Ammonia nitrogen recovery and volume reduction of anaerobic digestates by vacuum evaporation without chemical additives

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In the transition from fossil to a bio-based economy, it has become an important challenge to maximally recover and reuse water and valuable nutrients from manure and digestate processing to reach a circular economy in agriculture. Vacuum evaporation is a robust and proven technology that has an attractive potential to separate water and concentrate nutrients in easily transportable and high-value green fertilizers while at the same time reducing digestate volume (Lindmark et al., 2011; Vaneeckhaute et al., 2012, 2013). The key issue of digestate fractioning is to increase economic and environmental viability of biogas plants by reducing digestates volume and convert this by-product into transportable and value-added bio-fertilizers, thus reducing digestate management cost. In fact, biogas digestate use as a fertiliser falls under the European Nitrogen Directive (91/676/CEE) and biogas plants are to be equipped to enable the storage of manure and digestate for at least six months of the year. An additional bottleneck is that long-term applications of digestate or manure on the same land can lead to a phosphorus excess deposition due to the N/P ratio in such organic fertilizer and spreading plans computed only on the nitrogen basis. There is thus a need to develop digestate and manure treatment technologies to enable their volume reduction and the decoupling of N and P. In addition, such biogas plants also have available a surplus heat energy from the combined heat and power (CHP) units that is not always used optimally.

Vacuum evaporation could be a valuable technology to solve these problems. This process consists in the removal of water from liquid products through its evaporation at negative pressure and subsequent recovery as a condensate. It could advantageously make use of the excess heat from the engine of the co-generation unit of the biogas plant and offers the possibility of reducing storage and transportation cost of digestate (Chiumenti et al., 2013). When vacuum evaporation technology is applied to biogas digestate, usually, digestate is first degassed by adding sulphuric acid leading to a pH decrease below 5 that allows subsequent trapping of ammonia nitrogen in the concentrate. Condensate usually requires an additional cleaning phase with a reverse osmosis membrane filtration to catch the residual organic contaminants and allow water reuse or discharge. During this acidification, ammonia nitrogen is converted into ammonium sulphate which may lead to soil acidification and microbial ammonium oxidation to nitrate, the latter being easily leachable.

If vacuum evaporation gains attractiveness in the biogas sector, there is a lack of information concerning its long term use, digestate behaviour leading among other pitfalls to pipe clogging over the evaporation process. In addition, vacuum evaporation could be used to recover ammonia nitrogen in the condensate instead of trapping it in the concentrate, thus allowing the production of a liquid nitrogen fertilizer and the decoupling from P (mostly retained in the solid fraction of digestate) without adding chemicals to the process. In fact, condensates obtained from non-acidified digestate treated by vacuum evaporation present high ammonia content (Chiumenti et al., 2013; Guercini et al., 2014). This work aims at evaluating ammonia-nitrogen and water separation of digestate over time through vacuum evaporation treatment under different temperature and vacuum conditions and without any chemical addition. Liquid fractions of digestate (LF-DIG) from two agricultural biogas plants were obtained after mechanical solid-liquid separation with a screw-press. Total solids were 6.11 and 6.13%, volatile solids were of 61.03 and 57.56%, total Kjeldhal nitrogen (TKN) was 6.42 and 3.94 g kg^{-1}and total ammonia nitrogen (TAN) was 4.47 and 3.52 g kg^{-1} for Faascht and Kehlen LF-DIG, respectively. LF-DIG samples were evaporated under different vacuum and temperature conditions (Table 1) in a pilot-scale evaporator of 5 L total volume. For each evaporation campaign a batch of 1 L of digestate was treated over a period of 180 minutes. Condensate fractions were collected hourly in a condenser cooled at 12°C. TAN was measured on each condensate fraction by vapour distillation followed by acid titration.

Water removal rate showed a linear trend over the treatment duration (Figure 1a). A linear regression of the percentage of water removal over time was modelled for each working conditions and is presented in Table 1. Determination coefficients were above 0.95 for most of the regressions (8 out of 11). Water removal rate was strongly affected by the digestate origin (Table 1). LF-DIG from the Kehlen always had a water removal rate lower than half of that of the Faascht biogas plant when evaporated in the same conditions. For example, at 80°C and 30 hPa, 22.6 and 8.6 % of water was removed each hour from the LF-DIG of Faascht and Kehlen, respectively. To achieve a water removal rate higher than 10% per hour for the LF-DIG from Faascht at 70°C and 80°C, a negative pressure lower than 20 and 30 hPa must be applied. For the LF-DIG from Khelen, a water removal rate of approx. 8.5% was achieved under the same conditions. Differences in evaporation rates between digestate origins could not be explained by their main composition but demonstrated the importance of adapting the evaporation process to specific digestate sources.

Water and ammonia removal rates over time are presented in Figure 1a and b, respectively, for the LF-DIG from Faascht. In less than 3 hours, about 50% of water was removed (Figure 1a) and more than 70% of ammonia nitrogen could be recovered in the condensate (Figure 1b). TAN content in each condensate fraction ranged between 3 and 20 g L^{-1}.

These results confirmed that vacuum evaporation is a valuable technique for water removal but also for ammonia nitrogen fractioning and recovery from biogas digestate. In perspective we aim at improving the decoupling of water and ammonia nitrogen from the condensate through reverse osmosis and combining membrane filtration with vacuum evaporation for improved fractioning of biogas digestate in the frame of the up-coming bio-based economy.

Table 1. Vacuum evaporation conditions and percentage of hourly volume reduction of the digestate.

Temperature (°C)	vacuum pressure (hPa)	Digestate origin	Percentage of hourly volume reduction (% h^{-1})	R^2
70	**20**	Faascht	16.59	0.97
		Kehlen	8.41	0.98
	25	Faascht	3.30	0.99
		Kehlen	1.24	0.81
	30	Faascht	0.65	0.73
80	**30**	Faascht	22.59	0.86
		Kehlen	8.65	0.99
	35	Faascht	8.44	0.96
	40	Faascht	9.37	0.97
		Kehlen	1.28	0.98
	45	Faascht	0.81	0.97

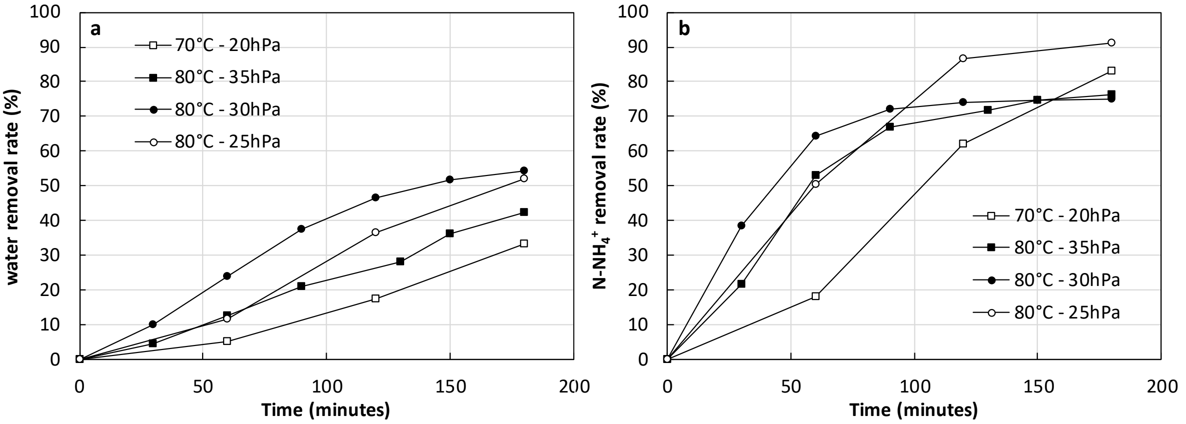

Figure 2. Water (a) and ammonia-nitrogen (b) removal rates through vacuum evaporation of digestate from the Faascht biogas plant under different temperature and vacuum conditions.

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