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Enhancement of the performance of anaerobic fluidized bed bioreactors (AFBBRs) by a new starch based flocculant

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ABSTRACT

In this study, laboratory-scale anaerobic fluidized bed bioreactors (AFBBRs) using granular activated carbon as bedding material were employed for treating a primary treated sewage effluent (PTSE) with or without refractory organic pollutants (ROPs). A new starch based flocculant (NSBF) combining a nature starch based cationic flocculants and trace nutrients was prepared and applied in the AFBBR. The impact of NSBF on the performance of AFBBR was mainly evaluated in terms of organic and nutrient removal and microbial activity. Membrane fouling based on critical flux was assessed when the bioreactor used as pretreatment for microfiltration. The results indicated that the addition of NSBF in AFBBR (NSBF–AFBBR) not only attained improved organic (9–10%) and nutrient removal (10–20%), higher biomass growth ($3.0\ g_{biomass}/L_{GAC}$) and net bed expansion (18 cm), but also doubled the critical flux (from 15 L/m^3 h to 30 L/m^3 h) in the microfiltration system. In addition, NSBF–AFBBR could retain 10% better DOC removal efficiency at different recirculation rates for treating PTSE with ROPs. When increasing organic loading rate from 21.6 kg COD/m^3 d to 43.2 kg COD/m^3 d, NSBF–AFBBR achieved comparatively constant organic removal of 55% whereas the efficiency in AFBBR alone decreased dramatically from 47% to 34%. Thus, NSBF could act as a performance enhancer for AFBBR.

1. Introduction

Continued population growth, contamination of surface water and groundwater and frequent droughts have contributed to inadequate water supplies and water qualities deterioration. Public concerns over health and the environment have led to a need to treat effluents to a higher level. As one of the most hazardous pollutants, refractory organic pollutants (ROPs) such as humic substances in wastewater are generally hard-to-decompose by microorganisms in secondary treatment process. Even though they usually present a very low concentrations in the wastewater compared to other pollutants, they are very harmful to the human health and environment due to their persistence against chemical/biological degradation [1]. They can react with disinfectants such as chlorine and form trihalomethanes (THMs) and other halogenated by-products as well as organic halides. Many of these halogenated organic compounds are carcinogens or mutagens and are toxic at high concentrations. Thus, the hazardous pollutants including ROPs need to be removed to permissible limits for the safe disposal of wastewater.

Biological wastewater treatment is one of the most cost-effective ways to remove the organic and nutrient contents from wastewaters. In anaerobic treatment processes, anaerobic fluidized bed bioreactor (AFBBR) that utilizes small fluidized media particles to induce extensive cell immobilization has emerged as a good alternative for wastewater treatment with the merits of high surface area available for biomass and substrate, high organic loading rate and short hydraulic retention time over other kinds of anaerobic processes [2,3]. Maloney et al. [4] have reported that treatment of propellant wastewater by AFBBR was effective in laboratory and field feasibility studies. The AFBBR was able to reduce the concentration of diaminotoluene (DNT) by more than 90% at the high-strength source and could meet discharge permit limitations. Atikovic et al. [5] also investigated the biological degradation of AFBBR which has been shown to be an effective method for removing perchlorate and royal demolition explosive (RDX) in army ammunition production wastewater.

However, the most significant variable in the digestion of FBBR is the selection of support media for microbial adhesion, as anaerobic digestion has a low growth rate of anaerobic bacteria [6].

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Depending on previous studies, many supporting media have been used in FBBR such as granular activated carbon (GAC), sand, perlite, zeolite, lava rocks and synthetic resin with considerably successful application [2,7,8]. Use of GAC in FBBR is an emerging technology for difficult-to-degrade organics, operated under anaerobic conditions, as it has a strong affinity for attaching organic substances thus offering an ideal environment for enhanced biodegradation. In AFBBR, there are two removal mechanisms occurring simultaneously: (i) the GAC acts primarily as a support media and the adsorbed organics are biodegraded by biofilm attached on GAC and (ii) the adsorptive capacity of the GAC can cut-off peaks of influent concentration through adsorption and later desorbs the contaminants when the bacteria have reduced the aqueous phase concentration, which allows the bacteria to work at a relatively steady state mass removal [9]. Khodadoust et al. [10] evaluated anaerobic GAC–FBBRs for treating wastewater containing pentachlorophenol (PCP). Throughout the various phases of reactor operation, more than 99% PCP and 95% COD were reduced. GAC provided an excellent attachment surface for the biofilm in addition to effectively adsorbing PCP and its biotransformation compounds. In another study, Maloney et al. [9] demonstrated a pilot scale AFBBR containing GAC to treat a pinkwater consists of trinitrotoluene (TNT) and RDX as well as other hazardous by-products. The results showed that TNT and RDX could be effectively treated by anaerobic bacteria under widely varied contaminant concentrations. The system not only lowered the total cost on a yearly basis, but also eliminated the generation of hazardous waste.

Starch is an effective natural polymer for creating reactive cationic moieties using positively charged groups, for instance, amino, imino, ammonium, etc. [11]. Although inorganic and organic synthetic polymer flocculants have been superior to starch based flocculants due to their high flocculating efficiency, non-biodegradable property presents the major drawback of polymeric flocculants, which will lead to secondary pollution for the environment and health impact for human being [12]. Since starch derivatives offer inherent advantages over inorganic and synthetic polymer flocculants such as being derived from a renewable source of raw materials, very low cost, and easily degradable in the environment after use [13], the starch flocculants can cause less ecological problems in the long term than a persistent one while providing carbon source for the microbial activities in biological treatment processes. The previous study found that the natural starch based cationic flocculant could enhance the biomass growth and aggregation process in a fluidized bed GAC bioreactor [14].

In this study, a new starch based flocculant (NSBF) developed from previous study [15] was applied to AFBBR for improving organic and nutrient removal from a primary treated sewage effluent (PTSE). This modified NSBF was evaluated through both of the AFBBR's performance and microbial aspects. The main objectives of this study are: (i) to investigate the effects of NSBF addition on treating PTSE with and without ROPs in terms of organic and nutrient removal, oxidation–reduction potential (ORP), bed expansion and biomass growth, (ii) to evaluate the fouling potential of the effluent from AFBBR to a submerged microfiltration (SMF) system using critical flux as indicator, and (iii) to evaluate the performance of AFBBR (with and without NSBF) on removing organics addition under different hydrodynamic conditions.

2. Materials and methods

2.1. Wastewater

Table 1 shows the composition of the synthetic wastewater used in this study. The synthetic wastewater originally contained biodegradable organic pollutants together with some trace nutrients, which was used to simulate PTSE (just after primary treatment process). The ROPs in the PTSE contained natural organic matter such as humic acid, tannic acid, lignin, polysaccharide and other high molecular carbohydrates, which contributed about 10 mg/L dissolved organic matter to PTSE. The synthetic PTSE with and without ROPs has DOC of 110–125 mg/L and 100–115 mg/L respectively.

Table 1
Composition of synthetic PTSE used.

Compound	Concentration (mg/L)
Glucose	230
$(NH_4)_2SO_4$	71
KH_2PO_4	13.2
Trace nutrients	
$MgSO_4{\cdot}7H_2O$	5.07
$CaCl_2{\cdot}2H_2O$	0.368
$MnCl_2{\cdot}4H_2O$	0.275
$ZnSO_4{\cdot}7H_2O$	0.44
$FeCl_3$	1.45
$CuSO_4{\cdot}5H_2O$	0.391
$CoCl_2{\cdot}6H_2O$	0.42
$Na_2MoO_4{\cdot}2H_2O$	1.26
Yeast extract	20
Refractory organic pollutants	
Humic acid	4.2
Tannic acid	4.2
(Sodium) lignin sulfonate	2.4
Sodium lauryl sulphate	0.94
Acacia gum powder	4.7
Arabic acid (polysaccharide)	5

2.2. GAC used

The coal based GAC (ACTICARB GS1300, Activated Carbon Technologies Pty Ltd., Australia) was used in this study. This coal based GAC has a surface area of >1100 BETm^2/g, an iodine number of >1100 mg/(g min) and maximum ash content of 10%. Prior to use in experiments, the GAC was rinsed with distilled water to remove fines and dried at 105 °C in the oven.

2.3. New starch based flocculant (NSBF)

The NSBF used in this study was the combination of a nature starch based cationic flocculant and trace nutrients ($CaCl_2$, $MgSO_4$ and $FeCl_3$) which were helpful for biomass growth. The starch based cationic flocculant was provided by HYDRA 2002 Research, Development and Consulting Ltd., Hungary. The major components of this flocculant are cationic starch ether and water. It is completely soluble in water with a density of 1050 kg/m^3.

2.4. AFBBR

In this study, laboratory-scale AFBBRs with 1200 mm long and 25 mm inner diameter were employed. 200 mL of fresh GAC was added in each AFBBR to have an actual (non-fluidized) filter depth of 500 mm. PTSE was pumped through the AFBBRs at the flow rate of 14.4 L/d and organic loading rate of 21.6 kg COD/m^3 d. Fluidization of GAC with the initial bed expansion of 10 cm was achieved through recycling the effluent from near the top to the bottom assembly at the superficial velocity of 40.76 cm/min. NSBF was continuously added to AFBBRs by dosing pumps with a dosage of 22 mg/L (water treated). Samples of feedings and the effluents from AFBBRs were taken after filtering through 0.45 μm filter prior to analyzing DOC (Analytikjena Multi N/C 2000 Analyzer) and nutrients (NOVA 60, Merck). The ORP and bed expansion were measured every day and the samples were taken every 5 days for analyz-