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ABSTRACT

A novel two-interconnected fluidized bed system was developed to separate fine and coarse particles by means of particle size difference. Coarse (212~300 μm) and fine (63~106 μm) particles were separated perfectly using the solid separator. The effects of the fluidizing velocity, solid injection velocity, diameter of solid injection nozzle, and solid height on the solid separation rate were investigated. Moreover, continuous solid separation and circulation test up to 20 hours was performed to check feasibility of stable operation.

INTRODUCTION

Two-interconnected fluidized bed systems are widely used in various processes. Among those processes, sorption enhanced steam methane reforming and sorption enhanced water-gas shift processes use two particles, CO_2 absorbent and reforming or WGS catalyst, in one fluidized bed to enhance reforming or shift reactivity by fixation of CO_2 into the CO_2 absorbent. However, the CO_2 absorbent should be transported to another reactor to regenerate (release CO_2) at higher temperature. In this case, catalyst will be transported to the regenerator with CO_2 absorbent and it can cause decay of reactivity of catalyst and requires higher solid circulation rate (1). Therefore, it will be extremely desirable if only CO_2 absorbent can be transported to the regenerator.

To solve these problems, cyclone or segregation phenomena have been considered as the possible methods for selective solid circulation. However, segregation method is inapplicable if two particles have narrow size difference or density difference and perfect separation is impossible. Moreover, if we use cyclone method, fast fluidized bed or riser should be used to transport the solid mixture to the cyclone, but the fast fluidized bed system cannot be used for low reaction rate particle because of low residence time in the fast fluidized bed and perfect separation is also impossible (2).

In this study, a novel two-interconnected fluidized bed system was developed to separate fine and coarse particles by means of particle size difference using solid separator equipped with metal screen. Coarse (212~300 μm) and fine (63~106 μm) glass bead particles were used as bed material representing WGS or reforming catalyst and CO_2 absorbent, respectively. For perfect solid separation, metal screen was used and solid injection method was used as the driving force for solid separation. First, solid separation rate and effects of variables were investigated.

Next, continuous solid separation and circulation was demonstrated using two-interconnected fluidized beds system.

SOLID SEPARATION TEST

Experimental

Figure 1 shows a fluidized bed system for solid separation test. The major components consist of plenums, bubbling beds, solid separator, solid injection nozzle, cyclone, and valve for solid collection. The plenum is 0.15 m high with an internal diameter of 0.15 m. The bubbling bed consists of lower transparent column, solid separator column, and upper transparent column and each column has 0.5, 0.3, 0.3 m high and 0.15 m I.D. A perforated gas distributor has 24 holes with 1 mm I.D. and separates the fluidization column and the plenum. A differential pressure transducer (Siemens, Smart type, 0~1,000 mmH_2O) was used to measure pressure drop across the bed and the measured data was recorded into the PC through DAQ system (Agilent, 34970A).

Air was used as fluidizing and solid injection gas and two MFCs (Brooks, 5851E & 5850E) were used to control the flow rates. Mixture of coarse (212~300) and fine (63~106 μm) glass beads were used as bed material representing WGS or reforming catalyst and CO_2 absorbent, respectively. A metal screen (80 mesh, 180 μm, 0.017 m^2) was installed at an angle of 30^o against the column wall. Fine particles passed the metal screen returns to the bubbling bed through the solid return pipe and the valve.

A solid injection nozzle was installed through the plenum and the distributor. There are solid intake holes on the solid injection nozzle. Further details of the solid injection method using the solid injection nozzle are available elsewhere (3).

The gas flow rate to the plenum (for fluidization) and the solid injection nozzle, inside diameter of the solid injection nozzle, and the solid height were considered as the experimental variables. The solid separation rate was measured by particle weight measurement technique (4). At the steady-state condition, we closed the valve. After capturing of the solids, solid separation rate was calculated based on the weight of solids and time. The detail experimental conditions are provided in Table 1.

Table 1 Summary of experimental conditions and variables (solid separation test)

Variables	Values
Solids (glass beads)	Fine (63~106 μm) + Coarse (212~300 μm)
Mixing ratio of fine to coarse	2
Solid height (static bed height) [m]	0.3, 0.4, 0.5
Fluidization velocity [m/s]	0.016(2U_{mf}), 0.024(3U_{mf}), 0.032(4U_{mf})
Solid injection nozzle inside diameter [mm]	3.7(1/4"), 7.5(3/8")
Solid intake hole diameter [mm]	5
No. of solid intake holes [#]	4
Solid injection velocity [m/s]	1.08~2.95

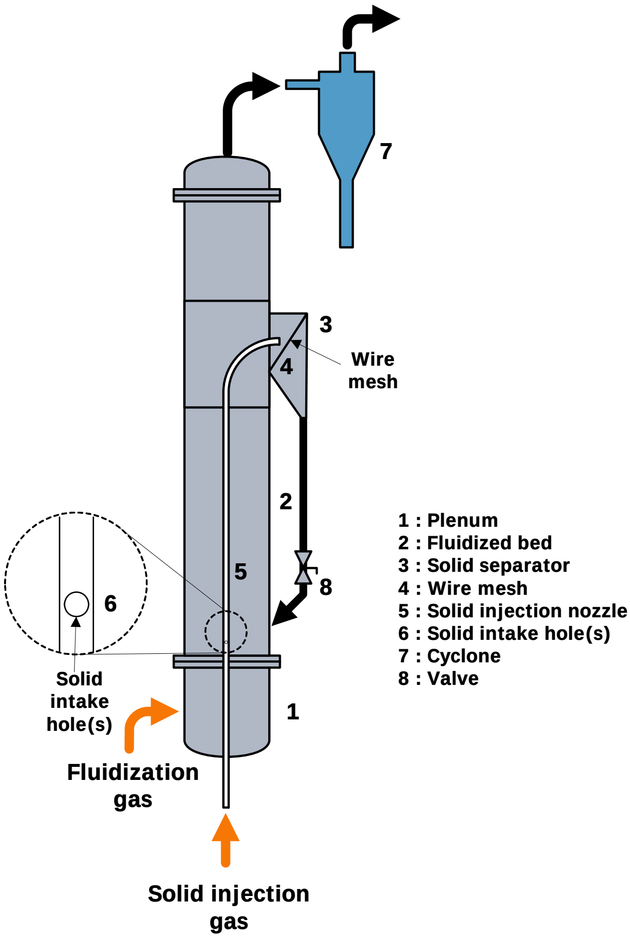

Figure 1. Schematic of solid separation test apparatus.

Results and discussion

To determine gas flow rate through bubbling fluidized beds, minimum fluidization velocity was determined by bed pressure drop measurement and it was 0.008 m/s for the solid mixture. To check the perfect solid separation, separated solid by the solid separator was sampled and analyzed the particle size using the standard sieve (140 mesh, 106 μm). All samples were smaller than 106 μm and we could conclude that the perfect separation is possible by using the solid separator.

Fig. 2(a) and (b) show effects of solid injection velocity, solid height (static bed height), and fluidization velocity on solid separation rate. For two kinds of solid injection nozzles (3.7 and 7.5 mm I.D.), the solid separation rate increased as the solid injection velocity and the solid height increased because the solid injection rate and possibility to contact with the solid separator increased. However, the effect of the fluidization velocity (2~4 U_{mf}) was negligible within the range of this study.

Comparison between Fig. 2(a) and (b) indicates that solid separation rate increased as the diameter of solid injection nozzle increased because the solid injection rate increased as the diameter of solid injection nozzle increased (5).

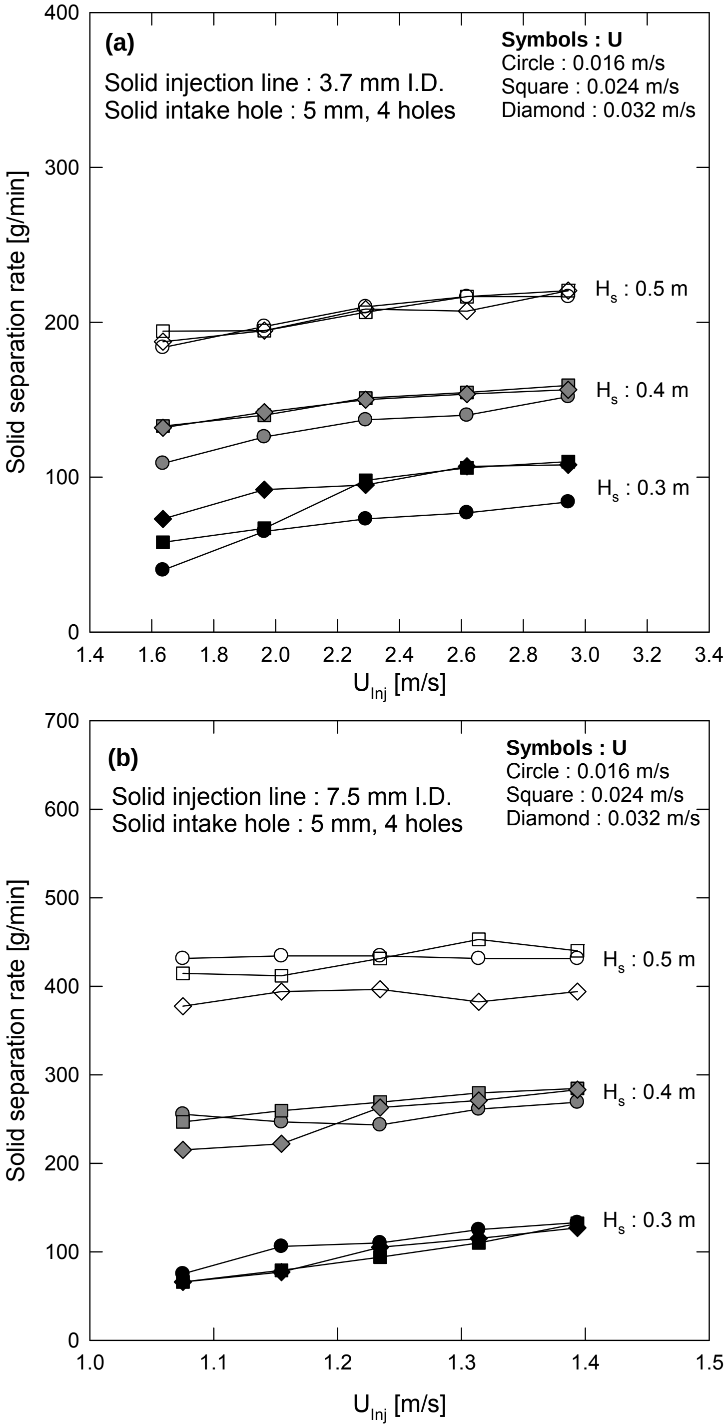

Figure 2. Solid separation rate versus solid injection velocity.

CONTINUOUS SOLID SEPARATION AND CIRCULATION TEST

The blockage of aperture in the metal screen could be a serious problem when we use the solid separator. Therefore, long-term operation is prerequisite to prove feasibility of the solid separator. Moreover, demonstration of continuous solid separation and circulation simultaneously is also prerequisite to use the solid separator for two-interconnected fluidized bed system. In this study, continuous solid separation and circulation was demonstrated by using two-interconnected fluidized beds system. For solid circulation, novel solid circulation system using solid injection nozzle (6) was adopted.

Experimental

Fig. 3 shows a fluidized bed system for continuous solid separation and circulation test. Two fluidized beds were used for solid separation (fluidized bed A) and solid circulation (fluidized bed B), respectively. The fluidized bed A is the same as that of Fig. 1. The fluidized bed B consists of plenums, bubbling beds, solid injection nozzle, cyclone, riser, and solid return leg. The plenum is 0.15 m high with an internal diameter of 0.15 m. The bubbling bed is 0.8 m high with an internal diameter of 0.15 m. A perforated gas distributor has 24 holes with 1 mm I.D. and separates the fluidization column and the plenum. A solid injection nozzle was installed through the plenum and the distributor in the fluidized bed B. There are solid intake holes on the solid injection nozzle. A differential pressure transducer (SIEMENS, Smart type, 0~1,000 mmH_2O) was used to measure pressure drop across the bed and the measured data was recorded into the PC through DAQ system (Agilent, 34970A). Air was used as fluidizing and solid injection gas for each fluidized bed and four MFCs (Brooks, 5851E & 5850E) were used to control the gas flow rates. Solid mixture (fine (63~106 μm) + coarse (212~300 μm)) and fine (63~106 μm) particles were charged as initial bed materials for the fluidized bed A and B, respectively. The detail experimental conditions are provided in Table 2.

During the continuous solid separation and circulation test, traces of fluidization gas velocity, solid injection velocity, bed pressure drop, and solid separation rate were measured and investigated.

Table 2 Summary of experimental conditions and variables

Item	Fluidized bed A	Fluidized bed B
Solids (glass beads)	Fine (63~106 μm) + Coarse (212~300 μm)	Fine (63~106 μm)
Mixing ratio of fine to coarse	2	-
Separation area [m^2]	0.017	-
Static bed height [m]	0.4	0.3
Fluidization velocity [m/s]	0.030	0.015
Solid injection nozzle inside diameter [mm]	7.5(3/8")	3.7(1/4")
Solid intake hole diameter [mm]	5	2
No. of solid intake holes [#]	4	1
Solid injection velocity [m/s]	1.2	0.7

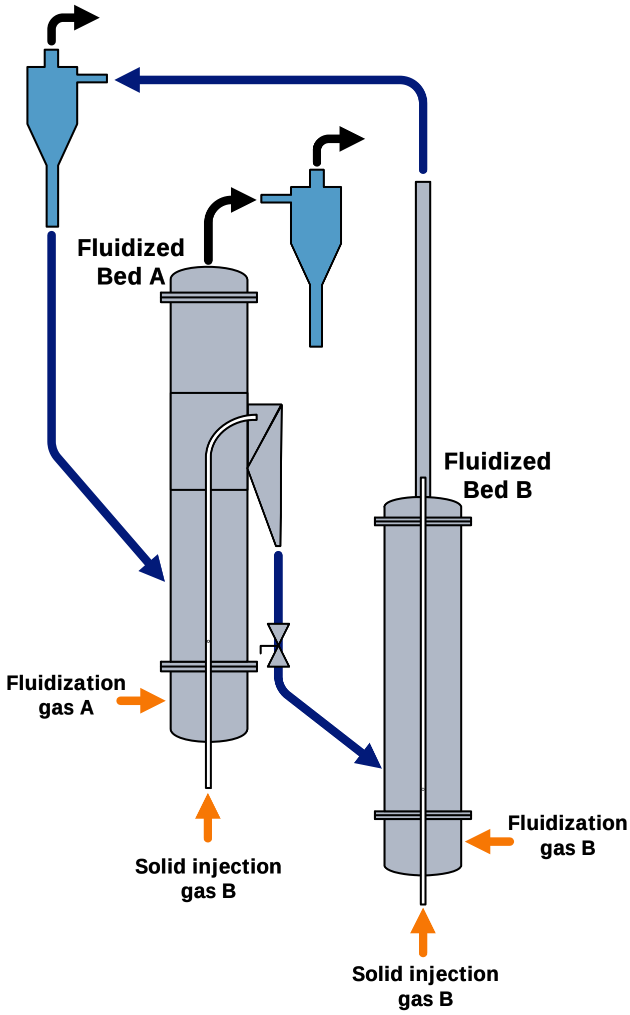

Figure 3. Schematic of solid separation and circulation test apparatus.

Results and discussion

Fig. 4(a) to (d) show traces of flow rate for fluidization, flow rate for solid injection, bed pressure drop in each bed, and solid separation rate. Total operation time was about 20 hours. During continuous solid separation and circulation, flow rate for fluidization and solid injection were maintained almost constantly, as shown in Fig. 4(a) and (b). Moreover, bed pressure drop profiles were also almost stable and these results indicate that the solid height in the bed A and B were maintained almost constantly and continuous solid separation and circulation is feasible using the novel two-interconnected fluidized beds system. The separated solid in the bed A was transported to the bed B and the same amount of solids were recycled to the bed A though the solid injection nozzle and the riser in bed B and therefore, the stable bed pressure drops (same solid height) were maintained. The solid separation rate was maintained almost constantly as shown in Fig. 4(d). This result indicates that blocking of aperture in metal screen is negligible during 20 hours operation.

After the continuous operation of solid separation and circulation test, bed material was sampled from the fluidized bed B and analyzed the particle size using the standard sieve (140 mesh, 106 μm). The solids from the fluidized bed B contained only fines (smaller than 106 μm) and we could conclude that the perfect particle separation was possible during 20 hours operation.

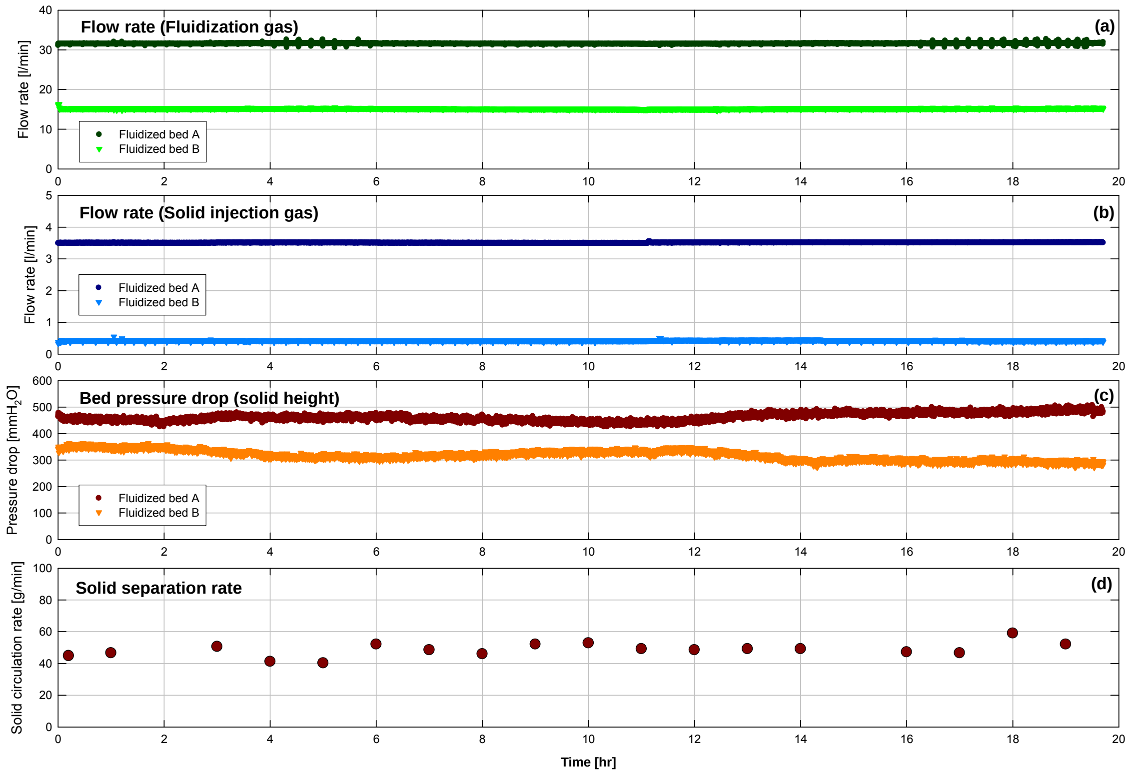

Figure 4. Traces of gas flow rate, pressure drop, and solid separation rate during continuous long-term operation.

CONCLUSIONS

The novel two-interconnected fluidized beds system for selective solid circulation using solid separator was developed. The solid separation rate increased as the gas velocity through the solid injection nozzle, solid height, and diameter of solid injection nozzle increased. However, the effect of the fluidization velocity was negligible. Coarse (212~300 μm) and fine (63~106 μm) particles were separated perfectly using the solid separator and the solid separation rate was ranged from 40 to 453 g/min. We also proposed two-interconnected fluidized beds system for selective solid circulation equipped with the developed solid separator and the solid circulation system. Long-term operation of continuous solid circulation up to 20 hours has been performed to check feasibility of stable operation. The pressure drop profiles in two beds and the solid separation rate were maintained steadily, and therefore, we could conclude that solid separation and circulation were smooth and stable.

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NOTATION

H_s : static bed height [m]
U : fluidizing gas velocity [m/s]
U_{inj} : gas velocity through the solid injection nozzle [m/s]
U_{mf} : minimum fluidization velocity [m/s]

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