Combustion of Fuel-Water Slurries Injected in a Fluidized Bed

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Fuel-water slurries (FWS) and similar nonconventional fuels can be conveniently burnt in atmospheric and pressurized fluidized bed combustors (Byam and Wright, 1987). Roberts et al. (1983) and Cen et al. (1983) observed that char aggregates were formed in the bed. Massimilla and Miccio (1986) reported that, together with 1–8 mm aggregates and with flying carbon of about 45 μm in size, bed particles with carbon spots (<30 μm) were found. They related the generation of aggregates (*A*-phase), carbon deposits on bed solids (*S*-phase), and flying carbon (*F*-phase) to the interaction between hot beds and air-assisted jets of an Upper-Freeport coal-based slurry. This note deals with further experiments made on the influence of the FWS parent fuel and on that of the velocity of injecting air.

Properties of FWS's and parent fuels are compared in Table 1 to those of the UF-FWS used previously. The UF- and the SA-FWS were both made of high volatile, bituminous coals, but the SA-coal had a smaller Swelling Index. PC- and EC-FWS were both based on low-ash fuels, but volatile content of electrode coke was much smaller.

The combustor was made of a 370-mm-ID and 4.5-m-high AISI 310 cylindrical vessel. FWS was injected in the bed by means of an air-assisted disperser with a 6-mm-ID nozzle. Post-combustion of elutriable carbonaceous fines in the low-temperature freeboard was negligible. The bed, made of 85 kg of 0.60–

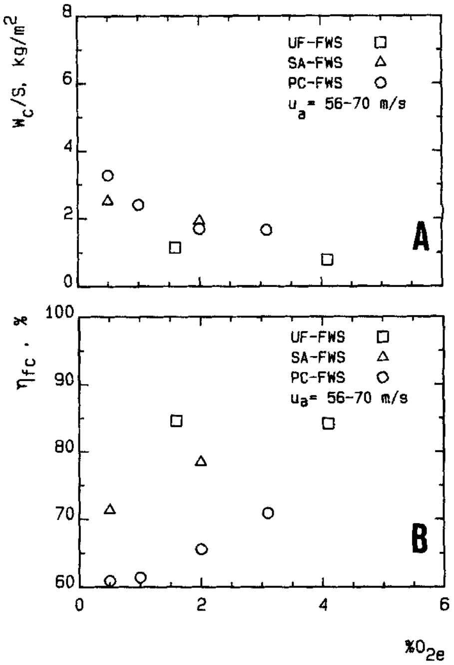

Figure 1. Specific bed carbon content (*A*) and fixed carbon combustion efficiency (*B*) as a function of oxygen concentration in flue gas.

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Table 1. Properties of Fuel-Water Slurries

	UF-FWS	SA-FWS	PC-FWS	EC-FWS
Slurry				
Typical Water Content, wt. %	30.0	35.0	30.0	40.0
Parent Fuel	Upper Freeport Coal	South-African Coal	Petroleum Coke	Electrode Coke
Net Caloric Value, $J \cdot g^{-1}$	31400	27700	34400	31500
Proximate Analysis				
% on Dry Basis				
Fixed Carbon	58.34	61.2	84.01	90.98
Volatile Matter	29.38	23.1	13.44	3.87
Ash	12.28	15.7	2.55	5.15
Free Swelling Index*	7.5	1-2		
Particle Size Distribution				
90th percentile, μm	129.0	130.4	96.5	120.0
50th percentile (median), μm	22.4	42.8	9.5	48.8
10th percentile, μm	3.0	6.4	2.5	9.3
Mean Value, μm	43.5	56.3	32.6	59.2

*ASTM D720

Table 2. Characteristics of *A*-, *S*- and *F*-Phases

	A-Phase	S-Phase	F-Phase
UF-FWS	Spongy, friable carbon aggregates containing sand	carbon-spotted sand surface	grey/black
SA-FWS	Relatively compact, sand-free carbon aggregates	carbon-spotted sand surface	grey/black
PC-FWS	Relatively compact, sand-free carbon aggregates	carbon-coated sand surface	grey/black
EC-FWS	Absent	absent*	silver

*Bed sand maintained its yellow color

0.85-mm silica sand, was operated at 850°C and a superficial fluidizing velocity (at bed temperature) of 1.3 m/s. Air velocity at the FWS disperser (u_a) varied between 0 and 100 m/s, with an air-to-FWS mass feed ratio in the range 0–0.5. Oxygen concentration in flue gas ($\%O_{2e}$) ranged from 0.5 to 4.6%. Measurements included carbon elutriation rates (E_c), efficiencies of fixed carbon combustion (η_{fc}), size distributions and carbon contents of bed samples. Bed carbon content W_c was split into W_{cA}, W_{cS} and W_{cF} relative to the *A*-, *S*- and *F*-phases (Massimilla and Miccio, 1986).

The EC-FWS was not able to sustain combustion, and a large amount of fines was collected from the cyclones after start-up. Steady-state operation was reached with other FWS's. In these cases, the mass rate F_P of carbon burnt in the bed and the mass rate E_c roughly balanced the F_{fc} carbon feed rate, being within ±10%: $F_{fc} = F_P + E_c$. Supplementing previous findings with UF-FWS, it was found that 1 to 10 mm sand-free carbon aggregates were formed when using SA- or PC-FWS. Moreover, in the case of PC-FWS, deposition of carbon on sand surface occurred as a uniform coating. Neither aggregates nor carbon deposits on sand particles were found in experiments with EC-FWS (Table 2).

Specific bed carbon loading (W_c/S) and combustion efficiencies (η_{fc}) for SA- and PC-FWS are presented in Figures 1, 2 and 3 together with those for UF-FWS. Increasing $\%O_{2e}$ (Figure 1A) and u_a (Figure 2A) results in the reduction of W_c/S, which would imply an increase of η_{fc}, should results by Arena et al.

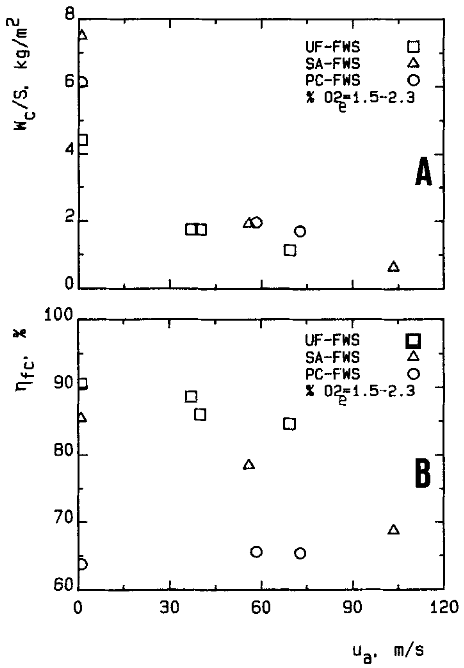

Figure 2. Specific bed carbon content (*A*) and fixed carbon combustion efficiency (*B*) as a function of air velocity at the FWS disperser.

(1983) for coal also apply to FWS. Figures 1B and 2B show that it is not always so. Actually, not only W_c/S, but its distribution in W_{cA}/S, W_{cS}/S, and W_{cF}/S is also relevant in this respect (Figure 3). Such distribution depends on both the FWS fuel and u_a. Lower η_{fc} is associated with larger amounts of fines W_{cF}/S, whereas higher η_{fc} is found with larger W_{cA}/S.

Conclusion

FWS combustion efficiency depends strongly on properties of fuel. Coal swelling enhances formation of carbonaceous aggregates as well as char deposition on bed particles. In turn, these increase carbon residence time in the bed and combustion efficiency. It appears that the tendency of coals to agglomerate,

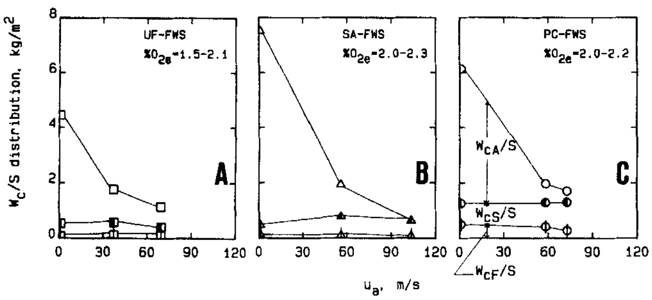

Figure 3. Specific bed carbon contents related to *A*-, *S*- and *F*-phases as a function of air velocity at the FWS disperser.

which is a drawback to the combustion efficiency of FWS's in flames (Beér, 1985), turns out to be useful to their combustion in FBC systems. In any case, substantial amounts of carbon fines tend to escape from the bed so that the combustor freeboard must be properly designed in order to obtain acceptable combustion efficiencies. Decreasing air velocity at the FWS disperser reduces the generation rate of carbon fines in respect to the formation rates of aggregates and carbon-covered sand. It is unlikely, however, that large FWS-fired fluidized beds can be operated at $u_a = 0$ because of the need of controlling aggregate size and avoiding bed defluidization.

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Notation

$\%O_{2e}$ = oxygen molar fraction at combustor exit
E_c = carbon elutriation rate
F_{fc} = fixed carbon feed rate
F_p = mass rate of carbon burnt in the bed
S = cross section of the combustor
u_a = air velocity at the FWS dispersing nozzle
W_c = bed carbon content
W_{cA}, W_{cF}, W_{cS} = bed carbon contents in *A*-, *F*- and *S*-phases
η_{fc} = fixed carbon combustion efficiency

Literature Cited

Arena, U., M. D'Amore, and L. Massimilla, "Carbon Attrition During the Fluidized Combustion of Coal," *AIChE J.*, **29**, 40 (1983).

Beér, J. S. M., "Coal-Water Fuel Combustion: Fundamentals and Application. A North America Overview," 2nd Eur. Conf. on Coal Liquid Mixtures, London (1985).

Byam, Jr., J. W., and S. J. Wright, "Coal-Water-Mixture Testing in the Grimethorpe PFB Test Facility," *FBC Comes of Age*, John P. Mustonen, Amer. Soc. of Mech. Eng., 191 (1987).

Cen, K., X. Cao, Z. Yval, S. Kang, J. Hong, M. Xie, D. Lu, M. Ni, and Y. Chen, "Combustion and Gasification of Coal-Water Slurry in Fluidized Beds," *Proc. Int. Conf. on FBC*, Philadelphia, 253 (1983).

Massimilla, L., and M. Miccio, "The Mechanism of Combustion of a Coal-Water Slurry in a Fluidized Bed," *Proc. Int. Symp. on Combustion*, Combustion Inst., Pittsburgh, 357 (1986).

Roberts, A. G., K. K. Pillai, S. N. Barker, and L. K. Carpenter, "Combustion of 'Run-of-Mine' Coal and Coal-Water Mixtures in a Small PFBC," *Proc. Int. Conf. on FBC*, Philadelphia, 482 (1983).

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