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Combined industrial and domestic wastewater treatment by periodic allocating water hybrid hydrolysis acidification reactor followed by SBR

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ABSTRACT

A pilot-scale hybrid hydrolysis acidification reactor (HHAR) with periodic water allocation mode operation followed by sequencing batch reactor (SBR) in anoxic and aerobic metabolic function was evaluated for the treatment of low-biodegradable combined industrial and domestic wastewater. The HHAR combines the advantages of both the UASB reactor and AF, omitting the three-phase separator. Furthermore, it has lower average up-flow velocity (0.38–0.92 m/h) and higher periodic up-flow velocity (6 m/h), which made the reactor keep higher MLSS concentration (more than 10,000 mg/L) and sludge-bed is in periodic "expansion-sedimentation-expansion" state. When HRT less than 10 h, the B/C variation was positive and reached the maximum value of 0.07 at 8 h. SBR with a total cycle period of 4.5 h was applied as the post-treatment process to remove residual COD, NH_3-N and TN. At steady stage, the pilot-scale SBR effluent COD, NH_3-N and TN concentration was 65, 0.75 and 17.71 mg/L, corresponding in this case to full-scale SBR plant effluent was 93, 16.4 and 34 mg/L. Comparison results indicated that the application of HHAR–SBR system to treat combined industrial and domestic wastewater can improve effluent quality significantly.

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1. Introduction

In eastern china, many industrial areas were established, and the municipal wastewater treatment plants initially designed for treatment of domestic wastewater had to accept the increasing industrial wastewater. Although the industrial wastewater was pre-treated before being discharged into the municipal treatment plants, the residual compounds of the pre-treatment effluent were always with low-biodegradable (BOD/COD ratio ~0.1), high total nitrogen (more than 50 mg/L) and NH_3-N (more than 35 mg/L). And the influent characteristics of municipal treatment plants were greatly changed. So, it is difficult for those municipal treatment plants designed for domestic sewage to meet the upgrading discharge standard.

It is well known that hydrolysis acidification process can improve the biodegradability of wastewater by decomposing complicated molecules to smaller ones and suspended solids (SS) to dissolvable matters [1,2]. The hydrolysis acidification process has been extensively used to treat the complex wastewater with poor biodegradability [3–5] or abundant SS [1,6]. Therefore, it will be an appropriate choice for applying hydrolysis acidification as the pre-treatment of combined industrial and domestic wastewater.

As well known, hydrolysis acidification is the first stage of anaerobic process. And they have similar design features. Over the last decade, many anaerobic reactor systems were developed such as up-flow anaerobic sludge bed (UASB), anaerobic filter (AF), anaerobic fluidized bed (FB) and expand bed (EB), anaerobic hybrid reactor (AHR) and so on. Among the different anaerobic reactors, FB and EB reactors were proved to be the most efficient with the excellent effluent quality due to the sufficient contact of sludge and wastewater. However, few full-scale FB/EB systems have been commissioned because of high energy demand for fluidization and the difficulty in construction and operation [7,8].

In order to overcome the disadvantages of FB/EB system, a periodic water allocation hybrid hydrolysis acidification reactor, which consists of a periodic allocation tank and hybrid hydrolysis acidification reactor, was designed. The hybrid reactor combines the positive aspects of both the UASB reactor and AF, and many studies have been carried out with hybrid reactors [9–12]. The allocation tank with a total cycle period consisted of filling, vacuumizing and allocating. Filling time is usually several minutes, while allocating time is in the range of 10–20 s. Because the filling time is a few times of allocating time, periodic water allocation can gain higher up-flow velocity. Compared with continuous water allocation, this periodic water allocation can decrease dead zones and result in better sludge and wastewater contact.

After hydrolysis acidification, biodegradability was increased and the partial COD, total nitrogen (TN) and SS were removed. However, COD, TN, NH_3-N concentrations of hydrolysis treatment

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process generally cannot meet the discharge standard. Therefore, post-treatment is necessary. Because of the simultaneous treatment of nitrogen, carbon in an activated sludge sequencing batch reactor (SBR) is possible by alternating the aerobic, anoxic and anaerobic [13,14]. So, it is an attractive choice to apply SBR as the post-treatment.

In this paper, a pilot-scale hybrid hydrolysis acidification reactor (HHAR) followed by SBR was studied at ambient temperature. This study firstly explained the application of this novel process for the treatment of combined industrial and domestic wastewater with the pilot-scale plant. As pre-treatment of combined industrial and domestic wastewater, the effectiveness of HHAR was evaluated, and the overall efficiency of HHAR–SBR system was assessed by comparing to the full-scale SBR plant.

2. Methods and materials

2.1. Wastewater

The industrial wastewater of the combined wastewater was mainly from papermaking industries, tanning industries, and printing and dyeing industries. The percentage of industrial wastewater was more than 60%. The main characteristics of the wastewater used as feed in this study are presented in Table 1. These characteristics were indicative of a combined industrial and domestic wastewater.

2.2. Characteristics of the HHAR–SBR system and operation

This HHAR–SBR system consisted of a hybrid hydrolysis acidification reactor (HHAR) with periodic water allocation mode operation followed by sequencing batch reactor (SBR). HHAR was applied as the pre-treatment of SBR. For combined industrial and domestic wastewater, the system could perform better and more efficient. This was due to the hydrolysis of complicated molecules and suspended solids in HHAR stage, allowing an increase of biodegradability and the content of soluble and easily biodegradable organic matter. This is helpful for improving COD and ammonia nitrogen removal rate, in addition, providing sufficient carbon source for denitrification.

A scheme of the HHAR–SBR system is shown in Fig. 1. The HHAR and SBR were designed and fabricated with metallic material. The active volume of HHAR was 30 m^3 and its total height and internal diameter were 7.0 and 2.5 m, respectively. In the top 1/3 of the reactor was filled with plastic media. Eight sampling ports allowed us to take samples from the reactor at different heights of 0.5 m, 1.0 m, 1.5 m, 2.0 m, 2.5 m, 3.5 m, 4.5 m and 5.5 m. The allocation tank with the working volume of 83 L (internal diameter 0.5 m, working height: 0.42), it was placed at the top of the hybrid reactor, the lowest water level of allocation tank was 1.5 m higher than hybrid reactor effluent level. The wastewater was firstly pumped into water allocation tank. With the rising of water level, the air inside the allocation pipe was drawn out by the exhaust pipe to make the pipeline to form a partial vacuum and water level rise within the pipe. When the water level reached the highest point, water allocation started, and the water level dropped. When the water level dropped to the lowest point, the vacuum was destroyed. Then water allocation ended, the total allocation time was about 15 s. During the water allocation, wastewater and the sludge of the bottom reactor were mixed vigorously to make the sludge bed expansion. After water allocation ended, sludge bed down to the original position. Therefore, with the period of filling and allocating, the sludge bed was in the periodic "expansion-sedimentation-expansion" state.

Table 1
Main characteristics of combined industrial and domestic wastewater (mg/L, except pH).

S. no.	Parameters	Value
1	pH	6.75–7.08
2	Total dissolved solids (TDS)	2500
3	Suspended solids (SS)	302–410
4	Chemical oxygen demand (COD)	182–636
5	Biological oxygen demand (BOD_5)	150–210
6	Total nitrogen (TN)	36.2–75.7
7	Ammonia nitrogen (NH_3-N)	9.1–51.6
8	Phosphates	0.98–2.76
9	Temperature (°C)	11–22

The SBR had an active volume of 15 m^3 with the size of 2.5 m × 2.5 m × 1.5 m. Dissolved oxygen was supplied using porous diffusers placed at the bottom of the reactors. A mechanical stirrer with regulated rotation speed (36 rpm) was used to provide liquid mixing during denitrification. The SBR operation cycles were controlled by a programmable PLC. SBR with a total cycle period of 4.5 h (FILL: 30 min; STIR: 50 min; REACT: 120 min (aeration); SETTLE: 50 min; DECANT: 35 min), with five cycles performed per day, stirring was started after filling for 15 min.

The pilot system was located in the municipal wastewater treatment plant of Haining City of Zhejiang Province, and was fed with raw combined industrial and domestic wastewater after sand removal. To start-up the reactor, the excess sludge of the full-scale SBR was used as inoculums, and the HHAR and SBR reactors had an overall biomass concentration of 10 and 3.5 g/L volatile suspended solids (VSS), respectively. The HHAR–SBR system was operated at ambient temperature (11–22 °C) for a period of about 240 days.

2.3. Analytical methods

The influent and effluent samples were collected daily. They were analyzed immediately or stored in a refrigerator at 4 °C until the analyses were carried. Temperature and pH was detected using online 340i pH meter (WTW Company, Germany). COD, BOD_5, NH_4^+, TN, mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were measured according to Standard Methods [15].

3. Results and discussion

3.1. Characteristic of HHAR

3.1.1. The up-flow velocity

As we known, the wastewater up-flow velocity is a key operation parameter of anaerobic bioreactors, which can affect the concentration of activated sludge and sludge-wastewater contact efficiency. Such as, the up-flow velocity of UASB and EGSB reactors are in the range of 0–3 m/h and 3–10 m/h, respectively. In this study, a novel hybrid hydrolysis acidification reactor with periodic water allocation tank was applied. Here, the influent was continuously pump to the allocation tank, meanwhile allocating of the tank was intermittent. So, the reactor has continuous up-flow velocity for influent and periodic instantaneous up-flow velocity for allocating. The average up-flow velocity was varied with different hydraulic retention time (HRT), while periodic up-flow velocity was constant, as a consequence of constant water allocation quantity and allocating time. The average up-flow velocity varied in the range of 0.38–0.92 m/h, the lower velocity can keep higher MLSS. The periodic up-flow velocity was 6 m/h, the higher velocity can make sludge bed to completely fluidize [16]. The details are presented in Table 2.

3.1.2. The activated sludge concentration

The MLSS along the reactor was measured, which can reflect the activated sludge concentration. As shown in Fig. 2, the MLSS

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