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Investigation On The Minimum Fluidization Velocity Of Mixture Containing Biomass Materials And Sands

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ABSTRACT

Biomass materials were difficult to be fluidized alone because of their irregular shapes and large space ratio. In this work, minimum fluidization velocities (v_{mf}) were determined by experiments for different proportions of mixtures containing sands and biomass materials, such as rice husk, sawdust and cornstalk. A novel method for the determination of v_{mf} was proposed. The method was simpler and more fitted to the 2-components system containing biomass materials and sands than Ergun equation. It is important that the method can be used to determine the v_{mf} of heat fluidized bed gasifier. The results of experiments showed that the mixture with lower concentration of biomass materials was more easily to be fluidized than higher ones. The optimum concentration of rice husk, sawdust and cornstalk in mixture were 5%, 10% and 10%, respectively. The mixture was not able to be fluidized when the concentration of biomass materials exceeded 15%.

KEYWORDS

Fluidization;
Particle;
Gases;
Minimum fluidization velocity;
Fluidized bed;
Biomass materials.

INTRODUCTION

Gasification of biomass is widely used for obtaining potential renewable energy and chemicals[9, 15]. Biomass materials, e.g. rice husk, sawdust and cornstalk can be gasified in gasifier and the producer gas containing H_2, CO and CH_4 are produced. The gas can be used to synthesize methanol and other organic compounds[11]. Three kinds of gasifiers - fixed bed, bubbling bed and fluidized bed are used for gasification of biomass[7]. For the good heat and mass transfer between the gas and solid phases, and best temperature distribution, the fluidized bed is the best gasifier for gasification of biomass[8, 12]. The minimum fluidization velocity is a key parameter to design of fluidized bed gasifier, without which the dimension of gasifier can not be decided. Generally, the minimum fluidization velocity was determined by experiment[10, 14]. However, there are great difficulties in determination of v_{mf} for mixture containing biomass materials and sands. Although researchers have set up some models for calculation of v_{mf} based on Ergun Equation[6, 13], these models were applied validly in a narrow range of concentrations of biomass materials because of the special characters of the mixture[2, 5]. Other researchers also investigated the fluidized characteristics of air-solid mixture in a fluidized bed[3, 16]. In our work, a method combined experimental data of ΔP and a theoretical analysis was used to determine the v_{mf}. The v_{mf} determined by this method (Method III) was more accurate than calculated by Ergun Equation.

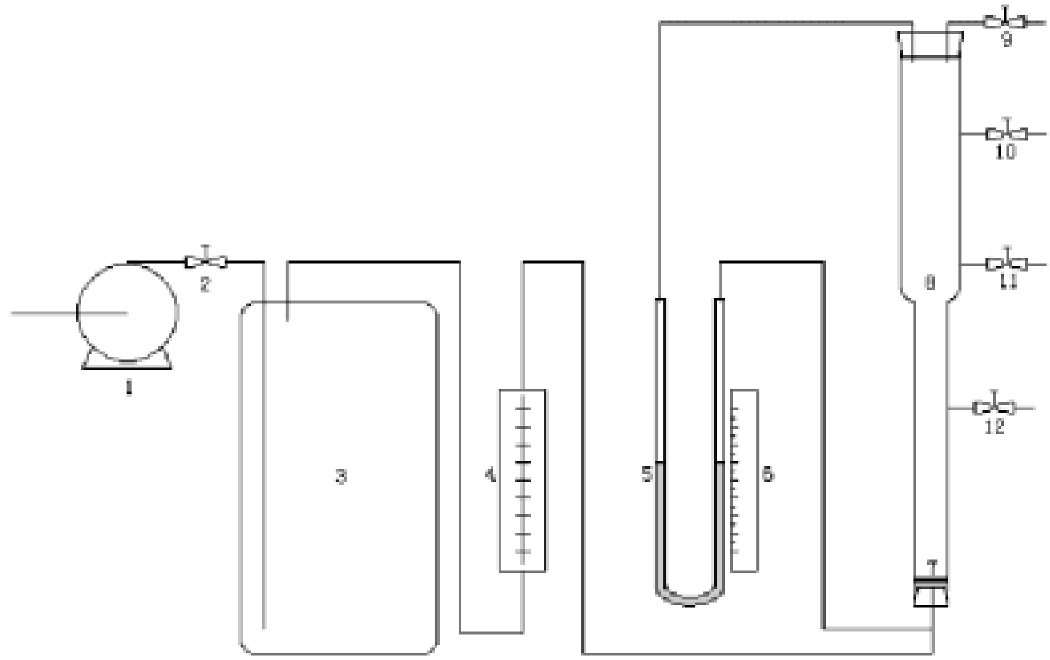
MATERIALS AND METHODS

Materials

Biomass materials used in our experiments are rice husk, saw dust and cornstalk. The characters of different biomass are listed in TABLE 1. The inert additive is silica sand. An experimental system was set up to determine the v_{mf}. Figure 1 shows the process of the fluidized bed system. The fluidized bed tube is combined by a fluidized section with 50 mm inner diameter (ID), 400 mm long and a separated

TABLE 1: The characters of biomass materials and sands

	density (kg/m^3)	d_p ($\times 10^{-6}$m)	Spacing ratio	Moisture (%)
rice husk	230	3192 (8000×2000×1000)	0.52	11.4
saw dust	480	Φ344	0.50	11.8
cornstalk	320	Φ427	0.49	11.2
sand	2600	457(Φ380-Φ550)	0.36	0



1. compressor. 2. 9.10.11.12. valves. 3. buffer tank. 4. rotameter. 5. manometer. 6. ruler. 7. air distributor. 8. fluidized bed

Figure 1: The apparatus for the determination of v_{mf}

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section with 80 mm inner diameter, 800 mm long. All experiments were carried out under ambient temperature and 1 atmosphere pressure.

Methods

At first, pressure drops (p_0) in empty bed were experimentally determined. Then the 2-component-systems containing biomass materials and sands were fluidized and the pressure drops (p_f) along the fluidized bed were obtained at different superficial gas velocities (v_a). The relative pressure drop (ΔP) was equal to the difference of p_0 and p_f. The ΔP could be used to judge if the mixture was fluidized or not. During the fixed bed period, ΔP increased with the increasing of superficial gas velocities, whereas during fluidized period, ΔP changed slightly with the increasing of v_a because the resistance decreased. The minimum fluidization velocity was obtained in critical point between fixed bed and fluidized bed periods. According to fluidization theories, the force caused by ΔP should be equal to the weight of mixture when it was fluidized in fluidized bed. Ergun Equation was used to calculate ΔP (Equation 1) during fixed bed periods and v_{mf} was theoretically obtained. However, the equation was unfitted to the biomass particles. In this work, the experimental ΔP instead of Ergun' results was adopted to determine v_{mf}, which was more accurate than that calculated by Ergun Equation.

RESULTS AND DISCUSSION

ΔP was able to be calculated by Equation 1 to 5 during fixed bed periods[1, 4].

$$\Delta P = H_s f'(\frac{\rho_f v_{mf}^2}{d_p})(\frac{1-\varepsilon}{\varepsilon^3}) \tag{1}$$

$$f' = \frac{150}{\dfrac{\rho_f v_{mf} d_p}{\mu(1-\varepsilon)}} + 1.75 \tag{2}$$

$$d_p = \frac{1}{\dfrac{x_1}{d_{p1}} + \dfrac{x_2}{d_{p2}}} \tag{3}$$

$$H_s = \frac{\dfrac{w_{s1}}{\rho_{s1}(1-\varepsilon_{s1})} + \dfrac{w_{s2}}{\rho_{s2}(1-\varepsilon_{s2})}}{A} \tag{4}$$

TABLE 2: d_p, H_s and ε for different concentrations of biomass materials (w_s=100g)

Weight Of mixture	x_1 (%)	d_p ($\times10^{-6}$m)	H_s ($\times10^{-2}$m)	ε
rice husk	1	461	3.5	0.382
	3	469	4.4	0.417
	5	477	5.2	0.429
	10	500	7.4	0.462
	15	524	9.5	0.475
sawdust	1	456	3.2	0.361
	3	453	3.6	0.383
	5	450	4.0	0.402
	10	442	4.9	0.423
	15	436	5.8	0.438
cornstalk	1	457	3.3	0.364
	3	456	3.9	0.390
	5	455	4.5	0.409
	10	454	5.9	0.431
	15	452	7.3	0.445

$$\varepsilon = \frac{AH_s - (\dfrac{w_{s1}}{\rho_{s1}} + \dfrac{w_{s2}}{\rho_{s2}})}{AH_s} \tag{5}$$

Some parameters were list in TABLE 2.

When the particles of mixture were fluidized during fluidized bed periods, the force caused by ΔP should make the particles suspended in the fluid. Thus,

$$\Delta P = \frac{w_s g}{A} \tag{6}$$

Using Equations 1 and 6, the v_{mf} could be calculated by Equations 7 and 8

$$\frac{w_s g}{A} = \frac{1.75H_s(1-\varepsilon)}{\varepsilon^3}\frac{v_{mf}^2\rho_f}{d_p} + \frac{150\mu H_s(1-\varepsilon)^2}{\varepsilon^3}\frac{v_{mf}}{d_p^2} \tag{7}$$

$$v_{mf} = \frac{-\dfrac{300\mu H_s(1-\varepsilon)^2}{\varepsilon^3 d_p^2} + \sqrt{\dfrac{150^2\mu^2 H_s^2(1-\varepsilon)^4}{\varepsilon^6 d_p^4} + \dfrac{7w_s g}{A}\dfrac{H_s(1-\varepsilon)\rho_f}{\varepsilon^3 d_p}}}{\dfrac{3.5H_s(1-\varepsilon)\rho_f}{\varepsilon^3 d_p}} \tag{8}$$

Herein, the sphericity Φ was presumed as 1. The typical method of v_{mf} determination was shown in figure 2. The mixture containing different weights of sands and biomass materials were mixed com-

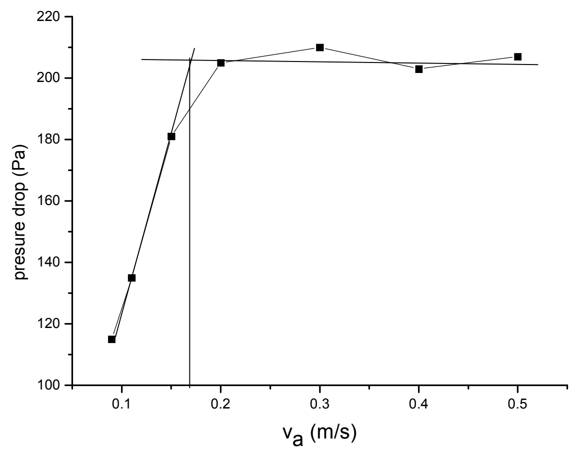

Figure 2: The minimum fluidization velocity for a typical case

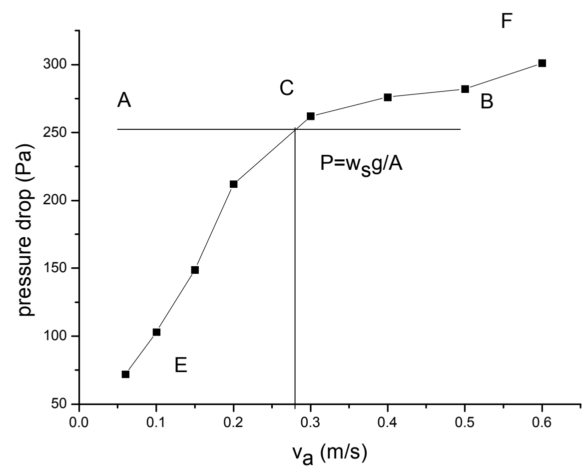

Figure 3: The v_{mf} under certain conditions obtained by the method III

pletely before put into fluidized bed. The pressure drop (ΔP) across the fluidized bed was increased with the increasing of air flow velocity until the mixture was fluidized completely, when the pressure drop would change slightly.

However, the curve of ΔP to v_a was not similar as that shown in figure 2 under most of conditions. v_{mf} of biomass materials was difficult to be obtained under certain conditions (Figure 3). According to the fluidization theory, ΔP in critical fluidized point should be equal to the weight of the particles. So v_{mf2} could be obtained using the intersectant point (Point C, Figure 3) of Equation 7 (Line AB, Figure 3) and the curve of ΔP (Curve EF, Figure 3). It was called Method III in this paper.

ΔP for different biomass materials were plotted in figures 4 to 6. The experimental v_{mf}, calculated v_{mf1} and v_{mf2} were listed in TABLES 3 to 5.

From TABLES 3 to 5, it is clear that the relative errors of the v_{mf1} calculated by Equation 9 are greater than those of v_{mf2} obtained by Method III. At low concentrations of biomass materials, v_{mf1} is in good agreement with the v_{mf}, for the mixture with a same fluidization character as sand. However, when the concentrations of biomass materials increased, the friction between biomass particles, the space ratio and etc. were increased greatly. So the relative error of v_{mf1} would increase sharply with the increasing of x_1, whereas the concentrations of biomass materials had less influence on the relative errors of v_{mf2}, for only the experimental ΔP was used. The results of experiments showed that the weight of mixture in fluidized bed influenced on the v_{mf}, it had not been considered in Equation 1 (see TABLES 3 to 5). Method III was a simple and feasible method to determine the v_{mf} in fluidized bed because of the small relative errors under most conditions.

During defluidization, the bed was expanded largely because of the friction of biomass; the pressure drops were much less than that during fluidization. For biomass gasification, the pressure drop at the beginning of fluidization was more important since biomass particles were heating up fast. The pressure drops were decreased after the start-up of gasification system. The minimum fluidization velocity measured with increasing air velocity was more valuable than that with widely used decreased air velocity.

When the concentration of biomass materials in mixture was low, the mixture had the fluidization characters seem as pure sands which was fluidized easily. Meantime, the ΔP increased regularly and then keeps almost stable after the mixture was fluidized completely. When the concentrations of biomass materials in mixture increased, the ΔP changed greatly with the increasing of air flow velocities, for the friction between biomass particles increased. The mixture is difficult to be fluidized when the composition of rice husk is larger than 10%. After the concentrations of biomass materials higher than 15%, all three kinds of biomass materials were not able to

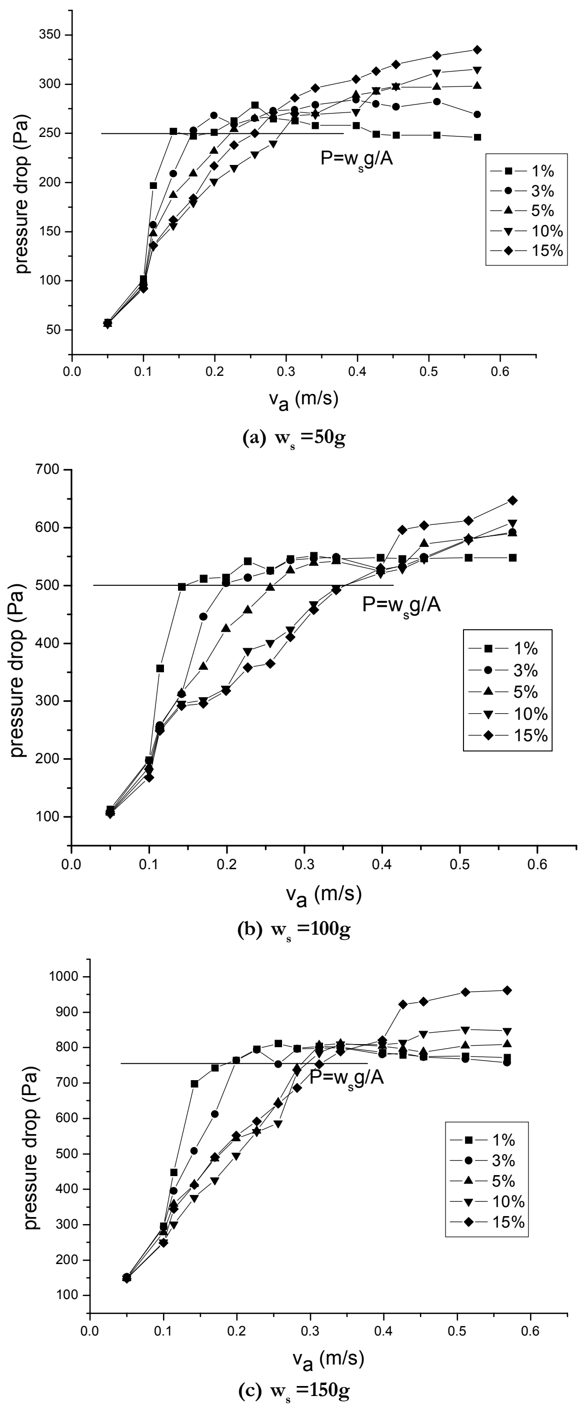

Figure 4: The relationship between ΔP and v_a for rice husk

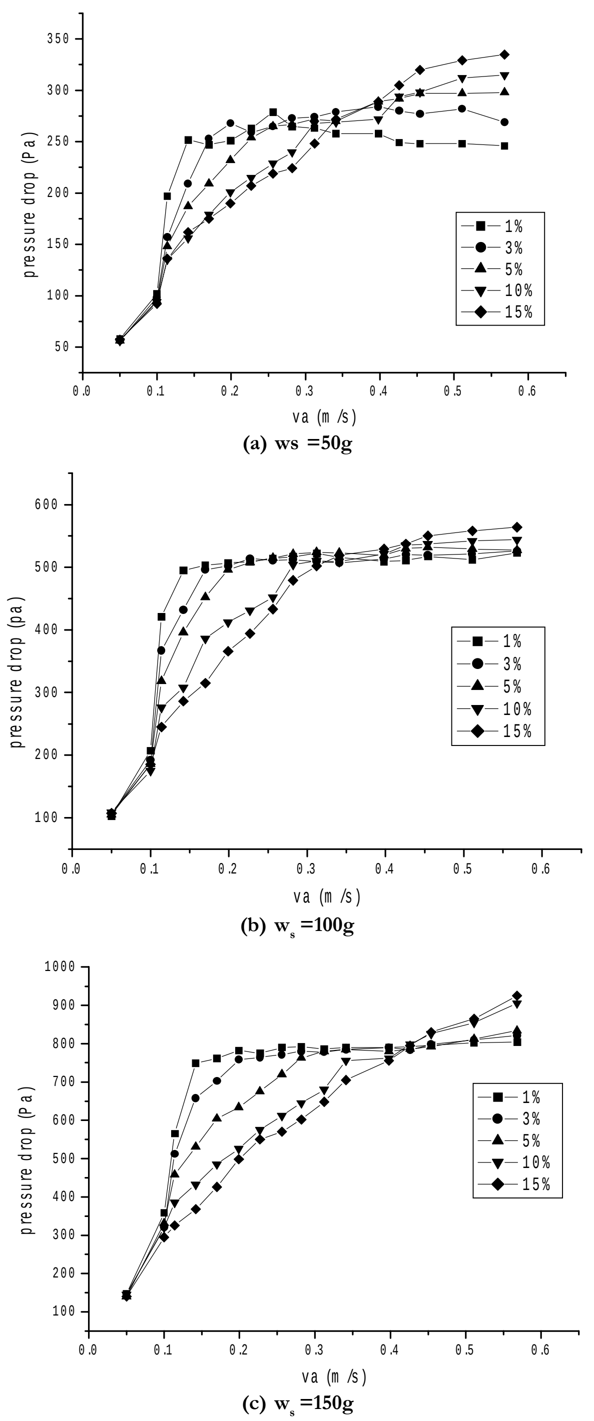

Figure 5: The relationship between ΔP and v_a for sawdust

be fluidized. Fluidized efficiency is not only influenced by the composition of mixture, but also by the total weight of mixture or height of mixture in bed. Large total weight of mixture in fluidized bed was disadvantageous to fluidization. In this experimental apparatus, 100g of mixture was able to be fluidized. Larger w_s (>150) of mixture in fluidized bed was not able to be fluidized. Because the rice husk had more irregular shape than sawdust and cornstalk, rice husk was more difficult to be fluidized

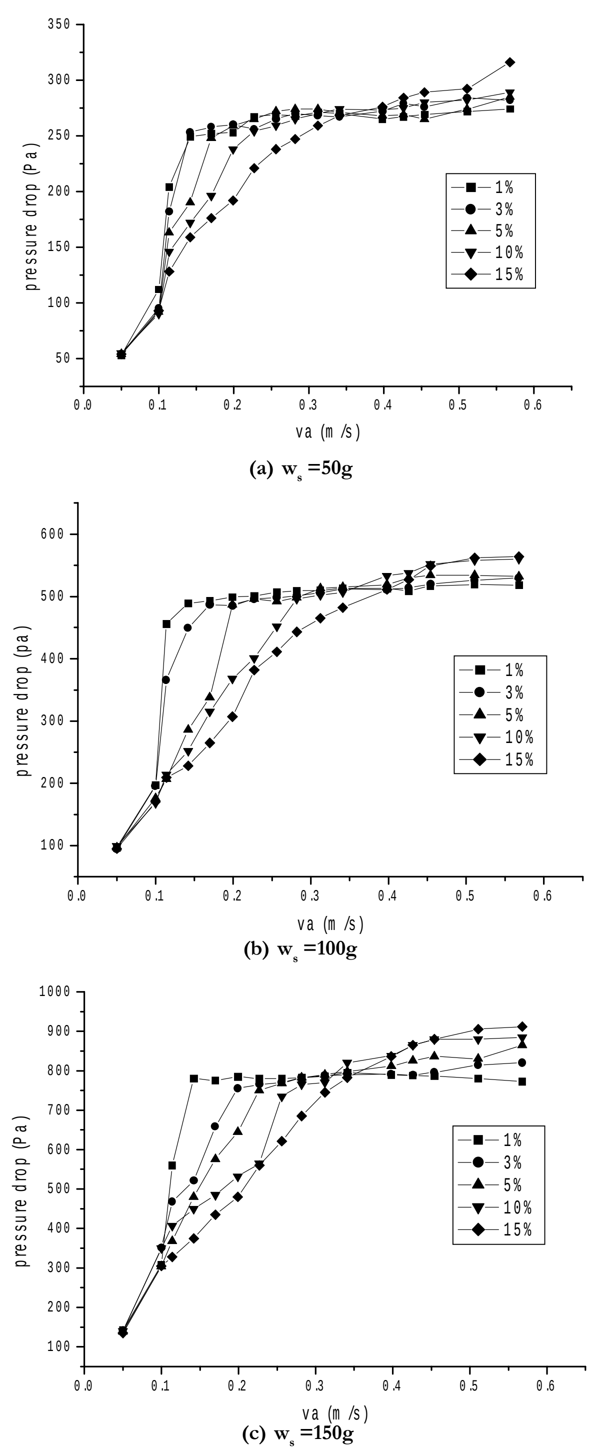

Figure 6: The relationship between ΔP and v_a for cornstalk

than other two biomass materials. When w_s=100g, the optimum concentrations of rice husk in mixture was 5%, and v_{mf} = 0.26m/s. The optimum concentrations of sawdust and cornstalk were 10%, and v_{mf} = 0.28m/s and 0.25m/s, respectively.

TABLE 3: The v_{mf} (m/s) of rice husk obtained by different methods

Rice husk	X_1 (%)	V_{mf}	V_{mf1}	relative error (%)	V_{mf2}	relative error (%)
	1	0.12	0.149	24.2	0.12	0
	3	0.17	0.176	3.5	0.18	5.9
w_s=50g	5	0.22	0.174	-20.9	0.22	0
	10	0.33	0.185	-43.9	0.30	-9.1
	15	N	0.181	-	0.33	-
	1	0.13	0.149	14.6	0.13	0
	3	0.19	0.176	-7.4	0.18	-5.3
w_s=100g	5	0.26	0.174	-33.1	0.24	-7.7
	10	0.35	0.185	-58.9	0.32	-8.6
	15	N	0.181	-	0.33	-
	1	0.15	0.149	14.6	0.17	13.3
	3	0.20	0.176	-12.0	0.21	5.0
w_s=150g	5	0.35	0.174	-50.3	0.30	-14.3
	10	N	0.185	-	0.30	-
	15	N	0.181	-	0.32	-

The v_{mf} of heat fluidized bed gasifier was almost immeasurable since the high temperature, pressure or invisibility. PIV (particle image velocimetry) and LDV (laser Doppler velocimetry) can not be used in gasification system. However, the pressure drop between any two points was easy to be measured. Using the pressure drop curve as figure 3 and Equation 7, the v_{mf} of heat fluidized bed was able to be determined.

CONCLUSION

Biomass materials were difficult to be fluidized alone because of the irregular shapes and large space ratio. In this work, the minimum fluidization velocities of mixture containing sands and biomass materials such as rice husk, sawdust and cornstalk were determined by experiments, calculated by Ergun Equation and by Method III. Method III was more accurate than Ergun Equation and simpler than experiment for 2-components system containing biomass materials and sands. The results of experiments showed that the mixture with lower concentration

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TABLE 4: The v_{mf} (m/s) of sawdust obtained by different methods

sawdust	x_1 (%)	v_{mf}	v_{mf1}	relative error	v_{mf2}	relative error
	1	0.12	0.128	6.7	0.12	0
	3	0.15	0.142	-5.3	0.17	13.3
w_s=50g	5	0.18	0.154	-14.4	0.20	11.1
	10	0.25	0.152	-39.2	0.25	0
	15	0.31	0.146	-52.9	0.30	-3.2
	1	0.13	0.128	-1.5	0.13	0
	3	0.15	0.142	-5.3	0.17	13.3
w_s=100g	5	0.20	0.154	-23.0	0.22	10.0
	10	0.28	0.152	-45.7	0.29	3.6
	15	N	0.146	-	0.34	-
	1	0.13	0.128	-1.5	0.14	7.7
	3	0.18	0.142	-21.1	0.21	16.7
w_s=150g	5	0.27	0.154	-43.0	0.29	7.4
	10	0.32	0.152	-52.5	0.33	3.1
	15	N	0.146	-	0.42	-

TABLE 5: The v_{mf} (m/s) of corn stalk obtained by different methods

corn stalk	x_1 (%)	v_{mf}	v_{mf1}	relative error	v_{mf2}	relative error
	1	0.12	0.129	7.5	0.12	0
	3	0.14	0.144	2.9	0.15	7.1
w_s=50g	5	0.17	0.151	-11.2	0.18	5.9
	10	0.21	0.144	-31.4	0.20	-5.0
	15	0.28	0.135	-51.8	0.31	10.7
	1	0.13	0.129	-0.8	0.13	0
	3	0.15	0.144	-4.0	0.17	13.3
w_s=100g	5	0.19	0.151	-22.9	0.21	10.5
	10	0.26	0.144	-44.6	0.26	0
	15	N	0.135	-	0.41	-
	1	0.14	0.129	-7.9	0.14	0
	3	0.19	0.144	-24.2	0.19	0
w_s=150g	5	0.22	0.151	-31.4	0.22	0
	10	0.28	0.144	-48.6	0.30	7.1
	15	N	0.135	-	0.35	-

of biomass materials was more easily to be fluidized than higher ones. The optimum concentration of rice husk, sawdust and corn stalk in mixture were 5%, 10% and 10%, respectively. The mixture was not able to be fluidized when the concentration of biomass materials exceeded 15%. The weight of mixture had also influence on the fluidization. In our apparatus, more than 150g of mixture was not able to be fluidized.

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