The loop seal aeration affects the suspension density at the dense bed zone in a circulating fluidized bed

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Abstract

A suspension density influences thermal load in a circulating fluidized bed boiler (CFBB). This research studied the loop seal aeration affecting the cross-sectional average suspension density in the riser. The experiment in the riser had a cross-sectional area of 100 x 100 mm^2 and 4500 mm high above the distributor plate. A loop seal was constructed with the same cross-sectional area where the supply and recycle chambers were incorporated. The sand with an average diameter of 310 μm was used as the bed particle and a density of 2500 kg/m^3. It was found that the suspension density in the dilute bed and dense bed zones increased with the superficial velocity within the loop seal, but it decreased along with the riser height. In the dense bed zone, the sensitivity of suspension density increased with the superficial velocity at 5 m/s and 6 m/s but was constant at 7 m/s and was inversely related to the superficial velocity.

Keywords: Loop seal, Suspension density, CFB, Dense bed, Superficial velocity

1. Introduction

Circulating fluidized beds (CFB) are used for steam production (CFBB) in CFB boilers [22, 7, 32, 18] and a gasifier in CFB reactors (CFBR) [9, 33, 11, 35], which are popularly present due to many advantages, such as high combustion efficiency, using various fuels, and the simple structure. In addition, it also releases less pollution into the atmosphere (NOx and SOx) [2] compared to other generators.

The CFBB operates by burning fuel inside a riser to exchange thermal energy with the membrane water tubes installed on the inner walls. Both suspension density and solid circulation rate affect the heat transfer between particles and membrane tubes, so they are very essential factors for steam production rate.

The cross-sectional average suspension density, which causes by air supplied through a distributor plate at the bottom of a riser, decreases along with riser height [13, 14, 5, 8, 34] but slightly increases at the riser exit due to the influence of the reflection of particles [6], so the characteristics of riser exit affect the suspension density [23, 28, 4, 24]. The suspension density increases with the particle

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size and density [12, 10] because of the influence of the solid circulation rate. In addition, the secondary aeration affects the suspension density along the riser height and the inflection point between the dilute bed zone and dense bed zone [3, 17].

The solid circulation rate in the CEB system is controlled by a loop seal that is a non-mechanical valve because it can operate under high pressure and temperature and has an uncomplicated structure. A loop seal consists of a supply chamber and a recycle chamber, and it operates by the air supplied through a distributor plate at both chambers to drive solid particles from the return leg toward the riser [19]. The supply chamber connected to a return leg has a higher pressure than the recycle chamber connected to a riser because the solid particles accumulate in the supply chamber more amount than [1], so solid particles can continually move from a return leg through a loop seal toward a riser. The solid particles inside the loop seal behave like fluids, that are called fluidization behavior [27].

The air supplied on the loop seal drives the solid particles into a riser, so the solid circulation rate increases with the superficial velocity and air flow rate in the loop seal [30, 21]. The loop seal structures and the characteristic aerations also affect the solid circulation rate [20, 31, 26] because of the influence of the moving pattern of the solid particles inside the loop seal. The particle inertia resists the movement of solid particles in the CFB system [29], so the solid circulation rate decreases with the size and density of solid particles that increase. In addition, the solid circulation rate also increases with the bed inventory [25] because the solid particles circulate more in the system.

However, the heat transfer between the solid particles and the membrane water tubes in the riser increases with the cross-sectional average suspension density and the solid circulation rate. Therefore, air supplied on the loop seal affects the suspension density in the riser due to the influence of the solid circulation rate. This research studied the loop seal aerations affecting the cross-sectional average suspension density at the dense bed zone in the riser.

2. Experimental setup

This research experimented with a circulating fluidized bed system, as shown in Fig. 1, in which the riser had a cross-sectional area of 100 x 100 mm^2 and 4500 mm high above the distributor plate. The solid particles inside the riser are carried by air supplied through a distributor plate to rise and

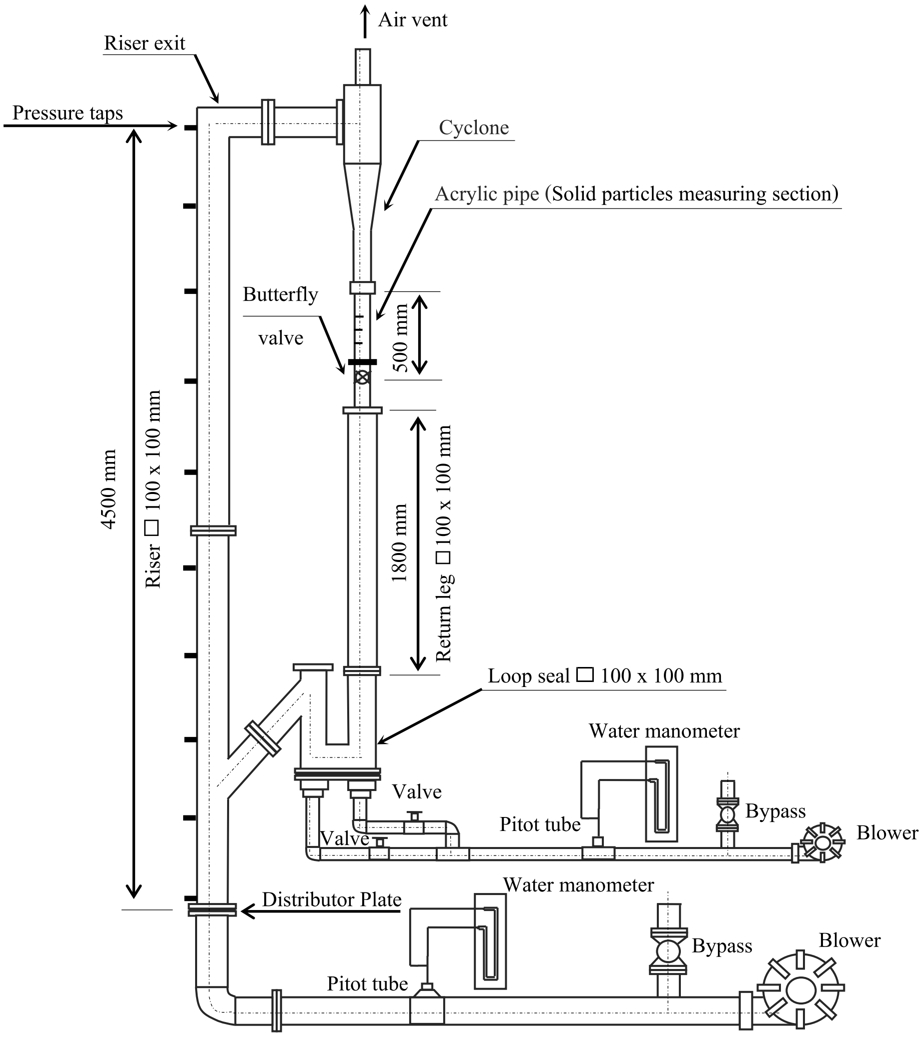

Fig. 1. Arrangement of this experimental apparatus.

distribute along with the riser height, in which the solid particles that leave the riser exit are trapped by the cyclone to fall toward the return leg and move into the loop seal. The ten pressure taps, which had an equal distance of 500 mm, were installed on the riser wall to find the suspension density on the riser.

The air supplied on the loop seal drives the solid particles from the return leg into the riser to continually circulate. Thus, the loop seal is a valve that controls a solid circulation rate in the CFB system. This experiment used the U-type loop seal that consisted of the supply chamber and the recycle chamber as 100 x 100 mm^2, in which both chambers were connected by the horizontal passage as 100 x 100 mm^2 and 50 mm lengths, as shown in Fig. 2. The pressure taps were installed on the wall of the recycle chamber located at 150 mm and 450 mm above the distributor plate.

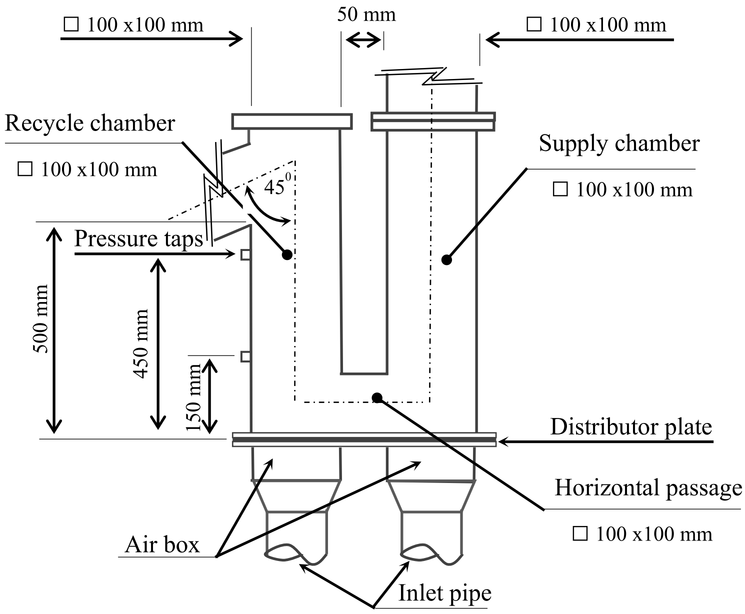

Fig. 2. Loop-seal detail in this experiment.

The solid circulation rate (G_s) is measured by opening and closing the butterfly valve installed inside a clear acrylic pipe to count the time of accumulative particles [15]. The acrylic pipe, which had a diameter of 1 inch, 500 mm lengths, and a volumetric scale, was installed above the return leg, as shown in Fig. 1. The acrylic pipe in this experiment, which was the solid particles measuring section, had a small size because can collect the data accurately.

In this experiment, the superficial velocity (U_g), which is the fast fluidized bed behavior of the solid particle inside the riser, was varied as 5 m/s - 7 m/s. The superficial velocity within the loop seal (U) in terms of the minimum fluidization velocity (U_{mf}) ratio or the fluidization number (U/U_{mf}) was tested in the range 3.12 – 6.53. The bed inventory (M) was kept at 50 kg through the experiment. Sand, Geldart's group B, having an average diameter (d_p) of 315 μm, density (ρ_p) of 2500 kg/m^3, and minimum fluidization velocity (U_{mf}) of 0.078 m/s, was used as the bed particle. Each experimented case was repeated three times to find the average before analyzing the data for the accuracy of the results.

3. Theoretical analysis

The cross-sectional average suspension density in the riser (ρ_s), which neglects the acceleration of solid particles and the effect of friction on the riser wall, can be estimated by the following Eq. (1).

$$\rho_s = \frac{\Delta P_R}{g \Delta H} \quad (1)$$

The superficial velocity within the riser (U_g), which is controlled by adjusting the bypass by valves installed at the air supply pipes, can calculate by the following Eq. (2) and Eq. (3). An air velocity is measured by a Pitot tube with a water manometer. The superficial velocity within the loop seal (U) can find by the same method.

$$v_a = \sqrt{\frac{2\rho_w g \Delta h}{\rho_a}} \tag{2}$$

$$A_p v_a = A_r U_g \tag{3}$$

4. Results and discussion

The air supplied on a loop seal, which is a significant factor, drives solid particles from a return leg toward a riser. It is found that the solid circulation rate (G_s) obtained from this research agrees with other researchers, and it increases with the fluidization number (U/U_{mf}), as shown in Fig. 3. In addition, air supplied on the riser or the superficial velocity within a riser (U_g) carries solid particles to rise in a riser height, so the solid circulation rate (G_s) increases with the superficial velocity in a riser (U_g), as shown in Fig. 4.

Air supplied through a distributor plate causes the fluidization behavior for solid particles inside the chamber, in which the pressure drop is constant. Thus, pressure drop in the recycle chamber (ΔP_r) stably trends with the fluidization number (U/U_{mf}) and superficial velocity in a riser (U_g) that increase, as shown in Fig. 5.

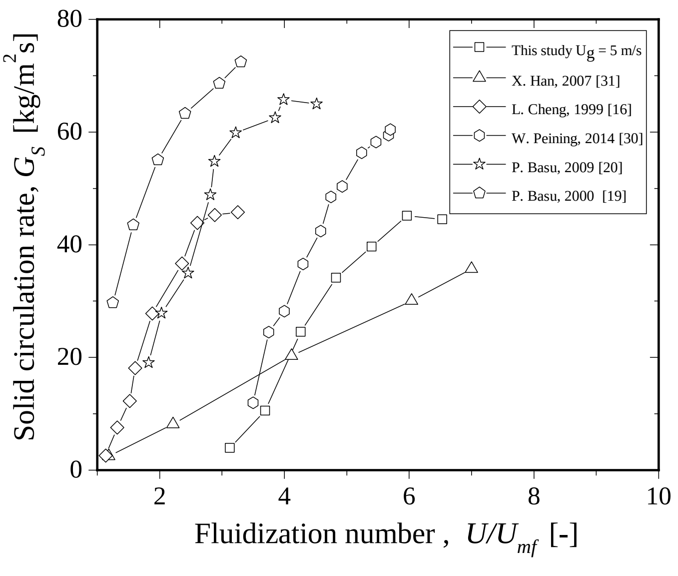

Fig. 3. Comparison of the solid circulation rate (G_s).

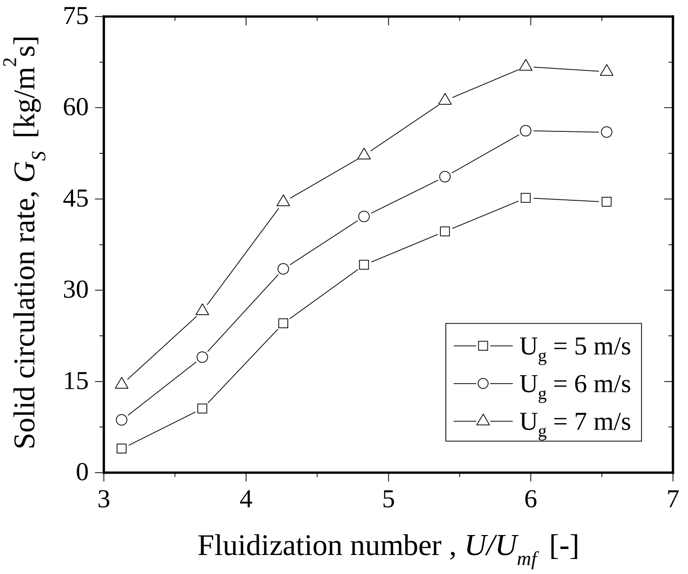

Fig. 4. Effect of the fluidization number (U/U_{mf}) on the solid circulation rate (G_s).

The superficial velocity in the riser (U_g) strongly influences the distribution of solid particles at the lower of the riser. Thus, the cross-sectional average suspension density (ρ_s) decreases with the riser height (H) and is divided into two zones clearly, which have a dilute bed and dense bed at the upper and lower inflection point, respectively, as shown in Fig. 6(a) – Fig. 6(c). The cross-sectional average suspension density (ρ_s) increases with the fluidization number (U/U_{mf}) because the increasing loop seal aeration drives solid particles toward the riser with a large amount. However, the air increasingly supplied in a riser carries solid particles out of a riser with a large amount, so the cross-sectional average suspension density (ρ_s) decreases with the increasing superficial velocity (U_g).

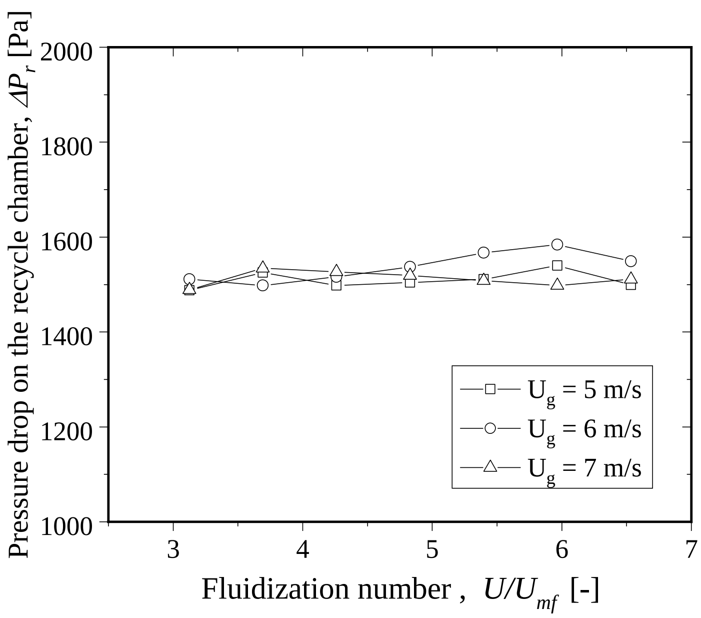

Fig. 5. Effect of the fluidization number (U/U_{mf}) on the pressure drop on the recycle chamber (ΔP_r).

Considering the dense bed zone in Fig. 6(a) – Fig. 6(c), the sensitivity of suspension density (H/ρ_s) is defined by the riser height (H) in terms of the cross-sectional average suspension density (ρ_s) ratio. It was found that the sensitivity of suspension density (H/ρ_s) increases with the fluidization number (U/U_{mf}) for the superficial velocity (U_g) as 5 m/s and 6 m/s, as shown in Fig. 7 because the particle accumulation in the bottom of the riser increases with the increasing loop seal aeration.

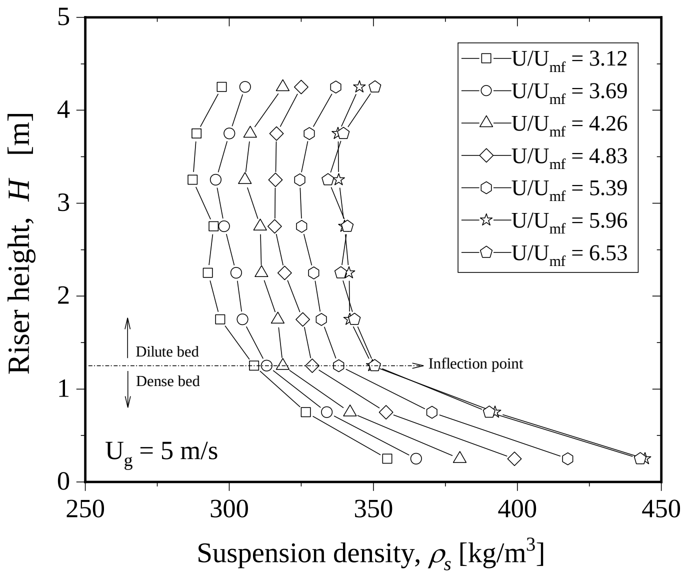

Fig. 6 (a). Effect of the cross-sectional average suspension density (ρ_s) along the riser height (H) on the fluidization number (U/U_{mf}) for the superficial velocity (U_g) as 5 m/s.

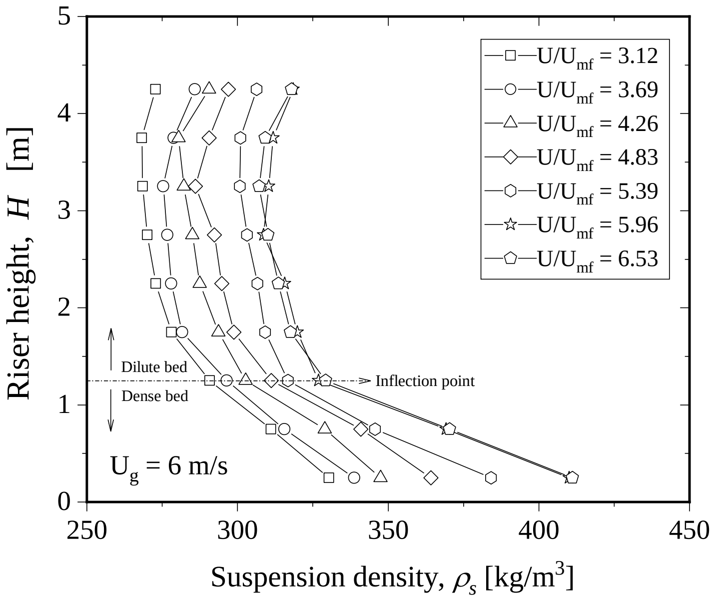

Fig. 6 (b). Effect of the cross-sectional average suspension density (ρ_s) along the riser height (H) on the fluidization number (U/U_{mf}) for the superficial velocity (U_g) as 6 m/s.

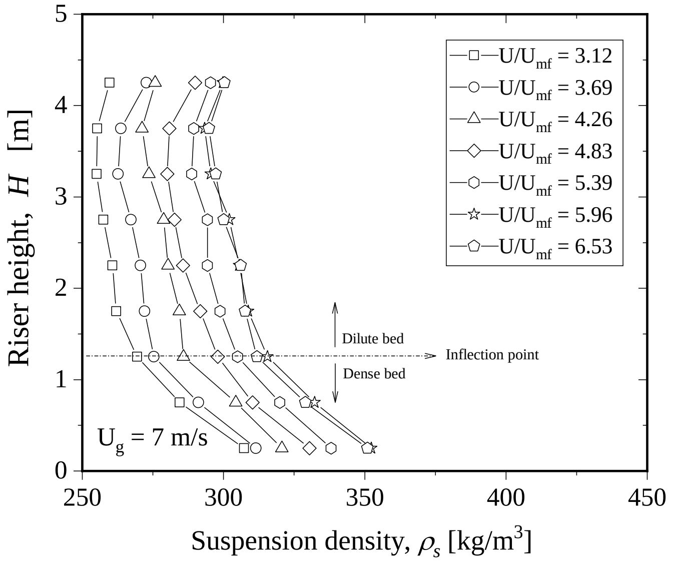

Fig. 6 (c). Effect of the cross-sectional average suspension density (ρ_s) along the riser height (H) on the fluidization number (U/U_{mf}) for the superficial velocity (U_g) as 7 m/s.

However, the high superficial velocity (U_g) that is fast enough can carry solid particles that accumulate in the riser bottom to rise along with the riser height and out of the riser quickly. Thus, the sensitivity of suspension density (H/ρ_s) constantly tends with the superficial velocity (U_g) as 7 m/s. For the same reason, the sensitivity of suspension density (H/ρ_s) has the most value with the superficial velocity (U_g) as 5 m/s, as shown in Fig. 7. In this experiment, the sensitivity of suspension density (H/ρ_s) had the coefficient of determinations (R^2) as 0.82- 0.87.

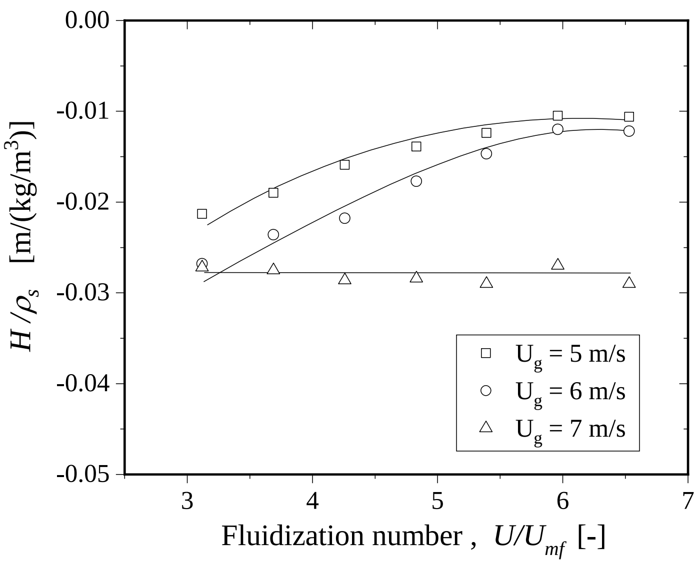

Fig. 7. Effect of the fluidization number (U/U_{mf}) on the sensitivity of suspension density (H/ρ_s).

5. Conclusion

The solid circulation rate (G_s) increased with the fluidization number (U/U_{mf}) and the superficial velocity in a riser (U_g). Both the fluidization number (U/U_{mf}) and the superficial velocity in a riser (U_g) did not affect the pressure drop in the recycle chamber (ΔP_r). The cross-sectional average suspension density (ρ_s) increased with the fluidization number (U/U_{mf}), and it decreased with the riser height (H), which had the dilute bed at the upper and the dense bed at the lower inflection point. The sensitivity of suspension density (H/ρ_s) was inversely related to the superficial velocity (U_g) and increased with the increasing fluidization number (U/U_{mf}) for a superficial velocity (U_g) as 5 m/s and 6 m/s but was constant with the high superficial velocity (U_g) as 7 m/s.

The obtained information from this experiment can use to design the membrane water tubes installed on the inner walls of a riser and the immersed tubes inside the riser bottom to control thermal load in the CFB system.

Nomenclature

A_p	cross-sectional area of the pipe [m^2]
A_r	cross-sectional area of the riser [m^2]
d_p	average particle diameter [μm]
G_S	solid circulation rate [$kg/m^2 \cdot s$]
g	gravity acceleration [m/s^2]
H	riser height [m]
ΔH	distance of pressure taps on the riser [m]
H/ρ_s	sensitivity of suspension density [$m/(kg/m^3)$]
Δh	water level in the manometer [m]
M	bed inventory [kg]
ΔP_R	pressure drop in the riser [Pa]
ΔP_r	pressure drop in the recycle chamber [Pa]
U	superficial velocity within the loop seal [m/s]
U_g	superficial velocity within the riser [m/s]
U/U_{mf}	fluidization number within the loop seal [$-$]
U_{mf}	minimum fluidization velocity [m/s]
v_a	air velocity [m/s]
ρ_a	air density [kg/m^3]
ρ_p	particle density [kg/m^3]

ρ_s cross-sectional average suspension density [kg/m^3]

ρ_w water density [kg/m^3]

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