SO_2 REMOVAL FROM FLUE GAS USING GAS-SOLID TREATMENT PROCESS

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Abstract: *This paper describes the design of wet flue gas desulphurization (FGD) spray tower system for the removal of sulphur dioxide (SO_2) from flue gas. The objective is the design of the scrubber system; the scrubber thickness, diameter of pipe network, rate of energy gained, and SO_2 removal efficiency. The SO_2 removal efficiency depends on the concentration of the slurries, the particle size of the sorbents. The paper also show that the scrubber system is simple in construction and requires less initial cost as compared to the other conventional systems. The process produces valuable by-products, gypsum, which is used to manufacture wallboard. The production of saleable by-product such as gypsum minimizes waste management difficulties after operation. Magnesium hydroxide (MgOH) has been demonstrated to control emission of sulphuric acid mist and reduce visible opacity. The process obtains high SO_2 remove efficiency of 99% which is the major hallmark of the process. In addition, this process can produce gypsum of 99% purity and obtain reagent utilization of 99.9%. Thus, these advantages will serve as basis for the selection of flue gas treatment in coal-fired power plants.*

Keywords: Emissions, Desulphurization, Flue Gas, Scrubber, Sulphur Dioxide
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INTRODUCTION

Sulphur dioxide (SO_2) is considered as one of the gravest chemical threats to the global environment. Sulphur dioxide is a major pollutant that is originating from many sources, it can result from the burning products of coal, oils , and gases, combustion of petroleum products in internal combustion engines, refining of petroleum, smelting of ores containing sulphur, and manufacture of sulphuric acid [1]. The amount of this pollution depends upon the size, type of plant and the efficiency of conversion of sulphur dioxide to sulphur. Pollutant sulphur dioxide gas is widely accepted to be harmful entities in the environment in their incipient emission form. Also contributes to smog, ozone depletion, and acid rain as a result of chemical reaction with other atmosphere component. 20ppm sulphur dioxide causes eye irritation and 1% causes skin irritation, the range of between detection and injury is large, and acute sulphur dioxide poisoning is extremely rare as the vapour becomes unbearably irritating the eye and upper lung before serious injury is inflected [1]. SO_2 with concentration above 20ppm gives marked irritant, choking and sneeze-inducing effects. Thus, emission of SO_2 into the air is controlled such that the concentration is below the permitted quality industrial exposure standards.

There are three major approaches recognized for controlling sulphur dioxides pollution. The first is to use fuels of naturally low sulphur content. The second approach is the desulphurization of the fuel, which in the case of oil is usually accomplished by hydrogen processing. The third method is the removal of sulphur compound from stack gases primarily from large combustion operation such as power generator [2].

Currently, efforts to control sulphur dioxide emissions are focused more on post combustion desulphurization process. Development of an economical method of removing sulphur dioxide from the flue gas produced by combustion facilities is urgently needed to mitigate the threatening acid rain problem.

Many methods are available for removing sulphur dioxide emission from stacks, all these fit into three process types adsorption, catalytic oxidation and absorption. According to Olson et al [2], in a coal-fired plant, scrubbers or flue gas desulphurization (FGD) systems are used for removing sulphur dioxide from exhaust combustion of flue gases. The most common types of FGD contact the flue gases with an alkaline sorbent such as lime/limestone. There are two methods either wet or dry-wet scrubbing process use a liquid absorbent to absorb the SO_2 gas and in dry scrubbing, dry or wet spray to absorb SO_2 gas and form dry particles that are collected in a bag house or electrostatic precipitator.

According to Gosavi [3], wet FGD can achieve 95% sulphur dioxide removal without additives and 99+% removal with magnesium-enhanced lime (MEL) wet scrubbing. MEL is the alkaline scrubbing liquid, contains soluble magnesium sulphite. This compound is the reagent that makes ultra-high removal of SO_2 from flue gas possible. The MEL FGD system can be operated with high degree of reliability, because of the scrubbing liquid contains less than 100ppm of dissolved calcium ions, which in turn reduces undesirable gypsum scaling. This process is being studied by employing absorption method.

Sulphur dioxide (SO_2) from the exhaust combustion flue gases of power plants that burn coal or oil to produce steam for the turbines that drive their electricity generators uses Flue Gas Desulphurization process commonly known as FGD. Flue gas desulphurization is any process that absorbs gaseous sulphur dioxide (SO_2) from flue gas to produce solid sulphur compounds, which are collected for sale or disposal [4].

As SO_2 is responsible for acid rain formation, stringent environmental protection regulations have been enacted in many countries to limit the amount of sulphur dioxide emissions from power plants and other industrial facilities [5].

Prior to the advent of strict environmental protection regulations, tall flue gas stack (i.e. chimney) was built to disperse rather than remove the sulphur dioxide emissions [6]. However, that only led to the transport of the emissions to other regions. For that reason, a number of countries also have regulations limiting the height of flue gas stacks. Higher the stack, better it is for dispersion of the emissions.

Sulphur dioxide (SO_2) which is produces during combustion of coal in power plants and reacts with atmospheric water and oxygen to produce sulphuric acid (H_2SO_4) [7]. This sulphuric acid is a component acid rain, which lowers pH of soil and fresh water bodies, resulting to substantial damage to the natural environment and chemical weathering of statues and structure and also aggravates existing respiratory diseases in humans and also to their development. Even healthy individuals experience Broncho constriction when exposed for a minutes to levels of 1.6ppm [8].

According to Biondo and Marten [9], air pollution has become a global problem because of its boundary-less condition. Industries and many scale plants worldwide have been practicing variety of control methods over the year to meet the standards. Many of government and non-governmental organizations are involved in continental research to reduce and control SO_2 (air pollutants) to meet the pollution control standards.

This paper is relevant in creating awareness on the need for SO_2 reduction from the exhaust gas of power plants that burns fossil fuels. It will ultimately serve the purpose of developing in the readers a proper concern for our deteriorating environment.

DEVELOPMENT OF MATHEMATICAL MODEL

The approached employed in this paper is to design the wet FGD spray tower system analytically determining the design of the scrubber system, the scrubber thickness, diameter of pipe network, rate of energy gained, and including SO_2 removal efficiency.

Design of the Scrubber System

The waste gas flow rates are the most important parameters in designing a scrubber, for a steady flow involving a stream of specific fluid flowing through a cylindrical control volume of the scrubber system is given as [11]:

$$\ell_1 A_1 V_1 = \ell_2 A_2 V_2 = m \quad \dots\dots\dots\dots\dots \quad (1)$$

Where, ℓ_1 and ℓ_2 are respective densities, m is the mass flow rate of exhaust gas. A_1 and A2, the cross sectional areas, and V_1 and V_2 are the velocities respectively.

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

$$P_e = KE[t/D]^3$$

Where, P_e is the collapsing pressure. E, is the modulus of elasticity. K, is numerical coefficient. D, is the diameter of the scrubber and the t, is the thickness of the scrubber. Rearrange the equation to make thickness (t) as the subject of the equation.

$$P_e = KE[t/D]^3 \dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

$$t = \sqrt[3]{(P_e * D)/(K * E)}$$

The diameter of the pipe network can be obtained by considering the scrubbering liquid and its velocity is expressed as:

$$d_p = [4Q_L/\pi V] \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3)$$

Where, d_p is the diameter of pipe. Q_L is the scrubbing liquid flow rate and V is the velocity of the scrubbing liquid respectively.

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

$$h_L = \Delta P/\ell g \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (4)$$

Where, h_L is the head loss of pipe network. ΔP, is 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 as:

$$\Delta E = m[\Delta P/\ell] \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (5)$$

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

To determine the mechanical power delivered to the pump, an expression of the pump efficiency is given as:

$$P_{pump} = [\Delta E/\eta pump] \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Temperature rise may be due to mechanical inefficiency and its very minimal. However, in an ideal situation, the temperature rise should be less since part of the heat generated will be transferred to the pump casing and to the surrounding air. The temperature rise of the scrubbering liquid can be expressed as:

$$E_{Loss} = mC_p\Delta T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

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

$$Q_G = A_C U_g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where, Q_G is the exhaust gas flow rate. A_C, is the spray tower cross sectional area and U_g is the gas velocity.

Neglecting variation of gas volume due to absorption, the SO_2 removal of the wet scrubber is given as [14]:

$$\eta = [(C_{in} - C_{out})/C_{in}] \times 100\% \ldots\ldots\ldots (9)$$

Where, C_{in} is the SO_2 inlet concentration and C_{out} is the outlet concentration of SO_2 Further, required sulphur dioxide (SO_2) removal efficiency is expressed in terms of percentage and Number of Transfer Unit (NTU). NTU is particularly useful means of mass transfer “work” that is required for scrubber to achieve a desired level of SO_2 emissions. NTU is calculated from percentage removal using the following equation [15]:

$$NTU = -LN[(1 - SO_2\%)/100] \ldots (10)$$

RESULTS AND DISCUSSION

The theoretically determined results for the wet spray tower (FGD) system design and sulphur dioxide (SO_2) removal efficiency of the scrubbing tower system using the design (FGD) equations and data given in Table 1, and other assumed values to predict the sulphur dioxide removal efficiency by considering air pollutant emission standard for coal-burning power plant.

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 results obtained from the model for various design parameters for the wet stray 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%

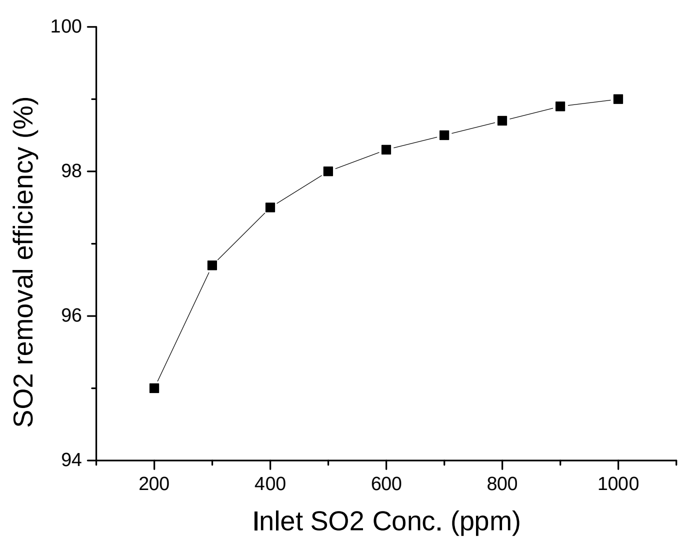

Fig. 1: Effect of SO_2 Inlet Concentrations on SO_2 Removal Efficiency

The removal efficiency is the ratio of the amount absorbed to the initial concentration and with rise in the initial concentration of SO_2 both the numerator and the denominator were increased almost at the same extent. As shown in

Fig. 1, the SO_2 removal efficiency is directly proportional to the inlet concentration of SO_2 (i.e. the SO_2 removal efficiency increases as inlet concentration of SO_2 increases). The SO_2 outlet concentrations obtain in the range of SO_2 inlet concentration of 900-100 ppm is low enough from the point of meeting the emission standard of air pollutants for coal-burning power plant.

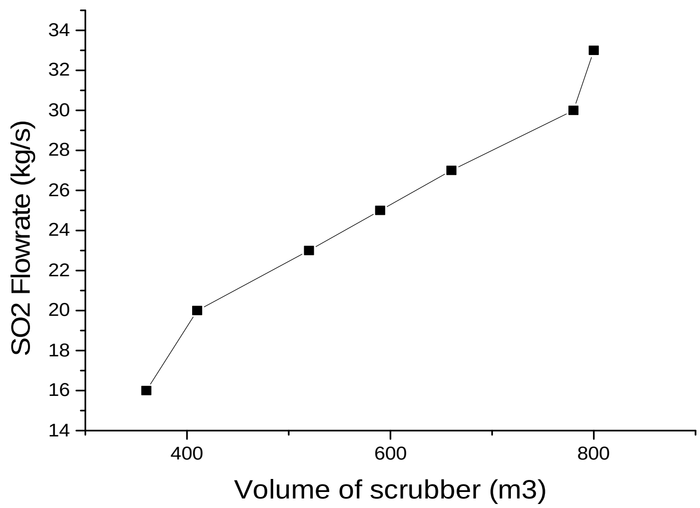

Fig. 2: Effect of Mass Flow Rate of the Exhaust Gas versus Volume of the Scrubber

Fig. 2 illustrates the relationship of mass flow rate of exhaust gas and the volume of the spray scrubber system. The results show that volume of spray scrubber system is the directly proportional to the mass flow rate of exhaust gas, thus, the volume of the scrubber increases with the mass flow rate of exhaust gas increase. Volume of the scrubber which is dependent on the area and the height of the scrubber is affected when area and the height varies as shown in Fig. 3 and 4. This prediction was obtained using Microsoft office Excel. However, in most process industries the mass flow rate of exhaust gas is normally constant.

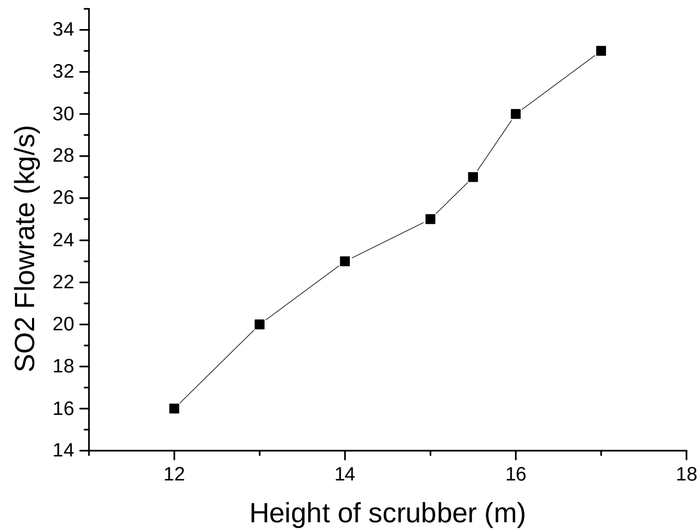

Fig. 3: Effect of Mass Flow Rate of Exhaust Gas on the Height of the Scrubber

Fig. 3 illustrates the relationship between the height of the scrubber and the mass flow rate of the exhaust gas. As expected, increase mass flow rate of exhaust gas increases the height of the scrubber. The height of the scrubber is dependent on mass flow rate in this work. The height of the scrubber was determined by considering typical height to diameter ratio of cylindrical shell of approximately 2:1. Large height is required to remove SO_2 from flue gas because it affects the rate and efficiency of absorption.

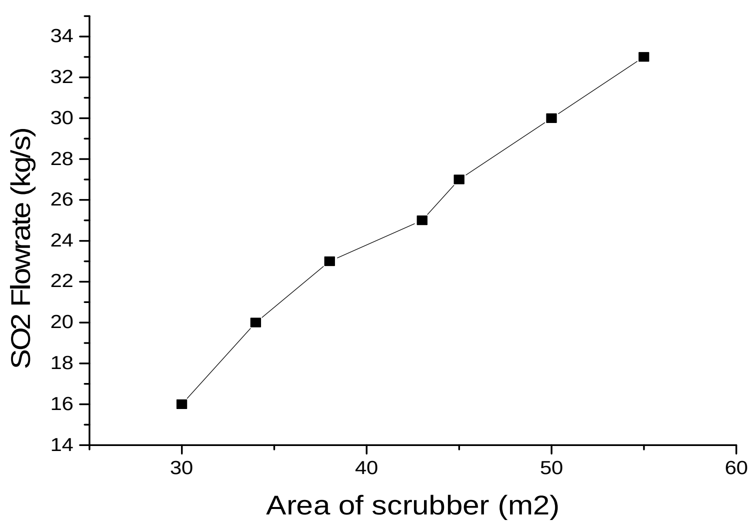

Fig. 4: Effect of Mass Flow Rate of Exhaust Gas and Scrubber Area

The area of the scrubber is dependently determined by the mass flow rate of exhaust gas in the design of the scrubber and it is likely affected when the flow rate of exhaust gas is altered during designing of the scrubber as seen in Fig. 4.

CONCLUSIONS

The awareness on the need for removal of SO_2 from flue gas of power plants that burns fossil fuels is of global interest and this paper have highlighted some possible ways of handling SO_2 emissions. Increased public awareness posed by global warming has led to greater concern over the impact of anthropogenic emissions of industrial production. The emission of harmful gases has been the subject claims and there is an urgent need to minimize the increase in emissions level. This paper contributes significant knowledge of SO_2 from flue gas treatment process to both researcher and agencies involves in SO_2 emission control.

In spite of noticeable progress in conventional flue gas desulphurization process development, claims for more efficient, economic, and by-product management innovations become more and more important. The following conclusions are extracted in this paper. The lime/limestone scrubbing is the most conventionally used process compare to the MEL. The MEL process is chosen because of its high reactivity, technical and economical reliability. The introduction of magnesium-enhanced lime (MEL) slurry greatly increases SO_2 capture efficiency and prevents calcium-based deposits from forming on the sides of the absorber.

The SO_2 removal efficiency depends on the concentration of the slurries, the particle size of the sorbents. The scrubber system is simple in construction and requires less initial cost as compared to the other conventional systems. The process produces valuable by-products, gypsum, which is used to manufacture wallboard. The production of saleable by-product such as gypsum minimizes waste management difficulties after operation. Magnesium hydroxide (MgOH) has been demonstrated to control emission of sulphuric acid mist and reduce visible opacity and also reduce sulphur trioxde (SO_3) when injected into a furnace and slag build up. The process obtains high SO_2 remove efficiency of 99% which is the major hallmark of the process. In addition, this process can produce gypsum of 99% purity and obtain reagent utilization of 99.9%. These advantages will serve as basis for the selection of flue gas treatment in coal-fired power plants.

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