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Pig Slurry Treatment by a Combined Helophytes-Biodiscs System

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Abstract

Pig slurry was treated in a pilot wastewater treatment plant composed of a rotobioreactor based on rotating microalgae-biofilm discs, and a helophytes floating filter. Slurry in this work included cleaning water and its main characteristics were: 8,400-5,500 mg $O_2 \cdot L^{-1}$ COD, 1,575-800 mg $O_2 \cdot L^{-1}$ BOD_5 and 2,275-1,799 mg$\cdot L^{-1}$ total nitrogen. Prior to the experiment, the rotobioreactor was conditioned adding pig slurry for 15 days in order to adapt the microorganisms biofilm to that substrate; at the end of the conditioning period, COD was 3,200 mg $O_2 \cdot L^{-1}$. The experiment was carried out for 10 days, adding 200 L pig slurry$\cdot$day^{-1} to the rotobioreactor. The mixture in the reactor (diluted pig slurry) flowed by plug-flow to the helophytes floating filter to continue the depuration process. After 10-day treatment, the daily average reduction achieved was 88.3% COD, 97.6% BOD_5, 78.5% phosphorous and 85.6% total nitrogen. From the results it was estimated that a load of 1 $m^3 \cdot day^{-1}$ pig slurry would require about 1,008 m^2 discs area in the reactor and 54 m^2 of helophytes floating filter.

Keywords: Bioreactor, Biofilm, Helophytes, Phytodepuration, Pig slurry.

1. Introduction

Pork is the most produced and consumed meat in the world. The annual production of pork is about 115 million tons (Mt), 48% in China, 20% in the European Union and 9% in the United States (FAO, 2014). Thus, massive quantities of pig manure wastes are produced. Pig manure collection and handling vary from farm to farm; some farms collect separately solid (feces) and liquid fractions (urine) but it is more frequent to gather both fractions along with the cleaning water in a mixture, commonly known as pig slurry. Global pig slurry production is around 8.12 billion tons per year and about half of that is produced in China. The entire pig slurry production in the UE-28 is 148.6 Mt per year, being Germany the highest producer (26.7Mt), followed by Spain (25.5 Mt), France (14.4 Mt) and Poland (13.8 Mt) (Foged *et al.*, 2011). Pig slurry is an important source of water and soil pollution due to its high content in organic matter and nitrogen, and to the usual high livestock density per geographic area. On the other hand pig manure and slurry contain significant quantities of essential and minor plant nutrients that can benefit crops and improve soil quality as long as rules and principles of good practices are followed. However, the fact that excessive nitrogen fertilization is a cause of diffuse groundwater pollution has led to fertilizing restrictions, especially in vulnerable zones. Most often there is an excess of slurry that cannot be applied to the soil and that must be treated to avoid environmental problems. Among the slurry treatment technologies it can be highlighted the anaerobic treatment for organic matter removal, the thermal drying of slurry and digested sludge, and the aerobic digestion (aeration) for organic matter degradation and oxidation of ammoniacal nitrogen to nitric nitrogen. Extensive wastewater treatment processes, based on helophytes filters, have been also experimented for slurry depuration (Fernández, 2003). Complete slurry treatment must involve a denitrification stage for reducing the total nitrogen (N_T) content in the effluent. Conventional technologies are expensive and energy-intensive; their feasibility usually depends on public sector resources, economic incentives, framework conditions and national context. This work presents a non-conventional system for pig slurry treatment developed by the Agroenergy Group at the Technical University of Madrid (GA-UPM). This system combines a rotating biological contactor based on microalgae biofilms, which was called biodiscs rotobioreactor (BD-RBR), and a helophytes floating filter (HFF). Such system is easy to install in farms and requires little investment and low energy input.

2. Material and methods

The experiment was carried out in the GA-UPM facilities (Madrid, Spain) (longitude: 3º44’12”, latitude 40º26’26”) in October, 2015. Slurry came from the slurry pit of a pig farm located in Toledo (Spain). It was transported to the GA-UPM (80 km) and sieved through a 2 mm sieve to remove solids; afterwards, it was stored in a tank until the experiment started. Sieved slurry composition, according to standard analytical methods, is shown in Table I. Sieved pig slurry was treated in the wastewater treatment (WWT) pilot plant of GA-UPM, an own design that combined a biodiscs rotobioreactor (BD-RBR) developed and patented by UPM (Fernández, 2013) and a constructed wetland based on floating helophytes, also called helophytes floating filter (HFF). In essence, the BD-RBR was a longitudinal tank of 4.3 m^3 volume equipped with 152 biodiscs of 1 m diameter each, mounted on a steel shaft. Biodiscs supported active biofilms with aerobic micro-organisms, like bacteria and microalgae that were previously conditioned to slurry. In all, they had a net

Table I. Characterization of sieved slurry

Parameters	pH	EC $mS \cdot cm^{-1}$	COD $mg \cdot L^{-1}$	BOD_5 $mg \cdot L^{-1}$	N_T $mg \cdot L^{-1}$	Org-N $mg \cdot L^{-1}$	NH_4-N $mg \cdot L^{-1}$	NO_3-N $mg \cdot L^{-1}$	P_T $mg \cdot L^{-1}$	K $mg \cdot L^{-1}$
Values	7.94	29.7	8,000	2,000	2,923	1,093	1,009	822	426	1,726

Figure 1. BD-RBR system developed by GA-UPM.

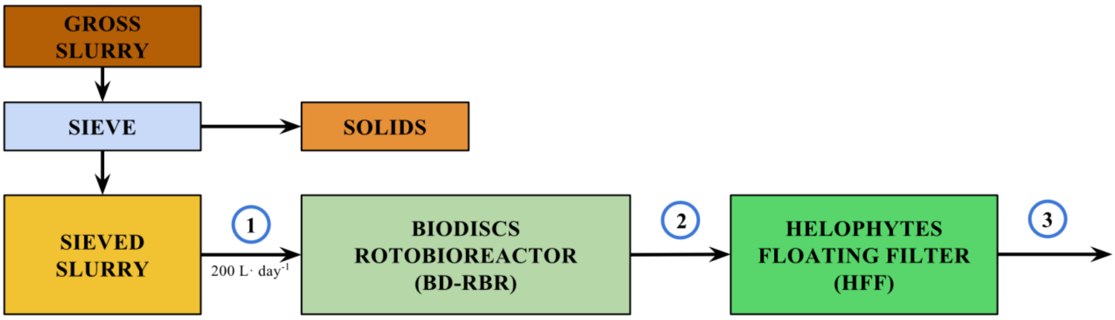

Figure 2. Flow diagram. Numbers represent sampling points.

biofilm area of 197 m^2 (Figure 1). They were made up of 5 mm wide cellular polypropylene plate coated with fabric sheet (120 $g \cdot m^{-2}$). In between biodiscs, 40 cm diameter x 2.5 cm wide expanded polystyrene (20 $g \cdot m^{-3}$ density) discs were placed to enhance shaft buoyancy. The effluent of BD-RBR flowed out to a constructed wetland of 0.45 x 5.5 x 2 m (H x L x W) size vegetated with cattail (*Typha domingensis* Pers.), which was grown as a floating filter (Fernández, 1997-1998; Layman Report, 2005) since spring' 2015. When the experiment began, cattails were fully established and the aerial plant parts had been even mowed once. The flow diagram of the WWT pilot plant is given in Figure 2; as shown, the BD-RBR was fed with sieved slurry to be mixed/aerated by means of the rotating discs; then it flowed to the HFF by plug-flow. Prior to the start of the experiment, the BD-RBR was conditioned by gradual addition of slurry until reaching 3,200 $mg \cdot L^{-1}$. After 15 days of operation, a slurry- conditioned multi-specific biofilm was formed on the biodiscs.

The experiment was conducted for 10 days (from October 27 to November 5, 2015), once the conditioning process was over. The BD-RBR was fed with 200 L sieved slurry per day. Taking into account that the sieved slurry was kept in a tank, its composition was expected to vary over the time; therefore, it was sampled every day at the inlet of the system. Likewise, samplings were daily taken at the outlets of the BD-RBR and the HFF to be immediately analyzed. After 8-day period, the system was maintained in "batch" mode, but samplings continued for two days more in order to determine the reduction of the pollutant load. The daily mean reduction (%) of the pollutant load in each step of the treatment (BD-RBR, HFF) was calculated as:

$$\frac{[(\text{influent value at day } n^{-1}) - (\text{effluent value at day } n)]}{(\text{effluent value at day } n^{-1})}$$

3. Results and Discussion

Mean results of the parameters studied for BD-RBR influent, BD-RBR effluent and HFF effluent over the 10-

day experiment are shown in Table II. Table III shows the mean reduction (%) of the pollutant load in each step of the treatment (BD-RBR, HFF). As shown in Table II, pH in the substrate at the three studied steps varied within a narrow range during the experiment, going from pH=8.1 in the influent to pH=7.1 in BD-RBR and HFF effluents. These data showed that there was little likelihood that ammonia emissions had occurred, from the substrate to the atmosphere. Electrical Conductivity decreased by 38% in the BD-RBR and 60% in the HFF (Table III). The global reduction was significant (75%). As regards the organic matter, BOD_5 experimented higher reduction than COD after the steps of BD-RBR and HFF, reaching global mean reductions of 98% for BOD_5 and 88% for COD. The relative COD reduction in the HFF (78%) was higher than the reduction in the BD-RBR (46%); in the case of BOD_5, the values found for the percentage of reduction were similar, 88% in the HFF and 82% in the BD-RBR. The decrease in the ratio BOD_5 to COD, from the BD-RBR to the HFF effluent, suggested that the system was more effective in the removal of organic matter.

Nitrogen global reduction was 86%, but with different behavior among the nitrogen species, as it can be observed in Table IV and Figure 3. The N_T reduction was higher in the HFF (62%) than in the BD-RBR (56%), while the global reduction was 86%. The decrease of organic nitrogen was higher in HFF (67%) than in the BD-RBR (48%); the global reduction was 85%. NH_4-N was the major nitrogen species (1314 mg·L^{-1}) in the slurry; the global reduction achieved 97%; the higher reduction was due to BD-RBR step (86%). This was partly due to NH_4-N oxidation, as shown by the increase in nitrates content in the BD-RBR effluent; however, in the HFF step, the reduction in NH_4-N was high (78%). As expected, the design in two steps (BD-RBR followed by HFF) was more effective than a single step. Concerning the phosphorous results (Table III), the P content in the sieved slurry (396 mg·L^{-1}) was globally reduced by 78% after the treatment, with a 53% reduction in the BD-RBR step and 56% in the HFF. Results from this work showed that, in the tested treatment system, COD reduction at the step of BD-RBR was 3 g·m^{-2}·day^{-1} and, at the step of HFF, 46 g·m^{-2}·day^{-1}. By extrapolation, it was inferred that the treatment of 1 m^3 slurry with 5,500 mg·L^{-1} COD would require about 1,008 m^2 biodiscs area in the BD-RBR step plus 54 m^2 wetland area in the HFF step.

Table II. Mean values ($\bar{x}$+s.d.) of the samplings of sieved slurry, BD-RBR effluent and HFF effluent carried out during the experiment (n=10).

Parameter	**Sieved slurry**	**BD-RBR effluent**	**HFF effluent**
pH	8.1±0.1	7.1±0.2	7.1±0.1
EC (mS·cm^{-1})	36.4±3.9	24.0±7.0	9.2±4.5
COD (mg·L^{-1})	6330±1168	3264±497	728±204
BOD_5 (mg·L^{-1})	1118±220	188±65	24±15
N_T (mg·L^{-1})	2080±266	897±162	300±166
P_T (mg·L^{-1})	396±161	164±21	71±23

Table III. Mean reduction (%) of the pollutant load recorded in the BD-RBR and the HFF steps and global reduction in the system (n=10).

Parameter	**Reduction at BD-RBR effluent**	**Reduction at HFF effluent**	**Global reduction**
EC	38.0	60.4	74.8
COD	45.9	78.3	88.3
BOD_5	82.1	87.6	97.6
N_T	56.2	61.7	85.6
P_T	53.4	56.2	78.5

Table IV. Mean content ($\bar{x}$+s.d.) and reduction (%) of nitrogen species (organic N, ammonia-N, nitrate-N and total N) in the sieved slurry (influent in the system), BD-RBR effluent and HFF effluent (n=10)

Nitrogen species	**Mean content (mg·L^{-1})**			**Reduction (%)**		
	Sieved slurry	**BD-RBR effluent**	**HFF effluent**	**BD-RBR step**	**HFF step**	**Global**
N-org	336±105	148±52	41±16	48.4	66.9	85.1
NH_4-N	1314±216	175±33	38±24	86.3	78.1	96.8
NO_3-N	430±129	575±149	221±174	-43.1	46.7	44.4
N_T	2080±266	897±162	300±166	56.2	61.7	85.6

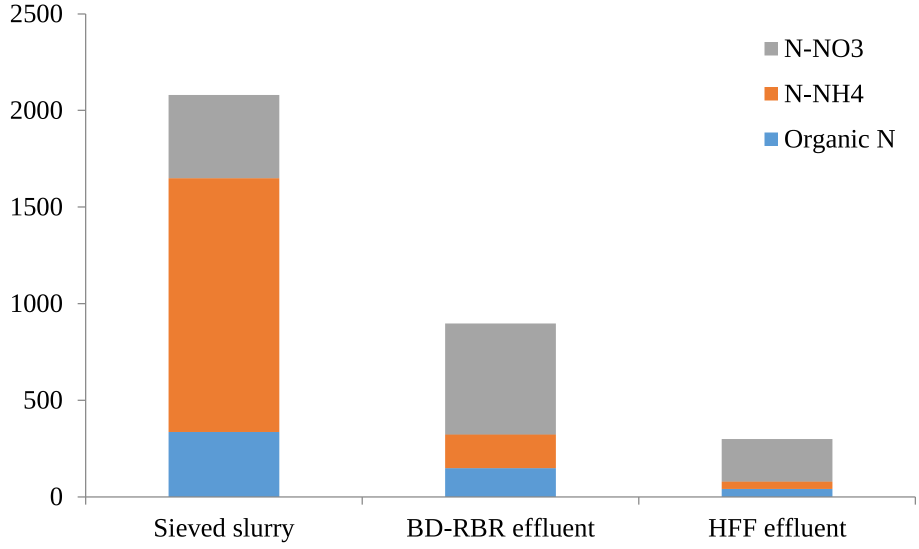

Figure 3. Variation of the content of nitrogen species (organic, ammonium and nitrate nitrogen) in sieved slurry and BD-RBR and HFF effluents. Mean values over the 10-day experiment.

4. Conclusion

The BD-RBR + HFF system tested for sieved slurry treatment allowed achieving good results in terms of pollutant load reduction: 85.6% in total nitrogen, 78.5% in total phosphorus, 88.3% in COD and 97.6% in BOD_5. NH_4-N is one of the most problematic contaminant in pig slurry; it is worth noting that the reduction achieved was very high (96.8%). The levels achieved in the present experiment showed that the treatment plant needed resizing for pig slurry treatment; the results obtained can be used as indicators for future designs of pig slurry treatment plants. For a practical implementation of the BD-RBR + HFF system, the slurry treatment facility must be dimensioned according to the daily pollutant load entering into the system and to the binding requirements for effluent discharge, always taking into account that the depuration capacity of BD-RBR is proportional to the biodiscs area and that the efficiency of HFF is proportional to the area occupied by the floating filter.

References

Fernández J. (1997-1998), Procedimiento de depuración de aguas residuales y vertidos contaminantes en base a cultivos de macrofitas emergentes convertidas en flotantes. Patente española nº de publicación: ES 2 120 388 B1 http://lp.espacenet.com/publicationDetails/biblio?DB=lp.espacenet.com&II=2&ND=3&adjacent=true&locale=es_LP&FT=D&date=19981016&CC=ES&NR=2120388A1&KC=A1]. International patent: WO 1998045213 A1. Available at: http://www.google.es/patents/WO1998045213A1?cl=es

Fernandéz J. (2003), Utilización de plantas acuáticas para la depuración de purines. Mundo Ganadero 155: 38-40. ISSN: 0214-9192. Available at: http://www.mapama.gob.es/ministerio/pags/biblioteca/revistas/pdf_mg/mg_2003_155_38_40.pdf

Fernández J. (2013), Fotobiorreactor de soporte flotante. Patente española ES 1 099 707 U, de fecha de prioridad 20. 12. 2013. PCT WO 2015092093 A1. Available at: http://www.google.com/patents/WO2015092093A1?cl=en)

Foged H. L., Flotats X., Blasi A.B., Palatsi J., Magri A., and Schelde K.M., (2011), Inventory of manure processing activities in Europe. Technical Report No. I concerning "Manure Processing Activities in Europe" to the European Commission, Directorate-General Environment. 138 pp. Available at: http://agro-technology-atlas.eu/docs/21010_technical_report_II_manure_processing_technologies.pdf

Food and Agriculture Organization of the United Nations (FAO) (2004), FAOSTAT database. Available at: http://www.fao.org/faostat/en/#data [Accessed in February 2017]

Layman Report (2005), Layman Report of LIFE02 ENV/E/182, New floating macrophyte filter systems for the Mediterranean region "Macrophytes". Reporting Date: 15 November 2005. Available at: http://www.fundacionglobalnature.org/macrophytes/documentacion/Informe%20Layman_ing.pdf