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

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Introduction

There are several published studies describing the possibilities of the thermal utilisation of the pistachio hard shells (PS) such as combustion, pyrolysis and gasification on laboratory scale equipment, however the potential of the co-gasification of the PS in semi-industrial scale gasifier was not evaluated before. The importance of the study is in the describing of the potential of locally based biomass by-product for decentralised production producer gas, which can be easily utilised for heat or electricity generation.

The *Pistacia vera* is a small tree which produces pistachios. Global pistachio production has been on an upward trend for more than a decade, with 1.3 million tonnes of pistachios produced in 2021, according to the latest verified data. The biggest producers are Iran, USA, Turkey and China. The granulometry of the pistachio shell is very homogenous and it is not necessary to modify it before the gasification process when using a standard facility for standard EN plus A1 pellets utilisation.

The process of gasification is a thermochemical conversion where chemical bonds of the material are destroyed by the impact of increased temperature and a limited amount of oxidising media. The equivalence ratio (ER)usually ranges from 0.1 to 0.5 while process temperatures are held between 650 and 1200 °C, dependent on the gasification principle (fixed bed, fluidised bed or entrained flow). The gasification media can be the atmospheric air as well as steam or an oxy/steam mixture.

Materials and Methods

PS were obtained from the supplier of Californian Pistachios with cores included (verified quality for consummation by human). The whole nuts were divided across the workplace and evenly eaten while empty, salivated shells were returned to the laboratory. PS were stored in the laboratory for the several months before the experiments. For the gasification test the mixture of PS with certified wood pellets of EN plus A1 quality was used in ratio 15/85.

The technology utilised for the purpose of this research is based on a semi-industrial scale sliding bed gasification reactor equipped with a circular grate. The fuel and oxidising media flows define this reactor as so called cross/updraft with tangential air income. The reactor works in an autothermal regime – partial combustion of the fuel suffices the necessary gasification temperature. In consequence, the producer gas is diluted with CO_2 (combustion product) and its LHV parameter is lowered. On the other hand, the energy spent on the heating up of the reactor is spared. A more detailed description of the performance of this technology on wood biomass is included in: [1], on terrified biomass in: [2] and on solid recovered fuel in: [3]

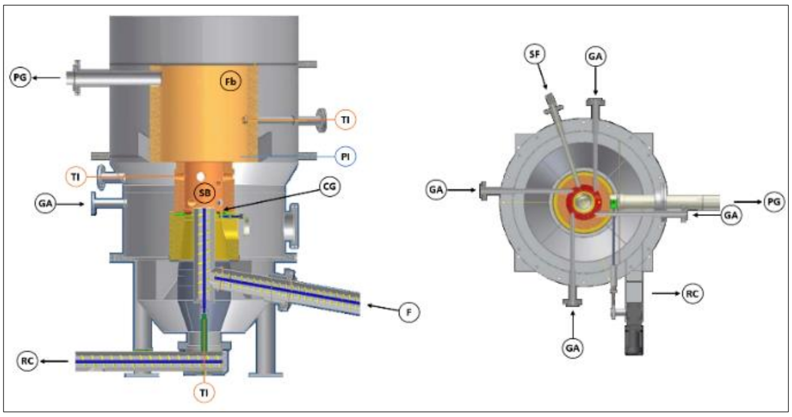

Figure 1 - Cross/updraft gasification reactor with a sliding bed over circular grate (Čespiva, 2022).
CG – circular grate; F – fuel input; Fb – freeboard; GA – gasification air input; PG – producer gas output; RC – residual char output; PI – pressure indicator; SB – sliding bed; SF – star-up flame; TI – temperature indicator.

The experimental gasification process was held under low load regime with ER reaching only 0.42, while the flow of the fuel was equal to 15.9 kg/h. The gasification temperature was held between 625.4 and 704.7 °C during the whole time of the experimental measurement, with an average value equal to 649.7 °C. The pressure within the reactor was -0.1 kPa to the atmospheric.

The solid residue was collected from a drop zone below the reactor and consequently sampled and analysed. The analyses included ultimate and proximate analyses, including LHV value and pH determination. The content of C^r, H^r, N^r and S^r was determined using CHNS628 (Leco, USA). The amount of O^r was calculated following the EN 16993 standard. The content of W^r was determined as a gravimetric difference in VF110 electric furnace (Memmert, Germany) (ISO 181234-2). A^r was determined in LEO 5/11 furnace (LAC, Czech Republic) following (ISO 18122). The lower heating value (LHV) was calculated (ISO 18125).

The pH value was determined in accordance with the standard (ISO 10523:2008) by using selective indicator papers (Lach:ner, Czech Republic) with detection range from 6.0 to 7.5. The material was dissolved in water for 24 hours prior the measurement.

Results and discussion

The setup of the gasification technology sufficed the stabilised production of the gas parameters of which are summarised in Table 1. below. 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 much lower content of CO and H_2, which is only 6.5 and 4.8 % vol, respectively. The presence of CO_2 is a natural consequence of the partial combustion of the fuel for autothermal operation of reactor.

Table 1. Parameters of the sampled producer gas.

CO (%)	CH_4 (%)	CO_2 (%)	H_2 (%)	O_2 (%)	N_2 (%)	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

The carbonaceous material derived from PS gasification was analysed in accordance with the above-mentioned procedure.

Table 2 below depicts the results of the ultimate and proximate analyses where data from the analyses of the raw material are included for comparison. The bulk density of this material was estimated to be 226.4 kg/m^3. The pH was determined to be 9.52 on the pH scale. The alkalinity of the material can be advantageous in adjusting the pH of acidic soils as with the use of wood ash. Moreover the advantage of the described material usage is the carbon mass fraction, which positively effect the soil properties from the water retention point of view. [4]

Table 2 - Gasified PS characteristics.

	Carbon (% wt.)	Hydrogen (% wt.)	Nitrogen (% wt.)	Sulphur (% wt.)	Oxygen (% wt.)	LHV (MJ/kg)	pH (-)	Density* kg/m^3
Raw	43.85	5.38	<0.2	0.02	40.94	16.00	-	286.9
Gasified	62.08	4.71	0.21	0.02	27.69	22.51	9.52	226.4

Conclusion

The C content within the produced residues was equal to 62.08% wt. on average, which makes this material very interesting in numerous applications where carbonaceous structure is of the essence, for instance, as a sorption material, purification element of flue gas or water or as a carrier during the CO2 storage. The specific properties of the material in different applications should be further investigated.

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