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Degradation of formaldehyde in anaerobic sequencing batch biofilm reactor (ASBBR)

N.S. Pereira, M. Zaiat*

Laboratório de Processos Biológicos (LPB), Departamento de Hidráulica e Saneamento, Escola de Engenharia de São Carlos (EESC), Universidade de São Paulo (USP), Engenharia Ambiental, Bloco 4-F, Av. João Dagnone, 1100 Santa Angelina, 13.563-120 São Carlos, SP, Brazil

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ABSTRACT

The present study evaluated the degradation of formaldehyde in a bench-scale anaerobic sequencing batch reactor, which contained biomass immobilized in polyurethane foam matrices. The reactor was operated for 212 days at 35 °C with 8 h sequential cycles, under different affluent formaldehyde concentrations ranging from 31.6 to 1104.4 mg/L (formaldehyde loading rates from 0.08 to 2.78 kg/m^3 day). The results indicate excellent reactor stability and over 99% efficiency in formaldehyde removal, with average effluent formaldehyde concentration of 3.6 ± 1.7 mg/L. Formaldehyde degradation rates increased from 204.9 to 698.3 mg/L h as the initial concentration of formaldehyde was increased from around 100 to around 1100 mg/L. However, accumulation of organic matter was observed in the effluent (chemical oxygen demand (COD) values above 500 mg/L) due to the presence of non-degraded organic acids, especially acetic and propionic acids. This observation poses an important question regarding the anaerobic route of formaldehyde degradation, which might differ substantially from that reported in the literature. The anaerobic degradation pathway can be associated with the formation of long-chain oligomers from formaldehyde. Such long- or short-chain polymers are probably the precursors of organic acid formation by means of acidogenic anaerobic microorganisms.

1. Introduction

Formaldehyde is commonly used as a raw material in a great number of industrial processes. This compound is widely used due to its high reactivity, colorless nature, stability, purity in commercial form and low cost [1]. Relatively high formaldehyde concentrations can be present in wastewater, which contains 0.2–4.0 g/L of formaldehyde from industrial production of adhesives [2]. Other industrial wastewater can reach concentrations as high as 10 g/L [3]. Such formaldehyde-rich industrial wastewater may cause microbial activity inhibition in biological processes [4]. Formaldehyde can react directly with DNA, RNA and proteins, thereby damaging cells and causing the death of microorganisms [5]. Due to its mutagenic and carcinogenic effects [6,7], discharging formaldehyde into the aquatic environment without treatment can cause serious damage to the aquatic life. Moreover, formaldehyde discharges resulting from anatomy laboratories, where it is largely used as preservative of anatomic pieces, can cause serious disturbances to biological wastewater treatment plants [8].

The anaerobic treatment, presenting low energetic consumption and small sludge production, is an alternative method for degradation of toxic compounds such as formaldehyde. Although some industrial processes apply physico-chemical or aerobic processes for the treatment of wastewaters containing formaldehyde, the search for anaerobic technologies is growing, motivated especially from an economic point of view.

Some researches on treatment of formaldehyde pointed to the feasibility of its anaerobic degradation [3,9–11]. Nevertheless, the literature contains little definite information about the anaerobic degradation and toxicity of formaldehyde. Many studies were completed with different kinds of anaerobic reactors, using formaldehyde as the sole carbon source or with several co-substrates, and fed in as a slug or in a continuous manner. These studies do not point to any consensus about the concentrations that can inhibit microbial activity [5,12–14]. In addition, the pathways of anaerobic formaldehyde degradation and the microorganisms involved in this process are still discrepant [4,10,14].

Most research indicates that formaldehyde is successfully degraded by anaerobic consortia in continuously fed reactors operated under high cellular retention times [12,15,16]. However, in some cases, as in anatomy laboratories, the formaldehyde is dis-

* Corresponding author. Tel.: +55 16 3373 8360; fax: +55 16 3373 9550.
E-mail address: zaiat@sc.usp.br (M. Zaiat).

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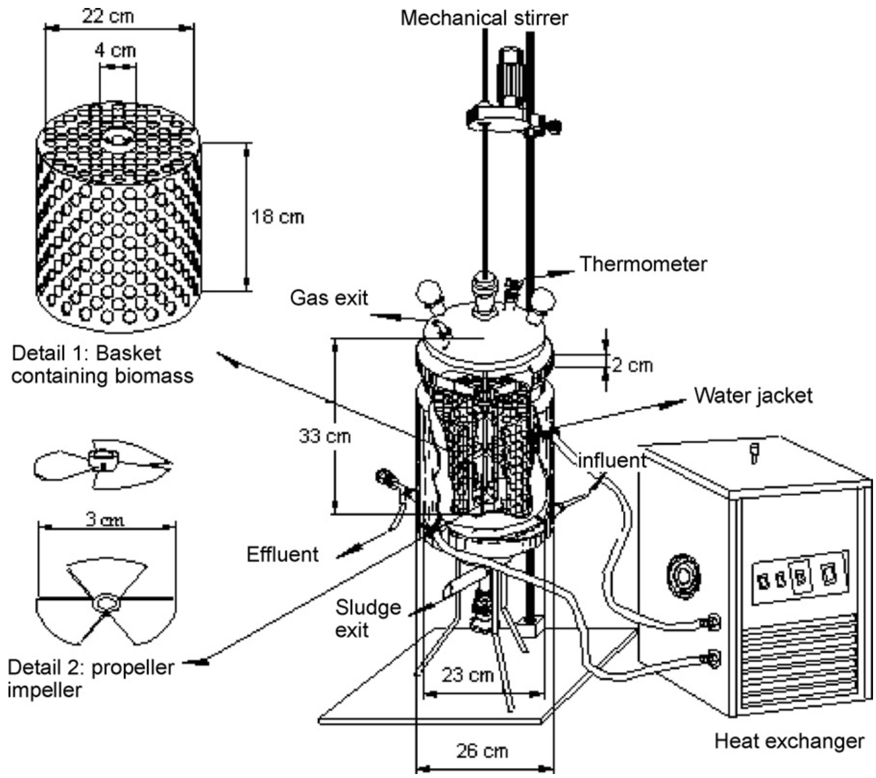

Fig. 1. Schematic of the ASBBR.

charged intermittently and the discontinuous regimen can be the best choice. Batch reactors have been studied for formaldehyde degradation, but the studies were performed in very small systems, with the primary goal of evaluating the degradation pathway or the toxicity limit [5,13–15]. Technological aspects of the operation of batch reactors have not been evaluated, hindering the possible application of such an alternative.

In this way, the aim of the present work was the evaluation of formaldehyde degradation in an anaerobic sequencing batch biofilm reactor (ASBBR), filled with polyurethane foam matrices for biomass immobilization.

2. Materials and methods

2.1. Anaerobic sequencing batch biofilm reactor

The anaerobic sequencing batch biofilm reactor (Fig. 1) consisted of a 23 cm diameter cylindrical glass flask with total capacity of 5 L. The biomass was immobilized in 1 cm cubic particles of polyurethane foam (apparent density of 23 kg/m^3) placed in a basket inside the cylindrical flask. Three 3 cm diameter propeller impellers provided mechanical mixing. The reactor was surrounded by a water jacket that allowed the operation to proceed at a constant temperature throughout the experiment.

2.2. Inoculum

For use as an inoculum, sludge was taken from a full-scale up-flow anaerobic sludge blanket (UASB) reactor treating poultry slaughterhouse wastewater. The sludge was thoroughly mixed with 70 g of cubic polyurethane particles, resulting in 22 g SSV-volatile suspended solids/L of biomass concentration at the beginning of the experiment.

2.3. Synthetic wastewater

The reactor was fed with synthetic wastewater prepared with formaldehyde, mineral medium [17] and vitamin solution [18] (Table 1). Formaldehyde was obtained from a formalin solution containing 38% formaldehyde and 10% methanol as a stabilizing agent. The substrate was refrigerated at 4 °C to maintain its characteristics throughout the experiment. Before entering the reactor, the liquid medium was heated to 35 °C in a heat exchanger.

2.4. Reactor operation

The experiments with formaldehyde-based substrates were performed with a progressive increment of formaldehyde concentration from 31.6 ± 8.7 to 1104.4 ± 130.8 mg/L. The reactor was operated under each influent formaldehyde concentration up to the stability of the system, after which temporal formaldehyde profiles in a cycle were recorded. The reactor was operated for 212 days (633 consecutive cycles) at 35 ± 1 °C with 8 h sequential cycles and constant agitation intensity of 300 rpm. In each cycle, the reactor was fed with 4.2 L of synthetic wastewater for 7 min and, after 465 min of reaction, discharged for 7 min. An idle time of 1 min was set between the feed and discharge operations.

2.5. Analytical methods

Formaldehyde concentrations were determined based on the colorimetric method proposed by Bailey and Rankin [19]. This method is based on the catalytic effect of formaldehyde on the hydrogen peroxide oxidation of *p*-phenylenediamine.

Analyses of chemical oxygen demand (COD), pH and solids were performed according to the standard methods for the examination of water and wastewater [20]. Formic acid was analyzed by high-pressure liquid chromatography (Shimadzu LC-10 AD