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Combustion of biomass in jet flames

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Abstract

Flames of mixed wood, sawdust, fermentation-process residues and grain residues have been fired at 15 kW thermal input to determine flame ignition, temperature levels, NOx emissions, combustibles burnout as well as fly ash slagging propensity. South African Middleburg coal has been combusted under similar conditions. Near the burner, the in-flame temperatures of the coal flame are around 100 °C higher than in the biomass flames and the fastest ignition has been observed for the coal flame. Combustibles burnout is good, exceeding 94.2% for all the fuels. For mixed wood and saw dust, around 50–60% of the fuel nitrogen has been converted to NO whilst for the fermentation and grain residues as well as for the coal, the nitrogen conversion rates are in the 14–18% range.

Ash deposition experiments have been carried out in the 950–1200 °C temperature range. Around three times more deposit (when normalized to the fuel ash content) is formed for biomass fuels than for the coal. For biomass fuels, a good correlation between deposition rate and particles temperature has been obtained. Sticking efficiency of the impacting particles has been estimated to be 0.03–0.09 at 970 °C and around 0.4 at 1170 °C.

Keywords: Biomass combustion; Jet flames; Nitrogen oxides; Ash deposition; Sticking efficiency

1. Introduction and objectives

Combustion of alternative fuels, including biomass, has become of considerable importance in the current energy scenario. There are several reasons for this. Firstly, resources protection and climate precaution (CO_2 neutrality) play an important role and co-firing of biomass fuels in power station boilers has become relevant in countries where financial incentives for its implementation have been instituted. Secondly, conversion of by-products into thermal energy has become a viable option for decreasing the production costs. A good example is the food industry where sugar beets chips or meat and bone meal are considered as an option to substitute fossil fuels. These are typically single-flame fired units of thermal input not larger than 20 MW.

There exist several reviews on co-firing of coals with biomass as exemplified by Refs. [1–3]. The issue of burner design for coal–biomass flames was investigated by Abbas et al. [4], Gerhardt et al. [5] studied coal/sewage-sludge flames with emphasis on NOx emissions whilst Wu et al. [6] examined formation of fine particles in co-firing.

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Table 1
Fuels used.

	Middelburg coal	Mixed wood	Sawdust	Fermentation residue	Grain residue
Proximate analysis wt.% (as fired)					
Moisture	6.1	6.6	6.7	14.7	12.1
Ash	10.0	1.7	0.5	7.3	6.2
Volatiles	30.4	75.5	78.4	60.4	66.2
Fixed carbon	53.5	16.2	14.4	17.6	15.5
Ultimate analysis wt.% (as fired)					
C	66.2	46.5	47.5	40.0	40.3
H	4.0	5.6	5.9	4.8	5.4
S	0.87	0.03	0.06	0.24	0.18
N	1.75	0.26	0.09	1.54	2.14
Cl	<0.05	0.02	0	0.33	0.15
O	11.0	39.3	39.2	31.1	33.5
Stoichiometric air requirement kg air/kg fuel (as fired)					
	8.7425	5.6205	5.8282	5.0850	5.2800
Amount of combustion products at $\lambda = 1$ kmol/kg (as fired)					
Wet	0.3186	0.2233	0.2319	0.2054	0.2129
Dry	0.2952	0.1917	0.1987	0.1732	0.1792
Calorific values MJ/kg (as fired)					
GCV	26.4	18.3	18. 8	15.6	16.3
LCV	25.3	17.0	17.3	14.2	14.8
Ash fusibility temperatures (°C)					
Softening	1240	1220	1200	1020	1060
Hemispherical	1350	1240	1300	1140	1260
Fluid	1370	1250	1310	1160	1350
Ash composition expressed as oxides wt.% (X-ray fluorescence)					
SiO_2	41.1	10.1	7.6	14.2	55.7
Al_2O_3	32.5	2.73	2.22	0.44	1.9
TiO_2	1.19	0.3	0.4	0.04	0.2
Fe_2O_3	2.03	3.0	4.7	5.0	2.1
MgO	2.40	4.2	6.1	6.5	2.4
CaO	9.12	50.8	41.8	18.7	6.6
Na_2O	1.07	0.8	0.8	0.7	0.3
K_2O	0.92	17.5	17.3	24.2	16.5
P_2O_5	2.54	4.9	4.8	21.9	10.1
SO_3	7.05	2.9	2.9	4.8	2.7
MnO	–	1.5	9.4	0.26	0.16
ZrO_2	–	0.03	0.01	–	0.03
NiO	–	0.03	0.1	–	–
Cl	–	0.4	0.1	4.0	1.30

28.957 kg/kmol is used for the molecular mass of air.

Van de Kamp and Morgan [7] carried out trails at 2 MW thermal input and burned straw, waste paper and municipal sewage-sludge with two bituminous coals. They focused on the effect of co-firing on NOx, SOx and char burnout in Type I and Type II (IFRF classification [8]) flames. In several works ash deposition was investigated as exemplified by Refs. [9–11]. Only very few publications exist which underline characteristics of pure biomass flames [12,13].

The objective of our work is to determine flame ignition, temperature levels, NOx and CO emissions, combustibles burnout (carbon-in-ash) as well as slagging propensity of jet flames of pulverized biomass. In order to facilitate comparison with pulverized coal flames a reference coal has also been combusted. In our work we generate data which are needed for design of burners fired with pulverized biomass. Such data concerning pure biomass flames are also essential when a mechanistic interpretation of the effects observed during co-firing of biomass and coal is required.

2. Experimental

2.1. Fuels

Mixed wood, sawdust, residues of fermentation process of a bio-gas plant, as well as grain (crops) residue are the primary fuels considered. For comparison, the South African (Middleburg)