Particulate matter formation during softwood combustion in a drop tube furnace: a preliminary study

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Introduction

The demand for energy is growing globally. For this reason, new and reasonable alternatives are sought for their satisfaction. Biomass is considered a good alternative of the fossil fuels. Moreover, biomass is the largest renewable energy source. It is characterized by its huge availability and low net emissions of CO_2 [1]. Other advantage of this energy renewable resource is that it can be converted into liquid or gas fuels (biofuels) [2, 3, 4]. The food and furniture industries and the agriculture produce large quantities of biomass residues every year [5], and those residues are very promising regarding their energy potential and impact on the environment. These biomasses based fuels may be used in both residential heating and industrial energy systems [6, 7, 8]. It is thus important to study the biomass combustion and the related environmentally harmful by-products.
The aim of this work is to investigate particulate matter (PM) formation during the combustion of softwood in a drop tube furnace. This biomass residue [9] is currently produced and distributed in Bulgarian in form of pellets. Table 1 presents the chemical characteristics of the softwood used in this study.

Table 1. Chemical characteristics of the softwood.

Parameter	Value	Parameter	Value
Proximate analysis (wt.%, as analyzed)		Ash analysis (wt.%, dry basis)	
Moisture	6.89	SiO_2	2.74
Ash	0.65	Al_2O_3	5.37
Volatiles	78.77	Fe_2O_3	1.72
Fixed carbon	13.64	MnO	1.60
Ultimate analysis (wt.%, as received)		CaO	33.29
Carbon	47.77	MgO	7.44
Hydrogen	6.48	BaO	0.18
Nitrogen	0.1435	Na_2O	0.98
Sulfur	0.02	K_2O	15.76
Oxygen	38.05	Cr_2O_3	0.01
Net calorific value (MJ/kg, as received)	17.38	TiO_2	0.32
		ZnO	0.93
		CuO	0.03
		SrO	0.01
		P_2O_5	5.78

Materials and Methods

The experiments were carried out in a drop tube furnace (DTF) that allows conducting experiments under well controlled conditions. In brief, the combustion chamber is a cylindrical electrically heated ceramic tube, with a total length of 1.75 m and an inner diameter of 35 mm. The furnace wall temperatures are continuously monitored by three type-K thermocouples uniformly distributed along the combustion chamber. A water-cooled injector, placed at the top of the DTF, is used to feed the biomass residues and the air to the combustion chamber. A twin-screw volumetric feeder transfers the pulverized solid fuels to an ejector system from

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which the particles are air-transported to the water-cooled injector. A detailed description of the DTF may be found elsewhere [10, 11, 12].
In this study, the softwood pellets were crushed and sieved to particle sizes between 150 to 200 µm. Experiments were performed at two DTF wall temperatures (1000 and 1100 ºC) and an inlet air temperature of 25 ºC. The pulverized softwood feed rate was always around 23 g/h and the primary + secondary air flow rate was 0.0037 Nm^3/min.
PM emissions were made with the aid of an in-house made cyclone and a Dekati quartz-microfiber filter, mounted in series at the exit of the DTF. In addition, flue gas chemical composition was accomplished with the aid of conventional analyzers placed after the Dekati filter. Subsequently, selected samples were analyzed using a scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDS) detector.

Preliminary results

Table 2 shows the combustion products composition from the combustion of softwood at two DTF wall temperatures, and Figures 1 and 2 show typical SEM images of PM samples collected in the in-house made cyclone and in the quartz-microfiber filter. As expected, the size of the PM collected in the cyclone is much larger than that of the PM collected in the filter. Moreover, chemical analysis made using the EDS revealed that the carbon present in the PM collected in the cyclone is marginal, but that present in the PM collected in the filter is significant. This methodology allows not only separating larger from smaller PM, but also identifying and quantifying the amounts of soot present in the flue gas of the DTF.
Currently, work is being carried out for various biomass residues and DTF operating conditions in order to study the formation of PM, including soot, during their combustion under well controlled conditions.

Table 2. Combustion products composition.

DTF wall temperature, ºC	Combustion products		
	O_2 (vol.%)	CO (vol. ppm)	PM (mg/Nm^3)
1000	19.4	117	87
1100	19.1	227	85

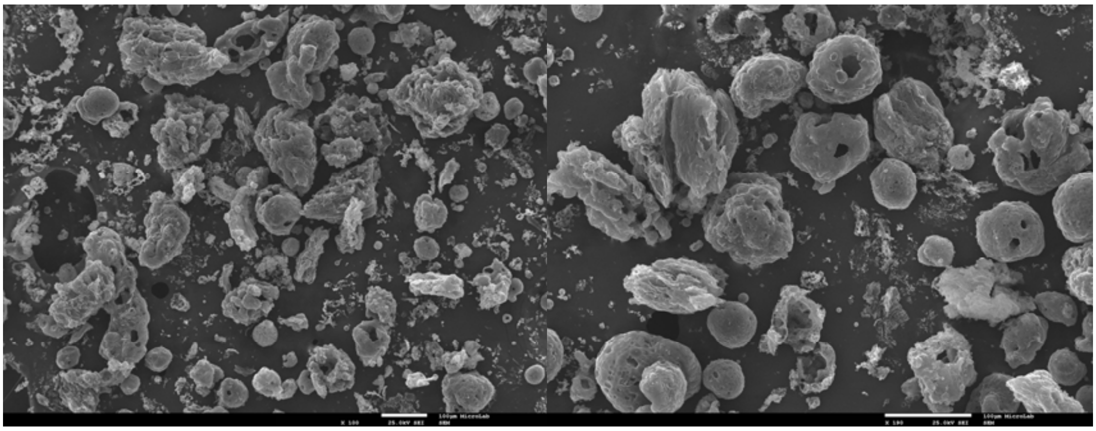

Figure 1. Typical SEM images of selected PM collected in the in-house made cyclone.

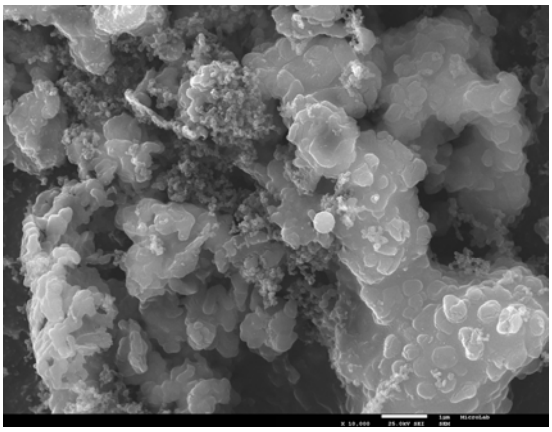

Figure 2. Typical SEM image of selected PM collected in the quartz-microfiber filter.

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References

[1] D. Koruba, J. Piotrowski, J. Latosinska, Biomass – alternative renewable energy source to the fossil fuels, E3S Web of Conference 14, 02015 (2017), Energy and Fuels 2016.
[2] http://eco-globe.com/biomass-energy-alternative-fossil-fuels/
[3] V. Kirubakaran, V. Sivaramakrishnan, R. Nalini, T. Sekar, M. Premalatha, P. Subramanian, A review on gasification of biomass, Renewable and Sustainable Energy Reviews 13 (2009) 179-186.
[4] http://www.volund.dk/Biomass_energy/Technologies/Gasification_of_biomass
[5] E. Vandamme, T. Anthonis, S. Dobbelaere, Industrial Biomass: Source of Chemicals, Materials, and Energy!, Royal Belgian Academy of Science, ISBN 9789065690777, February 2011.
[6] https://www.renewableenergyhub.co.uk/biomass-boiler-information/commercial-and-industrial-biomass.html
[7] https://www.sigmathermal.com/wood-biomass-energy/
[8] N. S. Rathore, N. L. Panwar, Industrial Application of Biomass Based Gasification System, World Applied Sciences Journal 5 (4): 406-409, 2008.
[9] Axel Trade 2009 LTD, Samokov, Bulgaria.
[10] G. Wang, R. B. Silva, J. L. T. Azevedo, S. Martins-Dias, M. Costa, Evaluation of the combustion behaviour and ash characteristics of biomass waste derived fuels, pine and coal in a drop tube furnace, Fuel 117 (2014) 809-824.
[11] T. Botelho, M. Costa, M. Wilk, A. Magdziarz, Evaluation of the combustion characteristics of raw and torrefied grape pomace in a thermogravimetric analyzer and in a drop tube furnace, Fuel 212 (2018) 95-100.
[12] V. Branco, M. Costa, Effect of particle size on the burnout and emissions of particulate matter from the combustion of pulverized agricultural residues in a drop tube furnace, Energy Conversion and Management 149 (2017) 774-780.