

## SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

The STSM applicant submits this report for approval to the STSM coordinator

**Action number: CM 1404 SMARTCATs**

**STSM title: Experimental investigation of kinetic parameters characterizing the combustion of solid biofuels**

**STSM start and end date: 26/03/2018 to 06/04/2018**

**Grantee name: Tsvetelina Stanimirova Petrova**

### PURPOSE OF THE STSM

Biomass is considered as good alternative of the fossil fuels. Moreover, the biomass is the largest renewable energy source. It is characterized with huge availability and low emissions of CO<sub>2</sub> [1]. Other advantage of this energy source is that it can be converted into liquid or gas, to be formed to the pellets/chips or directly burned [2, 3, 4]. The food and furniture industry, tourism and agriculture produce significant quantities of rest biomass every year [5].

Biomass based fuels are used in both residential heating and industrial energy systems [6, 7, 8]. Therefore, it is important to study secondary combustion by-products.

The aim of this STSM was to investigate specific characteristics of biomass based fuel, which is currently produced and distributed at the Bulgarian fuel market. For that purpose, softwood residues were pelletized [9] and investigated according to the work plan. In the frame of this mission the emissions of several specific air pollutants were measured during biomass combustion: soot, char, fly ash, tar and various gaseous products (O<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub>, HC).

This Short Term Scientific Mission is good opportunity to set up a collaboration between our institution in the field of renewable energy source within the SMARTCATs COST Action CM 1404. The global objective is to further extend this particular research for detailed investigations and characterization of the combustion/pyrolysis/gasification of different types of biomass matter.

In particular, the STSM allows to extend my knowledge and to gain experience in an area which is very promising regarding to its energy potential and impact on the environment.

### DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

The research group of prof. Mario Costa at the Instituto Superior Técnico, Lisboa has significant expertise in this field of biomass combustion and utilisation. The laboratory has proper equipment based on drop tube

furnace (DTF) that allows the performance of the planned experiments. In this installation the combustion process can be conducted at well controlled conditions, covering wide temperature range.

Prior to this STSM proximate and ultimate analyses of the studied fuel were performed at Technical University of Sofia. The results are shown on Table 1 and 2.

Table 1. Proximate analysis

Parameter measured	Dark pellets (with softwood bark)
Moisture ( $W^a$ ), %	6.89
Ashes ( $A^a$ ), %	0.65
Volatile organic compounds ( $V^a$ ), %	78.77
Fixed carbon, %	13.64

Table 2. Ultimate analysis

Fuel	Parameter measured	Unit of measure	Mean value	Range
Dark pellets	w-% C	%	47.77	47.75 – 47.79
	w-% H	%	6.48	6.40 – 6.56
	w-% N	%	0.1435	0.136 – 0.151
	w-% S	%	0.02	NA
	w-% O <sub>2</sub>	%	45.59	
	Net calorific value $Q_i^d$ - dry mass	MJ/kg	19.00	18.94 – 19.06
	Net calorific value $Q_i^r$ - as received	MJ/kg	17.38	17.33 – 17.43

### Experimental equipment

The current experiment was conducted using the equipment (drop tube furnace - DTF), assembled and tested in the work group of prof. Mario Costa, Instituto Tecnico Superior, Lisboa, Portugal. This equipment allows conducting the experiments at well controlled conditions. The DTF operates at maximum temperature of 1300°C. Three thermocouples, type K, are distributed uniformly along the combustion chamber. The combustion chamber is cylindrical ceramic tube with inner diameter 35 mm and length 1.75 mm. Detailed description of the DTF is presented in [10, 11, 12]. Photo of the installation is shown on Fig.1.

The investigation was performed at three different temperatures in DTF: 900°C, 1000°C and 1100°C. Every test lasts about 6 hours. The DTF works with pulverized fuel. Therefore, the softwood pellets were grinded and sieved to the size between 150 to 200µm. The fuel feeding rate was 23 g/h. The feeding machine is shown on Fig.2. The primary air, with velocity 4.3 l/min, was used as transport agent. The secondary air flow was 1.2 l/min. To ensure the proper conditions of the experiments, the primary and secondary air flow were

continuously controlled during the tests. A pump drives the exhausted gases from the total filter to the gas analyzer. Its suction flow rate was 10 l/min.

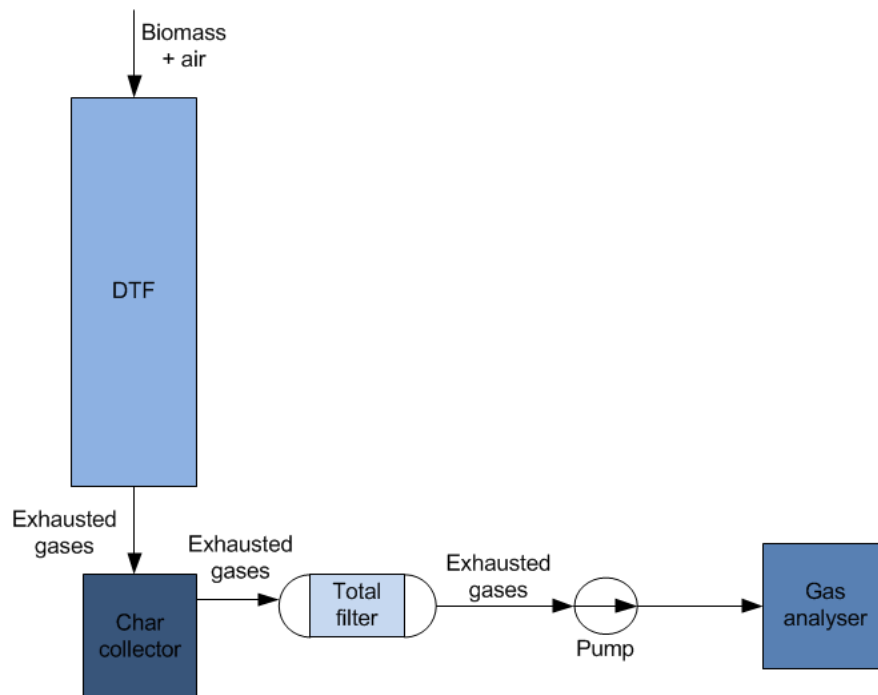


Fig.1 The installation



Fig.2 The feeding machine

The applied experimental procedure can be expressed in terms of the following simplified schematic interpretation (see Scheme 1).



Scheme 1. Experimental procedure

The exhausted gases initially pass through the char collector (Fig.3). In this part of the installation the char is separated from the total flow of the exhaust gases. The next step envisages that the soot, PMs, tar and other species will be collected in the total filter. The total filter is quartz-microfiber disc with diameter 47 mm. It is placed in the total filter holder, shown on Fig.4. The gas analyser was connected after the total filter. In this way, it was possible to measure the following gas phase products: O<sub>2</sub>, CO, CO<sub>2</sub> and NO<sub>x</sub>.



Fig. 3 The char collector and the total filter



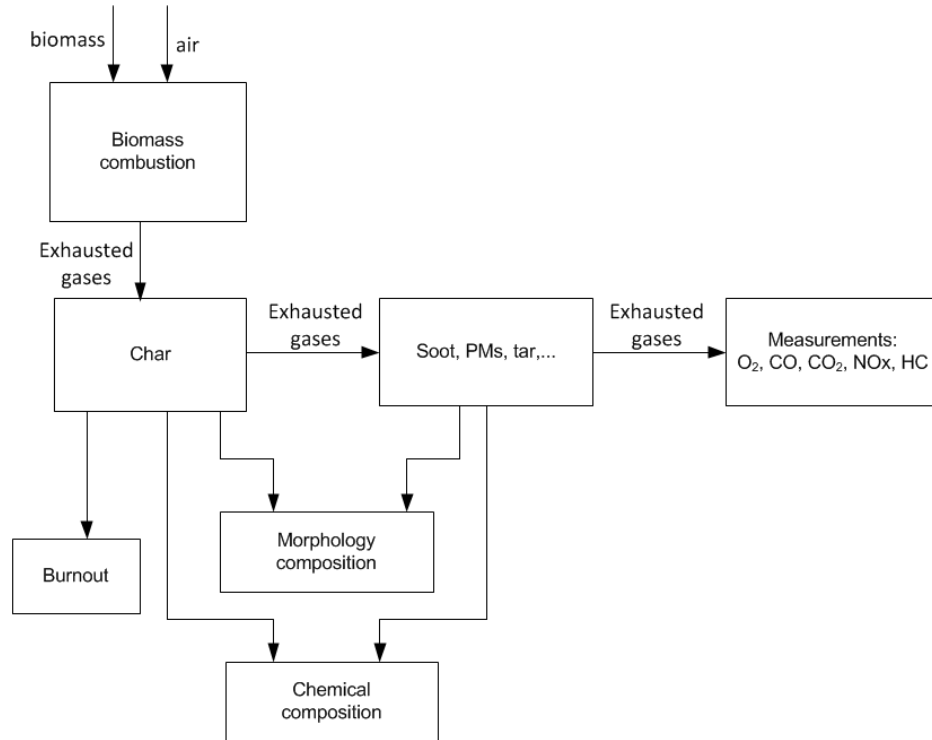
Fig. 4 The total filter holder

A morphology and chemical composition of the collected char and soot were done by Scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDS) detector.

Both samples, collected at the char collector and total filter were additionally examined via burnout.

#### DESCRIPTION OF THE MAIN RESULTS OBTAINED

Scheme 2 presents general interpretation of the implemented work plan during this STSM.



Scheme 2. Experiments performed according to the work plan

After every experiment, the collected amounts of the char and the soot were weighted and stored for further investigations. The received samples at three different temperatures are given in Table 3.

Table 3. Mass of the collected samples

Temperature in DTF	900°C*	1000°C	1100°C
Mass of the char (g)	0.06375	0.18759	0.18567
Mass of the soot (g)	0.06215	0.13692	0.13154

\*Results obtained at 900°C need to be repeated



Fig. 5 Char collector after an experiment



Fig. 6 Total filter after an experiment

Char and soot were obtained in terms of their mass rate. Thus, the samples in this experiment were collected at three different temperatures. The results are presented on Fig. 7 and 8. As expected, the results obtained at 1100°C show slightly lower mass rate than those obtained at 1000°C. However, surprisingly the results obtained at 900°C show opposite trend. Revision of the implemented experimental procedure suggests that this result is assumed to be due to incorrect test sample preparation. Therefore, the experiment at this experiment test will be repeated.

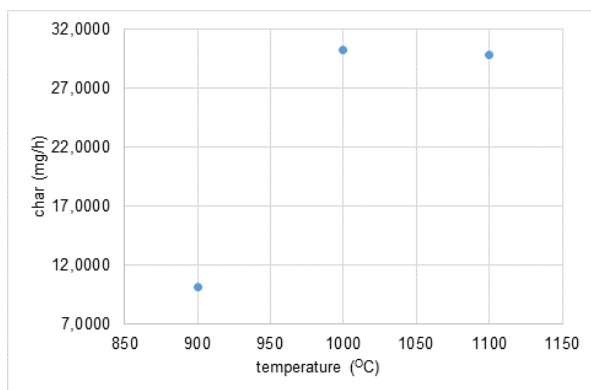


Fig. 7 Char at three different temperatures

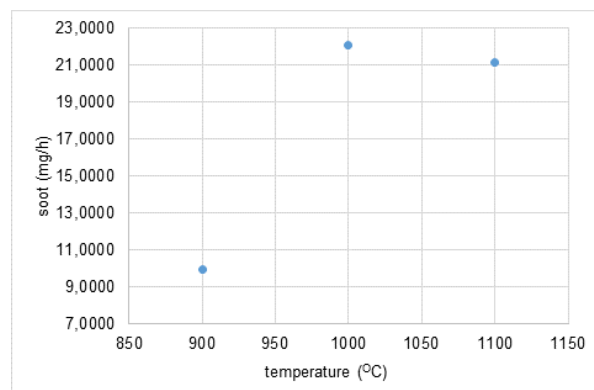


Fig. 8 Soot at three different temperatures

The main gas phase products obtained simultaneously with the char and the soot are given in Table 4.

Table 4. Gas analyser measurements

Time duration (h)	DTF wall temperature (°C)	Biomass feed rate (g/h)	Average amount of				
			O <sub>2</sub> (%)	CO (ppm)	CO <sub>2</sub> (%)	NO <sub>x</sub> (ppm)	HC (ppm)
6:15	900	23	19.9952	4.1500	0.1368	0.42	0.42
6:12	1000	23	19.4132	117.3235	0.7656	6.62	0
6:13	1100	23	19.1583	227.2	0.9643	3.09	0

Morphology analyses was carried out of the collected samples of char. Fig. 9 and 10 show SEM images from char samples taken at different temperatures (1000°C and 1100°C). Obviously the collected material consists not only of char but also tar was observed. It is assumed that the tar is formed due to eventual condensation that is occurring during the sampling process. It is expected that this process is caused by the lower temperature in the char collector.



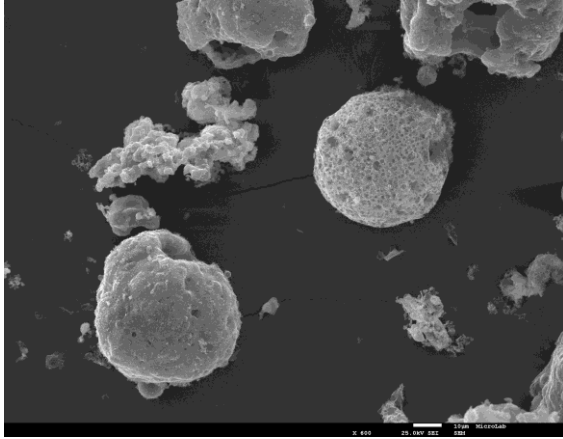


Fig.9 Char at 1000°C

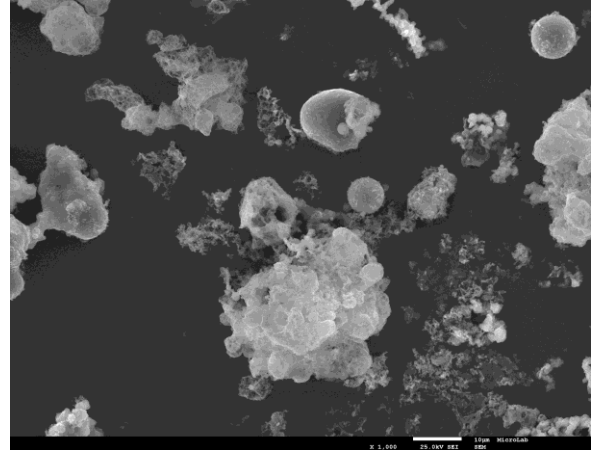


Fig.10 Char at 1100°C

Morphology analyses was done also for the soot collected from the total filter during the experiments. The results obtained with SEM are shown on Fig. 11 and Fig. 12 for the soot samples collected at two different temperatures. The images show two general type of structures - particulate matter and tar.

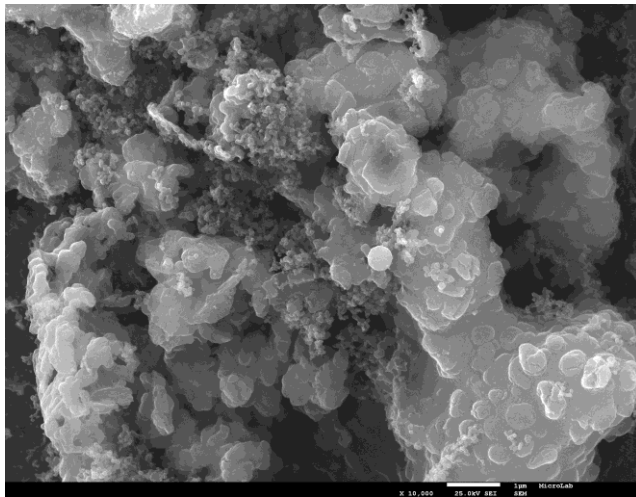


Fig.11 Soot at 1000°C

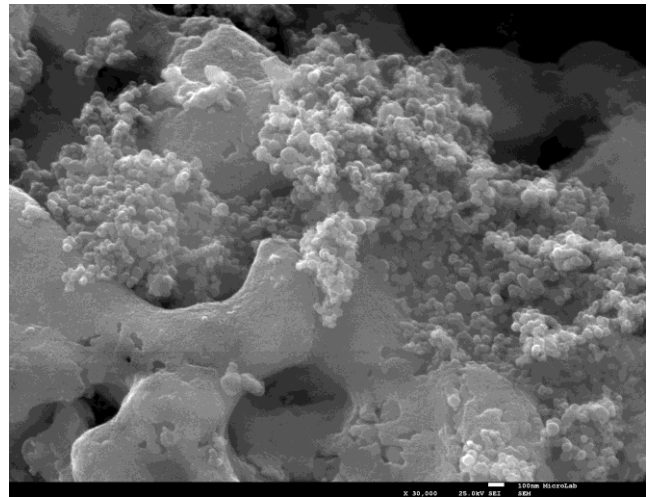


Fig.12 Soot at 1100°C

Chemical composition analysis was carried out for the samples of char and soot described above. Fig. 13 is an example of the results for the chemical composition of the char collected at 1100°C. The results were obtained by the SEM and are herein presented in weight %: C - 80.91, O<sub>2</sub> - 13.27, Mg - 0.59, Si - 0.25, S - 0.66, K - 1.18, Ca - 3.14.

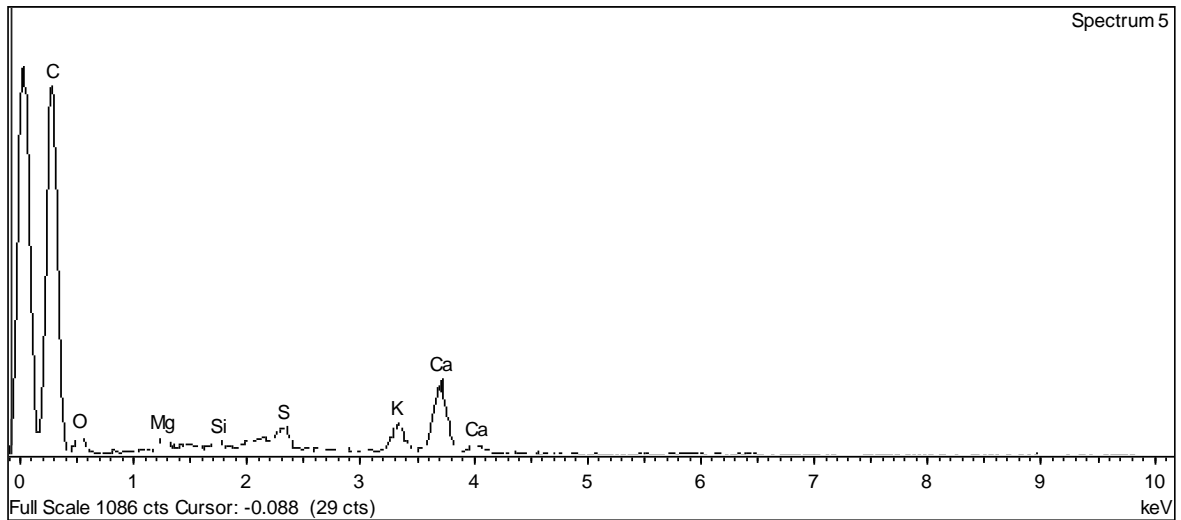


Fig.13 SEM results for a char collected at 1100°C

Furthermore, detailed analysis of the chemical composition was done by energy dispersive X-ray spectroscopy detector for the samples of char and soot. Fig. 14 and 15 demonstrate the relative distribution of the main elements in the samples of char and soot, obtained during the biomass combustion at 1100°C. The results show that the predominant elements are carbon, oxygen and calcium.

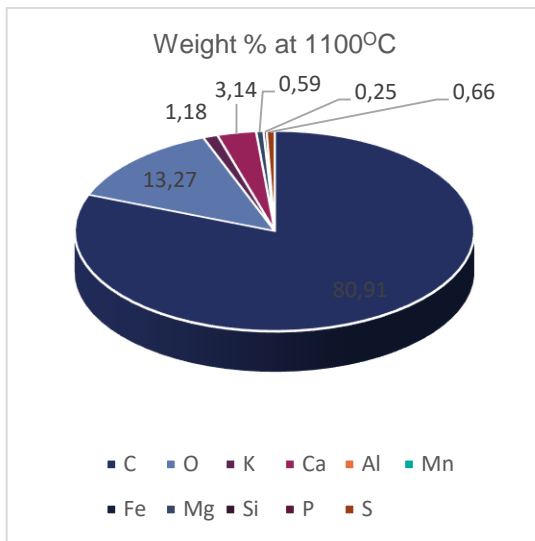


Fig.14 Chemical composition of the char at 1100°C

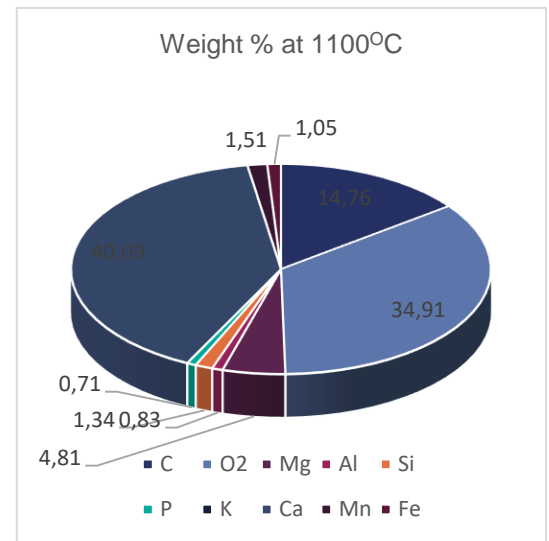


Fig.15 Chemical composition of the soot at 1100°C

In addition, the collected test samples from the total filter were subsequently analyzed for the ash content following the procedures used for the proximate analysis of solid fuels.

The results are summarised in Table 5. As expected, higher combustion temperature led to smaller amount of ash and larger amount of soot, respectively (see the results for the soot test samples). However, the results for the char did not follow the same trend.



Table 5. Total ash content after burnout

Temperature (°C)	Char			Soot		
	900	1000	1100	900	1000	1100
Initial (g)	14.45634	15.39537	14.73784	14.42493	14.26727	15.51291
Final (g)	14.45068	15.37793	14.72977	14.42296	14.2563	14.49111
Ash (%)	99.96085	99.88672	99.94524	99.98634	99.92311	93.41323

## FUTURE COLLABORATIONS

The STSM was focused on the combustion of alternative bio-fuels that are usually characterized with low level of the air pollutants. But there is plenty of biomass that have been seen as such recently. However, their chemical-kinetic parameters are not fully understood in terms of the mechanisms of soot, tar and char formation.

During this STSM the work plan was successfully implemented despite the limited time constrains. There is ongoing work on the ash analysis. The results will be available within few weeks.

The outcome of this collaboration can be summarised as follows:

This work aimed at laying down the foundations of long term collaboration between the two institutions – Technical University of Sofia (Bulgaria) and Instituto Tecnico Superior, Lisboa (Portugal) in the field of renewable energy source investigation. Based on the received results, further investigation was planned using different types of biomass matter, mainly agriculture residue (e.g. coffee husk, sunflower pellets and cherry stones). These residues from the food industry are received in big amount every year and they have big energy potential. Both research teams, consider the good option for further investigations in the field of biomass combustion and air pollutants. This future study will be in line with the goals of WG2 - Chemistry for control of by-products in Smart Energy Carrier conversion. It would be very useful also to measure the PMs for each fuel.

Currently, there is an ongoing discussion about future possibility of:

- modeling of the biomass combustion process which was studied in the frame of this STSM;
- new investigations on combustion and/or gasification of the above mentioned biomass.

## 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, DOI: 10.1051/e3sconf/20171402015

[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](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, ISSN 1818-4952

[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] Vera 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