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Diluted spouted bed at high temperature for the treatment of sludge wastes

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In order to determine the optimum operating conditions of conical spouted beds at high temperature for the treatment of sludge wastes, operation regime of dilute spouted bed (jet spouted bed) has been delimited. The effect of gas inlet temperature on the operation regimes has been determined at gas inlet temperature range of 25-800ºC. It has been proven that the conical spouted beds allow for stable operation at temperatures over room temperature.

Introduction

The great amount of common sludge wastes (no dangerous) coming from paper industrial activity, is characterized because they present high moisture content, therefore they are sticky solids (Kudra et al., 2002). The diluted spouted bed regime has a vigorous movement for the solid and a uniform gas-solid contact, which is necessary in operations with sticky solids and highly exothermal reactions. In the same way, it allows for working in a close to uniform way with a wide particle size distribution (Olazar et al., 1993a).

Despite some authors have studied the effect of gas inlet temperature (over room temperature) on the hydrodynamics and on stable operating conditions at high temperature at the minimum spouting velocity in conventional spouted beds, (Wu et al. 1987; Altwicker et al., 1992; Ye et al., 1992; Yang et al., 1996; Wei et al., 2006) and in conical spouted beds (Olazar et al., 2006), the few studies of hydrodynamics in the dilute spouted bed regime (Markowski and Kaminsky, 1983; Bilbao et al., 1987; San José et al., 1991, 1992, 2005; Olazar et al., 1992, 1993a, b, 1994) have been carried out at room temperature.

In this paper, spouted bed technology for treatment of industrial sludge wastes has been studied, what will allow in last term energetic valorization of them. In order to determine the optimum operation conditions of this contact method at high temperature, operation regime of diluted spouted bed (jet spouted bed) has been delimited in conical contactors.

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Experimental Section

The experimental unit designed at pilot plant scale, shown in Figure 1, basically consists of a blower that supplies a maximum flow rate of 300 Nm^3h^{-1} at a pressure of 15kPa, an electric resistance for preheating the air, thermocouples for measuring the temperature and two high efficiency cyclones in order to collect the ashes and fine particles. The air flow rate is measured by means of three rotameters, used in the ranges from 0 to 2.5, from 2.5 to 25 and from 25 to 300 Nm^3h^{-1}, respectively and by means of two mass flow meters, one for the 0-15 l/min range and the other one for the 0-65 l/min range, a system of valves allow for choosing the suitable rotameter and mass flow meter for the desired flow rate.

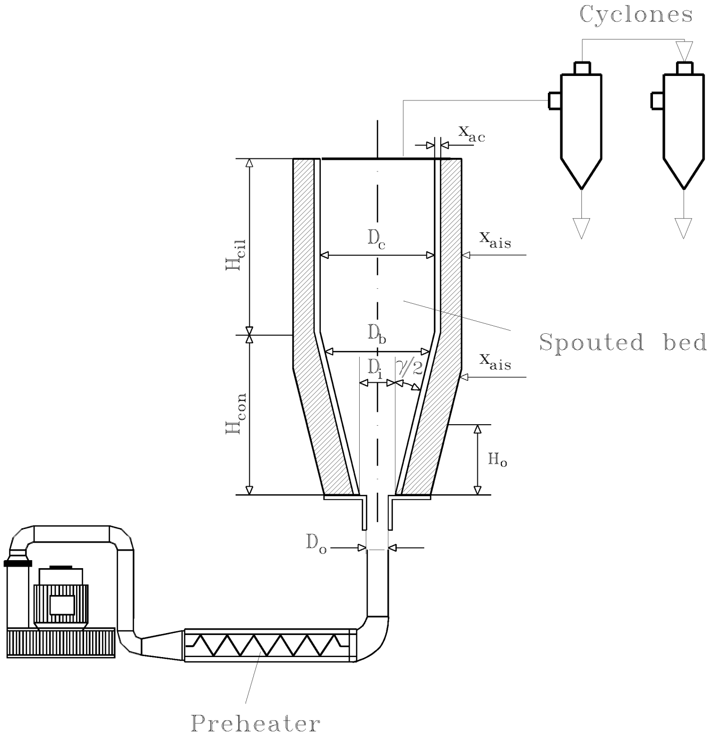

Figure 1. Scheme of the pilot plant and of the conical spouted bed reactor

The reactor utilized, Figure 1, is made of AISI-310S heat-resistant stainless steel and is externally insulated with 0.05 m quartz fibre. The dimensions of the reactor are: cone angle, γ between 28 and 45°; contactor inlet diameter, D_i= 0.03 m; gas inlet diameter, D_o, in the range of 0.01-0.03 and values of the stagnant bed height, H_o, in the range between 0.02 and 0.30 m.

The solids used are inert materials of different particle diameter and density and sphericity, whose properties are set out in Table 1.

The hydrodynamic study has been carried out at in a reactor at a range of temperatures between 25 and 800 ºC in beds consisting of inert materials.

Table 1 Properties of the materials studied

Material	Sauter diameter $\overline{d_S}$ (10^{-3}) (m)	Density ρ_s (kg/m^3)	Shape ϕ	Voidage ε_o	Geldart classification
Sand	1.08	2650	0.9	0.32	D
Sludge wastes	2.81	1123	0.9	0.34	D

Results

1.1 Conditions for stable operations

In order to delimit the conditions of stable operation and the operating regimes of uniform beds made up of sand at high temperatures, an experimental study on stability has been carried out similar to that carried out for materials of different nature at room temperature (Olazar et al., 1992) increasing the velocity from fixed bed, the spouted bed regime is obtained with uniform voidage and increasing velocity minimum dilute spouted bed velocity (jet spouted velocity) has been obtained for different particles at different temperatures over room temperature when the spout and annular zones are no longer differentiated and the bed voidage is uniform (over 0.75).

Operation maps are shown in plots of stagnant bed height, H_o, vs. gas velocity, u. The borders between the different regimes, drawn with solids lines, Borders between the different regimes, drawn with solid lines, have been obtained experimentally (the experimental points are the base for tracing these borders) and represent minimum spouting velocity and minimum dilute spouted bed (jet spouted) bed velocity. In addition, an outline of the particle movement in the reactor in the different regimes is shown

The results in Figure 2 correspond to the experimental system of angle γ= 36º, beds consisting of sand of Sauter diameter $\overline{d_S}$ = 1.08 mm, contactor inlet diameter, D_i= 0.03 m; bed inlet diameter, D_o= 0.03 m at gas inlet temperature of 300 and of 500 ºC. It is noteworthy that this experimental system is stable at all the stagnant bed height studied. As it is observed, as spouting velocity increases operation map passes from fixed bed to spouted bed regime and increasing gas velocity dilute spouted bed (jet spouting) regime is reached for low stagnant bed heights. As it is observed, minimum spouted bed velocity and minimum dilute spouted bed (jet spouted bed) velocity increase as stagnant bed height increases so the stable operation zone in the dilute spouted bed regime decreases. As gas inlet temperature increases, both minimum spouting velocity and minimum dilute spouted bed velocity increase, so the stable operation zone decreases.

Gas velocity depends on the properties of the fluid (density and viscosity) that change with temperature. Minimum spouted bed velocity only depends on density whereas minimum dilute spouted bed (jet spouting) velocity not only depends on gas density, but also depends on gas viscosity, however, the effect of gas density prevails on the effect of gas viscosity, Therefore, as temperature increases, fluid density decreases and fluid viscosity increases, as a consequence the global effect is a pronounced increase in minimum dilute spouting (jet spouting) velocity.

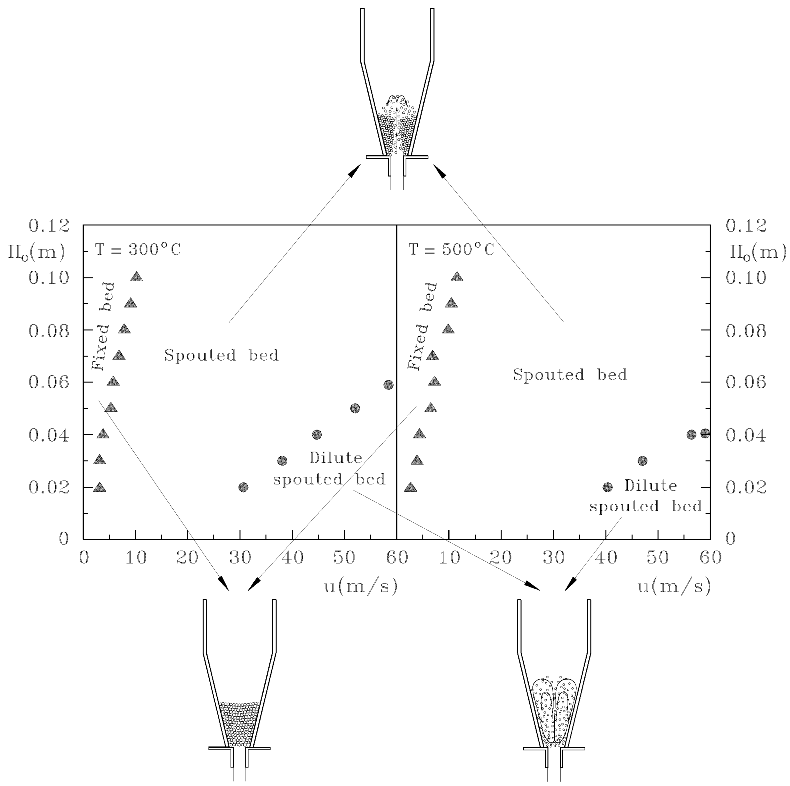

Figure 2. Operation map for beds consisting of sand of Sauter particle diameter $\overline{d_S}$ *=1.08 mm and particle circulation in the conical reactor in the different regimes. Experimental system:* γ*= 36º;* D_i*=* D_o*= 0.03 m at gas inlet temperature of 300 and of 500 ºC.*

Conclusions

On the basis of on a wide experimental study on stability in a pilot plant in a wide range of operating conditions at a temperature range of 25-800ºC, the good behaviour of the spouted beds of conical geometry for treatment of industrial sludge wastes has been proven.

The experimental systems studied are stable at a range of gas inlet temperatures 25-800 ºC. The experimental systems are stable with all the geometric factors and the experimental conditions studied. The increasing of gas inlet temperature increase minimum spouted bed and minimum dilute spouted bed spouting velocities, so stable operation zones decrease. The effect relies in that gas velocity depends on properties of the fluid (density and viscosity) that change with temperature. Minimum spouting velocity only depends on density and dilute spouted bed (jet spouted bed) velocity depends on both density and viscosity of the gas.

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Nomenclature

D_c, D_b, D_i, D_o	Diameter of the column, top diameter of the stagnant bed, of the bed bottom, and of the bed inlet, respectively, m
$\overline{d_S}$	Sauter diameter of the particle, m
H_o, H_{con}, H_{cil}	Height of the stagnant bed of the conical section and of the cylindrical section, respectively, m
u	Velocity of the gas referred to D_i, ms^{-1}
x_{ais}, x_{ac}	Thickness of the reactor wall and of the insulation, respectively, ms^{-1}
Greek letters	
ε_o	Voidage of fixed bed
ϕ	Sphericity, dimensionless
γ	Angle of the conical contactor, deg
ρ_s	Density of the solid, kg m^{-3}

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