flue gas. There are several methods for eliminating SO_2 from exhaust fumes, which can be divided into three categories: absorption, catalytic oxidation, and adsorption. Scrubbers or flue gas desulphurization (FGD) systems are frequently used in coal-fired power plants to remove SO_2 from combustion exhausts, according to Olson et al. [2]. The most widely used systems use an alkaline sorbent, like limestone or lime. Wet scrubbing, which employs a liquid absorbent, and dry scrubbing, which uses small sprays to capture SO_2 and create dry particles collected in baghouses or electrostatic precipitators, are the two broad categories into which FGD operations fall.

According to Gosavi [3], wet FGD systems may remove up to 95% of SO_2 without the use of additives and over 99% when magnesium-enhanced lime (MEL) wet scrubbing is used. Ultra-high SO_2 removal efficiency is made possible by the MEL system's use of an alkaline scrubbing liquid that contains soluble magnesium sulphite as the active reagent. The liquid's reduced gypsum scaling and lower dissolved calcium ion concentration (less than 100 ppm) improve dependability. Thus, the absorption-based desulfurization method is the main focus of this investigation. The FGD process is used in coal- or oil-fired power plants to collect gaseous SO_2 from flue gases and transform it into solid sulfur compounds that can be disposed of or reused [4]. Strict environmental laws have been put in place worldwide to restrict SO_2 emissions from power stations and other industrial sources because they play a major role in the development of acid rain [5]. Tall chimneys were built to distribute rather than eliminate SO_2 emissions prior to such legislation [6], but this just served to shift contaminants to different areas. As a result, stack heights are now regulated in several nations to prevent dispersion.

One of the main ingredients of acid rain, sulfuric acid (H_2SO_4), is created when SO_2 combines with ambient oxygen and water during coal combustion [7]. This acid causes significant environmental harm, speeds up the weathering of buildings, and aggravates human respiratory disorders by lowering the pH of soil and freshwater bodies. Short-term exposure to 1.6 ppm SO_2 causes bronchoconstriction in even healthy people [8]. Biondo and Marten [9] assert that because air pollution is transboundary, it continues to be a worldwide problem. While governmental and non-governmental groups continue to carry out research targeted at lowering and controlling SO_2 emissions, industries around the world have deployed a variety of control measures to fulfill emission limits.

In addition to promoting a better knowledge of the environmental effects of unchecked sulphur dioxide pollution, this study aims to increase awareness of the pressing need to reduce SO_2 emissions from fossil fuel-based power plants.

DEVELOPMENT OF MATHEMATICAL MODEL

In order to determine important design parameters such the scrubber configuration, scrubber wall thickness, pipe network diameter, energy gain rate, and SO_2 removal efficiency, this research uses an analytical design technique for a wet FGD spray tower system.

The Scrubber System's Design

One of the most important factors in scrubber design is the waste gas flow rate. The flow relationship for steady-state operation, in which a particular fluid stream passes through a cylindrical control volume in the scrubber system, is as follows [11]:

$$l_1 A_1 V_1 = l_2 A_2 V_2 = m \quad (1)$$

Where, ℓ1 and ℓ2 are respective densities, m is the mass flow rate of exhaust gas. A1 and A2, the cross-sectional areas, and V1 and V2 are the velocities respectively.

The thickness of the scrubber can be obtained by from the equation [12]:

$$P_e = KE\left[\frac{t}{D}\right]^3 \quad (2)$$

Where Pe represents the collapsing pressure, E is the modulus of elasticity, K is a numerical coefficient, D denotes the scrubber diameter, and t is the scrubber thickness. The equation can be rearranged to express t (thickness) as the subject.

$$t = \sqrt[3]{\frac{P_e * D}{K * E}}$$

The diameter of the pipe network can be determined by considering the flow characteristics of the scrubbing liquid. The velocity relationship is given by:

$$d_p = \left[\frac{4Q_L}{nV}\right] \quad (3)$$

Where dp is the pipe diameter, QL is the scrubbing liquid flow rate, and V is the liquid velocity.

The head loss within the pipe network is expressed as [13]:

$$h_L = \frac{\Delta P}{lg} \quad 4$$

Where hL is the head loss, ΔP represents the pressure drop, ℓ is the density of water at room temperature, and g is the acceleration due to gravity.

The rate of energy gained by the scrubbing liquid is given by:

$$\Delta E = m\left[\frac{\Delta P}{l}\right] \quad 5$$

Here, m denotes the mass flow rate of the scrubbing liquid, ΔP is the pressure drop, and ℓ is the water density at room temperature.

The mechanical power delivered to the pump can be determined from the pump efficiency using:

$$P_{pump} = \left[\frac{\Delta E}{npump}\right] \quad 6$$

Temperature rise in the scrubbing liquid may occur due to mechanical inefficiencies, though it is generally minimal. Under ideal conditions, the temperature increase remains low, as part of the generated heat is transferred to the pump casing and surrounding air. The energy loss due to temperature rise can be expressed as:

$$E_{loss} = mC_p\Delta T \qquad 7$$

Using the exhaust gas flow rate and scrubber diameter, the gas velocity can be calculated as:

$$Q_G = A_c U_g \qquad 8$$

Where QG is the exhaust gas flow rate, Ac is the cross-sectional area of the spray tower, and Ug is the gas velocity. Assuming negligible variation in gas volume due to absorption, the SO_2 removal efficiency of the wet scrubber is defined as [14]:

$$\eta = \left[\frac{C_{in}-C_{out}}{C_{in}}\right] * 100\% \qquad 9$$

Where Cin and Cout represent the inlet and outlet SO_2 concentrations, respectively.

The necessary SO_2 removal efficiency can be quantified by the Number of Transfer Units (NTU), which signifies the extent of mass transfer required to meet a specific reduction target. This NTU value is derived from the desired percentage removal with the following equation [15]:

$$NTU = -LN\left[\frac{(1-SO_2\%)}{100}\right] \qquad 10$$

RESULTS AND DISCUSSION

This study predicts sulfur dioxide (SO_2) removal efficiency for a wet FGD spray tower, ensuring the design meets regulatory emission standards for coal-burning power plants. The theoretical design and efficiency were determined using standard FGD equations, the data in Table 1, and other assumed values.

Table 1: Exhaust Particle-Laden Gas Data [16]

Parameter	Specification
Volume flow rate	29.13m/s
Mass flow rate	33.08kg/s
Gas density	0.82kg/m
Dust burden (concentration)	22,859µg/m

The model's results for key design parameters of the wet spray tower system are presented in Table 2.

Table 2: Design Parameters for the Wet Stray Tower System

Parameter	Value
Area	$54m^2$
Diameter	8m
Height	$16m^2$
Volume	$804m^3$
Thickness	0.0215m
Diameter of the pipe network	0.1572m
Head loss of the pipe network	408m
Rate of energy gained by the scrubbing liquid	233kW
Pump power	274kW
Electric power	305kW
Gas velocity	$0.54ms^{-1}$
SO_2 removal efficiency	99%

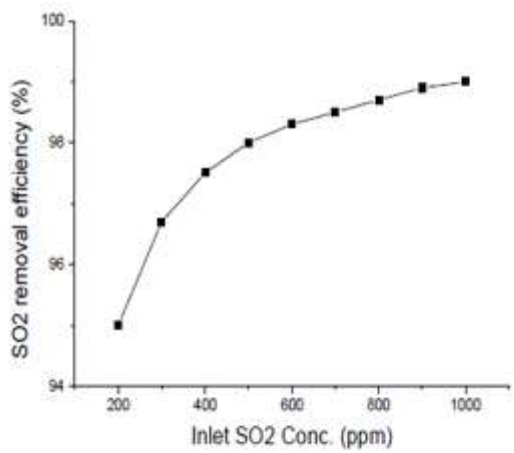

Fig 1: Effect of SO_2 inlet concentration on SO_2 removal efficiency

The removal efficiency is defined as the ratio of the absorbed amount to the initial concentration. As the inlet concentration of SO_2 increases, both the absorbed amount and the initial concentration rise almost proportionally. Consequently, the SO_2 removal efficiency increases with higher inlet SO_2 concentrations, as shown in Figure 1. The resulting outlet SO_2 concentrations, corresponding to inlet levels ranging from 900 to 100 ppm, are sufficiently low to meet air pollution emission standards for coal-fired power plants.

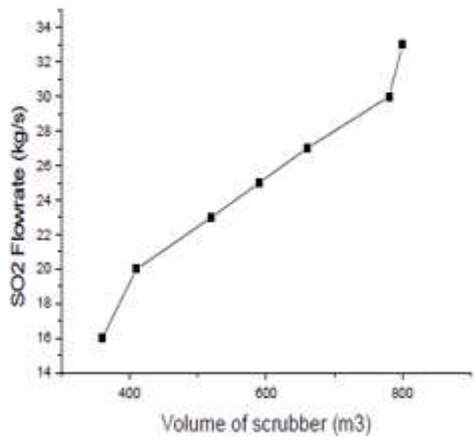

Fig 2: Effect of mass flow rate of the exhaust gas versus volume of the scrubber

The analysis, conducted using Microsoft Excel, shows a direct relationship between exhaust gas mass flow rate and spray scrubber volume (Figure 2), where volume must increase with flow rate. Furthermore, scrubber volume is dependent on its specific dimensions, varying with changes in both height and cross-sectional area (Figures 3 and 4). In practice, however, industrial processes often maintain a constant exhaust gas mass flow rate.

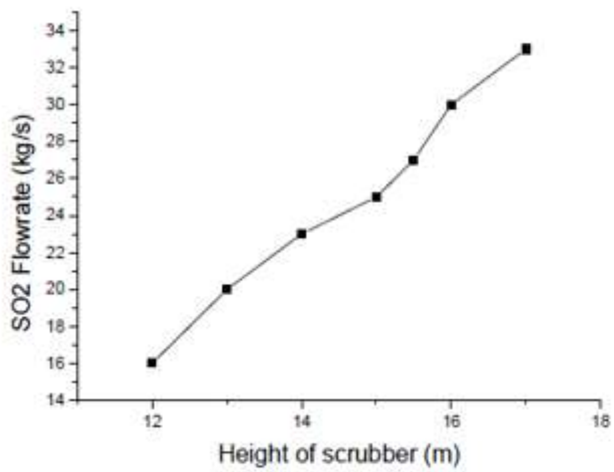

Fig 3: Effect of mass flow rate of exhaust gas on the height of the scrubber

The link between the exhaust gas mass flow rate and scrubber height is depicted in Figure 3. As expected, the scrubber height rises in proportion to an increase in the exhaust gas mass flow rate. The mass flow rate in this investigation directly affects the scrubber height. A normal cylindrical shell height-to-diameter ratio of roughly 2:1 was used to calculate the height. Since height greatly affects absorption rate and overall efficiency, a higher altitude is necessary for efficient SO_2 removal from flue gas.

In the scrubber design, the area is determined by the exhaust gas mass flow rate. As illustrated in Figure 4, variations in the exhaust gas flow rate during the design process are likely to influence the scrubber’s area.

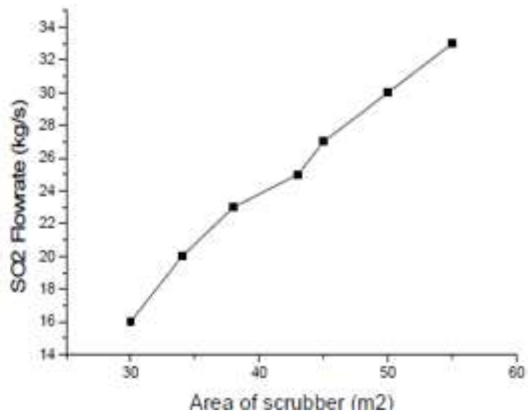

Fig 4: Effect of mass flow rate of exhaust gas and scrubber area

CONCLUSIONS

The necessity of removing SO_2 from fossil fuel power plants' flue gas has gained significant international attention, and this research has described workable strategies for controlling SO_2 emissions. The consequences of human emissions from industrial activity on the environment have come into sharper focus due to increased public concern about global warming. Hazardous gas emissions have grown to be a significant problem, highlighting the pressing need to lower emission levels. This study gives researchers and regulatory bodies involved in emission control important information about the removal of SO_2 from flue gas treatment procedures. Conventional flue gas desulphurization (FGD) methods have advanced, but there is still a growing need for more economical, efficient, and by-product-optimized advances.

Several important conclusions can be made from the analysis that has been presented. Although the lime/limestone scrubbing process is still the most popular desulphurization method currently in use, the magnesium-enhanced lime (MEL) process is recommended because of its higher reactivity, technical efficiency, and financial dependability. The efficiency of SO_2 capture is greatly increased by using MEL slurry, which also keeps calcium-based scaling off absorber walls. The concentration of the slurry and the size of the sorbent particles affect the SO_2 removal effectiveness. In addition, compared to traditional options, the scrubber system's design is less complicated and requires a smaller initial expenditure.

The creation of useful byproducts like gypsum, which may be used in the wallboard manufacturing process, is another benefit of this technique. The creation of commercially viable byproducts reduces the difficulties associated with post-operation waste management. Furthermore, when fed into the furnace, magnesium hydroxide ($Mg(OH)_2$) has been shown to be successful in reducing visual opacity, reducing sulfuric acid mist emissions, and minimizing sulfur trioxide (SO_3) generation, all of which help to minimize slag building. With the added ability to produce 99% pure gypsum and achieve 99.9% reagent usage, the process achieves an excellent SO_2 removal efficiency of up to 99%. The procedure is a great option for treating flue gas in coal-fired power plants because of these advantages.

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