The Ash Fusibility of Waste Biomass from the Agricultural Industry

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Introduction

The energy recovery of waste biomass from the agricultural and forestry industries is one of the options to reduce the production of waste from human activities and to reduce the carbon footprint of the heat or electricity production process. However, there are many problems associated with the combustion of waste biomass that need to be considered when deciding on the suitability of this use. Problems can be caused, for example, by the ash produced during the combustion of biofuel, which, due to its properties (Malaťák et al., 2008), can stick to the internal parts of the combustion plant and cause poorer heat transfer and corrosion of the structural material under the adhering ash layers. (Abreu et al., 2010). Estimation of the risk of ash slagging can be calculated on the basis of its chemical composition - the slagging/fouling indices (Vamvuka et al., 2011), (Pronobis et al., 2013), (Garcia-Maraver et al., 2017) or measured using an ash fusibility analyser. This paper deals with the assessment of ash melting temperatures of different types of non-wood waste biomass using calculated indexes and direct measurements of characteristic ash fusion temperatures.

Material and methods

The plant materials that have been tested can be divided into 10 groups according to their origin:

- bamboo (stalks, sander dust, fibres, offcuts)
- cocoa (shells, cake)
- coffee (husk, chaff, dust, spent ground)
- corn (cobs, stalks)
- oat (hulls, pellets)
- olive pits
- palm kernel shells
- rice husk
- sunflower (waste, hulls, hull pellets)
- wheat (bran, mix)

From the potential biofuel samples, ash was prepared at 550°C according to ISO 18122:2015 respectively ISO 18122:2022 and analysed. The concentrations of chlorine compounds in the form of chlorides, major elements in the form of oxides were determined. The characteristic melting temperatures of the ashes in oxidizing and reducing atmospheres were also measured.

Chlorides were analysed by ion chromatography with conductivity detection in aqueous ash leachate (1:10), the uncertainty of determination was 32%. Major elements were determined by X-ray fluorescence spectrometry (XRFS) and recalculated to oxides (Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, SO_3, K_2O, CaO, TiO_2, MnO, Fe_2O_3), the uncertainties were 5 to 25%. The ash fusibility temperatures were determined by LECO AF700 analyser according to ISO 21404:2020. The test pieces were shaped into an upright cylinder (diameter and height were 4 mm). The reducing atmosphere was created in the apparatus by a 60/40% CO/CO_2 mixture, while the oxidizing atmosphere was created by technical air. The working range of measurement was 700-1500°C, the uncertainty of determination was 20°C.

The slagging and fouling indexes were calculated (Horák et al., 2019) and compared with the ash fusion temperatures, especially the deformation temperatures in reduction and oxidation atmosphere. The deformation temperature (DT) is one from the characteristic ash fusion temperatures at which the first signs of melting occur by rounding the edges of the test piece (ISO 21404:2020).

Results and discussion

Two groups of plant biomass were selected for the presentation of the results. These are bamboo and wheat. Table 1. below depict the results of XRFS analyses and chlorides determination. The results of ash fusibility measurements are shown in Table 2. Calculated slagging and fouling indexes of the biomass samples ashes are given in Table 3.

Most of the results show that these two groups of plant biomass are not suitable for burning separately. Combustion in a mixture with for example wood fuels could decrease risk of negative impacts such as the slagging, fouling and corrosion.

Table 1. Concentration of the major elements and chlorides in the ash of the biomass samples.

Sample	Concentration of the major elements and chlorides in the ash [wt %] dry matter											
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Cl
Bamboo stalks	6.49	5.78	0.87	13.33	1.05	15.63	46.80	2.02	0.02	0.05	0.12	11.80
Bamboo sander dust	1.66	10.00	1.63	35.00	4.25	5.74	26.80	4.49	0.05	0.63	0.55	0.78
Bamboo fibers	0.25	6.95	1.49	50.00	3.59	2.93	20.60	4.94	0.14	0.78	1.31	0.27
Bamboo offcuts	1.01	5.26	1.03	45.00	4.16	4.73	25.50	4.60	0.05	0.24	0.48	0.70
Raw wheat bran	0.36	23.40	0.56	0.70	34.20	0.67	33.50	2.59	0.01	0.31	0.35	< 0.02
Milled wheat bran	0.35	21.20	0.53	1.17	33.00	0.70	36.30	3.66	0.00	0.34	0.38	< 0.02
Wheat bran	0.11	9.23	0.74	10.00	32.50	3.07	27.30	3.66	0.06	0.25	0.87	0.28
Wheat mix	< 0.02	11.40	0.12	1.60	44.20	0.70	28.70	2.90	< 0.10	0.29	0.30	1.50

Table 2. The characteristic melting temperatures of the ashes in oxidizing and reducing atmospheres.

Sample	Ash fusibility in reduction atmosphere [°C]				Ash fusibility in oxidation atmosphere [°C]			
	SST	DT	HT	FT	SST	DT	HT	FT
Bamboo stalks	nd	1 030	1 120	1 190	nd	1 050	1 250	1 280
Bamboo sander dust	nd	880	950	1000	840	910	1020	1150
Bamboo fibers	870	910	1120	1230	870	920	1120	1150
Bamboo offcuts	nd	860	1060	1130	nd	920	1070	1150
Raw wheat bran	nd	700	860	900	nd	700	730	750
Milled wheat bran	nd	< 700	890	920	nd	700	760	840
Wheat bran	nd	840	950	1010	nd	840	940	1030
Wheat mix	nd	< 700	880	900	nd	750	790	840

The abbreviations in the Table 2. have the following meaning:

- nd – not determined (SST was below the lowest limit of the method range, i.e. 700°C)
- SST – shrinkage starting temperature DT – deformation temperature
- HT – hemisphere temperature FT – flow temperature

Table 3. The slagging and fouling indexes of the biomass samples ashes.

Sample	Base-acid ratio B/A	Fouling index Fu	Slag viscosity index Sr	Bed agglomeration index BAI	Ash fusibility index AFI
Bamboo stalks	4.38	233	63	0.002	1 090
Bamboo sander dust	1.30	37	70	0.019	932
Bamboo fibers	0.73	15	79	0.063	960
Bamboo offcuts	0.89	24	81	0.018	950
Raw wheat bran	74.45	2 521	3	0.010	706
Milled wheat bran	55.69	2 041	4	0.010	712
Wheat bran	6.82	187	42	0.032	860
Wheat mix	48.09	1 381	10	0.010	758

The colours in the Table 3. means slagging and fouling inclinations:

green = low yellow = medium orange = high red = extremely high

Conclusions

Two groups of plant biomass (bamboo and wheat) were presented in this study. The properties and composition of their ashes were investigated and the risks of combustion these fuels were estimated.

References

Malaťák, J. & Vaculík, P., 2008. Biomasa pro výrobu energie. Praha, Česká zemědělská univerzita v Praze. ISBN 978-80-213-1810-6.

Abreu, P., Casaca, C., Costa, M., 2010. Ash deposition during the co-firing of bituminous coal with pine sawdust and olive stone in a laboratory furnace. Fuel 89, 4040–4048. DOI: 10.1016/j.fuel.2010.04.012.

Vamvuka, D. & Kakaras, E., 2011. Ash properties and environmental impact of various biomass and coal fuels and their blends. Fuel Process Technol. 92, 570–581. DOI: doi.org/10.1016/j.fuproc.2010.11.013.

Pronobis, M., Kalisz, S. & Polok, M., 2013. The impact of coal characteristics on the fouling of stoker-fi red boiler convection surfaces. Fuel. 112, 473–482. DOI: doi.org/10.1016/j. fuel.2013.05.044.

Garcia-Maraver, A., Mata-Sanchez, J., Carpio, M. &Perez-Jimenez, J.A., 2017. Critical review of predictive coefficients for biomass ash deposition tendency. J. Energy Inst. 90, 214–228. DOI: doi.org/10.1016/j.joei.2016.02.002.

ISO 18122:2022. Solid biofuels – Determination of ash content. International Organization for Standardization (2022).

ISO 21404:2020. Solid biofuels - Determination of ash melting behaviour. International Organization for Standardization (2020).

Horák J, Kuboňová L, Dej M, Laciok V, Tomšejová Š, Hopan F, Krpec K, Koloničný J., 2019. Effects of the type of biomass and ashing temperature on the properties of solid fuel ashes. Polish Journal of Chemical Technology 21(2), 43-51. DOI: 10.2478/pjct-2019-0019.

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