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Ultrafiltration as an advanced tertiary treatment of anaerobically digested swine manure liquid fraction: A practical and theoretical study

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ABSTRACT

The removal of the organic matter of the swine manure liquid fraction has been carried out by an integral process based on two stages: anaerobic digestion in an expanded granular sludge bed (EGSB) reactor followed by ultrafiltration (UF) as a tertiary treatment. The lab-scale EGSB reactor was operating for 39 weeks with a hydraulic retention time (HRT) of 3.8 days; leading to a 70% tCOD removal and a biogas production of 0.15 Nm^3 CH_4 kg^{-1} tCOD removed. The UF process was studied in two different geometry and configuration membrane modules: external tubular (E-T) and submerged hollow fiber (S-HF). Both lab-scale systems have been compared in terms of the filtration selectivity and productivity and the S-HF has been the most selective and productive configuration in the filtration of the EGSB effluent. The whole process (EGSB + S-HF) provides a permeate flow without solids and yields a tCOD removal around 90%. Finally this paper proposes a satisfactory model for the UF of the EGSB effluent in the S-HF module. Both the membrane intrinsic resistance (R_M) and the specific cake resistance (α) have been calculated.

1. Introduction

Traditionally swine manure has been used as a direct fertiliser on agricultural land. However, due to the present trend of raising large herds of livestock in smaller areas, the soil available is not often enough to spill all the manure produced. Nutrients such as nitrogen or phosphorous and the organic matter are the most problematic components of the manure. While the formers are culprits for contamination of soil and groundwater and for eutrophication of surface waters, the latter is believed to be responsible for acute water pollution incidents and for odour problems [1,2].

Anaerobic digestion is an established bioconversion technology for the organic fraction with simultaneous production of biogas. Most of the current full scale plants operate with anaerobic codigestion of pig manure with other organic wastes [3]. However, the degradation has proven to be difficult mainly due to the inhibition of the methanogenic bacteria by high amounts of ammonia in the digester [4,5]. Thus, the treated effluents use to contain high amounts of suspended solids or persistent organic substrates, which prevent them from being directly used for irrigation or spread on soils.

In order to improve the efficiency of the process and increase the biogas production and nutrient removal, more sophisticated treatment systems are being implemented [6]. The use of anaerobic digestion in combination with membrane technology is an alternative to achieve retention of microorganisms and allow operation with high biomass concentrations. This design was known under the acronym ADUF (Anaerobic Digestion with Ultrafiltration) and was originally intended at the early 90s as a treatment solution for highly COD laden wastewater like brewery and starch effluent [7]. The ADUF system has been applied for the treatment of pig manure at pilot scale in the BIOREK® concept [8]. The process consists of a digester (mesophilic or thermophilic) coupled to an external tubular UF membrane, leading to an anaerobic membrane bioreactor (AnMBR). The integral treatment is completed by an ammonia stripping step and a final reverse osmosis (RO) to achieve 90% COD removal and up to 99.9% ammonia removal efficiencies. It has also been studied the performance of a two stage anaerobic system based on an acidogenic reactor with a submerged UF membrane followed by a methanogenic reactor, with a lower part design as an upflow anaerobic sludge blanket (UASB) reactor. COD removal efficiency in this case was 80% and methane gas production was 0.32 Nm^3 CH_4 kg^{-1} tCOD removed [9].

The expanded granular sludge bed (EGSB) reactors were developed to overcome problems that can occur in the UASB such as preferential flows, hydraulic short cuts and dead zones. The use of higher upflow liquid velocities (4–10 $m\,h^{-1}$) and higher

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height/diameter ratios permit the partial expansion (fluidization) of the granular sludge bed, improving the biomass–wastewater contact. Soluble pollutants are efficiently treated in EGSB reactors but suspended solids are not substantially removed from the wastewater stream due to the high upflow velocities applied [10]. EGSB reactors have recently been applied to treat brewery, starch or palm oil mill wastewater [11]. EGSB reactors have shown to be suitable for the treatment of biodegradable toxic of inhibitory compounds such as metals [12]. Since they operate with high recirculation ratios, the inlet is dilute to levels no longer dangerous for bacterial activity [13]. Basing on the capacity of these reactors to overcome inhibition, this work proposes the use of an EGSB reactor for the anaerobic digestion of swine manure where, as it has been already commented, the ammonia interference is one of the major problems [4,5]. As far as we are concerned, EGSB reactors have never been used in this application, so one of the aims of the present research will be to explore the feasibility of this novel treatment.

The treatment of the liquid fraction of the swine manure (hereinafter called LFSM for simplicity) has been completed with a UF membrane in order to prevent the non-degraded suspended solids washout (Fig. 1). This membrane-coupling system could be an alternative for the effective treatment compared to the already cited, AnMBR in the BIOREK® process, or the two stage anaerobic system based on UASB reactors and UF membranes. Compared to these anaerobic digesters, higher loading rates are expected to be achieved in the EGSB reactor. There is a precedent of this membrane-coupled EGSB reactor proposed herein, but for treating domestic wastewater under moderate to low temperature at lab scale [14].

This paper is specially focused on the UF process applied as tertiary treatment of the EGSB effluent, as it is often the critical step because of the membrane clogging and the viscosity effect on mass transfer. Nevertheless, the final objective of this study is the integration of both treatments (EGSB and UF) in an AnMBR reactor which will be further achieved by the UF concentrate recirculation to the feed of the anaerobic reactor (drawn as a broken line in Fig. 1).

2. Materials and methods

2.1. Feed swine manure

Swine manure was collected from a farm located in Avila (Spain). The waste was filtered by a 0.5 mm screen to remove large particles and characterised according to the standard methods (Table 1) [15]. Then, it was stored at 4 °C prior to use.

Table 1
Liquid fraction swine manure (LFSM) characterisation.

Parameter	Unit	Average value ± SD
pH	–	8.01 ± 0.12
Total alkalinity	$g\,L^{-1}$	6.888 ± 0.207
tCOD	$g\,L^{-1}$	9.433 ± 0.472
sCOD	$g\,L^{-1}$	3.194 ± 0.160
BOD_5	$g\,L^{-1}$	3.950 ± 0.592
TS	$g\,L^{-1}$	14.494 ± 0.725
VS	$g\,L^{-1}$	9.501 ± 0.475
TSS	$g\,L^{-1}$	8.157 ± 0.408
VSS	$g\,L^{-1}$	5.228 ± 0.261
TKN	$g\,L^{-1}$	1.710 ± 0.068
NH_4-N	$g\,L^{-1}$	1.413 ± 0.071
Total P	$g\,L^{-1}$	0.203 ± 0.010

Special attention should be paid to the NH_4-N concentration of 1.4 $g\,L^{-1}$, unusually low due to the presence of seaweed in the feeding of the pigs from this current farm, that increases the nitrogen adsorption (reduction at origin). This value is below the estimated limit for inhibition of unadapted methanogenic cultures (1.5–2.5 $g\,L^{-1}$) that could increase up to 4 $g\,L^{-1}$ after adaptation [5].

2.2. EGSB reactor

The EGSB reactor was constructed of Plexiglas with a working volume of 3.2 L (52 mm i.d. and with a quiescent region of 220 mm i.d. at the top). The total volume of the reactor, including the sedimentation part, was 12.2 L. The reactor was installed in a chamber room maintained at a constant temperature of 30 °C. A recirculation pump was used to expand the bed and to control the up flow velocity. Biogas production was measured with an inverted tube (Fig. 2). Methane in the biogas and the volatile fatty acids (VFA) were both analysed by gas chromatography with a flame ionisation detector (FID).

The reactor was inoculated with 3 L of granular sludge taken from an UASB reactor treating wastewater from a paper mill factory to achieve a final sludge concentration of 14.2 $g\,TS\,L^{-1}$ and 9.9 $g\,VS\,L^{-1}$. The collapsed bed height was 99 cm and the expanded height 150 cm. After inoculating the reactor, the granular sludge was acclimated in a batch process with the LFSM for two weeks. Macro and micronutrients were added as follows: $(NH_4)_2HPO_4$ (0.25 $g\,L^{-1}$); KH_2PO_4 (0.02 $g\,L^{-1}$); $MgSO_4{\cdot}7H_2O$ (0.0015 $g\,L^{-1}$); $CaCl_2$ (0.001 $g\,L^{-1}$); H_3BO_3 (0.005 $g\,L^{-1}$); EDTA

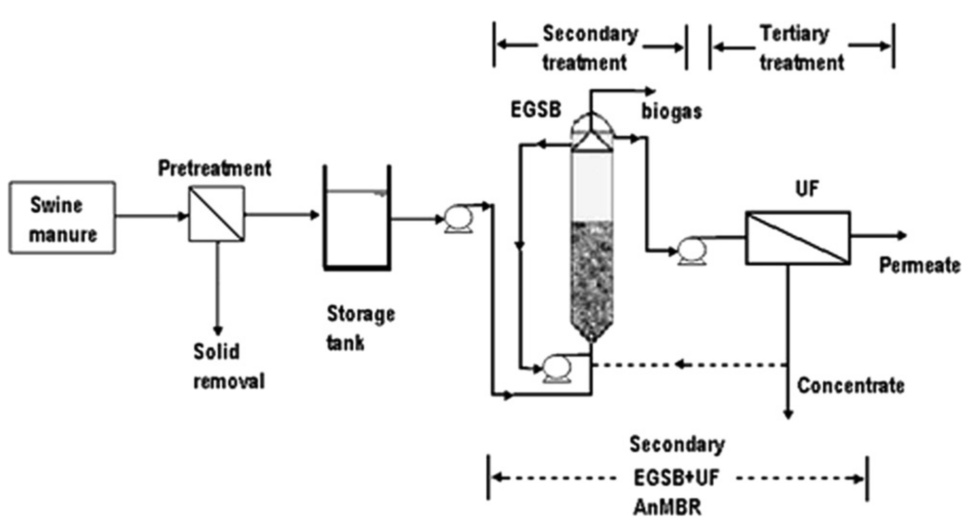

Fig. 1. Treatment of the liquid fraction of the swine manure by using EGSB and UF technologies.