Evaluation of slow pyrolysis of kitchen and garden biowaste to produce biochar

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Biowaste, which includes food and garden waste, represents a significant part of municipal waste. In line with the circular economy, biowaste can be treated as a source of valuable resources such as nutrients, organic matter and energy (EC, 2008). Pyrolysis of biowaste is an efficient and sustainable way to create large amounts of renewable bioenergy, such as biochar and bio-oil while reducing greenhouse gas emissions and additional pollutants (Awasthi et al., 2021). The main advantage of the pyrolysis process is that it allows the conversion of low-energy-density materials into high-energy-density biofuels (EEA, 2020). Special consideration should be given to biochar, which is a stable, porous carbon-rich substance and can be used in a wide range of applications, such as for soil improvement, water treatment, fuel or energy storage material (Panwar et al., 2019), (Amer and Elwardany, 2020). Additionally, the use of biochar made from organic waste has implications for mitigating greenhouse gas emissions, climate change, and can contribute to carbon sequestration (Panwar et al., 2019). This work aims to determine the characteristics of the tested biowaste and to determine the effect of the temperature at which the slow pyrolysis process was carried out on the yield and properties of the obtained biochar.

Biowaste samples used in this study included kitchen biowaste, spring garden biowaste, and autumn garden biowaste collected from households in the Silesia region of Poland. Kitchen biowaste consisted of vegetable and fruit waste, bread, pasta, rice, meat, dairy products, uneaten ready meals, eggshells, coffee grounds, tea leaves, and nut shells. The main component of spring garden biowaste was grass. Autumn garden biowaste mainly consisted of leaves and small twigs. The properties of the tested biowaste and the obtained biochar were determined by performing a proximate analysis, ultimate analysis and determining the higher heating value (HHV) using appropriate standards. The slow pyrolysis process was carried out on a laboratory batch scale in an electrically heated horizontal tube furnace (HTF) with a water-cooled vessel. Inside the furnace is a horizontal tube with an internal diameter of 4 cm and a length of 55 cm made of recrystallised alumina. Inside this tube, the atmosphere of the slow pyrolysis process can be controlled. Two ceramic crucibles were placed inside the HTF, each containing a sample of approximately 2.5 g. The slow pyrolysis processes were carried out at 400ºC, 500ºC and 600ºC, with a heating rate of 33ºC/min and an inert atmosphere (nitrogen), with a residence time of 1 h and a nitrogen flow rate of 2 l/min.

The high moisture content of all the biowaste tested indicates the need for pre-drying before slow pyrolysis. Among the studied biowaste, kitchen biowaste contains the highest volatile matter (76.55%), carbon (43.36%) and hydrogen (7.03%) and the least ash (6.81%), which has a positive impact on biochar production through the slow pyrolysis process. In addition, its HHV value (17.24 MJ/kg) is also the highest. On the other hand, kitchen biowaste, of all tested, contains the highest amount of nitrogen (3.12%), chlorine (0.71%) and sulphur (0.10%) which can negatively affect NO_x, SO_x or HCl emissions and can cause corrosion of the installation. All the properties of the tested kitchen biowaste are similar to literature values obtained in different regions of the world for food waste (Rago et al., 2018), (Chhabra et al., 2019). These results confirm the conclusions made by (Ilakovac et al., 2020), who found that regardless of the country, the composition of food waste generated in households is the same. Compared to the literature data of other garden wastes (Ward et al., 2014), (Dhyani and Bhaskar, 2018), the studied spring garden biowaste is characterised by higher contents of moisture (81.53%), ash (17.75%) and fixed carbon (39.82%) and lower contents of volatile matter (42.43%), carbon (31.94%), hydrogen (4.53%) and chlorine (0.05%). In contrast, the content of oxygen (42.82%), nitrogen (2.84%) and sulphur (0.07%) in spring garden biowaste is similar to literature data. In addition, compared to the literature data, the spring garden biowaste has a lower higher heating value (10.60 MJ/kg). In contrast, autumn garden biowaste has a higher moisture content (63.51%), nitrogen content (1.19%) and a much higher ash content (43.83%) compared to literature data. On the other hand, it has lower volatile matter (43.75%), carbon (29.99%), hydrogen (4.02%), oxygen (20.92%), chlorine (0.01%) and a lower HHV (11.16 MJ/kg). In addition, the fixed carbon (12.43%) and sulphur (0.03%) content is similar to literature data for garden waste. In addition, the obtained properties of the biowaste were compared with those of typical biomass materials used to produce biochar by pyrolysis, such as wood (Amer and Elwardany, 2020), almond shells (Chandraratne and Daful, 2022) and rice husks (Hu et al., 2015). It was shown that among the biowaste analyzed, kitchen biowaste has the most similar properties and thus should be best suited as a feedstock to produce biochar through the slow pyrolysis process. For all the biowaste tested, the mass yield of biochar decreases as the pyrolysis temperature increases.

Comparing all the biowaste analysed, the highest biochar yields at each pyrolysis temperature were obtained for autumn garden biowaste, while the lowest biochar yields were obtained for kitchen biowaste. However, the analysed autumn garden biowaste contained as much as 43.85% ash, the spring garden biowaste 17.75% and the kitchen biowaste 6.81%, which also affects the biochar yield on a dry basis, because the ash contained in the biowaste will also be present in the obtained biochar. Of all the biochar analysed, kitchen biochar obtained at a pyrolysis temperature of 400ºC showed the highest content of volatile matter (20.49%), carbon (58.02%), hydrogen (4.00%) and the highest HHV (22.68 MJ/kg). Furthermore, this biochar showed the lowest ash content (18.57%). These properties indicate that this biochar can be used as a fuel. On the other hand, the high nitrogen content (3.64%), which may cause increased NOx emissions, may have a negative impact. Compared to kitchen biowaste before slow pyrolysis, kitchen biochar obtained at any pyrolysis temperature has a higher carbon content, fixed carbon and a higher HHV, which means that kitchen biowaste is a suitable feedstock to produce biochar by slow pyrolysis. The properties of the obtained spring garden and autumn garden biochar were similar for the respective pyrolysis temperatures, whereas significantly different from those of the kitchen biochar. The both garden biochar contained more than three times as much ash as the kitchen biochar. This high ash content resulted in a lower volatile matter, carbon and hydrogen content than in the kitchen biochar. This also had an impact on HHV, which was at least twice as low compared to kitchen biochar. Furthermore, the biochar contained less carbon and had a lower HHV compared to the spring and autumn garden biowaste before pyrolysis.

To summarize, all the biowaste tested had a high moisture content (between 63.51% and 81.53%), which means that the biowaste needs to be dried before the slow pyrolysis process. The properties of the kitchen biowaste tested are comparable to those of food waste tested by other researchers in different regions of the world and are similar to those of typical biomasses used to produce biochar by slow pyrolysis. Both garden biowaste tested may have been contaminated (soil, rocks) during collection, which affected the high ash content of spring (17.75%) and autumn (43.83%) biowaste. This, in turn affected all the properties of the garden biowaste which differed significantly from both literature data of other garden wastes and from the properties of typical biomass feedstocks used to produce biochar in the slow pyrolysis. For all the biowaste tested, it was shown that the biochar yield decreased with increasing pyrolysis temperature. The maximum mass yield of biochar for kitchen, spring garden and autumn garden biowaste was 36.64%, 66.53% and 66.99%, respectively. Kitchen biochar, compared to kitchen biowaste before pyrolysis, had higher carbon content, fixed carbon and higher HHV. Both types of garden biochar contained less carbon and had a lower HHV than the garden biowaste from which it was produced. In addition, the garden biochar contained more than three times as much ash as the kitchen biochar.

European Commission (EC), 2008, Green Paper on the management of bio-waste in the European Union

Awasthi, M. K., Sarsaiya, S., Wainaina, S., Rajendran, K., Awasthi, S. K., Liu, T., Duan, Y., Jain, A., Sindhu, R., Binod, P., Pandey, A., Zhang, Z., Taherzadeh, M. J. (2021). Techno-economics and life-cycle assessment of biological and thermochemical treatment of bio-waste. Renewable and Sustainable Energy Reviews, 144. https://doi.org/10.1016/J.RSER.2021.110837

European Environment Agency (EEA). (2020). Bio-waste in Europe turning challenges into opportunities. No 04/2020. ISBN 978-92-9480-223-1; doi:10.2800/630938

Panwar, N. L., Pawar, A., Salvi, B. L. (2019). Comprehensive review on production and utilization of biochar. In SN Applied Sciences (Vol. 1, Issue 2). Springer Nature. https://doi.org/10.1007/s42452-019-0172-6

Amer, M., Elwardany, A. (2020). Biomass Carbonization. 10.5772/intechopen.90480

Rago, Y. P., Surroop, D., Mohee, R. (2018). Assessing the potential of biofuel (biochar) production from food wastes through thermal treatment. Bioresource Technology, 248, 258–264. https://doi.org/10.1016/j.biortech.2017.06.108

Chhabra, V., Bhattacharya, S., & Shastri, Y. (2019). Pyrolysis of mixed municipal solid waste: Characterisation, interaction effect and kinetic modelling using the thermogravimetric approach. Waste Management, 90, 152–167. https://doi.org/10.1016/j.wasman.2019.03.048

Ilakovac, B., Voca, N., Pezo, L., Cerjak, M. Quantification and determination of household food waste and its relation to sociodemographic characteristics in Croatia. Waste Manag. 2020 Feb 1;102:231-240. doi: 10.1016/j.wasman.2019.10.042. Epub 2019 Nov 1. PMID: 31683079.

Ward, J., Rasul, M. G., Bhuiya, M. M. K. (2014). Energy recovery from biomass by fast pyrolysis. Procedia Engineering, 90, 669–674. https://doi.org/10.1016/j.proeng.2014.11.791

Dhyani, V., Bhaskar, T. (2018). A comprehensive review on the pyrolysis of lignocellulosic biomass. Renewable Energy, 129, 695–716. https://doi.org/10.1016/j.renene.2017.04.035

Chandraratne, M., G. Daful, A. (2022). Recent Advances in Thermochemical Conversion of Biomass. In Recent Perspectives in Pyrolysis Research. IntechOpen. https://doi.org/10.5772/intechopen.100060

Hu, Q., Shao, J., Yang, H., Yao, D., Wang, X., & Chen, H. (2015). Effects of binders on the properties of bio-char pellets. Applied Energy, 157, 508–516. https://doi.org/10.1016/j.apenergy.2015.05.019