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# Removal of carbon dioxide in an experimental powder-particle spouted bed reactor

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ABSTRACT

The performance of a powder-particle spouted bed (PPSB) on the removal of $CO_2$ is investigated. A laboratory scale PPSB is employed to investigate the effects of operating parameters such as approach to saturation temperature, static bed height, Ca/C molar ratio, inlet $CO_2$ concentration and type of sorbent on $CO_2$ removal efficiency. The experimental results show that the $CO_2$ removal efficiency increases by increasing the static bed height, Ca/C molar ratio and inlet $CO_2$ concentration, and decreases by increasing the approach to saturation temperature and superficial gas velocity. Also it is concluded that maximum $CO_2$ removal efficiency could be up to 50% when approach to saturation temperature is 8 K, Ca/C molar ratio is 1.4 and the static bed height is 0.225 m.



## 1. Introduction

The increasing use of fossil fuels to meet energy needs has led to higher $CO_2$ emissions into the atmosphere. $CO_2$ which represents about 80% of greenhouse gases is the major atmospheric contaminant leading to the increase of earth temperature. $CO_2$ emissions will correspondingly increase in the absence of any capture/sequestration strategy. It is therefore necessary to develop and improve technologies to mitigate the release of $CO_2$ to the environment [1–3].

Many alternative strategies have been proposed to reduce the emission of $CO_2$. These strategies include fuel alternative, energy conservation, and improving power generation efficiencies. But their implementation may have limited impact on the reduction of $CO_2$ emission [4].

Applying $CO_2$ capture to a typical power plant is referred to as post-combustion capture, in which the low-pressure exhaust gases (currently emitted to the atmosphere) are passed through a separation process that removes $CO_2$. Post-combustion facilities can be applied to power plants or provided as a feature of new plants in the future. These technologies include physical adsorption, chemical solvent absorption, cryogenic separation, membrane separation, mineral sequestration, and biological fixation [4,5].

Several novel types of gas–liquid contactors for acid gas absorption have been developed owing to the existence of significant mass transfer limitations in traditional gas–liquid contactors such as packed columns, spray columns and bubble columns [6]. In 1999 a new type of semi-dry flue gas desulphurization (FGD) process was developed by applying a PPSB to a low temperature desulphurization process. In this process, slurry of fine $SO_2$ sorbent is fed continuously into a spouted bed in which coarse particles are spouted by the hot flue gas. The effect of different operating parameters such as approach to saturation temperature, apparent residence time, Ca/S molar ratio, inlet $SO_2$ concentration and type of sorbents were considered. Also the utilization rate of $SO_2$ sorbent and ways to enhance the efficiency of $SO_2$ removal was investigated [7]. Ma et al. [8] used easily available and non-expensive limestone ($CaCO_3$) as $SO_2$ sorbent in a PPSB. They considered the effect of different operating conditions to find the optimum operating conditions for $SO_2$ removal efficiency. They concluded that the diameter of sorbent particle and approach to saturation temperature have considerable influence on $SO_2$ removal efficiency. The optimal temperature of the inlet flue gas in a PPSB was considered by Xu et al. [9]. They demonstrated that $SO_2$ removal efficiency in excess of 95% can be achieved at Ca/S = 1.2 and inlet temperature of 420 K. They also concluded that their PPSB semi-dry process has lower cost, less complicated configuration and simpler disposal of used sorbent. The influences of $CO_2$ and $O_2$ on $SO_2$ removal from the flue gas using a PPSB were also investigated by Ma et al. [10]. The experimental results showed that $O_2$ concentration does not affect $SO_2$ removal from the flue gas for the range of $O_2$ concentrations used in the experiments. The influence of $CO_2$ on $SO_2$ removal was found to depend on the approach to saturation temperature.

*Abbreviations:* PPSB, powder-particle spouted bed; FGD, flue gas desulphurization.

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**Nomenclature**

| | |
|---|---|
| *Ca/C* | Ca/C molar ratio |
| *E* [%] | $CO_2$ removal efficiency |
| $F_w$ | water content of slurry (g-water/g-sorbent) |
| $H_c$ [m] | static bed height |
| $H_m$ [m] | maximum spoutable bed height |
| RH | relative humidity of gas |
| $T_b$ [K] | bed temperature |
| $T_{in}$ [K] | inlet gas temperature |
| $T_s$ [K] | saturation temperature |
| $\Delta T$ [K] | approach to saturation temperature |
| $U_g$ [m s$^{-1}$] | superficial gas velocity |
| $U_{ms}$ [m s$^{-1}$] | minimum spouting velocity |
| $W_s$ [g min$^{-1}$] | mass flow rate of slurry |
| $Y_{in}$ [ppm] | inlet $CO_2$ concentration |
| $Y_{out}$ [ppm] | outlet $CO_2$ concentration |

PPSB also was used in a semi-dry process for production of very fine calcium carbonate powder [11]. The experiments showed that this method could produce very fine calcium carbonate powders with the mean particle size around 1 μm and the $Ca(OH)_2$ conversion around 90%.

The performance of such systems on the removal of $CO_2$ is seldom studied. Thus in the present study, the possibility of using non-expensive hydrated lime as a $CO_2$ sorbent in the PPSB process is investigated. Although a few works on removal of $CO_2$ with lime at low temperatures were conducted by some investigators with other conventional processes [12,13], further studies are required for this system. Moreover, the effect of different operating conditions on $CO_2$ removal efficiency is investigated.

## 2. Basic concept and reaction mechanism

In the PPSB, which is a coned-bottom fluidized bed without a gas distributor, some types of coarse medium particles are used for spouting of the reactant powder. A slurry of fine $Ca(OH)_2$ is fed continuously into the bed in which coarse particles are spouted with hot flue gas containing $CO_2$. When the slurry droplets come into contact with the coarse particles, they break up and a thin film of slurry covers the surface of coarse particles. The reaction between $CO_2$ in the gas phase and the sorbent in the slurry take place on the surface of coarse particles. At the same time, the slurry covering the particles dries and no water remains in the reactor. Because of movement of coarse particles, the dried and reacted sorbents which are in the powder form are separated from the surface of coarse particles. Finally the dried and reacted powders are entrained from the bed with the gas stream. A schematic diagram of the PPSB is shown in Fig. 1.

In the present process, the coarse particles not only act as a support for the slurry film, but also play a key role in providing a large surface area for contacting the reactants [6]. In this process, like a semi-dry FGD process [9] heat and mass transfer and the chemical reaction occur in the reactor simultaneously. In general the process includes:

1. Mass transfer of $CO_2$ from the gas stream to the droplet surface.
2. Absorption of $CO_2$ at the droplet surface, dissolution of $CO_2$ in the droplet and dissociation:

$$CO_{2(g)} \rightarrow CO_{2(aq)} \quad (1)$$

$$CO_{2(aq)} + H_2O = H_2CO_3 \quad (2)$$

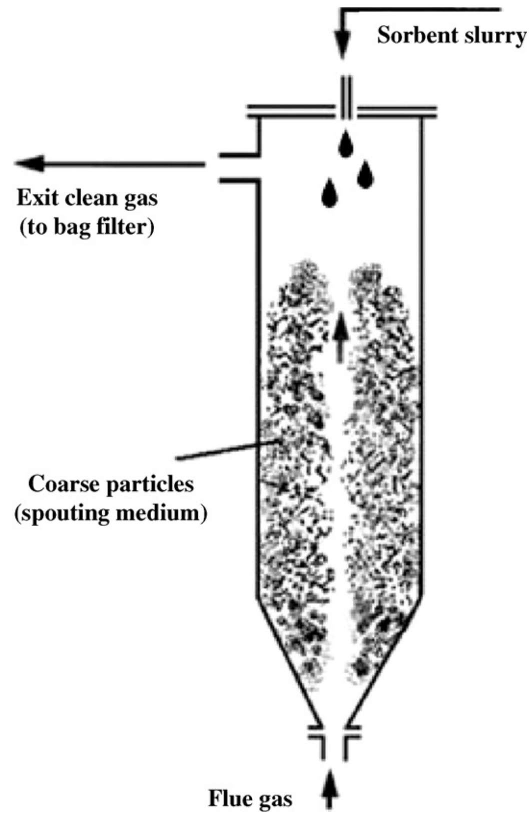


**Fig. 1.** A schematic diagram of the powder-particle spouted bed.

$$H_2CO_{3(l)} = HCO_3^- + H^+ = CO_3^{2-} + 2H^+ \quad (3)$$

3. Chemical reaction between dissolved $CO_2$ and the dissolved $CO_2$ reagent:
   (i) Dissolution of hydrated lime sorbent in the slurry droplet:

$$Ca(OH)_{2(g)} = Ca(OH)_{2(aq)} = Ca^{2+} + 2OH^- \quad (4)$$

   (ii) Precipitation of calcium carbonate:

$$CO_3^{2-} + Ca^{2+} = CaCO_{3(g)} \quad (5)$$

4. Evaporation of the water in the droplet.

Generally, the overall chemical reaction, which occurs with hydrated lime, can be expressed in a simple form as:

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O \quad (6)$$

## 3. Materials and methods

The reactor was a Pyrex glass column with 880 mm height, 104 mm I.D. and 48° cone angle. The diameter of gas inlet orifice was 7 mm. To prevent heat loss, the bed wall was covered with glass wool. Spherical glass beads of 500–840 μm diameters with average diameter of 670 μm and density of 2400 kg/m$^3$ were used as spouting medium. Air supplied by a central air compressor, was passed through an oil filter. The de-oiled air was mixed with $CO_2$ from a cylinder to form the (simulated) flue gas. Commercial $CO_2$ gas with 99.5% purity was purchased from the market in 20 kg cylinders. The flow rate of air was monitored by a velocity meter and the flow of $CO_2$ was adjusted with a rotameter. The mixture of air and $CO_2$ was preheated by an electronic heater and from the bottom, fed to the PPSB reactor. The $CO_2$ concentrations at the inlet and outlet of PPSB were measured by an infra-red $CO_2$ gas monitor (0–3000 ppm, Guardian Plus, Edinburgh Instruments Limited). The