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Abstract:
In order to enhance agricultural biogas plant efficiency, impact of solid digestate post-treatments and recirculation on methane yield were evaluated at lab scale. Several full-scale solid digestates were characterized to determine their residual methane potential. Subsequently, effects of thermo-alkaline or short-term aerobic post-treatments on solid digestate methane potential were measured. Results show that direct recirculation of 50% of agricultural solid digestate leads to a low increase on plant methane yield (less than 3%). Therefore, post-treatment cost has to be carefully taken into account as potential gains are weak. Thermo-alkaline treatment leads to a 30-45% increase of the solid digestate methane yield but its cost at full scale is not profitable. On the contrary, short-term aeration post-treatment can be performed at low cost at industrial scale but it leads to methane losses since the remaining easily biodegradable fractions are degraded instead of lignocellulosic ones.

Keywords: Solid digestate; Post-treatment; Recirculation

Session – Post-treatments anaerobic effluents/digestates

Introduction
At full scale, Hydraulic Retention Time (HRT) and feedstock type are the two key parameters affecting biogas plant efficiency (Ruile et al., 2015). To ensure a high efficiency, HRT has to be adapted as a function of the feedstock (Muha et al., 2015). However, current co-digestion processes and empirical selection of the HRT in agricultural biogas plants often lead to remaining methane potential in the digestate. Therefore, a good management practice of digestates has to be identified in order to enhance efficiency and environmental footprint of agricultural biogas plants. For liquid digestates, coverage and heating of the storage tank were identified as good practices (Bacenetti et al., 2016; Lijo et al., 2017) and they are often implemented at the industrial scale. However, for solid digestate, there is currently no good management clearly advised. This study focuses on increasing agricultural biogas plant efficiency by recirculating part of the solid digestate. Additionally, two post-treatments were tested to enhance biodegradability and methane yield of solid digestates: (i) a thermo-alkaline post-treatment using soda, as it was proven to be an efficient pretreatment to degrade lignin (Carrere et al., 2016), (ii) a short-term and controlled aerobic post-treatment, as long-term composting of solid digestate leads to low methane yields (Menardo et al., 2010). Impact and interest of such practices are evaluated regarding potential economic gains at full scale.

Material and Methods
<u>Origin and characterisation of solid digestates</u>
Solid digestates were sampled from screw-press facilities in six agricultural biogas plants located in France. Total solids (TS) and volatile solids (VS) were measured according to standard protocols (APHA method) and BMPs were prepared similarly to Rouches et al., (2016) and performed following standardized practices (Holliger et al., 2016).

Evaluation of direct recirculation strategy

Two hypotheses were made: (1) solid digestate was not replacing substrate; (2) a reasonable quantity of solid digestate that can be recirculated corresponds to 50% of the total amount produced. Indeed, part of it needs to be returned to the soil and a higher amount would probably increase digester total solids too much. Direct recirculation consists in the farmer picking up solid digestate at the outlet of the screw press and reincorporating it into the hopper. BMP values, corrected by a 0.8 factor (Holliger et al., 2017), were used to simulate recirculation process at full scale.

Soda post-treatment

Thermo-alkaline soda post-treatment was performed on three of the digestates. Soda was added to solid digestate at 2%w and maintained at 55°C for 3 days at 120 rpm. Then, inoculum was added and BMP tests were started.

Short-term aerobic post-treatment

Short-term aerobic post-treatment was evaluated on two solid digestates. Solid digestates were placed inside 2.5L bioreactors equipped with an aeration system. Several short duration (1.5 to 6 days) and airflow (1.5 to 30 L/h/kg of TS) were tested at 30°C. Finally, mass loss due to respiration was evaluated by trapping the emitted CO_2 in a soda solution, of which conductivity was measured. It was considered that all carbon losses under the form of CO_2 during the post-treatment would have otherwise given biogas (ratio 60% CH_4/40% CO_2). BMPs and matter fractionating method (Jimenez et al., 2015) were performed on treated solid digestates.

Results

Data on biogas plants, solid digestates characterization and the impact of the direct recirculation are summarized in Table 1. For all plants, recirculation of 50% of the total amount of solid digestate produced leads to an increase in plant methane yield as solid digestate still contains biodegradable organic matter. However, this increase is relatively low (1-2.6%). Economic gains from this additional methane are between 8.5 and 28 k€/year. Even with the added operational costs, such strategy should be beneficial for biogas plants. The following question is raised: can additional post-treatment be economically viable?

Table 1 Agricultural biogas plant features and effect of direct recirculation strategy on plant methane yield.

Plant name	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
Main type of waste	Catch crop beet pulp	Bovine manure & cereal waste	Bovine manure & straws	Swine manure & beet pulp	bovine manure & food waste	Green waste
HRT (days)	120	100	120	25	80	18
Type of valorization	upgrading	upgrading	CHP	CHP	upgrading	upgrading
Methane production (Nm^3/year)	1 060 000	1 060000	1 201 000	775 000	1 020 000	1 020 000
Incomes (k€/year)	1130	1130	745	500	1088	1090
Quantity of solid dig. produced (tons/year)	1100	1500	2000	1600	2400	2600
Volatile solids (% fresh matter)	21	16	20	20	19	29
BMP of solid dig. without treatment (Nml CH4/g VS)	129	150	145	155	158	67.5
Plant methane yield increase if 50% solid dig. directly recirculated (%)	0.98	1.34	1.85	2.6	2.58	1.87
Economic gains from methane (k€/year)	11.2	15	13.8	8.5	28	20.5

Thermo-alkaline post-treatment using soda was tested on plant A, B, C and had a positive impact on the solid digestate methane yield. BMP values indeed increased respectively by 45%, 35% and 30% (see Table 2). However, additional gains towards direct recirculation, around 5000 €/year, are too small regarding additional CAPEX (treatment tank) and OPEX (soda, heating & mixing). Therefore, thermo-alkaline post-treatment is too expensive and not viable at full scale.

Table 2 Effect of thermo-alkaline post-treatment on plant methane yield and economic gains

Plant Name	**Plant A**	**Plant B**	**Plant C**
BMP of solid dig. without treatment (Nml CH4/g VS)	129	150	145
Plant methane yield increase if 50% solid dig. directly recirculated (%)	0.98	1.34	1.85
BMP of solid dig. with thermo-alkaline treatment (Nml CH4/g VS)	188	209	195
Plant methane yield increase if 50% solid dig. is post-treated & recirculated (%)	1.43	1.86	2.48
Economic gains from methane (k€/year)	16.3	21.1	18.5
Net gains towards direct recirculation (k€/year)	5	6.1	4.7

Thus, low-cost post-treatments have to be considered such as short-term aeration post-treatment. This post-treatment was performed on solid digestates of plants B and C. Carbon loss due to respiration was always detected and taken into account when methane yield was calculated. For plant B (Figure 1), when a strong aeration was applied (10 or 20 L/h/kg TS), methane yield was 10-20% lower than the control (untreated blank). Even for lower airflow (1.6 L/h/kg TS) but longer duration, the methane yield was not significantly enhanced. For plant C solid digestate, similar results were found (data not shown). Methane loss was around 15% whatever the applied airflow and duration.

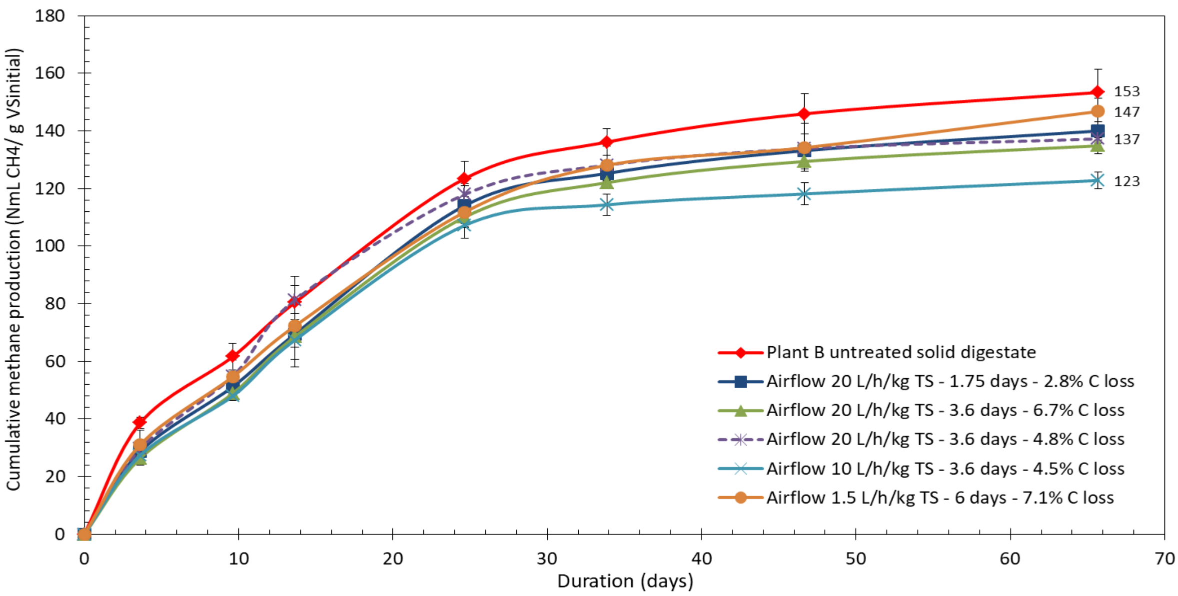

Figure 1 Effects of several short-term aerations on methane potential of plant B solid digestate (mass loss included)

Such results can be explained by the composition of the organic matter of solid digestate (Figure 2). Indeed, a fraction of easily biodegradable organic matter (solubles, proteins, sugars) remains in the solid digestate; for instance, 19% in plant B solid digestate (SPOM+SEOM). During the short-term aeration post-treatment, lignin and holocelluloses fractions are not degraded by aerobic endogenous microorganisms. Instead, easy-to-degrade fractions, which would have given methane in a direct recirculation strategy, are respired under the form of CO_2. Thus, in the case of a solid digestate aerated 6 days at low air flow, the easily biodegradable fraction (SPOM+SEOM) was reduced by 20%. Endogenous microorganisms do not display naturally, under aerobic conditions, ligninolytic activities and they only degrade the easily degradable matter. Lower methane yields obtained can be explained by: (1) almost no gain in solid digestate biodegradability as lignin fraction is not degraded; (2) matter loss due to respiration. Thus, despite its interesting lower cost, a short-term aeration post-treatment does not permit to enhance methane yield of solid digestate.

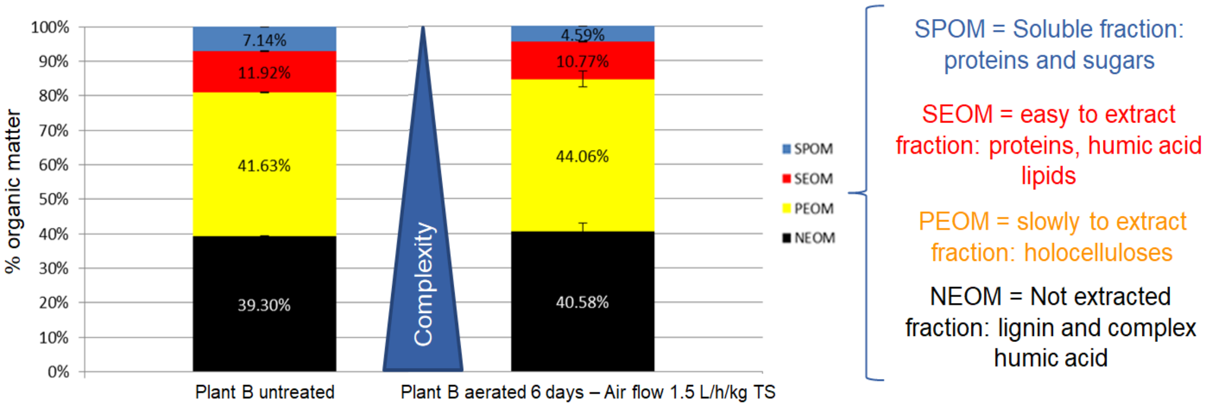

Figure 2 Example of the effect of short term aerobic post-treatment on organic matter bioaccessibility

Conclusions

We have shown, at lab scale, that direct recirculation of solid digestate can be a good strategy to slightly enhance agricultural plant methane yield by 1-2.6%. For farmers, such increases are interesting as this strategy is easy to implement at full scale. Some agricultural biogas plants in France are already performing this strategy but a full-scale study is still needed to clearly evaluate its economic interest (OPEX determination).

Thermo-alkaline and short-term aerobic post-treatments do not appear to be beneficial in comparison to direct recirculation as methane yield or/and economic gains are weaker.

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