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Nitrogen and water recovery from animal slurries by a new integrated ultrafiltration, reverse osmosis and cold stripping process: A case study

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ABSTRACT

The correct management of livestock manure represents one of the major challenge for the agricultural sector development, as it may ensure environmental and economic sustainability of livestock farming. In this work, a new treatment process called N-Free®, was monitored on two plants treating digested cattle manure (DCM) and digested swine manure (DSM). The process is characterized by sequential integration of solid/liquid separations, ultrafiltration, reverse osmosis and cold ammonia stripping. Solid and liquid streams were characterized regarding TS, TKN, $N-NH_4^+$, P and K content allowing to draw a complete mass balance. The main results were a substantial reduction of initial digestate volume (38 and 51% in DCM and DSM respectively) as clean water and a high $N-NH_4^+$ removal percentage (47 and 71% in DCM and DSM respectively), through cold ammonia stripping, allowing the production of up to 1.8 m^3 concentrated ammonium sulfate, every 100 m^3 of treated digestate. The concentrated streams, rich in either organic or mineral N, P and K, can be efficiently used for land application. The N-Free® technology demonstrated to be a valuable candidate for the path toward nutrient and water recycle, in a new sustainable agriculture and farming concept.

1. Introduction

The development of livestock production sector has led to a great concern for its environmental impact, due to the production of huge volumes of wastewaters characterized by a high organic and mineral load, mainly nitrogen (N) and phosphorous (P) (Petersen et al., 2007).

It is well known that losses of N due to spread of manure on land may contribute to environmental pollution through several ways: ammonia and nitrogen oxides emission to atmosphere (ApSimon et al., 1991; Bouwman, 1990; Skiba et al., 1997) and nitrate leaching to ground and surface water bodies (Smith and Chambers, 1997).

NH_3 in atmosphere is known to accelerate the formation of particulate matter (PM) and can make up a large portion of its final mass (Clarisse et al., 2009). Ammonium sulfate and nitrate can make up to 60% of fine particulate $PM_{2.5}$ and 40% of the total mass respectively (Clarisse et al., 2009). NH_3 accounts for almost half of all reactive nitrogen released in the atmosphere, having an important role in the acidification and the eutrophication processes (Clarisse et al., 2009).

In aquatic ecosystems, excess N and P concentrations might cause diverse problems such as toxic algal blooms, oxygen depletion, fish kills, loss of biodiversity and aquatic plant beds. Nutrients enrichment degrades aquatic ecosystems and

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impair the use of water for drinking, industry, agriculture and other purposes (Carpenter et al., 1998).

Current environmental legislations do not deal with, hence do not restrict, potassium (K) application in agricultural soils. Nevertheless, K excess related to its growing concentration in soil, has been reported as a cause for mineral deficiencies, imbalances, immune suppression and reproductive losses in herbivores (Masse et al., 2007).

During the last decades, the problem of manure management has dramatically grown forcing European Community to draw Nitrate Directive guidelines (Council Directive 91/676/EEC) followed by corresponding Italian Rules (Dlgs. 152/99, Dm. 7/4/2006), born to overcome these issues by the application of recommended management practices (RMPs), in particular regulating manure disposal and its agronomical use, limiting nitrogen load in agricultural soils (170 kg N ha^{-1}). In Northern Italy, over 70% of Utilized Agricultural Area (UAA) is defined as Nitrate Vulnerable Zone (National Strategic Nitrate Plan, 2009) while 81% of total ammonia emission in the atmosphere is directly correlated with manure management (ARPA, 2010). Moreover, manure incorrect land application leads to a substantial decrease in nutrients availability for plant growth (Chambers et al., 2006), implying the need to integrate cultures fertilizing with chemical products and the increase of agronomical practices economic and environmental costs.

Anaerobic digestion (AD) is a useful technology to produce renewable energy from manure thus to encourage its proper treatment, recycling and disposal, instead of causing environmental pollution and uncontrolled release of greenhouse gases (Kaparaju and Rintala, 2011). The AD treatment of manure and wastewater results, also, in the production of a biologically stable and partially hygienized organic product, i.e. the digestate that could be efficiently used in agriculture as fertilizer and/or organic amendment (Tambone et al., 2009).

Nevertheless, farm land availability is often not sufficient to meet in force regulation on nutrients load limits hence it is necessary to reduce and/or export materials/nutrients to other land. To do this, digested wastewater or slurry must be concentrated or separated into different fractions to be exported from the farm in an economically feasible way.

Solid–liquid separation has been commonly used as a physical treatment process for animal slurries, mainly to improve slurry handling properties, by removing coarse solids and fiber (Burton, 2007). Relatively low cost and simple technologies such as settling basins, screen and press screw separators, have also been applied for the removal of solid material from dilute slurries (Preez et al., 2005). More advanced technologies such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have long been employed in both municipal and industrial wastewater operations (Rautenbach et al., 1996) and are more recently exploited for nutrient concentration and liquid manure treatment (Masse et al., 2007).

In this broad context a new process called N-Free® based on solid/liquid separation and membrane technology was developed, allowing fractionation of digestates and recovery of concentrated streams. This technology has found, recently, in collaboration with the University of Milan (Italy), full scale application in North Italy to treat anaerobic digested animal slurries because anaerobic pre-treatment allows chemical and physical modification of slurries, i.e. organic matter degradation and organic N ammonification (Schievano et al., 2009) allowing high process performances.

The objective of this research was to monitor this process at full scale level to evaluate its efficiency in terms of mass and nutrients balances, with particular reference to N removal from digestate.

2. Methods

2.1. *N-Free® process*

The N-Free® process (Fiolini e Savani s.r.l., Brescia, Italy) is characterized by a series of physical/chemical treatments which allow separation of digestate liquid fraction from digestate solid fraction by means of solids and concentrates and the production of ammonium sulfate. The N-Free® unit operates in batch mode, treating about 14 m^3 of digestate for each cycle. The number of cycles per day, depending on total daily treated volume (50 or 100 m^3 day^{-1}), normally ranges from 4 to 7. In this work, two N-Free® plants located in Northern Italy Nitrate Vulnerable Zones were monitored: the first treats 50 m^3 day^{-1} of digested cattle manure (further called DCM) and the second treats 100 m^3 day^{-1} of digested swine manure (further called DSM).

The process scheme is summarized in Fig. 1. The first separation is achieved with a screw press (SP) separator (Doda, Mantova-Italy). The separation resulted in a solid and liquid stream. As second step, the liquid fraction of the SP is added of a polyamide flocculant and sent to a decanter centrifuge (DC) (MAMMOTH 570/3, Pieralisi, Jesi-Italy), allowing the separation of another solid fraction vs. liquid stream. The liquid enters in the UF unit, that is equipped with a 40 kDa grafted Polyacrylonitrile membrane (PAN) (Orelis, France) with a maximum exercise pressure ranging from 3.5 to 4.5 bar. The permeate liquid proceeds to the last separation unit, i.e. the RO step, which includes two consecutive passages on RO membranes (Dow, USA). The permeate from the RO is finally refined in zeolites bed and then discharged to surface water bodies. On the other hand the concentrate from the RO enters into the cold stripping unit; sludge is added with 15–18 kg m^{-3} sludge of lime which allows pH raising up to 12–12.5. At these conditions, the equilibrium NH_4^+/NH_3 is completely shifted to NH_3 which is easily stripped as gaseous ammonia by using a controlled air flow. Air plus ammonia is then scrubbed with sulfuric acid producing liquid ammonium sulfate (8% on a wet weight basis as N). Any further missing technical characteristics and data regarding the N-Free® system design and operation were not available from manufacturer as protected by patent.

2.2. *Sampling and chemical characterization of N-Free® liquid and solid streams*

Liquid and solid streams were sampled from the observed N-Free® plants 3 times during 3 months of plant normal functioning, after the end of one batch cycle. Each sample was took in triplicates, for a total of 9 samples for each step of the process. Samples were stored in 1 l bottles at 4 °C overnight and then analyzed.