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Bioresource Technology 96 (2005) 351–358

BIORESOURCE TECHNOLOGY

Piggery wastewater characterisation for biological nitrogen removal process design

H. Boursier [a], F. Béline [a,*], E. Paul [b]

[a] Cemagref, Livestock and Municipal Waste Management Research Unit, 17 Avenue de Cucillé, CS 64427, Rennes Cedex 35044, France
[b] INSA Toulouse, Laboratory of Environmental Process Engineering, (LIPE, EA833), 135 Avenue de Rangueil, 31077 Toulouse Cedex 4, France

Received in revised form 14 January 2004; accepted 26 March 2004
Available online 10 May 2004

Abstract

In intensive farming areas, the design of biological nitrogen removal plants for piggery wastewater requires the determination of the chemical oxygen demand (COD) fractions of the effluent. For this purpose, an experimental procedure was developed to quantify the inert soluble (S_I) and particulate (X_I) COD fractions, as well as the readily (S_S) and the slowly (X_S) biodegradable COD fractions. For the four wastewaters tested, the S_I and the X_I fractions were equal to 3–4 $g\,O_2\,l^{-1}$ and 17–28 $g\,O_2\,l^{-1}$, respectively, which resulted in a total inert fraction of 42–84% of total COD. The S_S and the X_S fractions were very variable, ranging 0–5 $g\,O_2\,l^{-1}$ and 4–25 $g\,O_2\,l^{-1}$ respectively, depending on the farm management practices and the storage conditions prior to biological treatment. From these results, the denitrification potential of the piggery wastewaters for biological nitrogen removal treatment could be assessed.

Keywords: Piggery wastewater; Wastewater characterisation; Chemical oxygen demand fractionation; Biological process; Respirometry; Hydrolysis constant

1. Introduction

Due to intensive farming methods, livestock waste management is a major problem in Brittany, France. Out of the 76 nitrate vulnerable zones defined in France as regards to agricultural soils organic nitrogen inputs, 71 are located in Brittany (Rapion et al., 2001). This situation is mainly caused by pig production and has led to nitrate water pollution. To solve this problem, legislation (Circular DERF/SDAFMA/98-3002, 1998) was applied, which defines an upper limit on organic N amount produced annually by farms above which animal waste treatment or export is obligatory.

From a technology basis, biological processes appear to be the main treatment alternatives for nitrogen removal from animal wastes (Germirli et al., 1993). Effluent characterisation is the first stage in assessing the biological treatment strategy. It provides the main experimental basis for the choice and the design of the biological treatment process. The traditional characterisation is sufficient for comparing various effluents and selecting physical, chemical, or biological treatment alternatives (Orhon et al., 1999d). However, a more precise characterisation is generally recommended and the choice of parameters depends on the selected process. For biological nitrogen removal treatment, the characterisation of influent organic matter amount and quality is of primary importance, because these variables are related to the denitrification kinetics and the oxygen requirements. A fractionation of the effluent organic content as regard to its biodegradability is thus required.

Wastewater organic matter fractionation, expressed in chemical oxygen demand (COD) units, was first developed for municipal wastewater characterisation (Ekama et al., 1986; Henze, 1992; Orhon et al., 1997; Spérandio and Paul, 2000). More recently, it has been applied to some industrial wastewaters (Orhon et al., 1995, 1999b). Piggery wastewater is a very strong waste compared to domestic wastewater and only very few data have been reported on pig slurry COD fractionation in the literature (Andreottola et al., 1997). To overcome this shortfall, the present study aimed at

* Corresponding author. Tel.: +33-2-23-48-21-21; fax: +33-2-23-48-21-15.
E-mail address: fabrice.beline@cemagref.fr (F. Béline).

0960-8524/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2004.03.007

(i) developing a procedure, based on domestic and industrial wastewater knowledge, to determine COD fractions in piggery wastewaters, and (ii) collecting experimental data on piggery wastewater COD fractions.

2. Methods

As a first step, the wastewater total COD (TCOD) was divided into an inert organic fraction and a biodegradable organic fraction. Only the latter fraction undergoes transformations during the biological process, through aerobic biodegradation and denitrification, while the inert fraction by-passes the treatment. Following this, the inert fraction could be split into soluble (S_I) and particulate (X_I) inert fractions by physical separation such as filtration or centrifugation. Concerning the biodegradable fraction, it contains a wide spectrum of organic compounds from simple molecules like volatile fatty acids to complex polymers like proteins. The biodegradation rates associated to these compounds vary substantially. Therefore, a subdivision of the biodegradable fraction into readily (S_S) and slowly (X_S) biodegradable fractions was required (Dold et al., 1980). This separation should be based on biodegradation kinetics and not on physical or chemical characteristics, in order to be reliable for activated sludge process design. Eq. (1) summarizes the COD fractionation described above and adopted in this study for piggery wastewater.

$$\mathrm{TCOD} = S_I + X_I + S_S + X_S \tag{1}$$

2.1. Determination of the inert organic fractions

Various methods have been presented in the literature for the quantification of S_I (Chuchoba, 1985; Germirli et al., 1991) and X_I (Lesouef et al., 1992; Orhon et al., 1994, 1999c) in municipal and industrial wastewaters. The procedures generally consist of long-term aeration tests of the raw and soluble wastewater seeded with acclimated sludge and measurements of the initial and final, total and soluble COD in the wastewater samples. According to Orhon et al. (1999c), for a reliable analysis, the two reactors should be operated long enough for the completion of all biological activity. The main concern in the determination of inert fractions is the production of residual microbial products, in soluble form (S_P) and in particulate form (X_P), originated from biomass lysis during the tests. The determination of S_P and X_P can be done using the stoichiometric constants associated with the lysis process. However, these constants vary with the effluent and should thus be calculated for each wastewater. Concerning piggery wastewater, previous works (Germirli et al., 1993) showed that S_P was negligible

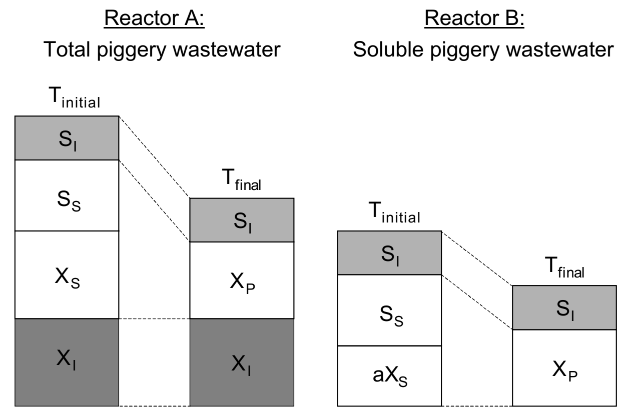

Fig. 1. Evolution of the organic fractions of raw piggery wastewater in reactors A and B containing total and soluble wastewaters during a long-term aeration test (derived from Lesouef et al. (1992)). Fraction aX_S represents the soluble fraction of X_S.

(<7%) as compared to S_I. This consideration (i.e. $S_P \approx 0$ mg O_2 l^{-1}) allowed us to simplify the characterisation procedure for inert fractions of piggery wastewater. In this case, COD transformations during a long-term aeration test of total and soluble wastewater are illustrated on Fig. 1. In both reactors A and B, the inert fractions S_I and X_I by-pass the system while the biodegradable fractions are converted into particulate microbial products (X_P). In this study, the reactors were not seeded with activated sludge because piggery wastewater already contains a sufficient active biomass amount.

Measurement of the soluble final COD in reactors A and B gives directly the S_I fraction of the influent (Eq. (2)).

$$S_I = \mathrm{COD}_{A,\mathrm{soluble}}(T_F) = \mathrm{COD}_{B,\mathrm{soluble}}(T_F) \tag{2}$$

where

$\mathrm{COD}_{A,\mathrm{soluble}}(T_F)$ = final soluble COD of wastewater in reactor A

$\mathrm{COD}_{B,\mathrm{soluble}}(T_F)$ = final soluble COD of wastewater in reactor B

The fraction X_P in reactor B represents the particulate organic fraction originated from the biodegradation of both fraction S_S and the soluble part of fraction X_S (aX_S). Thus, it is possible to calculate the stoichiometric constant Y_{XP} describing the fraction of biodegradable COD converted into particulate microbial products (Eq. (3)).

$$Y_{XP} = \frac{X_P}{S_S + aX_S} = \frac{\mathrm{COD}_{B,\mathrm{total}}(T_F) - \mathrm{COD}_{B,\mathrm{soluble}}(T_F)}{\mathrm{COD}_{B,\mathrm{total}}(T_0) - \mathrm{COD}_{B,\mathrm{soluble}}(T_F)} \tag{3}$$

where

$\mathrm{COD}_{B,\mathrm{total}}(T_0)$ = initial total COD of wastewater in reactor B