International Journal of Advanced Research Foundation
Website: www.ijarf.com, Volume 2, Issue 6, June 2015)

Various methods to reduce SO_2 emission- a review

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***Abstract*—The emission of SO_2 as a result of burning of fossil fuels, especially coal, causes harmful impacts on the environment, human health, livestock, and plants. Various techniques have been employed to cut off the emission of SO_2 during the last generations. However, the amount of SO_2 discharged in the atmosphere is huge and its emission is estimated to augment sharply in the years to come. In this paper, a review of various flue gas desulphurization (FGD) processes has been presented with a view to help develop a novel and green process for the removal of SO_2. The FGD processes have been described, their applications have been assessed and their costs have been analyzed. The effect of parameters such as temperature, SO_2 concentration in flue gas and pH has also been presented and optimum conditions for achieving high efficiency have been reviewed.**

***IndexTerms*—SO_2, Flue gas, emission, absorption.**

I. Introduction

Flue gas emissions, which are exhaust gases produced at power plants, have been a cause of serious air pollution since a long time [1]. These emissions generally consist of H_2O, O_2, SO_2, CO_2, CO and a variety of particulates. As SO_2 is a major problematic constituent in flue gas due to its deleterious impact on both health and environment, its abatement in flue gases is of significant concern. SO_2 is a hazardous gas that is generated by industrial activities like electric power generation, combustion of fossil fuels and roasting of sulphideore in metallurgy. A great amount of SO_2 is also added to air due to volcanic eruption. Moreover, these oxides react with the moisture in air forming sulfuric acid, which then leads to acid rain.

Due to the lowering of the permissible emission limits, various SO_2 removal techniques have been explored by researchers and a large number of flue gas desulphurization (FGD) methods such as dry-, semidry- and wet-processes have been developed. In these processes, solvents like limestone, calcium hydroxide and magnesium hydroxide slurries, sodium hydroxide solutions and other organic solvents are used as absorbent. The most common flue gas desulphurization processes are mainly based on scrubbing using limestone slurries as absorbent. However, these processes are non-regenerative wherein the byproduct is either converted to gypsum or discarded in a landfill. Various regenerative FGD processes like Wellmann-Lord are also possible in which SO_2 can be recovered by stripping or as elemental sulphur by reacting with H_2S. This regenerated sulphur can be used in bleaching as a feed chemical, hydrosulphite manufacture, for pH adjustment and residual peroxide destruction [2].

Various parameters need to be considered while selecting a process for SO_2 removal from flue gases. It should be a safe, green, and economical method with negligible losses and no fouling problem. The purpose of this paper is to investigate various FGD methods and to review the findings on the techniques used for the removal of SO_2 from flue gases.

II. Methods of SO_2 removal

Lutpi et al. investigated a technique that helps to solve the problems occurring due to SO_2 emissions in environment, and also to neutralize the caustic and hazardous red mud in economical ways. This study was carried out by using a laboratory scale reactor to examine the absorption of SO_2 with red mud slurry and liquor samples. These samples undergo alkalinity tests to determine the intensity of carbonate and hydroxide ions present, before the absorption study. In their research, they examined the efficiency of red mud as an adsorbent for the absorption of SO_2 and investigated the ability of these gases to neutralize the red mud. It was observed that the alkalinity of the red mud slurry and liquor decreased slowly with the increase of acid. Moreover, the results for absorption study showed that SO_2 gas neutralized the red mud liquor faster than the red mud slurry.Thus, further research can be considered using red mud as an absorbent as it exhibited good performance with respect to sulphur capacity [3].

Dou et al.studied flue gas desulfurization, where the SO_2 was removed by absorbing and reacting SO_2 with limestone slurry, and limestone scrubbing was accomplished in a spraying reactor. Experimental investigations were carried out and the pH value of the liquid phase, droplet size of the spray and the flow rates of liquid and gas was calculated. In wet Flue Gas Desulfurization process, SO_2 diffuses through the gas phase to a liquid surface. Here it dissolves and is transferred by diffusion or convective mixing into the liquid phase. The rate of SO_2 transfer depends on a number of factors such as the solubility of SO_2 and its displacement from equilibrium. By this experiment SO_2 removal efficiency and residual limestone content of the gypsum for different limestone concentrations was calculated. The results obtained showed that the SO_2 removal efficiencies increased with increasing the limestone concentration. Also, SO_2 removal efficiencies increased with increase in the pH value of slurry upto a certain extent. When L/G ratio increases, the SO_2 removal efficiency increases, i.e. when L/G ratio is greater than 13, SO_2 removal efficiency can reach upto 96%. This process was analyzed using the two-film theory of gas–liquid mass-transfer, and this indicates that the removal rate is controlled by a combination of both gas-film and liquid-film diffusions [4].

Zhang and Wang, in their paper, developed a fast suspension bed (FSB) flue gas desulfurization (FGD) scrubber aiming for removal efficiency as high as those of wet scrubber with effective cost. With an innovative flue gas distribution apparatus, this FSB scrubber can enhance both gas-liquid and gas-solid reaction. Also, this scrubber can prevent choking due to lime slurry depositing onto the scrubber inner surface. They investigated the effect of various operating parameters including Ca/S ratio, approach to saturation temperature, flue gas flow rate and slurry particles diameter and distribution on SO_2 removal efficiency. Furthermore, mechanism of desulfurization reaction was examined. Saturation temperature and Ca/S ratio have significant influence on SO_2 removal efficiency. Also, it was examined that SO_2 removal efficiency increases significantly with decrease of saturation temperature and increase in Ca/S ratio. The optimal operating parameters were determined by estimating economy and safety aspects of the FSB-FGD. They found that, the optimal approach to saturation temperature is about 10°C, the optimum Ca/S ratio 1.5 and the optimal slurry diameter is 50μm. Also, SO_2 removal of this innovative FSB-FGD process is higher than 90% [5].

In this paper, Dzhonova-Atanasova et al. studied the method of Wellman-Lord to remove SO_2 from flue gases of combustion system. In this method, the absorption of sulphur dioxide takes place with sodium sulphite solution to form sodium bisulphite as a product. In a packed absorber, sulphur dioxide is absorbed by sodium sulphite and the resulting solution is sent to an evaporator. In the evaporator, sodium sulphite gets dissolved in the water by condensation of steam that gets evaporated with SO_2. This regenerated sodium sulphite solution can be sent back to the absorber. In this paper the authors have compared Wellman-Lord method with other basic methods of flue gas desulfurization and they found that this method is economical as compared to the other methods. They have also mentioned various techniques to improve the existing Wellman-Lord method. Various solutions were proposed to substantially reduce the steam consumptionof the method on the basis of a significant increase of the SO_2concentration in the saturated absorbent. A new technology was introduced, on the basis of the improved method of Wellman-Lord, which has the following advantages over the typical Wellman-Lord method: lower steam consumption with about 60 %; also, the heat for evaporation of the solution can be utilized in the condenser for heating district heating water; lower capital costs [6].

Gao et al. investigated two methods: a plasma technology of Corona Radical Shower(CRS) and a semi-dry flue gas cleaning technology for simultaneously removing multi-pollutants from flue gas. In this research, the simultaneous removals of SO_2 and NO_xusing CRS system was achieved through two processes according to the different additional gases; using NH_3 as additional gas and using O_2 as additional gas. In semi-dry flue gas cleaning technology for multi-pollutants simultaneous removal, acidic substances such as SO_2, HCl, HF are removed by $Ca(OH)_2$-based absorbent from flue-gas and this is then converted into saline material. In semi-dry flue gas cleaning technology, composite absorbent with multi-component and high activity combined with multi-stage humidifier were used to control multi-pollutants simultaneously. In this paper, it was observed that CRS of ammonia and CRS of oxygen as additional gas can obtain high $DeSO_2$ removal efficiency. While, the semi-dry flue gas cleaning technology can achieve high multi-pollutants removal efficiency through multistage humidification and improving additive [7].

In their paper, Özyuğuran, Ersoy-Meriçboyu investigated and compared the desulfurization efficiencies of different hydrated lime and dolomite sorbents. Sulfation experiments were performed at 338 K. A thermobalance was used to record the weight increase of the sorbents during their reaction with SO_2. Total sulfation capacity and conversion values of the hydrated lime and hydrated dolomite sorbents were examined. The relation between the total sulfation capacities of hydrated lime and dolomite sorbents with their surface areas and mean pore radius was also determined. It was observed that total sulfation capacities of hydrated sorbents increased with the increase in their surface areas and the decrease in their mean pore radius. Thus, it was concluded that the physical properties of sorbents have great influence on their sulfation properties [8].

In their paper, Fellner and Khandl compared different methods for evaluation of limestone reactivity and showed that the reactivity is related to the porosity of limestone grains. Eight samples of limestone were investigated and their chemical composition was analyzed using classical analytical methods. Also, the degree of conversion of limestone as a function of reaction time was plotted for the reaction of limestone suspension with 0.5 M-H_2SO_4 and 0.5 M-H_2SO_3. Half-time of the reactions for examined samples was also presented. It was observed that there is a linear dependence between both sets of results. Therefore the tests carried out with sulfuric acid are equivalent to those realized with sulfurous acid. It was concluded that the reactivity of limestone powder depends remarkably on the reaction surface of samples. It was seen that there is a correlation between apparent porosity and kinetics of the reaction [9].

In their paper, Un et al. explained the removal of SO_2 absorbed into sulfuric acid solution from simulated flue gases on platinum expanded mesh anode as three dimensional packed bed electrode in a batch mode. In this study, SO_2 was converted to sulfate by electrochemical oxidation while it was being absorbed in the sulfuric acid solution. The effects of various parameters such as current density, gas flow rate, and initial SO_2 concentration were determined. It was found that the investment and energy costs can be kept lower in electrochemical absorption. Furthermore, no chemicals are required in this process. Therefore, electrochemical oxidation of SO_2 can be considered as a process in which no waste is produced. Also, it was seen that this method gives a removal efficiency of 100% which meets the regulations requirement. Hence, the results of this investigation have shown that absorption and electrochemical removal of SO_2 can be performed on an expanded mesh platinum anode in one step [10].

Guo and Gao, in their work, aimed at finding the simultaneous absorption characteristic of SO_2 and NO_2 by limestone slurry, which is the most widely used absorbent in wet flue gas desulfurization system. Further, they determined the effect of inlet NO_2 concentration on SO_2 removal and found that SO_2 removal efficiency decreased when NO_2 concentration was increased from 100 ppm to 300 ppm. They also examined the effect of inlet SO_2 concentration on NO_2 removal and found that when inlet SO_2 concentration was increased from 200 ppm to 1000 ppm, NO_2 removal efficiency increased to 57%. While investigating the effect of temperature they observed that when reaction temperature was increased from 25°C to 55°C, both the removal efficiency of SO_2 and NO_2 decreased about 10%. Furthermore, SO_2 removal efficiency increased with increasing O_2 content. For the SO_2 removal process in their study, the maximum removal efficiency of SO_2 was found to be 90%–96% [11].

Mehrara et al. introduced a new technique to reduce emissions in air by using amine based absorbers to reduce concentration of SO_2. In their experiments, various parameters such as SO_2 concentration, column pressure, temperature of absorption are investigated in a steady state condition. They changed the proportion between sulfuric acid and amine to adjust the pH value. They found that desulfurization efficiency increased with the increase in pH. The experimental result indicated that the efficiency of absorption into amine solution decreases with an increase in SO_2 concentration of the inlet gas. Also, results showed that the best performance was achieved at 110°C. Furthermore, the results showed that an increase in SO_2 concentration from 2400 to 7800 decreases the performance of absorption by about 34%, and desulfurization efficiency increases very smoothly with increase in G/L value for more absorbent and more contact area in the scrubber. Thus, they categorized the experiment as a selective high efficient desulfurization process [3].

Krzyżyńska et al. conducted bench and pilot scale studies on the simultaneous removals of SO_2, NO_x, and mercury from coal combustion flue gas using a limestone based wet flue gas desulfurization (FGD) scrubber. This bench-scale experimental apparatus made use of a flow-through gas-liquid impinger to simulate a wet Flue Gas Desulphurization scrubber. Simultaneous removal of SO_2, NO_x, and Hg was tested at 55°C by using SO_2 concentration of 1,500 ppm. The effect of SO_2 concentration on the simultaneous removal of NO_x, SO_2, and Hg was performed. It was observed that the lack of SO_2 in flue gas causes a dramatic decrease in Hg, NO, and NO_x removal efficiency. Also, increasing the temperature accelerates the reaction rate, but decreases gas solubility in the liquid. Their research demonstrated that sodium chlorite could be used as an effective additive for the simultaneous removal of SO_2, NO_x, and Hg in wet scrubber simulators fed by limestone slurry in bench- and pilot-scale systems. Also, they observed that, all bench-scale experiments resulted in SO_2 removal efficiency near 100% [12].

Liu et al. conducted a study for developing a novel and green process by designing a series of electrochemical reactions through SO_2 absorption-and-conversion process. The study that they conducted focused on the chemical and sustainable fundamentals and the pH optimization for the SO_2 oxidation. In this electrochemical process, the SO_2 was designed to be absorbed into aqueous solution along with alkaline, then oxidized to sulfate, and then transformed into bisulfate. The anodic reaction uses H_2O to supply H+ ions which is scavenged by O_2 from air in the cathodic reaction. The H+ scavenging increases the SO_2 absorption and its further oxidation. Consequently, the SO_2 conversion forms $NaHSO_4$ electrochemically as a sulphur-containing product. $NaHSO_4$ is a valuable chemical and widely used as an additive and as a replacement of H_2SO_4 in industry for pH adjustment and catalytic reactions. The results showed that alkaline condition at pH > 7.0 is beneficial to the SO_2 absorption. This new process can fully comply with the principles of green chemistry and seems feasible. If flexibly applied in a wet Flue Gas Desulphurization process for SO_2 removal, this could be an environmentally-sustainable technique. This new process immobilizes the SO_2 waste in the form of non-calcium product by means of a cheap and non-toxic material, and thereby avoids the concern over any secondary pollution [13].

In their paper, Deshwal and Lee chose euchlorine solution for the removal of $NO_x$and SO_2 from flue gases in a lab-scale bubbling reactor. They carried out a number of preliminary experiments to assess the physical characteristics, including the gas phase and liquid phase mass transfer coefficients and their correlation equations were established. They found that at high euchlorine feeding rates, SO_2 and NO were removed effectively. Removal efficiency around 100% and 72% was observed for SO_2 and NO_x respectively at a scrubbing temperature of 45 degree Celsius. Also, the oxidizing and absorption ability of euchlorine was not affected by pH, thus making it a superior oxidative absorbent as compared to sodium chlorite. Sulphate, nitrate and chloride are the by-products of the reaction which are not hazardous materials, thus causing no secondary pollution. The mass balance of these ions was confirmed. Hence, euchlorine, generated from chlorate-chloride process will not only reduce the cost, but also solve the problem of pH adjustment encountered while using sodium chlorite [14].

The most widely used process in the absorption of SO_2 is with slurry containing $CaCO_3$ and transforming the SO_2 into gypsum, explained in a paper by Nikolai et al. They presented a new technology for removal of SO_2 from flue gases and transforming it into building gypsum, especially proper for small and medium sized boilers.The requirements were: controlling the pH, ensuring high mass transfer coefficient at low pressure drop, ensuring conditions that prevent desorption of SO_2 from slurry, maintaining the temperature and separating of all particles larger than 0.5mm to prevent the plugging of nozzles. The best choices of columns are the packed bed columns with maximum ratio of effective to specific surface area as there is a possibility of fouling. The technological scheme of the installation determines that the absorption is practically gas side controlled. Thus, for a given system, the absorption can be calculated using data from literature, eliminating the necessity for performing experiments.These calculations showed that the degree of absorption was 99.9% when three absorbers were used while it was 99.98% when two absorbers were used. Thus, the degree of absorption would be greater than that of any other existing installation that operates with gypsum technology [15].

Ljutzkanov et al., in their paper, presented the results of the investigations connected with creating a unit for the oxidation of $CaSO_3$ during the removal of SO_2 from flue gases, and drying of the product to gypsum for building purposes. To increase the absorption rate, the hydrocycloneblock for separation of the bigger crystals was removed. Also, due to high capital investments the centrifuge used for separation of solution was eliminated and the sulphites in the slurry were oxidized completely dry. In addition to this, $CaSO_4.2H_2O$ was dried in a spray dryer without preliminary separation of the liquid phase. This required almost complete oxidation of the $CaSO_3$ to $CaSO_4$ in the oxidizer. The design of a new oxidizer was proposed, which was divided into 4 chambers by vertical partitions with regular distribution of air by perforated horizontal tubes in the slurry. The air distribution using various plates with different orifice diameter and catalyst concentrations were investigated. The results showed that by injecting water with the air every 30 minutes, the process can be carried out continuously without stopping for cleaning of the orifices. It was seen that at Fe ion concentration of 0.15g/l and Mnion concentration of 0.57 g/l, over 99% of the slurry got converted to gypsum for 9 hours. Thus, this data was used for designing an oxidizer for purification of flue gases from SO_2[16].

The data for equilibrium partial pressure of SO_2over the slurry, needed for theselection of absorbers and their calculation at temperatures at which the industrial apparatuses for the absorption of SO_2 from flue gases operate, was presented by Ljutzkanov et al. Up until that time, there were installations for carrying out SO_2 absorption with $CaCO_3$ slurry only for big capacity boilers. Also, the equilibrium data was available in literature only for a temperature of 25 degree Celsius. Thus experiments were carried out for obtaining equilibrium data for the partial pressure of SO_2 over slurry containing $CaCO_3$, $CaSO_3$ and $CaSO_4$ at different temperatures. It was found that the increasing of the temperature from 25 degree Celsius to 45 degree Celsius leads to about 3 times increase in the partial pressure of SO_2 at lower partial pressures. When it increases to 60 degree Celsius, the increase in partial pressure is about 10 times [17].

Dzhonova-Atanasova et al. presented a review of the main principles, technological solutions and study results on flue gas desulfurization (FGD) with an emphasis on wet limestone-gypsum technology, which is the most common FGD process. There are about 20 different kinds of SO_2 removal techniques available. For wet limestone-gypsum technology, data shows that their SO_2 removal efficiency varies from 84 to 99%. Various methods of wet flue gas desulfurization were investigated. Also, a Computational Fluid Dynamics (CFD) model for a flue gas desulfurization plant of wet scrubber type, and its application to an operating plant was presented. The effects of adding an organic acid while using $CaCO_3$ as sorbent for SO_3 removal, has also been examined. Investigations were made to find out the effects of different parameters on SO_2 removal efficiency. The degree of desulfurization, residual limestone content of gypsum, liquid phase concentrations were measured while varying parameters like concentration of SO_2, temperature, etc. Though the present world level of removal efficiency of wet FGD technology is about 95%, the amount of SO_2 discharged in the atmosphere is huge. Thus, these findings help in the selection of apparatuses and equipment and examining new solutions [18].

Stergarsek et al., in their paper, worked to develop non-stationary models of wet calcite flue gas desulphurization process and use these models to optimize this process with respect to investment and operating costs. Non-stationary Flue gas desulphurization models were developed for spray scrubber and falling film absorber and comparative results were obtained. It was observed that falling film absorber offers less expensive operation as compared to spray tower. The rate of scaling for different materials was also investigated in a continuous small pilot flue gas desulphurization arrangement. New facts were experimentally developed that allowed the consideration of falling film absorbers that could avoid scaling problems in long term operation. The equipment were critically analyzed and its integration led to reduction of tanks, valves, pumps, pipes etc. and hence offered significant potential for investment and operating savings. Also, according to the risk analysis, the risk of failure of the entire system also decreased due to the diminished number of the equipment [19].

Resnik et al. presented the experimental research work in applying aqueous ammonia solution for the simultaneous reduction of acidic gaseous emission from fossil fuel-fired utility plants which was performed at the National Energy Technology. The traditional method known as monoethanolamine (MEA) process for flue gas purification faces the disadvantages of low carbon dioxide loading capacity, equipment corrosion and amine degradation by SO_2 and O_2. This method could be replaced with the aqua ammonia process which would capture all three major acids, SO_2, CO_2,

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NO_X. The experiment was carried out in a semi-continuous reactor at different temperatures and the rates of acid absorption in aqueous ammonia solution were measured. This method could reduce the total cost and complexity of emission control systems. Also, the by-products of this process, ammonium sulphate, ammonium nitrate and ammonium bicarbonate are useful as fertilizers. These by-products would promote the burning of cheap and abundant high-sulphur coals. It was estimated that the thermal energy consumption using Aqua Ammonia process could be at least 75% less than if MEA process is used [20].

Sarkar et al. made an attempt to develop a generalized theoretical model using the residence time distribution (RTD) approach, for predicting the removal efficiency of SO_2 in a co-current gas-liquid scrubber. This model takes into consideration, the concentration distribution of SO_2 in liquid and gas phase as a function of droplet diameter, pH level of liquid, gas and liquid flow rates and the height of the scrubber. Experiments were conducted by passing an air stream containing a trace amount of SO_2 horizontally along with a spray of water droplets. It was observed that as the gas flow rate increases, the removal efficiency decreases. On the other hand, as the liquid flow rate increases, the removal efficiency increases. As the scrubber height increases, the outlet concentration of SO_2 in the liquid phase increases. Also, as the pH of the inlet liquid and time increases, the removal efficiency increases. The experiment results showed that the theoretical equations based on physical mass transfer very closely predict the performance of the scrubber for the removal of SO_2. Thus, this model fits very well for the scrubbing of SO_2 [21].

In his paper, Srivastava presented a review of the state of the art in flue gas desulphurization (FGD) technologies in coal-fired boilers. The paper describes these technologies, assesses their applications, and characterizes their performance. An analysis of the costs associated with limestone forced oxidation (LSFO), lime spray drying (LSD), and magnesium-enhanced lime (MEL) FGD technology applications is also presented. The design SO_2 removal efficiencies associated with applications of these technologies were examined. The review of the pattern of past FGD installations in various parts of the world reveals that wet FGD technologies have been predominantly selected over other FGD technologies. It was observed that most wet limestone systems were designed for 90% SO_2 removal, whereas the state-of-the-art wet scrubbers are capable of routinely achieving SO_2 removal efficiencies of more than 95%. The cost analyses indicate that the capital cost of an LSD system is always lower than those of LSFO and MEL systems, due to less complex hardware used in LSD [22]. In their paper, Tsuji et al, investigated the photochemical removal of SO_2 and CO_2 using a 172nm Xe_2excimer lamp, using a 146nm Kr_2excimer lamp as a new VUV source, without using any catalysts. The conversions for each gas while using the two lamps were compared. It was found that the conversions after 30 min photo irradiation were 45% in N_2 and 75% in air using a 172nm excimer lamp, whereas they were 39% in N_2 and 8% in air using a 146nm excimer lamp. The removal rate of SO_2 in air using the 50mW/cm2 172nm lamp was 3.9 times faster than that obtained by using 25mW/cm2 146nm lamp. Thus, SO_2 removal in a flow system for practical application using a 172nm lamp was examined. It was observed that about one-half of the initial SO_2 can be removed using a flow system in air. In order to increase the removal rate of SO_2 in air, further experiments using a side-on-type excimer lamp were meant to be conducted [23].

Unguresan and Jantschi, in their paper, investigated a number of methods used in order to remove sulphur and sulphur oxides from fuels before combustion and from the resulted gas after combustion. The advantages and disadvantages of the most important systems of gas absorption were explained. The electrochemical methods of desulphurization were also investigated. The authors studied the feasibility of electrochemical removal of sulphite ions arising from the absorption of SO_2 in an aqueous electrolyte. Various parameters such as removal efficiency, current efficiency, and energy consumption were determined at different initial sulphite ion and electrolyte concentrations and applied currents. Thus, the electrochemical method can successfully be used for SO_2 removal from flue gases. It was observed that the chemical methods for SO_2 removal involve obtaining big quantities of waste products and are very expensive. On the other hand, the electrochemical methods are not polluting and hence are used more often than the chemical methods. These processes do not consume much energy and the rate of the processes can be rigorously controlled [24].

Xiuping et al. in their work, investigated the SO_2 absorption technique with sodium citrate by using the rotating packed bed (RPB) and the effects of various operating parameters, like the rotation speed of RPB, liquid-gas ratio, inlet gas flow rate, inlet concentration of SO_2 in flue gas, sodium citrate buffer concentration and initial pH of absorption solution, on the SO_2 concentration in the absorption solution or removal efficiency ofSO_2 were determined. They also obtained the appropriate Liquid-Gas ratio. The investigation showed that increase in concentration of SO2 decrease the efficiency, while higher the concentration of citrate higher the efficiency. It also showed that, higher pH may affect the absorption process significantly. Higher rotation speed of (RPB) N is favorable to increase the absorption rate, resulting in higher absorptionefficiency and absorption capability of solution,and shorter operation time [25].

Altwicker and Kleinstreuer studied the absorption of SO_2 into falling water droplets and investigated the oxidation and oxidation inhibition of the sulphur species. They employed the 'string-of-falling-drops' generator that has the ability to generate one or more monodisperse drop streams which could be exposed to pollutants at particular concentrations. At the end of the exposure time, the droplets are collected and analysis is carried out. During the reaction, oxidation was observed which may be due to the excess of impurities and oxygen in the liquid phase relative to the initial sulphur concentration at the time of drop formation. The inhibition of oxidation under catalyzed state as well as without a catalyst was determined. The advantage of this laboratory system is its potential to generate drop streams of varying drop velocities, numbers, and sizes encompassing the range in clouds and raindrops. The authors gave a comprehensive description of the process to justify its use as a laboratory toll to aid in initial rate studies and the study of various gaseous pollutants. They intend on extending the investigations to simultaneous gas and particle scavenging [26].

III. CONCLUSION

The present study deals with the removal of SO_2 from flue gases using various techniques.The review describes the practical FGD processes, their characteristics, assesses their use, determines which of these are feasible, characterizes the SO_2 removal performance of the processes and analyses their costs. Processes using limestone slurry as an absorbent are the most widely applied FGD technologies. According to the data, most wet limestone systems are designed for about 90% SO_2 removal. However, newer technologies and methods are available that are capable of achieving SO_2 removal efficiencies of more than 95%. The appropriate method can be selected based on the energy consumption, cost analysis, SO_2 removal efficiency, reaction controllability, etc.

The removal of SO_2 from exhaust gases from various industrial sources has received considerable attention over the years. Research and development of the FGD technology has been focusing on improving the efficiency of removal of SO_2, minimizing energy consumption and cost. At the present world level of 95% of SO_2 removal efficiency by existing technologies, the amount of SO_2 discharged in the atmosphere is huge. Thus, the aim of this review paper is to help find the right direction in exploring new solutions.

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