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Absorption of SO_2 in a three-Phase Bubble Column and Foam-Bed Slurry Reactor

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ABSTRACT

Absorption of SO_2 slurry of $CaCO_3$ from a mixture of 1000 ppm SO_2 in air has been studied in a semi-batch bubble column and foam-bed slurry reactor. Concentration of SO_2 at the inlet and exit of the reactor was measured using a ZRJFAY36, Fuji, Japan make infrared SO_2analyzer. With solids loading of 4 kg $m^{-3}$$CaCO_3$, and 20 lpm of inlet gas flow rate containing 1000 ppm of SO_2, 98.3% of SO_2 removal efficiency was observed in case of bubble column reactor. In case of foam bed contactor, SO_2 absorption decreased from 98.3% to 95% due to the presence ofsurface active agenti.e triton x-100 and calcium sulfate hemihydrate was obtained as the final FGD product. Characterization of the final product was done using FT-IR and TGA analysis.

Keywords-* SO_2 *absorption, Bubble column reactor, Foam-bed reactor, Surface active agent.

Introduction

Combustion of coal and diesel fuels results in the large emissionof SO_2, which is considered to be the chief contaminant for the environment pollution and nowadays, it has become a widely concerned environmental issue(Huang et al., 2014).Due to the lowering of the permissible limits, various SO_2 removal techniques have been explored by researchers and a large number of flue gas desulfurization (FGD) methods such as dry and wet processes have been developed(Gound et al., 2015). In these processes, solvents like limestone, calcium hydroxide, magnesium hydroxide, sodium hypochlorite, ionic liquids and other organic solvents are used as absorbents(Mehrara et al., 2013).

Duo et al. studied the FGD, where the SO_2 was removed by absorbing and reacting SO_2 with limestone slurry, and limestone scrubbing was accomplished in a spraying reactor(Dou et al., 2009). It was concluded that the desulfurization efficiencies of the systems depend strongly onoperation parameters such as pH value, temperature, sulfur dioxide concentration, and particle size or type of the sorbent material(Schultes, 1998). Dagaonkar et al. studied the absorption of sulfur dioxide into aqueous slurries containing fine suspended reactive particles of calcium and magnesium hydroxide was performed in a stirred cell at relatively high mass transfer coefficients(Dagaonkar et al., 2001).Mondal and Chelluboyana, reported that 100% efficiency for SO_2 removal was achieved but the operating gas flow rate was very low which resulted in large time consumption(Mondal et al., 2013). Conventional spray towers use slurry for absorption which requires small droplets for high efficiency and the spray nozzles are prone to choking(Bandyopadhyay and Biswas, 2006). Alternatively,a large quantity of dust laden exhaust gases can be treated with relatively much less amount of liquid using a foam-bed reactor and can be used advantageously for absorptive removal of various gases. Also, a foam bed reactor offers large gas-interfacial area and long contact time, high gas hold-up and fairly low to moderate pressure drops(Jana and Bhaskarwar, 2011) but if the reaction is very fast, then interfacial resistant dominant over large interfacial area and thus rate of absorption will be deceased (Asolekar et al., 1985; Biswas and Kumar, 1981; Shah and Mahalingam, 1984).

In the present work, absorption of sulfur dioxide from a lean gaseous mixture into limestone slurry in a semi-batch bubble column reactor and foam-bed reactor has been studied. The effects of surface active agent were studied in foam-bed reactor on SO_2 absorption. The FGD (flue gas desulfurization) product obtained in absence and presence of absorption was also observed.

EXPERIMENTAL

Materials and Methods

Various chemicals used as reactants and for the analysis of products are as follows. Calcium hydroxide (GR, MERCK Ltd. Mumbai), Calcium carbonate (AR, LobaChemie Mumbai), and 5000 ppm sulfur-dioxide gas (Instrument Grade, Dinesh Gases Pvt. Ltd., Jaipur) were used as reactants.

Set-up

The experimental set-up used in the present studies is shown schematically in Fig.1. It comprises of a glass column, SO_2 cylinder, air compressor, rotameter for air, rotameter for SO_2, and a mixer for SO_2 and air. The glass column, 0.74 m long and 10.5×10^{-2} m internal diameter is connected at the bottom to a glass cone with the help of flanges. A gas distributer plate, 2.0×10^{-3} m thick and made up of perspex is placed between the flanges. There are 31 holes of 1.0×10^{-3} m diameter and arranged in triangular pitch. Concentration of SO_2 at the inlet and exit of the reactor was measured using a ZRJFAY36, Fuji, Japan make infrared SO_2analyzer.

PROCEDURE

A mixture of sulfur dioxide and air at the rate of 3.33 x 10^{-4} m^3 s^{-1} was monitored using calibrated rotameters and allowed to flow through the reactor. When the flow rates of these gases became steady, 2.5 x 10^{-4} m^3 of reactant slurry containing 4 kg m^{-3} of calcium hydroxide was carefully poured into the reactor. Inlet and outlet concentrations of sulfur dioxide were measured using a ZRJFAY36, Fuji, Japan make infrared SO_2analyzer. Additional experiments were performed for collection of experimental data for different variables studied in this work. Similar experiments were performed using calcium carbonate slurry.

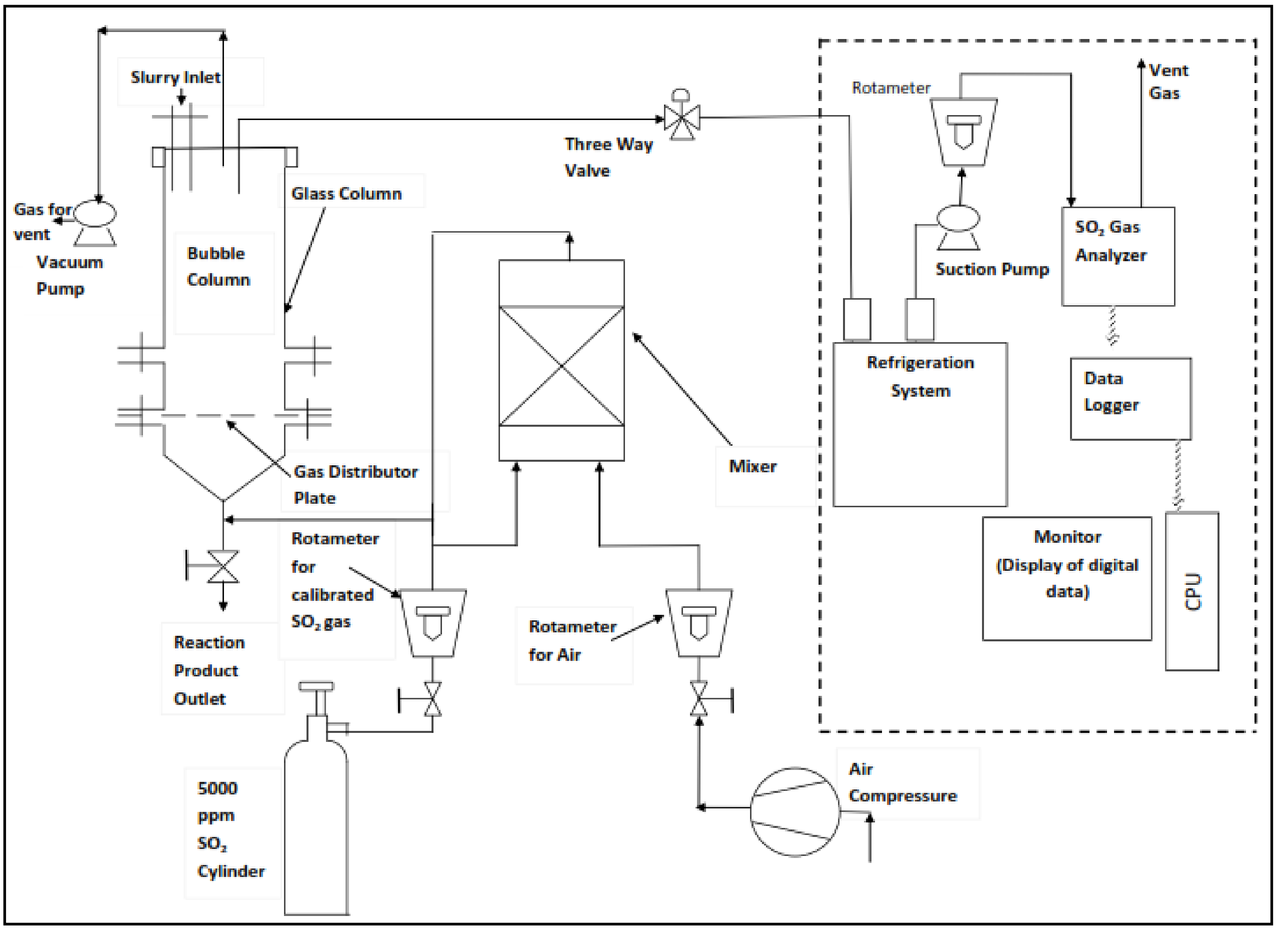

Figure 1 Line diagram for SO_2 absorption apparatus

RESULTS AND DISCUSSION

Effect of surface active agent in bubble column on removal of SO_2

To study the effect of surface active agent, experiments were conducted at the superficial velocity of gas of 3.85x10^{-2} m s^{-1} and inlet SO_2 gas concentration of 1000 ppm, initial loading of calcium carbonate 4.0 kg m $^{-3}$ and slurry volume of 2.50x10^{-4} m^3. It was observed that percentage removal of SO_2 in absence of surface active agent that is in bubble column reactor is 98.3% whereas in presence of triton x-100 surfactant (C_{S0}=582 ppm) decrease to 95%. This is because the absorption of SO_2 in calcium carbonate slurry is at instantaneous rate this mean gas absorption is diffusion film controlled. Thus, due to presence of surface active agent, a new resistance film appear which hinders the diffusion of SO_2 molecule to liquid film (Garg et al., 2000). This results in decrease of absorption rate and percent removal also. It was observed by few authors that if the reaction is very fast, interfacial resistance is dominating to high interfacial area in a foam-bed reactor (Asolekar et al., 1985; Biswas et al., 1987; Shah and Mahalingam, 1984)

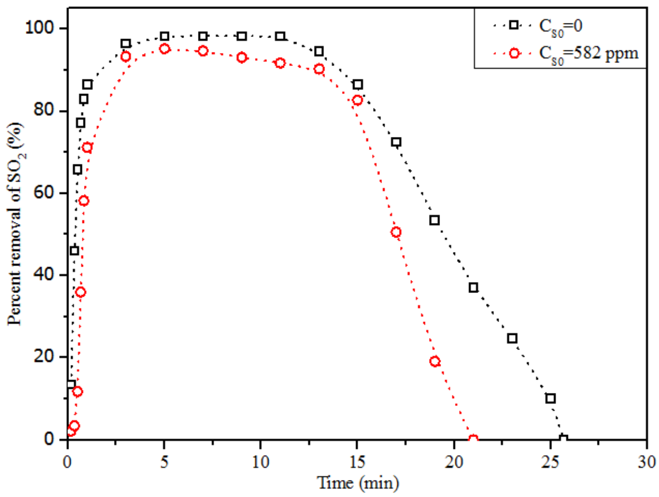

Figure 2 Percent removal of SO_2 in bubble column with/without surface active agent

FT-IR spectra of FGD product in presence and absence of surface active agent

To obtain information about the functional group in FGD product obtained in bubble and foam bed reactor, chemical, FTIR were measured. FT-IR spectra were taken by a Perkin-Elmer (UATR Two) IR spectrometer, using KBr. *FT-IR* spectra of FGD products have been presented in figure 3(a) and 3(b). It is observed that, O-H stretch (3611–3556 cm^{-1}) O-H bend (1620 cm^{-1}), SO_4^{2-} bend (1150 cm^{-1}) (Nosov et al., 1976). This spectroscopy reveals that the FGD product is calcium sulfate hemihydrates.

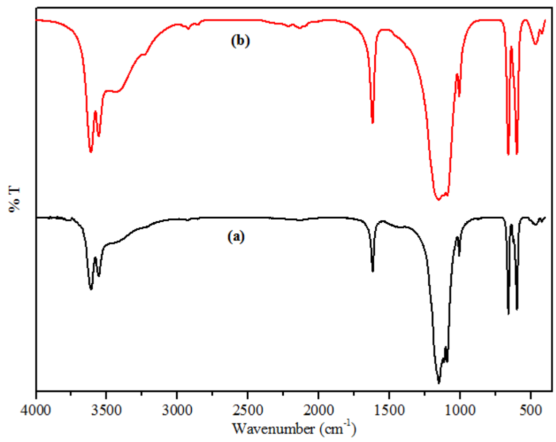

Figure 3 FT-IR spectra of FGD product obtained by (a) bubble column (without surface active) and (b) foam-bed reactor (in presence of surface active agent, Triton X-100)

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TGA of FGD product in presence and absence of surface active agent

Thermogravimetric analysis (TGA) of gypsum has been carried out to the study of the conversion of gypsum to anhydrite at about 200 ^{o}C using the thermogravimetric technique. Theoretically, the gypsum phase (CaSO4. 2H2O) has 20.91% of water of hydration and the hemihydrate phase CaSO4. 0.5H2O) has 6.20% of water of hydration. Figure 4 represents the thermogravimetric curve of the FGD pruducts. It can be observed from the figure that the product obtained in both bubble and foam-bed reactor in the laboratory had a weight loss of about 6.11% at 150 ^{o}C. This confirms that the product is calcium sulfate hemidydrate matched with the result of FT-IT.

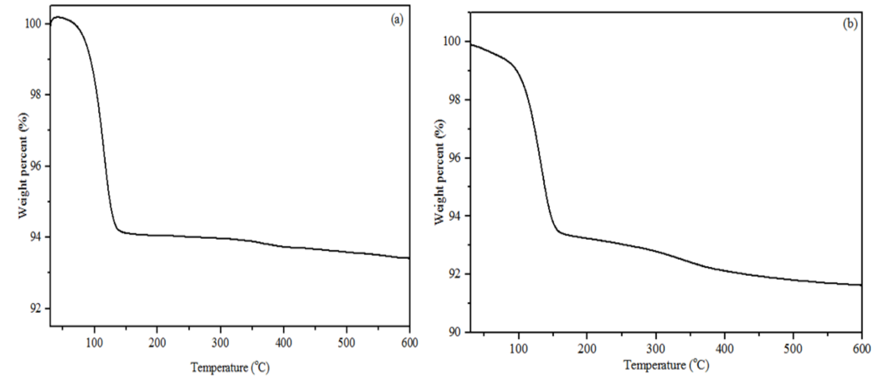

Figure 4 TGA analysis of FGD product obtained by (a) bubble column (without surface active) and (b) foam-bed reactor (in presence of surface active agent, Triton X-100)

SEM image of FGD product in presence and absence of surface active agent

Figure 5 provides the SEM micrographs for the synthesized calcium sulfate hemidydrate samples obtained in presence and absence of surface active agent. It can be observed that the morphology of the synthesized calcium sulfate hemidydratecrystals. It can be observed that the morphology of the gypsum crystals was needle shaped and rod-like as discussed by Rashad et. al. (Rashad et al., 2004).

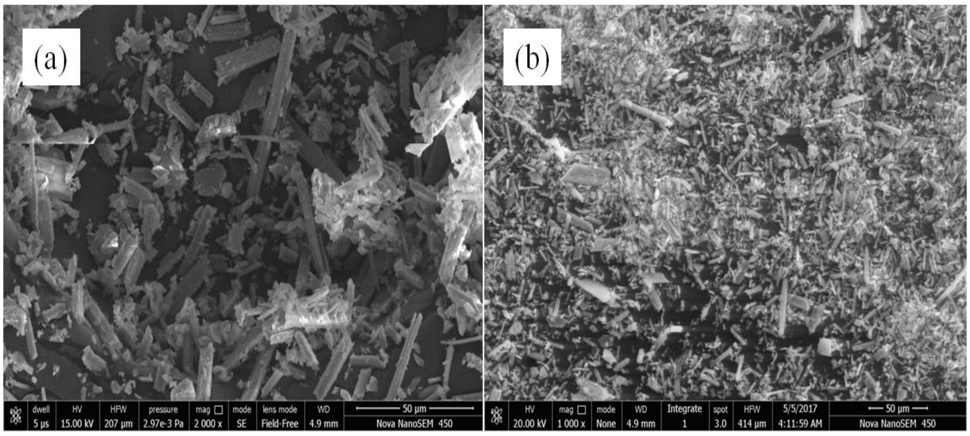

Figure 5 SEM image of FGD product obtained by (a) bubble column (without surface active) and (b) foam-bed reactor (in presence of surface active agent, Triton X-100)

CONCLUSION

In the present work, absorption of sulfur dioxide from a lean gaseous mixture into limestone slurry in a semi-batch bubble column reactor and foam-bed reactor has been studied. The effects of surface active agent were studied in foam-bed reactor on SO_2 absorption. The FGD (flue gas desulfurization) product obtained in absence and presence of absorption was also observed. In case of bubble column, SO_2 removal was observed to be 98% and it decreased to 95% when foam-bed reactor was used for absorption in the presence of surface active agent i.e.triton x-100. This was due to the fact that due to presence of surface active agent, a new resistance film appear which hinders the diffusion of SO_2 molecule to liquid film. FT-IR and TGA analysis of the FGD product were used for the characterization and the results revealed that calcium sulfate hemihydrate was obtained .

NOMENCLATURE

C_{B0} Initial solids loading in feed slurry, kg m^{-3}

$C_{AG,0}$ Initial concentration of SO_2 in feed gas, ppm

C_{B0hl} Initial concentration of hydrated lime in slurry, kg m^{-3}

C_{B0cc} Initial concentration of calcium carbonate in slurry, kg m^{-3}

C_{S0} Concentration of Triton X-100 (surfactant) in slurry, ppm

V_G Superficial velocity of gas, m s^{-1}

V_{sl} Volume of slurry, m^3

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