Supplementary material

Treatment of the anaerobic digestate with wood ash: State-of-the-art and possibilities

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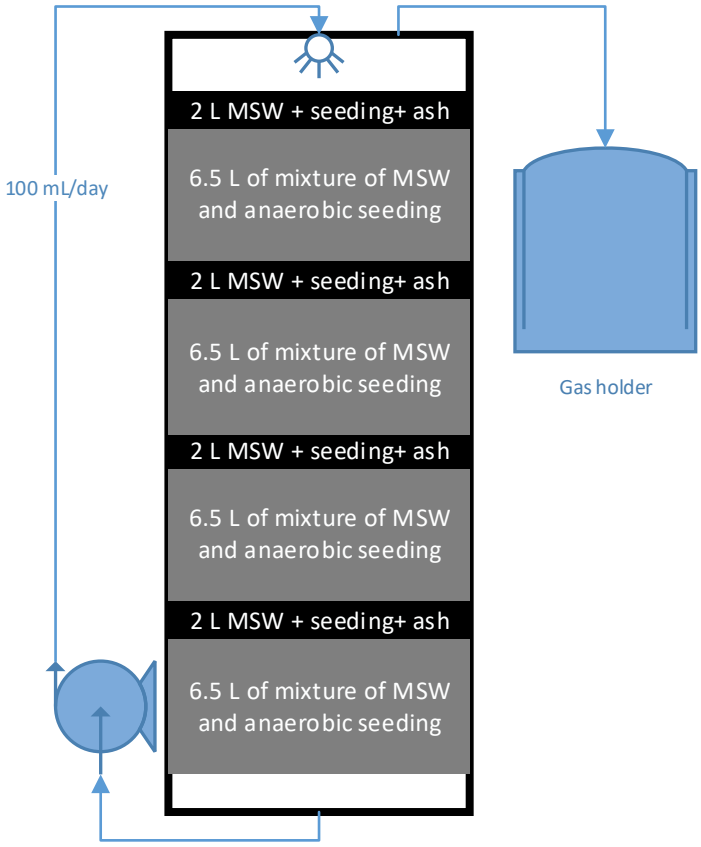

Figure S1. Leaching or percolate bed reactor employed by Lo et al. [35] to assess the feasibility of using MSW fly ash as interim cover of MSW landfill. The mixture of MSW and anaerobic seeding was prepared with 11 parts of the former and 6 parts of the latter. The 3 doses of MSW fly ash tested included in the interim covers 0 (control experiment), 55 or 110 g of this material. Reproduced with the permission of Journal of Hazardous Materials (Elsevier).

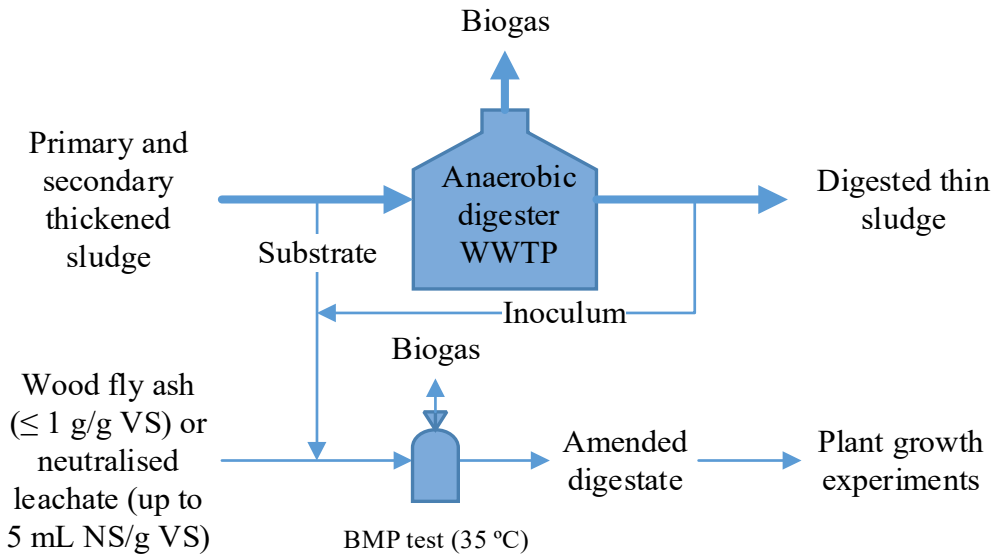

Figure S2. Optimisation of the process of valorisation of the thickened sludge from the WWTP via co-digestion with wood fly ash or using the neutralised leachate of the wood ash as source of trace elements while preventing the increase of the pH. This figure was elaborated based on the description provided by Bauer et al [38].

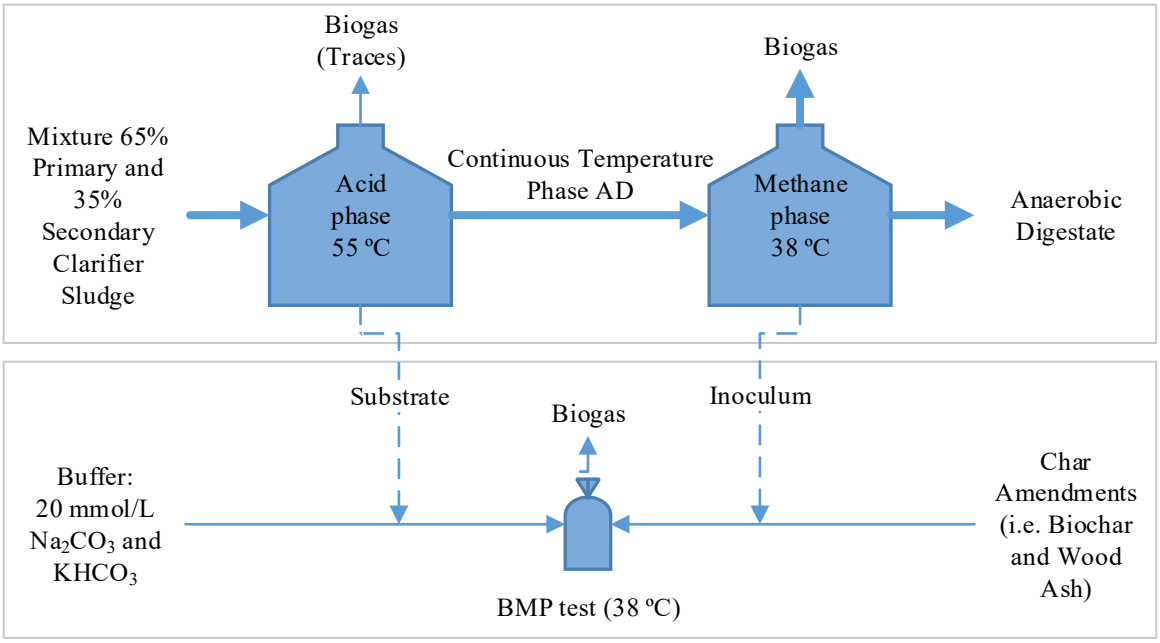

Figure S3. Optimisation of the temperature-phased AD by means of using char amendments (i.e. biochar and wood ash). In order to conduct the BMP tests, Cimon et al. [39] took the substrate from the first stage of the AD process and the inoculum from the second phase. This figure was elaborated based on the description provided by Cimon et al. [39].

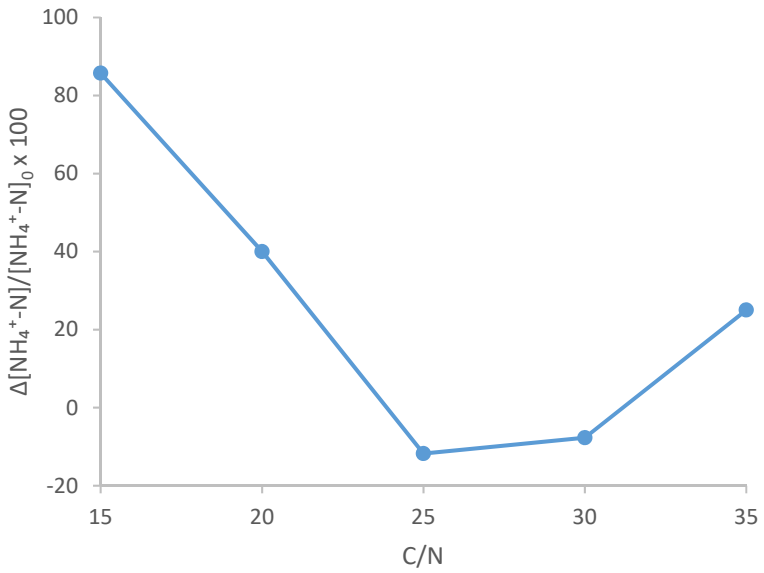

Figure S4. Experimental values of maturity based on the work of Wang et al. [58] about trying to optimising the feedstock composition for a greater methane production during the anaerobic co-digestion of dairy manure, chicken manure and wheat straw.

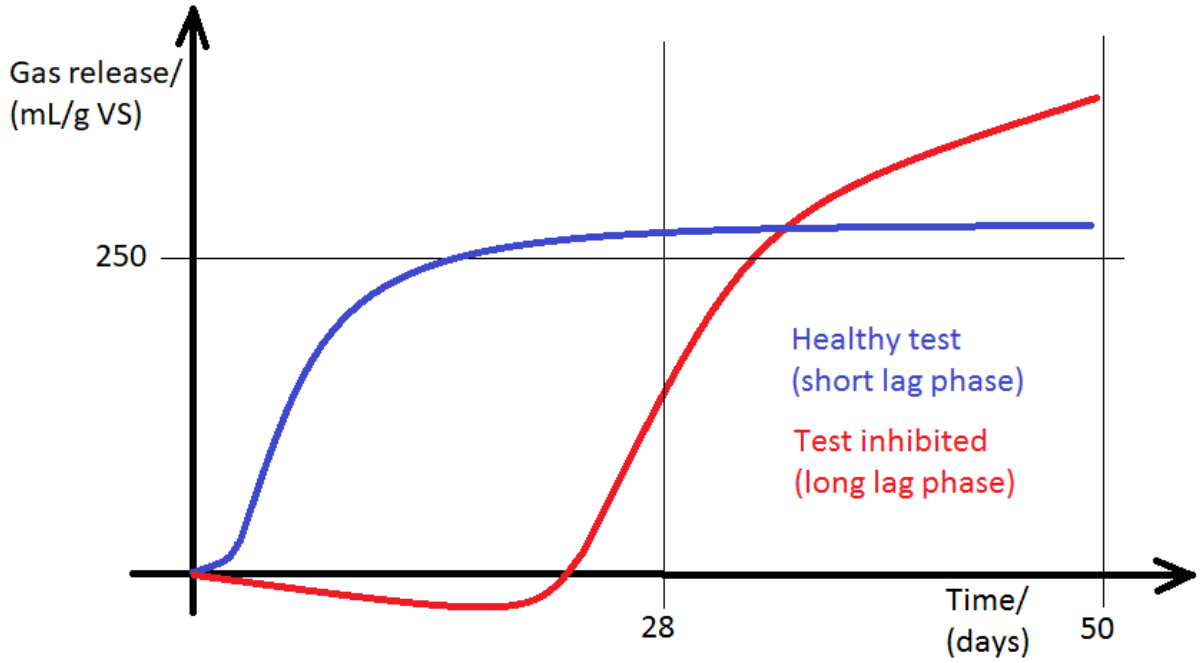

Figure S5. Inhibited BMP test by high COD concentration can lead to regard samples as stable when they are releasing more gas than the stablished upper limit. This example is a modification of the figure 17 of the RBP test methodology [49,50].

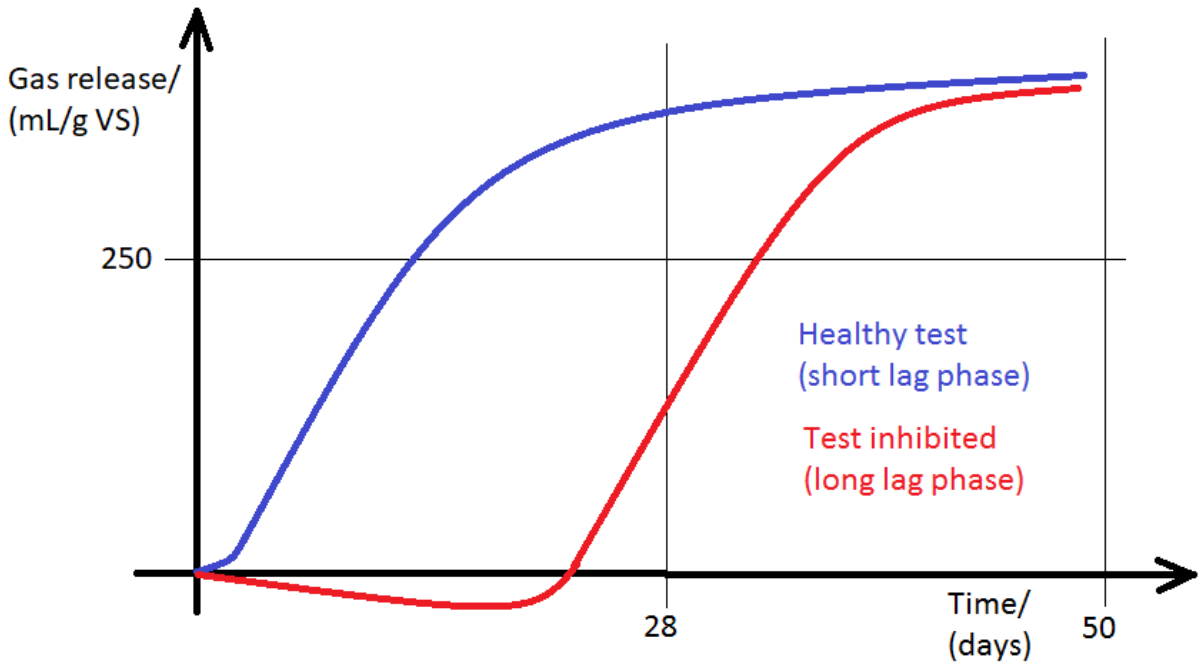

Figure S6. Inhibited BMP test by low S/I can lead to regard samples as stable when they are releasing more gas than the stablished upper limit. This example is a modification of the figure 17 of the RBP test methodology [49,50].

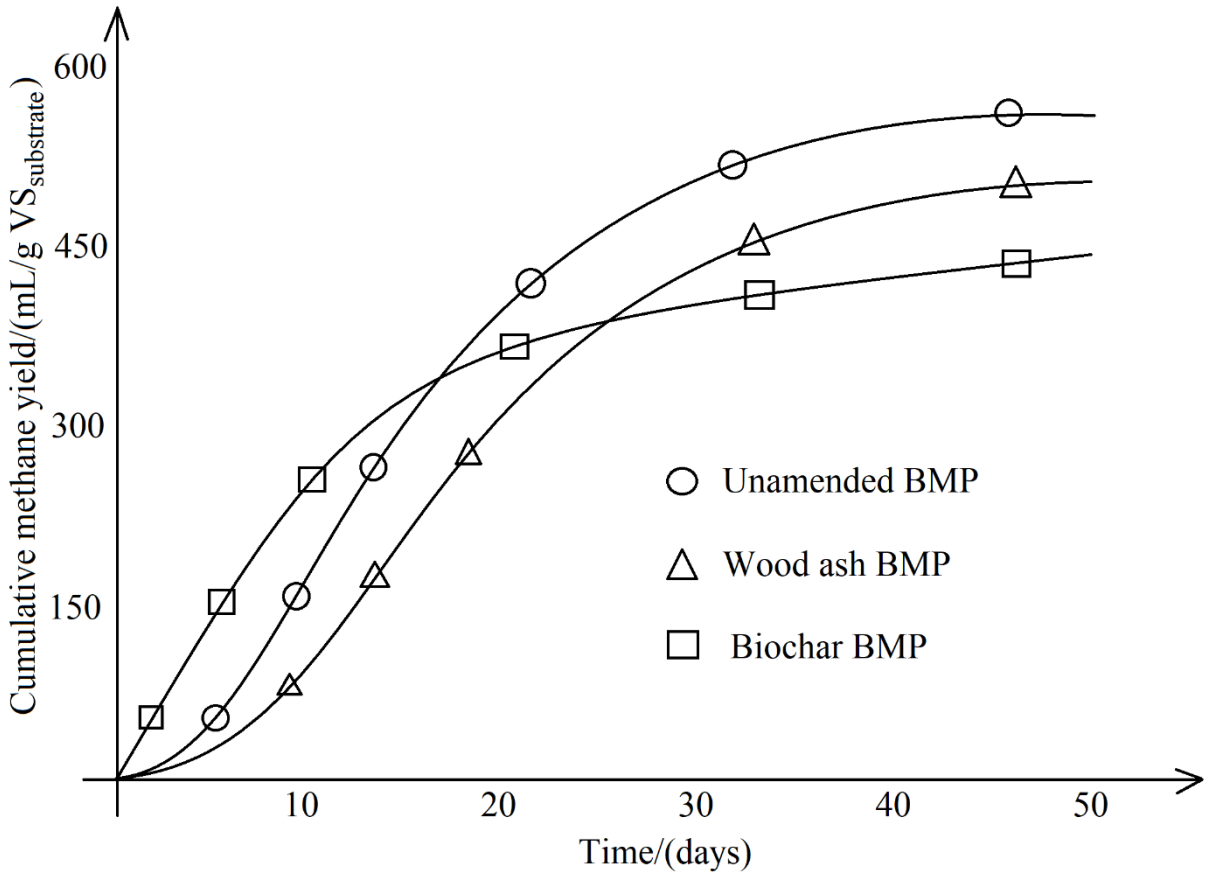

Figure S7. Summary of the results of Cimon et al. [39] (reproduced with the permission of Elsevier): Both the use of biochar and the wood ash resulted in lower yield than the control experiment (i.e. unamended BMP). Only a significant decrease in the lag phase and an increase in the methane production rate could be found when using the biochar as additive. According to Cimon et al. [39], the lower total amount of biogas released, compared to the unamended BMP, when using the powdered biochar to carry out the BMP test (Figure S3) was due to the adsorption of the VFA, thus less substrate is available for the microbes. The lower total amount of biogas production, compared to the control BMP, when using the wood ash to carry out the BMP test (Figure S2) was due to the greater amount of trace metals available for the microbes that increased the CUE. Reproduced with the permission of Bioresource Technology (Elsevier).

Calculation of the blending ratio or wood ash and anaerobic digestate based on the threshold values in the UK regulation

The following assumptions were made for the calculation:

1. Consider the threshold value reported in the UK Quality Protocol of PL ash [84] for the WA. According to this Quality Protocol [84], the incineration fuel can contain up to 10 % of forestry waste (e.g. woodchip) but it needs to have a minimum of 85 % of PL.
2. WA that meet the Quality Protocol of PL ash [84] is no longer regarded as a waste.
3. The blend of WA and anaerobic digestate is not regarded as a waste.
4. Consider a moisture content of 5 % for the PL ash and 90 % for the anaerobic digestate.

The specifications for the heavy metals in the PL ash and the anaerobic digestate (Table S1) were used to determine the blending ratio of WA and digestate (Table S2).

Table S1. Upper limits of heavy metals reported in the EoW criteria of anaerobic digestate and PL ash [48,84].

Metal/(mg/kg fresh weight)	PL ash [1]	Digestate (< 1 kg N/t)	Digestate (> 9 kg N/t)
As	17	0.12	1.2
Cd	3		
Co	11		
Cr	31	8	80
Cu	596	16	160
Hg	0.5	0.08	0.8
Mn	3,500		
Mo	45		
Ni	24	4	40
Pb	244	16	160
Se	11		
V	20		
Zn	2,063	32	320

[1] Reported in dry weight but employed in fresh weight for the calculation considering the low moisture content of the ash (< 5 %).

Table S2. Calculation of the blending ratio based on the content of Zn in the anaerobic digestate supplemented with WA.

		< 1 kg N/t	< 9 kg N/t	DOSE/(g TS wood ash/g TS digestate)	0.147345		1.473545	
		MIN	MAX	DOSE/(% w/w)	1.55%		15.51%	
mg/kg	PLA	Digestate	Digestate	g wood ash/kg anaerobic digestate	15.51	15.52	155.11	155.12
As	17				0.26367	0.26384	2.63687	2.63704
Cd	3	0.12	1.2		0.04653	0.04656	0.46533	0.46536
Co	11				0.17061	0.17072	1.70621	1.70632
Cr	31	8	80		0.48081	0.48112	4.80841	4.80872
Cu	596	16	160		9.24396	9.24992	92.44556	92.45152
Hg	0.5	0.08	0.8		0.007755	0.00776	0.077555	0.07756
Mn [1]	3500				54.285	54.32	542.885	542.92
Mo	45				0.69795	0.6984	6.97995	6.9804
Ni	24	4	40		0.37224	0.37248	3.72264	3.72288
Pb	244	16	160		3.78444	3.78688	37.84684	37.84928
Se	11				0.17061	0.17072	1.70621	1.70632
V	20				0.3102	0.3104	3.1022	3.1024
Zn [2]	2063	32	320		31.99713	32.01776	319.9919	320.0126

[1] The upper limit for the manganese is not reported for the anaerobic digestate in the BSI PAS 110:2014 [48]. The reason might be that UK Quality Protocol for anaerobic digestate [83] specifies the biowaste types acceptable for the production of quality digestate, which general contain a low amount of this heavy metal.

[2] The second highest allowance in the PL ash is for the zinc, and it was found that the concentration of this element is the limiting factor that determines the blending ratio of wood ash and anaerobic digestate.