Combustion characteristics of solid biofuels

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General aspects

The industrial and economic growth requires energy supply at reasonable prices and availability. Combustion of fossil fuels is still cost-effective and world's primary source of energy and it will perhaps continue to be for the next decades. Thus, the influence of the secondary combustion products on the environment, climate and the quality of life of the living organisms and the humans as well as the speed of the fuels' consumption put huge expectations on the relevant research areas. It requires development of easy accessible alternative fuels that can be utilized using low-emission combustion technologies. At the same time, the contemporary technologies demand development and implementation of innovations and improvements of the energy-efficiency and fuel utilization processes.
Biomass is considered as the largest and most sustainable energy resource due to its huge availability and low net CO_2 emissions [1 and 2]. Solid biofuel as renewable energy source are currently being produced from huge variety of rest biomass matter. It is known to be suitable for producing energy of all type: electricity, heat and transportation [2]. Last decades the use of solid biofuels for residence heating has been largely promoted within the European Union. However, typical residential heating facilities, producing up to 20 – 25 kW, are available in different modifications (household heating boilers; cookers; simple stoves; open fire etc). According to the recent EU legislation e.g. [3-8] the certified facilities should meet particular environmental standards. However, it is observed [2, 9-11] that even the so called state-of the-art equipment still emits, directly into the atmosphere, considerable amount of air pollutants like: *unburned volatile organic matter (UVOM)*, NO_X, *particulate matter* (e.g. PM_{10} and $PM_{2.5}$) etc. Thus many EU countries still show significant exceedance of the prescribed EU limits for these pollutants.
There is still a lack of detailed understanding of the physical and chemical transformations, occurring in combustion/pyrolysis of fuels that are produced from different type of rest matter. For pragmatic reasons, most of the numerical calculations are carried out with reduced mechanisms [12-14]. Despite the great effort [15], there is still a lot to be done for the detailed chemical-kinetic modeling of numerous alternative solid fuels. This knowledge is of crucial importance for the development of large-scale processes for biomass utilization and emission reduction and significant research is needed.
The present work is focused on investigating the potential of several alternative fuels for „cleaner" combustion and efficient fuel utilization at minimum exhaust emissions. The attention is drawn on alternative fuels that are currently being produced in the country (e.g. *solid biofuels*, *RDF*, *landfill gas* and others), but their particular properties are still not fully explored.
This study aims at developing a complex methodological approach focused on the following aspects:

1) characterization of the main fuel-specific chemical and physical parameters;
2) investigation of the key chemical-kinetic parameters, characterizing the process of fuel combustion/pyrolysis as well as pollution formation;
3) observation of the fuel's potential for cleaner and more efficient utilization.

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Applied methodology and preliminary results

The currently analyzed samples of solid biofuels are collected and provided by the producer [16], according to the reference standards BDS EN 14780 and ISO 18135. Some fuel properties are investigated by the producer, while others are being obtained at Technical University of Sofia (TU-Sofia) and/or external laboratories. Due to privacy reasons the data, obtained in external for TU-Sofia laboratories cannot be presented in this abstract.
Proximate and *ultimate analyses* are being carried out of test samples, prepared in accordance with ISO 16559 and ISO 14780. The fuel parameters under investigation are those, relevant to the purposes of this study (see Table 1).

Table 1. Key parameters of solid biofuels

		Chemical characterization	
№	**Fuel parameter**	**Solid biofuels[1, 2]**	**Reference standards**
1	*Calorific value*	●; X	BDS EN 14918:2010
2	*Content of volatiles*	●	BDS EN ISO 18123:2015
3	*Ashes*	●; X	BDS EN ISO 18122:2015
4	*Moisture*	●; X	BDS EN ISO 18134-3:2015
5	*Carbon (C)*	●	BDS EN ISO 16948:2015
6	*Hydrogen (H)*	●	
7	*Nitrogen (N)*	●	
8	*Sulfur (S)*	●	BDS EN ISO 16994:2016
9	*Chlorine (Cl)*	●	
10	*Fluorine (F)*		
11	*Bromine (Br)*		
12	*Major elements*	●	BDS EN ISO 16967:2015
13	*Traces of elements*		BDS EN ISO 16968:2015
		Physical parameters	
14	*Bulk density*	●; X	BDS EN ISO 17828:2016

[1] Parameters for which the analyses were completed at CTT for the available fuels (marked with X).
[2] Parameters that are currently being examined at CTT and external laboratories (marked with ●).

The list of fuels is expected to be extended, with respect to their provision by the contacted producers. The examined solid biofuels are as follows: two types of *softwood pellets* and *chips*, together with a representative sample of *softwood bark*. The investigated blends of pellets and chips are produced from 100 % softwood without chemical impurities. The producer certifies that these fuels comply with the requirements of the standard BDS EN 14961-2:2011, Class A1.
Concerning the samples of softwood bark the aim is to establish the optimal proportion of this type of rest matter to be used as feedstock for solid biofuel production. This and other types of wood rest matter need to be utilized in an adequate and reasonable manner, at minimum negative influence on the fuel specific parameters.
The *low calorific value (LCV)* of the fuel was calculated in its operational mass (Q_i^r). The calculations are based on reference default values for the elemental composition of the investigated solid biofuel [17]. Two different empirical methods were implemented:

- the so-called *Mendeleev's equation*:

$$Q_i^r = 339.39C^r + 1257H^r + 108.94\,(S^r - O^r) - 25.14\,(9\,H^r + W_t^r), \frac{kJ}{kg}, \qquad \text{eq.1}$$

- and the *Knorre's equation* (eq. 2):

$$Q_i^r = 138.27\left(\frac{8}{3}C^r + 8H^r - O^r\right)\cdot m - 25.14\,(9\,H^r + W_t^r), \frac{kJ}{kg}. \qquad \text{eq. 2}$$

Here C, H, S, O and W is the content of carbon, hydrogen and oxygen in operational mass of the fuel (%). The coefficient m in eq.2 is dimensionless and for wood equals to 1.04 [18]. This type of calculations is used in thermal power plant engineering and connects the net calorific value and the elemental composition of fuel (see e.g. [18-20]). The results were compared with those, experimentally obtained in external laboratories, applying BDS EN 14918:2010. The difference between the calculated and the experimentally measured values of *LCV* for bright and dark pellets is *below 4 and 2 %* respectively for both empirical methods (eq.1 and 2).

Furthermore, the *total* and *analytical moisture* (on operating fuel mass, W_t^r *and* W^a), and the *ash content* (on dry fuel, A^d) were measured. The *bulk density* (BD^r) is the only physical parameter currently measured at TU-Sofia as the fuel sample was received. The applied test methods comply with the standard methods, described in Table 1.

The analysis of the *content of volatiles* is in process together with the rest of the parameters, described in Table 1. The preliminary results of the proximate analyses, BD and calculated *LCV* that were currently carried out at CEE, TU-Sofia, are listed in Table 2. The relative uncertainty is derived by the ratio of the accuracy of the analytical balance and the derived mass of the test sample.

Table 2. Initial results of proximate analyses of solid biofuels

Measured value ± relative uncertainty, %							
Parameter		***Bright pellets***	***Dark pellets***	***Bright chips***	***Dark chips***	***Bark***	***Exp. conditions***
Analytical moisture	W^a	2.19±0.46	1.52±0.66	1.99±0.50	2.25±0.44	3.78±0.26	40 ºC, atm. p
Total moisture	W_t^r	7.97±0.13	7.67±0.13	8.34±0.12	8.32±0.12	10.95±0.17	105 ºC, atm. p
Ash (on dry fuel)	A^d	0.32±3.41	0.59±1.83	0.38±2.91	0.38±2.84	3.27± 0.34	550 ºC, atm. p
Physical parameter in kg/ m³							
Bulk density	*BD*	614	653	152	154	66	22 ºC, atm. p
Calculated LCV in kJ/kg							
LCV (eq.1)	Q_i^r	17127.65	18127.65	17012.16	17015.77	15970.41	NA
LCV (eq.2)	Q_i^r	17129.90	17129.90	17014.29	17018.23	15972.52	NA

Prospective

Fuel-specific chemical and physical characteristics of numerous alternative fuels have been widely studied during the last decades. However, some key chemical kinetics parameters (e.g. the fuel autoignition, the rate of fuel's conversion etc.) play significant role in controlling the combustion and the emission's reduction processes. Recent EU regulations e.g. [7] require detailed research. This part of the work is planned to be carried out in terms of interdisciplinary cooperation with Action's partner institutions. Currently, there is an ongoing discussion with TU Vienna.

The experimentally obtained results shall be used for modeling the combustion/pyrolysis of the investigated blends of fuel. The goal is to observe their potential for "cleaner" and efficient utilization.

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