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Effect of torrefaction on energy properties and thermal behaviour of millet stalk

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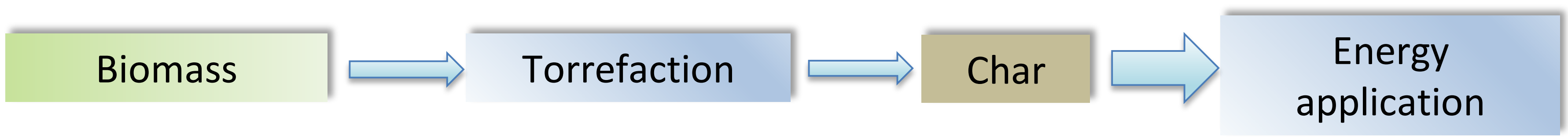
In the aspect of circular economy, the fundamental requirement is to recover energy from industry sectors.

Biomass residues from agro-industry are one of most attractive sources for bioenergy.

Cereals and other crops	**2020**	**Share (%) Pay**	**2021**	**Share (%) Pay**	**Change (%)**
Total	**71 277 723**	**100**	**61 720 345**	**100,0**	**-13,4**
Millet	5 711	0,0	4 320	0,0	-24,4
Canary grass	12 551	0,0	6 059	0,0	-51,7
Mahlut - Mixed grain	0	0,0	0	0,0	0,0

Torrefaction - pretreatment of biomass for energy processes

Torrefaction is the proces of slow heating of biomass in an inert or oxygen-deficit environment which take place in a range of temperature 250-300^{o}C (max 320)^{O}C. The final product bio-char is obtained – product with lower moisture and higher energy content.



The aim of the work is to compering the changes in energy and chemical properties of millet stalk **(*Panicum miliaceum* L.)** before and after torrefaction process.

Thermal decomposition of both materials via termogravimetric analyses to determinate the conditions of the combustion process for their application as fuel was also studied.

Material → Torrefaction → Combustion

TG/DTA analyses

Materials

Millet (*Panicum miliaceum* L.)

Millet stalk

Samples:
II – 1
II - 7

Methods

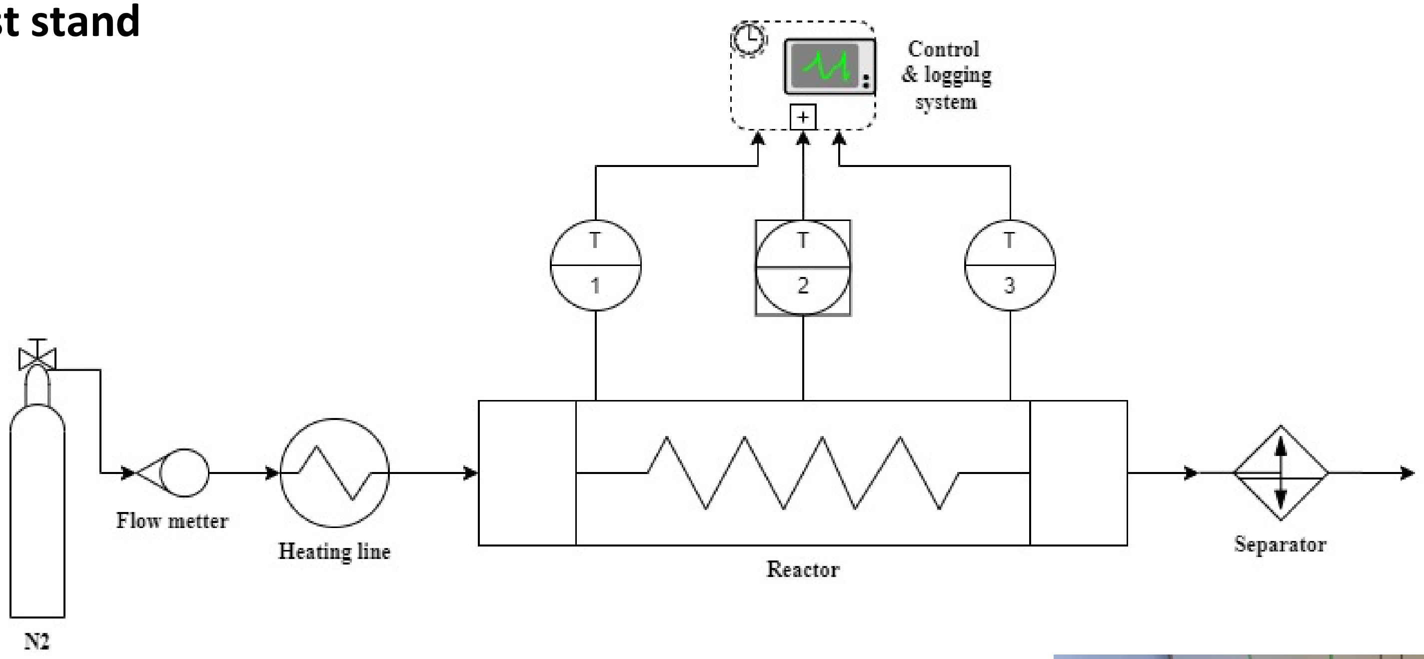
Torrefaction

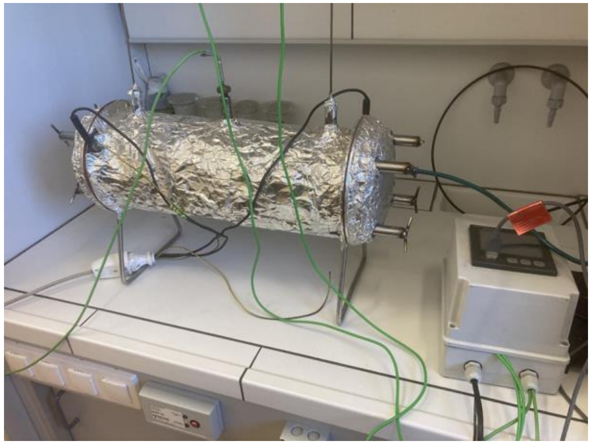
The torrefaction procedure involved several stages:

- ✓ the raw material samples were pulverised in a SM-100 laboratory cutting mill to a screen size of 250 μm;
- ✓ the grinded sample of 10 g +/- 0.1 g was placed in the reactor and purged with nitrogen (N_2) for 10 min at a flow rate of 50 l/min;
- ✓ initiation of the reactor heating system with the gas flow rate reduction to 10 l/min;
- ✓ setting the sample residance time for **45 minutes** at the temperature, i.e. **275** and **300 °C**, respectively.

Torrefaction

Test stand





Torrefied material

Methods

1. **The energy parameters**:

- **moisture -** PN-EN ISO 18134
- **ash -** PN-EN ISO 18122 and PN-ISO 117
- **volatile matter -** PN-EN ISO 18123
- **elementary analysis** using Vario Macro Cube analyser 2.
- **higher heating value (HHV)** with the use of the IKA Calorimeters C 5000 according to PN-EN 14918:2010 and PN-ISO 1928 standard

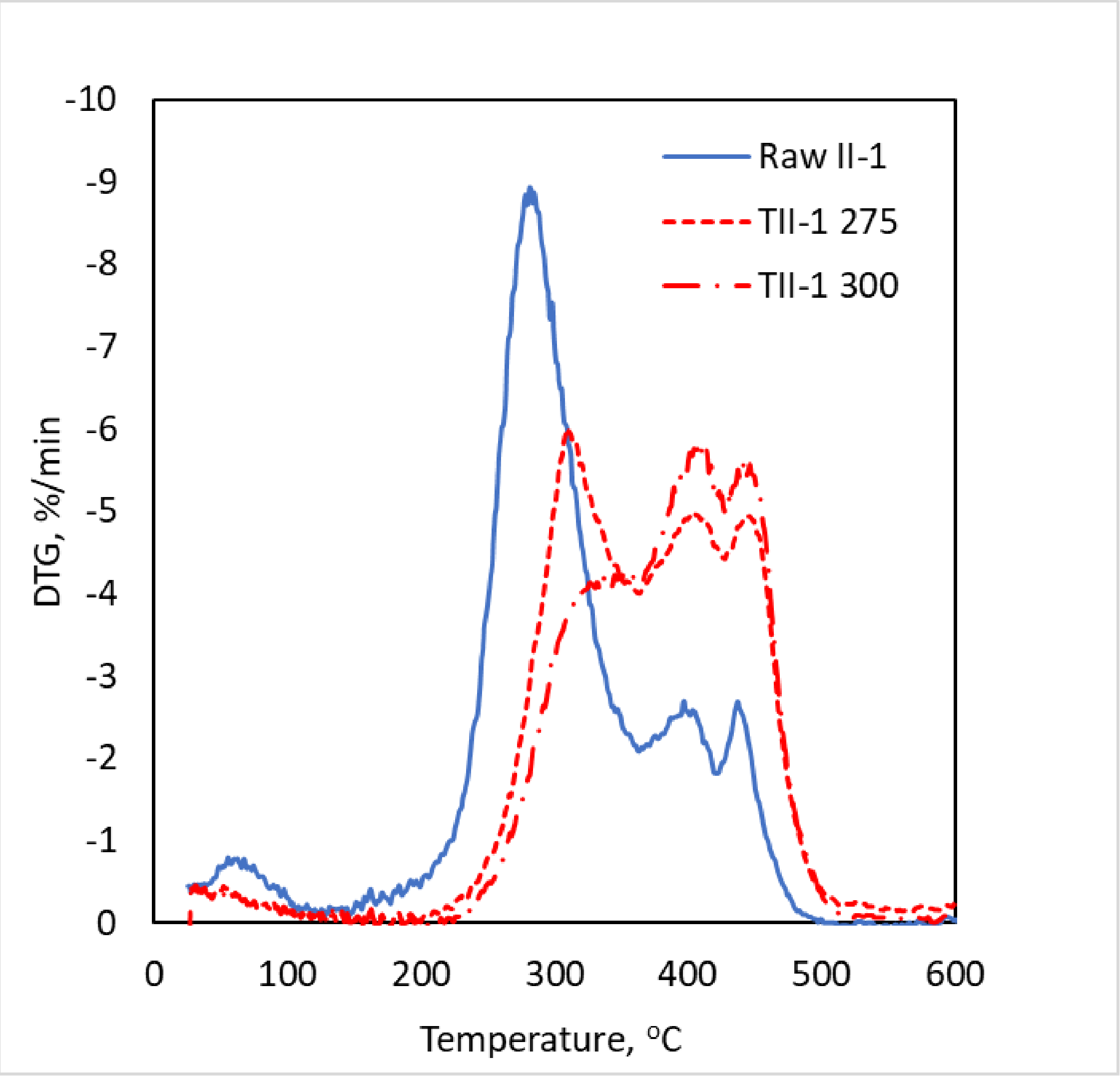
2. The simultaneous thermal analysis (TG-DTG) was carried out in NETZSCH STA 449 F3 Jupiter device.

- in a dry air atmosphere with the gas flow of 70 mL/min
- temperature up to 800^{o}C
- heating rate: 10 K/min

The proximate and ultimate analysis

Samples	Proximate analysis wt%			Ultimate analysis wt%					HHV MJ/kg
	Moisture	Ash d.m.	Volatile matter d.m.	C	H	N	S	O	
				d.m					
II-1	7.12	4.64	77.33	46.60	6.18	0.96	0.09	45.69	**17.15**
II-7	7.02	4.62	77.74	46.95	6.53	1.09	0.08	45.35	**17.30**
II-1/300	2.80	11.69	42.12	64.90	4.37	1.26	0.15	29.27	**24.57**
II-1/275	2.98	11.14	51.57	60.09	4.61	1.24	0.18	33.78	**22.72**

TG/DTG curves – combustion process



The maximum values of peaks on the DTG (Differential Thermogravimetry) curves and their temperatures at individual stages of combustion

MATERIAL	Temp. range	DTG	DTG_{max}	T_{DTG}
Stage	°C	%	%/min	°C
RAW II-1				
I	55-195	65.25	8.98	281.5
II	195-421	12.95	2.72	369.5
III	421-513	8.57	2.69	436.9
TII-1 275				
I	127-364	37.90	5.83	309.7
II	364-428	27.11	4.79	403.2
III	428-525	19.50	4.75	446.0
TII-1 300				
I	127-365	30.84	4.16	351.9
II	365-429	30.93	5.72	412.2
III	429-525	21.86	5.48	446.1

To evaluate the combustion properties based on information obtained from TGA, the following combustion parameters were calculated:

- **comprehensive combustion index**

$$S = \frac{(-R_p) \cdot (-R_v)}{T_i^2 \cdot T_b}$$

- **ignition index**

$$D_i = \frac{(-R_p)}{t_i \cdot t_p}$$

- **flammability index**

$$D_b = \frac{(-R_p)}{\Delta t_{1/2} \cdot t_i \cdot t_b}$$

- **burnout index**

$$C = \frac{(-R_p)}{T_i^2}$$

where:

- R_p - maximum weight loss rate (%/min)
- R_v - average mass loss rate (%/min)
- T_i - ignition temperature (^oC)
- T_b - burnout temperature (^oC)
- t_i – ignition time (min)
- t_p - peak time (min)
- $\Delta t_{1/2}$ - time range at half value of R_p (min)
- t_b - burnout time (min)

Combustion index

Sam-ple	Initation temp., T_i	Burn out temp. T_b	Initation time, t_i	Burn out time t_b	Combust in time, t_c	$S \cdot 10^7$	$D_i \cdot 10^2$	$D_b \cdot 10^4$	$C \cdot 10^4$
-	^oC	^oC	min	min	min	$\%^2 /(min^2K^3)$	$\%/min^3$	$\%/min^4$	$\%/(minK^2)$
RAWI I-1	248.6	457.4	28.9	48.6	19.7	12.54	0.97	2.17	1.45
TII-1 275	272.8	470.1	31.1	49.8	18.7	7.13	0.54	1.18	0.78
TII-1 300	281.4	472.8	31.9	50.1	18.2	6.54	0.41	1.08	0.72

Conclusions

- Torrefaction improve the energy parameters of millet stalk. Millet stalk torrefied in 300ºC has more favourable parameters from energy point of view.
- The burning profiles of for raw and torrefied materials show the characteristic peaks in the range of temperatures typical for biomass degradation (dehydration, devolatilization, gases and char combustion).
- For the torrefied materials the parameters such as initation and burn out temperature, or max mass lost taking place in higher temperature what is connected with eliminates the low energy content volatiles.
- Torrefaction process upgrade paramters of millet stalk to higher-quality fuel and can be used for heat generation, power production.
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Thank you

for your attention