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Jetting transition velocity in a jetting fluidized bed with two nozzles

Qingjie Guo [a,*], Jiyu Zhang [b], Joachim Werther [a]

[a] *Department of Chemical Engineering I, Technical University Hamburg-Harburg, D-21071 Hamburg, Germany*

[b] *Department of Chemical Engineering, Fuzhou University, Fuzhou 350002, PR China*

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Abstract

Jetting fluidized transition velocity (u_{jtv}) is investigated in a 300 mm × 50 mm 2D jetting fluidized bed with two nozzles for eight materials, including four binary mixtures. The experiments show that the peak in the curve major frequency versus jetting gas velocity corresponds to u_{jtv}. The u_{jtv} increases with increasing nozzle distance, particle diameter, but decreases with increasing static bed height and nozzle diameter. A correlation is proposed for prediction of u_{jtv}.

Keywords: Binary mixture; Jetting transition gas velocity; Power spectrum density function; Jetting fluidized bed

1. Introduction

Jetting fluidized beds are extensively employed in various industrial processes [1], such as catalytic and flame processes, coal combustion and gasification, treatment of wastes, coating and granulation, and cleaning of dusty gases. Because of the increasing interest for above applications, a wealthy knowledge [1–8] has been obtained on flow characteristics in a jetting fluidized with one nozzle. However, only a few investigations [9–12] have been carried out in a jetting fluidized bed with two or more separate nozzles. Based on X-ray techniques, Yates et al. [9] studied gas discharge behavior from two separate nozzles at variable nozzle distance using FCC powders (Geldart group A). A simple correlation was obtained to predict the bubble coalescence height. However, the maximum jet velocity used in the study was only 8 m/s. Luo et al. [10] investigated jet momentum dissipation in a 300 mm × 50 mm 2D fluidized bed with two nozzles using a multi-channel pitot-tube system. In an 8.0 m in height and 0.5 m i.d. jetting fluidized bed with two nozzles, Guo et al. [11] defined three patterns, i.e. separate jet, flow transition, and jet coalescence and presented a transition equation. Meanwhile, Guo et al. [12] also studied voidage distribution in such jetting fluidized bed, for large nozzle separation the radial voidage distribution at low axial height is divided into two jet regions and an emulsion region between two jets. While, for the small nozzle distance with low-axial position, the radial voidage profile consisted of two jet and two emulsion regions near the bed border, as well as an emulsion region between two nozzles.

In this investigation, a jetting transition gas velocity (u_{jtv}) is examined by analyzing pressure signals measured in a 2D jetting fluidized bed with two nozzles. Finally, a correlation is developed to predict u_{jtv}.

2. Experimental apparatus and measurement method

2.1. Experimental apparatus

The experimental system is schematically shown in Fig. 1, which mainly consists of a jetting bed, a V-type distributor, two nozzles, a segregating column, and a plenum chamber. The fluidized bed has a 300 mm × 50 mm cross-section with 2600 mm in height, and is made of plexiglass. A V-type distributor located at the bottom of fluidized bed has an 70°-inclination angle and is 0.2 m high. The segregating column is 0.55 m in height with a cross-section of 113 mm × 55 mm. Two nozzles are located 10 mm above the V-type distributor in the center of the fluidized bed. Fluidization air, measured by four rotometers, is supplied to the nozzle (the jet flow rate), the V-type distributor (the V flow rate), and the plenum chamber. Sixteen measuring ports are evenly distributed along the wall of the fluidized bed. During the experiments, the air from the V-type gas distributor and the plenum chamber is referred to as the annular flow rate and kept at the minimum fluidization condition. The physical

* Corresponding author. Tel.: +49-40-42878-2627; fax: +49-40-42878-2678.
E-mail address: q.guo@tu-harburg.de (Q. Guo).

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Nomenclature

d_p	particle diameter (mm)
d_0	nozzle diameter (m)
f	frequency (Hz)
f_m	major frequency (Hz)
H_0	static bed height (m)
P	distance between two nozzles (m)
u_j	jetting gas velocity (m/s)
u_{j1}, u_{j2}	jetting gas velocity of two nozzles (m/s)
u_{jtv}	jetting transition gas velocity (m/s)
u_{mf}	minimum fluidization velocity (m/s)

Greek letters

ρ_p	particle density (kg/m^3)

properties of fluidized particles tested are listed in Table 1. To prevent separation of the binary mixtures, the segregating column was filled with silicone pellets ($d_p = 2.17$ mm). The binary mixture properties were calculated by Goosens et al's [13] equation [7].

2.2. Measurement apparatus

The pressure signals sampling system consisted of three pressure probes made of copper (4.0 mm i.d.) with the measuring port of the probe covered with 200 μm stainless mesh, three pressure differential sensors (Micro Switch140PC1D), an A/D, and a computer. Three probes were located at 0.07, 0.15 and 0.31 m above the top of the V-type distributor. The pressure probe was connected to the high port of a pressure transducer with the remaining channel exposed to the atmosphere. The working capacity of the pressure sensor was 5.0 kPa. For each run, 5500 points were sampled at a 111 Hz sampling rate. Pressure signals were either stored on a hard disk or processed on line. The jets in the jetting fluidized beds are dominant in governing flow dynamic behavior of the bed. A comparison of the power spectrum density function (PSDF) at three measuring probes indicates that the PSDF diagrams had similar shapes and the same major frequency with different amplitudes. Thus, the pressure signals at 0.07 m were utilized to study the dynamic behavior of the bed. In the present investigation, the static bed height ranged from 0.34 to 0.60 m.

To study flow behaviors in the bed, moving images of the fluidized bed were recorded by a National M-8 video recorder and analyzed frame-by-frame (25 frames per s) by a Panasonic HD-100 video player and Sth VCD software.

3. Results and discussion

3.1. Effect of jetting gas velocity on major frequency under various nozzle distances

Some PSDF diagrams of the pressure signals for four jet gas velocities are given in Fig. 2. Multi-stage PSDF was adopted in this test and the detailed description was reported elsewhere [6,7]. At a jetting gas velocity (u_j) of 17.5 m/s, the PSDF has a larger peak at a frequency of 1.64 Hz, indicating that the two jets have the same formation frequency with no jets coalescence (separate jet pattern) occurring, which was demonstrated by the frame-to-frame analysis

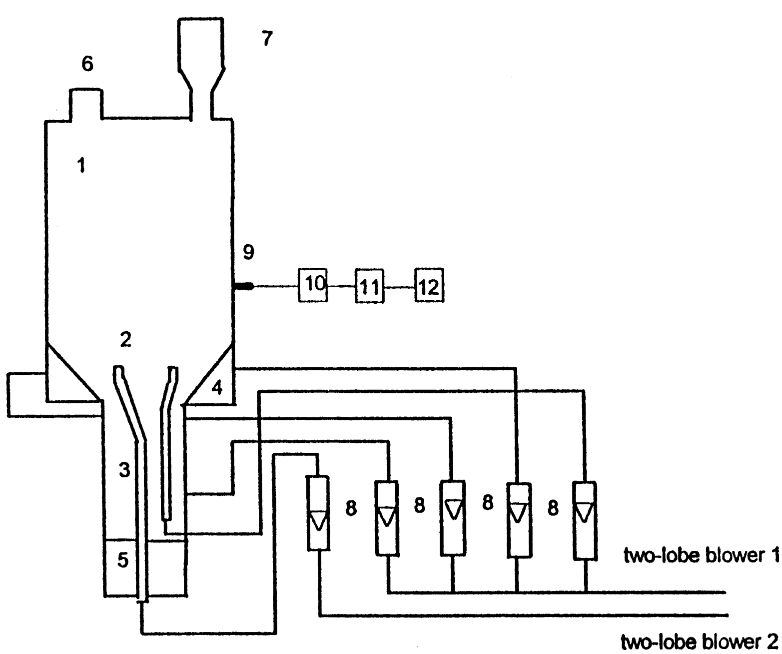

Fig. 1. Schematic diagram of experimental apparatus: (1) jetting fluidized bed; (2) nozzle; (3) segregating column; (4) V gas distributor; (5) plenum chamber; (6) filter port; (7) adding material tank; (8) flowmeter; (9) pressure tap; (10) pressure sensor; (11) A/D; (12) computer.

Table 1
Physical properties of experimental particles

Particulate	ρ_p (kg/m^3)	d_p (mm)	u_{mf} (m/s)	Geldart group
Millet	1335	1.64	0.58	D
Resin	1474	0.74	0.22	B
Sand	2717	1.51	0.99	D
Glass beads	2673	1.13	0.64	D
Millet (20%) + resin (80%)	1444	0.84	0.31	B
Millet (30%) + resin (70%)	1430	0.90	0.34	B
Millet (40%) + resin (60%)	1415	0.96	0.38	D
Sand (30%) + resin (70%)	1708	0.82	0.28	D

of flow pictures. At $u_j = 33.6$ m/s, the major frequency is 2.32 Hz. At $u_j = 42.1$ m/s, the PSDF has two peaks, 1.97 and 1.12 Hz, the former corresponds to major frequency and the latter to separate jet formation frequency. Observations show that these two patterns occur alternatively, however, jet coalescence pattern predominates over separate jet pattern. As jet gas velocity is increased to 45.0 m/s, there is one obvious peak in PSDF suggesting that jet coalescence pattern becomes dominant because of a larger jet conical resulting from a higher jet gas velocity.

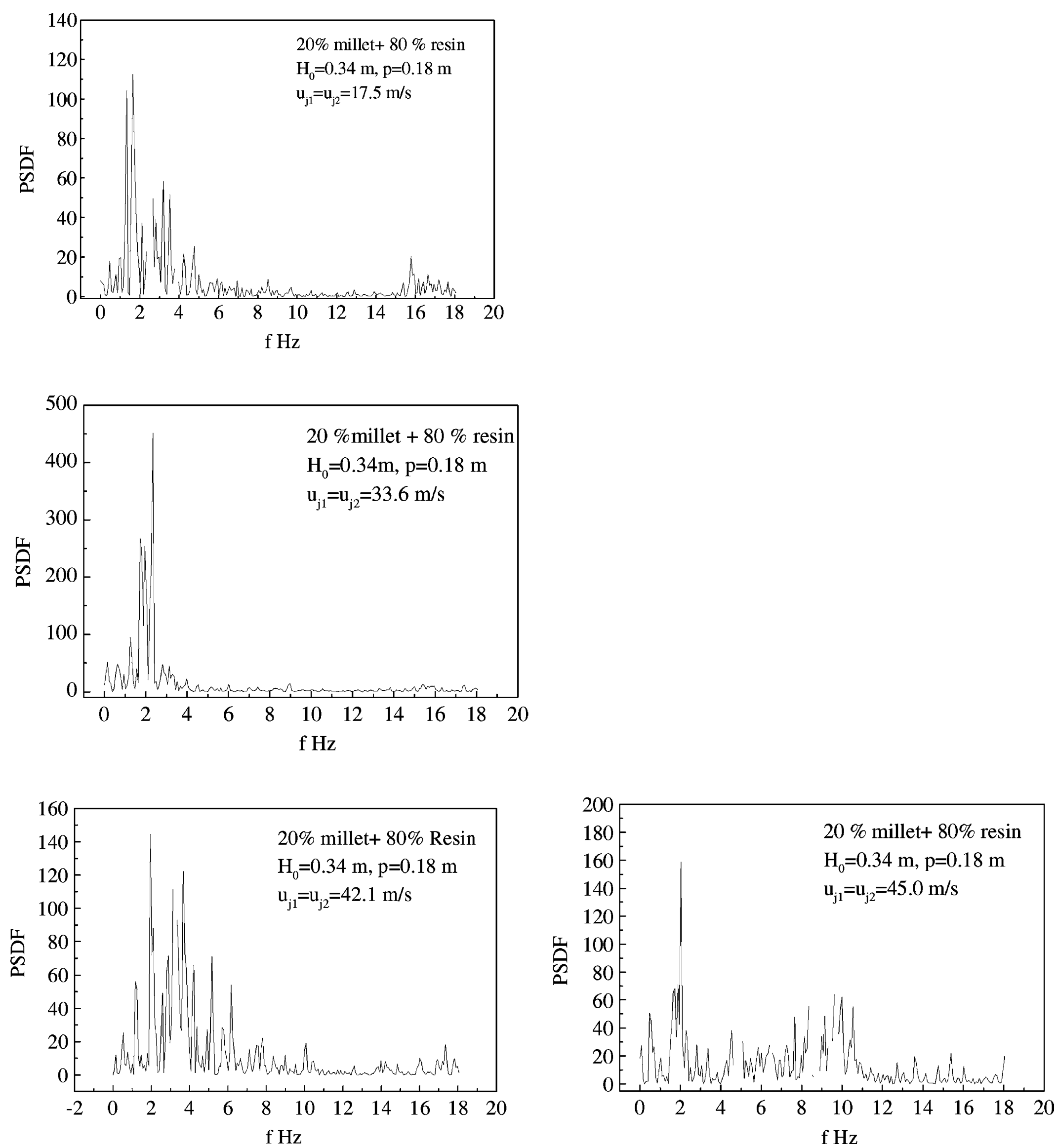

Fig. 2. The PSDF figures for various jetting gas velocities under: $H_0 = 0.34$ m; $P = 0.18$ m.

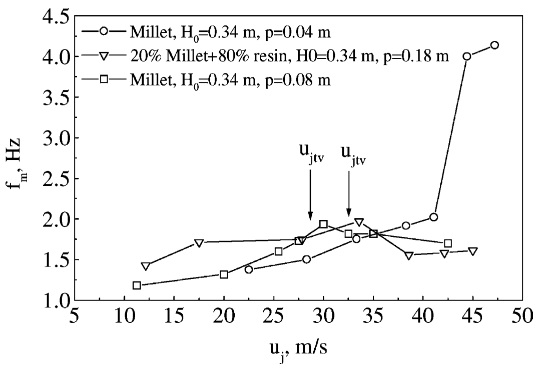

Fig. 3. Variation of major frequency with jet gas velocities for different nozzle distance.

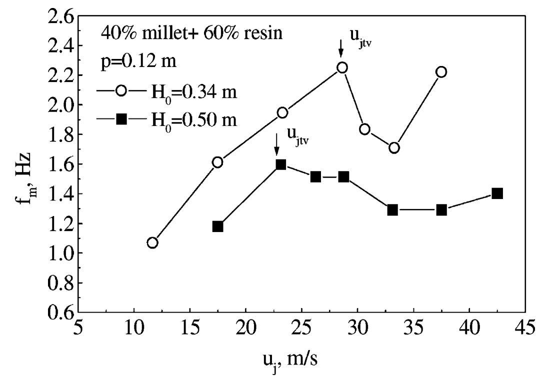

Fig. 5. Major frequency vs. jet gas velocity for different static bed height.

Fig. 3 exhibits the effect of jet gas velocity on the major frequency at various nozzle distances. At a nozzle distance of 0.18 m, two jets are characterized by separate jet pattern as jetting gas velocity is <33.5 m/s. Therefore, the major frequency of separate jet pattern increases with increasing jet gas velocity. Such finding is in agreement with the conclusions derived by previous investigation in the jetting fluidized bed with one jet [3,4,6]. The reason is that increasing jet gas velocity leads to higher jet formation frequency. On the other hand, the jet gas velocity is increased further resulting in larger jet penetration depth and larger jet conical volume, which makes two jets coalesce within the penetration depth. According to Guo et al.'s finding [11], separate jet pattern, which appears with greater nozzle distance, is defined as jets existing independently within the jet penetration depth, as shown in Fig. 4a. With smaller nozzle distance, jet coalescence within the penetration depth is defined as jet coalescence pattern, as illustrated in Fig. 4b. The flow transition pattern is defined as jet coalescence pattern and separate jet pattern appear alternatively. Jet coalescence pattern occurs at a jetting gas velocity of 33.5 m/s. It should be pointed out that jet coalescence causes jet gas to diffuse into emulsion phase and jet gas momentum to lose. Therefore, the major frequency decreases and then increases with jet gas velocity >33.5 m/s.

Fig. 3 also illustrates the jet coalescence transition velocity is 30.0 m/s at a nozzle distance of 0.08 m. As the nozzle distance decreases to 0.04 m, there exists no u_{jtv} in the curve major frequency versus jet gas velocity due to the fact that these two jets starts to coalesce as they leave the nozzle exit even at low jet gas velocity.

3.2. *Effect of static bed height*

The major frequencies are plotted against jet gas velocity under two static bed heights, as shown in Fig. 5. Apparently, the u_{jt} is decreased with an increase in static bed height because the large static bed height gives rise to high coalescence probability of two jets.

3.3. *Effect of nozzle diameter*

Fig. 6a illustrates the influence of jet gas velocity on the major frequency for different nozzle diameters. It is found from such figure that the jet transition gas velocity is increased from 31.3 to 59.39 m/s as the nozzle diameter is decreased from 8.0 to 5.0 mm at a given static bed height (0.40 m). Since, a greater jet nozzle diameter implies a larger jet conical volume, suggesting that the jetting velocity has great effect on the jet transition gas velocity. It is of great importance to adopt an appropriate nozzle diameter

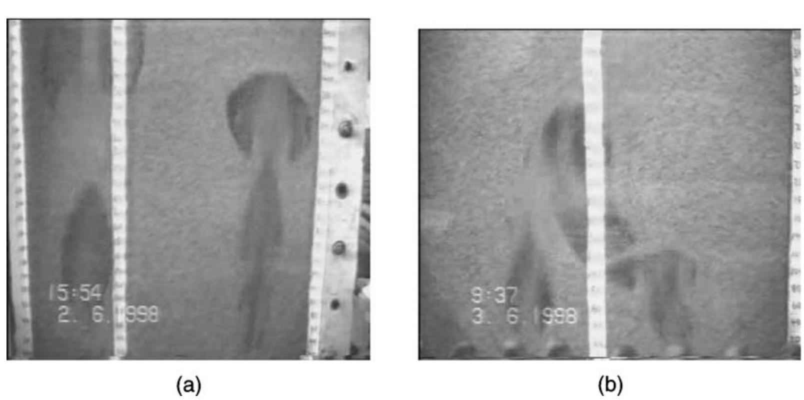

Fig. 4. Typical pictures for separate: (a) jet pattern and (b) the jet coalescence pattern.

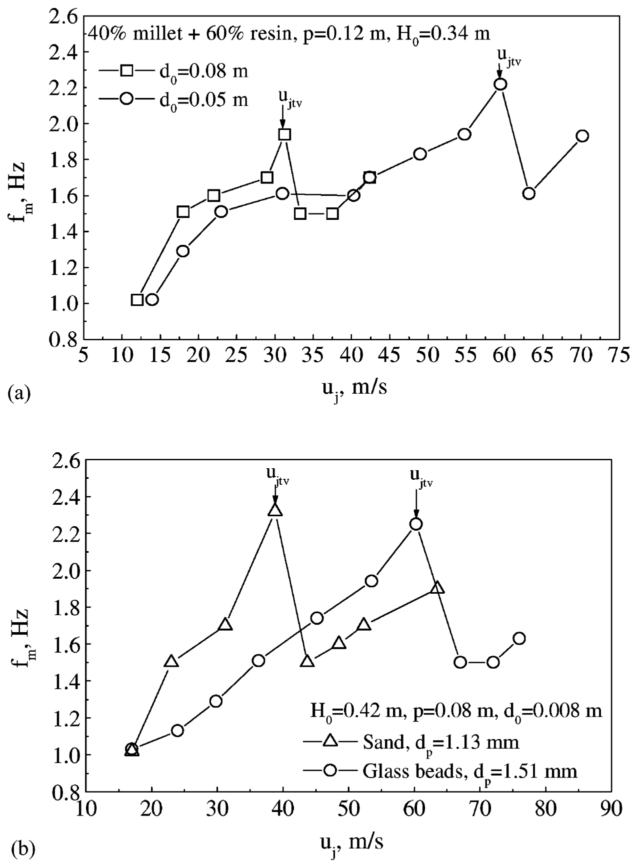

Fig. 6. Effect of jet gas velocity on major frequency with: (a) different nozzle diameter and (b) various particle diameters.

in design and scale-up of a multi-jet jetting fluidized bed of ash-agglomeration pulverized coal gasification, which operates at the jetting gas velocity varied from 30.0 to 65.0 m/s.

3.4. Effect of particle diameter

Effect of particle diameter on major frequency for various jet velocities is as shown in Fig. 6b. The increasing particle diameter results in larger jetting transition velocity due to larger particle diameter leading to smaller jet penetration depth and smaller jet conical volume [7], indicating that the larger jetting gas velocity can cause jet coalescence.

3.5. A correlation of jetting transition gas velocity

In summary, a jetting transition gas velocity is a function of jetting gas velocity, nozzle distance, static bed height, and particle diameter. On the basis of experimental data, a correlation is proposed for prediction u_{jtv}, expressed by

$$\frac{u_{jtv}}{u_{mf}} = 21.36\left(\frac{p}{d_0}\right)^{1.06}\left(\frac{H_0}{d_p}\right)^{-0.24}$$

4. Conclusions

Pressure signals are used to investigate the jetting fluidized transition velocity (u_{jtv}) in a 300 mm × 50 mm 2D jetting fluidized bed by using eight materials, including four binary mixtures. It is found that the peak in the curve major frequency versus jetting gas velocity corresponds to u_{jtv}. The u_{jtv} increases with increasing nozzle distance, particle diameter, but decreasing with increasing static bed height and nozzle diameter. Finally, a correlation is proposed for prediction u_{jtv}.

Acknowledgements

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