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Hydraulic characteristics and performance modeling of a modified anaerobic baffled reactor (MABR)

Shengnan Li, Jun Nan *, Feng Gao

State Key Laboratory of Urban Water Resource and Environment, School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin 150090, PR China

HIGHLIGHTS

- A modified anaerobic baffled reactor (MABR) was proposed.
- Hydraulic characteristics study on the MABR was presented.
- BioWin software was used for performance modeling of the MABR.
- The mixing patterns and dead space together affected the hydraulic performance.
- BioWin was a useful tool in the analysis of the reactor performance.

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ABSTRACT

The modified anaerobic baffled reactor (MABR) is a type of anaerobic baffled reactor (ABR) with improved design concepts and principles. Residence time distribution (RTD) analysis at hydraulic residence times (HRTs) of 12, 16, 20 and 24 h was performed to investigate the mixing patterns and dead space. The BioWin computer modeling software was developed to simulate the performance of the reactor. The model was calibrated using values from experimental runs at HRTs of 12, 16, 20 and 24 h and validated with experimental runs at HRTs of 8 and 10 h. The results of a hydraulic characteristics study showed that the mixing patterns for all test conditions fell between plug flow and completely mixed and the longer the HRT was, the closer the mixing pattern was to plug flow. However, a negative correlation between the dead space and the mixing pattern was observed, the longer the HRT was, the greater the dead space was. The simulated values of effluent chemical oxygen demand (COD) concentration, effluent total suspended solids (TSS) concentration, biogas flow and effluent pH value were predicted with the measured values by absolute relative errors (AREs) of less than 11.7%, 12.4%, 12.9% and 4.3%, respectively, for all test conditions. The model successfully characterized the biomass characteristics in the reactor illustrate that BioWin can well reflect the actual operating performance of the MABR.

1. Introduction

The anaerobic baffled reactor (ABR) was initially developed at Stanford University by McCarty and his co-workers to treat high-strength wastewater [1]. Conceptually, the ABR may be represented as a series of the up-flow anaerobic sludge blanket (UASB) reactors. It consists of a series of vertical baffles that force the wastewater to flow under and over them as it passes from the inlet to outlet of the reactor [2]. Biomass within the reactor gently rises and settles as a result of flow characteristics and gas production in each compartment [3,4]. The technological challenge to improve the anaerobic reactors lies in providing the best growth environment for acidogenic bacteria and methanogens, and enhancing the bacterial activity taking place per unit of reactor volume. In addition, the contact between the microorganisms and their substrate is critical to efficient anaerobic reactor operation.

The modified anaerobic baffled reactor (MABR), which is a type of ABR with improved design concepts and principles, achieves these objectives by an efficient design: (1) considering that the growth rate of methanogens is slower than that of acidogenic bacteria, the compartments are designed as a form of different volume ratio according to the retention times of acidogenic bacteria and methanogens to create suitable matrix and environmental conditions for the two different microorganisms and enable the two bacterial groups to develop in favorable conditions; (2) the baffles are transformed into a series of angles with the peaks facing each

* Corresponding author. Tel.: +86 451 86685762.
E-mail addresses: lishengnan_830309@163.com (S. Li), nanjun_hit2212@163.com (J. Nan), xiaogao0859@126.com (F. Gao).

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other, which can improve the contact between the microorganisms and their substrate because the flow rate between the two adjacent baffles continuously changes when the wastewater flows through the inoculated sludge.

The conversion of organic and inorganic matter in an anaerobic digestion process is primarily governed by two interrelated factors: the reactor's hydrodynamics, which are predominantly impacted by its construction, and the performance of the microbiological processes [5]. The strong interdependence of hydraulics and kinetics means that the hydraulic performance directly affects the pollutant removal performance [6,7]. In previous ABR studies, Grobicki and Stuckey evaluated the hydrodynamic characteristics by tracking the fate of an inert tracer lithium (Li^+) in the effluent, which was previously described by Levenspiel as the residence time distribution (RTD) [8,9]. The model provides a useful method for evaluating the mixing patterns (plug flow or completely mixed) and the dead space based on the probability distribution of the material age at the exit of a reactor.

The construct of the MABR underscores its potential as an efficient technology that is economically feasible for wastewater treatment. However, modeling is necessary for identifying actions for better control of the process operation. Over the years, various modeling approaches representing anaerobic digestion have been developed, in pursuit of a better understanding of the microbial and system dynamics for different feeding regimes and environmental conditions [10–14]. Also, the computer modeling software has become widely adopted in wastewater engineering over the past two decades [15]. Although they were principally developed as a research tool, they are currently employed for the design and optimization of reactors. The BioWin computer modeling software (EnviroSim Associates Ltd., Flamborough, Ontario, Canada) is a Windows-based computer simulation model that is increasingly employed to predict anaerobic digestion processes; it is primarily employed to simulate wastewater treatment.

In this study, a series of RTD studies of the MABR was performed to investigate hydraulic characteristics to illustrate that the variance of the hydraulic retention time (HRT) affected the mixing pattern and the dead space. The study was also developed, calibrated, verified and presented using the novel application of BioWin to simulate and evaluate the performance of the reactor. The objectives of this study are to determine the appropriate HRT for the hydraulic performance of the MABR and to certify the theoretical results by simulating the results to explain that the BioWin computer modeling software can better reflect the actual operating performance of the reactor.

2. Materials and methods

2.1. Apparatus

The laboratory-scale MABR in the study was composed of Perspex and includes four sequential compartments. The reactor was 740 mm long, 100 mm wide and 1000 mm deep with a total liquid volume of 54.8 L. Acidogenesis predominated in the former two compartments, and methanogenesis was dominant in the subsequent compartments. The peculiarities of the MABR were that the four compartments with the volume ratio of 3:1:5:5 and the baffles were transformed into a series of 120-degree angles, the peaks faced each other and the wave height was 20 mm. Temperature control was accomplished by a water jacket to maintain the operation at a constant mesophilic temperature of 30 ± 0.5 °C, and the produced gas was discharged via portholes at the top of each compartment. The upper half space of each compartment was coated with elastic packing that was composed of polyethylene plastic. This type of packing facilitated uniform gas and water distribution and enabled easy growth of the biofilm. A peristaltic pump (Longer WT600-2, Longer pump Co., China) was used to feed wastewater into the reactor at different flow rates that ranged between 114.2 and 38.1 mL/min, which corresponded to an HRT of 8 to 24 h. The schematic of the experimental apparatus is presented in Fig. 1.

2.2. Inoculum and synthetic wastewater

The anaerobic sludge used as inoculum in the reactor originated from the sludge of the anaerobic treatment tower and treats beer wastewater of Huarun Snow Brewery Company, which is located in Harbin in Heilongjiang province, China. The sludge was gray black anaerobic flocculent sludge with a slight odor, and the pH

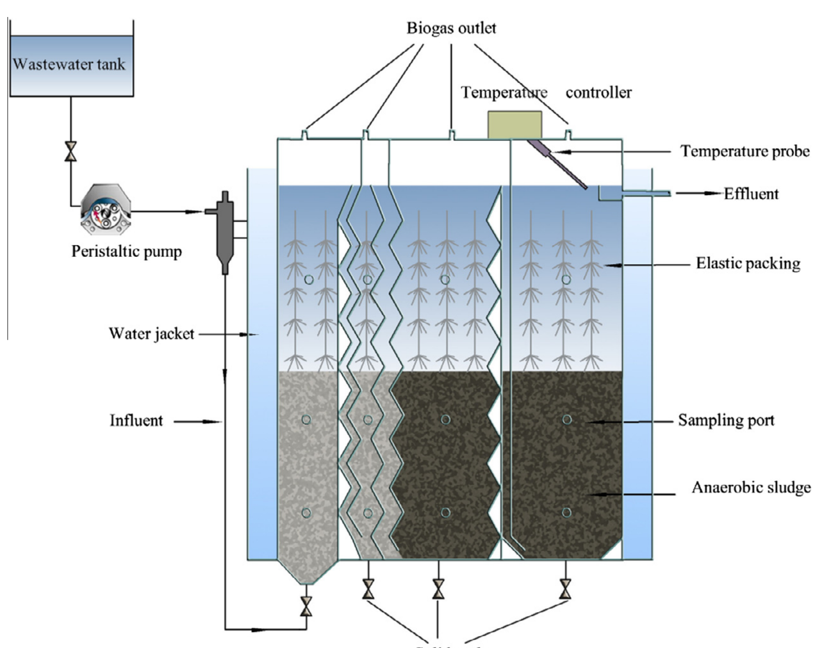

Fig. 1. Schematic of the modified anaerobic baffled reactor (MABR).