INTERNATIONAL JOURNAL OF ENERGY RESEARCH, VOL. 15, 249–255 (1991)

SHORT COMMUNICATION

COMBUSTION BEHAVIOUR OF COAL AND CARBON IN SPOUTED AND SPOUT-FLUID BEDS

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KEY WORDS Spouted bed combustor Spout-fluid bed combustor Coal combustion

INTRODUCTION

The phenomenon of spouting and its application, particularly for drying, has been reviewed elsewhere (Mathur and Epstein, 1974; Epstein and Grace, 1984; Bridgwater, 1985). The application of a spouted bed as a combustor to burn gas (Khoshnoodi and Weinberg, 1978; Khoe and Weve, 1983), liquid (Arbib and Levy, 1982), and solid fuels (Lim *et al.*, 1984; Bhattacharya and Shah, 1987) showed an acceptable performance. Recently, Zhao *et al.* (1987*a*, 1987*b*) and Lim *et al.* (1988) demonstrated the possibility of burning low grade coal in the spout-fluid bed (SFB), which combines features of the spouted bed (SB), where all air enters as a jet through a central orifice, and the fluid bed (FB), in which air is uniformly distributed across the bed bottom. These three modes of contacting are illustrated in Figure 1. Advantages of SB or SFB over FB for combustion are

(i) the ability to burn lower quality fuels, both in terms of calorific content and stickiness
(ii) easier underbed feeding by pneumatic conveying with the spouting air (Zhao *et al.*, 1987*a*)
(iii) lower NO_x emission
(iv) better limestone utilization in the case of burning coal (Shirley and Litt, 1987) with sulphur oxide removal.

The experimental results reported by Lim *et al.* (1988) showed that, compared with SB and FB combustors, the SFB combustor tends to give somewhat higher efficiencies at low temperatures, and greater temperature uniformity due to better solid mixing, which in turn reduces inert particle-char segregation.

This paper presents the experimental study of batch combustion of Thai lignite and pyrolysed electrode carbon in SB and SFB combustors. The combustion behaviours of evolved coal volatiles and char particle fragmentation are also investigated and are compared with pyrolysed electrode carbon.

EXPERIMENTAL DETAILS

The experiments were carried out in a cylindrical stainless steel combustion column of 108 mm internal diameter and 800 mm high with a wall thickness of 4 mm (see Figure 2). The base of the column was welded with a flat 4 mm stainless steel distributor plate which formed the top cover of the plenum chamber of length 100 mm and of 108 mm internal diameter. The distributor plate, which has a 10 mm central orifice covered

0363–907X/91/030249–07$05.00

Received 14 June 1990
Revised 20 September 1990

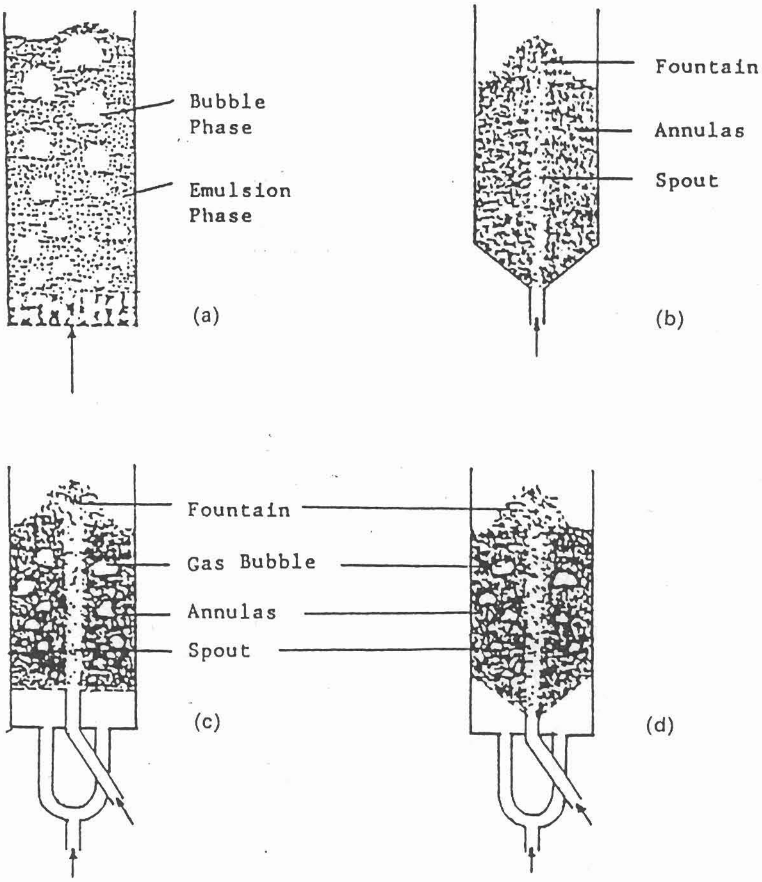
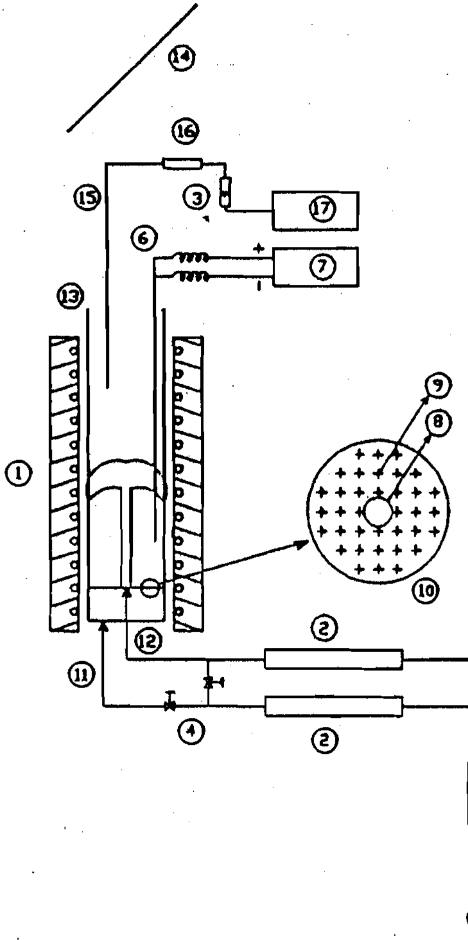


Figure 1. Schematic comparison of (*a*) fluidized bed, (*b*) spouted bed, (*c*) spout-fluid bed with flat base, and (*d*) spout-fluid bed with conical base

with a 1 mm mesh screen to prevent particles entering the gas pipeline, was perforated with 164 holes of 1 mm diameter for auxiliary air. Electrically preheated combustion air, the flow rate of which can be adjusted by means of glove valves, is separately supplied to the central orifice and to the small holes through the plenum chamber. The combustor was externally heated by a 500 mm-long cylindrical resistance heater (4·5 kW) under automatic control. The bed temperature was measured by a K-type thermocouple at the centre of the annulus 40 mm above the distributor plate. Above the combustor, an inclined mirror was installed in order to allow visual observation of the combustion.

Sand of 2·19 mm was used as the inert bed material with a static bed height of 80 mm, and its properties are shown in Table 1. Lignite samples were prepared by crushing lumps, and screening them to different size fractions. Carbon samples were obtained from the carbon electrodes of dry cell batteries. They were first cut, and then ground to a nearly spherical shape using sandpaper. Their equivalent diameters were indirectly determined from the measured weight and density. To minimize the effect of small volatile content in the carbon samples, these were pyrolysed in a nitrogen atmosphere at 1123 K for 30 min. All the samples were oven dried for 24 hours before testing. The properties of lignite and pyrolysed carbon samples are also shown in Table 1.

The bed was preheated under the SFB mode to about 700 K, and then 2–3 g of 1–2 mm lignite particles were dropped into the bed batchwise from above to increase its temperature, and then the operation was



(1) Cylindrical heater
(2) Air preheater
(3) Rotameter
(4) Valve
(5) Air
(6) Thermocouple
(7) Temperature controller
(8) Central orifice
(9) 1 mm hole
(10) Distributor plate
(11) Auxiliary air
(12) Spouting air
(13) Combustor
(14) Mirror
(15) Gas sampling tube
(16) Filter
(17) Gas analyser and vacuum pump

Figure 2. Schematic diagram of experimental equipment

Table 1. Approximate analysis of lignite and properties of sand particle and pyrolysed electrode carbon

Lignite	
Volatile, %	47·38
Fixed carbon, %	47·03
Ash, %	5·39
Apparent density, g/cm^3	1·27
Sand	
Diameter, mm	2–2·39
Bulk density, g/cm^3	1·45
True density, g/cm^3	2·63
Pyrolysed electrode carbon	
Apparent Density, g/cm^3	1.63

changed to the desired mode (SB or SFB) with the specific ratio of superficial gas velocity to the minimum superficial spouting velocity ($U/U_{ms} = 1{\cdot}25$, constant for this study). The bed preheating was then continued to the desired temperature. As soon as the inventory of lignite had burned out, the following experiments were performed:

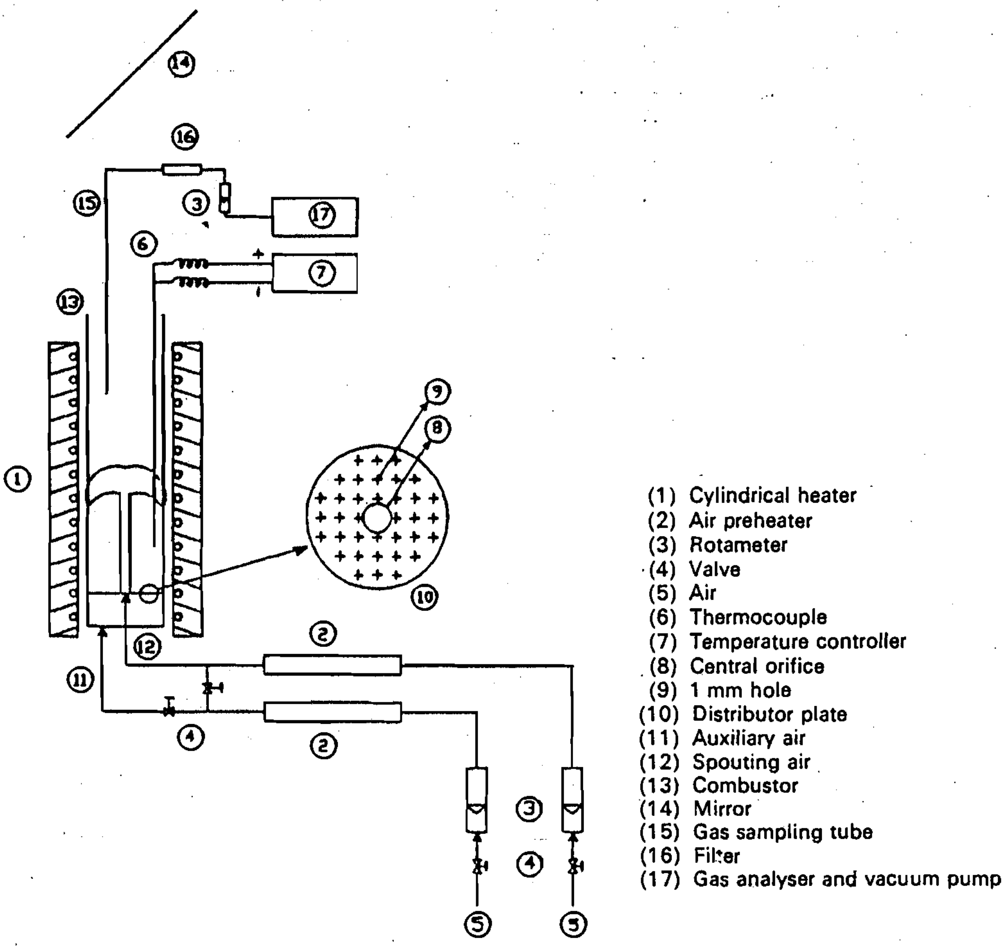


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Table 1. Approximate analysis of lignite and properties of sand particle and pyrolysed electrode carbon

Lignite	
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Bulk density, g/cm^3	1·45
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Single particle combustion

This experiment was performed for both SB and SFB modes. A 6·3–8 mm lignite particle was dropped into the bed from above. The particle ignition, volatile combustion, char fragmentation and combustion were visually observed. For comparison purposes, the same experiment was carried out using a pyrolysed electrode carbon particle of the same size.

Burnout time

This experiment was performed for both SB and SFB modes. A 2 g batch of uniformly sized lignite particles was dropped into the bed from above. Volatiles and/or char burnout times were measured visually with a stopwatch. The particle size ranges studied were 8–9·53 mm, 6·3–8 mm, 4·7–6·3 mm, 4–4·7 mm, 3·35–4 mm, and 2·79–3·35 mm. To ensure reproducible results, at least two tests were performed for each particle size.

The fluctuation of bed temperature during both the above experiments was within ± 20 K.

RESULTS AND DISCUSSION

Single particle combustion

When a 6·3–8 mm lignite particle was dropped into the bed, the heterogeneous ignition of fine particles resulting from abrasion between itself and inert sand particles was clearly observed. After 2–4 s, volatile combustion started in the form of a diffusion flame surrounding the particle as it travelled from the spout to the fountain region and then fell back to the bed surface in the annulus region. It went downwards into the annulus with the inert sand and was entrained again to the spout region to complete the cyclic movement. Volatile combustion inside the annulus and spout regions was difficult to observe. However it is expected that the volatile flame envelope will be extinguished inside the annulus region owing to the high heat loss rate from the flame front to the surrounding sand particles, and will appear again when the coal is entrained into the spout region (see Figure 3). Similar behaviour has also been reported to be observed in the particulate and bubble phases of a two-dimensional fluidized bed combustor (Prins *et al.*, 1989).

The breakage of lignite particles into large fragments during the volatile combustion period, known as primary fragmentation, was observed. This was due to the thermal stresses resulting from rapid heating and internal pressure developed by the rapid release of volatiles (Chirone *et al.*, 1982). The volatile combustion in the case of these fragments was similar to that described above.

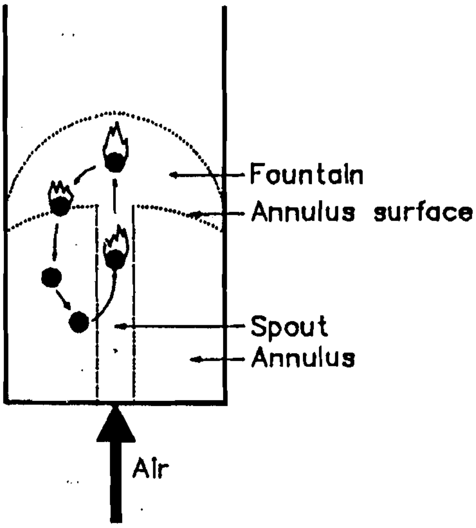

Figure 3. Sketch of volatile combustion in each region of spouted bed combustor

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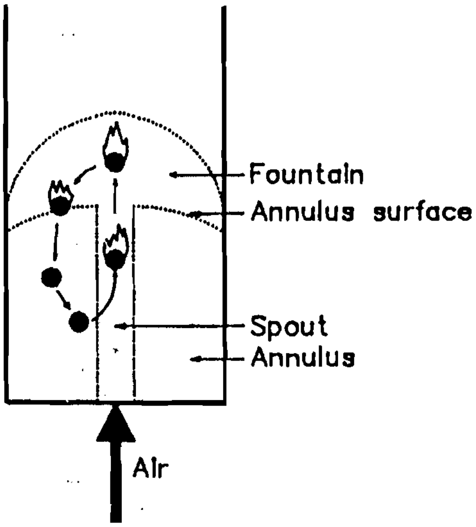


Figure 3. Sketch of volatile combustion in each region of spouted bed combustor

Char combustion occurred after the volatiles were driven off. The secondary fragmentation of char particle, which resulted from the combined effects of collisions and the burning out of bridges connecting parts of the particle (Chirone *et al.*, 1982), was also observed. Char attrition, which generated fines by surface abrasion (Arena *et al.*, 1983) and perimeter percolative fragmentation (Kerstein and Niksa, 1984; Reyes and Jensen, 1986), increases the surface area for reaction and carbon loss, and hence lowers the burnout time.

For the case of pyrolysed electrode carbon particle, ignition time delay was longer than lignite, and glowing combustion of carbon with cyclic movement pattern was observed without any volatile flame. The particle size decreased gradually, and no fragmentation occurred.

The single particle combustion of lignite and carbon in a spouted bed can be represented as shown in Figure 4. Similar behaviour was observed when lignite and carbon samples were burned in the SFB mode at 973 K bed temperature, U/U_{ms} = 1·25, and with the ratio of air flow rate q at the annulus inlet to the total gas flow rate Q equal to 0·2.

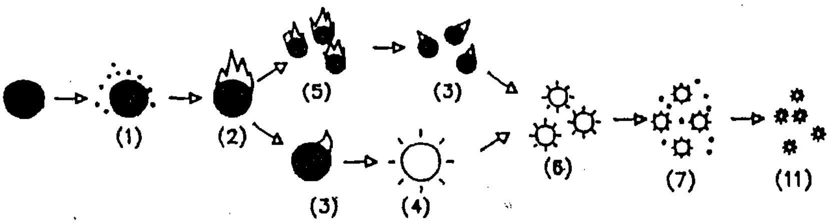
Burnout time

For all the size ranges studied, the lignite particles burned as sketched in Fig. 4*a* with the cyclic movement pattern described previously. The smallest particles tended to float on the bed surface during the volatile combustion period. The degree of fragmentation increased with particle size. Figure 5 shows the burnout times of volatile and char in a spouted bed combustor operated at U/U_{ms} = 1·25 and at a bed temperature of 973 K. The burnout times of volatiles and char increase with the initial particle diameter.

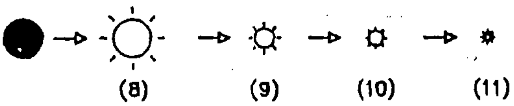
Because of fragmentation, which can significantly increase the particle surface area, increase in burnout time was small for the two largest sizes.

CONCLUSIONS

The combustion of both lignite and electrode carbon particles in SB and SFB combustors showed a pattern of cyclical movement between annulus, spout, and fountain regions. The particle residence times in these regions, therefore, will play an important role on the overall combustion rate. More investigation is needed



(a) Lignite



(b) Electrode carbon

Figure 4. Sketch of events that happen to a single (*a*) lignite and (*b*) pyrolysed electrode carbon particle from the moment of introduction into the spouted bed combustor; (1) = pyrolysis with attrition, (2) = volatile ignition and combustion as diffusion flame, (3) = volatile flame extinction, (4) = glowing combustion of char, (5) = breakage to large fragments and continue burning of evolved volatile, (6), (7) = glowing combustion of char particles resulting from fragmentation and attrition, (8)–(10) = glowing combustion of electrode carbon particle as particle size decreases, and (11) = char burnout

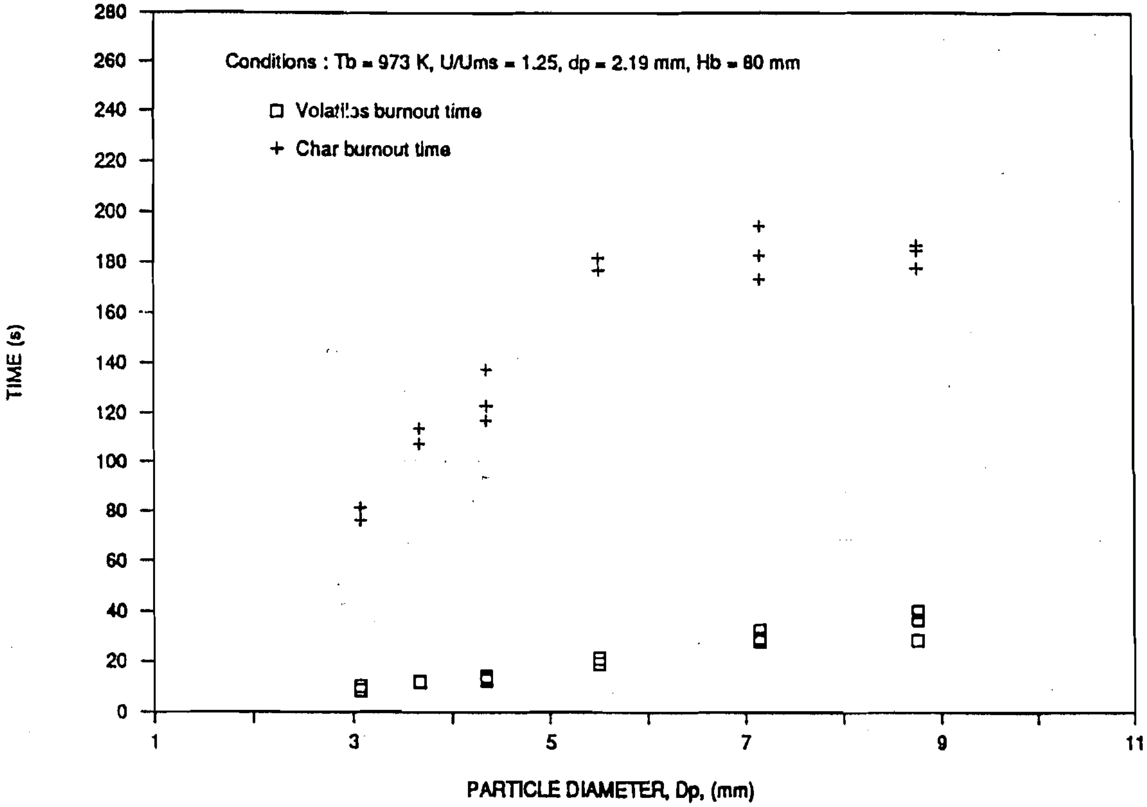


Figure 5. Burnout times of volatiles (□) and char (+) in spouted bed

into this subject. The volatiles evolved from lignite particles burned as an enveloping diffusion flame in the spout and fountain regions. Fragmentation was observed only in the case of lignite during volatile and residual char combustion, whereas carbon particles burned without fragmentation.

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