SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: CM 1404 SMARTCATs
STSM title: Biomass gasification in a Drop Tube Furnace
STSM start and end date: 24/03/2019 to 06/04/2019
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PURPOSE OF THE STSM:

The biomass residues are received every year in big amount because of agriculture and food industry. Bulgaria has traditions in the cultivation of agricultural produce, which is used for human and animals food, as well as biofuel raw materials [1]. Nowadays, the use of this biomass residues is rising and this process is encouraged by Ministry of Energy [2]. The main opportunities for utilization are combustion/pyrolysis or gasification. In Bulgaria the complete characterization of this relatively new alternative fuels has not been studied yet, unlike the traditionally used coal or wood. It is very important to know the by-products obtained at different conditions, i.e. to find optimal utilization way.
The main goal of this STSM is to study the products from biomass gasification (sunflower husks and colza) and its by- products accompanying the process.
In addition to this, the following biomasses: colza, sunflower husks, softwood with a bark, grape pomace peach stones and cherry stones were carbonized in an inert atmosphere.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

This work is still in progress and only some preliminary results during the STSM are presented. Final and detailed results will be summarized in comming publication.
Six types of biomass were investigated within the STSM period. Their thermo – chemical characteristics are summarized in Table 1.

Table 1. Chemical characteristics of investigated biomass

Parameter	Type of biomass					
	Colza	**Cherry stones**	**Peach stones***	**Grape pomace***	**Softwood with a bark**	**Sunflower husks**
Proximate analyses						
Moisture (Wa), %	9.86	9.98	8.12		6.89	7.52
Ashes (Aa), %	4.59	1.13	1.16		0.65	2.88
Volatile organic compounds (Va), %	78.53	81.12	78.62		78.77	76.93
Fixed carbon, %	4.59	7.76	12.10		13.69	12.67
Ultimate analyses						
w-% C	49.64	54.29	49.90		47.77	54.04
w-% H	8.24	7.90	6.28		6.48	8.45

w-% N	2.67	4.40	1.01		0.14	3.00
w-% S	<0.05	<0.05	<0.05		<0.02	<0.05
w-% Cl	<0.10	<0.10	<0.10		na	<0.10
w-% O2	24.85	22.15	33.38		38.05	23.96
Ash analysis (wt %, dry basis)						
SiO_2	2.47	3.58			2.74	1.01
Al_2O_3	0.97	0.43			5.37	0.15
Fe_2O_3	0.25	0.43			1.72	0.92
MnO	0.06	0.05			1.60	0.02
CaO	29.07	13.00			33.29	20.44
MgO	9.36	10.57			7.44	11.95
BaO	0.05	0.01			0.18	0.01
Na_2O	2.48	0.8			0.98	0.57
K_2O	17.80	24.16			15.76	28.78
Cr_2O_3	<0.01	<0.01			<0.01	0.07
TiO_2	0.08	0.14			0.32	0.14
ZnO	0.01	0.08			0.93	0.06
CuO	0.01	0.07			0.03	0.03
SrO	0.01	0.03			0.01	0.02
P_2O_5	11.67	26.65			5.78	5.88
Moisture at 105ºC	0.23	5.60			0.61	4.40
Losses on ignition (LOI)	25.68	19.74			23.82	29.51
High heating value, (MJ/kg, dry basis)						
HHV	18.69	23.62	22.36		19.00	20.28

* The analysis has been performed

Experimental equipment

I. Familiarization with the experimental equipment

I.1. Gasification

I got acquainted with the gasification installation (see Figure 1). The gasification is conducted in a 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.

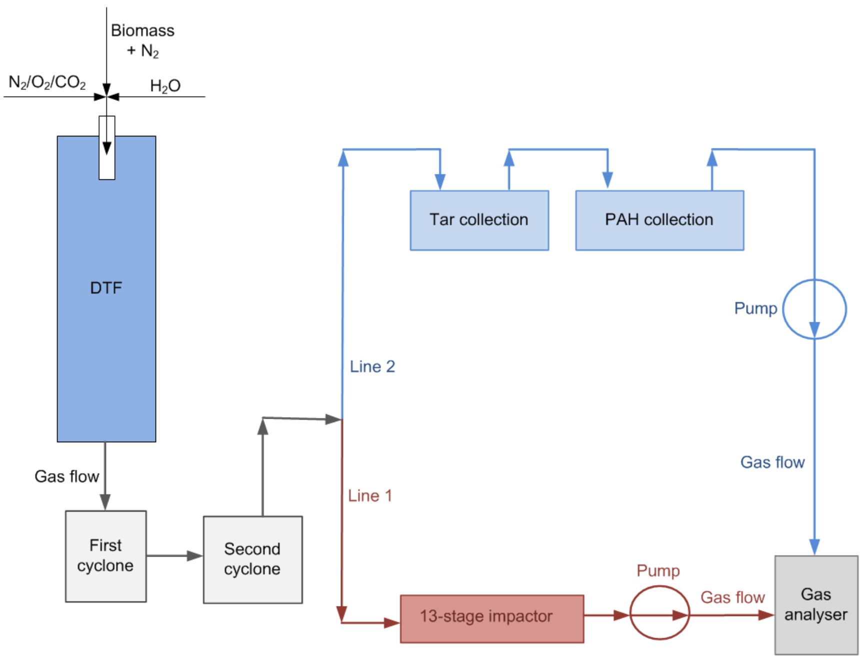

Figure 1. Experimental gasification procedure

After the DTF, there are two cyclones – the first one is house-made and the second is stainless steel

Dekati cyclone S110. Both of them are for collecting the large char particles with a size bigger than 10 μm [3]. After the second cyclone, two types of sampling lines were assembled:

- ***Line 1- Collection and measurement of char, soot and gas composition***. In this case, the flue gases go into a vertical 13-stage impactor (Dekati Low Pressure Impactor, DLPI). Its purpose is to collect particles with different sizes (see Table 2, when the numbers of stages are numbered from bottom to top). Thus, the particles size distribution can be derived [4, 5]. The second cyclone and the 13-stage impactor have electrical heating jackets, which keep a constant temperature of 150^{0}C. It is necessary for avoiding the condensation in both devices. After the impactor, a gas analyser identifies the gas composition.
- ***Line 2- Sampling and measurement of tar, PAH and gas composition.*** The system for collection of tar and PAH consists of two separate modules with independent cooling systems. The first module is for capturing the tar. This module operates at constant temperature of 0^{0}C and has two flasks. The first flask is empty and is used for condensation of the steam, if it is present in the gas flow. The second one is filled with 50 ml isopropanol and its purpose is to extract the tar from the flue gases. The second module operates at constant temperature of -20^{0}C. There are two flasks in this module. The first flask if filled with 100 ml isopropanol for capturing the PAH. The second one is to capture eventually drifted liquid from the previous flasks. This ensures that only gases are passed to the gas analyzer. The gas analyzer is connected to the end of the gasification installation for monitoring gases products like: CO, CO_2, O_2, N_2, etc.

Table 2. The particle diameter in 13-stage impactor

Impactor stage	Aerodinamic diameter, μm
1	0.030
2	0.06
3	0.108
4	0.17
5	0.26
6	0.4
7	0.65
8	1.0
9	1.6
10	2.5
11	4.4
12	6.8
13	10

I.2. Carbonization

The carbonization allows obtaining the char (coke) from different feedstocks (coal, biomass, etc.) [6]. The process is conducted without air [7]. The result is a fuel with increased carbon content and higher calorific value [8].

The carbonization is done in Laminar reactor of type Horizontal Tube Furnace (HTF) at an inert atmosphere (nitrogen). The sketch of the installation is given on Figure 2.

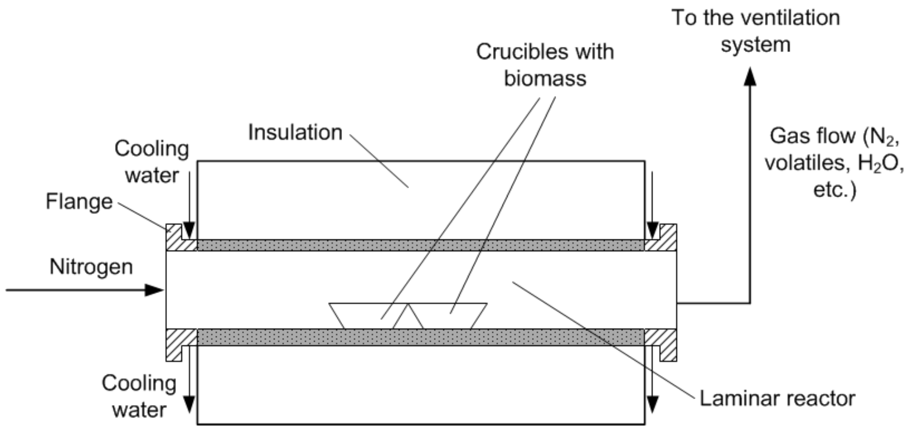

Figure 2. Sketch of carbonization installation

II. Experimental work

II.1. Gasification

The DTF operates at well controlled conditions. Detailed description of the DTF is done elsewhere [9,10, 11]. The reactor has the lollowing general characteristics:

- Maximum operating temperature of 1300^{0}C;
- Three thermocouples, type K, distributed uniformly along the DTF chamber;
- Vertically positioned cylindrical ceramic tube with inner diameter 35 mm and length 1.75 mm.

During my STSM, I acquainted with the main gasification equipment as well as the auxiliary systems needed for providing appropriate conditions for the gasification process. These auxiliary systems are:

- The feeding system;
- The system for nitrogen, oxygen and CO_2;
- Eventually - the steam system, it depends on the choosen gasification mixture.

The additional systems and tools needed for assesment of the gasification process are:

- System for collecting char and soot;
- System for collecting tar and PAH;
- System for monitoring of the outlet gas flow.

I have participated in the process of preparation of the 13-stage impactor, e.g. measuring the filters, numbering, assembling/dismantling and storage them for further investigations. The impactor has 13 filters, every of them put in the separate holder (see Figure 3). The filters are aluminium foils with a diameter of 25mm. The holded particles in every filter are with a different size because the size and the numbers of the holes on the upper side of each filter holder are different (see Figure 4).

Figure 3. Filter holders of 13-stage impactor

Figure 4. Upper part of three different impactor's holders

The gasification is an ongoing work which will be finalized in the frame of the COST Action implementation period.

II.2. Carbonization

The HTF has the following characteristics [12]:

- Maximum operating temperature of 1300^{0}C;
- Heating rate of 33^{0}C/min;
- Alumina recrystalized tube, with a length of 55cm and an inner diameter of 4cm;
- Water cooled flanges;
- Possibility to work under vacuum or controlled atmosphere;
- Insulation with rigid ceramic fibre;

- Thermocouple type S.

Experimental procedure
The carbonization was carried out for six types of biomass: grape pomace, colza, sunflower husks, dark softwood with a bark, cherry stones and peach stones. The experiments were performed under the following conditions: residence time of 1 hour, temperature of 500^{0}C and nitrogen flow rate of 1 l/min.
The experimental procedure was performed in the following sequence:

- Two porcelain crucibles were placed in the HTF;
- Only biomass particles of size below 1mm were used;
- Prior to the experiment, the HTF was purged for 20 min with nitrogen in order to be sure that the carbonization process will be conducted in inert atmosphere/without presence of oxygen;
- The temperature increases with a heaing rate of 33 ^{o}C/min and after it reaches 500 ^{o}C the samples are heated for 1 hour;
- After the experiment, the HTF was coolled down to around 100^{0}C.

DESCRIPTION OF THE MAIN RESULTS

The investigated biomass was chemically characterized trough proximate, ultimate and ash analyses. In addition the calorific values were obtained in calorimetric bomb (Table 1).

Carbonization
This experiment aims at investigating the biochar yield, derived from different biomass feedstock with agricultural origin. In addition, the obtained biochar is being characterized through SEM, EDS and BET analyses.
After each experiment the obtained biochar was weighed and stored for the further investigations. The derived data is given on Table 3. The biochar yield was calculated as follows:

Biochar yield = (biochar/used biomass)*100, %

Table 3. The biochar yield, obtained from the different feedstock

Type of biomass	Biomass	Biochar	Biochar yield
	g	g	%
Grape pomace	1.05827	0.37108	35.07
Sunflower husks	1.03350	0.32539	31.48
Colza	1.05104	0.30133	28.66
Softwood with a bark	1.04948	0.27655	26.35
Cherry stones	1.06175	0.31040	29.24
Peach stones	1.05236	0.33959	32.26

FUTURE COLLABORATIONS

The future work will be a continuation and finalization of the work done during this STSM.
The planned further collaboration can be summarized as follows:

- The obtained biochar is being analizied by SEM, TGA and BET analyses;
- Publication of a conference paper with the carbonization results;
- The gasification experiments is still in progress.
- The finalized results shall be published in a journal paper.
- The opportunities to extend this work were discussed in the frame of future collaboration initiatives. The possible extention envisages the investigation of different biomass types and at various operating conditions.

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