Experimental Research on Gas-solid Flow in a Dual Fluidized Bed

Jun Li, Changqing Dong*, Junjiao Zhang and Yongping Yang

***Abstract*--Chemical-looping combustion (CLC) is a new method for the combustion of fuel gas with inherent separation of carbon dioxide. The cold interconnected fluidized beds (Ø100) were set-up for the hot model design in this work. The pressure drop of both air reactor (AR) and fuel reactor (FR) were measured and used for CLC system design. The effects of superficial gas velocity on pressure distribution of both AR and FR were presented. Before fluidization, the pressure drop characteristics of two reactors in interconnected dual fluidized bed for CLC sharply increase with the increasing of gas velocity, which just similar to that of conventional circulating fluidized bed. And after fluidization, the pressure drop of two reactors in dual fluidized bed decreased with the increasing gas velocity. It could be seen that u_{FR} must be increased with an enhancive u_{AR} value to ensure exchange of bed material, and the higher of the gas velocity, the more material could be exchanged.**

***Keywords*--Chemical looping combustion; Pressure drop; Dual fluidized bed**

I. NOMENCLATURE

AR	Air reactor
FR	Fuel reactor
□PT	Pressure drop between air box and outlet of reactor (Pa)
□Pd	Resistance of distribution plate (Pa)
□Pd_{FR}	Resistance of distribution plate of fuel reactor (Pa)
□Pd_{AR}	Resistance of distribution plate of air reactor (Pa)
□Pb	Pressure drop in main reactor (Pa)
□Pb_{FR}	Pressure drop in fuel reactor (Pa)
u_{AR}	Superficial gas velocity in air reactor (m/s)
u_{FR}	Superficial gas velocity in fuelreactor (m/s)
u_{mf}	The minimum fluidized gas velocity
Greek letters	
ρ	Particle density (kg/m^3)
$ρ_0$	Packing density of particle (kg/m^3)

II. INTRODUCTION

Nowadays, the increasing greenhouse gas emission aggravates the increase of earth temperature and causes global climate changes. Combustion of fossil fuels releases a massive amount of carbon as CO_2 into the atmosphere. It is estimated that fossil fuel based power generation contributes to about one-third of the total CO_2 released from fuel combustion today. Thus, power generation via fossil fuel combustion with effective CO_2 capture is going to become a key contributor to the energy supply in future. CLC has been proposed as a new technology which would satisfy the urgent need [1], [3], [4], [7]-[9].

A CLC system consists of a fuel reactor and an air reactor. The oxygen is transferred by the oxygen carrier from the air reactor to the fuel reactor. In this way, the nitrogen from the air leaves the system from the air reactor, whereas the flue gas from the fuel reactor consists of only CO_2 and water. After water condensation, almost pure CO_2 can be obtained without any loss of energy for separation. Many research works including the oxygen carrier development, system analysis and the reactor design have been carried out on this field [2],[5],[6],[8].

The CLC process requires a good contact between gas and oxygen carrier, as well as an exchange of oxygen carrier between the air reactor and the fuel reactor. Lyngfeltet al. proposed interconnected fluidized beds for chemical looping combustion using gaseous fuels, which was similar to a circulating fluidized bed boiler. The configuration of the interconnected fluidized beds possessed good gas-solid contact efficiency and reactivity as well as a high mixing rate of solids [10]-[13].

A CLC cold process using interconnected fluidized beds (Ø100) is proposed in this paper. The configuration

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comprises a higher velocity fluidized bed as an air reactor with a cyclone and a lower velocity fluidized bed as a fuel reactor with a cyclone too. Two fluidized beds are directly connected through the cyclones. There exists a specially designed configuration in the two fluidized beds. The configuration allows the looping position height change at the range of 100-1000mm from the bottom of the fluidized beds according to different conditions, and the total CLC system was visualized built based on Polymethyl Methacrylate (PMMA) for watching the flow characteristics of solid in the interconnected fluidized beds. In this paper, pressure changes in deferent point of fuel reactor and air reactor, the pressure drop of dual fluidized bed will be investigated experimental. The present article intends to provide some process fundamentals about the cold process of chemical looping combustion in the novel dual fluidized bed.

III. EXPERIMENTAL

A. Experimental set-up

The experiment was conducted in two bench scale interconnected fluidized beds which were directly connected through their cyclones. And the two beds (1500mm in length and 100mm i.d.) were made of PMMA. The distribution plates in main reactors were opened 20 holes(Φ6mm) equally. The opening ratio was 17.2%. And the distribution plates were covered by 80 meshes net in Taylor Standard. The experimental setup was illustrated schematically in Fig.1. It consisted of air-feed system, air reactor (AR), fuel reactor (FR), dust collector and pressure measurement system.

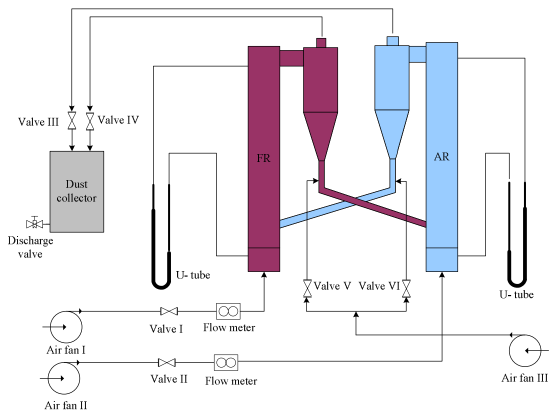

Fig.1. Schematic diagram of the experimental set-up

The measurement method of pressure drop between two different points was that the two ends of U tube were connected to the two points whose pressure need be investigated respectively. □PT (pressure drop between air box and outlet of main reactor) and □Pd (resistance of distribution plate)can be obtained using this method. According to □PT and □Pd ,□Pb , reactor pressure drop,□PT-□Pd, was obtained. The air flow rates were measured by two vortex flow meters. The accuracy was ±1.5%F.S., the linearity was ±(0.5-1.5)%F.S., and the repeatability was ±0.2% F.S.

B. Material

The physical properties of quartz sand used in this experiment were showed in table I.

TABLE I

PHYSICAL PROPERTIES OF QUARTZ SAND

Item	ρ(kg/m3)	ρ_0 (kg/m3)	Particle-size (mm)
Data	2.65	1.5	0.38-0.83

C. Pressure Drop Characteristics without Bed Material

To investigate the pressure variation of dual fluidized bed used in CLC system without material, the characteristics of which were obtained by experiments on vacant beds in different four conditions. FR fan was opened gradually with AR fan closed; AR fan was opened gradually with FR fan closed; FR fan was opened gradually with AR fan opened partly; AR fan opened gradually with FR fan opened partly. The first and the second operation conditions experiments were carried out for obtaining the resistance characteristics curve of distribution plates. And the last two experiments were carried out for gaining the pressure characteristics of the interconnected dual fluidized bed in CLC system.

D. Pressure Drop Characteristics with Bed Material

Pressure distribution of dual fluidized beds can reflect the movement and dynamic characteristics of bed material. This experiment investigated the flow characteristics of dual fluidized beds through measuring pressure distribution and pressure fluctuation under different fluidization conditions. With the existence of pressure drop caused by frictional resistance between gas and solid, pressure drop curve was employed to describe different fluidization patterns and get the minimum fluidization velocity.

Experiment with material in a certain bed material height (150mm) was carried out different conditions. FR fan was opened gradually with AR fan closed; AR fan was opened gradually with FR fan closed; FR fan was opened gradually with AR fan opened partly; AR fan was opened gradually with FR fan opened partly.

IV. RESULTS AND DISCUSSION

A. Resistance Characteristics Curve of Distribution Plates

To obtain the pressure drop of AR and FR, testing experiments of distribution plates' resistance were operated on vacant bed. The resistance characteristics curve of distribution plates of AR and FR were showed in Fig.2 and Fig.3 respectively. Two approximately curve equations of the characteristics which were obtained from the curves can reflect the resistance characteristics curve of distribution plates. The equations of AR and FR are showed in (1) and (2).

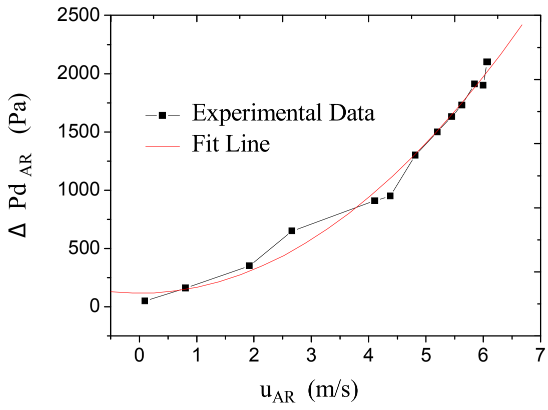

Fig. 2. Resistance characteristics curve of AR distribution plates

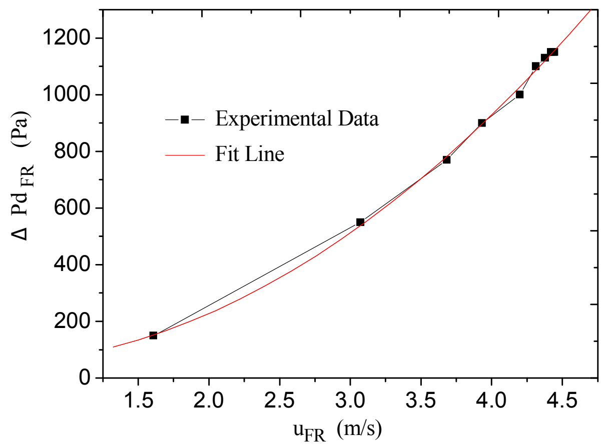

Fig. 3. Resistance characteristics curve of FR distribution plates

$$\Delta Pd_{AR} = 52u^2{}_{AR} - 2.5u_{AR} + 116 \qquad (1)$$

$$\Delta Pd_{FR} = 65.9u^2{}_{FR} - 44.7u_{FR} + 53.5 \qquad (2)$$

B. Pressure Drop Characteristics of Dual Fluidized Beds without Material

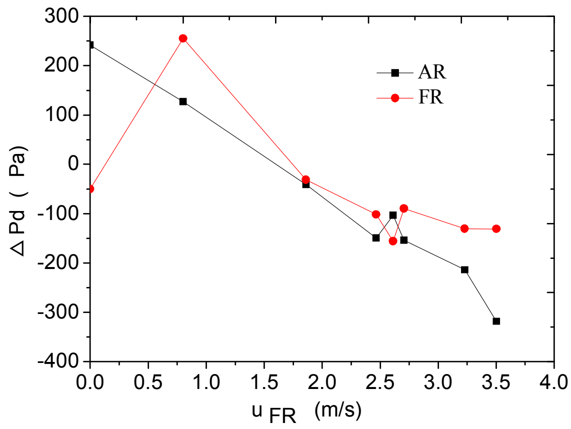

Fig. 4. Pressure drop curve with the increasing of u_{FR}

Firstly, the AR fan was opened partly, and the value of AR superficial gas velocity (u_{AR}) was 4.8m/s. Then the FR fan was opened gradually. The experimental results were showed in Fig.4.

When the FR was closed firstly, the pressure drop of FR was -50Pa, the reason was that the air flow from AR fan exert influence on the FR bed, so the pressure of outlet of the FR main reactor was higher than the bottom of FR. When the FR was opened step by step, The pressure drop of FR sharply increased firstly, and then decreased gradually with the increasing of superficial gas velocity (u_{FR}). And the pressure drop of AR decreased with the increasing of gas velocity. Both of the pressure drops began to fluctuate at the value of u_{FR} was 2.5m/s. Because the pressure drop reflected the quantity of bed material, so the fluctuation scope can be used for judging the quantity of exchanged material during interconnected fluidized beds.

Secondly, the FR fan was opened partly, and the value of FR superficial gas velocity (u_{FR}) was 3.5m/s. Then the AR fan was opened gradually. The experimental results are showed in Fig.5.

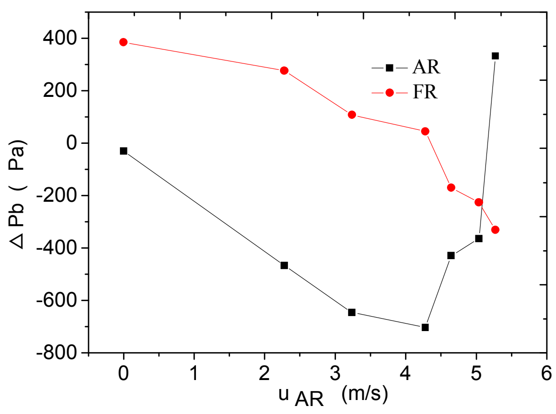

Fig. 5. Pressure drop curve with the increasing of u_{AR}

There was an obvious turning point in the AR pressure drop curve. Before the turning point, the similar curve trends were showed with the curve of the Fig.4. When the AR fan was opened step by step, the AR pressure drop sharply increased to 200pa, and then decreased gradually with the increasing of superficial gas velocity (u_{AR}). And the FR pressure drop decreased with the increasing of gas velocity. After the turning point, the pressure drop of AR began to increase. The main reason was that the air flow from FR not reached to the bottom of AR when the AR gas velocity increased up to 4.5m/s. The overall influence of FR only exerted on the top of AR, and the pressure of AR bottom increased with the increasing of AR gas velocity, when the AR gas velocity reached to 4.5m/s, the pressure of AR bottom was higher than the pressure of AR outlet. Both of the pressure drops began to cross at u_{AR} was 4m/s. Because the pressure drop reflected the quantity of bed material, so the fluctuation scope can be used for judging the quantity of exchanged material during interconnected fluidized beds.

C. Pressure Drop Characteristics of Dual Fluidized Bed with Material

At the first operation condition, the bed material height of both AR and FR was adjusted to 150mm, the FR fan was closed, and then AR fan was opened gradually. The experimental results were showed in Fig.6.

The data suggested that the value of u_{mf} was 1.5m/s .As the u_{AR} was lower than 1.5m/s, the bed material of AR was in the un-fluidized situation, and the u_{AR} was higher than 1.5m/s, the bed material of AR began to fluidize. After fluidization, the pressure drop of conventional circulating fluidized bed kept a certain value with the continuous increasing of gas velocity. However, the pressure drop of dual fluidized bed decreased with the increasing of u_{AR}. Because the pressure drop reflected the quantity of bed material, when the u_{AR} increased over 2.5m/s， some of bed material was exchanged to the FR. The higher u_{AF} was, the more bed material was exchanged, and the value of AR pressure drop was smaller. Almost all bed material was exchanged to the FR, when the gas velocity reached to 4.5m/s.

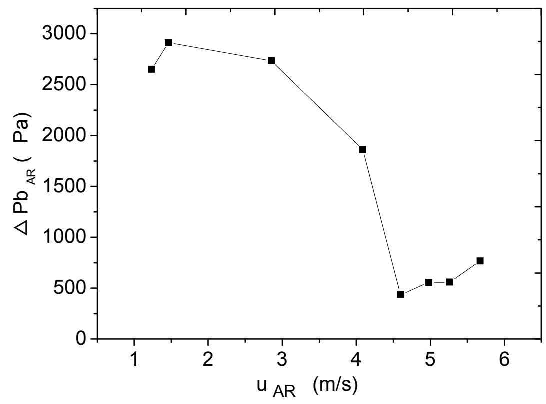

Fig. 6. Pressure drop curve of both AR and FR with increasing of u_{AR} under FR fan closed condition

At the second operation condition, the bed material height of both AR and FR was adjusted to 150mm, the AR fan was closed, and then FR fan was opened gradually. The experimental results were showed in Fig.7.

The trend of the pressure drop curve of FR was similar to that of AR (Fig.6). The difference of both operation conditions was that the value of u_{mf} was 3.3m/s. and the pressure drop was gradually reduced with the continuous increased of gas velocity, in part due to the beginning of materials transported to AR.

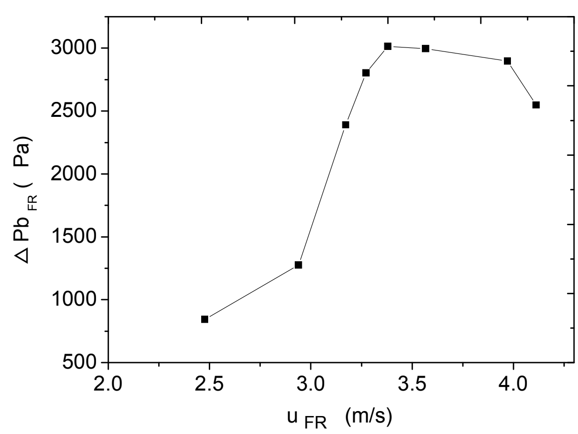

Fig. 7. Pressure drop curve of both AR and FR with the increasing of u_{FR} under AR fan closed condition

At the third operation condition, the bed material heights of both AR and FR were adjusted to 150mm, the AR fan was opened partly, and the values of u_{AR} were 2.2m/s and 4.0m/s respectively. Then FR fan was opened gradually. The experimental results were showed in Fig.8.and Fig.9.

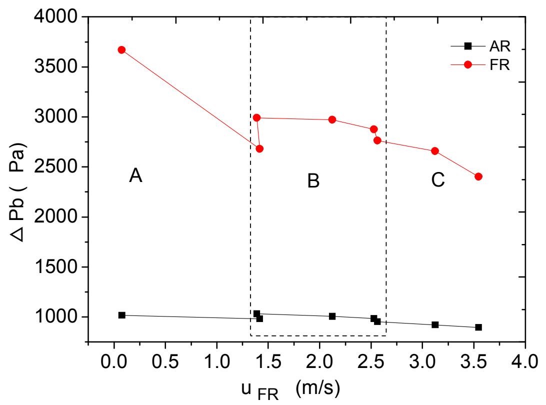

Fig. 8. Pressure drop curve of both AR and FR with the increasing of u_{AR} (u_{FR}=2.2m/s)

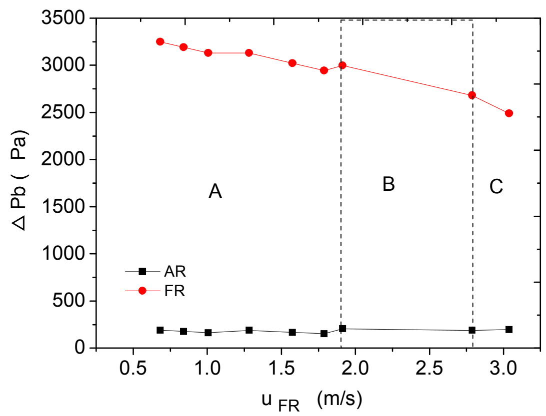

Fig. 9. Pressure drop curve of both AR and FR with the increasing of u_{AR} (u_{FR}=4.0m/s)

Three main stages (A, B and C) were observed obviously in above mentioned experimental process. A represented that both two reactors were in bubbling stage, B represented that there was some bed material exchanged well, and C represented that the large quantity of bed material was transported from FR to AR.

This phenomenon can be explained reasonably using the theory of fluidization. When the FR fan began to operate, the FR pressure drop sharply increased to 3000Pa and then the pressure drop decreased lightly with the increasing of u_{FR}. At the same time, the AR pressure drop fluctuated in small scope. The main reason was that the bed material of AR and FR began to exchange. Meanwhile, the pressure drop decreased gradually with the increasing of u_{AR}. This phenomenon in dual fluidized bed was similar to that of conventional circulating fluidize bed as well.

In the condition of u_{AR} fixed at 2.2m/s and u_{FR} increased, the dual fluidized bed pressure drop started fluctuation at u_{FR} =4.0m/s. while the u_{AR} fixed at 4.0m/s, the value of u_{FR} caused fluctuation was 2.0m/s, which was a greater obviously, and also the fluctuation value of pressure drop was bigger in later condition than former condition. It could be seen that u_{FR} must be increased with an enhancive u_{AR} value to ensure exchange of bed material, and the higher of the gas velocity, the more material could be exchanged.

V. CONCLUSIONS

Before fluidization, the pressure drop characteristic of both AR and FR in interconnected dual fluidized bed for CLC sharply increase with the gas velocity increasing, the characteristic just similar to that of conventional circulating fluidized bed. However, after fluidization, the pressure drop of both AR and Fr in dual fluidized bed will decrease with gas velocity increasing, because the two air flows from AR and FR influence each other, which is different from the conventional fluidized bed.

There is a reasonable velocity range, making AR and FR pressure drop in fluctuations state. It could be seen that u_{FR} must be increased with an enhancive u_{AR} value to ensure exchange of bed material, and the higher of the gas velocity, the more material could be exchanged.

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