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CARBON ATTRITION DURING THE FLUIDIZED COMBUSTION AND GASIFICATION OF COAL

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MASTER

SUMMARY

The work performed in the period 1 June 1982-31 August 1982 has been mainly directed to putting into operation an atmospheric fluidized bed combustor 370 mm ID and carrying out preliminary experiments. This equipment shall be used to check the correlations for bed carbon attrition rates found on a laboratory scale and to investigate elutriation phenomena.

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1. INTRODUCTION

The lack of well established scale-up criteria in the design of fluid bed combustors and gasifiers makes the transition from laboratory to industrial installations particularly expensive in time and money. The poor understanding of the mechanisms of the physical and chemical phenomena occurring in the bed results in unadequate mathematical modelling of the process. Carbon attrition in the bed during combustion is one of phenomena heavily affecting the satisfactory scale-up of a fluid bed combustor (Béer et al., 1980).

Following previous experimental work with bench and laboratory scale apparatus (Donsì et al., 1979, 1980, 1981; D'Amore et al., 1980; Cammarota et al., 1981; Chirone et al., 1981, 1982; Massimilla et al., 1982; Arena et al., 1983), a pre-pilot fluidized bed combustor 370 mm ID has been built. In this report, a description of the equipment is presented, and operation procedures and measuring techniques described. Some preliminary results particularly concerning attrition phenomena are also discussed.

2. EXPERIMENTAL

2.1. Apparatus

The combustor, sketched in Fig. 1, consists of a cylindrical vessel, 370 mm ID and 4.5 m high. The hot section is made out of AISI 310 steel, to stand temperatures up to 950°C and operate with high sulfur coals. Refractory lining has been avoided to ensure a rapid start-up.

The vessel consists of sections of different lengths. Each of them is devoted to a specific function and can be readily substituted or, if necessary, modified. The first section from the bottom contains the plenum chamber and the distributor, which is of the pipe type, with 55 vertical pipes, each discharging through 4 horizontal holes, 2 mm ID. The second section, 250 mm high, contains the lower portion of the bed and is fitted with several external ports. The horizontal discharging nozzle of the start-up burner is located in one of these ports. The heat transfer section was initially designed to

contain 8 horizontal tubes each connected at both ends with the outside cooling system. Difficulties in pipe temperature control under different coal feed rate suggested switching to a different arrangement of the cooling surface. Only three horizontal, fixed pipes are used with this arrangement. Five movable closed end pipes are inserted into the bed through the remaining ports, their penetration depending on the requested heat removal rate. These movable pipes consist of two concentric tubes, 23 mm and 9 mm OD respectively. Cooling water is fed into the annulus between the two tubes and discharged through the inner tube. A disengaging section is fitted above the heat transfer section up to the overall height of 4.5 m. A two stage cyclone, the first with medium and the second with high efficiency, is inserted on the flue gas line. The second can be disconnected for operation at high fluidization velocities, to avoid build up of pressure in the combustor. A stack discharges the flue gas into the atmosphere.

The combustor is mounted on a supporting structure with a platform for operation at the cyclone level. The entire vessel is thermally insulated by means of ceramic fibre. The thickness of the insulation is 100 mm for the lower sections (plenum chamber, start-up and heat transfer sections), 70 mm for the section corresponding to the upper portion of the bed and to the splashing zone, and 25 mm for the disengaging section. Being experiments directed to measure attrited carbon rates, insulation of disengaging section is limited to a minimum in order to obtain a rapid temperature decay in the freeboard and avoid post-combustion of carbonaceous fines. Photographs of the plant are shown in Photographs 1-5.

2.2. Ancillary equipment

Air feeding system: A blower discharges air up to $200 \text{ m}^3 \cdot \text{h}^{-1}$ at a pressure of 0.9 atm. The flow of air is controlled with a by-pass and monitored by rotameters. Air is partly used for the pneumatic conveying of the coal to the bed and operating the start-up burner. Manometers and thermometers

are placed throughout the air circuit.

Start-up burner: Bed is preheated by injecting hot gases below its top level. The burner, shown in Fig. 2 has been specially designed for this application. It is a propane diffusion flame burner, fitted with a multi-orifice head. The combustion air flows concentrically around the burner. A bluff body further improves flame stabilization, as required by the pressure fluctuations induced by the submerged discharging of the combustion products in the fluidized bed. The combustion chamber, 66 mm ID and 330 mm long, is shaped at the discharge end as a converging nozzle, to fit the pipe discharging into the bed. The burner is operated at propane flow rates up to 2800 l h^{-1} , corresponding to a heat production rate of $56.000 \text{ kcal h}^{-1}$. Combustion temperature is limited at 1000°C by controlling the rate of additional air.

Coal feeding system: The coal is fed by a DOSAPRO Milton Roy volumetric feeder discharging from the hopper to the pneumatic conveying device. The volumetric feeder, of the concentric screw type, accurately regulates the coal flow rate and is continuously adjustable in the range $5\text{--}30 \text{ Kgh}^{-1}$. The coal downstream the feeder falls by gravity in a vertical pipe 22 mm ID and 960 mm high and then is transported by air in a short inclined pipe leading to the bed. Coal flow is performed by the air jet formed on the axis of this pipe by a nozzle at the entrance of the pneumatic conveying line. This arrangement allows conveying air flow rate to be reduced to $9 \text{ m}^3 \text{ h}^{-1}$, i.e. at most 12% of overall fluidizing air. The transport line discharges into the bed 125 mm above the distributor.

Cooling water system: A closed loop using distilled water has been set up in order to reduce maintenance of cooling pipes. A volumetric pump circulates the water at a rate sufficiently high to avoid vaporization in the heat exchange pipes. The water is fed in parallel to the heat transfer fixed and movable pipes. It is cooled in an external heat exchanger of concentric tubes by means of tap water.

Gas analyzers: The flue gases are analyzed on-line by means of a paramagnetic O_2 analyzer and two IR analyzers for CO and CO_2 . The sampling point is downstream the second cyclone. The gas is sucked by a membrane pump. The sampling line is equipped with: a heat exchanger for a preliminary cooling of the gas; a paper filter for retaining dust particles; a condenser for water condensation; two more paper Balston filters with high efficiency, and a silica gel filter. The line has a controlled by-pass in order to sample a large gas flow rate, which ensures short residence times in the circuit, and feed to the analyzers only a small fraction of it. Gas sampling in the freeboard is carried out using 5 different sampling water-cooled probes intruding horizontally in the vessel. They are placed at different heights from the top of the expanded bed up to the upper end of the column. Thermocouples are placed similarly along the freeboard. The probes, 3 mm ID, are moved radially in the vessel and can be connected to the line of the analyzers.

2.3. Experimental technique

Start up procedure: First, fluidization is set up at a value of fluidizing gas flow rate high enough to allow intense agitation of bed material. Then the burner is lighted up with hot gas discharging directly inside the bed. Solids mixing prevents the solid from reaching high temperatures at the burner mouth. The bed reaches the ignition temperature of the coal (about $600^\circ C$) in less than one hour. The further temperature rise can be assisted by coal feeding afterwards. The burner flame is turned off as the selected bed operative temperature is attained and fluidization flow rate set at the chosen operative value. Altogether, reaching steady-state, when bed carbon loading and outlet gas composition level off to fixed values for given operative conditions, takes about two hours.

2.4. Operative conditions

Similarly to previous investigations carried out with the 140 mm ID combustor (Arena et al., 1983) fluidization velocities are 80, 130

and 160 cm s^{-1} at bed temperature of 850°C in the present experiments.

The same South African coal referred to in previous DOE Reports 1 to 3 is used. Coal feed size is 1-3 mm. The inert bed material is silica sand, 0.2-0.4 mm size with a minimum fluidizing velocity U_o of 2 cm s^{-1} at bed temperature. Quiescent bed height is of 55 cm.

A single run, about 10 hours long, covers three or four tests at different excess air factors in the range between 0.94-1.35. Solids carryover due to elutriation and bed sampling compensates for ashes accumulation in the bed during each experiment. Overflow, therefore, is not required to keep constant bed level.

Measurements include: gas composition at combustor outlet and, occasionally, at different freeboard heights, bed carbon loading W_c , bed carbon particle size distribution and average $\bar{d} = 1/\sum(x_i/d_i)$, flow rate and size distribution of elutriated carbon. In addition, bed and freeboard temperatures are monitored.

3. RESULTS

Temperature profiles in the combustor are reported in Fig. 3.

The flow rate of overall elutriated carbon E_c is given in Fig. 4, as a function of excess air factor e , for different fluidization velocities. The tendency of E_c to increase as excess air factor decreases and fluidization velocity increases, already shown by laboratory scale tests, is confirmed. This trend is similar to that of bed carbon loading W_c in Fig. 5. Comparison between results obtained under comparable conditions in experiments carried out with 140 (Donsi et al., 1981; Arena et al., 1983) and those in experiments with 370 mm ID combustor in the present work is in Figs. 6 and 7. Elutriated carbon flow rates and bed carbon are respectively referred to unit bed cross section in these figures. A satisfactory agreement between results from the two combustors above appears in both these illustrations.

The linear relationship between E_c and bed carbon loading W_c proposed by Donsi et al. (1981) is tested in Fig. 8. It appears that equation $E_c = kW_c$ holds for data from the 140 mm and the 370 mm combustors as well.

However, k is for given fluidizing velocity systematically somewhat larger for results from experiments with the 370 mm combustor.

The elutriated attrited carbon E'''_c is obtained from the relationship

$$E'''_c = E_c - E'_c - E''_c \quad (1)$$

where E'_c is the contribution of fines in feed coal and E''_c is the contribution of unburnt residues of coal particles. Under conditions of present work, if attrition in coal feeding line is neglected, it is $E'_c=0$. E''_c is calculated neglecting fragmentation and assuming that elutriable particle sizes can be evaluated on the basis of free falling velocities at the gas temperature at the top of the freeboard. If carbon fines post-combustion is neglected, E'''_c is the attrited carbon rate. The relationship predicting the contribution of attrited fines to elutriation:

$$E'''_c = k(U-U_o) W_c / \bar{d} \quad (2)$$

found from previous experiments with the 140 mm ID combustor can be tested for the larger unit now available. The product $(U-U_o)W_c/\bar{d}$ is proportional to the carbon surface exposed to attrition $W_c/\bar{d}$ times the excess fluidizing velocity U in respect to the minimum for fluidization U_o . Results are reported in Fig. 9. The solid line in this figure represents the fitting of all tests for different bed temperatures, excess air factors and coal sizes, performed in the 140 mm ID combustor (Donsì et al., 1981; Arena et al., 1983). The range of abscissa is considerably increased by the data from the 370 mm ID combustor, those related to the smaller unit being all included in the dashed area close to axes origin. A more critical comparison is obtained by referring E'''_c to bed cross section, as done in Fig. 10 according to the relationship:

$$\frac{E''_c}{S} = k \frac{W_c (U - U_o)}{S \bar{d}_c} \quad (3)$$

There is a good agreement between results obtained with the two combustors.

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Fig. 1 - The experimental apparatus. 1) coal hopper; 2) screw feeder; 3) pneumatic conveying line; 4) start-up burner; 5) air distributor; 6) bed solid sampling bottle; 7) manometer; 8) gas analysers; 9) safety valve; 10) safety disk; 11) cyclones; 12) fines collecting bottle; 13) pressure or thermocouple taps; 14) gas sampling probes; 15) movable water cooling probes; 16) thermocouple; 17) fixed water cooling tubes.

Photograph 1 - Overall view of the combustor.

Photograph 2 - The unlagged lower section of the combustor.

Photograph 3 - The two stage cyclone.

Photograph 4 - The start-up burner.

Photograph 5 - The screw feeder.

Fig. 2 - The start-up burner. 1)photo detector access; 2)flame sight tube; 3)spark igniter access; 4) combustion chamber; 5) cooling water inlet/outlet; 6)combustion air inlet; 7)flange to the fluidized bed combustor; 8)gate valve; 9)mica wall; 10)metal coil; 11)fuel duct bearing; 12)burner tip holes; 13)burner tip; 14)stabilizing disk; 15)fuel duct.

Fig. 3 - Axial temperature profiles of the combustor.

Fig. 4 - Overall elutriated carbon rate as a function of the excess air factor.

Fig. 5 - Bed carbon loading as a function of the excess air factor.

Fig. 6 - Elutriated carbon rates per unit bed cross section as a function of the excess air factor.

The comparison between results for 140 mm and 370 mm ID combustor.

Fig. 7 - Bed carbon loading per unit bed cross section as a function of the excess air factor.

The comparison between results for 140 and 370 mm ID combustor.

Fig. 8 - Elutriated carbon rates as a function of bed carbon loading.
The comparison between results for 140 and 370 mm ID combustor.

Fig. 9 - Correlation for attrited carbon rate E''' as a function of $\frac{W_c (U - U_o)}{d_c}$ according to Eq. 2.

Fig. 10 - Correlation for attrited carbon rate E''_c per unit bed cross section as a function of $\frac{W_c (U - U_0)}{S \bar{d}_c}$ according to Eq. 3.