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HYDRODYNAMIC CHARACTERISTICS OF FINE PARTICLES IN THE RISER AND STANDPIPE OF A CIRCULATING FLUIDIZED BED

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Abstract－The hydrodynamic properties in the riser and standpipe, and the cyclone efficiency have been determined in a circulating fluidized bed (CFB) unit consisting of a riser (0.05 m-ID×3.8 m high), a standpipe (0.068 m-ID×2.5 m high) as a primary cyclone/bubbling fluidized bed, and a secondary cyclone. Silica gel powder (mean diameter = 46 μm) was used as the bed material. The effects of gas velocity in the riser and initial solid loading on the solid circulation rate, and the solid holdups in the riser and standpipe have been determined. The effects of gas velocity in the standpipe on the efficiencies of primary and secondary cyclones have been also determined as functions of solid circulation rate and solid entrainment rate. The solid circulation rate increases with increases in the gas velocity in the riser and in the initial solid loading. The efficiencies of primary and secondary cyclones increase with an increase in the gas velocity in the riser. However, the efficiency of primary cyclone decreases and that of secondary cyclone increases slightly, with an increase in the gas velocity in the standpipe.

Key words: Circulating Fluidized Bed, Solid Circulation Rate, Gas Velocity, Solid Holdup

INTRODUCTION

Numerous research works have been carried out to determine the hydrodynamic properties in circulating fluidized beds, because they can be utilized in various kinds of gas-solid contacting processes and reactions [Yerushalmi and Cankurt, 1979; Kwauk, 1980; Li et al., 1980; Horio, 1990]. Li and Kwauk [1980] and Arena et al. [1986] studied the variation of solid holdup in the axial direction in the circulating fluidized beds. Nishiyama et al. [1993] measured the velocity distributions of solid in the radial and axial directions in the acceleration zone of a cirulating fluidized bed. Recently, Kullendorff and Andersson [1986] and Cho et al. [1993] examined the effects of injection of the secondary air on the performance of a circulating fluidized bed, because the injection of the secondary air to the bed can influence the axial distribution of solid holdup, stoichiometry of the reaction, and the fluidizing characteristics within the riser. However, little information is available to use the standpipe as a chemical reactor to perform the slow gas-solid reactions such as defluorination of UO_2 [Baran and Rez, 1979] and reduction of UO_3 and iron ore. Rotary kilns have been generally used in cement, nuclear fuel manufacturing and hydrometallurgical industries for slow gas-solid reactions.

This work has been intended to determine the hydrodynamic properties in the standpipe and cyclone to utilize the standpipe as a chemical reactor. The results of this study can be employed directly to carry out the calcination and reduction of UO_3 to UO_2 in the riser, and for the slow defluorination of UO_2 in the standpipe at higher gas velocities. To provide prerequisite knowledge for designing such a reactor or contactor, the effects of gas velocity in the riser and initial solid loading on the solid circulation rate, and solid holdup in the riser and standpipe have been determined in a cold model of circulating fluidized bed system. The effects of gas velocity in the standpipe and the inlet size of cyclone on the efficiencies of primary and secondary cyclones have been also determined as functions of solid circulation rate and solid entrainment rate.

EXPERIMENTAL

The circulating fluidized bed (CFB) unit was composed of a riser (0.05 m-ID×3.8 m high), a standpipe (0.068 m-ID×2.5 m high) as a primary cyclone/bubbling fluidized bed, and a secondary cyclone as shown in Fig. 1. The riser and standpipe were constructed of four pieces of acrylic column. Sintered metal filters (pore size = 10 μm) were used as gas distributors in the riser and standpipe. Silica gel powders whose mean size is 46 μm and density is 1000 kg/m^3 were fluidized by air. The terminal and minimum fluidization velocities of the powder were 0.07 and 0.0013 m/s, respectively. The entrained solid particles were separated by two-stage cyclones and a bag filter, and returned to the standpipe. A bubbling bed forms at the base of standpipe, and solid particles were returned to the bottom of the riser through a V-valve [Li et al., 1982; Knowlton, 1986] at the bottom of the standpipe since nonmechanical recycle device (V-valve) can improve the process reliability in the high temperature operation as reported by Merrow [1985]. When the aeration gas is added to the V-valve, solids do not begin to flow immediately because they have a certain threshold of aeration gas flow, thereby, they begin to flow by the additional aeration gas. To measure the solid circulation rate, a knife gate valve [Zenz, 1986; Kuramoto et al., 1986] was installed at 1.5 m above the distributor in the standpipe. The knife gate valve was quickly operated by a mechanically driven air actuator which is electrically actuated by a solenoid

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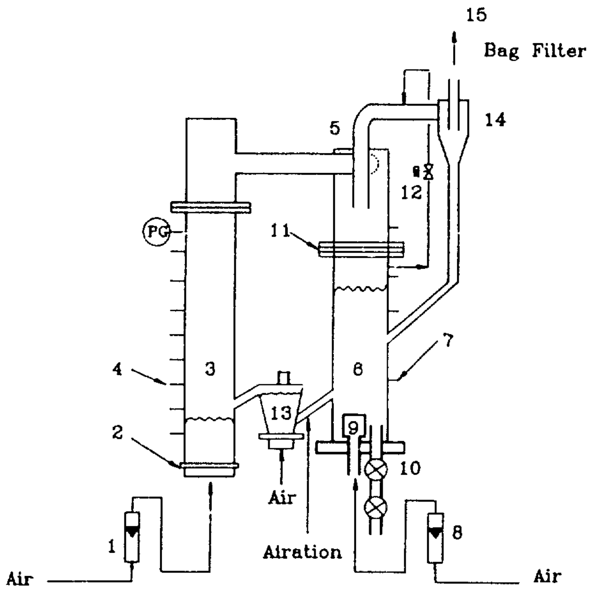

Fig. 1. Schematic diagram of experimental apparatus for the cold circulating bed.

1. Flow meter for riser	9. Gas distributor
2. Gas distributor for riser	10. Powder discharge valve
3. Riser	11. Knife gate valve
4. Pressure tap for riser	12. Solenoid valve
5. Primary cyclone	13. V valve
6. Standpipe	14. Secondary cyclone
7. Pressure tap for standpipe	15. Vent to bag filter
8. Flowmeter for standpipe	

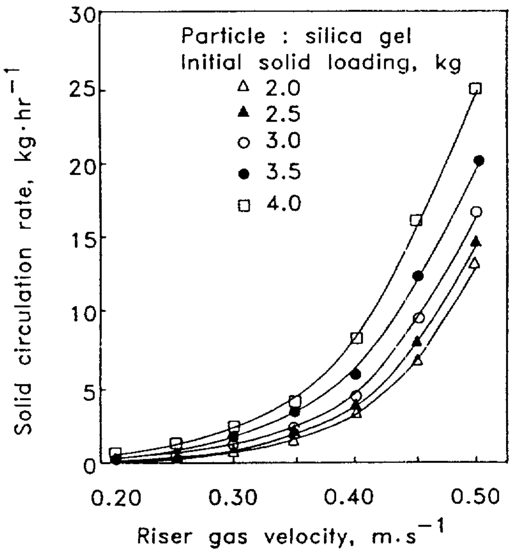

Fig. 2. Effect of superficial gas velocity on solid circulation rate in riser.

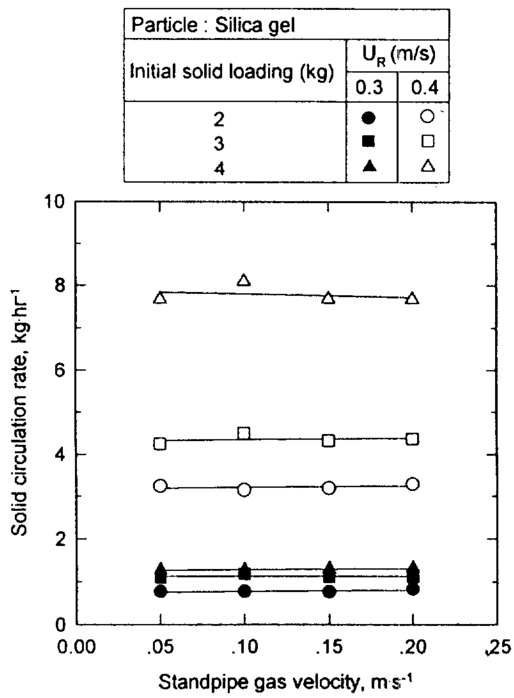

Fig. 3. Effect of superficial gas velocity on solid circulation rate in standpipe.

valve, equalizing the pressure of standpipe simultaneously. The knife gate and solenoid valves were interlocked, and these two valves were operated reversibly without affecting the overall behavior. The solid circulation rate was determined by measuring the amount of piled-up solids above the knife gate valve in the standpipe. Ten pressure taps were mounted flush on the column wall at 0.4 m height intervals from the distributor and covered with a 500 mesh screen to prevent the leakage of particles to manometers. The average axial particle holdup profiles were determined from the measurement of differential pressure drops through the column. Solid holdups within the riser were measured by the settled solid bed height after ceasing the fluidizing gas supply. To get a 99% conversion level of UO_2, the design value of the solid circulation rate has to be 15 kg/hr from a pilot scale test obtaining 2 kg UO_2/hr. Therefore, the gas velocity and initial solid loading in the riser can be chosen as 0.2-0.5 m/s and 2.0-4.0 kg, respectively. To determine the effects of gas velocities in the riser and standpipe on the efficiencies of cyclones, two different inlet nozzle sizes of primary and secondary cyclones were selected.

RESULTS AND DISCUSSION

1. Solid Circulation Rate

The effects of gas velocity in the riser (U_R) and standpipe (U_S) and initial solid loading (I_{so}) on the solid circulation rate (G_s) are shown in Fig. 2. As can be seen in this figure, the solid circulation rate increases with increases in the gas velocity in the riser and in the initial solid loading. However, the solid circulation rate is almost independent of gas velocity in the standpipe in the experimental extent as shown in Fig. 3.

2. Axial Solid Distribution and Average Solid Holdup

The axial solid distributions in the riser and standpipe can be deduced from the axial pressure profiles with various initial solid loading and gas velocities in the riser and standpipe. This measurement was based on the assumption that the pressure gradient at an axial position is proportional to the amount of solids at that position [Yerushalmi and Cankurt, 1979; Youchou and Kwauk, 1980; Weinstein et al., 1983; Hartge et al., 1986]. It has been found that the axial solid distributions in the riser exhibit S-sha-

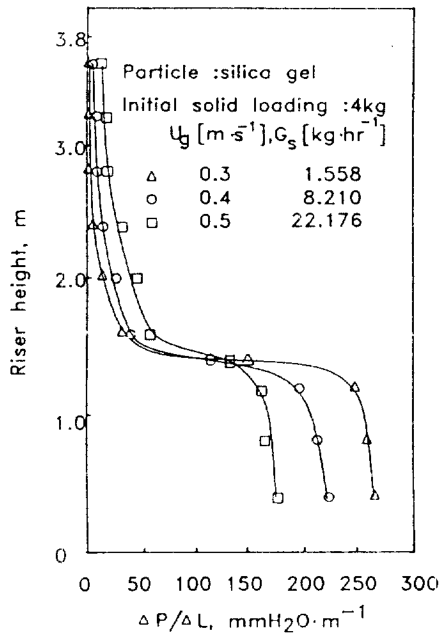

Fig. 4. Pressure profile in riser.

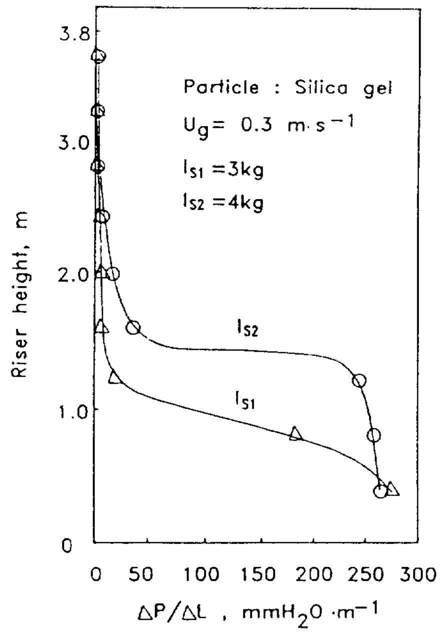

Fig. 5. Pressure profile in riser.

ped curves with an inflection point at a position of 1.4 m above the distributor at which dilute and dense regions are divided as shown in Fig. 4 [Li et al., 1980; Hartge et al., 1986; Weinstein et al., 1983]. The location of an inflection point goes upwards with increases of the initial solid loading (Fig. 5). However, it is nearly invariant with increases in the gas velocity in the riser (Fig. 4).

The solid fraction decreases in dense region but it increases in dilute region with increases in the gas velocity in the riser. As can be seen in Fig. 6, the average solid holdup in the riser slightly decreases with increases in the gas velocity in the riser as reported by several investigators [Li and Kwauk, 1980; Takeuchi et al., 1986b; Horio et al., 1988]. And that of in the standpipe

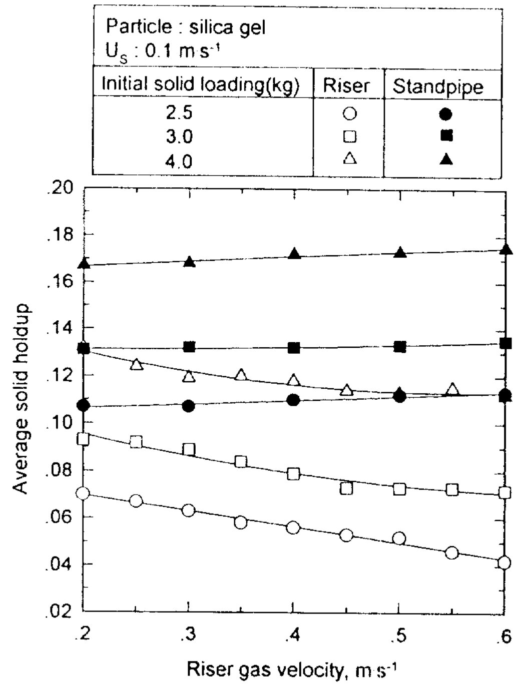

Fig. 6. Effect of riser gas velocity on solid holdup in riser and standpipe.

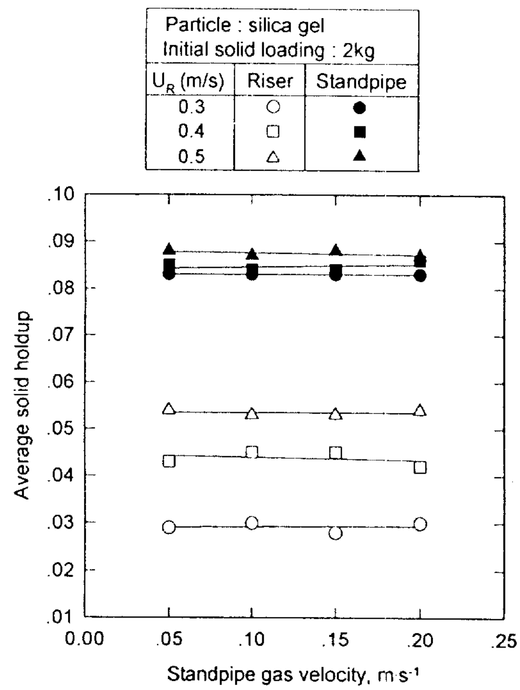

Fig. 7. Effect of standpipe gas velocity on solid holdup in riser and standpipe.

increased a little with increases in the gas velocity in the riser. However, the average solid holdups in the riser and standpipe are almost independent of gas velocity in the standpipe as shown in Fig. 7.

3. Relationships among Overall Pressure Drop, Solid Circulation Rate, Initial Solid Loading and Gas Velocity

The relationships among solid circulation rate (G_s), riser gas

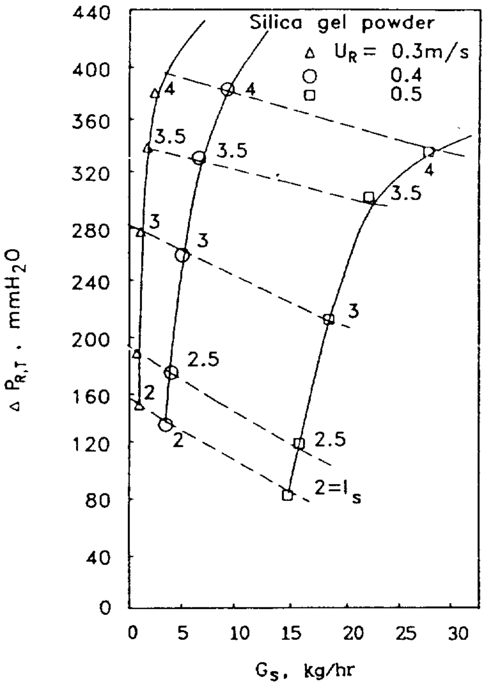

Fig. 8. The map of total differential pressure of riser and solid circulation rate.

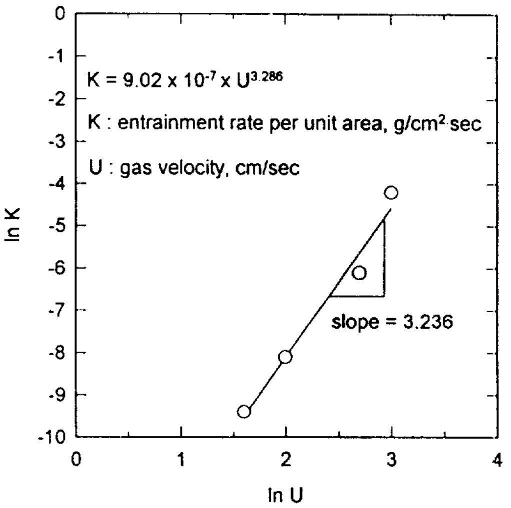

Fig. 9. Correlation of entrainment rate to the fluidizing gas velocity in standpipe (silica powder).

velocity (U_R), initial solid loading (I_{so}) and overall pressure drop ($\Delta P_{R,T}$) in the riser are shown in Fig. 8.

Since I_{so} and U_R are the control variables, the solid circulation rate can be obtained from Fig. 8 with the measurement of $\Delta P_{R,T}$. As shown in this figure, the gas velocity in the riser can strongly affect on the solid circulation rate.

4. Cyclone Performance

The efficiency of primary cyclone (E_1) can be determined from

$$E_1 = 1 - F_{1h}/G_s \qquad (1)$$

where F_{1h} and G_s are the entrainment rate from the primary cyclone and solid circulation rate, respectively.

The efficiency of secondary cyclone (E_2) can be determined

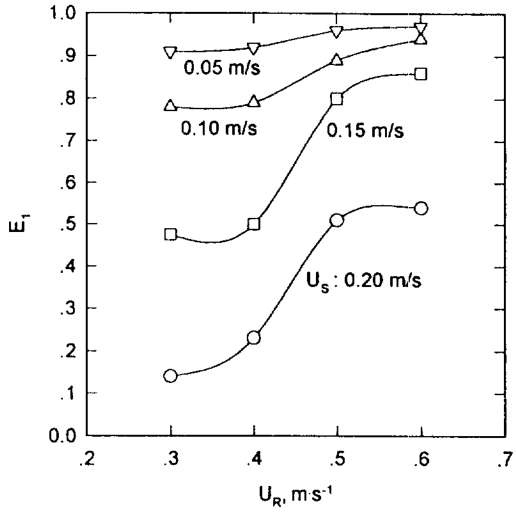

Fig. 10. Efficiency of primary cyclone.

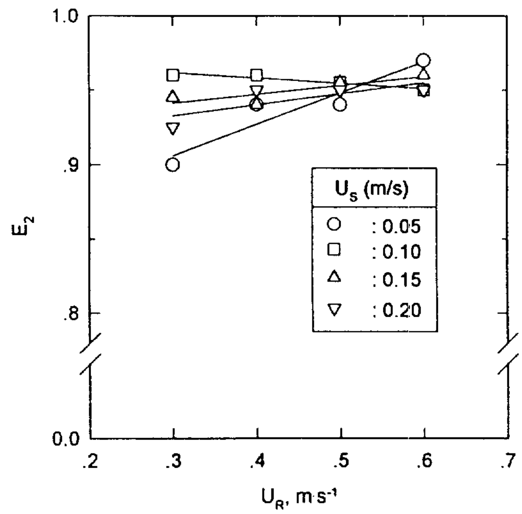

Fig. 11. Efficiency of secondary cyclone.

from the following relation:

$$E_2 = F_{2l}/F_{1h} \qquad (2)$$

where F_{1h} and F_{2l} are the amounts of particles recycled from the primary and secondary cyclones, respectively.

The entrainment rate in the primary cyclone can be determined from the material balance at the secondary cyclone as:

$$F_{1h} = F_{2l} + F_{2h} \qquad (3)$$

where F_{2h} is the entrainment from the secondary cyclone.

The effect of gas velocity on the solid entrainment in the standpipe has been determined under the existence of cyclone action of pure gas from the riser ($U_R = 0.5$ m/s). The entrainment solid flux has been correlated with gas velocity in the standpipe as (refer to Fig. 9):

$$K = 9.02 \times 10^{-7}\ U_s^{3.286} \qquad (4)$$

where K is the entrainment solid flux, and U_s is the superficial gas velocity in standpipe. The entrainment solid flux increases with increases in the gas velocity in the standpipe. The effects of gas velocities in the riser and standpipe on the efficiency of the primary and secondary cyclones are shown in Fig. 10 and 11.

CONCLUSIONS

From the results of this study, the solid circulation rate increases with increases in the gas velocity in the riser and initial solid loading. The average solid holdups in the riser and standpipe increase with an increase in the initial solid loading. The solid holdup in the riser slightly decreases with increases in the gas velocity in the riser, and that in the standpipe increases a little. However the solid holdups in the riser and standpipe are almost independent of the gas velocities in the standpipe. The axial solid distributions in the riser exhibit S-shaped curves with inflection points from which the dilute and dense regions in the bed can be divided. The location of inflection point goes upward with an increase in the initial solid loading but, it is nearly constant with the variation of gas velocity in the riser. The solid fraction in dense region decreases, but increases in dilute region with an increase in the gas velocity in the riser. The efficiencies of primary and secondary cyclones increase with an increase in the gas velocity in the riser. However, the efficiency of primary cyclone decreases and that of secondary cyclone increases slightly, with an increase in the gas velocity in the standpipe.

NOMENCLATURE

E_1, E_2 : efficiency of the primary and secondary cyclones, respectively
F_{1h}, F_{2h} : entrainment from the primary and secondary cyclones, respectively [kg/s]
F_{1l}, F_{2l} : amount of recycled particles from the primary and secondary cyclones, respectively [kg/s]
G_s : solid circulation rate [kg/s]
I_{so} : initial solid loading [kg]
K : entrainment solid flux [kg/m²s]
ΔL : unit length of a column [m]
U_g : superficial gas velocity [m/s]
U_R : superficial gas velocity in riser [m/s]
U_s : superficial velocity in standpipe [m/s]
$\Delta P_{R,T}$: overall pressure drop in riser [mm-H_2O]

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