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ABSTRACT

There are many gas-solid reaction systems which take place simultaneously in a single reactor, such as coal gasification. By splitting the reactions, high concentrated gases can be obtained without separation processes. Dual fluidized bed was proposed for this purpose. Similarly, simultaneous adsorption/desorption systems with dry sorbent for CO_2 capture and the gasification reaction system with a char combustor and a gasifier separately were developed.

For improving gas and solid mixing efficiencies of the dual fluidized beds, a hitherto unknown partitioned fluidized bed (PFB) is proposed. A basic concept of PFB is that lower parts between two separated fluidized beds are linked (opened), whereas upper parts are blocked by walls. Solid mixing occurs in lower parts with preventing gas mixing. The solid residence time becomes longer than that of dual fluidized bed and the high conversion of solid can be obtained.

In this study, the gas and the solid mixing behaviors were investigated in three partitioned fluidized beds (left, center and right). The size of each fluidized bed is 7 cm (w) X 7 cm (d) X 30 cm (h) and partitioned above the 7 cm of distributor. Air and CO_2-air mixture were used as fluidizing gas in each partitioned fluidized bed. For the gas mixing experiments, glass bead particles with 150 micron and density of 2.5 g/cm^3 were introduced. Outlet gas concentrations of each fluidized bed were analyzed by IR and then the gas exchanges between the reactors were calculated. For the solid mixing experiments, the polypropylene particles with 1000 micron and the density of 0.883 g/cm^3 were continuously fed into the reactor. The gas mixing percentages were 0.4 ~ 16.0% of input gas amounts with varying gas velocities. The solid discharge rates in center and right side can be controlled by operating conditions.

INTRODUCTION

Dual fluidized bed is proposed for the high concentrated product gas, is developed in oxidation and reduction reaction of oxygen donor particles in chemical looping combuston systems, adsorption and desorption reaction systems with dry sorbent for CO_2 capture, and the biomass gasification reactor with char combustor.

In chemical looping combustion (CLC), circulating particles are oxygen donor, consisting of metal oxide, are reduced to metal with methane in fuel reactor. Reduced metal particles are oxidized to metal oxide with air in air reactor. In fuel reactor, the produced gas is only CO_2 and H_2O, and CO_2 is recovered by condensing water. The sequestration ready CO_2 can be obtained in combustion of methane with air.

In general, one reactor is exothermic, and the other is endothermic reaction. For supplying the heat to endothermic reactor, the heat carrier solids are circulated between two reactors.

For effective heat transfer from one reactor to another, Lee et al. (1) suggested the annular type reactor, with endothermic reaction inside and exothermic reaction outside as internally circulated fluidized beds.

Simplifying the dual fluidized bed system, Johansson et al. (2) Chalmers University in Sweden investigated the gas leakages between the two reactors in CLC system. Their results show the 10 to 35% gas exchange rates.

In biomass gasification with dual fluidized bed, biomass is gasified with steam in gasification reactor and produced gas and char. Char is transported to char combustor and combusted with air. Heated bed materials in char combustor are transported to biomass gasification reactor and supplied the energy for gasification reaction. (3).

The solid residence time depend on solid feed rate in a fluidized bed. In dual bed system, the solid residence time depends on the sum of solid feed rates and solid circulation rates. If the requirement of heat is increased, it is necessary to increase the solid circulation rates. It brings the short residence time of solids and reduces the solid conversion.

For solving the disadvantage of the dual fluidized bed, partitioned fluidized bed is proposed. It is opened in lower part and blocked in upper part of the fluidized beds. Solid mixing occurs in lower parts and no gas mixing is allowed. The solid residence time is longer than that of dual fluidized bed and the high conversion of solid can be obtained.

The purposes of this study are to understand the gas and solid mixing characteristics and to quantify the solid flux between the reactors under varying operating conditions.

EXPERIMENTAL

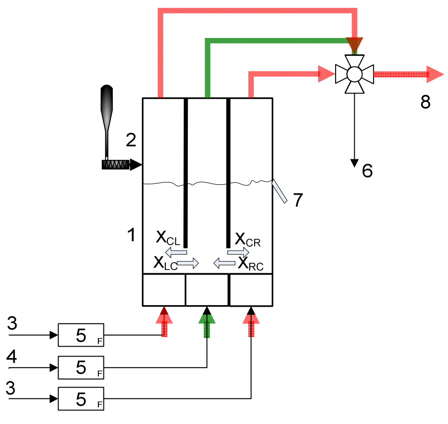

Figure 1. Schematic diagram of three partitioned fluidized bed apparatus

1. Three partitioned fluidized bed
2. Solid screw feeder & solid hopper
3. Air
4. Air + CO_2
5. Mass flow controller
6. Gas Analysis System
7. Solid discharge
8. Vent

The tests were carried out in a three partitioned fluidized bed reactor with 7 cm X 7 cm, and 30 cm height transparent Plexiglas and partitioned above the 7 cm of distributor, as shown in Fig. 1. The distributor was made of stainless steel perforated plate with 1 cm pitch, 1 mm hole, and partitioned calming section.

For the gas exchange experiments, glass beads with size of 150 micron and density of 2.5 g/cm^3 were used as fluidizing particles. Air and CO_2-air mixture were introduced through rotameter as fluidizing gases and O_2 and CO_2 outlet gas concentrations in each partitioned fluidized bed were analyzed by IR. The gas exchange rates were calculated by material balances. Supposing that CO_2-nitrogen mixture is fed into the left-side bed and air (O_2-nitrogne mixture) is fed into the center bed. At first, CO_2, O_2 compositions and flow rates at the inlet and the outlet of the each bed should be measured and/or calculated respectively. Then, substitutes them into below equations;

$$XLC = \frac{V_C \times y_{C,CO_2}}{F_L \times x_{L,CO_2}} \tag{1}$$

$$XCL = \frac{V_L \times y_{L,O_2}}{F_C \times x_{C,O_2}} \tag{2}$$

Where, the XLC (Eq. 1) is the gas exchange ratio from the left side bed to the center bed and the XLC (Eq. 2) is vice versa. F and V are inlet and outlet flow rates respectively. x and y are inlet and outlet mole fractions respectively. Subscripts of L and C mean left and center beds each other.

For the solid mixing experiments, the polypropylene (PP) with particle size of 1000 micron and density of 0.883 g/cm^3 were continuously fed into the glass beads fluidized bed with 500 g/h by the screw feeder. Discharged solids in center and right side were collected at every 10 minutes and measured the weight of glass beads and PPs.

RESULTS AND DISCUSSION

Gas Exchange Experiments

The effect of gas velocity on gas mixing is shown in Fig. 2. In these experiments, the gas velocity of each reactor was same. Left side, center and right side gas velocities were 1.5, 2, 2.5 and 3 times of minimum fluidizing velocity (U_{mf}).

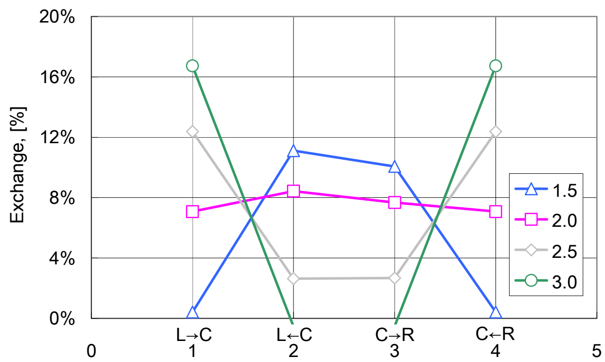

Figure 2. The gas exchange rate with gas velocities.

With Increasing the gas velocity from 1.5 to 3.0 U_{mf}, gas exchange rates from the center to left(XCL) and right(XCR) were decreased while the gas flows from the left and right to center (XLC and XRC) were increased. In case of 1.5 * U_{mf} condition, XCL and XCR were 11% and 10% respectively, whereas both XLC and XRC were about 0.5%. It means that the gas flows from left or right sides to center are negligible while the gas flows from the center to left or right sides should be considered cautiously. In 2.0 U_{mf} conditions, gas exchange rate of each reactor was 8 %, In 3 U_{mf} conditions, both XLC and XRC were about 17% and XCL and XCR could be negligible, almost zero. Generally bed densities and bed heights are changed accordingly with the gas velocities and the hydrodynamics of fluidized bed, such as bubble characteristics. Therefore the pressure drop between the top and the bottom of the bed are generated by exchanging the gas flow. The pressure drop can be adjusted at each reactor.

The main mechanism of gas mixing is bubble hydrodynamics. The bubble size is increased with bed height by coalescence of bubbles. Due to the coalescence of the bubbles from the left side and the center reactors, gases in the bubbles are well mixed. The bubble will burst at the boundary of the reactor, one bubble go through left side and the another bubble go through center side. So the gas exchange was occurred between reactors. If bubble is not disintegrated at the boundary of the reactor, that is, bubbles go through center or left side, that means there is only one side flow between reactors.

The Fig. 3 shows the effect of gas velocity of left and right sides on gas exchange rate with keeping the center gas velocity (1.5 U_{mf}). The gas velocities of the left and the right sides were same. In this result, there is no gas transfer from side to center direction (XLC and XRC are almost zero). With increasing the side gas velocity from 1.5 U_{mf} to 3 U_{mf}, gas exchange rate from center to side was decreased to 3%. While in the case of UL, UC and UR is 3, 3 and 3 U_{mf}, respectively, both XLC and XRC were 17%, UL, UC and UR is 3, 1.5 and 3 U_{mf}, respectively, XLC and XRC were less than 0.5% and XCL and XCR were 3%. With increasing the center gas velocity, gas exchange rate XLC and XRC were increased while XCL and XCR were decreased. As can be seen in Figs. 2 and 3, gas exchange ratio can be minimized within 17% by controlling the operating conditions, such as gas velocities of each bed.

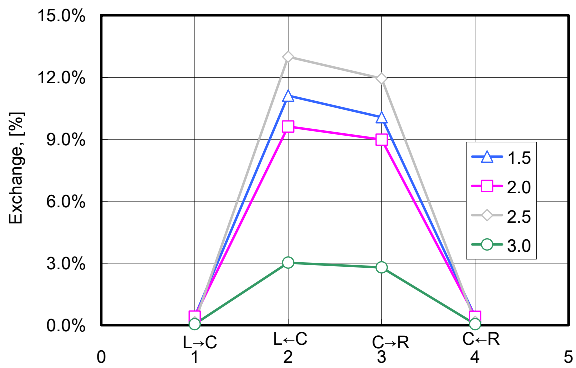

Figure 3. The gas exchange rate under varying the left and right gas velocities with keeping Uc=1.5 U_{mf}.

As can be seen in Fig. 3, the trend of gas exchange behaviors at 2.5 Umf is somewhat different from those at other velocity conditions. In this study, we repeated same experiments at this velocity condition several times. However, each time we tried, we got similar results. It is considered that these phenomena occur due to the overall effect of hydrodynamics and diffusions between gases and solids. In addition, there is a great possibility that analysis error may be happened because of the low concentrations of CO_2 and O_2. Further observations are needed.

Solid Mixing Experiments

The PP particles are fed into the glass beads fluidizing bed. The feeder is located in left-hand side in a partitioned fluidized bed. Time histories of overflow discharge rate in center and right side reactor with keeping the velocity of left side, center and right side (2 U_{mf} each) are shown in Figure 4.

After feeding of PP particles, the total discharge rate is approach to 800 g/hr. The discharge rate of center and right side is almost same in this condition. Discharge rate of PP particles are increased with time, because total amount of fed PP particles are continuously increased. The PP feed rate is 500 g/hr and the discharge rate is about 800 g/hr. However converted feed rates from weight to volume were almost same as each other. Particles initially discharged are almost glass beads, the weight of same volume is greater than that of PP feed rates, because the density of the glass beads is higher than that of the PP particles, so the discharge rate becomes higher than the feed rate.

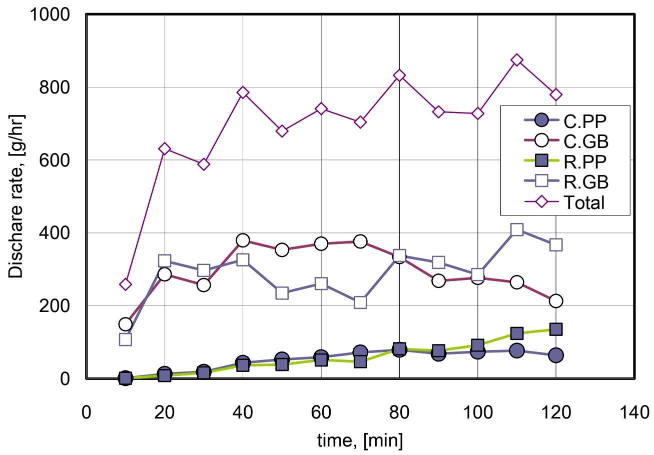

Figure 4. Overflow discharge rate in center and right side reactor with time in U_L, U_C, and U_R =2 U_{mf}.

The movement of particles in the left reactor is mainly downward for discharge, and the movement of particles in center and right side reactor is upward. The solid behavior is affected by the side-to-side rocking motion of bubbles (4). There are clouds and wakes in bubbles, and solids in clouds and wakes are continuously exchanged the particles in dense phase. The bubble is rising to the top of fluidized bed and burst out in the surface of fluidized bed. The particles in bubble will spread out evenly to the fluidized bed surface. The solid movement in the bed surface is downward in the wall side, because of the continuously upward solid movement in the center by rising of bubbles.

The PP particle weight percent in center and right side reactor with time is shown in Figure 5. The gas velocity of left, center and right is 2, 2 and 2 U_{mf}, respectively.

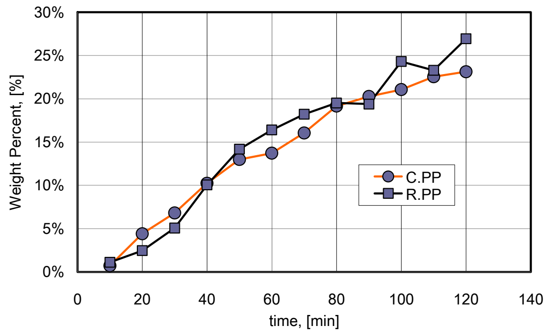

Figure 5. The PP particle weight percent in center and right side reactor with time, gas velocity of left, center and right = 2 Umf.

PP Solid weight percent is increased with time. In addition, owing to the highly efficient mixing characteristics of fluidized bed, the PP concentrations of the beds and those of the outlet was almost same. In the view point of particle concentrations, partitioned fluidized bed behaves very similar with continuous stirred tank reactor (CSTR).

For comparing the solid discharge rate with the center and right gas velocity, the operating conditions of velocity of left, center and right are selected as 3, 2, 4 and 3, 4, 2 Umf. The results are shown in Fig. 6 and Fig 7, respectively.

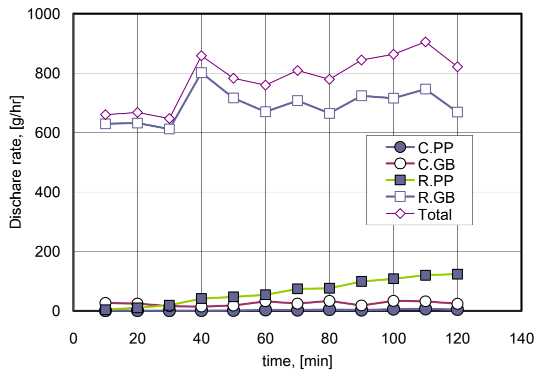

Figure 6. Overflow discharge rate in center and right side reactor with time in U_L,=3, U_C=2 and U_R =4 U_{mf}.

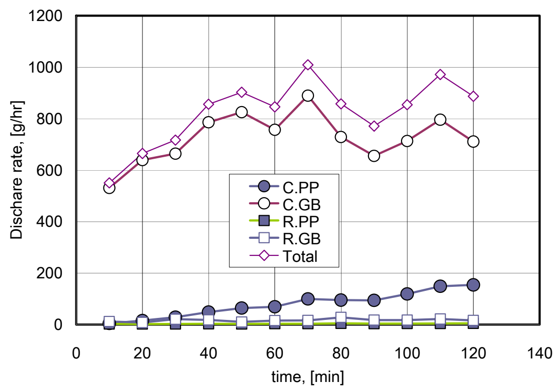

Figure 7. Overflow discharge rate in center and right side reactor with time in U_L,=3, U_C=4 and U_R =2 U_{mf}.

The bed density is a function of operating conditions. Solid hold-up, ε_S, is a function of gas velocity. With gas velocity, ε_S is decreased. With the different gas velocity, it bring a different bed density, there is a different bed pressure between the beds, so the solids are flowed from the higher density bed to lower density bed. That is why the solid discharge rate of higher gas velocity is greater than that of the lower gas velocity.

The PP particle weight percent in center and right side reactor with time is shown in Figure 8. The gas velocity of left, center and right is 3,2,4. In the result, PP particle concentration is same in center and right reactor, The result of 3,4,2 condition showed same particle concentration.

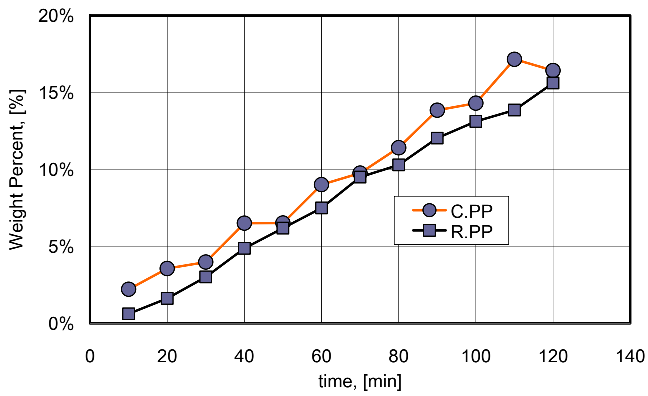

Figure 8. The PP particle weight percent U_L,=3, U_C=2 and U_R =4 U_{mf}.

The solid discharged rate in the center is expressed by the ratio of center gas velocity and right one, shown in Fig. 9.

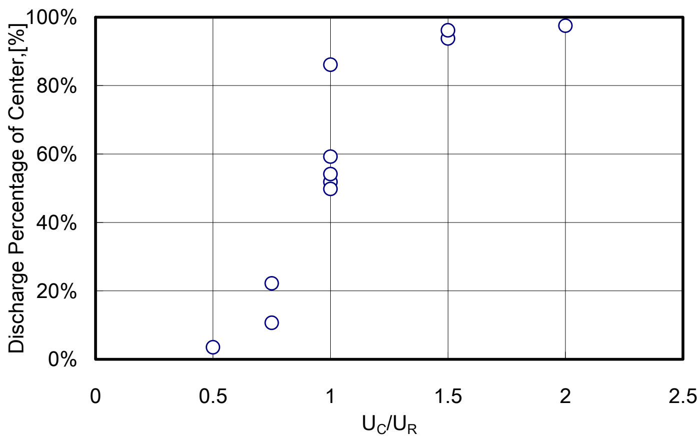

Figure 9. The effect of overflow fraction of center versus velocity ratio of center and right side.

The same ratio of gas velocity in the center and right, the overflow percentage of center side was almost 50%. With the different gas velocity, there is a different bed pressure between the beds there is solid flow from the higher density bed to lower density bed. In a range of velocity ratio between 0.5 and 1.5, the solid discharge is proportional to the ratio of the center to the right side gas velocity.

This result shows that the discharge rate in each side can be controlled by the operating conditions.

CONCLUSIONS

Gas and solid mixing experiments in three partitioned fluidized bed were executed. Gas mixing between the partitioned fluidized beds can be minimized by controlling the gas velocity within 17%.

Center and right side solid discharge rate can be controlled by the each side fluidized bed gas velocity. The discharge percentage of center is mainly affected by the ratio of U_C to U_R. Solid mixing in three partitioned fluidized bed can be considered CSTR.

ACKNOWLEDGEMENT

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NOTATION

U	gas velocity, mf; minimum fluidizing, L; left, C; Center, R; Right
X	gas exchange rate, CL ; center to left CR ; center to right (and vice versa)
ε_S	solid hold-up

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