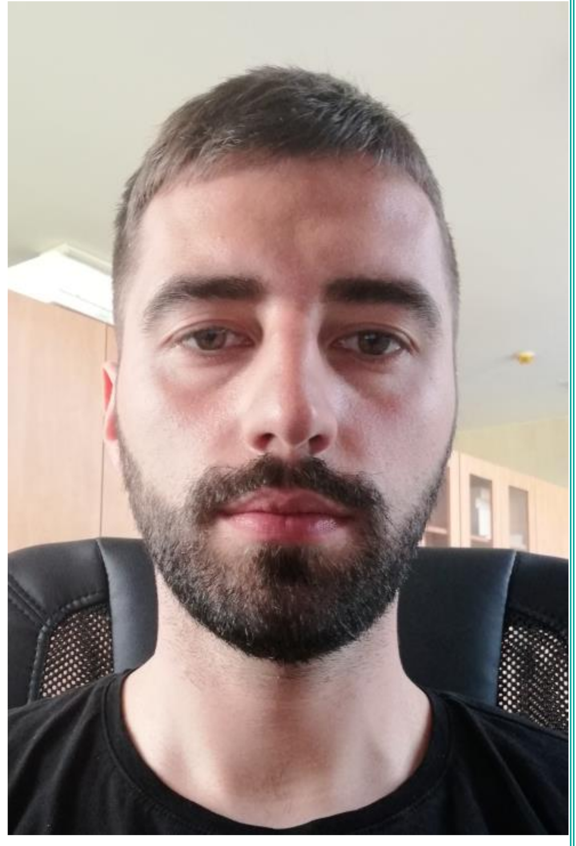
Gasified pistachio shells as a multi-purpose material in sustainable chains



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Introduction

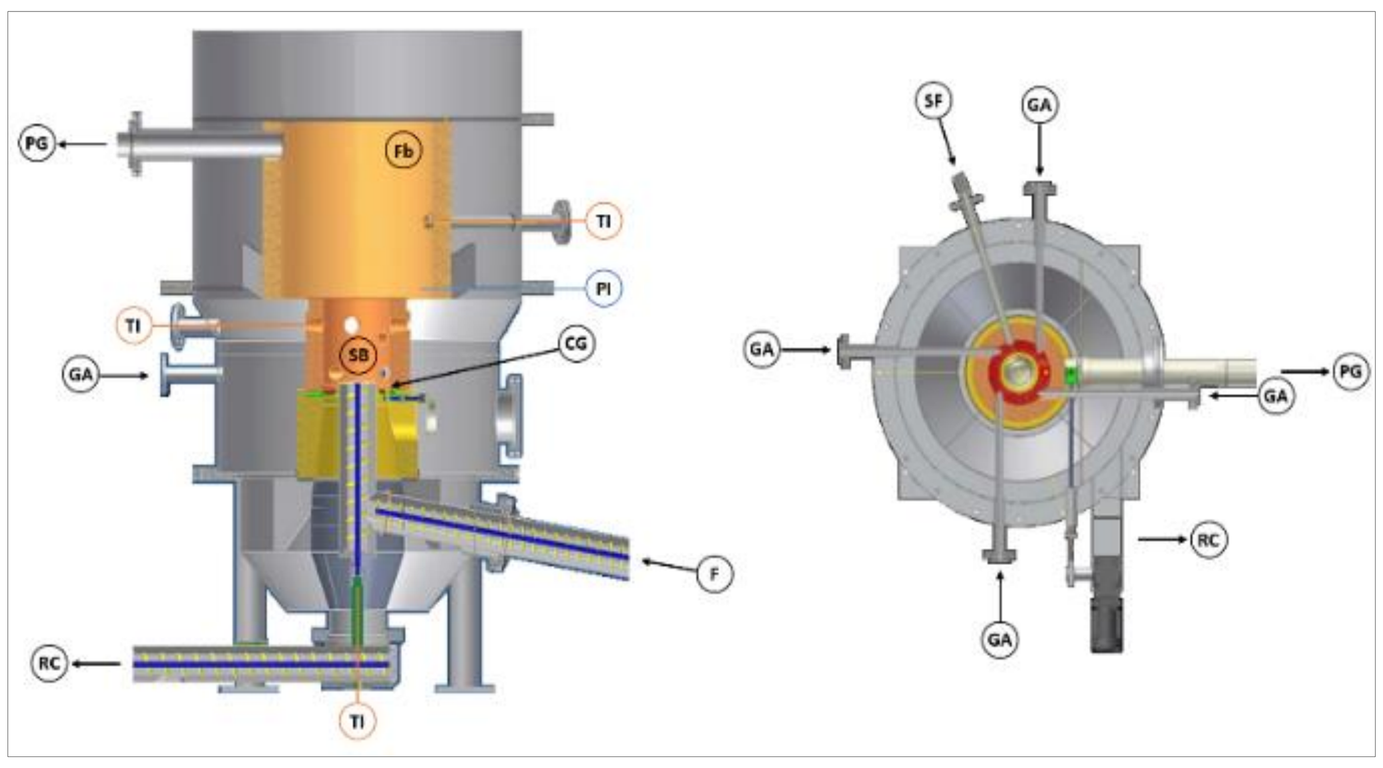

Figure 1: Cross/updraft gasification reactor with a sliding bed over circular grate

The simultaneous production of a valuable form of energy from waste material at the same time as the production of valuable by-products with wide possibilities of application is an example of the main idea of the circular economy.

Gasification is one of the most feasible thermochemical processes, besides pyrolysis and torrefaction, for producing high-quality sustainable multi-purpose materials which can replace fossil fuels originating from waste feedstock. One of the promising waste materials is pistachio shells (PS). Global pistachio production has been on an upward trend for more than a decade, with 1.3 million tonnes of pistachios produced in 2021, while the shell weighs about 35 – 45 $\%_{wt.}$ of the whole nut. The granulometry of the PS is very homogenous and it is not necessary to modify it before its utilisation in a standard facility designed originally for standard EN plus A1 pellets. The potential of the co-gasification of the pistachio shell on the semi-industrial scale with a cross/updraft gasification reactor (Figure 1) has not been evaluated yet as well as the char properties and possibilities of its consequence utilisation.

The novelty of the study consists of the usage of a combination of uniquely designed gasification unit with unique waste material as part of a circular economy chain.

Results & Discussion

The setup of the gasification technology sufficed for the stabilised production of the gas parameters which are summarised in Table 1. The producer gas was rich in CH_4 (14.2 $\%_{vol.}$) and despite the relatively high content of N_2 (69.8% vol.), the LHV = 6.53 MJ/m^3 is sufficient and very promising, compared to similar studies on fixed bed gasification reactors. On the other hand, high CH_4 is compensated by a much lower content of CO and H_2, which is only 6.5 and 4.8 % vol, respectively.

CO [$\%_{vol.}$]	CH_4 [$\%_{vol.}$]	CO_2 [$\%_{vol.}$]	H_2 [$\%_{vol.}$]	O_2 [$\%_{vol.}$]	N_2 [$\%_{vol.}$]	LHV [MJ/m^3]	Q [l/min]	τ [min]
6.5	14.2	4.7	4.8	0	69.8	6.33	2.2	60

Table 1: Parameters of the sampled producer gas

Efficiency determination is a tool for direct comparison of gasification processes regardless of reactor design type, fuel characteristics and operating conditions. The Hot Gas Efficiency (HGE) value presents the efficiency of converting the input energy from feedstock material to the producer gas, including its sensible heat, while the Cold Gas Efficiency (CGE) does not include this value. HGE reached 89.6% during the described measurement, while CGE reached 73.9%. These efficiencies were determined according to the following equations:

$$\mathrm{HGE} = \frac{\dot{V}_g \cdot \rho_g \cdot (\Delta T \cdot c_p + \sum LHV_{CO,H_2,CH_4})}{\dot{m}_f \cdot LHV_f} \quad [\%]$$

$$\mathrm{CGE} = \frac{\dot{V}_g \cdot \rho_g \cdot LHV_g}{\dot{m}_f \cdot LHV_f} \quad [\%]$$

The bulk density of raw PS material was estimated to be 286.9 kg/m^3, while the bulk density of gasified PS was estimated to be 226.4 kg·m^{-3}. The pH of gasified PS was determined to be 9.52 on the pH scale.

Cellulose, hemicelullose and lignin can be identified by infrared spectroscopy. Infrared spectroscopy revealed the occurrence of alkane (C-C), alkene (C=C), hydroxy (-OH), alkyl (C-H), ester (C=O), alkoxy (C-O) and ether (C-O-C) functional groups of gasified PS. The most intensive bands in both spectra at 3,336 cm^{-1} are connected to the presence of -OH bonds.

	C^r [$\%_{wt.}$]	H^r [$\%_{wt.}$]	N^r [$\%_{wt.}$]	S^r [$\%_{wt.}$]	O^r [$\%_{wt.}$]	W^r [$\%_{wt.}$]	A^r [$\%_{wt.}$]	LHV [MJ/kg]
Raw PS	43.85	5.38	<0.2	<0.02	40.94	8.64	0.97	16.00
Gasified PS	62.08	4.71	0.21	0.02	27.69	2.96	2.33	22.51

Table 2: Raw and gasified PS characteristics; ^{r} – raw state

Al_2O_3 [$\%_{wt.}$]	CaO [$\%_{wt.}$]	Cl [$\%_{wt.}$]	Cr_2O_3 [$\%_{wt.}$]	CuO [$\%_{wt.}$]	Fe_2O_3 [$\%_{wt.}$]	K_2O [$\%_{wt.}$]
0.58	2.40	32.50	0.0003	0.0005	0.05	7.44
MgO [$\%_{wt.}$]	MnO [$\%_{wt.}$]	Na_2O [$\%_{wt.}$]	NiO [$\%_{wt.}$]	P_2O_5 [$\%_{wt.}$]	PbO [$\%_{wt.}$]	SiO_2 [$\%_{wt.}$]
0.15	0.0009	40.08	0.0006	0.94	0.0014	0.34
SO_3 [$\%_{wt.}$]	SrO [$\%_{wt.}$]	TiO_2 [$\%_{wt.}$]	ZnO [$\%_{wt.}$]			
1.13	0.0017	0.0011	0.0014			

Table 3: Detailed analyse of the PS ash

In comparison with biochar originating from different feedstocks (kenaf stems and rice husk), treated by pyrolysis, the most significant differences are in Cl and Na_2O mass fractions. High mass fractions of these two compounds may be caused by pre-treatment of the pistachio before selling – the addition of NaCl for their flavouring. However, the combination of Na and Cl may positively affect the soil salinity and subsequently yield of some crops such as *Raphanus sativus*.

The ash itself is fully compliant with the Government Decree on the Assessment of Soil Contamination and Remediation Needs of Finnland and therefore its application, or even the application of biochar, could not cause a deterioration of soil quality beyond listed limit values in this legislative document. What's more, the biochar from pistachio shells proved can be usilised for heavy metals adsorbing.

Conclusions

The simultaneous production of a valuable form of energy from waste material at the same time as the production of valuable by-products with wide possibilities of application is an example of the main idea of the circular economy. The pistachio shells as a homogenous waste material proved to be an appropriate feedstock for co-gasification with wood pellets in pilot-scale cross/updraft type reactor resulting in technologically applicable producer gas and valuable biochar with many possible consequent usages.

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