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Distribution and spatial variability of sludges in a wastewater stabilization pond system without desludging for a long period of time

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ABSTRACT

This paper describes the sludge accumulation and its characteristics after several years of operation (15–20 years) of an urban wastewater treatment system using stabilization ponds (anaerobic, facultative, and maturation ponds) in southern Spain. The rate of sludge accumulation (0.011 m^3/person year for anaerobic pond) was lower than previously reported by other authors (0.04 m^3/person year) due to the effects of degradation and consolidation after this long period of time, and the vertical distributions of humidity and volatile solids indicate a consolidation and mineralization of sludge with depth. Confirmation of this fact by new experimental data might require a reconsideration of desludging times in such systems.

Principal component analysis revealed some specific features of the data structure, and three principal components were identified which collectively accounted for 91.1% of the total variance. Principal components analysis results were confirmed by cluster analysis. Three clusters of variables were detected, corresponding to the three previously identified components. These results confirm that there are clear differences in the physico-chemical properties of sludges deposited in each pond. Vertical distributions of parameters indicate a consolidation and mineralization of sludge with depth. This supports the hypothesis of consolidation, mineralization, and volume reduction of sludge after long periods of time.

1. Introduction

Due to the European Directive 91/271/CEE concerning the purification of wastewater, since the year 2005 almost all wastewater must be treated with appropriate technologies. In small municipalities (<2000 equiv. inhabitants) possible solutions for wastewater treatment depend on suitably trained staff to run the facilities and on their energy requirements. The selection of the best treatment system in each case must be supported by six criteria (EPA, 1997): (i) processes which require a minimum number of operators should be selected; (ii) equipment requiring minimal maintenance should be selected; (iii) there should be effective operation over a wide range of levels of flow and load; (iv) energy consumption should be minimal; (v) facilities where potential failures of equipment and processes cause the minimum deterioration of effluent quality should be chosen; and (vi) there should be maximum integration of the treatment system into the environment.

Wastewater stabilization ponds (WSPs) are a simple low-cost, low-maintenance process for treating urban wastewater that is recommended for small populations where vast stretches of land are available (>7 m^2/equiv. inhabitant). A typical system consists of several constructed ponds operating in series. Treatment of the wastewater occurs as constituents are removed by sedimentation and/or transformed by biological and chemical processes. WSPs reproduce self-purification phenomena that occur naturally in watercourses (Salas et al., 2007). In a way, the system could be defined as “a compartmentalized river”, which simulates the first stage of anaerobic conditions that occur in channels when there is a discharge with a strong organic biodegradable content, whereas later stages are similar to situations that occur downstream of the spill in the process of naturally recovering the initial conditions of the water body. A sludge layer forms in the bottom of the ponds due to the sedimentation of influent suspended solids as well as algae and bacteria that grow in the pond.

The accumulation of sewage sludges from urban wastewater treatment is a growing environmental problem. During the period 1992–2000 the production of sludge in the EU reached around eight million tons of dry waste matter per year (Magoarou, 2000), while a similar amount was produced in the USA in 2000 (Englande and Reimers, 2001). The generation of sludge in the anaerobic stage is

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estimated at 30–40 litres/capita equiv. per year (Mara, 1976). Due to its high residence time in the ponds, the sludge is stabilized, and volatile-mineral average relationships are around 40–60% (Salas et al., 2007). With the system of common impoundments, anaerobic ponds (AP), facultative ponds (FP) and maturation ponds (MP), it is only necessary to carry out the removal of sludge every 5–10 years in the first stage of the life of the facility.

This sludge accumulation is greatest in primary ponds and can affect performance by reducing the effective pond volume and shortening hydraulic residence time (Schneiter et al., 1984; Peña et al., 2000). Saqqar and Pescod (1995) studied sludge accumulation in Jordan; Goncalves (2002) reported data on sludge accumulation in Brazil; and Papadopoulos et al. (2003) studied sludge accumulation patterns in anaerobic ponds under Mediterranean climatic conditions in France and northern Greece. Nelson and Yang (2004) reported data on sludge accumulation characteristics in Mexico and stated that more regional data are needed to determine the sludge accumulation rate, sludge distribution, and sludge characteristics.

There are still gaps in the existing data of ponds operated for periods of over 10 years without sludge disposal. Data collection in this regard will facilitate the understanding of the evolution of the accumulated sludge and the need for periodic removal. In addition the study of the spatial variation of characteristics among the various ponds allows further information about the sedimentation of sludge and the processes occuring in.

The aim of this paper is to present and analyze the sludge accumulation pattern in the Center for New Water Technologies (CENTA) Foundation Experimental Center Stabilization Lagoons unit and its physico-chemical characteristics after 20 years of operations without desludging. Multivariate analysis tools are used to study the spatial variations in the physico-chemical characteristics of the sludge.

2. Materials and methods

2.1. Stabilization pond system

The system studied was located at the R&D Wastewater Treatment Plant (37°21′38″N, 6°20′4″W) of the CENTA Foundation, located in the town of Carriónde los Céspedes, Seville, Spain. The experimental plant receives untreated wastewater from Carrión de los Céspedes, with approximately 2500 people. Part of the influent is directed to the system investigated after the pretreatment unit. Table 1 shows average values for raw wastewater.

The studied system consists of three stabilization ponds: one anaerobic pond (AP), a facultative pond (FP), and two maturation ponds (MIP and MIIP) operated in series. The general characteristics of these ponds are presented in Fig. 1, and the unit performance is shown in Table 2.

Table 1
Characteristic influent parameters.

Parameter	Medium	Maximum	Minimum
pH	7.8	8.0	7.5
Electrical conductivity (μS/cm at 20 °C)	1821	2003	1690
Total suspended solids (mg/L)	340	562	209
Chemical oxygen demand (mg O_2/L)	904	1280	524
Biochemical oxygen demand (mg O_2/L)	471	708	281
Ammonium (mg N/L)	86	111	32
Phosphate (mg phosphate/L)	40	60	6

2.2. Sampling and analysis

The bathymetric and sampling campaigns were carried out in winter 2010 after 15 years of operation of the anaerobic pond and 20 years of operation of the facultative and maturation ponds.

The accumulation rates and distribution of sludge were determined by measuring the thickness of the sludge layer at several locations in each pond using a grid according to the size of the pond.

In order to characterize accumulation and mineralization rates during its operation periods, 12 sampling points were located throughout the system, two in the anaerobic pond (influent and effluent), four in the facultative pond (influent, effluent, centre right, centre left), and three in each maturation pond (influent, centre, and effluent).

A home-made sludge-core sampler with a transparent plexiglass tube with a diameter of 10 cm and length of 3.5 m was used. The tube was opened at its base and supplied with a movable lid which adheres well to the base of the tube, preventing any flow when it is closed. The lid was connected to a long chain hanging freely outside the tube.

The procedure of sludge-core sampling consisted of: (i) lowering the tube vertically into the pond (at the point of sampling) until it reached the bottom; (ii) strongly pulling the chain to close the bottom of the tube, holding the core sample undisturbed in the tube; (iii) up the tube; (iv) pouring the tube contents into a polyethylene container; (v) refrigeration of containers until laboratory analysis.

Samples from the anaerobic pond were divided into three different sub-samples in order to study the vertical differences in the properties of sludge.

Laboratory analyses of parameters including pH, ORP, total solids (TS), fixed solids (FS), volatile solids (VS), Kjeldahl nitrogen, and ammonium nitrogen were performed on grab samples in

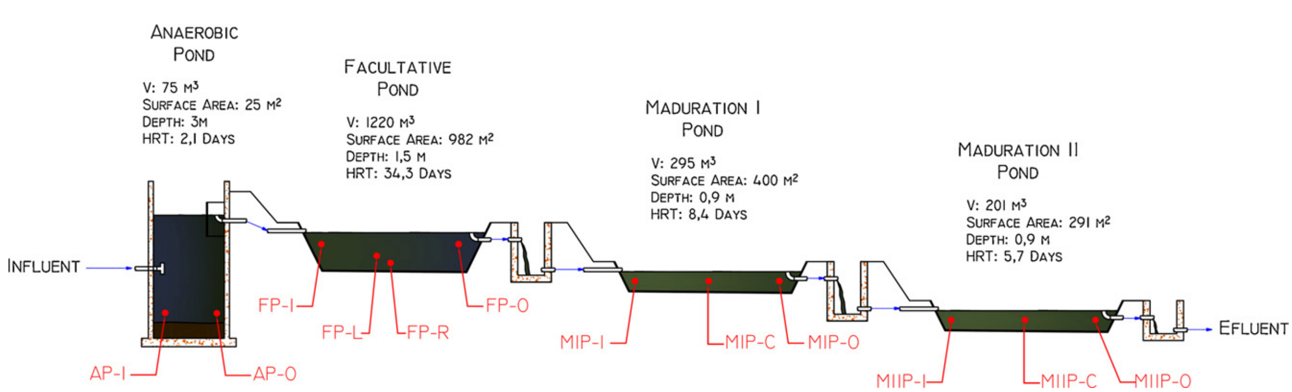

Fig. 1. Diagram of the system with dimensions and sampling points.