Journal of Cleaner Production 86 (2015) 15–23

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Treatment of dairy industry wastewater by oxygen injection: performance and outlay parameters from the full scale implementation

Santiago Martín-Rilo*, Ricardo N. Coimbra, Javier Martín-Villacorta, Marta Otero*

Department of Applied Chemistry and Physics, IMARENABIO, University of León, Campus de Vegazana, 24071 León, Spain

ARTICLE INFO

Article history:
Received 14 March 2014
Received in revised form
9 May 2014
Accepted 10 August 2014
Available online 21 August 2014

Keywords:
Dairy industry
Wastewater
Oxygen injection
COD removal
Operating costs
Performance indicators

ABSTRACT

This work presents the application of a new system for wastewater treatment in the food industry, which is based in the injection of pure oxygen in the homogenization tank of a traditional physicochemical treatment. This system operates stably under a wide variety of both input chemical oxygen demand (COD) and total suspended solids (TSS). Compared with the previous physicochemical system, it has been proved that the new one is more efficient and implies important economic savings for the dairy. Compared with a traditional anaerobic treatment, it has been shown that the oxygen injection system avoids the relatively high costs associated to the initial investment and operating costs and is environmentally friendlier. In this work it is shown that oxygen injection may be an interesting option for the dairy industry wastewater treatment.

1. Introduction

The dairy industry is one of the most important industries in Spain. In this country (Spain) there are 29,196 food companies, representing 14% of the Spanish industry, and employs 439,635 workers (19%). The dairy subsector has 1563 companies, ie, 5% of all agri-business and agri-food 7% of employment (27,745 workers) (FIAB, 2012). Around 84% of Spanish dairy companies have less than 10 employees, 12% between 10 and 25, 2% between 25 and 100, and the remaining 2% more than 100 workers (FIAB, 2012). In 2012, the annual Spanish milk production at source amounted to 6,809,300 t, of which 6,114,800 t were cow's milk, 364,000 t sheep's milk and 330,500 t of goat's milk (FENIL, 2012a). The dairy products are distributed as follows: drinking milk (3,747,000 t), yogurt (792,000 t), cheese (139.100 t), butter (41,000 t) and cream (131,600 t) (FENIL, 2013). Spain imported in 2012, 571,963 t of liquid milk, condensed, concentrated or powdered 265,192 t of yogurt and other fermented milks, 250,440 t of cheese, 18,619 t of butter and 12,937 t of cream (FENIL, 2013). On the other hand, in 2012 Spain exported 221,206 t of liquid milk, condensed, concentrated or powdered form, 113,128 t of yogurt and other fermented milk, 55,750 t of cheese, 19,324 t of butter and 57,661 t of cream (FENIL, 2012b). Also, the annual per capita consumption in 2012 was 147.52 kg/inhabitant of drinking milk, 7.95 kg/inhabitant of cheese, 9.86 kg/inhabitant of yogurt, 0.3 kg/inhabitant of butter and 0.96 kg/inhabitant of cream (FENIL, 2013).

The production processes of dairy products results in a significant volume of liquid wastes, which, together with water used for washing and cleaning operations, results in a large production of wastewater (Arvanitoyannis and Giakoundis, 2006). Considering all Spanish dairies, around 12 Mm^3 of wastewater are generated annually, which represents 4.2 Gg of COD (MAGRAMA, 2012). Due to the large volumes produced and to its high organic load, dairy wastewater mismanagement would negatively affect the availability and quality of aquatic resources. In fact, it has been pointed out that dairy effluents and their treatment constitute a major environmental issue for this sort of industry (Kubota and da Rosa, 2013; Willers et al., 2014).

Abbreviations: BOD_5, Biological Oxygen Demand (mg/L) 5 days; COD, Chemical oxygen demand (mg/L); UASB, Upflow anaerobic sludge blanket; FOG, Fat oils and grease; SBR, Sequential batch reactor; HRT, Hydraulic retention time; DAF, Dissolved air flotation; STP, Sewage treatment plant; PID, Proportional integral derivative; BNR, Biological nitrogen removal; TSS, Total suspended solids (g/L); TKN, Total Kjeldahl nitrogen (mg/L); TN, Total Nitrogen (mg/L); TP, Total Phosphorus (mg/L); P, Pump; H_2O_2, Hydrogen Peroxide.

* Corresponding authors.
E-mail addresses: s.martin@lactiber.es (S. Martín-Rilo), marta.otero@unileon.es (M. Otero).

http://dx.doi.org/10.1016/j.jclepro.2014.08.026
0959-6526/© 2014 Elsevier Ltd. All rights reserved.

Due to leakage as milk or dairy products processing base, several components are systematically present in industrial wastewater from the dairy industry: lactose, lipids, casein and other proteins (Passeggi et al., 2012). However, depending on the type of product, equipment and processes involved in the dairy transformation, effluent characteristics vary widely, mainly depending on the plant (Arvanitoyannis and Giakoundis, 2006). Furthermore, the effluents may be acidic or basic depending on the chemical basis of the cleaning products that are being used. Therefore, for the proper design of a wastewater treatment plant, the specific conditions of the dairy industry must be considered (Demirel et al., 2005).

Anaerobic and facultative ponds have been traditionally used for the treatment of dairy wastewater (Bhatia and Goyal, 2014). Although associated costs are relatively low, this sort of treatment has very low efficiency and ability to control actions. Furthermore, giving the soil availability limitations, more intensive and efficient systems would be desirable. Moreover, for a matter of sustainability, solutions involving energy savings and operating costs reductions must be searched (Aydiner et al., 2014). In this sense, anaerobic technology, which involves the production of methane as byproduct, has been considered as a cost-effective alternative for the treatment of waste from the food industry (Kastner et al., 2012) and, specifically, dairy wastewater (Hassan and Nelson, 2012). From the various anaerobic technologies that have been applied to the treatment of dairy wastewater, anaerobic filters (Lim and Fox, 2011) and, especially, upflow anaerobic sludge blanket (UASB) reactors and/or related systems (Ramasamy et al., 2004; Demirel et al., 2005) have been the most studied for the dairy industry.

UASB reactors allow for the treatment of a large volume of wastewater in a relatively short time, which is advantageous for the food industry. However, the use of UASB reactors for wastewater treatment of the dairy industry accounts with several limitations from a practical point of view (Passeggi et al., 2012 and references therein). Among them, long hydrolysis times may be required, and the fat, oils and grease (FOG) may accumulate in the mud. Also, the growth of dispersed slurries, sludge accumulation and FOG washing inside the anaerobic reactor may cause operational problems. In order to overcome these limitations, pretreatment methods, such as removal of fat by dissolved air flotation (DAF) and/or contact reactors have been used. Then, Passeggi et al. (2012) proposed a modified UASB reactor with a scum extraction device and a lamella settler. These authors (Passeggi et al., 2012) proved that this system was simpler, required fewer processing units and smaller reactor volume than a traditional UASB (Asplund, 2005) so investment and operational costs were lower.

Under the present financial crisis, industry is pressed to find out as cheap as possible solutions but also stricter requirements are continually being set for the treatment of industrial wastewater, including dairy industry. Moreover, there is a demand for concepts and processes that may ensure maximum flexibility for the treatment facilities. In the specific case of dairy industry, Kubota and da Rosa (2013) highlighted the benefits of searching for innovative and creative solutions for the implementation of cleaner production technologies. In this sense, oxygen injection may be an interesting option for the treatment of dairy wastewater that has been scarcely explored. Oxygen processes may offer high performance reserves allowing existing plants to be adapted for new tasks without carrying out structural extensions or large investments. Due to concern about odour and corrosion, oxygen injection has been often used to control biogenic production of hydrogen sulfide in sewers (Gutiérrez et al., 2008). Also, Martin et al. (2013) have recently proposed the utilization of oxygen injection as a mitigation measure for pulp mills' effluents before discharge. However, to our best knowledge, no data have been published on the application of oxygen injection to the treatment of wastewater from the dairy industry. Taking this into account, this work presents, for the very first time, results on the starting of an oxidation wastewater treatment based on the injection of pure oxygen in homogenization ponds prior to conventional physicochemical treatment in a dairy industry. In order to assess the sustainability of the system, performance indicators (Labuschagne et al., 2005; Chee Tahir and Darton, 2010) were obtained and compared to those of a traditional UASB dairy wastewater plant (Asplund, 2005).

2. Materials and methods

2.1. COD oxidation by oxygen injection (pre-biological)

As an alternative to traditional treatment methods of wastewater from the dairy industry it is here proposed a simple treatment based on the injection of pure oxygen in order to assure the oxidation of COD in wastewater. Such a treatment allows for avoiding the main problems of the standard UASB reactors, which are next described:

a) The first problem that is avoided is the one caused by the content of FOG in the wastewater from the dairy industry. In standard UASB reactors, this FOG leads to the accumulation of a fatty sludge in the surface, thus preventing the release of biogas and causing biomass flotation. The accumulation of solids below the upper cover of the reactor creates a biogas deficiency due to: i) the blockage of the phase separator, ii) the poor contact between the biomass and the substrate due to the floating of the portion of the biomass, and iii) the loss of viability of biomass.
b) A second problem encountered by UASB treatments when applied to dairy effluents is the loss of solids in the reactor effluent. This is caused by the adsorptive nature of the flocculant biomass and fatty material. If the biomass is not retained in the reactor, flushing occurs, and biological activity stops.
c) A third problem is related to the large space requirements due to the big volumes of the UASB digester, clarifier and FOG digester.

The first problem is avoided by the injection system, since an excellent performance (>80% COD removal) is achieved by pure oxygen dissolution, while assuring the homogenization of the biological raft. Besides being a mixing system "liquid–liquid" type, aerosol formation is eliminated and consequently it is avoided the development of odour and air pollution by bacteria and organic load in the area next to the treatment plant.

Regarding the second problem (washing of biomass), it must be taken into account that the injection of pure oxygen allows for high concentrations of dissolved O_2. When using pure oxygen, the O_2 saturation concentration in water is nearly five times than when using air. This provides a "driving force" of the oxygen transfer from the liquid into the activated sludge flocs, producing sludge with much higher efficiency than working with air. The following aspects should be considered when considering air or pure oxygen injection:

- Microorganisms are in better micro oxygenation conditions under oxygen injection, which explains that a larger number of them may work "very effectively".
- Under low concentration of dissolved O_2, oxygen avid activated sludge flocs assume a conformation to ensure maximum surface contact with the liquid, tending to be "light and fragile" (it produces the effect called "bulking").