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## ABSTRACT

A circulating fluidized bed coal gasifier cold model which consists of an acrylic riser, a downer, and a bubbling fluidized bed were set up. Flow behaviors were investigated using silica sand with the solid mass flux up to 336 kg/m$^2$•s. The effects of the solid inventory and the seals between the three reaction zones on the solid mass flux were investigated and discussed.

## INTRODUCTION

Clean coal technology using gasification is a promising clean way to convert coal into electricity, hydrogen and other valuable energy products. Most existing coal gasification technologies are suitable for high quality coal such as bituminous and petroleum refinery waste products but inefficient, less reliable and expensive for low-rank coals such as lignite, sub-bituminous coal and high ash coal (1-3). However, these low-rank coals share approximately 50% of the whole coal resources and ensure power generation for another 80 years. Low-rank coals always contain ash and high moisture. The conventional coal gasification process with a high temperature could melt the ash, forming a glassy slag that eventually eats through the ceramic tiles that protect the reactors` steel walls. Therefore, more advanced coal gasification technologies at low temperature are required in order to use these coals effectively and to reduce greenhouse gas emissions. Integrated gasification combined cycles (IGCC) technology has proved to be commercially viable against conventional coal fired power plants. Recently, advanced coal based IGCC (A-IGCC) and advanced integrated gasification fuel cells combined cycles (A-IGFC) using exergy recuperation technology have been proposed (1), in which high temperature thermal energy exhausted from a gas turbine or solid oxide fuel cells (SOFC), is recuperated thermally into pressurized steam and then recuperated chemically into hydrogen and CO via steam gasification of coal in the gasifier. Net electrical efficiencies of A-IGCC and A-IGFC are expected to reach 57 and 65%, respectively. Comparing with the conventional oxygen-blown coal gasification at high temperatures (1100-1500 °C), coal gasification with steam could be performed at lower temperatures (700-1000° C), and the energy for oxygen production can be reduced to a great extent. This low-temperature gasification technology should be also benefit for the low-grade coal gasification.

Dual-bed circulating fluidized bed system (DCFB), in which coal is pyrolyzed/gasified in one bed and the unreacted char is combusted in the other bed, and the heat from the combustion of char is transferred by the rapid and large solids circulation, was developed for the steam gasification of coal. However, the produced tar, light hydrocarbon gases and inorganic gases at the initial pyrolysis stage were found to severely hinder the gasification of the char (4). Therefore, the produced volatiles in pyrolysis stage should be removed out from the char surface in order to maintain the catalyst activity and to enhance the efficiency of char gasification (2,3). In the present study, a triple-bed combined circulating fluidized bed (TCFB) system, which composed of a downer, a bubbling fluidized bed (BFB), and a riser, is proposed. The coal could be pyrolyzed rapidly in the downer at first, and then, the obtained gas and tar are separated from the char using a gas-solid separator. The charcoal enters the BFB to be gasified with the steam. The unreacted char flows into the riser to be combusted with air. The produced heat can be carried by inert solid medium such as sand, and circulated into the downer with a high mass flux and the BFB to provide the heat needed in the pyrolysis and gasification processes. TCFB is expected to replace the dual fluidized bed gasification (DFBG) system, in which pyrolysis and gasification are carried out at one bed and char combustion at the other bed (3), and improve the whole gasification efficiency. In this study, such a TCFB coal gasifier cold model was set up, and the flow behaviors were investigated.

## EXPERIMENTAL

The schematic diagram of experimental system is shown in Fig. 1. The system is composed of an acrylic riser (0.05 m-I.D.X6 m-high), a solid distributor for downer, a downer (0.1 m-I.D.X1.3 m), a gas-solid separator, a BFB (0.37X0.08X1.5 m). Sand particles with a density of 2600 kg/m$^3$ and an average particle size of 80 μm (minimum fluidization velocity=0.0058m/s) were used as bed materials. During the operation, solids coming from the BFB were carried upwards by air along the riser tube. At the top of the riser, the solids passed through a smooth elbow into a cyclone for gas-solid separation. At the top of the downer, the solid were redistributed by a solids distributor located below the dipleg of the cyclone. The solids were overflow into 7 vertically positioned brass tube with a diameter of 15 mm with the assistant of minimum fluidization gas. The downward flow air was introduced into the downer at the entrance of the downer. The co-current down-flow gas-solid flowed down along the downer, and at the end of the downer, the solids was

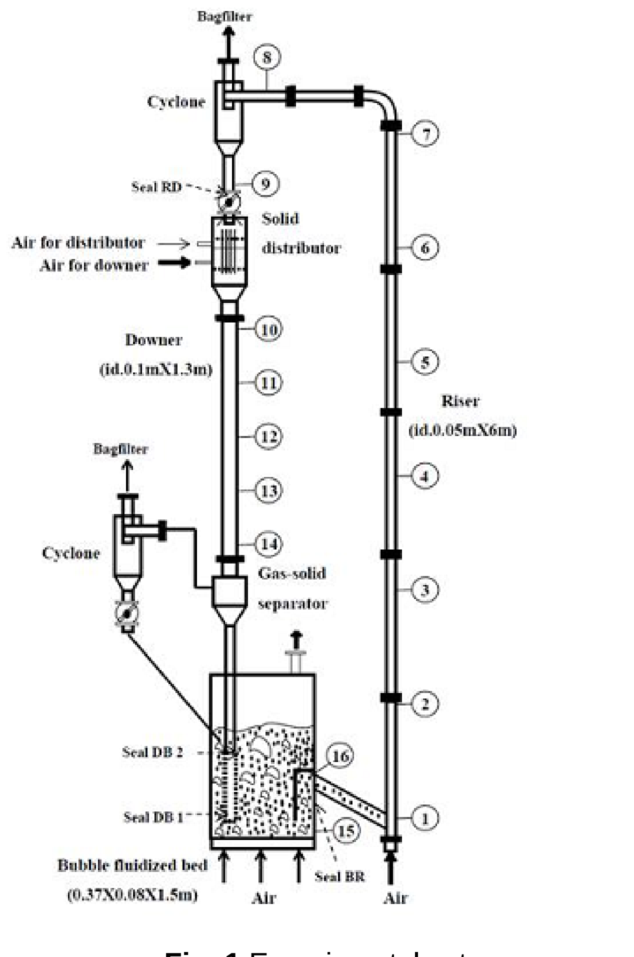


**Fig. 1** Experimental setup

separated with the gas by a quick inertial separator with an efficiency of more than 96% and returned to the BFB. The solids entrained by the gas was further separated by a cyclone and returned to the BFB. The superficial gas velocities of the riser and the downer ranged from 3 to 8 m/s and from 0 to 5 m/s, respectively, but that of BFB was fixed at 0.03 m/s.

The seal between the BFB and the riser (seal BR) and the seal between downer and BFB (seal DB) that hinder the gas bypassing from riser to BFB and from downer to BFB, respectively, were non-mechanical seals. The exit position of the seal BR was fixed at the 0.3 m high above the distributor of BFB. In order to investigate the effect of the length of the seal DB tube (0.05 m-I.D.) inserted into the BFB on the flow behaviors, two exit positions, i.e., 0.1 m (seal DB1) and 0.95 m (seal DB2) above the distributor of the BFB, of the seal tube were chosen. The seal between the riser and the downer (seal RD) was realized by adjusting the openness of a mechanical valve to form a moving bed layer which blocks the gas from the riser to the downer but keeps the particles flowing into the downer. 16 pressure taps were installed along the CFB systems as shown in Fig.1 and differential pressure sensors (Keyence Corp., AP48) were used. The output signals from the differential pressure sensors were acquired at a sampling frequency of 50Hz via a data acquisition system (CONTEC, AIO-163202FX) and a laptop computer. Solids mass flux ($G_s$) was measured using a butterfly valve with amounts of accumulated particles for a given time period, and determined from the mean value with five times measurements at steady state.

## RESULTS AND DISCUSSION

### The Effect of the Seal DB on Flow Behaviors

The effects of the similar seals DB and BR on the flow behaviors of binary fluidized bed system with a $G_s$ lower than 25 kg/m$^2$•s have been investigated by Xu et al (5). As shown in Fig.1, the seal DB tube was inserted into the BFB, and a moving bed was formed inside the tube during the operation and used as the seal to block the gas from the downer to flow into the BFB. It should be noted that the moving bed height is proportional to the distance inserted into the BFB. However, the pressure drop across this seal, which has great effect on the particle moving velocity in the seal, is proportional to the moving bed length (6). Thus, a long inserted tube could

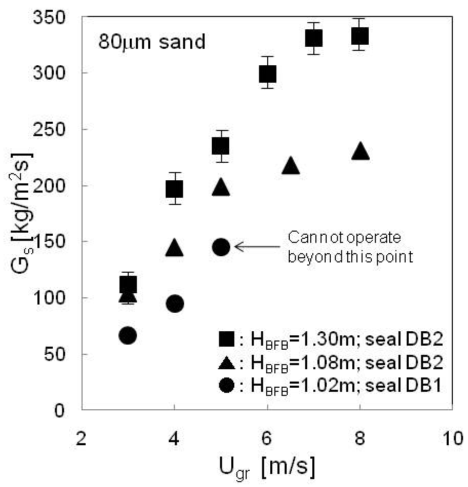


**Fig.2** Effect of the seal DB on the solids mass flux

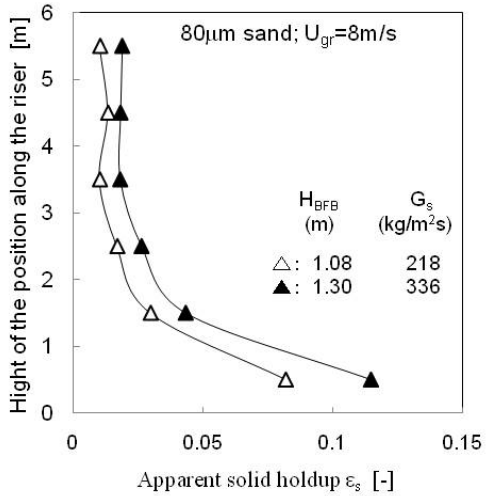


**Fig.3** Axial profile of apparent solids holdup in the

slow down the particle moving in the seal and affect the whole solids mass flux in the TCFB. The effect of the length of the seal DB on $G_s$ is shown in Fig.2. In the case of seal DB1, when the bed height of BFB ($H_{BFB}$) was 1.02 m, $G_s$ increased with the increase in gas velocity in riser ($U_{gr}$). However, it is found that the moving bed height in the seal began to increase with the increase in $G_s$ after $G_s$ was over 100 kg/m$^2$•s. When the $G_s$ increased beyond 145 kg/m$^2$•s, the moving bed height abruptly increased to the level of gas-solid separator, stopping solids circulation. This phenomenon was not found by Xu et al.(5) when the $G_s$ was low. In order to solve this problem, the inserted seal tube was shortened to the position the seal DB2. In this case, the moving bed height formed in the seal tube is much shorter than that in the case of the seal DB1.

As a result, the negative effect of the seal DB on $G_s$ disappeared in the operating conditions of this study, and as shown in Fig.2, $G_s$ above 330 kg/m$^2$•s can be obtained when $H_{BFB}$ is 1.30 m. Fig.2 also shows that $G_s$ increases with $H_{BFB}$. Many reports in the literature suggested that $G_s$ can be increased by increasing the solids inventory or the static bed height in the standpipe in various other CFB systems (7-10). In order to obtain high solids mass flux in TCFB, high packed bed height in BFB is necessary.

Fig. 3 shows a typical axial profile of the apparent solid holdup $\varepsilon_s$ in the riser of the

TCFB when using the seal DB2. Similar to those in several previous studies of high density riser flow (6, 7-12), a particle flow structure with a dense phase at bottom and a relatively dilute phase in the top section was also appeared in the riser of this TCFB. Average solid holdup along the riser increased as $G_s$ increased. The average $\varepsilon_s$ in the bottom section of the riser, especially in the case of $G_s$=336 kg/m$^2$•s, is up to approximately 0.12.

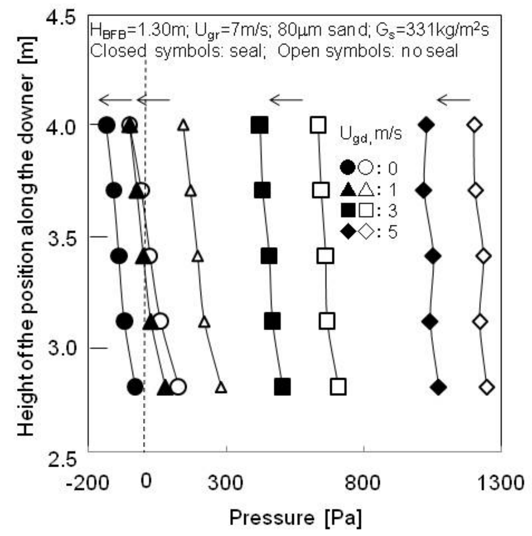


**Fig.4** Effect of the seal RD on the pressure distribution along the downer

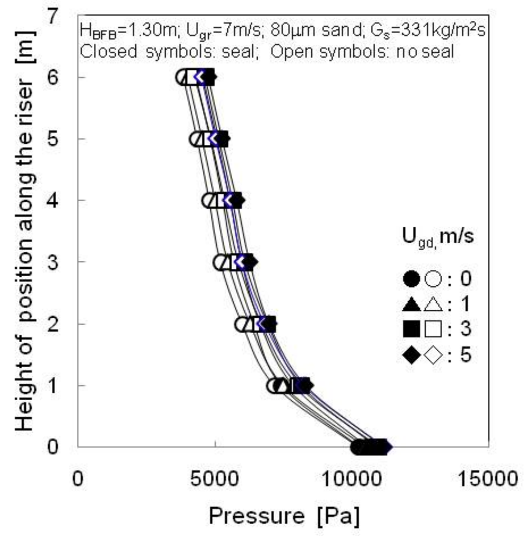


**Fig. 5** The effect of the seal RD on the pressure distribution along the riser

**Effect of the Gas Seal RD on the Pressure Distribution along Riser and Downer**

As stated above, the gas seal between the riser and the downer (seal RD) was realized by adjusting the openness of a mechanical valve to form a moving bed layer between cyclone and the downer. If no valve is set here, a part of gas from the riser could enter the downer accompanying with the solids because the gas-solid separation efficiency could reduce when no seal below the dipleg of the cyclone, especially in the case of low $G_s$.

The effect of the seal RD on the pressure distribution along the downer is shown in Fig. 4. In any case, the pressure distribution along the downer with the seal RD was different with that without the seal, and the static pressure at any point decreased to some extent due to the seal. When the superficial gas velocity for the downer ($U_{gd}$) was set to zero, the static pressures along the whole area in the present downer were negative in the seal state, but only the static pressure at the entrance zone was negative in the non-seal state. It suggested that the gas from the riser entered the downer in the non-seal state, resulting in the static pressure increased. On the other hand, when the downflow gas was introduced, the static pressure increased with the increasing of $U_{gd}$. In the present study, because the length of the downer was only 1.3 m, many downer characterizations were unfortunately not observed in detail.

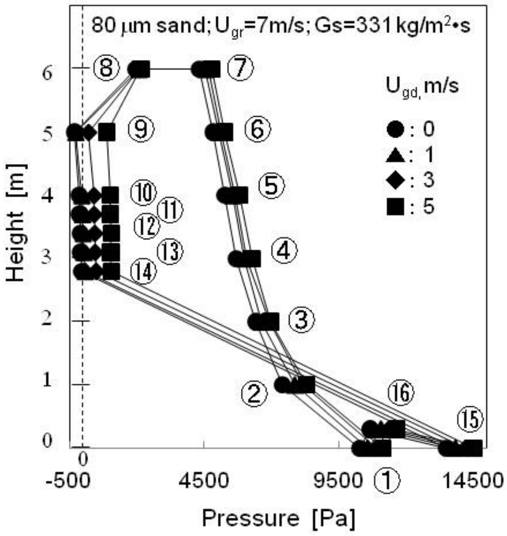


**Fig.6** Pressure loops around the TCFB system

Fig. 5 shows the effect of the seal RD on the pressure distribution along the riser at the same operating conditions as those in Fig.4. No obvious effect of the seal RD on the riser pressure distribution was found. As shown in Fig.1, there is a cyclone between the seal RD and the riser. The seal RD could increase the cyclone`s separation efficiency because it served as the valve of the cyclone dipleg (13), but it could not lead the gas to return back to the riser. Fig. 6 shows the pressure loops around the TCFB in the seal state. As can be seen, although the static pressure around the TCFB increased to some extent with the increase in $U_{gd}$, the pressure difference between point 15 and 16, which served as the driving force for the particles moving from BFB to the riser, almost kept at a constant value with a maximum deviation of 2.7%, indicating that the $U_{gd}$ has no obvious effect on the solids mass flux in the seal state. Also, due to the seal RD, no effect on the static pressure at the point 8 was found.

## CONCLUSIONS

Experiments on the effect of the gas seal on the flow behaviors of a triple-bed combined circulating fluidization system was carried out using silica sand with an average particle size of 80 μm as a bed material at solids mass flux ranges from 80 to 336 kg/m$^2$•s and the superficial gas velocity of the riser ranges from 3 to 8 m/s. In order to keep the TCFB systems running at high solid fluxes, the seal between the downer and BFB should have low resistance to the solids moving. The seal between riser and downer has great effects on the pressure distribution in the downer.

## ACKNOWLEDGMENTS

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