A Study of Solid Particles Feeding Tehnic by Fluidization

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UNE TECHNIQUE D'ALIMENTATION
EN PARTICULES SOLIDES PAR FLUIDISATION

L'étude des réactions hétérogènes dans un four à chute à l'échelle du laboratoire nécessite l'utilisation d'une technique d'alimentation et de dispersion afin de débiter des masses de solides autour de 1 g/h. Dans ce présent travail, une technique basée sur la fluidisation est proposée. Un mélange de chaux et de sable est fluidisé à une vitesse superficielle plus élevée que la vitesse terminale de chute des particules de chaux, qui par conséquent sont transportées hors du lit. L'influence des divers paramètres tels que le diamètre des particules, le pourcentage de chaux dans le mélange, la hauteur du lit et la vitesse de fluidisation du gaz sur l'écoulement ont été étudiés. Les conditions opératoires permettant d'obtenir des débits de solides constants ont été optimisées. Une méthode relativement simple permettant d'évaluer la quantité de solide évacuée a été développée et des résultats satisfaisants ont été obtenus.

A STUDY OF A SOLID PARTICLES FEEDING TECHNIC
BY FLUIDISATION

The study of heterogeneous reactions in a drop tube furnace, at a laboratory scale, needs a continuous feeding and dispersing technic to yield mass flow rates as low as 1 g/h. In the present work, a solution based on fluidization, is proposed. A mixture of lime and sand is fluidized at a superficial velocity higher than the free fall velocity of the lime particles which are therefore carried over by the fluidizing gas stream out of the bed. The effects of various parameters such as the particles diameter, the lime content in the solid mixture, the height of the fluidized bed and the gas fluidizing velocity, on the flow have been investigated. The operating conditions leading to the obtention of a constant solid rate have been optimized. A simple method of evaluating the mass of the evacuated and dispersed lime particles have been developed, and satisfactory results were obtained.

PROCEDIMIENTO DE ALIMENTACIÓN
EN PARTÍCULAS SÓLIDAS POR FLUIDIZACIÓN

El estudio de las reacciones heterogéneas en un horno tubular a escala de laboratorio precisa la utilización de una técnica de alimentación y de dispersión, con objeto de fraccionar las masas sólidas a razón de, aproximadamente, 1 g/h. En el presente trabajo, se propone un procedimiento fundado en la fluidización. Así, se procede a la fluidización con una velocidad superficial más elevada que la velocidad terminal de caída de las partículas de cal, lo cual tiene como consecuencia su transporte fuera del lecho. Se

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ha estudiado la influencia de los diversos parámetros en presencia, como, por ejemplo, el diámetro de las partículas, el porcentaje de la cal en la mezcla, la altura del lecho y la velocidad de fluidización del gas, y todo ello con respecto al flujo circulatorio. Así, se han optimizado las condiciones operatorios que permiten obtener caudales sólidos constantes. Se ha desarrollado también un método relativamente sencillo que permite evaluar la cantidad de sólido evacuado, habiéndose obtenido resultados satisfactorios.

INTRODUCTION

Solid sorbents such as calcium hydroxide, calcium carbonate and calcium oxide are often used to reduce pollutant contents in flue gases [1] and [2]. Efficient technics of feeding and dispersing the sorbent particles in a reactor are required. The design of such feeding systems is however not easy since it requires a good experience on the way to deal with the problems and difficulties encountered during dust transport, namely, the electrostatic behaviour, agglomeration, packing and compression of the solid particles [3].

Among the various studies mentioned in the literature [4, 5 and 6] the endless screw technic seems to be widely used, particularly for generating large quantities of powder. The drawbacks of such technic are the formation of agglomerates, the irregularity in keeping constant rates and the difficulties to feed small quantities of solid particles.

An appropriate technic for feeding small quantities of dust is described in some published works [7, 8 and 9]. It is based on the principle of a rotating brush that removes continuously a thin layer of particles whose thickness is controlled by the velocity of a moving cylinder, considered itself as a part of the feed stock reservoir. Such a technic requires however important gas rates to avoid stuffing and yield a good dispersion.

In the present study, a feeding and dispersing process of small quantities of lime particles is proposed. It consists of the fluidization of a mixture of lime and sand in a vertical reactor where individual lime particles are entrained by the fluidizing gas stream. Note that such a technique might have a wide range of application in the gas purification processes as long as the solid particles used are dusty and powdery. The effects of various parameters such as the particle diameter, the lime content in the solid mixture, the height of the fluidized bed and the gas fluidizing velocity, on the efficiency of the feeding process have been studied, and the operating conditions leading to the obtention of constant solid rates have been determined. Moreover, a simple method of quantifying the amount of solid particle transported by the carrier gas based on a simple pressure drop measurement, has been tested.

1 EXPERIMENTAL PART

A 70 cm high vertical reactor with an inside diameter of 4 cm has been used to carry out the experiments. It is connected at the bottom to a nitrogen distribution system and at the top to a filter designed to collect the calcium hydroxide particles entrained by the fluidized gas stream. A manometer is used to measure the pressure drop through the filter. The schematic representation of the experimental set up is shown in Figure 1. The fluidized bed consists of 10 µm $Ca(OH)_2$ particles mixed with either 100 or 200 µm sand. Such a mixture is required in order to avoid slugging and channelling effects. An initial mass of the bed equal to 50 g has been used during the experiments.

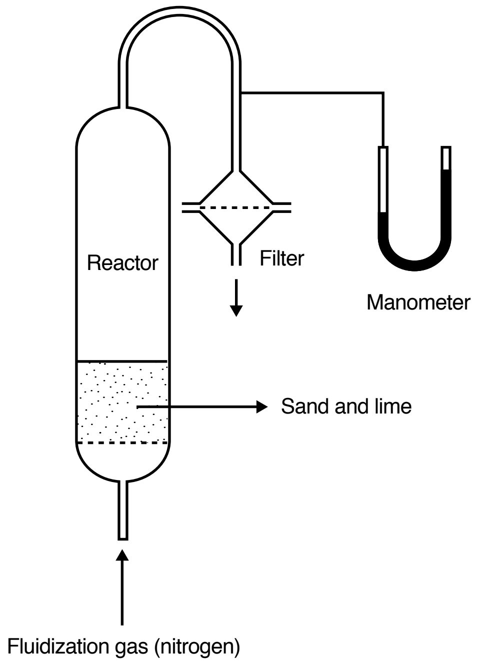

Figure 1

Experimental set up.

The main objective hence is to fluidize the bed and to transport or evacuate through the fluidizing gas stream a part of the calcium hydroxide particles without carrying along sand.

Note that the lime reserve is not renewed during the process. This could be done by injecting continuously the lime particles into the reactor through a vertical fine-gauge carrier tube connected to an external feeder.

2 RESULTS AND DISCUSSION

The gas fluidizing velocity must be taken higher than the $Ca(OH)_2$ particle free fall velocity but lower than that of the sand in order to avoid sand transport. The determination of the free fall velocity is therefore required. It is expressed from a model [10] as:

$$V_p = \frac{g}{D_p} \tag{1}$$

where

$$D_p = \frac{3 \cdot \rho_g \cdot V_p \cdot C_D}{8 \cdot \rho_p \cdot R_p} \tag{2}$$

and

$$C_D = \frac{24}{Re_p}\left(1 + \frac{(Re_p)^{\frac{2}{3}}}{6}\right) \tag{3}$$

Re_p being the particle Reynolds number defined as:

$$Re_p = \frac{\rho_g \cdot V_p \cdot d_p}{\mu_g} \tag{4}$$

A series of experiments with regards to the effects of various operating parameters have been carried out to determine the optimal conditions for a constant and regular entrainment of calcium hydroxide particles by the gas stream.

Results of measurements of the pressure drop through the filter as a function of time for a 10 cm/sec gas fluidizing velocity, 40% mass composition of lime in the mixture and 200 µm sand particles are shown in Figure 2. The pressure drop seems to increase linearly during the early stages of the process, meaning that the solid rate remains constant during this time interval. To confirm this fact, measurements of the amount of $Ca(OH)_2$ particles collected on the filter versus time, in the same operating conditions as the previous experiment, could easly be realized.

It would be interesting to develop a method of evaluating the mass of lime transported by the carrier gas from a simple pressure drop measurement. This has been done by simply weighting the amount of lime collected on the filter for the corresponding pressure drop. A typical calibration curve (Fig. 3), valid only for the given operating conditions, is hence obtained.

The influence of the sand mean particle diameter on the pressure drop, hence on the evacuated mass of lime,

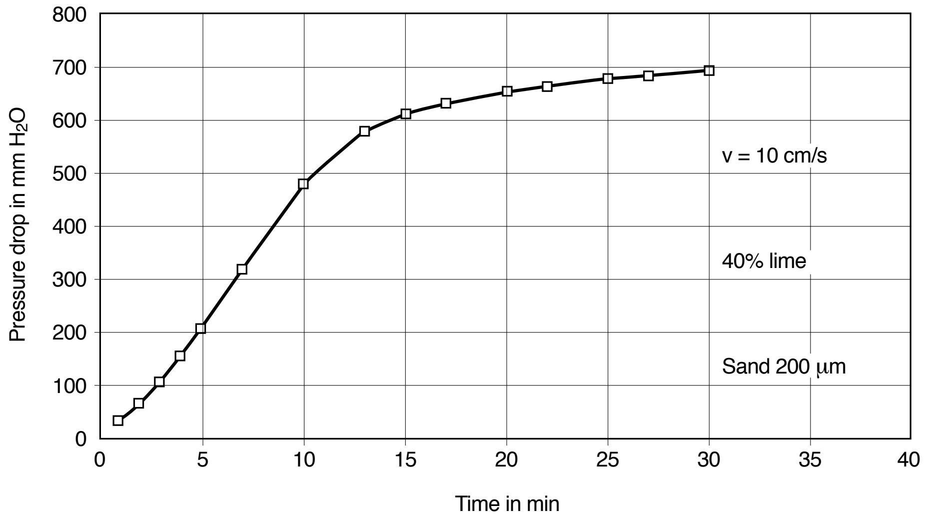

Figure 2

Pressure drop through the filter versus time.

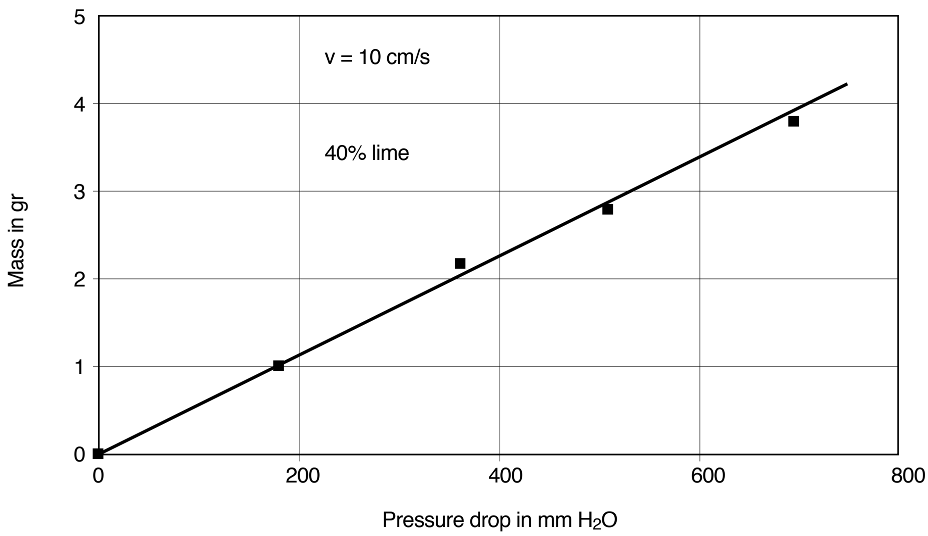

Figure 3

Amount of lime transported versus the pressure drop.

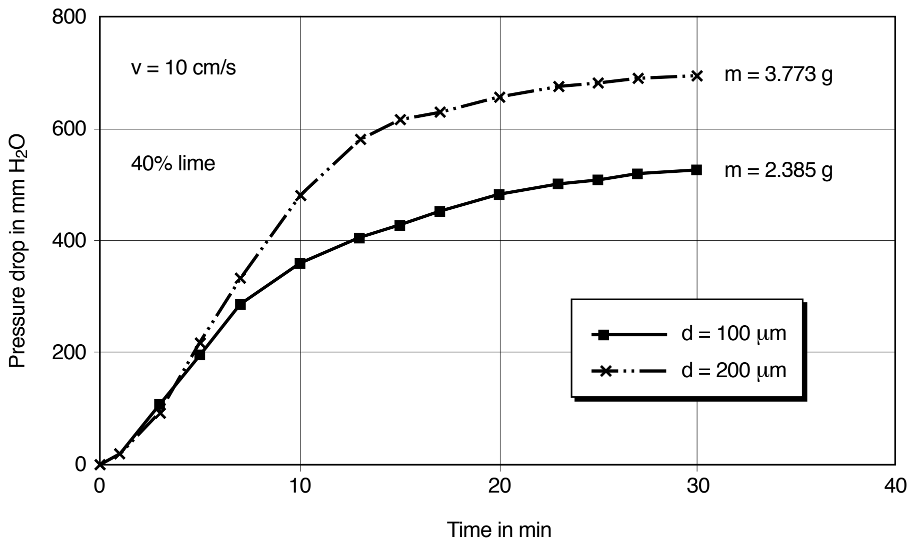

Figure 4

Effect of the sand particle diameter on the pressure drop.

is represented in Figure 4. It can be seen, during the early stages of the process, that the calcium hydroxide particles are more regularly transported in the case of 200 than 100 µm sand. It has been observed also that the mass of lime collected on the filter after 30 minutes increased when increasing the sand particles diameter. This corresponds indeed to 18.9% of the initial mass of the bed for the 200 µm sand as compared to 11.9% for the 100 µm sand. This might be explained by the fact that the intraparticle forces are more important when decreasing the sand particle diameter.

Experiments showing the effects of the lime content in the solid mixture, for a 10 cm/sec gas fluidizing velocity and a 200 µm sand, have been carried out. The results are shown in Figure 5. It can be noticed that an increase of the calcium hydroxide content brings about an increase of the amount of $Ca(OH)_2$ transported by the gas stream since, after 30 minutes, 3.773 g were recovered in the case of a solid mixture containing 40% calcium hydroxide by comparison to 0.653 g obtained in the case of 10%. However, for lime content lower than 5% no entrainment was observed. This result is in fact fairly interesting since it indicates the conditions in which it is possible to use lime as a reactive in fluidized bed reactor.

Figure 6 shows results of ultrasound granulometric measurements of two $Ca(OH)_2$ samples corresponding to the lime initially used in the bed and the one collected on the filter after processing respectively. It can be seen that the evacuated lime presents a smaller

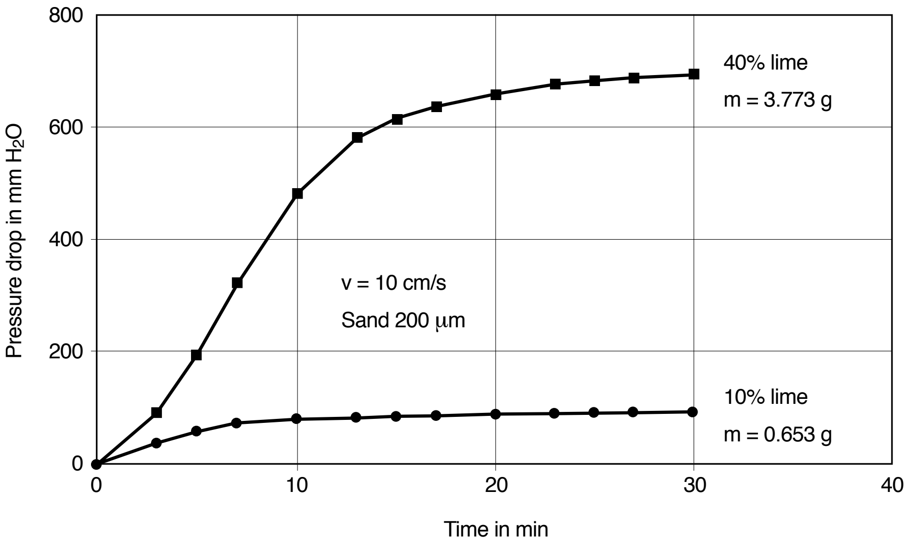

Figure 5

Influence of the lime content on the pressure drop.

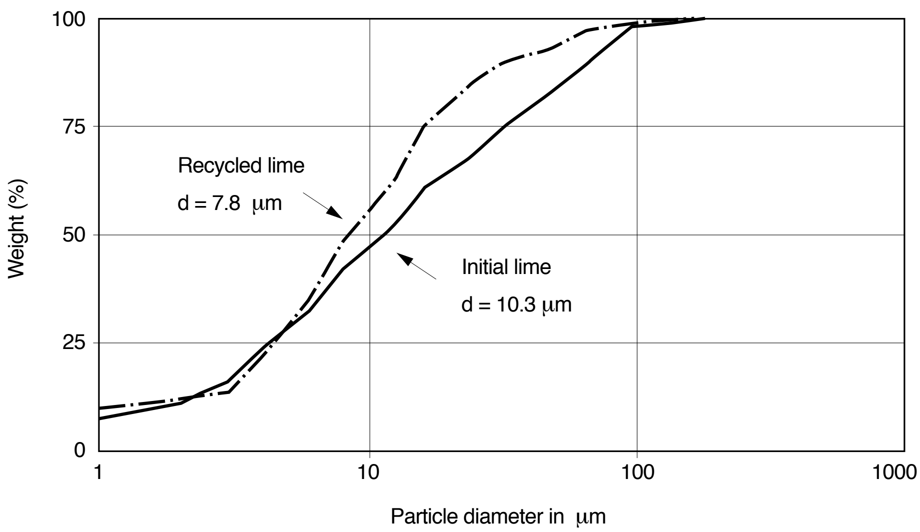

Figure 6

Granulometric measurements of lime particles.

granulometry (d = 7.8 µm) than that of the one initially mixed with sand (d = 10.3 µm). This means that only the thinner particles are transported by the gas stream. This is in fact fairly coherent since such particles have smaller free fall velocities compared to the one remaining in the bed.

The effects of the nature of the lime has been investigated and results of measurements are reported on Figure 7. Indeed, the lime collected on the filter has been used afterwards in a fluidized bed consisting of 10% lime and 90% sand. Because of its narrower size distribution, the solid rate of the recycled lime was maintained constant during 40 minutes as compared to the time (15 minutes) corresponding to the lime initially used. During these time intervals, 10 and 30% of the mass of lime were evacuated at constant rates for the initially used and the recycled lime respectively.

An other parameter that affects the flow of the particles is the gas fluidizing velocity. Results of measurements reported in Figure 8 show that an increase of the gas velocity causes an increase of the ratio of the recovered over the initial mass of calcium hydroxide. This can be explained by the fact that the percent of lime particles, having a free fall velocity lower than the gas fluidizing velocity and then able to be transported, increases.

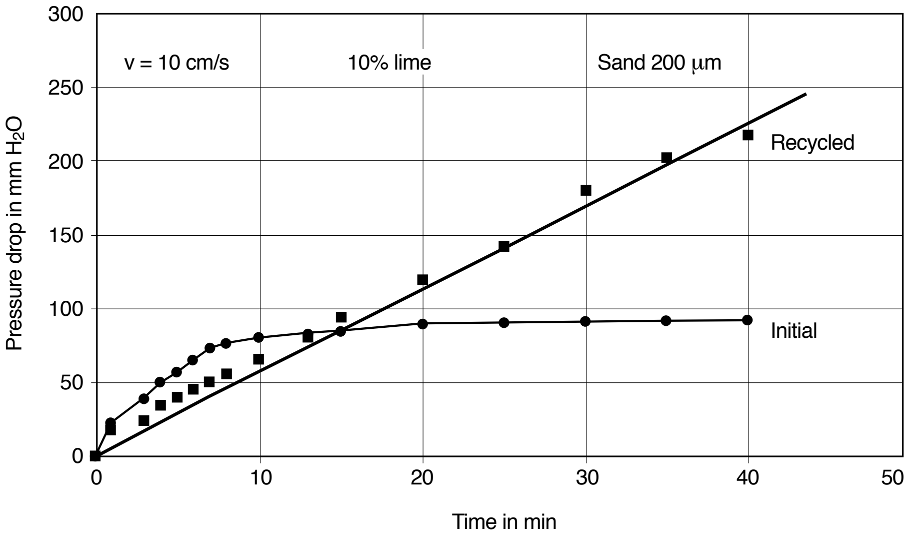

Figure 7

Effect of the nature of lime on the pressure drop.

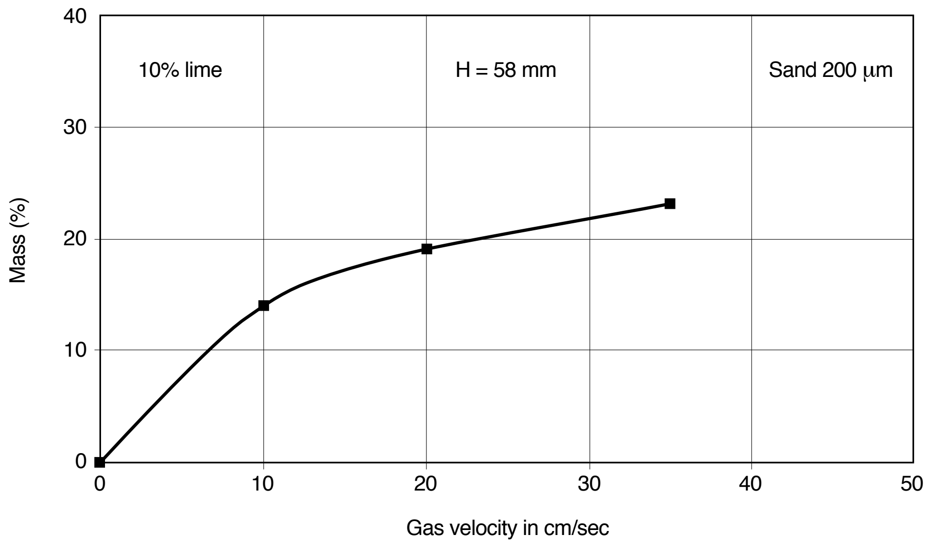

Figure 8

Effect of the gas fluidizing velocity on the maximum mass of lime transported

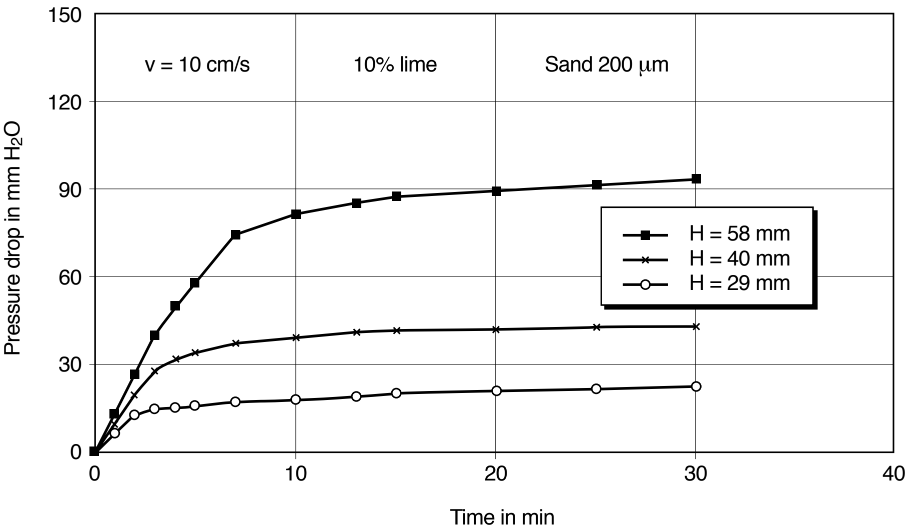

Figure 9

Influence of the initial bed height on the pressure drop.

The influence of the initial height of the bed on the particle transport, for a given gas velocity, lime content and sand diameter, is shown in Figure 9. It can be seen that the pressure drop, hence the amount of lime collected on the filter, increases when increasing the height, particularly for large period of time. This is quiet obvious since the mass of calcium hydroxide initially in the bed becomes more important when increasing the height. Moreover, it seems that an increase of the initial height brings about a decrease of the bed initial porosity, yielding therefore to an increase of the gas velocity inside the bed. This might explain in fact why the amount of lime collected increases when increasing the height for very short periods of time.

CONCLUSION

The study of the effects of various operating parameters on the amount of lime transported by the gas stream has led to the following conclusions:

- The amount of lime transported is deduced from a simple pressure drop measurement.
- It is possible to feed and disperse small quantities of calcium hydroxide (few grams per hour), particularly for a lime content lower than 40%.
- Constant calcium hydroxide rates could be maintained during 15 minutes for the initially used lime and 40 minutes for the recycled one.
- More regular rates were obtained when using large size sand particles and relatively important bed heights.

NOMENCLATURE

C_D Drag coefficient
d_p Particle diameter (m)
D_p Drag function
g Gravity (m/sec^2)
R_p Radius of the particle (m)
Re_p Particle Reynolds number
V_g gas velocity (m/sec)
V_p Particle free fall velocity (m/sec)
ρ_g Gas density (kg/m^3)
ρ_p particle density (kg/m^3)
μ_g Gas viscosity (kg/m.sec).

REFERENCES

1 Sahar A. and E. Kehat (1991), Sulfur dioxide removal from hot flue gases by lime suspension spray in tube reactor. *Ind. Eng. Chem. Res.*, **30**, p. 435.

2 Allal K.M., M. Abbessi and A. Mansour (1992), Determination of the kinetical data for the reaction of SO_2 with CaO using a thermobalance. *Trans. I. Chem.*, **70**, p. 140.

3 Therssen E. (1993), Étude de la dévolatilisation de charbons pulvérisés dans une flamme plate de propane. Applications à l'interprétation de leur comportement en flammes industrielles. *Ph.d Thesis,* University of Lilles Flandres Artois.

4 Beck N.C and A.N. Hayhurst (1990), The early stages of the combustion of pulverized coal at high temperature I: the kinetics of devolatilization. *Combustion and Flamme*, **79**, p. 47.

5 Beck N.C. and A.N. Hayhurst (1990), The early stages of the combustion of pulverized coal at high temperature II: Measurements of the size and composition. *Combustion and Flamme*, **80**, p. 170.

6 Maloney D.J. and R.G. Jenkins (1984), Coupled heat and mass transport and chemical kinetic rate limitations during coal rapid pyrolysis. *20th Symp. on Combustion*, p. 1435.

7 Steidl D. (1990), Partikelgrossenermittlung in Aerosolen. *Aerosol-Technology Seminar*, p. 152.

8 Loeffler F. and A. Zahradnicek (1976), Eine neuen Dosiervorichtung zur Erzeugung von Aerosolen aus vorgegebenen feinkornigen Festoffen. *Staub Reinhaltung der Luft*, **36**, p. 425.

9 Jodeit H. and F. Loeffler (1983), Experimentelle Bestimmung Abscheideeigenschaften von tiefenfiltern mit einem neuen Filterprufstand. *Staub Journal*, **100**, p. 152.

10 Amsden A.A., P.J. O'Rourke and T.D. Butler (1989), KIVA II: A computer programm for chemically reactive flow with sprays, *LA-11560-MS*, Los Alamos, May 1989.

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