Operating Conditions of Binary Mixtures of Biomass Wastes in Spouted Bed Contactors for Using Energy

M.J. San José*, S. Alvarez, L.B. López, and I. García

Departamento de Ingeniería Química, Facultad de Ciencia y Tecnología, Universidad del País Vasco Aptdo 644. 48080 Bilbao. Spain. Tel: 34-94-6015362. Fax: 34-94-6013500 e-mail: mariajose.sanjose@ehu.es

ABSTRACT

The applicability of conical spouted bed reactors for the treatment of biomass wastes has been studied by means of a hydrodynamic study with binary mixtures of biomass wastes of different size in different experimental conditions. The validity of the ranges of the geometric factors of the contactor and of the contactor-particle system for stable spouting established in a previous paper has been proven for beds made of binary mixtures of biomass wastes.

Keywords: spouted beds, biomass wastes, operating conditions, binary mixtures, thermal treatment

1 INTRODUCTION

Due to the increasing costs of fossil fuels, interest has grown in the use of renewable energy Different methods can be followed for the use of the biomass feedstocks, as combustion, gasification, pyrolysis. Spouted Bed technology is very useful for applications where a vigorous movement of the solids is required, as happens in the handling of solids that are sticky, of irregular texture and with a wide particle size distribution [1].

Spouted Bed technology is suitable for thermal treatment of biomass by combustion and by pyrolysis. Therefore, it would be adequate for using energy of biomass wastes with carbon dioxide and sulphur-derived compounds retention from flue gases with the addition of a sorbent, at high temperatures, due to the ability to handle granular and fibrous materials and mixtures of different sizes and textures with low segregation [2-3].

In this paper, the hydrodynamics of beds consisting of mixtures of biomass wastes of different characteristics in spouted beds of different geometry (contactor angle and gas inlet diameter) and in different operating conditions (stagnant bed height, particle diameter and gas velocity) has been studied.

2 EXPERIMENTAL

The experimental unit, Figure 1, design at pilot plant scale is provided with a blower that supplies a maximum air flow rate of 300 $Nm^3\ h^{-1}$ at a pressure of 15 kPa. The flow rate is measured by means of two mass flow meters in the ranges of 50-300 and 0-100 $m^3\ h^{-1}$, with both being controlled by a computer. The accuracy of this control is 0.5% of the measured flow rate [4-5].

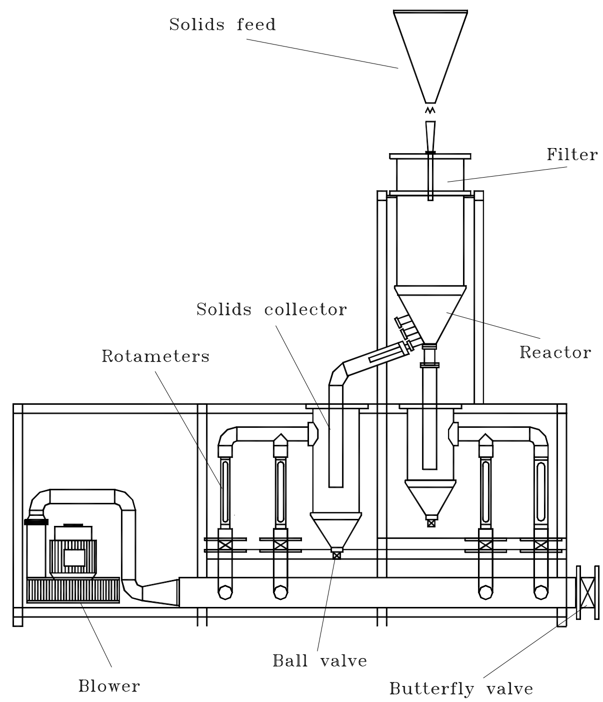

Figure 1: Diagram of the experimental equipment.

The measurement of the bed pressure drop is sent to a differential pressure transducer (Siemens Teleperm), which quantifies these measurements within the 0-100% range [4]. This transducer sends the 4-20 mA signal to a data logger (Alhborn Almeno 2290-8), which is connected to a computer where the data are registered and processed by means of the software AMR-Control. The software AMR-Control also registers and processes the air velocity data, which allows for the acquisition of continuous curves of pressure drop against air velocity.

Five conical contactors made of poly(methyl methacrylate) have been used. Figure 2 shows the geometric factors of these contactors, whose dimensions are as follows: column diameter, D_c, 0.36 m; contactor angle, γ, between 28 and 45°; height of the conical section, H_c, from 0.60 to 0.36 m; gas inlet diameter, D_o, in the range of 0.03-

0.06 m. The values of the stagnant bed height, H_o, used are in the range between 0.05 and 0.25 m. Operation has been carried out at the minimum spouting velocity and at velocities 20 and 30% above this value.

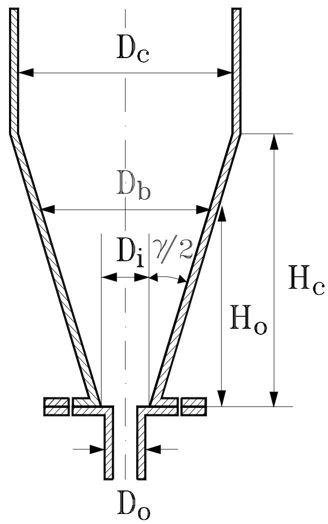

Figure 2: Geometric factors of the contactor and of the draft tube.

The solids used have been binary mixtures (sawdust, shavings, bark, leaves, branches and wood chips) of different Sauter average diameter between 1 and 40 mm.

3 RESULTS

In order to prove the applicability of the spouting regime for treatment of binary mixtures of biomass wastes, a hydrodynamic study has been carried out.

In order to illustrate the different regimes in beds made up of binary mixtures of biomass wastes with air velocity, in Figure 3 an outline of the evolution of particle population in the different regimes is shown for beds made up of binary mixtures of biomass wastes. After the fixed bed, Figure 3a, increasing gas velocity, the stable regime of spouting is reached, Figure 3b, the velocity corresponding to the beginning of the regime of spouting is the minimum spouting velocity. Increasing the velocity, both annular and spout zones characteristic of classical spouting become progressively confused (transition zone) and a particle movement outlined in Figure 3c is obtained. The transition evolves until the spout and annular zones are no longer differentiated and bed voidage is uniform, a new situation that corresponds to incipient jet spouting. The velocity corresponding to the beginning of the jet spouting regime (dilute spouted bed) is the minimum jet spouting velocity. Once this regime is reached, it stays stable at higher gas velocities, with the particle movement outlined in Figure 3d.

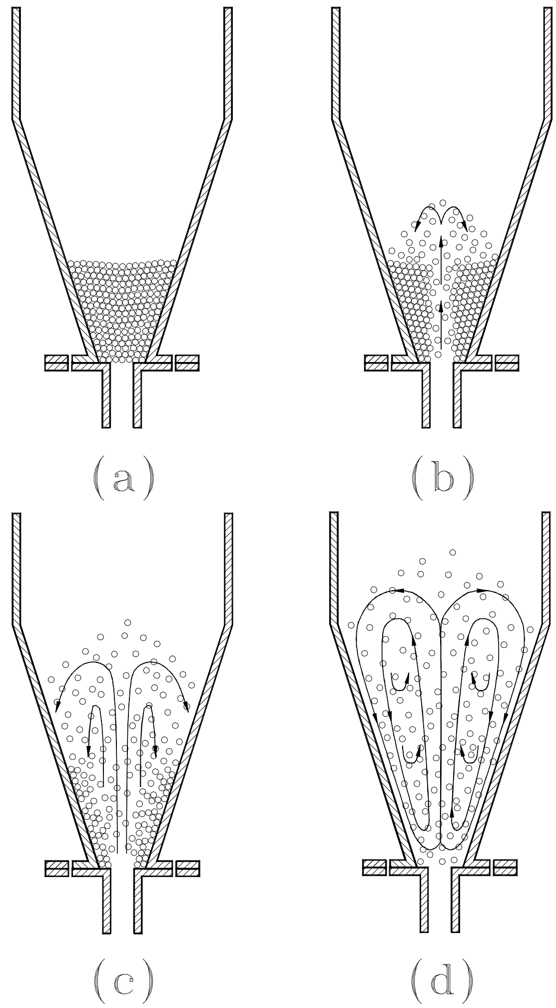

Figure 3: Particle states in the contactor for the different regimes.

The stable operating conditions in cylindrical spouted beds with a central draft tube have been plotted in a classic diagram such as the proposed by Mathur and Gishler [6] for conventional spouted beds. In this diagram the stagnant bed height, H_o, has been plotted against the gas velocity, u. The borders between the different regimes, drawn with solid lines, have been obtained experimentally (the points drawn are the experimental base for tracing these borders), by increasing gas velocity for each stagnant bed height.

The stability diagram H_o against u for the conical contactor angle γ= 36º, gas inlet diameter, D_o= 0.03 m, with a bed of binary mixtures of 50 wt % of wood chips and sawdust of Sauter average diameter $\overline{d}_S$ 3 and 1 mm, respectively is shown in Figure 4.

Beginning in the fixed bed, increasing gas velocity the minimum spouting velocity is obtained, nevertheless the stable regime of spouted bed is not reached directly from the fixed bed, but also gas velocity must be increased to

Clean Technology 2009, www.ct-si.org, ISBN 978-1-4398-1787-2

obtain minimum complete spouting velocity. Furthermore, it is noticeable that this system is stable at all studied stagnant bed heights and that as stagnant bed height is increased minimum spouting velocity, as well as, minimum complete spouting velocity increase and the difference between minimum spouting velocity and minimum complete spouting velocity increases, so the stable operation zone in spouted bed regime decreases. This hydrodynamics is peculiar in beds of sawdust and mixtures of wood residues in conical spouted beds [7] and it has its origin in the deficient fluidity of sawdust and in cross-linkage between particles due to the fact that they are mainly long and irregular.

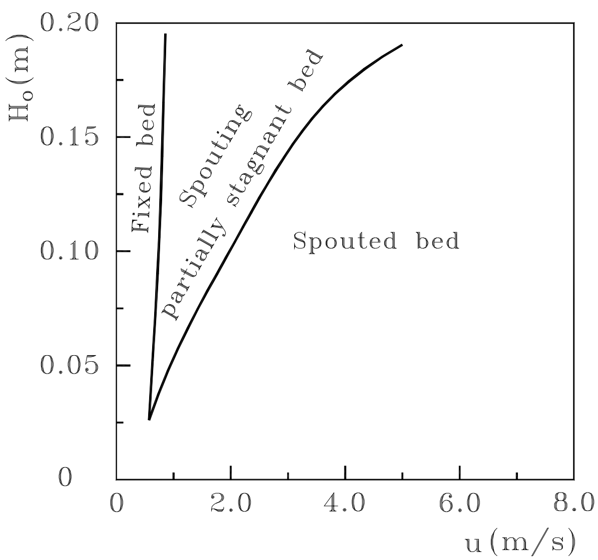

Figure 4: Operation map for a binary mixture of 50 wt % of wood chips and sawdust of Sauter average diameter $\overline{d_S}$ 3 and 1 mm. Experimental system: γ= 36º, D_o= 0.03 m, H_o= 0.20 m.

The experimental applicability ranges of the different regimes in conical spouted bed are compared in Figure 5, in which the application conditions of other methods for gas-solid contact, in a map of velocity modulus $u^*= u\,[\rho^2/\Delta\rho\, g\, \mu]^{1/3}$ vs. the modulus related to particle size-density, $d_p^*= Ar^{1/3}$ are shown for binary mixtures of biomass wastes of different particle size or density. The ranges corresponding to the Geldart classification [8-9] have been expressed on the abscissa axis of Figure 5. The calculated terminal velocity curve, u_t, has been drawn with a stroke line. The values of minimum fluidization velocity, u_{mf}, have been drawn with a dotted line. They are within a range, as the value calculated would vary according to the correlation used.

The experimental values (points) for uniform beds made up of binary mixtures of biomass wastes of different particle diameter have been plotted. The conical spouted beds cover a very wide range of application conditions, fluidized beds, turbulent fluidized beds and transport bed and fast fluidized bed and part of the conditions of other contact regimes like cylindrical spouted beds and jet spouted beds [10]. In this Figure, the velocity is referred to the upper diameter corresponding to the stagnant bed height, D_b.

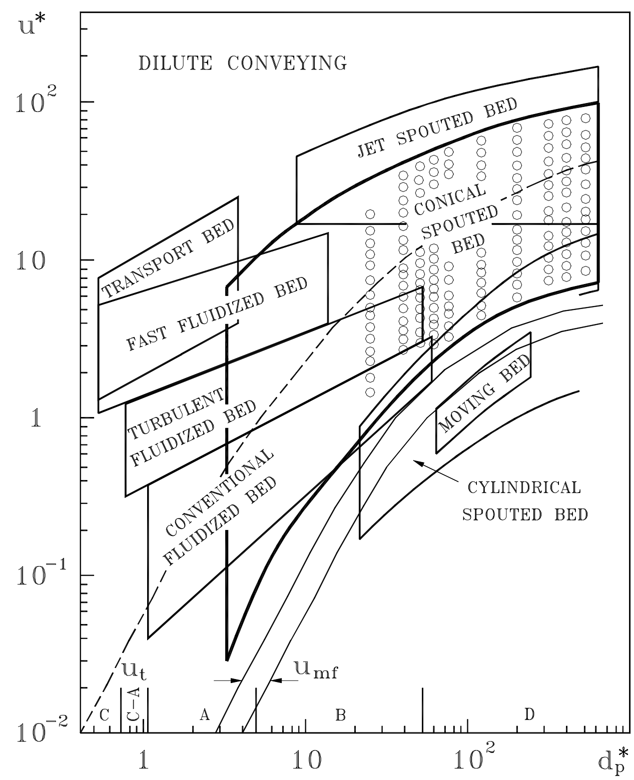

Figure 5: Applicability ranges of the regimes in conical spouted beds and other methods for gas-solid contact.

4 CONCLUSIONS

In order to determine the stable operating conditions and the applicability of this method in spouted bed regime for the treatment of binary mixtures of biomass wastes, the operation regimes have been delimited, a hydrodynamic study has been carried out with beds consisting of binary mixtures of biomass wastes of different particle diameter obtaining finally the operation map for different experimental conditions.

Beginning in the fixed bed, as gas velocity is increased the stable regime of spouted bed is not reached directly, but also gas velocity must be increased to obtain minimum complete spouting velocity. Nevertheless, beds consisting of mixtures of binary mixtures of biomass wastes are stable for all studied conditions. Minimum spouting velocity increases as stagnant bed height is increased, therefore operating zone in stable spouted bed regime decreases.

The ranges of the geometric factors of the contactor and of the contactor-particle system for stable spouting established in a previous paper for beds made up of granular materials and glass spheres have been proven to be valid for beds made up of biomass wastes.

The conical spouted beds cover a very wide range of application conditions, fluidized beds, turbulent fluidized beds and transport bed and fast fluidized bed and part of the conditions of other contact regimes like cylindrical spouted beds and jet spouted beds.

Therefore, the results of hydrodynamics conditions in the treatment of binary mixtures of biomass wastes have determined that the spouted bed in exclusively conical contactors allows for operating of binary mixtures of biomass wastes in stable regime and without significant segregation in a wide range of geometric factors and operating conditions, so this contact regime has good prospects for its use in operations and processes that requires handling with particles of Sauter average diameter.

ACKNOWLEDGMENTS

This work was carried out with the financial support of the University and of the County Council of Biscay (Project DIPE 07/09).

5 NOMENCLATURE

Ar	Archimedes number, $g\, d_p^3 \rho(\rho-\rho_s)/m^2$
D_b, D_c, D_i, D_o	Upper diameter of stagnant bed height, of the column, of the bed base and of the gas inlet, respectively, m
d_p	Particle diameter, m
d_p*	modulus related to particle size-density, $Ar^{1/3}$
g	gravity, ms^{-2}
$\overline{d}_S$	Sauter average particle diameter, m
H_c, H_o	Height of the conical section of the contactor and of the stagnant bed, respectively, m
$(Re_o)_{ms}$	Reynolds number of minimum spouting referred to D_o, $u_o\, \rho\, d_p / \mu$
u	Velocity of the gas referred to D_i, m s^{-1}
u*	velocity modulus referred to D_b, $u^* = u\, [\rho^2 / \Delta\rho\, g\, \mu]^{1/3}$
ϕ	Particle sphericity
γ	Contactor angle, deg
ρ_s	Solid density, kg m^{-3}
ρ	Gas density, kg m^{-3}

REFERENCES

[1] M.J. San José, M. Olazar, A.T. Aguayo, J.M. Arandes and J. Bilbao, Expansion of Spouted Beds in Conical Contactors, Chem. Eng. J. 51, 45-52, 1993.

[2] M. Olazar, M.J. San José, F.J. Peñas, A.T. Aguayo and J. Bilbao, Stability and Hydrodynamics of Conical Spouted Beds with Binary Mixtures, Ind. Eng. Chem. Res., 32, 2826-2834, 1993.

[3] M.J. San José, M. Olazar, F.J. Peñas, and J. Bilbao, Segregation in Conical Spouted Beds with Binary and Tertiary Mixtures of Equidensity Spherical Particles, Ind. Eng. Chem. Res., 33, 1838-1844, 1994.

[4] M. Olazar, M.J. San José, S. Alvarez, A. Morales and J. Bilbao, Design in Conical Spouted Beds for the Handling of Low-Density Solids, Ind. Eng. Chem. Res., 43, 655-661, 2004.

[5] M.J. San José, S. Alvarez, A. Ortiz de Salazar, M. Olazar and J. Bilbao, Spout Geometry in Shallow Spouted Beds with Solids of Different Density and Different Sphericity, Ind. Eng. Chem. Res., 44, 8393-8400, 2005.

[6] K.B. Mathur and P.E. Gishler, A Technique for Contacting Gases with Coarse Solid Particles, AIChE J., 1, 157-164, 1955.

[7] M. Olazar, M.J. San José, R. Llamosas and J. Bilbao, Hydrodynamics of Sawdust and Mixtures of Wood Residues in Conical Spouted Beds, Ind. Eng. Chem. Res., 33, 993-1000, 1994.

[8] Geldart, D., Types of Gas Fluidization, Powder Technol., 7(5), 285-292, 1973.

[9] Geldart, D., *Gas Fluidization Technology*, John Wiley, New York, 1986.

[10] M. Olazar, M.J. San José, G. Zabala and J. Bilbao, A New Reactor in Jet Spouted Bed Regime for Catalytic Polymerizations, Chem. Eng. Sci., 49, 4579-4588, 1994.