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Control of Solid Mass Flow Rate in Circulating Fluidized Bed by a Pulsed Gas Flow

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As a coal-fired power generation technology for further improvement of power generation efficiency of coal-fired power generation, exergy recuperation type coal gasification power generation technology, a triple-bed circulating fluidized bed, has been proposed. The authors analysed the flow characteristics of the triple-bed circulating fluidized bed, it has the flow characteristics of the riser and downer perform the proposed approach to representation by the equivalent circuit model. This equivalent circuit has the nature of the low-pass filter. A combination of the low-pass filter and the pulse voltage is used as a switching power supply. Then, we applied that the pulsed gas supply to the riser combined with a low-pass filter characteristics to control the particle circulation rate of the triple-bed circulating fluidized bed. We used an electric circuit simulator SPICE to calculation of circuit behaviour. Circuit constant is to use the value from the experiment, the input pulse height is set to 80 V. When the input pulse width is changed, the output current is changed depending on the pulse width. Moreover, when changing the density of the pulse, the output current is changing depending on the pulse density. This result by giving a pulsed gas supply to the riser, it shows the possibility controlling the particle circulation rate of the triple-bed circulating fluidized bed.

1. Introduction

It is necessary to improve response the power generation efficiency of thermal power plants to the increase of power demand, thermal power plants based on coal gasification technology have been developed worldwide (Henderson). Assuming a next-generation high-efficiency coal gasification combined cycle power generation (Tsutsumi), a triple-bed circulating fluidized bed (TBCFB) consists of riser as a combustion furnace, downer as pyrolysis furnace, bubbling fluidized bed as steam gasification reactor, has been proposed and developed as coal gasification reactor (Guan et al., 2010). The proposed triple bed circulating fluidized bed is a system which has downer, bubble fluidized bed, riser, moving bed, particle distributor, gas seal bed, gas-solid separator, etc. The TBCFB is a very complex system. Then, this system has a number of parameters to control, it is expected to show a complex flow behaviour of fluidized bed (Guan et al, 2010b). It was reported that the flow characteristics of large scale cold model of this system (Fushimi et al.,2011), additional flow analysis is required to control the particle circulation for stable operation of the gasifier system for practical usage.

2. Measurement of particle circulation rate in the triple-bed circulating fluidized bed

Figure 1 is a schematic image of a large TBCFB cold model (Guan et al, 2011) . This cold model consists of riser (0.1 m ID × 16.6 m height), downer (0.1 m ID × 6.5 m height), gas-solid separation equipment, bubbling fluidized bed (BFB, 0.75 m × 0.27 m × 3.4 m), gas seal bed (GSB, 0.158 m ID × 5.0 m). In this cold model, it has been measured the particle circulation rate using silica sand particles, which density and average diameter is 2,600 kgm^{-3} and 83 μm (minimum fluidization velocity (Umf) = 0.0058 ms^{-1}). The superficial gas velocity of riser is in the range of from 5 to 12 ms^{-1} and of gas-seal bed is from 0 to 0.094 ms^{-1}, the superficial gas velocity of the BFB is fixed to 0.0041 ms^{-1}. Pressure was measured by pressure sensors (Keyence, AP48) placed along to the whole TBCFB system. The output signals of the sensor were acquired through the data

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acquisition system (CONTEC, AIO-163202FX) and a laptop computer at 100 Hz sampling frequency. A solid mass flux (Gs) as particle circulation rate was measured using a valve based on the time required to accumulate the amount of certain particles.

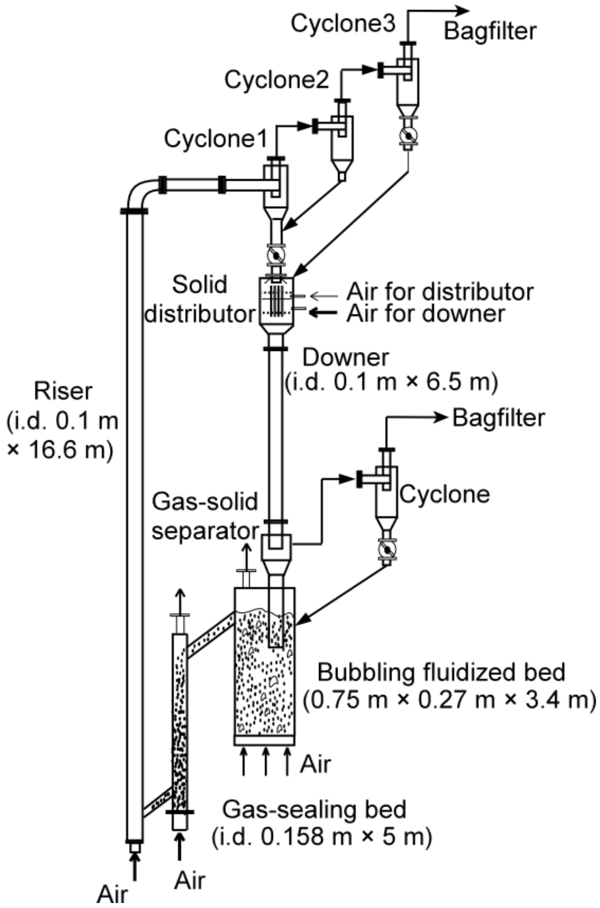

Figure 1: Schematic image of the triple-bed circulating fluidized bed gasifier (TBCFB)

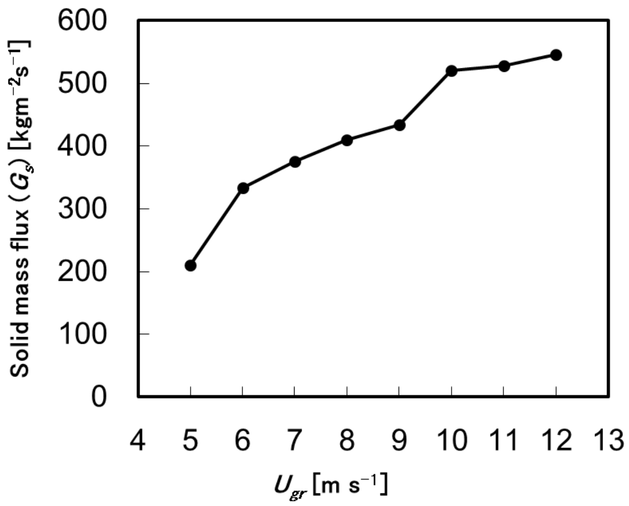

Figure 2: Effect of the gas velocity in the riser on the solid mass flux

Figure 2 shows a solid mass flux(Gs) as the particle circulation rate as a function of the riser the superficial gas velocity (Ugr). At this time, the superficial gas velocity of GSB (Ugg) was set to 0.094 ms^{-1}. When Ugr = 5 ms^{-1}, Gs was 210 $kgm^{-2}s^{-1}$. In Ugr = 12 ms^{-1} has reached to 546 $kgm^{-2}s^{-1}$. In this system, along with the increase of the riser gas superficial velocity, a total particle circulation rate was increased. However, the lowest rate of the riser gas superficial velocity of particles circulation is established in this system was present. In this experimental system, a Ugr = 5 ms^{-1}, in which less than the gas superficial velocity, not performed the particle circulation. In this report, by performing the pulsed gas supply to the riser for the control of the particle circulation, aimed at the particle circulation rate control, which corresponds to the gas superficial velocity of less than 5 ms^{-1}.

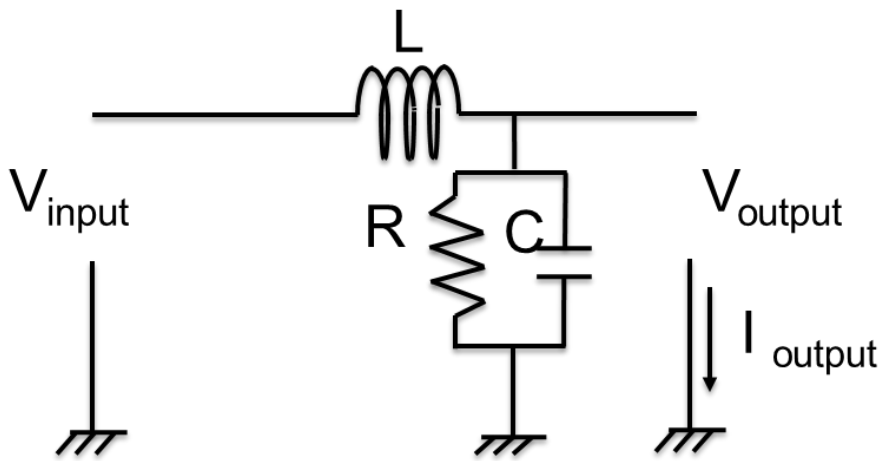

Figure 3: Equivalent circuit model of the riser/downer flow

3. Equivalent circuit model of the triple-bed circulating fluidized bed

The authors have, so far, to analyse the flow characteristics of the triple-bed circulating fluidized bed, it has been proposed a method that the flow characteristics of the riser and downer is expressed by an equivalent circuit model (Ishizuka et al., 2015). The equivalent circuit model of the riser and the downer is shown in Figure 3. Modelling was based on the similarity between the flow characteristics of the fluidized bed and an electrical properties of electrical circuit. The basic similarity between the electrical characteristics and flow properties is defined by the following equation.

$$P = FsRa \tag{1}$$

$$P = Ma\frac{dFs}{dt} \tag{2}$$

$$Fs = Ca\frac{dP}{dt} \tag{3}$$

Eq(1) is Ohm's law, it expressed for fluid resistance. Eq(2) is the inductance of the fluidised bed. It was obtained from the definition of the inductance of the electrical circuit. Further, Eq(3) is a fluid compliance, which were obtained from the definition of capacitance in electronic.

This equivalent circuit has the nature of the low-pass filter. Output control by a combination of the low-pass filter and a pulse voltage is used as a switching power supply. Thus, we were proposed that apply a pulsed gas supply to the riser for the particle circulation rate control of the TBCFB combined with a low-pass filter characteristics of the riser.

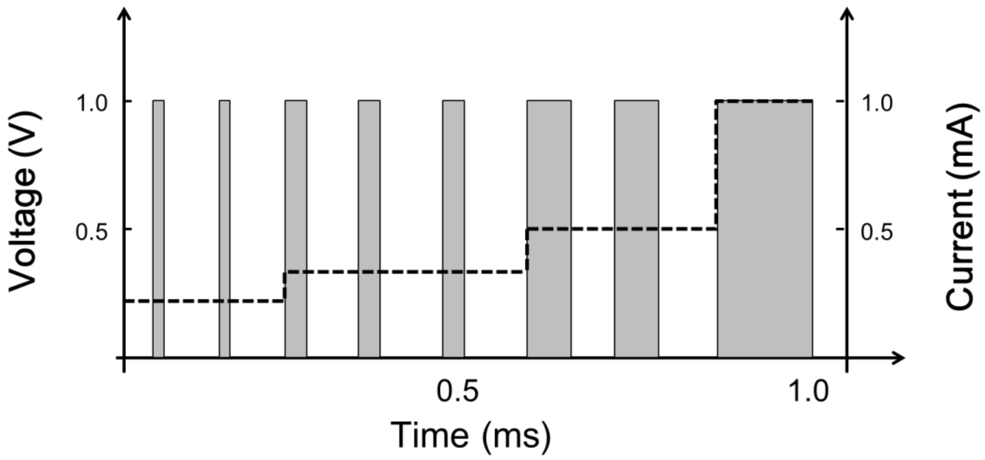

Figure 4: Input-output characteristic of pulse and low pass filter. Solid line: input pulse voltage. Dot line: output current

4. Control of particle circulation rate by the pulsed gas supply

The behaviour supplied pulsed gas to the riser of the TBCFB was studied using an equivalent circuit model of the riser and circuit simulation software. Figure 4 shows the relationship between input and output applied the input pulse voltage in the equivalent circuit of the riser. Output currents were compared by the waveform difference of the input pulse voltage. Input pulses were assumed two types pulse modulation. One is in the case of changing the pulse width fixing the repetition frequency of the pulse (Pulse Width Modulation) and other is to fix the width of the pulse when changing the repetition frequency of the pulses (Pulse Density Modulation). The calculation of the pulse input to these equivalent circuits were carried out using the electric circuit simulator (LTspice, Liner Technology). In the equivalent circuit as shown in Figure 3, circuit constants were used in the value of a reference (Ishizuka et al., 2015). The input pulse height was 80 V, resistance was 2 kΩ, capacitance was 0.5 mF and inductance was 1.0 mH. It is shown the voltage of the pulse input in solid line, output current as a dotted line in the Figure 4.

5. Result and discussion

Figure 5 (a) - (d) show calculation result of the pulse width modulation, and (e) ~ (g) shows the results of a pulse density modulation. In case of pulse width modulation, when changing by increasing the pulse width of the pulse voltage to be input, the output current depending on an increase in the pulse width is increased. In case of pulse density modulation, when performing pulse density modulated by changing the period of the pulse, the output current depending on the density increase of the pulse is increased. The upper limit of the output current is when the pulse is continuous in all of the modulation. Further, it is able to control up to about approximately one third with respect to the upper limit of the output current. From these results, particle circulation rate conditions corresponding to the gas superficial velocity of less than 5 ms^{-1} may be possible to achieve applied a pulse modulation and pulse gas supply. However, when the actually performing pulsed gas supply, it is expected that there is the particle circulation rate of lowest as a threshold value. Due to the decrease in the pulse density and pulse width, a large fluctuation has appeared in output current, thereby there is a threshold that particle circulation is not satisfied. In the Figure 5, the output current from the start of the pulse is seen an increase in the output current until stabilize with time delay. Because the output current changes with a delay time when changing the modulation of the pulse. Therefore, to control of the particle circulation rate by the pulse, it is necessary the actual dynamic characteristics of the flow properties of the circulating fluidized bed. Then, there is a possibility of control in the start and stop procedure of the particle circulation by pulse method.

6. Conclusions

In this report, to control the particle circulation rate of the TBCFB, we have proposed a method of performing a pulsed gas supply to the riser. Denoting the flow characteristics of the riser portion of the circulating fluidized

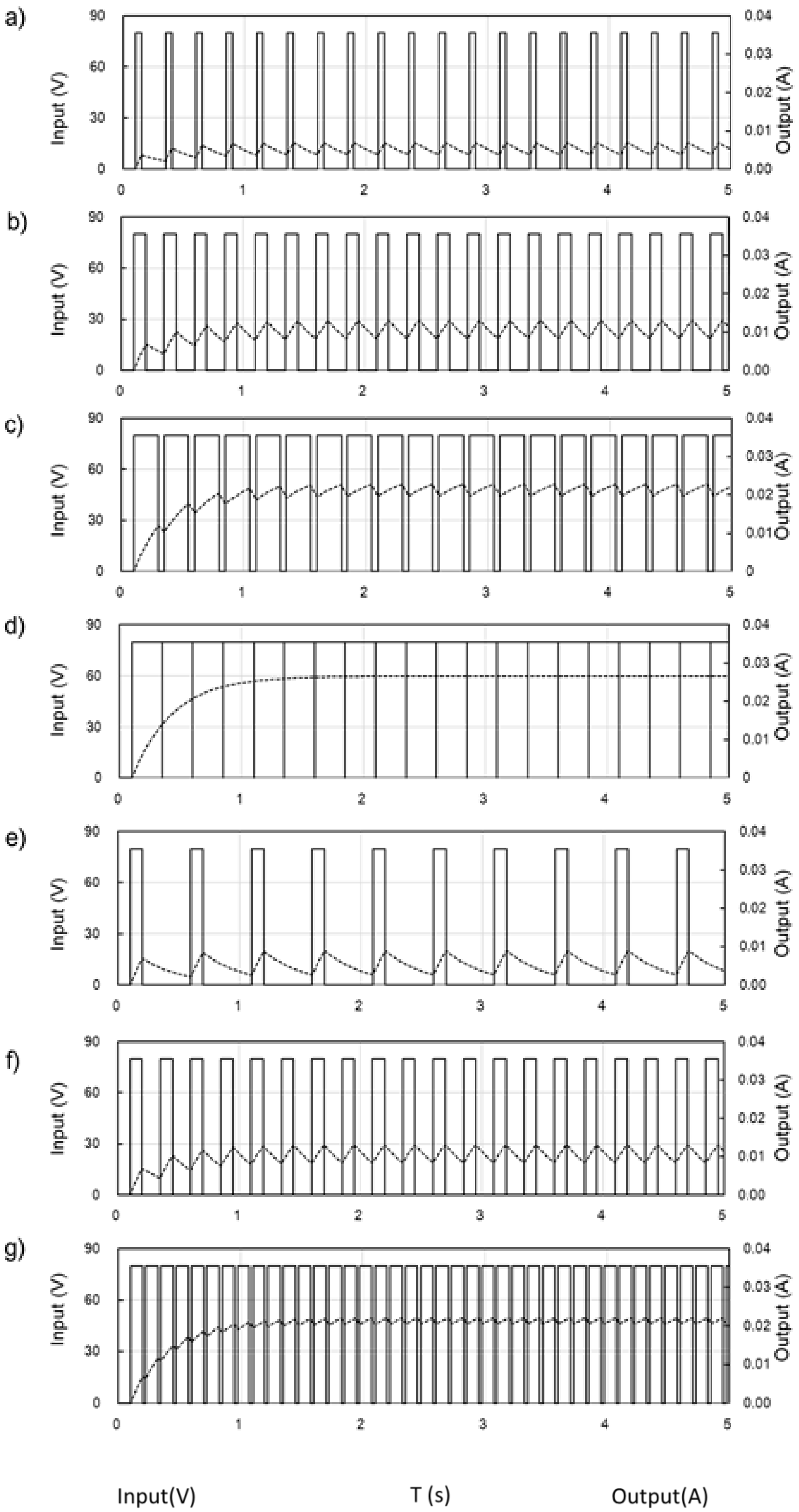

Figure 5: Input-output characteristic of equivalent circuit model. Solid line: input pulse. Dot line: output current. Pulse width modulation: a) 0.05 s, b) 0.1 s, c) 0.2 s, d) 0.25s. Pulse density modulation e), f), g)

bed in the equivalent circuit, since the low-pass filter, to consider the possibility of circulation quantity control using the equivalent circuit model and an electric circuit simulation. Results, a pulse input by changing the PDM or PWM, that is by changing the output, it was possible as an electrical circuit. By providing a pulsed gas supply to the riser, it indicated the possibility of controlling the particle circulation rate of the triple-bed circulating fluidized bed (TBCFB).

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