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One way of representing the size and shape of biomass particles in combustion modeling

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ABSTRACT

This study aims to provide a geometrical description of biomass particles that can be used in combustion models. The particle size of wood and herbaceous biomass was compared using light microscope, 2D dynamic imaging, laser diffraction, sieve analysis and focused beam reflectance measurement. The results from light microscope and 2D dynamic imaging analysis were compared and it showed that the data on particle width, measured by these two techniques, were identical. Indeed, 2D dynamic imaging was found to be the most convenient particle characterization method, providing information on both the shape and the external surface area. Importantly, a way to quantify all three dimensions of biomass particles has been established. It was recommended to represent a biomass particle in combustion models as an infinite cylinder with the volume-to-surface ratio (V/A) measured using 2D dynamic imaging.

1. Introduction

Biomass firing is used for power generation and is considered an important step in the reduction of greenhouse gas emissions. Anthropogenic CO_2 emissions can be decreased by biomass co-firing due to the lower regeneration time of biomass compared to bituminous coal. Thus, CO_2 released with biofuels can be reconsumed faster by plants via photosynthesis than the time needed to regenerate coal. The milling process is a necessary step in suspension firing [1]. Size reduction improves fuel conversion processes because of the creation of larger reactive surface areas [2,3]. Biomass is, due to its fibrous structure, difficult to mill. Since the heating value of biomass is lower than coal, more biomass has to be used in order to achieve the same power output [4,5]. Increased energy input into biomass comminution affects the total efficiency of a power plant, and too large particles often cause problems with flame stability and burnout. Fuel characterization plays an important role in combustion modeling [6–11]. The surface area and volume of the particle are important parameters since they determine combustion rates and define residence time. Various biomass shapes result in different volume-to-surface area ratios, which are important parameters in describing heat and mass transfer processes. For a given volume, spheres represent the largest volume-to-surface area ratio of any shape, which makes an assumption of spherical particles in combustion modeling rather conservative. Particle size analysis methods that assume a constant (spherical) shape are inadequate for biomass characterization since irregularly shaped particles are most often present. Furthermore, a disagreement between particle size distributions obtained by many particle size measurement techniques has been observed [12]. Most particle analyzers use one geometrical parameter by assuming a spherical form. However, as the fuel particle shape becomes more complex, at least two parameters (width and length) are necessary to describe the particle size. Despite numerous studies on biomass particles [7,13,14,9–11], there is no consensus on how to represent a biomass particle in combustion models. The common way involves approximating of the particle shape to regular geometrical bodies (e.g. parallelepiped, cylinder, cubes, ellipsoids). In combustion models from Yang et al. [14] and Yin et al. [13], particles are represented by cylindrical and spherical shapes, whereas Thunman et al. [7] treat particles in a one-dimensional model as plates, cylinders, and spheres. The accuracy of particle models depends on both correct size distribution and

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Nomenclature

A	particle surface area [m^2]	Q_3	cumulative particle distribution, based on volume [%]
AR	aspect ratio	$SPHT$	circularity (sphericity)
b	particle width [m]	$Symm$	symmetry
c_p	specific heat capacity [J (kg K)$^{-1}$]	t	time [s]
d	diameter [m]	T	temperature [°C]
f	dimensionality factor	V	volume [m^3]
l	particle length [m]	w	size class weight
L	chord length [m]	$x_{c\,min}$	smallest maximal chord [m]
m	number of size classes	$x_{Ma\,min}$	Martin minimum diameter [m]
n	number of counts per size class	$x_{Fe\,max}$	Feret maximum diameter [m]
M_i	class midpoint [m]	ρ	density [kg m^{-3}]
N	class number	λ	thermal conductivity [W (m K)$^{-1}$]
P	perimeter of a particle projection [m]	e	effective
r	particle radius [m]	p	particle
r_1, r_2	distances from the area center to the particle edges [m]	s	solid phase
$\overline{q_3}$	histogram	$total$	total
q_3	frequency particle distribution, based on volume [% mm^{-1}]		

characterization of fuel inhomogeneity in terms of shape and structure. The objective of this study is twofold: (1) to provide a geometrical description of biomass particles that can be used in combustion model; (2) to make suggestions for the size and shape of biomass particles. In this work, the biomass particles' size and shape are characterized by using both 2D dynamic imaging analysis and microscopy. 2D dynamic imaging results are compared with particle size data obtained using focused beam reflectance measurement, laser diffraction, and sieving techniques.

2. Materials and methods

2.1. Raw material characterization

Table 1 lists samples which were used in the particle size and shape characterization study. Wheat straw and wood pellets represent the fuel types which are commonly used for suspension fired combustion with 100% biomass. It is a challenge to obtain high operational flexibility at power plants by application of a broad biofuel range. Therefore, poplar, which is among the fastest growing trees in the world, was selected for this study [15]. The moisture content and bulk density were measured using standard methods described in EN ISO 18134-1:2015 and EN ISO 17828:2015. The ash content was determined using a standard ash test at 550°C, according to the procedure described in EN ISO 18122:2015. The 8 mm pellets, without additives or binding agents, were produced in Latvia (LatGran). The pellets were transported to Avedøre power plant and comminuted in the horizontal Loesche roller mill. Pulverized wood was sampled from the pipeline (running to the burners) through a side opening by using a rotorprobe. Pellets consisted of 10% hardwood and 90% softwood, and were produced from 70% fine sawdust and 30% coarse sawdust. A larger percentage of softwood contains Scots pine (Pinus sylvestris), Norway spruce (Picea abies) and European aspen (Populus tremula), whereas a smaller percentage of hardwood consists of birch (Betula spp) and alder (Alnus spp), according to the feedstock classification described in EN ISO 17225-1. The age of the roundwood with bark used for making pellets ranged from 15 to 95 years. Poplar and wheat straw samples were milled in a ZM200 rotor mill (Retsch GmbH, Germany) whereas pellets were comminuted in a LM 23.2 D horizontal roller mill (Loesche GmbH, Germany). All samples were milled to 0.5 mm. Biomass samples were sieved to the 0.71–1 mm particle size fraction. Under fast heating conditions, which are relevant to suspension firing, biomass particles with mean diameters < 0.425 mm may be considered as thermally thin based on the previous modeling results [16], while the intra-particle heat conduction in larger particles plays a key role in biomass devolatilization. The previous results also indicated that the larger wood particles (0.85–1 mm) required more than 1 s in the wire-mesh and drop tube reactors at 1000°C for complete conversion [17]. Therefore, the large biomass particles were selected for the shape characterization study because particles of size > 0.7 mm can often cause problems with flame stability and burnout. Prior to the analysis, biomass samples were divided into equal (100 mg) fractions using a PT100 micro-riffler (Retsch GmbH, Germany).

2.2. Particle size and shape characterization

2D dynamic imaging analysis. The particle size and shape were measured using the CAMSIZER (Retsch GmbH, Germany), designed for the particle size range from 0.03 to 30 mm. Particle shadows (projected area) were captured by two cameras: a zoom–camera, designed for the analysis of smaller particles, and a basic–camera

Table 1
Samples specification. The bulk density, ash (% dry basis) and moisture (% as received) content were determined for poplar, wheat straw and pulverized wood pellets. Samples were comminuted in the rotor- and Loesche roller mills. Prior to particle size and shape analysis, samples were collected using a rotorprobe and a micro-riffler.

Identifier	Samples		
	Poplar	Pulverized wood pellets	Wheat straw
Mill type	Rotor mill	Loesche roller mill	Rotor mill
Sampling method	Micro-riffler	Rotorprobe	Micro-riffler
Bulk density, g cm^{-3}	1.4	1.3	1.4
Ash, % dry basis	1.3	0.5	4.1
Moisture, % as received	7.9	7.8	10