Fluidization behavior of wood/sand mixtures

Citation for published version (APA):
Ramakers, B. J., de Ridder, R., & Kerkhof, P. J. A. M. (2004). Fluidization behavior of wood/sand mixtures. *Maderas. Ciencia y Tecnología*, *6*(2), 145-153.

Document status and date:
Published: 01/01/2004

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 16. Nov. 2023

FLUIDIZATION BEHAVIOR OF WOOD/SAND MIXTURES♣

Bram J. Ramakers[1], **Ronny de Ridder**[1], **Piet J.A.M. Kerkhof**[1]

[1]Eindhoven University of Technology, Faculty of Chemical Engineering and Chemistry, Transport Phenomena Group, Laboratory of Chemical Reactor Engineering, P.O. Box 513, NL 5600 MB, Eindhoven, The Netherlands.

Corresponding author: mailto:%20b.j.ramakers@tue.nl ; mailto:%20r.de.ridder@tue.nl ; mailto:%20p.j.a.m.kerkhof@tue.nl

Received: 05.10.2004. Accepted: 03.12.2004.

ABSTRACT

In conversion of biomass to secondary energy carriers, several routes are possible, such as gasification, combustion and pyrolysis. In many of these processes it is necessary or advantageous to dry the biomass before further processing. For wooden biomass, fluidized bed drying in superheated steam is a promising option. Given the difficulty to fluidize wood particles alone, it is very common to fluidize these kinds of particles with sand. This also gives better defined fluidization behavior. Especially when the wood particles come in various size and shape (i.e. from sawdust to chopped wood), this gives a more reliable scale-up. Also heat transfer to the wood particles may benefit from the use of sand. However, not much is known about fluidization behavior in pressurized steam of binary mixtures with large particle size ratio and large particle density ratio. Therefore minimum fluidization velocity and bed porosity of wood/sand mixtures in air have been experimentally determined and compared to correlations known from literature. The experimental values show a clear trend, but correlations from literature appear not to be very accurate. So more experiments have to be done to find a correlation that gives more accurate predictions in case of the specific particles used in this work. From segregation experiments could be found that, to keep the wood/sand bed well-mixed, finer sand (0.1-0.5 mm) with maximum 10 weight-% wood should be used, and the superficial gas velocity should be at least 3-4 times the minimum fluidization velocity.

Keywords: drying of wood, fluidization, binary mixture

INTRODUCTION

The desire for a sustainable society has led to research and development activities on the utilization of renewable energy sources. Biomass is considered to be such a resource: during the growth of plants and trees solar energy is stored as chemical energy, which can be released via direct or indirect combustion. In the overall process, CO_2 is fixed during the production of biomass and released again during combustion. Within this relatively short cycle, no net addition of CO_2 to the atmosphere takes place.

Conversion of biomass (after a preceding drying step) to intermediate energy carriers like gases or oils is probably much more attractive than direct combustion. Biomass as such is not very suitable for transport over long distances because it has a low bulk density, and liquefaction to an energy carrier such as oil, gas or electricity is an obvious solution. In biomass conversion there are several alternative routes, such as gasification, combustion, HTU-process, pyrolysis, etc.

In many of these processes it is necessary or advantageous to dry the biomass before further processing. From an energetic point of view such a drying step severely influences the economy of the whole plant. It is therefore necessary to optimize the drying step with respect to equipment, process conditions and pre-treatment; this optimization should be embedded in the optimal design and operation of the whole plant. In literature it is reported that drying with superheated steam may reduce both energy costs and the size of the drying equipment. For particulate biomass materials fluid bed steam drying is a promising option. The optimal design and operation rules for such a drying step can at present not be found from existing knowledge, but require more research.

As wood chips are rather difficult to fluidize, sand can be used as fluidizing medium. This also gives the benefit of a better described system in scale-up, when wooden particles of various sizes and shapes are used. Furthermore the sand will improve heat transport to the wooden particles in fluid bed drying. However, little is known about fluidization of binary mixtures with large size ratio and large density ratio. Therefore fluidization characteristics of various wood/sand mixtures are measured and fluidization behavior is observed, with cold air as fluidizing medium. These preliminary results will be used in designing a steam fluidized bed, in which fluidization characteristics of wood/sand mixtures in (superheated) steam will be measured, and in which the superheated steam fluidized bed drying of wood will be studied.

MATERIALS & METHODS

Theory

In the case of binary (polydisperse) systems, the minimum fluidization velocity u_{mf} (and fluidization‟quality”) of large and/or coarse particles can be reduced by the addition of smaller particles. To estimate u_{mf} for a binary system, it is necessary to take into account the different characteristics of mixing and segregation of two kinds of particles having different properties. A lot of studies have been done about fluidization of binary systems with large particle size ratio, as well as about fluidization of binary systems with large particle density ratio. But little is known about fluidization of binary systems with both large size ratio and large density ratio. Most correlations to calculate u_{mf} are of the Ergun equation type (Kunii, and Levenspiel 1969; San José *et al*., 1995; Pell 1990; Reina *et al*., 2000; Gautier *et al*., 1999), and many of these require precise knowledge of the shape factor and bed porosity at u_{mf}. These two parameters are very difficult to measure experimentally and their values can have high errors that cannot be estimated, especially when irregular and coarse particles are handled (i.e. demolition wood or other biomass). Therefore the use of these parameters should be avoided in predicting u_{mf} for wood/sand mixtures. Several alternatives for predicting the minimum fluidization velocity of a binary mixture are listed below.

Goossens *et al*. (1971) proposed the following equations to calculate the density and particle size of a binary mixture, which can be used in Reynolds-Archimedes correlations:

$$\frac{1}{\rho_m} = \frac{\omega_f}{\rho_f} + \frac{\omega_p}{\rho_p} \tag{1}$$

$$\frac{1}{\rho_m d_m} = \frac{\omega_f}{\rho_f d_f} + \frac{\omega_p}{\rho_p d_p} \tag{2}$$

The Wen and Yu (Wen and Yu, 1966; Noda *et al*., 1986) equation for a single component system is given by:

$$Ar = 24.5\, Re_{mf}^{2} + 1650\ Re_{mf} \tag{3}$$

Chyang and Huang (San José *et al*., 1995) found the following relation for coarse particles:

$$Re_{mf} = \left(33.33^{2} + 0.0333\ Ar\right)^{0.5} - 33.33 \tag{4}$$

Tannous et al. (San José *et al*., 1995) proposed the following equation for calculating the minimum fluidization velocity of coarse particles:

$$Re_{mf} = \left(25.83^{2} + 0.043 Ar\right)^{0.5} - 25.83 \tag{5}$$

Chiba *et al*. (1979) derived an equation for u_{mf} of the mixture which depends on u_{mf} of the single components:

$$u_{mf} = \frac{u_{mf}^{F}}{\left(1 - \frac{u_{mf}^{F}}{u_{mf}^{P}}\right) x^{F} + \frac{u_{mf}^{F}}{u_{mf}^{P}}} \tag{6}$$

Experimental setup

The experimental setup (figure 1) consists of a glass pipe of 7.56 cm in diameter and a height of 120 cm. The distributor is a metal sintered plate of 5 mm thickness. The superficial velocity of cold air can be adjusted between 0 and 2.2 m/s. During fluidization pressure drop over the bed, absolute pressure before bed entrance and bed height can be measured.

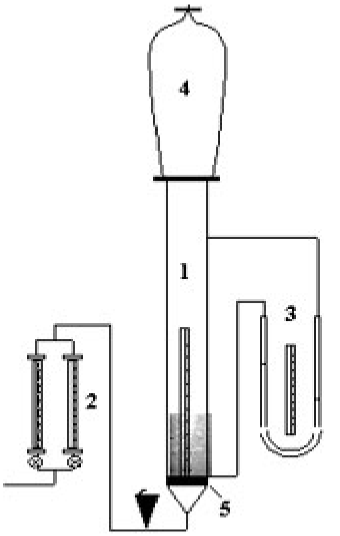

Figure 1. Diagram of the fluidized bed setup; (1) glass fluid bed column, (2) flow meter, (3) pressure drop meter, (4) dust bag, (5) distributor, (6) pressure meter.

The wooden particles used in the fluidization experiments were beech wood cylinders of 9 mm length and 6 mm in diameter. Three different size distributions of sand were used as fluidizing agent. The properties of the particles are listed in table 1. The diameter is listed as that of a volume-equivalent sphere.

Table 1: Properties of the used particles.

Particle	**Diameter [mm]**	**Density [kg/m^3]**
Wood	7.9	722
Sand (*fine*)	0.1-0.5	2629
Sand (*medium*)	0.4-0.6	2669
Sand (*coarse*)	0.8-1.2	2608

Prior to each experiment, the mixture was fluidized at high velocity (~1.5 m/s) for a few minutes. Then the airflow was suddenly stopped to obtain a well-mixed packed bed, with which all experiments started. Experiments are performed to find the minimum fluidization velocities and bed porosities of wood/sand mixtures at different ratios. Also segregation experiments are performed to examine bed mixing as a function of wood/sand ratio, type of sand and superficial gas velocity. These experiments started with a well-mixed bed, and after 1 minute fluidizing at a given airflow the airflow was cut.

The fraction of wood on top of the wood/sand bed was measured and used as a criterion of the quality of fluidization and mixing of the bed. In all experiments total bed mass was kept constant.

RESULTS & DISCUSSION

Fluidization parameters

Figure 2 shows plots for calculating the minimum fluidization velocity and the bed porosity at minimum fluidization velocity. The fluidization parameters found for the pure components are listed in table 2. The minimum fluidization velocities, calculated with the modified Wen and Yu (1966) equation, are also added to Table 2. It can be seen that the experimentally determined u_{mf} for the sand fractions are nicely positioned in the middle of the window of the fractions, calculated with equation (3). This should be the case, assumed that the sand fractions have a Gaussian distribution.

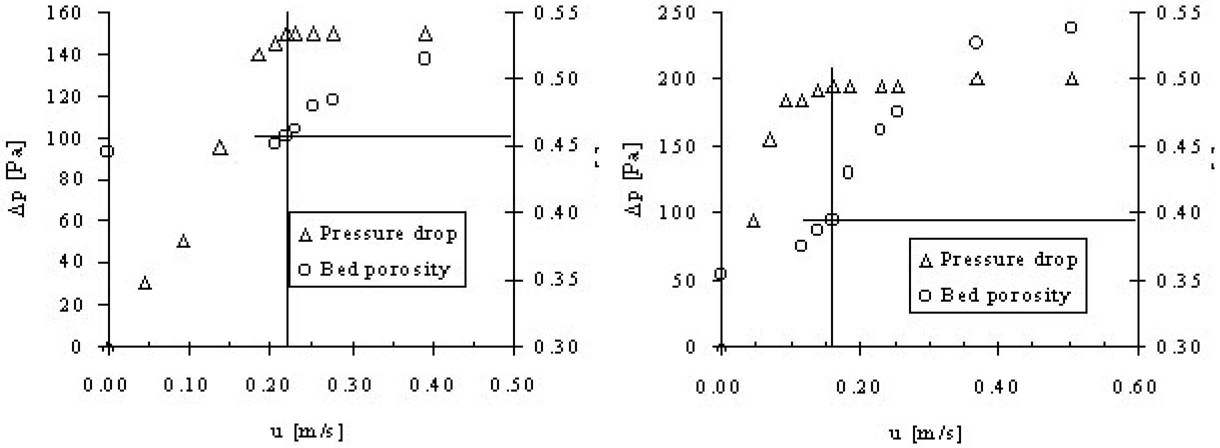

Figure 2. Plots for calculating the minimum fluidization velocity and the bed porosity at minimum fluidization velocity; (a) Sand (medium), 0 w-% wood; (b) Sand (fine), 20 w-% wood.

Table 2: Hydrodynamic parameters of the pure components.

Particle	u_{mf} [m/s]	e_{mf} [-]	Wen and Yu (1966)
Wood	1.30	0.425	1.30
Sand (*fine*)	0.13	0.494	0.01-0.20
Sand (*medium*)	0.22	0.457	0.13-0.27
Sand (*coarse*)	0.51	0.436	0.42-0.69

In Figure 3 the results of experiments with wood/sand mixtures are shown. From these figures can be seen that at a higher weight fraction of wood, the minimum fluidization velocity rises. This is due to the fact that the wood particles negatively influence the fluidization. The bed porosity, however, seems to minimize at 5 weight percent wood, and for fine sand even at 20 w-%. Mixtures in general have lower packed porosity than their pure component, with a minimum around 1:1 volume ratio (Chiba *et al*., 1979). With the particles used in this study that would be at 20 weight percent. This can be seen in Figure 3c. However, coarse and medium sand/wood mixtures have higher difference in u_{mf} in relation to the pure sand than in the case of fine sand/wood. Therefore their mixtures have a more expanded bed at u_{mf}, and the minimum in e_{mf} should shift to lower weight fractions of wood (Figures 3a and 3b).

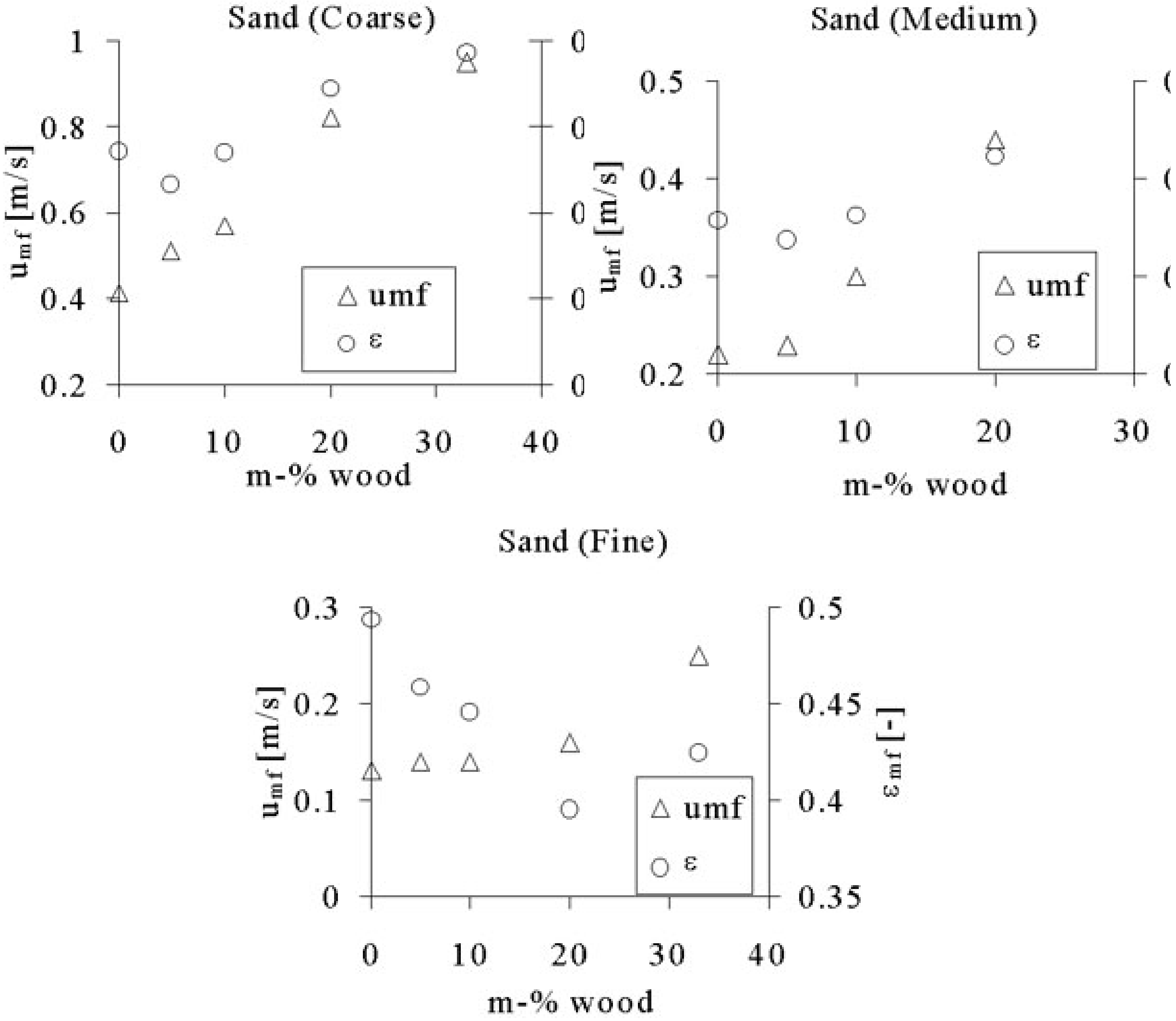

Figure 3. Minimum fluidization velocity and bed porosity at umf as function of the weight fraction of wood; (a) coarse sand/wood; (b) medium sand/wood; (c) fine sand/wood.

The values for u_{mf} determined in this work are compared to values calculated from literature correlations, stated in equations (1) to (6) (Figure 4). It can be clearly seen that in most cases there is an over or under prediction of u_{mf}. Wen and Yu, equation (3), appears to give the best prediction for all three types of sand. However, to get a more accurate prediction for u_{mf}, more experiments should be done to derive a correlation for u_{mf} that could be used for the specific particles used in this work. This is due to the great influence of shape, sizes and size ratio, and densities and density ratio of the particles on the fluidization behavior of the mixture.

Table 3: Uncertainties in measured experimental data.

Quantity	Estimated error
Pressure difference, D P	± 5 Pa
Minimum fluidization velocity, u_{mf}	± 0.02 m/s (Fine); ± 0.03 m/s (Medium); ± 0.05 m/s (Coarse)
Bed porosity at u_{mf}, e	± 0.01 (Fine); ± 0.015 (Medium); ± 0.025 (Coarse)

Segregation experiments

The results of the segregation experiments are shown in Figure 5. From these experiments it can be seen that less wood in the system, keeps the bed mixed at lower superficial gas velocities. Also the finer sand seems a better fluidizing agent for the wood particles used. For the future drying experiments there has to be a reasonable amount of wood in the bed. From this work, 10 weight percent wood in fine sand seems to give best prospect. Nevertheless, the superficial gas velocity has to be 3-4 times higher than u_{mf} in order to keep the bed well-mixed.

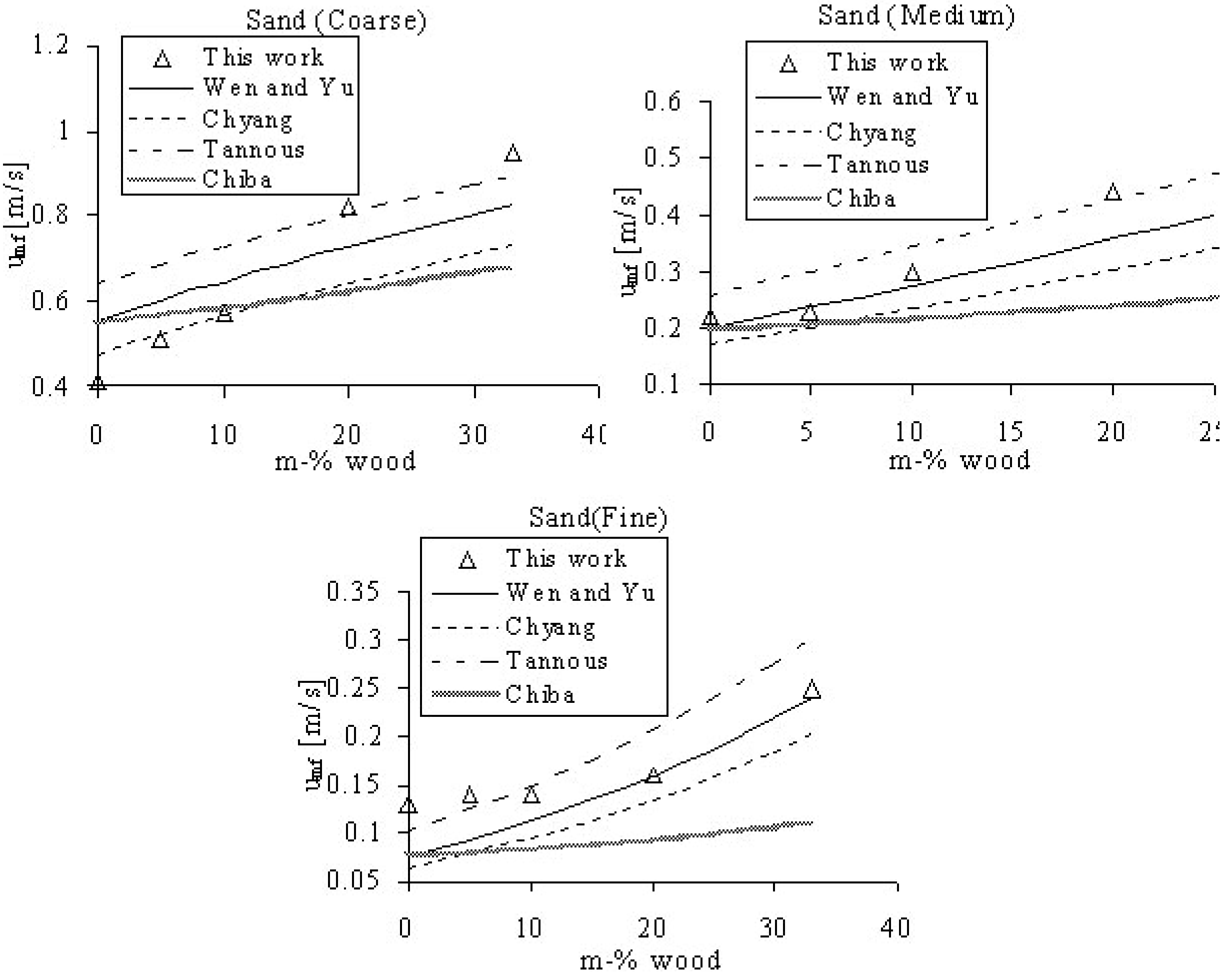

Figure 4. Minimum fluidization velocity found in this work compared to literature, equations (1) to (6).

CONCLUSIONS

The measurements of fluidization behavior of binary mixtures with large size ratio and large density ratio show clear trends in u_{mf} as well as in e_{mf}. However, it appears that using correlations from literature for calculating u_{mf}, doesn't predict the u_{mf} very well for the specific mixtures used in this work. More experiments should be done to derive a better correlation. Especially when in future work superheated steam will be used to fluidize wood/sand mixtures, the fluidization behavior of these specific mixtures in steam should be experimentally determined.

The segregation experiments show that in fluid bed drying of the wood particles used, fine sand is best used as fluidizing agent. Also the superficial gas velocity should be at least 3-4 times u_{mf} to have a well-mixed bed. The weight fraction of wood should then be 0.10 at most to keep the bed from segregating.

ACKNOWLEDGMENT

The authors would like to kindly thank the Council for Chemical Sciences of the Netherlands Organization for Scientific Research (CW-NWO, projectnr. 99602), Shell Global Solutions International B.V. and the Netherlands Organization for Energy and Environment (Novem) for funding this research.

NOTE

♣This paper was first presented at the IDS-2004, Sao Paulo and preselected for MADERAS:Ciencia y Tecnología journal.

LITERATURE

CHIBA, S.; CHIBA, T.; NIENOW, A.W.; KOBAYASHI, H. 1979. The minimum fluidization velocity, bed expansion and pressure-drop profile of binary particle mixtures. *Powder Technology* 22:255-269

GAUTHIER, D.; ZERGUERRAS, S.; FLAMANT, G. 1999. Influence of the particle distribution of powders on the velocities of minimum and complete fluidization. *Chemical Engineering Journa*l 74:181-196

GOOSSENS, W.R.A.; DUMONT, G.L.; SPAEPEN, G.L. 1971. *Chemical Engineering Progress Symposium Series* 67 (116):38-45

KUNII, D.; LEVENSPIEL, O. 1969. Fluidization Engineering. Wiley, New York

NODA, K.; UCHIDA, S.; MAKINO, T.; KAMO, H. 1986. Minimum fluidization velocity of binary mixtures of particles with large size ratio. *Powder Technology* 46:149-154

PELL, M. 1990. Gas fluidization, Handbook of Powder Technology. Vol. 8, Elsevier Science Publishers B.V., The Netherlands

REINA, J.; VELO, E.; PUIGJANER, L. 2000. Predicting the minimum fluidization velocity of polydisperse mixtures of scrap-wood particles. *Powder Technology* 111:245-251

SAN JOSÉ, M.J.; OLAZAR, M.; BENITO, P.L.; BOLBAO, J. 1995. Hydrodynamics and expansion of fluidized beds of coarse particles. *Transactions of the Institution of Chemical Engineers* Vol. 73, part A:473-479

WEN, C.J.; YU, Y.H. 1966. A generalized method for predicting the minimum fluidization velocity. *AIChE Journal* 12(3):610-612

NOTATION

Ar	Archimedes number	$Ar = \frac{g\, d^3\, \rho\left(\rho^P - \rho\right)}{\mu^2}$	-
d	Particle diameter		m
Re	Reynolds number	$Re = \frac{\rho\, u\, d}{\mu}$	-
u	Superficial gas velocity		m/s
ε	Bed porosity		-
μ	dynamic viscosity		kg/ms
ρ	fluid density		kg/m³
ϖ	Weight fraction		-

Subscripts		**Superscripts**	
mf	Minimum fluidization velocity	F	Small particle
m	mixture	P	Large particle