

HYDRODYNAMICS AND STABILITY OF PLASMA SPOUTED BEDS

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Abstract

The hydrodynamics and stability of plasma spouted beds are studied experimentally in a reactor unit having about 2 kg bed capacity. The influence of reactor geometry: base design, cone angle and torch nozzle exit diameter as well as solid size are investigated. The particulate solid used during the tests is alumina (corundum) with mean diameter ranging from 250 μm to 700 μm . Two cone angles are tested : 20° and 60°. The plasma gas used for most of the experiments is a mixture Ar/N₂ with 20% N₂. Gas flow rates vary from 10 to 50 LPM. The plasma power used during the experiments lies between 10 and 20 kW. Characterization of bed hydrodynamics and stability is carried out by measurement of the pressure drop across the bed and by visual observation of the bed behavior for each set of parameters tested.

Introduction

The plasma spouted bed reactor offers the possibility of treatment of granular materials at elevated temperatures with high volume density feed. A wide range of applications seems to be feasible in such reactors ; the bulk of these applications lies in the pyrometallurgical treatments of minerals/ores: calcination, roasting, etc. The slow development and application of plasma spouted bed reactors is mainly due to their operating complexity. The plasma jet is used as the vector for particle circulation, as heat source and as reacting fluid medium. In operating such reactors, it is necessary to respect some hydrodynamic criteria to insure the system stability (spouting regime). Very few studies ([1], [2], [3]) have been published on plasma spouted bed hydrodynamics, regimes and stability. The proposal of this work is the study of the influence of design parameters such as base design, conical base angle and torch nozzle exit diameter. The influence of solid size and operating parameters such as plasma power, gas flow rate and bed height are also investigated. The

experimental set-up development and the procedures used are presented together with the first results obtained on the attrition evolution and maximal spoutable bed depth measurement.

Experimental set-up

A schematic drawing of the experimental equipment is shown on Fig. 1.

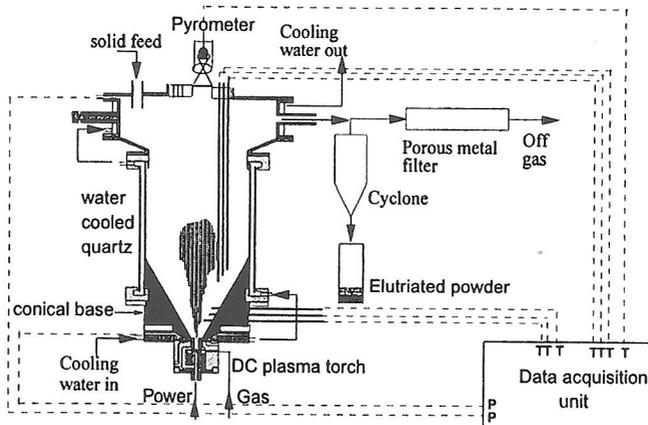


Fig. 1: Experimental set-up

The reactor vessel consists of three main parts: a conical base, a cylindrical central column and an upper, disengaging zone. The cylindrical part has an internal diameter of 143 mm and is made of water cooled quartz to permit visual observation of the different regimes during the operation. The conical part, made in alumina refractory, is designed in order to test the influence of the base geometry and cone angle on the spouted bed hydrodynamics. A DC plasma torch of the standard type is connected to the base of the reactor.

Bed main temperature and temperature profiles are measured using two sets of thermocouples: three from the side at the base and six from the top at the upper part of the bed. The position of all of the thermocouples can be varied. A two color pyrometer is used to monitor the temperature of the particles in the "fountain" where they reach their maximal temperature. The pressure drop across the bed is measured using two pressure taps: one at the inlet of the bed and the other at the top. Both taps are connected to a pressure recording device.

Results and discussion

The preliminary results have been carried out in a reactor with the base presenting the configuration shown in Fig. 2. The conical base has an angle of 60°. During

these experiments, two batches of raw material have been used (Alumina 30 and Alumina 60). The particle size distribution of those powders, determined by standard sieving, is summarized in Fig. 3.

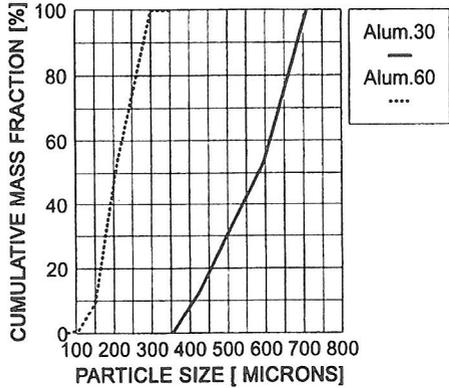
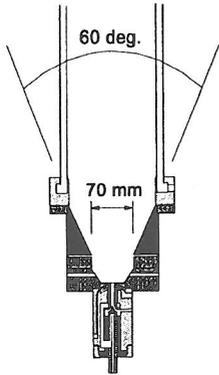


Fig. 2: Base design used during the tests.

Fig. 3: Size distribution of the raw material used.

Effect of base geometry

During the tests carried out using the reactor base geometry described above (Fig. 2), the observed behavior of the bed for the two raw materials is shown in Fig. 4. With both batches, the interaction of the plasma jet with the granular material is limited to a central zone in the reactor, the extent of which is more important for coarse than for fine materials.

These visual observations are confirmed by measurement of temperature profiles using the thermocouples located at different positions in the lower part of the bed as shown in Fig. 5.

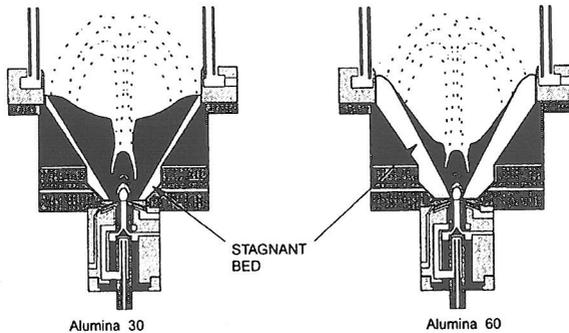


Fig. 4: Bed circulation with stagnant zones

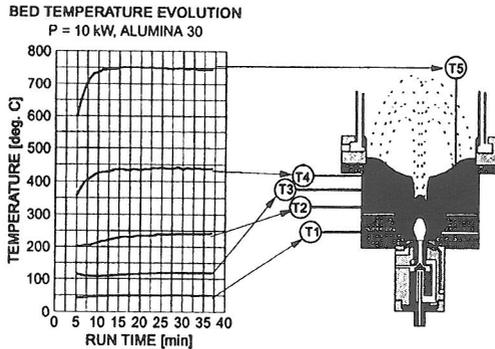


Fig. 5: Temperature profiles evolution

Following these observations, the design of the base is changed in order to eliminate the flat part near the torch nozzle exit believed to be responsible for material settlement and build up of a stagnant zone.

The new design (Fig. 1) also permits the use of different cone angles in order to experiment with the effect of this parameter on hydrodynamics of plasma spouted beds.

Attrition evolution

The attrition is the particle size reduction process occurring during the operation of a plasma spouted bed reactor. In continuous operation, the extent of particle size reduction due to attrition may be so important that it results in hydrodynamic instabilities. Some experiments have been carried out to assess the effect of plasma power and run time on the extent of attrition. For these experiments the alumina 30 batch is used as feed material. The particle size distribution evolution with run time and plasma power are presented in Fig. 6.

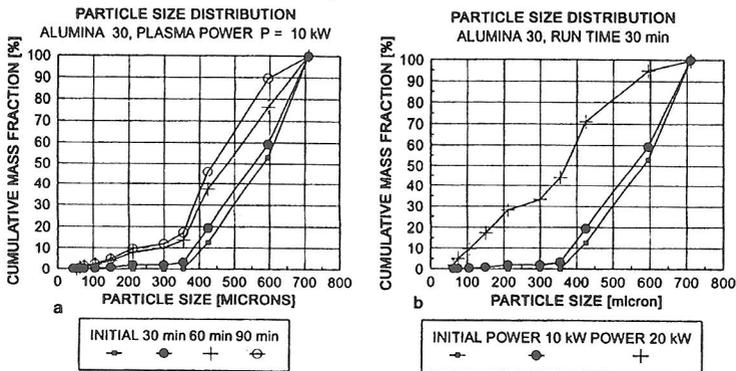


Fig. 6: Particle size distribution evolution with run time (a) and plasma power (b)

Fig. 6b shows that the extent of attrition may be more important when a plasma power of 20 kW is used compared to the extent of attrition occurring with a plasma power of 10 kW, for the same run time.

Maximum spoutable bed depth

For standard spouted beds, the maximum spoutable bed depth is the bed depth beyond which the spouting phenomenon ceases to occur, whatever the value of the flow rate [4]. The maximum spoutable bed depth for plasma spouted beds as defined by Flamant [3], corresponds to the height of feed material beyond which the plasma jet extinguishes. The following procedure is used to measure this parameter. The plasma torch is first ignited in the empty column, the gas flow rate and the plasma power are regulated. Then the granular material is fed into the reactor. Feeding, in 100 g increments, is continued until the plasma jet extinguishes. The height of the bed reached before the plasma extinction is the maximum spoutable bed depth under the conditions of the operation. Typical evolution of the pressure drop across the bed, measured during this operation, is presented in Fig. 7 for the two values of gas flow rate employed.

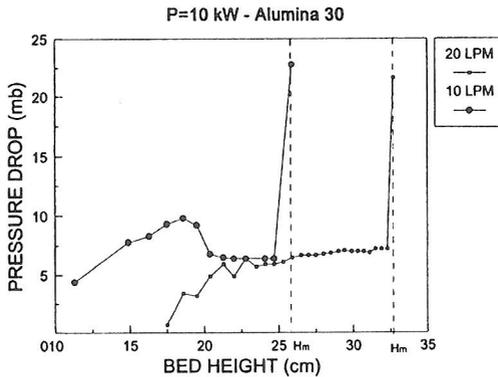


Fig. 7: Pressure drop evolution during the procedure of maximum spoutable bed depth measurement.

The results presented above are obtained with a conical base angle of 20°, a torch nozzle exit diameter of 4 mm and the use of the base design shown in Fig. 1. The first test results show that the maximum spoutable bed depth increases with gas flow rate.

Conclusions

The first tests investigating plasma spouted bed hydrodynamics show that the base geometry and its conical angle are both important parameters. Better bed stability

and recirculation have been obtained with the small cone angle, i.e. 20°. Operation with higher powers results in severe attrition due to higher gas velocity and higher temperature in the plasma jet. The maximum spoutable bed depth have been found to increase with gas flow rate. Further investigation on the influence of the base conical angle on bed hydrodynamics and stability is being pursued.

Acknowledgments

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