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High frequency ultrasound-induced sequence batch reactor as a practical solution for high rate wastewater treatment

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ABSTRACT

In practice, operation of conventional treatment systems with high biomass concentration is limited due to difficulty in the sludge sedimentation in clarifiers. In this study, high frequency ultrasound wave (1.7 MHz) was applied to enhance the sludge settling at high biomass concentration. Hence, performance of two sequence batch reactors (SBR) (with and without ultrasound) treating a synthetic dairy wastewater were compared. Experiments were conducted based on a central composite face-centered design and analyzed using response surface methodology. Aeration time (2–24 h), mixed liquor volatile suspended solids (2000–6000 mg/l), and COD_{in} (500–1500 mg/l) were selected as the operating variables to analyze, optimize and model the process. The results showed that high frequency ultrasound led to considerable increase in sludge settling velocity at high MLSS. COD removal and final turbidity were almost similar in the both systems, indicating that the ultrasound applied has not had any adverse effect on the microbial activity.

Introduction

Wastewater treatment is becoming ever more critical due to diminishing water resources, increasing wastewater disposal costs, and stricter discharge regulations that have lowered permissible contaminant levels in waste streams. Physical, chemical and biological methods are used to remove contaminants from wastewater. Table 1 presents a list of different methods used for the treatment of dairy wastewater [1–15]. Among these, biological methods are of more attention because of their lower cost and reliability [16]. In biological processes, micro-organisms convert the colloidal and dissolved carbonaceous organic matter in wastewater into various gases and cell tissue is then settled and removed in sedimentation tanks.

So far, many biological techniques from natural and constructed wetlands to high-technology solutions based on the activated sludge process have been used for treatment of wastewater that the core of them is concentration of active microbial community at biofilms or flocs [16–18]. Activated sludge process is the most widely used process for biological wastewater treatment in the world nowadays. Many efforts have been done by researchers in order to improve efficiency of this technology since the early 1920s. As wastewater treatment capacity is proportional to the total biomass of the reactor, one of the most important parameters that can improve the performance of biological wastewater treatment is providing a high biomass concentration in the systems [19]. However, the performance of process at high values of biomass can be limited by difficulty in the sludge sedimentation and separation in the secondary clarifiers at wastewater treatment plants [19].

Attempts to increasing of biomass concentration in conventional activated sludge processes have been extensively done. Biomass immobilization technique by providing solid surfaces in aeration tanks to facilitate the natural process of microbial attachment and granular bioreactors are the approaches experienced. Some examples are aerobic granular sludge (AGS) system, upflow anaerobic sludge blanket (UASB), expanded granular sludge bed (EGSB) bioreactor, and membrane bioreactor (MBR) [10–24]. These strategies, compared to the conventional activated sludge process, offer several advantages such as a denser and stronger microbial aggregate structure, excellent sludge settleability, ensured solid effluent separation, a higher biomass concentration, and the ability to withstand shock loadings. In other words, the treatment capacity of those systems can be increased without increasing their physical volume [24,25]. But, in spite of beneficent new technologies, the operation of aforementioned system is countered with many problems. For instance, production of granules in aerobic conditions is very difficult and also these

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Table 1
Different treatment methods examined for dairy industry wastewater.

Treatment method		BOD reduction %	COD reduction %	HRT	Coagulant	Reactor type/membrane type	Reference
Biological treatment	Aerobic	79.9 ± 0.3	87.0 ± 0.2,		–	SBR	[1]
		97.9	98.6	19 h	–	SBR	[2]
		–	90.2	4 days	–	SBR	[3]
		–	90	–	–	Granular sludge SBR	[4]
			>90	10	–	Batch reactor	[5]
	Anaerobic	–	> 90	0.7 day	–	UASB	[6]
		–	99–64.2	0.4–5 days	–	UASB	[6]
		–	90	2 days	–	UFAF two phase	[7]
		–	98.9	1.08 days	–	UASB and AS	[8]
		–	98	7.45	–	CSTR	[9]
Physico-chemical treatment processes	Coagulation/flocculation	87	–	–	Chitosan	–	[10]
		–	40	–	$FeCl_3 \cdot 6\ H_2O/Al_2(SO_4)_3 \cdot 18\ H_2O$	–	[11]
	Electrocoagulation (EC) process	–	98	7 min	–	–	[12]
	Membrane processes	–	>98	–	–	RO	[13]
		–	>98	–	–	NF–RO/RO–RO	[14]
Hybrid methods	MSBR	83.0 ± 0.2	89.3 ± 0.1	–	–	MF	[15]

SBR: Sequential batch reactor, MSBR: Membrane sequencing batch reactor, UASB: Upflow anaerobic sludge blanket, AS: Activated sludge, UFAF: Upflow anaerobic filter, RO: Reverse osmosis, NF: Nanofiltration, MF: Microfiltration

particles are unstable for toxic wastewater [26]. MBR, as systems that combine conventional biological wastewater treatment using suspended biomass with membrane separation, offers the advantages of higher product water quality, higher biomass concentration, and reduced footprint [27]. However, the widespread application of MBRs is constrained by membrane fouling [28,29]. Therefore, many problems accompany each of these systems.

Ultrasound is a cyclic sound pressure at a frequency above the normal hearing range of humans (>20 kHz). With propagation of ultrasound waves in the medium of fluid, the phenomenon of cavitation is generated [30,31]. The cavitation is the formation and implosion of induced bubbles due to pressure reduction under the fluid vapor pressure. After formation of cavitation bubbles, they continue to grow and finally collapse. This impels a shock wave and local turbulency through the fluid [30]. During the last decade, high power ultrasonics has become an alternative to many conventional food processing steps, such as homogenization, milling, high shear mixing, pasteurization and solid/liquid separation [32]. Also, it has shown to improve the efficiency of traditional processes such as filtration/screening, extraction, crystallization and fermentation [32]. The use of ultrasonics is often driven by economic benefits, yet in some cases a unique product functionality can be achieved.

Ultrasound has been used at large variety of applications in biotechnology and in the environmental field for the treatment or pretreatment of water and wastewater. The frequency of ultrasonic waves has direct effect on the size of the induced bubbles [33]. Low-frequency ultrasound (between 20 and 100 kHz), creating larger cavitation bubbles, generate more powerful hydrodynamic shear forces. Therefore, disintegration of sludge is carried out at this frequency [33]. In contrast, at high frequency range, the bubbles are smaller and more stable [34]. Formation of these thin bubbles, which is called stable cavitation, produces another important fluid hydrodynamics effect named microstreaming that causes moving of fluid at the along of transducer axis [30]. These waves hit the upper surface and return to the fluid that is known as acoustic fountain [35], which enhances the microbial flocculation and subsequently shortens the settling time with low sludge volume index (SVI).

Hence, the main aim of this study was to compare the process performance of two sequence batch reactors (SBR), conventional and ultrasound-induced, treating a synthetic dairy wastewater. A general factorial design was employed to describe and model the variation trends of four significant responses, i.e., chemical oxygen demand (COD) removal efficiency, final turbidity, sludge volume index (SVI), and sludge settling velocity as a function of three independent variables, aeration time, initial COD concentration, and biomass concentration.

Materials and methods

Bioreactor configuration and operation

Fig. 1 shows the schematic diagram of two types of aerobic SBRs. The glass bioreactor column was fabricated with an internal diameter of 8 cm and a liquid height of 50 cm. Total volume of each reactor was 2.5 l. Also, the working volume of each reactor was 2 l. In order to investigate the effect of ultrasound on performance of the biological system, one of the bioreactors was equipped with a 1.7 MHz piezoelectric ultrasound transducer (Model ANN-2517GRL, Annon Piezo Technology Co., Ltd., China). At the height

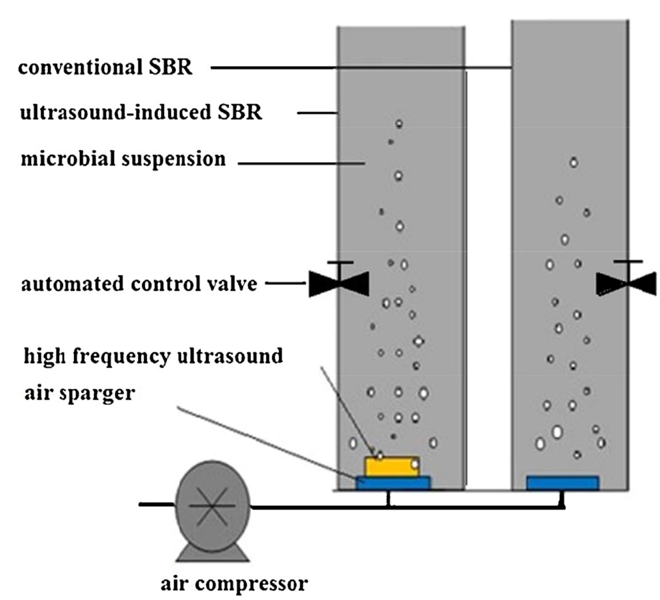

Fig. 1. Schematic representation of two reactors.