# Evaluation of Attrition Rate Constants of Char Burning in Fluidized Beds by Means of Laboratory-Scale Combustors

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Attrited carbon is a large fraction of the overall carbon elutriation from a fluidized coal combustor when gas velocity is significantly above the minimum for fluidization and feed size is coarser than 0.4 mm. Continuous fluidized combustion of a South African bituminous coal of particle size range varying between 0.4–1 and 6–9 mm in beds of sand fluidized at velocities between 0.8 and 1.6 m/s indicated that with the coal tested, the elutriation rate of attrited carbon fines (mostly <100 μm) was proportional to the surface of char exposed to the rubbing of bed solids (Arena et al., 1983). Using the nomenclature of that paper, the attrited carbon elutriation rate $E_c''{}'$—which, assuming limited postcombustion in the freeboard, is also the carbon attrition rate—is:

$$E_c''{}' = kW_c(U - U_o)/\bar{d} \qquad (1)$$

In this expression, the ratio of bed carbon loading $W_c$ to the bed char Sauter diameter $\bar{d}$ is proportional to the char external surface. $U$ and $U_o$ are the operating fluidization velocity and the experimental minimum fluidization velocity of sand, respectively, so that $(U - U_o)$ is the excess of gas velocity above the minimum. The carbon attrition rate constant $k$ is substantially unaffected by changes of the combustion air excess factor $e$ within the range $1 < e < 1.4$ of interest in ordinary fluidized combustion of coal, but depends on sand particle size, increasing from $1.86 \times 10^{-7}$ to $12.1 \times 10^{-7}$ as it increases from about 0.3 to about 1.1 mm. The comparison between attrition rate constants obtained when burning the above South African coal and a metallurgical coke (Arena et al., 1984) further suggests that $k$ may vary with the texture and the strength of the char and with the mechanical properties of bed solids. With the view of extending attrition tests to other coals and bed solids, the point was raised as to whether the 140 mm ID combustor previously used (Arena et al., 1983, 1984) was large enough to provide $E_c''{}'$, $W_c$, and $\bar{d}$ leading to values of $k$ substantially free from the effects induced by the scale of the combustor, but not too large to lose the advantage of less expensive tests with a smaller apparatus.

To this end, experiments of fluidized combustion of the South African coal (1–3 mm size) have been repeated, with various excess air factors, using a miniature 40 mm ID and a pre-pilot 370 mm ID combustor. The layout of these units is similar to that of the 140 mm ID combustor with the exception of the sam-

**Table 1. Characteristics of Combustors and Operating Ranges of Relevant Variables**

(Bed temp., 850°C; Pressure, 101.3 kPa; Inlet gas, air)

| | | | |
|---|---|---|---|
| Combustor dia., $D$, m | 0.040 | 0.140 | 0.370 |
| Combustor cross section, $S$, m$^2$ | 0.0013 | 0.0153 | 0.1067 |
| Combustor height, m | 1.15 | 4.5 | 4.5 |
| Bed sand size, $d$, mm | 0.2–0.4 | 0.2–0.4<br>0.6–0.85 | 0.2–0.4<br>0.6–0.85 |
| Mass of sand, kg | 0.180 | 7.65; 10 | 85; 125 |
| Expanded bed height, $H_b$, m | 0.15 | 0.53–0.70 | 0.55–1.00 |
| $H_b/D$ | 3.75 | 3.78–5.00 | 1.49–2.70 |
| Superficial gas velocity (at bed temp.) $U$, m/s | 0.8 | 0.8; 1.3; 1.6 | 0.8; 1.0<br>1.3; 1.6 |
| Excess air factor, $e$ | 0.9–1.4 | 0.9–1.4 | 0.9–1.4 |
| Coal feed rate, kg/h | 0.1–0.13 | 1.2–3.4 | 5–25 |
| Start-up burner power, kW | * | 15 | 70 |
| Thermal power output, kW | 0.7–0.95 | 8.8–25 | 65–200 |

*The 40 mm ID combustor was heated to operating temperature by an electrical furnace.

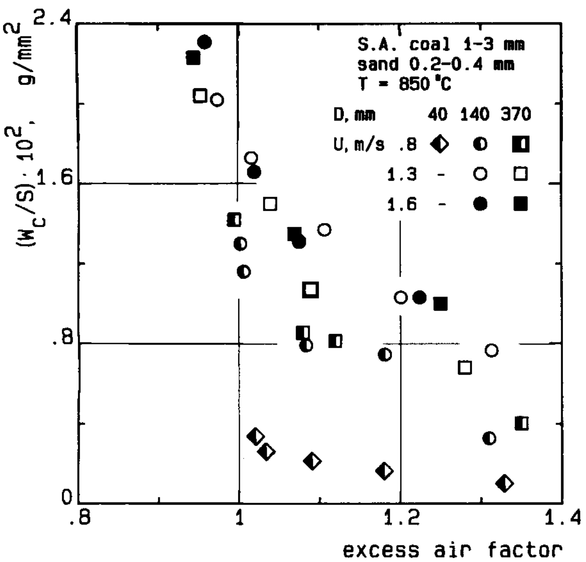


**Figure 1. Bed carbon loadings per unit combustor cross section as a function of excess air factor.**

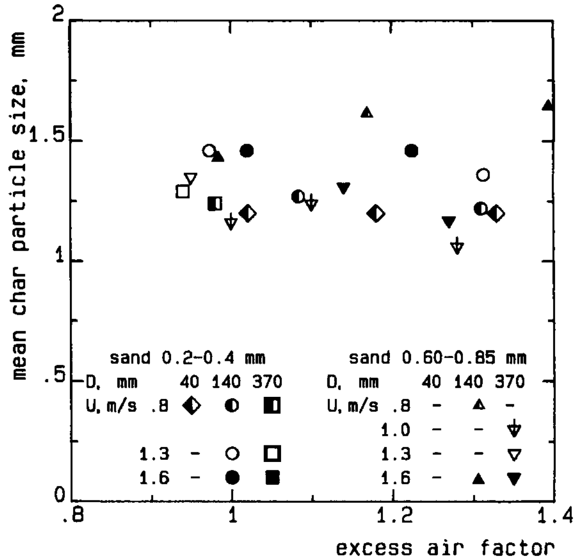


**Figure 3. Average bed char size for various operating conditions.**

pling equipment and auxiliary facilities, which are adjusted to the size of the apparatus (Meo, 1982). Relevant design data of the three combustors and the ranges of variables within which each unit has been operated are reported in Table 1. Two major restrictions to operation with the 40 mm ID combustor appear in this table. The first regards the size of the sand; the second, the gas velocity. The use of sand coarser than 0.2–0.4 mm enhances slug fluidization, which in turn promotes coal segregation on the top of the bed. At gas velocities higher than 0.8 m/s unburnt char particles larger than those generated by attrition are entrained in the carry-over due to the limited freeboard height. On the other hand, a higher combustor would increase the amounts of sand and char circulating in the freeboard due to the large height-to-diameter ratio of the unit.

Bed carbon loadings and attrited carbon elutriation rates per unit combustor cross section $W_c/S$ and $E_c''{}'/S$ are reported in Figures 1 and 2 as a function of the excess air factor $e$, with gas velocities $U$ as a parameter. Figure 1 shows that for the same $U$, specific bed carbon loadings for the 140 and 370 mm units are practically the same, whereas those relative to the 40 mm ID combustor are smaller by a factor of three at least. This depends on the dramatic changes in solid and gas flow patterns that result, even with the comparable $H_b/D$, from significant increases of $D$. Apart from other effects, gas bypassing as bubbles in beds of 140 and 370 mm dia. is much larger, which

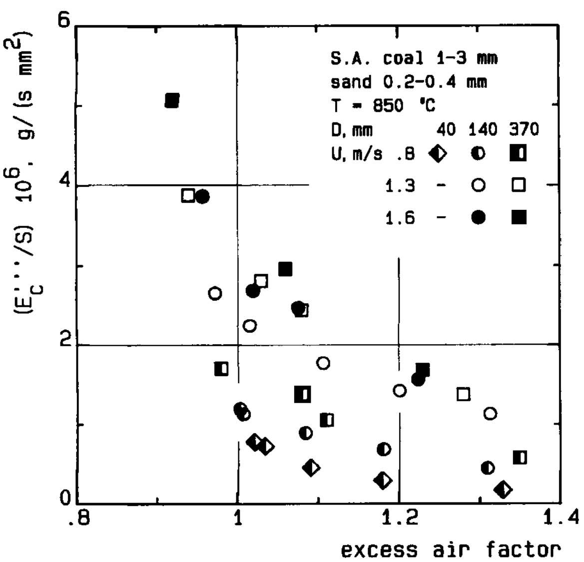


**Figure 2. Elutriation rates of attrited carbon per unit combustor cross section as a function of excess air factor.**

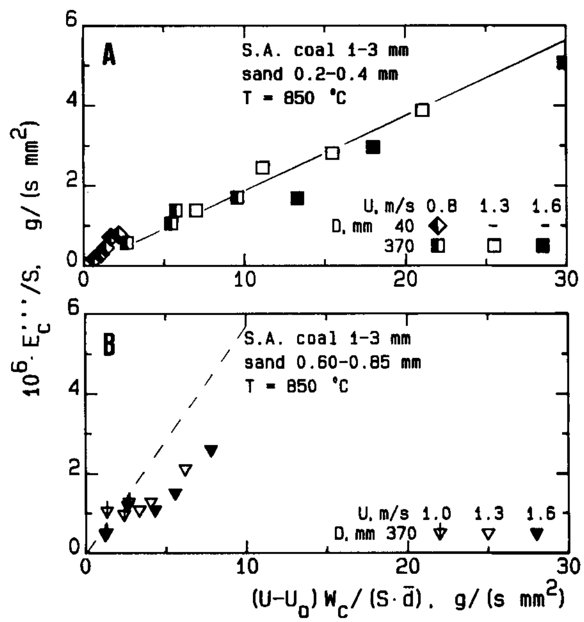


**Figure 4.** $E_c''{}'/S$ **vs.** $W_c(U-U_o)/(S\bar{d})$ **correlation.**

Results from experiments using 140 mm ID combustor (Arena et al., 1983):

A. ———— slope based on 121 previous runs

B. — — — slope based on 11 previous runs requires higher specific carbon loadings to ensure steady state operation for the same $U$ and $e$. It is rather interesting that specific attrited carbon elutriation rates in Figure 2 show the same trend, with a remarkable reduction when passing from the 370 and 140 to the 40 mm ID combustor. On the other hand, average bed char size $\bar{d}$ is substantially the same for all the three combustors for given $U$ and $e$, as shown in Figure 3.

Altogether, specific bed carbon exposed surface appears to be subject to wall effects, for combustor diameters smaller than 140 mm, which is not surprising considering that such effects have to be taken into account in the scale-up of catalytic fluidized bed reactors (de Groot, 1967; Calderbank and Toor, 1971). Changes of $E_c''{}'/S$, however, follow so closely those of $W_c/S$ to suggest that wall effects concentrate in the latter parameter so that once it is experimentally determined, the relationship expressed by Eq. 1 becomes substantially independent of the size of the combustor. This is confirmed by the correlation in Figure 4A, where the values of $E_c''{}'/S$ and $W_c(U - U_o)/S\bar{d}$ relative to the experiments with the 40 and 370 mm ID and 0.2–0.4 mm sand are compared with the straight line averaging data previously obtained with the same sand and the 140 mm ID combustor (Arena et al., 1983). A similar, although not so good, agreement appears in Figure 4B, where results obtained with the 140 and 370 mm ID combustors and 0.6–0.85 mm sand are compared.

In conclusion, experimental results suggest that the influence of the size of bed solids on char attrition can be conveniently investigated only with combustors larger than about 100 mm ID. The lower suitable diameter of the combustor to determine attrition rate constants is fixed by the constraints imposed by the size of bed solids and gas velocity, respectively, to the mixing of the char inside the bed and to the entrainment of relatively coarse unburnt char in outlet gas together with attrited carbon. With bed solids below 0.5 mm in size, a combustor as small as 40 mm ID has been properly used to investigate the attrition behavior of the coal tested if operated at gas velocities below 1.0 m/s. The attrition rate constant $k$ provided by this bench-scale apparatus is close to those obtained at higher velocities with larger units.

## Notation

$\bar{d}$ = surface-based average particle size
$D$ = combustor diameter
$e$ = combustion air excess factor
$E_c$ = overall carbon elutriation rate
$E_c''{}'$ = elutriation rate of attrited carbon fines
$H_b$ = expanded bed height
$k$ = attrition rate constant
$S$ = combustor cross section
$T$ = bed temperature
$U$ = fluidizing gas superficial velocity at bed temperature
$U_o$ = minimum fluidizing gas superficial velocity at bed temperature
$W_c$ = bed carbon loading

## Literature Cited


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*Manuscript received Oct. 19, 1984, and revision received June 3, 1985.*