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Modified UASB reactor for dairy industry wastewater: performance indicators and comparison with the traditional approach

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ABSTRACT

A new system for dairy wastewater treatment that is composed of a modified UASB (Up flow Anaerobic Sludge Bed) reactor with a scum extraction device and a lamella settler is presented in this work. The system operates stably with a high methanisation level and achieves a granulated sludge. The new system is compared with the traditional wastewater treatment approach, which includes a dissolved air flotation (DAF) unit, a pH conditioner, an anaerobic contact reactor and a clarifier. The performance indicators of both systems are compared. For similar methane recovery levels, the new system is simpler, with fewer processing units and a 40% lower volume per kg of COD (Chemical Oxygen Demand) to be treated compared with the traditional approach; hence the new system requires reduced investment and operational costs.

1. Introduction

The dairy industry is one of the most important industries in Uruguay with a production of 1770 million litres per year in 2009; 83% of this production is received by the process industry and 64% of the total is processed for export (MGAP, 2010). Depending on the type of product, equipment and unit processes entailed in the processing of dairy-based products, effluent characteristics may vary widely based on the industrial plant (Méndez et al., 1989; García et al., 1991; Perle et al., 1995; Danalewich et al., 1998; Vidal et al., 2000). Thus, to achieve an appropriate design of the treatment plant, specific conditions of the dairy industry must be considered (Demirel et al., 2005). Nonetheless, due to leakage while processing milk or milk-based products, several constituents are systematically found in dairy industrial wastewater: lactose, lipids, casein and other proteins. Lipids are found mainly in emulsions resulting from the initial processing stages of homogenisation. In addition, effluents will be acidic or basic based on the cleaning chemical used at any time during the process.

Considering all Uruguayan dairy industries, around 4 million of cubic meters of wastewater are produced per year, representing a discharge of 1.4 million kg of COD. For the most part, wastewater treatments are extensive systems, formed by anaerobic and facultative lagoons, with low efficiency and low possibility of control actions. This situation is similar in the neighbouring countries. In order to improve the wastewater treatment, more intensive and efficient systems must be introduced. Moreover, solutions with emphasis in energy saving and operational cost reduction must be encouraged. Greenhouse gas emission must also be prevented.

Application of the anaerobic digestion has increased over the years as a treatment technology that is applicable to high strength effluents without energy consumption and methane production as a by-product (van Lier et al., 2001). Among the reports of anaerobic treatments in dairy wastewater (Demirel et al., 2005), Up flow Anaerobic Sludge Bed (UASB) reactors (Gavala et al., 1999; Vidal et al., 2000; Ramasamy et al., 2004) and anaerobic filters are used (Ozturk et al., 1993; Vidal et al., 2000). However, dairy effluents have high lipid content and several problems were reported when UASB reactors were used (Vidal et al., 2000). Therefore, higher hydrolysis times are required, and the fat, oil and grease (FOG) accumulation in the sludge can occur. Nadais et al. (2003, 2005) proposed an intermittent operation method to avoid the FOG accumulation. Other researchers reported dispersed sludge growing, sludge wash out and FOG accumulation inside the reactor as operational problems (Hwu et al., 1997; Petruy and Lettinga, 1997). Attempts have been made to operate UASB reactors with dairy wastewater without prior FOG removal. For example, Nadais et al. (2001, 2006) developed an intermittent method to promote FOG degradation in a single step at the laboratory scale.

Rapid adsorption and significantly slow degradation of dairy fat emulsions were reported for batch studies using biomass that was not adapted to degrading fats or a substrate load as high as 12.6 g of

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fat per gram of VSS (Volatile Suspended Solids) (Petruy and Lettinga, 1997). Vidal et al. (2000) reported that the biodegradability rate of fat-rich dairy wastewater is limited by fat hydrolysis. They performed batch assays with non-adapted biomass. However, using moderate loads and substrate-adapted microorganisms, hydrolysis may not limit the biodegradability rate during a total treatment process. Thus, the total process rate may be limited by a reduced mass transfer rate due to Long Chain Fatty Acids (LCFA) adsorption onto sludge (Pereira et al., 2003, 2004) or by the inhibitory effect of LCFA on acetotrophic methanogenic populations (Perle et al., 1995; Hwu et al., 1996). According to Hwu et al. (1998), sludge floatation in UASB reactors due to LCFA adsorption at high LCFA levels may occur at lower LCFA concentrations than those that produce inhibitory effects. To understand the influence of the adsorption stage preceding lipid- and LCFA- degradation on the performance of UASB reactors, several studies were performed using an intermittent feed (Sayed, 1984; Nadais et al., 2006). Cavaleiro et al. (2008) reported that use of pulse-feeds resulted in an increased tolerance of acetotrophic methanogens to LCFA, and suggested that satisfactory results for continuous operation may be obtained following a biomass acclimation stage by using pulse-feed. Several studies demonstrated that the use of flocculent sludge instead of granular sludge results in a higher LCFA removal efficiency (Nadais et al., 2003) and more effective treatment of complex effluents (Sayed, 1987). In contrast, flocculent sludge appears to be less resistant to LCFA inhibition (Hwu et al., 1996).

In brief, the use of UASB reactors in dairy wastewater treatment has been associated with limited success because a considerable amount of organic material hydrolyses or degrades at an excessively low rate and normally accumulates within the sludge blanket due to entrainment or adsorption. The results are dilution of biomass, changes in mass transfer properties and impairment of sludge settling capacity. Sludge activity is therefore reduced and sludge wash out from the reactor through the outlet stream could occur (Sayed, 1984, 1987; Rinzema, 1993; Hwu et al., 1998).

Because it is difficult to treat complex effluents in sludge-blanket reactors, pre-treatment methods are normally used, such as fat separation using dissolved air floatation (DAF) (Campos et al., 2004; Puget et al., 2004; Asplund, 2005; Ross and Valentine, 2008). Otherwise, contact reactors are utilised (Asplund, 2005; Hamilton and Archer, 2007).

In this work, anaerobic treatment for a small dairy company in Uruguay (COLEME, Melo City) is presented. The industry had two UASB reactors of 40 m^3 each, that were previously built as the treatment plant. Nevertheless, these UASB reactors could not be operated properly because the FOG accumulation in the upper part of the reactors prevented the biogas from reaching the gas chamber device; sludge losses also occurred because of the dispersed growth of the sludge. Based on previous experience gained from evaluations of biological performance, modifications in the existing facilities were conducted. Subsequently, the updated proposal to treat dairy wastewater was successfully proven (Passeggi et al., 2009).

Performance indicators can be constructed to evaluate the business sustainability (Labuschagne et al., 2005; Chee Tahir and Darton, 2010). In this paper, performance of the new system is compared with a traditional wastewater plant including a DAF and a contact anaerobic reactor. Data for the comparisons were adopted from the work of Asplund (2005), who has analysed the performance of the wastewater treatment plant of Umeå Dairy, a Swedish dairy company. This case is selected only as an example of the traditional approach to treating dairy wastewater because of the extensive available data. Comparisons are made merely to validate the new technology compared to the traditionally accepted systems.

2. The modified UASB reactor concept

An alternative up-flow anaerobic reactor was developed to avoid the problems caused by the FOG content of dairy wastewater. In a standard UASB reactor, fatty scum accumulates under the biogas device, thus preventing the biogas from releasing and promotes biomass flotation. Solids accumulation under the biogas hood leads to reactor failure due to the following: i) clogging of the phase separator; ii) the poor contact between the biomass and the substrate due to floatation of part of the biomass; and iii) the loss of viable biomass.

Another problem that is encountered is the solids loss with the reactor effluent. This is caused by the flocculent nature of the biomass and the adsorption of fatty material. If biomass is not retained in the reactor, wash out occurs, and the biological activity disappears.

The first problem (scum formation) can be solved: biogas bubbles are used to float the fats; then, the oily scum that accumulated under the biogas hood is sucked out periodically. This modified reactor retains the advantages of the standard UASB and simultaneously acts as a gas floater.

The scum extracted from the reactor has both fatty material and biomass. The recuperation of this biomass is critical for preventing the reactor wash out. Thus, scum is transferred to a solids digester. Fats are degraded and the exit stream of the digester is returned to the reactor, which recovers the biomass.

The second problem (biomass wash out) is prevented with a lamella settler placed in the reactor discharge. The settled solids are reintroduced into the reactor periodically. Thus, biomass content in the reactor is preserved, which enables the continuity of operation of the reactor.

3. Materials and methods

The alternative treatment system was implemented in a small dairy factory in Melo City, Uruguay (COLEME, Cooperativa de Lechería de Melo), which processes 32,000 L of milk per day. Seventy-five percent of the milk received is used to produce cheese and the remaining 25% is used to produce pasteurised milk. The effluent production is 100 m^3 per day and the lipid content is approximately 40% of COD. The system is comprised of two 40 m^3 modified up-flow anaerobic sludge-blanket reactors with an internal fat separator and external sludge recovery by settling, in addition to a 5 m^3 digester tank for floating fatty scum. A 1 m^3 lamella settler was included after the reactors discharge, with the plates tilted at 60° and spaced at 5 cm, retaining part of the sludge carry-over from the reactors and returning it to the feed box by using pumping equipment. The lamella settler operates at a residence time of 15 min at full-load. The liquid settling tank outlet is discharged to a municipal sewer. Previous to the reactors, a 50 m^3 buffer tank was constructed. Fig. 1 shows the plant layout. Sludge from a slaughterhouse treatment lagoon was used as the inoculum.

For the reactor start up, an intermittent operation was performed. Because the factory works six days a week, one reactor was fed during the first three days of the week and then the feeding stream was switched to the other reactor. In this way, while one reactor was fed, the other was used with recirculation only, which was employed to maintain the desirable up-flow velocity. In the next weeks, the cycle was repeated. In a second stage, the intermittent operation was switched to a continuous operation, and sludge granulation occurred; settlement properties of sludge improved and the external lamella settler became less important in the process. Although the pH values of the feed varied between 5.0 and 11.5, it was not necessary to adjust the reactor inlet pH.