Integrated Absorption - Adsorption Process for SO_2 Capture Using Anion-Exchange Resin

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Highlights

- An integrated absorption-adsorption process for SO_2 removal from flue gases is proposed.
- The dynamic removal kinetics of the proposed process is investigated experimentally.
- The data obtained supports the feasibility of the proposed method.

1. Introduction

Since the 70's ion-exchange resins have been intensively investigated for their applicability as reversible adsorbents in purification of flue gases generated from the combustion of fossil fuels. After saturation the resin is regenerated via desorption and reused. Data of adsorption/desorption capacity is available for a variety of ion-exchange resins used as a solid adsorbent for pollutants like SO_2, H_2S, NO_2 [1]; SO_2 and CO_2 [2]. The flue gas desulfurization (FGD) by adsorption using ion-exchange resin is attractive because of the expected lower cost and energy consumption compared to the absorption by liquid sorbents, which is widely applied for gas purification currently. The advantage of the liquid sorbent is the possibility of a continuous operation and waste heat recovery, although the presence of liquid may hinder the ion-exchange process [3]. The present work complements the available information by adding new data on a promising waste-free absorption-adsorption method. The sorbent is a slurry of a solid granular adsorbent suspended in a liquid absorbent, i.e. particles of a synthetic anion-exchange resin suspended in water. The adsorbent is regenerated with ammonia (NH_3) solution, followed by decomposition of the resultant ammonium sulfite ($(NH_4)_2SO_3$) with nitric acid (HNO_3). The by-products are pure gaseous SO_2 and aqueous solution of ammonium nitrate (NH_4NO_3), which have wide applications as commercial products.

2. Methods

In the proposed FGD method the gas being treated contacts the sorbent in a bubble-cap tray column. The absorption-adsorption processes take place on the trays – SO_2 is absorbed in the water (transforming into sulfurous acid (H_2SO_3)) which is simultaneously adsorbed from the aqueous solution by the anion-exchange resin. When the sorbent on a given tray reaches saturation capacity, it is removed, treated in a regeneration unit and returned for reuse on the tray. The trays undergo regeneration cycles one at a time, while the rest of them continue operation. An innovative reactor was designed (Fig.1) by implementing powerful modern techniques – CFD simulation and additive manufacturing. The simulation results, revealing the flow pattern on a bubble-cap tray (Fig.1(a)), were used to compare different strategies for enhancing the mixing of the phases. Based on these results, a tray with a single bubble cap was manufactured by 3D printing from PETG. An experimental set-up was constructed – a glass column (ID=200 mm) with a single tray (Fig.1(b)). The sorbent used was a suspension of a synthetic anion-exchange resin (AmberLite® FPA66 with density close to that of water and particle diameter of about 0.5 mm) in distilled water at 20°C. The volume of the water-resin suspension was fixed at 4.5 L. The suspension was removed for regeneration after operation. Air-SO_2 mixture at 20°C was fed at the column bottom and distributed in the liquid sorbent by the bubble cap. The air (supplied by a centrifugal ventilator) was mixed with pure SO_2 from a pressurized gas cylinder. The air flow rate was controlled by a spherical valve (FC1, Fig.1(b)). The gas velocity was measured with a Prandtl tube inserted into the gas pipe and connected to a portable gas analyzer system (Optima 7 MRU). The SO_2 flow rate was

controlled by a rotameter with a manual valve (FC2, Fig.1(b)). The SO_2 concentration was measured by the gas analyzer at the gas inlet and the outlet pipes (C_0 and C_e, Fig.1(b), respectively).

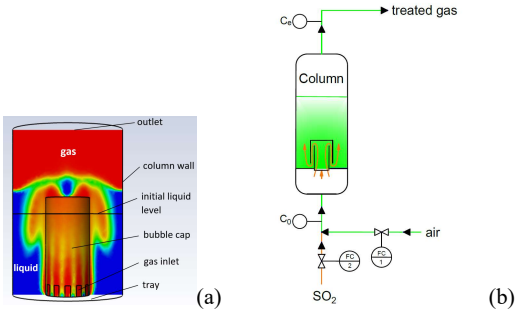

Figure 1. Experimental set-up: (a) Gas holdup countour plot on a bubble-cap tray; (b) Absorption-adsorption flow diagram.

3. Results and discussion

The results of the column breakthrough tests are presented in Fig. 2.

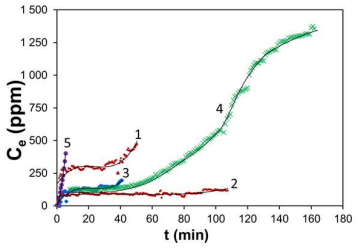

Table 1. Experimental conditions

Plot No	C_0 (ppm)	Gas flow rate (L/h)	Resin (g/L)
1	1500	5000	55
2	1500	5000	111
3	3500	5000	111
4	1500	15000	111
5	1500	5000	0 (water only)

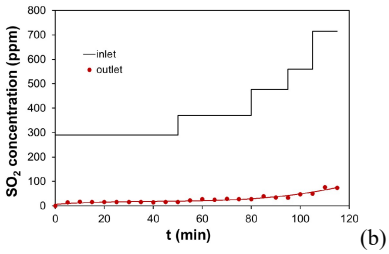

Figure 2. SO_2 breakthrough experiments: (a) At the first tray outlet (plot numbers in Table 1); (b) At the second tray inlet/outlet.

Fig. 2(a) shows that the breakthrough time decreases with the increase in SO_2 inlet concentration: 110 min for 1500 ppm (v/v), compared to 35 min for 3500 ppm (v/v) (plot 2 *vs* plot 3); the breakthrough time increases with the decrease in gas flow rate: 50 min for 15000 L/h, compared to 110 min for 5000 L/h (plot 4 *vs* plot 2); the breakthrough time increases with the resin concentration in the slurry: 30 min for 55 g/L resin, compared to 110 min for 111 g/L resin (plot 1 *vs* plot 2). In the zone before the breakthrough, C_e is higher at higher flow rate (plot 2 *vs* plot 4), C_e increases at higher C_0 (plot 2 *vs* plot 3) and at lower resin concentration (plot 2 *vs* plot 1). Plot 5, presenting absorption by water only (i.e. 0 g resin), demonstrates the superiority of the slurry as a sorbent. The gas treated per volume of dry adsorbent before breakthrough varies between 5400 and 17500 m^3/m^3, exceeding the value of 1500 m^3/m^3 reported in [2] for fixed-bed SO_2 adsorption from flue gases. To mimic the operation of a second identical tray downstream, the inlet SO_2 concentration was changed stepwise (Fig.2(b)), following the course of the outlet concentration from a single tray (Fig.2(a)). The results demonstrate that the breakthrough time of a two-tray column increases more than two times compared to a single tray.

4. Conclusions

The investigation of an innovative absorption – adsorption method shows promising results. New data is obtained on the influence of the gas flow rate, the SO_2 concentration and the resin concentration on the breakthrough time. The results complement the information on FGD by using ion-exchange resins and point to the feasibility of the proposed method.

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References

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Keywords
FGD; absorption – adsorption; bubble-cap tray; breakthrough test.