DIGESTATE TREATMENT BY MEANS OF A FULL SCALE MEMBRANE SYSTEM: AN INNOVATIVE METHOD FOR MANAGING SURPLUS NITROGEN AND FOR VALORISING FARM EFFLUENTS

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1 INTRODUCTION

The present study is a part of a comprehensive Research Project financed by Veneto Agricoltura and the Veneto Region, with the main objective of evaluating the most promising processes for the treatment of digestate and farming effluents, in the optic of complying with the Nitrates Directive. Membrane treatment, i.e. ultra-filtration and reverse osmosis, represents a high-tech system derived from other sectors, including industrial applications and the production of drinking water (US EPA, 2005). This particular type of plants represents an extremely new solution for the treatment of digestate or manure, but the benefits that this technology could offer make it particularly promising (Chiumenti et al., 2009). These plants are complex and the application of this technology to this field required intense studies and field tests. In order to verify the efficiency of these plants monitoring campaigns were conducted on full scale units located in Europe (Germany, Switzerland and Belgium in particular) treating digestate from anaerobic digestion plants. The present work aims to present the results of the first monitoring period carried out in Germany. The tests were performed analyzing the input and output flows, with particular attention to the destiny of N and P. Other tests are being conducted for improving the valorization of the different fractions obtained by this type of process.

2 MATERIALS AND METHODS

2.1 The anaerobic digestion plant

The anaerobic digestion (AD) plant that feeds the treatment plant is located in Lastrup, Germany, and has been operating since 2003. The biogas plant is composed of n.2 digesters (2.200 m^3 each), which are made of concrete and are equipped with insulation panels covered by protective metal panels. The produced biogas is captured and stored by means of a dual film plastic cover installed on each digester. The thermal regime of the process is mesophilic (35-38°C).

A covered tank, without heating system and insulation, serves as storage of digestate and determines an additional recovery of biogas. The plant is fed with swine manure, poultry manure and other biomasses, such as corn silage. The correct mix to be sent to the biogas plant is prepared in a dedicated tank, where solid and liquid feedstocks are loaded: this unit, equipped with heating system, is weighted by load cells in order to determine the exact quantity of each material. The typical poultry manure/swine manure/corn silage ratio is of 1/4/5. The total daily load of the biogas plant is of 90 t/day. The produced biogas powers a 836 kWe Coupled Heat and Power (CHP) unit: the electric energy is delivered to the grid, while the thermal energy is used for heating the digesters and for farm uses.

2.2 The post-treatment facility

Digestate produced by the anaerobic digestion plant is subject to an advanced physical treatment composed by different stages, represented by liquid/solid separation (SEP), centrifugation by decanter (DEC), ultra-filtration (UF) and reverse osmosis (RO). The first treatment stage is a coarse separation performed by means of typical farm equipment, the screw-press, which operates on raw digestate (ED_0) and determines the separation of coarser solids (SS_1). The clarified fraction of digestate (CH_1), hence, is mixed with flocculants and reaches the second treatment stage: this second process is performed by means of a decanter, horizontal rotating drum type, which determines the separation of another solid fraction (SS_2) from a clarified fraction (CH_2). While the solids are stored on a concrete slab, the liquid fraction is subject to the advanced separation stages. The first stage of the advanced filtration system is represented by an ultra-filtration unit, featuring ceramic membranes and composed by 6+6 parallel sub-units, operating at a pressure of 200 kPa. This first membrane separation determines the production of a concentrated fraction (CON_1), which is recirculated to the decanter flocculants dosing tank, and a filtered fraction, called permeate (PER_1), which is sent to final step, the reverse osmosis. The reverse osmosis unit is composed of a low pressure section (900 kPa) followed by a high pressure section (3.900 kPa), sequentially operating on n.4 filtering columns. The outputs of the final stage are represented by a concentrated fraction (CON_2), which is sent to storage tank, and the final permeate, representing the "clean" output of the treatment plant.

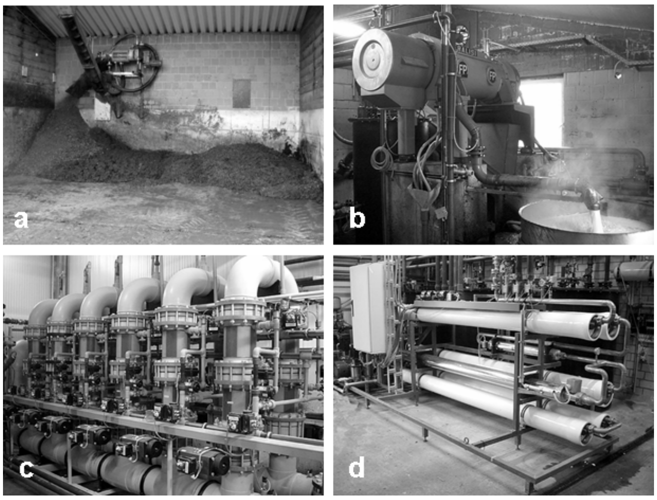

FIGURE 1 **Close ups of the main stages of the treatment: screw-press liquid/solid separation (a), decanter separation (b), ultra-filtration (c), reverse osmosis (d).**

2.3 Analytical methods

The inputs and outputs of each stage were sampled, on regular intervals of each day of the monitoring, and analysed to determine: - pH; - Total Solids (TS); - Volatile Solids (VS); - Chemical Oxygen Demand (COD); - total nitrogen (N-T); - total ammoniacal nitrogen ($N\text{-}NH_4^+$); - total phosphorus (P); total potassium (K); - nitrites e nitrates (NO_2^-, NO_3^-), only on liquid fractions; - conductivity (CE), only on liquid fractions; - redox potential (REDOX), only on liquid fractions. The main parameters (TS, VS, COD, TKN, $N\text{-}NH_4^+$, P, K, Mg, Ca, S, Cu) were determined by means of standard analytic methods (IRSA-CNR, Metodi per l'analisi delle acque, DIN 38414, ISO 11261, ISO 11732, ISO 11885). Nitrates and nitrites concentration was determined by means of Quantofix analytic kit. Electric conductivity and redox potential were determined by means of portable instruments equipped with electrochemical certified probes. The mass flows of different treatment stages were determined by flow meters and gravimetric methods. These measurements were performed on the liquid fractions (ED_0, CH_1, CH_2, PER_1, PER_2) and on the solid fractions (SS_1, SS_2, CON_2).

3 RESULTS AND DISCUSSION

3.1 Chemical-physical characteristics

The main chemical-physical characteristics of the inputs/output of each stage of the treatment process are reported in tables 1 and 2. The concentration of total solids was subject to a decrease determine by the progressive filtration sorted by the multi-stage process: in particular, total solids decreased from initial 71.0 g/l to 1.3 g/l of the final output (i.e. RO permeate), showing a significant reduction mainly sorted by the decanter, that determined a reduction of solids of 58.8% (from 59.2 g/l to 24.4 g/l.

The content of volatile solids, representing the organic fraction, decreased from 53.1 g/l of digestate to 2.5 g/l of UF permeate. In particular, the organic fraction represented almost 75% of digestate total solids, while the first two stages of the treatment determined a reduction of 32%. A similar result was obtained also for COD, which represents an estimation of the organic content, that was subject to a reduction of 91.8% with the first three stages of treatment (SEP+DEC+UF), as underlined by 4'660 mg/l of UF permeate.

Total nitrogen concentration on digestate resulted of 4.96 g/l. The first two separation stages (SEP+DEC) determined a slight reduction of total nitrogen, while the advanced filtering systems determined a higher reduction from 3.750 g/l of decanter output to 1.930 g/l after UF and 0.085 g/l after RO. The concentration of total nitrogen was reduced of more than 98%. As far as ammonium is concerned the tests showed that main removal, in terms of concentration, was sorted by the final stages of the process: from 2.28 g/l of digestate (ED) ammonium was reduced to 1.59 g/l of UF permeate to 0.025 g/l of RO permeate. The effect of the treatment on phosphorus, instead, was different: for this element the first two stages (SEP + DEC) determined a significant reduction from 2.205 g/l of digestate (ED) to 0.275 g/l of decanter liquid output (CH_2). Potassium concentration was reduced mainly in the last filtering stage (RO), from 2.740 g/l to 0.045 g/l of the final effluent. Conductivity ranged from 19.0 to 25.3 mS/cm in the first three phases of filtration (SEP+DEC+UF), while in the last step (RO) a substantial reduction was achieved, so that the final product showed a conductivity as low as 0.3 mS/cm.

As far as the solid fractions is concerned the outputs from screw-press and decanter (SS_1-SEP e SS_2-DEC), and concentrate from reverse osmosis (CON_2-RO) represent the "solid" output of the entire treatment process, while the concentrated fraction out of the ultra-filtration is not considered an output since it is recirculated to the decanter. The content of total solids resulted of 19.8% and of 15.8% for the outputs of screw-press and decanter respectively. The percentage of volatile solids in these fractions is relevant in comparison to the content of total solids, respectively 89.9% and 75.9%. Total nitrogen resulted 0.666% and 1.075% in solids from first (SEP) and second treatment stages (DEC). In these outputs ammonium represents only a small portion of total nitrogen, such as 0.184% and 0.217% (with N-NH_4^+/N-Tot ratio of about 0.2-0.3).

TABLE 1 **Characteristics of digestate and of the liquid effluents of the process**

Effluent	pH	TS (g/l)	VS (g/l)	COD (mg/l)	total N (g/l)	N-NH_4^+ (g/l)	P (g/l)	K (g/l)	Conductivity (mS/cm)
ED	7.9	71.0	53.1	56'500	4.960	2.280	1.205	5.355	21.6
CH_1	7.8	59.2	41.9	57'000	4.780	2.270	2.000	5.485	25.3
CH_2	8.1	24.4	14.6	16'200	3.750	2.130	0.275	4.255	21.5
PER_1	7.8	7.7	2.5	4'660	1.930	1.590	0.050	2.740	19.0
PER_2	8.1	1.3	-	-	0.085	0.025	-	0.045	0.3

TABLE 2 Characteristics of solid outputs of the different stages of the process

Effluent	TS (%)	VS (%)	Total N (%)	N-NH_4^+ (%)	P (%)	K (%)
SS_1	19.8	17.8	0.666	0.184	0.516	0.521
SS_2	15.9	12.1	1.075	0.217	0.743	0.470
CON_1	2.9	2.1	0.446	0.221	0.045	0.413
CON_2	2.9	0.7	0.662	0.543	0.008	0.997

3.2 Mass Balance

Digestate produced by the anaerobic digestion plant and sent to the treatment process resulted to be 3.600 t/h. The screw-press separation system determined an output of clarified digestate of 3.275 t/h, representing, also, the main input of the decanter. This effluent, in fact, is pumped in a mixing tank where it is mixed with concentrate from UF and with flocculants, prior to decanter separation. The flow of solids from the screw-press resulted of 0.325 t/h, corresponding to 9% of the total (AD plant output). The decanter produced 4.018 t/h of clarified liquid fraction and 0.945 t/h of solids: the solid fraction, called also "clay" for it consistency, represents 26% of the total. The throughput of the UF stage resulted to be of 4.963 t/h, with a consequent production of 2.330 t/h of permeate and 1.688 t/h of concentrate. The two-stage RO, fed with the permeate output from UF, produces as outputs 0.600 t/h of concentrate, representing 17% of initial input flow, and 1.730 t/h of permeate, filtered water that represents the final liquid output of the plant. The entire multi-stage digestate treatment plant, in fact, produced 48% of filtered water, 35% of solids stored on a concrete slab, and 17% of concentrate.

The combination of mass flows and chemical analyses, determined for each stream of every stage, allowed the determination of the mass balance of the entire process, with reference to nitrogen and phosphorus in particular. The results underline the distribution of nutrients in the different outputs of the process, expressed as flows (on hourly bases). As far as nitrogen is concerned, the input flow to the treatment plant resulted to be 0.018 t N/h. The first solid/liquid separation stage (screw-press) showed a limited efficiency on removing nitrogen form the liquid phase: the solid fraction, in fact, represents a flow of 0.002 t N/h, corresponding to a separation of 11% of the input. The second separation stage (decanter), instead, showed higher performance, with a removal of 0.011 t N/h from the liquid to the solid phase, equal to 61% of initial nitrogen. The remaining amount of nitrogen was removed by the advanced filtering system (UF+RO): the concentrated fraction from RO, in fact, represents, in terms of flow of nitrogen, 0.005 t N/h, corresponding to a diversion of 28% of initial nitrogen flow. Nitrogen flow in the permeate resulted irrelevant (<0.0001 t/h).

Phosphorus input flow to the treatment plant resulted to be 0.0086 t/h. The first stages of the process (SEP + DEC) showed a high efficiency of phosphorus removal: the flows of this element represented by the streams of solids were of 0.0017 t/h from the screw-press and of 0.0068 t/h from the decanter. Referred to the input these values are equivalent to a separation of input phosphorus of 20% and 79% respectively. The remaining 1% of this element was separated by the membrane system (UF + RO), so that the output in the liquid effluent, the permeate, resulted to be irrelevant.

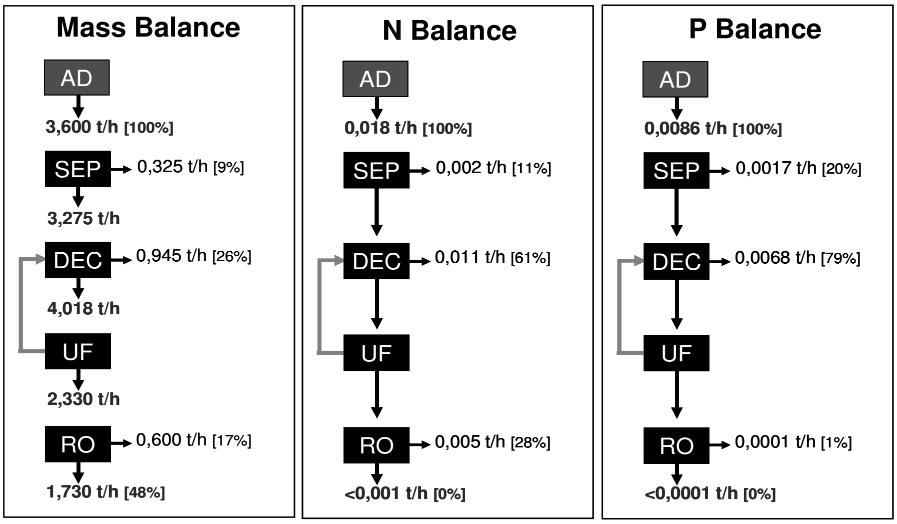

FIGURE 2 **Diagrams of mass balance, nitrogen and phosphorus balances of the entire process.**

4 CONCLUSIONS

The plant subject to the monitoring was a full scale membrane filtering system treating the effluent from an anaerobic digestion plant fed with animal wastes and other biomasses. Main objective of the study was to characterize the different outputs (liquid and solid) and to assess the efficiency in particular in terms of N and P separation, in order to understand if this technology could be considered a valid option for the management of livestock manure.

In terms of nitrogen diversion the pre-treatment allowed to obtain significant results, with a reduction of about 70% of initial nitrogen: this result was determined not by the screw-press separator, that separated from the main flow about 11% of nitrogen, but mainly by the decanter, that removed about 60% of initial nitrogen. The high separation performance of the decanter was partially determined by the recirculation of concentrate from ultra-filtration, but mainly by the use of flocculants in the separation process. The significant concentration of phosphorus in the solid phase represented an expected result (Chiumenti et al., 2008), but the entity of this separation resulted higher than the expectations. In some cases, the reduction gained by the first phases of treatment process could be sufficient. The process, in fact, determines the production of fractions containing about 70% of nitrogen and almost 100% of phosphorus, hence with elevate fertilizing potential, in reduced volumes of solids: a reduction of nitrogen is effectively achieved only with the dislocation of the product, but this becomes easier to perform with such products. The entire process, furthermore, determines the total removal of N from the liquid stream and the discharged water represents the 48% by weight of the treated digestate.

In conclusion, the multistage membrane filtration process proved to be effective in the treatment of digestate, producing a liquid effluent, the permeate, characterised by good quality: the possibility of discharging it on surface water is not easy to be assessed, since the list of requirements involves many parameters. This aspect will be subject to further studies. This product, anyway, could have multiple utilizations as process water (dilution of feedstocks, cleaning, etc.). Another aspect that will be subject to further studies is represented by the energy consumption of the entire process.

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