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Start-up and Performance of a Novel Reactor——Jet Biogas Inter-loop Anaerobic Fluidized Bed*

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Abstract A novel anaerobic reactor, jet biogas inter-loop anaerobic fluidized bed (JBILAFB), was designed and constructed. The start-up and performance of the reactor was investigated in the process of artificial glucose wastewater treatment. With the wastewater recycle ratio of 2.5 : 1, the recycled wastewater with biogas could mix sludge and wastewater in the JBILAFB reactor completely. The start-up of the JBILAFB reactor could be completed in less than 70 d through maintenance of hydraulic retention time (HRT) and stepwise increase of feed total organic carbon (TOC) concentration. After the start-up, with the volumetric TOC loadings of 14.3 $kg\cdot m^{-3}\cdot d^{-1}$, the TOC removal ratio, the effluent pH, and the volatile fatty acids (VFA)/alkalinity of the JBILAFB reactor were more than 80%, close to 7.0 and less than 0.4, respectively. Moreover, CH_4 was produced at more than 70% of the theoretical value. The reactor exhibited high stability under the condition of high volumetric TOC loading. Sludge granules in the JBILAFB reactor were developed during the start-up and their sizes were enlarged with the stepwise increase of volumetric TOC loadings from 0.8 $kg\cdot m^{-3}\cdot d^{-1}$ to 14.3 $kg\cdot m^{-3}\cdot d^{-1}$. Granules, an offwhite color and a similar spherical shape, were mainly comprised of global-like bacteria. These had good methanogenic activity and settleability, which were formed probably through adhesion of the bacteria. Some inorganic metal compounds such as Fe, Ca, Mg, Al, *etc.* were advantageous to the formation of the granules.
Keywords anaerobic reactor, jet biogas inter-loop anaerobic fluidized bed, wastewater treatment, start-up, granule sludge

1 INTRODUCTION

Anaerobic technology is one of most suitable methods for wastewater treatment, especially effluents containing high concentrations of organic carbon. The successful application of this technology to the treatment of industrial wastewater is critically dependent on the development of high rate anaerobic bioreactors. Over the last two decades, a number of high-rate anaerobic reactor systems have been developed, *e.g.*: anaerobic filter (AF), up-flow anaerobic sludge bed (UASB), internal circulation (IC) reactor, expanded granular sludge bed (EGSB), and anaerobic fluidized-bed (AFB). Among these anaerobic digestion processes, the fluidized-bed reactor is considered as a continuous-flow, completely-mixed homogeneous microbial system [1] and its configuration has several advantages over other anaerobic reactors, *e.g.*: high concentrations of biomass (close to 40 $kg\cdot m^{-3}$), large areas of mass transfer, high velocities of fluid flow (10–30 $m\cdot h^{-1}$), no clogging in the reactor, and small volume and land area requirements [2, 3]. Owing to these advantages, it is possible to work at the condition of high organic loading rates and short hydraulic retention time (HRT) [4]. Therefore, this reactor is wildly applied to the biological treatment of municipal and industrial wastewater [5, 6]. Potential AFB reactor applications for the treatment of hazardous waste with inhibitory/recalcitrant compositions have also been reported [7-9]. However the carrier and sludge in a traditional AFB reactor retain a suspending status only by drag forces of upflow wastewater [1], and the effect of biogas is often ignored [10]. Since the densities of the usual carriers such as active carbon and sand are higher than water, the carriers not colonized are more difficult to fluidize when the input flow rate is low. Therefore, a high recycle ratio, Q_r/Q (where, Q_r is the recycle rate, $L\cdot d^{-1}$; and Q is the feed rate, $L\cdot d^{-1}$), is necessary. Its value is about 10–50 [11] or even higher than 50 [12]. The higher liquid recycle ratio indicates stronger shearing forces. As anaerobic bacteria are slow growing microorganisms, a long start-up period is required and is a serious obstacle for their wide installation in the anaerobic treatment of industrial wastewater. This is attributed to the relatively strong hydrodynamic conditions in the reactor, which interfere with biomass adhesion during the start-up period. Reactor start-up is often considered to be the most unstable and difficult phase in anaerobic digestion. Its main task is to develop a highly active settleable sludge as quickly as possible. Thus the reduction of start-up time is one of the key parameters to increase the competitiveness of high-rate anaerobic reactors.

The gas can relatively expand the sludge bed better along the height of the reactor, even with low upflow velocity [13]. This concept will be worth trying to use biogas as one of the drag forces. A gas injection is simpler than a liquid recycling and low energy is required, because of low fluidization velocities. Moreover, several beneficial features can generally be offered by gas-lift systems. For instance, there may be a more efficient liquid mixing without the extreme shearing forces. Excessive attrition of aggregates by these forces is thus avoided, as aggregates may be dispersed randomly through the reactor.

To remedy the drawback of long start-up period and extend the application of AFB reactors, a novel anaerobic reactor-jet biogas inter-loop anaerobic fluidized bed (JBILAFB) was designed and constructed. Both biogas and upflow wastewater in the reactor

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were used as drag forces to keep the anaerobic sludge in suspension. This report describes the start-up and operation performance of the pilot-scale JBILAFB reactor, specifically the operation parameters, the loading capacity, and the specific sludge granules.

2 MATERIALS AND METHODS

2.1 Experimental system

The flow scheme of the laboratory-scale JBILAFB reactor is illustrated in Fig. 1. The design principle of this reactor is similar to that of the jet aerobic reactor. The difference is the biogas injected into the JBILAFB with the recycled wastewater. Since the biogas is recycled from the top to the bottom of the reactor, the drag forces of the carrier and sludge change from only upflow wastewater to both biogas and upflow wastewater, which can mix sludge and wastewater adequately in the reactor with low upflow velocity. Furthermore, poisonous gas such as H_2S produced during the anaerobic digestion can be eliminated immediately [14]. Also, the fluidization effect and mass transfer between the wastewater and the anaerobic sludge in the reactor improve at the low liquid recycle ratio.

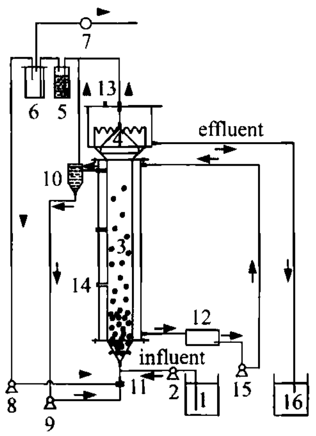

Figure 1 Schematic diagram of laboratory-scale JBILAFB reactor
1—feeding tank; 2—influent pump; 3—JBILAFB reactor; 4—setter part; 5—water airproof bottle; 6—gas stockpile bottle; 7—wet gas meter; 8—gas cycle pump; 9—water cycle pump; 10—gas-water separator; 11—micro-jet; 12—water bath with a temperature controller; 13—exhaust port; 14—sample point; 15—hot water cycle pump; 16—effluent tank
→ water flow; ▶ biogas flow; • bioparticle

A transparent Plexiglas column with conical bottoms was used as the reactor. The main components of the JBILAFB reactor included a reaction and a settler part, a biogas recycle pump, a micro-jet, a feed pump, a wastewater recycle pump, a water batch with a temperature controller, and feed and effluent tanks. The volume of the reaction part was about 9.0 L, 800 mm in height and 120 mm in internal diameter. An enlarged section of 370 mm height and 200 mm internal diameter was fitted at the top of the reaction part and used as the settler part, which consisted of a cover for accumulating biogas, a three-phase separator for biogas/wastewater/sludge and a trough for collecting the effluent. Biogas was collected using gas stockpile bottle after passing through a water lock bottle filled with saturated salt solution. The biogas production was measured with a wet gas meter. The recycled wastewater through an airproof gas-water separator and the biogas were continuously injected into the JBILAFB reactor by a water cycle pump and a gas cycle pump, respectively. The biogas and the recycled wastewater were mixed fully in a micro-jet. The recycled wastewater comes from the top of the reaction part to carry out internal loop, which can decrease the volume of the settler part and be advantageous to the separation of the water/sludge. Moreover, the influent was diluted and short circuit in the reactor was avoided by the recycled wastewater flow. Hot water maintained at (35 ± 1)°C was pumped from a recirculation water bath through the constant temperature jacket surrounding the reactor. Prior to the beginning of this experiment, the residual air in the closed JBILAFB reactor system was replaced by N_2 and the system was maintained at complete anaerobic environment.

2.2 Synthetic wastewater composition

The reactor was fed with synthetic wastewater with glucose as the sole carbon and energy source. The carbamide and KH_2PO_4 were the sole nitrogen and phosphor sources, respectively. The amount of carbamide and KH_2PO_4 in the synthetic wastewater was confirmed according to the COD/N/P ratio of 200 : 5 : 1. The influent further contained yeast leaching ointment and micronutrients. The nutrient composition of the solution was prepared according to Table 1. The $NaHCO_3$ was used to adjust the pH of the influent. The influent pH was kept at 7.0 ± 0.3. The synthetic wastewater was prepared daily and maintained at 4°C.

Table 1 Nutrient composition of solution

Constituent	Concentration /mg·L^{-1}	Constituent	Concentration /mg·L^{-1}
$MgCl_2·6H_2O$	125	KI	2.5
$FeSO_4·7H_2O$	25	$Na_2MoO_4·2H_2O$	0.5
$FeCl_2·4H_2O$	180	$ZnCl_2$	0.5
$CoCl_2·6H_2O$	2.5	H_3BO_4	0.5
$MnCl_2·4H_2O$	2.5	$NiCl_2·6H_2O$	0.5

2.3 Analytical methods

The analytical work performed is shown in Table 2. Conventional analysis items including pH, suspended solids (SS), and volatile suspended solids (VSS) were carried out according to the standard methods issued by the China National Environmental Protection Agency [15]. The liquid mixing time was measured using an electrical conductivity method and saturated potassium chloride solution was used as the tracer. The concentration of tracer was detected by a conductivity probe connected to a conductometer (model DDS-11A, Leici Instrument Plant of Shanghai,

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