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Torrefied Biomass Size for Combustion in Existing Boilers

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Abstract: A fundamental investigation was conducted on the combustion characteristics in air of different torrefied biomass particles size ranges. The targeted biomass types were waste crop, herbaceous and woody. The experimental setup that was used in this investigation consisted of a drop-tube furnace, operated at a wall temperature of 1400 K, and a three-color pyrometer, interfaced with the furnace. Entire luminous particle combustion profiles of individual particles were recorded. Results are compared with relevant past data on the combustion characteristics of single coal particles of different ranks, burned in the same furnace under identical operating conditions. The goal of this work is to identify the appropriate size of torrefied biomass particles whose combustion durations match those of 75-90 μm pulverized coal particles, which is a size typically used in pulverized fuel boilers. Such data will be useful in deciding the fuel sizing for co-firing coal with biomass.

Keywords: *Torrefied, Biomass, Size, Burn-out Time*

1. Introduction

Around 44% of the total power produced in the USA in 2011 was from coal according to Energy Information Administration [1, 2]. Co-firing different coal types has been studied earlier [3-6] to reduce harmful emissions from coal combustion. Co-firing renewable fuels such as biomass along with coal is also a promising technique for reducing pollutants from coal combustion as well [7-10]. Since biomass is plentiful and naturally grown, it is categorized as a renewable energy source. However, its low calorific value, high moisture content, hygroscopic nature and smoking during combustion reduce the appeal of biomass as a fuel. Torrefaction is a practical method for improving the properties of biomass as a fuel [11-13]. Torrefaction is a thermochemical pretreatment process, which can ameliorate the biomass utilization characteristics, including heating value, grindability and resistance to decay [14-17]. Torrefied biomass can be a suitable alternative fuel in existing large-scale pulverized coal boilers because torrefaction renders the properties of biomass to be closer to those of coal [18-21]. In power generation industry biomass and coal, grinding is a necessary and key step [22, 23]. Biomass particle shape and size are both important factors which could influence the physical properties of solid particles [24]. Biomass particle size plays an important role in fluidization in power plant boilers [25]. Regarding this matter, Marinelli et al. [26] reported that the finer the particle size and the greater the range of particle sizes, the greater the cohesive strength, and the lower the flow rate. Reduction in size increases the contact area between the particles, thereby increasing the cohesive forces. The size of biomass particles in pulverized combustion is expected to be larger than that of coal particles because of their typically lower bulk density, faster devolatilization rates and higher volatiles to

fixed carbon ratios. Also due to the different physical properties of biomass and coal, biomass particles will not be pulverized to the same size as coal particles [27]. On the other hand, the increase in particle size increases the ignition delay and quantity of unburned residue compared with a small volume of coal [28-32]. Hence finding the right biomass particle size to co-fire with coal is important to achieve good combustion efficiency. This has been addressed theoretically by Sastamoinen et al. [29] and experimentally by Mock et al. [33]. The latter authors burned pulverized torrefied wood, sewage sludge and coffee waste and found that particles in the range of (355-424) μm when exposed to a hot vertical gas stream (1340 K) move to the direction of the stream and burn completely. Larger particles fall to the bottom of the furnace and do not burn completely. Given the importance of biomass particle shape [28] and size in power generation boilers, this research further examined the burnout times of different pulverized torrefied biomasses in a gas temperature comparable to those implemented in Refs [28, 29, 33, 34]. In this work, actual direct measurements of the entire particle burn-out times were made for three different types of torrefied biomass and these times were compared with burn-out times of coals of different ranks [34]. Hence, the appropriate size of torrefied biomass particles that can be burned in time-frames comparable to those of typical coal particle sizes (75-90 μm) burned in utility boilers was determined.

2. Methods / Experimental

Pulverized corn straw and rice husk were obtained from the Harbin Institute of Technology, China. Pulverized miscanthus and beechwood were supplied by Ruhr-University Bochum, Germany. Sugarcane bagasse was obtained from a bio-ethanol production plant in Brazil. DDGS (Distiller's Dried Grains with Soluble) was provided by a North American ethanol-producing company. Torrefaction of all samples was carried out in a laboratory-scale muffle furnace in nitrogen. The furnaces were charged with small amounts (a few grams) of millimeter-size particles of biomass and, subsequently, they were heated to 275°C with heating rates in the order of 10 °C/min. Upon reaching the final temperature, each sample was treated at constant conditions for 30 min. All fuels were dried, chopped in a household blender, and size classified by sieving to obtain size cuts of (75-90) μm , (180-212) μm and (212-350) μm . Optical microscope photographs of each biomass burned herein are shown in Fig. 1. Therein, it can be observed that most types of biomass, except DDGS, are needle-like and, thus, have high length-to-diameter aspect ratios. It is also noted that the torrefaction process reduced the particle aspect ratios [35]. The proximate analysis and the ultimate analysis of the fuels, both on a dry basis, are given in Table 1.

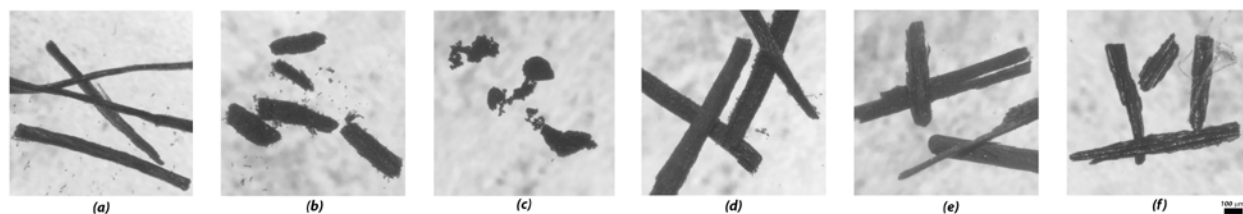


Figure 1: Images of biomass materials in size range of (180-212) μm (a) Bagasse, (b) Corn Straw, (c) DDGS, (d) Rice husk, (e) Miscanthus and (f) Beechwood.

Table 1. Chemical compositions of torrefied biomass

Rank / Fuel Source	Herbaceous biomass			Crop-derived wastes biomass		Woody biomass
	Corn Straw (Torrefied)	Miscanthus (Torrefied)	Sugarcane bagasse (Torrefied)	Corn DDGS (Torrefied)	Rice Husk (Torrefied)	Beechwood (Torrefied)
Proximate Analysis (dry basis)						
Volatile matter (%)	67.55	75.00	73.74	71.46	55.62	72.20
Fixed Carbon (%)	24.56	22.30	23.49	21.09	21.58	27.30
Ash (%)	7.89	2.70	2.71	7.45	22.80	0.50

The combustion of free-falling fuel particles took place in an electrically heated, laminar flow, vertical drop tube furnace at a gas temperature of $\sim 1350\text{K}$. The radiation cavity of this furnace (an ATS unit) was 25 cm long and was heated by hanging molybdenum disilicide elements. A vertical 7 cm i.d. transparent quartz tube was fitted in this furnace. Air was introduced into this tube through a water-cooled stainless steel injector and, also, through a flow straightener placed coaxially to the furnace injector, see Fig. 2. To enable single particle combustion, fuel particles were introduced through a port at the top of the injector by first placing them on the tip of a beveled needle syringe. Gentle taps on the needle allowed single particles to enter the injector and, subsequently, the furnace. Pyrometric observations of single particles were conducted from the top of the furnace injector, viewing downwards alongside the central axis of the furnace, Fig. 2, i.e., along with the particles' path line. Details of the pyrometer optics, electronics, calibration, and performance were given by Levendis et al. [36]. The voltage signals generated by the three detectors were amplified and then were processed by a microcomputer using the LabView software.

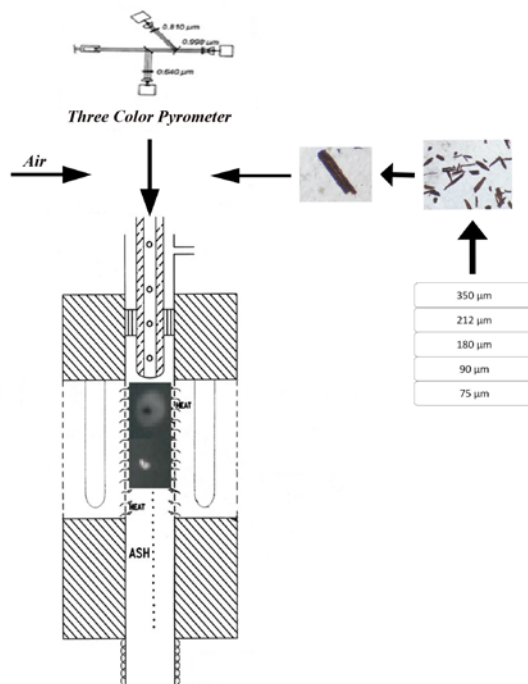


Figure 2: Schematic illustration of the drop tube furnace, particle introduction and combustion.

3. Results and Discussion

Figure 3a and 3b illustrate average combustion durations of volatiles and char particles of the three torrefied biomass types with nominal initial sizes in the ranges of (75-90) μm , (180-212) μm and (212-350) μm . In each range, the combustion histories of over 30 particles were recorded and average times were calculated. Shorter burn-out times were observed for the smaller size cut in volatile and char phases. DDGS experienced the longest combined burn-out times.

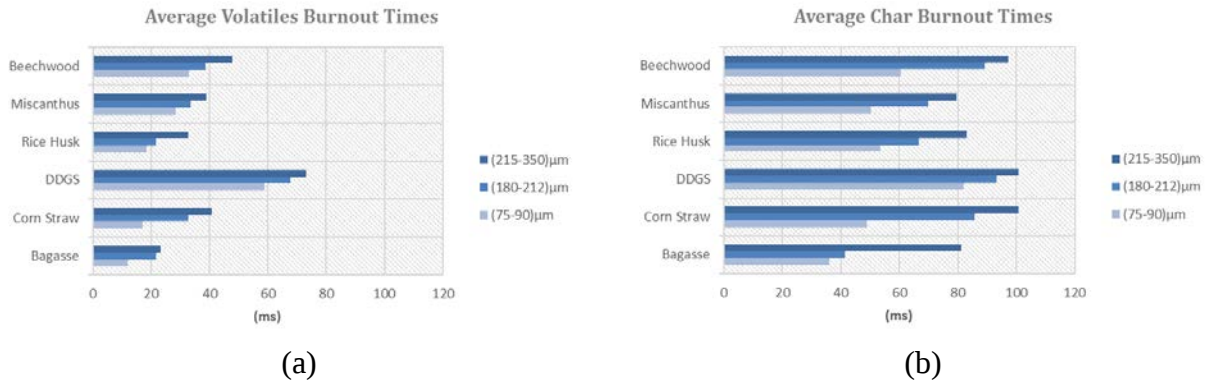


Figure. 3: Experimental data on combustion times of (a) volatile flames (b) chars of torrefied biomass particles in three ranges within 75-350 μm in a DTF at $T_g=1350$ K in air.

Based on experimental observations, particles of both (75-90) μm and (180-212) μm size cuts experienced complete burn-outs in the DTF, used in this study, without leaving any visible residues at its exit, where a white filter was placed. Therefore, the size cut of (180-212) μm for all torrefied biomass types has selected for further study. Cumulative (total) volatile and char burnout times for these particles are plotted in Figure 4; they span the time-frame of 60-160 s. Based on these results, appropriate torrefied biomass particle size would be suggested for co-firing with coal.

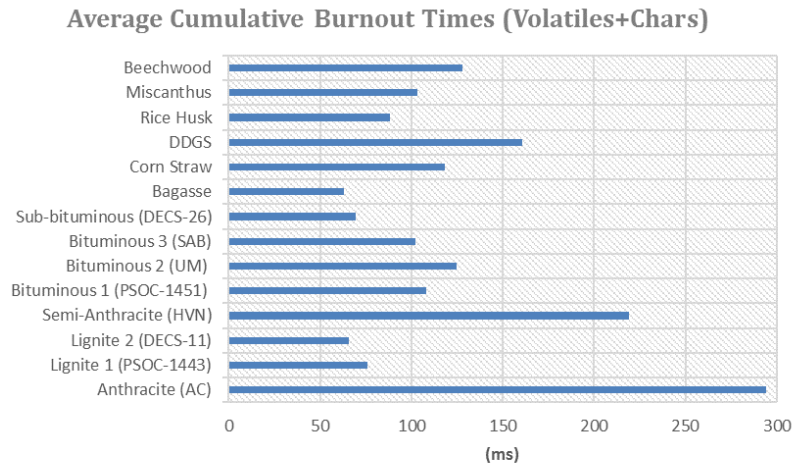


Figure 4: Comparison of cumulative combustion times of single particles of coal in the nominal size range of 75-90 μm and torrefied biomass of 180-212 μm burning in a DTF at 1350 K in air.

Previous studies in this laboratory burned single particles from five different ranks of coals [31, 37, 38] in the same DTF, in air, also at $T_g=1350$ K. Their size was 75-90 μm , which is a size

commonly burned in pulverized coal boilers. Burn-out times for lignite, sub-bituminous and bituminous coal particles were in the same range as those of the torrefied biomass particles mentioned above. Burnout times of anthracite and semi-Anthracite particles were longer, but those coals are not commonly burned.

4. Conclusions

The determination of particle size is essential to get the complete burnout time in co-firing coal with biomass. From the experimental results, particles with nominal sizes in the size cut of (180–212) μm or less burned completely in a DTF at $T_g=1350$ K. Particles in the size cut of (212–350) μm occasionally fell to the bottom of the furnace, partially burned. Accordingly, the maximum size of torrefied particles that could be reliably burned completely in this particular DTF at a gas temperature of 1350 K was in size range of (180–212) μm . After that, a comparison was made between burnout times of such biomass particles and pulverized coal and torrefied biomass. It was observed that combustion durations of the biomass match those of 75–90 μm pulverized coal particles, which is a size-cut typically used in pulverized fuel boilers.

5. References

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