A BI-DIMENSIONAL OPTICALLY ACCESSIBLE F.B.C. FOR COAL COMBUSTION STUDIES

P.G. Lignola*, G. Raso**, N. Di Muro**, R. Parri*, M. Bader*

(*) - Dipartimento di Ingegneria Chimica - Università - 80125 Napoli
(**) - Istituto di Ricerche sulla Combustione - CNR - 80125 Napoli

INTRODUCTION

Bi-dimensional fluidized beds have been since long adopted for studying fundamentals of fluidization. Optical accessibility has been a valid tool for analysis of bubbles and their interaction, in spite of the existing behavioural difference between three and two dimension experiments. A bi-dimensional bed has been recently used for application of mass spectrometric analysis of gas concentration profiles in single bubbles rising through a bed kept at minimum fluidization velocity (1).

Coal combustion and gasification in fluidized bed is now actively and intensively studied. Models of coal combustion process, including volatilization have been proposed. However lack of optical access into traditional fluidized bed combustors, renders difficult the comparison between model prediction and experimental result.

The idea of developing a bi-dimensional combustor, fitted with mass spectrometric probe seemed very appealing, though of not easy design and construction.

In this paper design and construction of a bi-dimensional fluidized bed combustor (F.B.C.) and result of first experiments performed are reported.

F.B.C. DESIGN

Very crude and preliminary calculations show that it is not possible to operate steadily a bi-dimensional fluidized bed coal combustor normally exposed to ambient. Assuming for a quartz sand bed (70-600 μm size) a temperature of 1150-1200 K, radiant heat transfer reaches values of 80 kW/sqm, which cannot be carried by enthalpy of fluidizing gas. Generation of this substantial power is not possible by means of combustion itself, owing to the small amount of coal in the bed. Consequently it is necessary to feed the F.B.C. with extra power in order to obtain a steady operation. Hypothesis of adopting Vycor™ silica glass covered with thin tin oxide layer has been discarded, since its application at these temperatures are not known, neither it was possible to assess the semiconductivity properties at high temperature of tin oxide layer.

The obvious solution to the problem was to design a furnace, fitted with windows, in which the bed had to be enclosed. The furnace essentially consists of a parallelepipedic enclosure, the dimension of which are 1070 mm height, and 890 mmx1440 mm base. Starting from the inside, furnace walls are made of Triton Kaowall (TM), which is particularly suitable for high temperature, of Calsil (TM), which has good insulating properties and is asbestos free and, for the outer layer, of Monolux 500,TM which has good mechanical properties, but can stand lower temperatures. The bottom has been made of CER 21/M (TM) which presents good mechanical properties even at high temperature. Thickness of insulation has been calculated on the basis of following assumption: outer wall temperature <333 K, inner wall temperature equal to maximum operation temperature, linear temperature gradient through walls. Constant thermal conductivity for each material, averaged on temperature has been used in calculations. Front, rear and top walls are removable. Furnace top possesses a slot, which coincides with highest level of bed free-board and can be connected to an exhaust line. A square window, 250 mmx250 mm, made of polished Vycor (TM) glass as been made on front and rear panel. Windows are parallel to the bed and permit its optical observation. Four electrical resistances, each providing 3.6 kW, are immersed into a ceramic support, which is 50 mm thick, 300 mm wide and 600 mm high. These resistances give the necessary power to furnace, for every possible regime of operation, since several series and series-parallel insertions are possible. Calculations show that at steady state about 4 kW are necessary for keeping furnace at 1223 K. However resistances are

capable of producing 14.4 kW, which are useful for shortening apparatus start up.

A proportional, integral temperature controller has been designed which features a thyristor power unit, and safety set points which can be triggered by maximum and minimum temperature and which can be overridden during start up procedure. For safety reasons, thermocouple failure triggers the power off. Owing to large heat capacity of furnace and prevalent radiant heat transfer within enclosure, uniform temperature is achieved throughout the bed.

The bed is confined by means of two polished Vycor (TM) glass walls, 18 mm apart, inserted into slots created on furnace sides. The transparent walls are made of a double layer of sheets, 6 mm thick, 300 mm wide and 300 mm high. Owing to the limited size of Vycor (TM) sheets the two layers are skintled in order to prevent air and solid materials leakage during operation. Vycor (TM) glass walls continue up to the top of furnace, consequently free board is kept at the same temperature of the bed. Figure 1 shows the apparatus.

Even gas distribution at bottom of bed is achieved by means of a distributor made of aluminum silicate, which practically consists of a porous plate (140-200 μm pore size) 20 mm thick. Great care has been taken to seal the junction between distributor and bed. To this end a special Triton Kaowall(TM) cement has been used.

Flow of fluidizing gas is measured by means of conventional rotameter. Inlet gas pressure is measured by conventional open tube manometers. Temperature of bed is measured by means of thermocouple. On each side of the bed at different heightsthree channels have been drilled and fitted with 12 mm alumina tubes for coal feeding and gas sampling.

Arriflex cine camera, 16 mm, at 50frames per second has bees used for optical observation and recording of F.B.C. behaviour. Analysis of single frames has been carried out by means of a graphic tablet hooked to an Apple IIe (TM) personal computer. Bubble areas were evaluated by means of specific software. Time variation of dimension of coal and char particles was also analyzed by means of the same technique.

A continuous sampling CO_2 analyzer was also used for monitoring coal combustion.

The whole apparatus performed as expected. The bed could be kept steady at temperature of 1223 K as long as necessary.

RESULTS

To the best of authors' knowledge, the bi-dimensional F.B.C. is the first that has been ever constructed. Consequently it seems that up to now no direct optical test has been made yet on general fluidodynamics behaviour of fluid beds at high temperatures. Results reported in the following refer to a bed 260 mm wide and 140 mm high of sand (density 2.6 g/cm^3). Mass of solids was kept constant at 1 kg. The first set of experiments that has been run was aimed at assessing the possibility of testing these fundamental aspects of fluidization.

Minimum fluidization velocity U_{mf} has been experimentally evaluated for sand of two different sizes: 300÷400 μm and 850÷1000 μm. In fig. 2 U_{mf} values measured at experimental conditions are reported against temperature. For both sizes U_{mf} decreases with increasing temperature. Results are in accord with those obtained by Botterill and Teoman (2) and can be easily explained on the basis of viscosity increase with increasing temperature. Comparison with available theoretical models has not been fully accomplished yet, owing to the limited number of data. However first trials seem to indicate that for smaller size, available theory extrapolated at operation temperatures underestimate U_{mf}, whereas for larger size U_{mf} is nearly correctly estimated at temperatures lower than 673 K and is overestimated at higher temperatures.

Several films have been shot by means of cine camera with the aim of measuring bed expansion and bubble volume fraction at different temperatures. Results refer to bed of sand 300÷400 μm size. In fig. 3 bed voidage is reported against relative fluidization velocity U/U_{mf} for different bed temperatures. Bed voidage was evaluated by measuring on film frame bed height at different U/U_{mf}. Data show that bed voidage depends on temperature.

Experimental technique features the possibility of measuring bubble size on film frame by means of graphic tablet digitization. In fig. 4 an example of digitized frame is reported. Bubble fraction at different U/U_{mf} and temperatures have been measured by means of the above technique. Results are reported in fig. 5.

Combustion at 1123 K of batch of five particles of South African char, approximately spherical, of 130 mg mass and 6 mm diameter each, has been followed by cine camera recording and by monitoring CO_2 concentration in exhaust gases. Burn-out time has been determined by observation of particle disappearance and by CO_2 monitoring. Same experiment has also been performed with batch of three particles of South African coal, each of 400 mg mass and of 9 mm diameter. Data are reported in fig. 6. Cine camera was run at immission of particles into the bed and after 228 s and 552 s. In fig. 7 char particle diameter against time is reported as evaluated by the two methods. Data obtained by film frame analyses and data obtained by calculation of particle diameter reduction from CO_2 concentration measurement, to compare fairly well. On the same diagram theoretical variation of char particle diameter with time has been reported. Curve is drawn assuming shrinking particle model and diffusion control.

Combustion of a batch of three South Africal coal particles tested also apparatus capabilities of following devolatilization. Coal particles were spherical with 9 mm diameter and with a weight of 400 mg each. Devolatilization phase could be followed at ease and flamelets generated by gas combustion were observed.

CONCLUSIONS

The first results confirm that the apparatus that has been developed can be a powerful tool for studying high temperature processes in fluidized beds. Specifically fundamental fluidodynamics of beds can be investigated and combustion process of coal can be followed, even during devolatilization phase. Hypotheses of current models can also be checked, though with the limitation deriving from bi-dimensionality.

ACKNOWLEDGMENT

The work has been performed with partial financial support from Ministero della Pubblica Istruzione of Italy.

REFERENCES

1) Lignola P.G., Donsì G. and Massimilla L.: A.I.Ch.E. Symposium Series 79, 19 (1983)
2) Botterill J.S.M., Teoman Y.: in "Fluidization" ed. Grace J.R. and Matsen J.M., Plenum Press, N.Y. (1980), p. 93

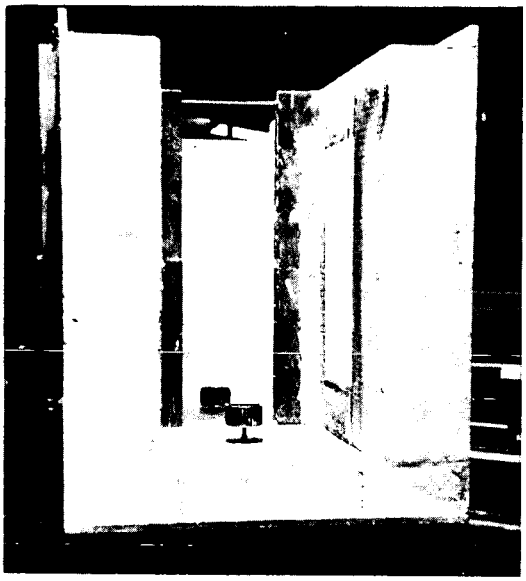

Fig. 1 - Furnace encloses F.B.C.

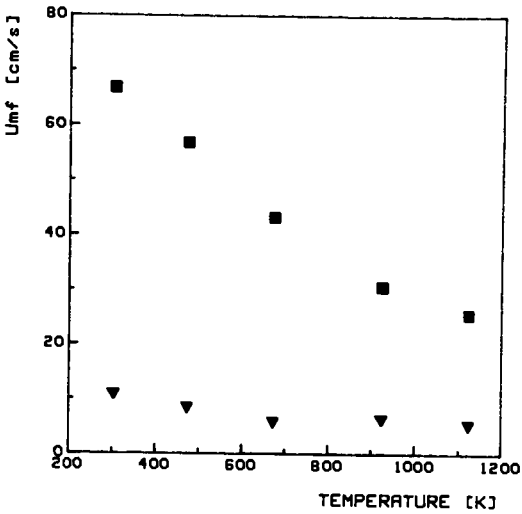

Fig. 2 - Minimum fluidization velocity vs temperature.
Bed solids: sand; ▼ 300 ÷ 400 μm; ■ 850 ÷ 1000 μm.

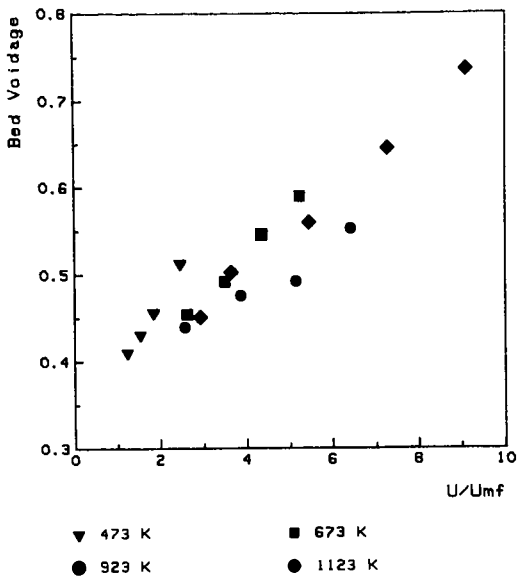

Fig. 3 - Bed voidage vs relative fluidization velocity for different temperatures. Bed solids: sand; 300 ÷ 400 μm.

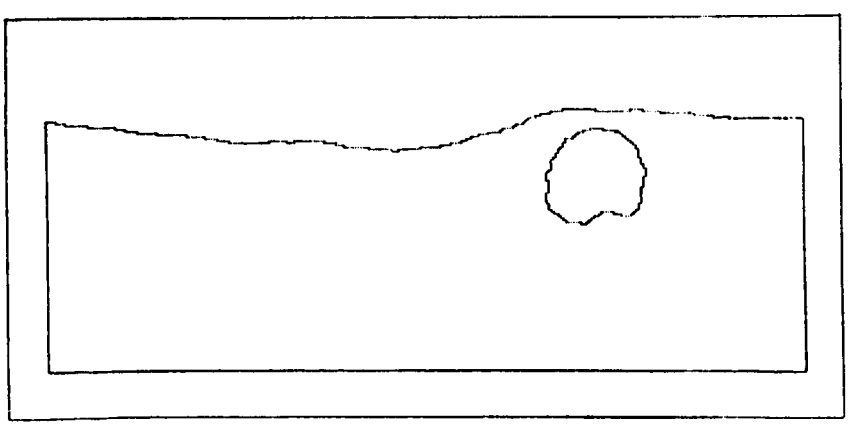

Fig. 4 - Example of digitized film frame showing a bubble rising thru the bed. Solid displacement caused by bubble ascent is evident. Bed solids: sand; 300 ÷ 400 μm; 1123 K.

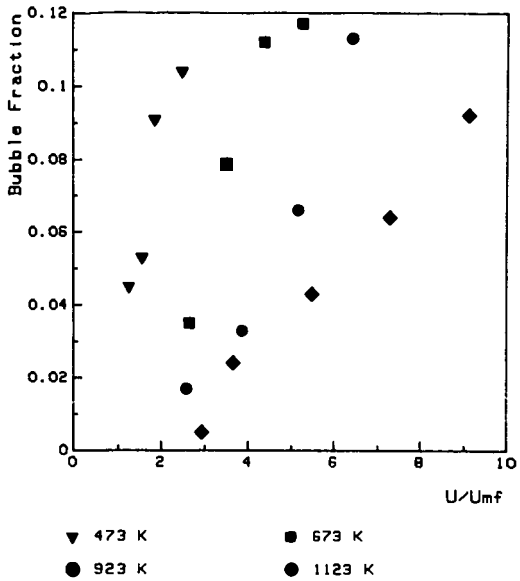

Fig. 5 - Bubble fraction vs relative fluidization velocity for different temperatures. Bed solids: sand; 300 ÷ 400 μm.

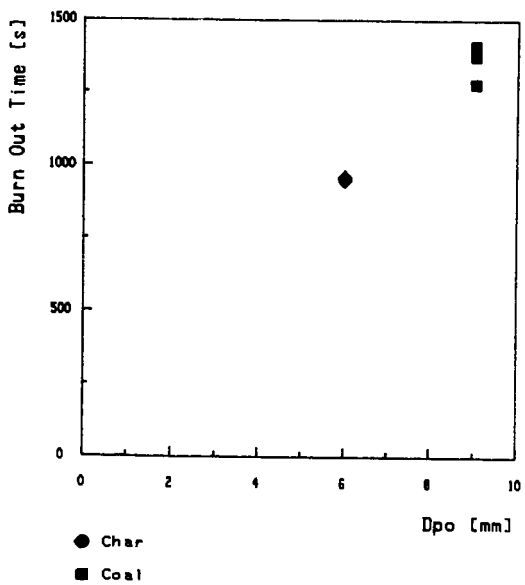

Fig. 6 - Burn out time vs particle diameter. Bed solids: sand; 300 ÷ 400 μm.

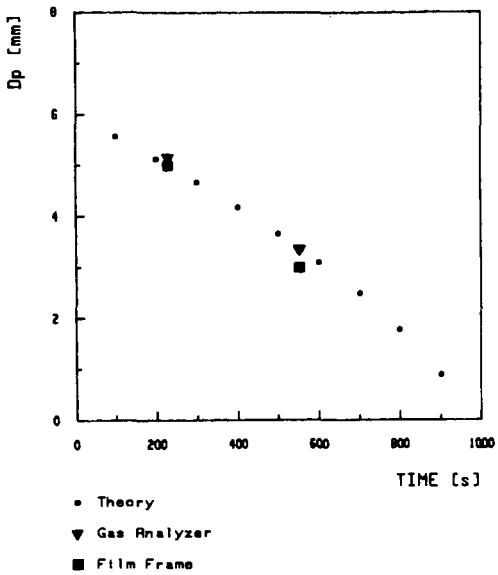

Fig. 7 - Reduction of char particle diameter vs time during combustion, as determined by film frame analysis and by treatment of the CO_2 analysis data. Bed solids: sand; 300 ÷ 400 μm; 1123 K.