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Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor

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ABSTRACT

Sludge settleability is considered one of the main drawbacks of sequencing batch reactors. The aim of this study therefore is to improve sludge settleability by introducing a novel, two-stage settling sequencing batch reactor (TSSBR) separated by an anoxic stage. The performance of the TSSBR was compared with that of a normal operating sequencing batch reactor (NOSBR), operating with the same cycle time. The results show a significant improvement in sludge settleability and nitrogen compound removal rates for the TSSBR over the NOSBR. The average removal efficiencies of NH_3-N, NO_3-N and NO_2-N have been improved from 76.6%, 86.4% and 87.3% respectively for the NOSBR to 89.2%, 95.2% and 96% respectively for the TSSBR. In addition, the average SVI_{30} for the NOSBR has been reduced from 42.04 ml/g to 31.17 ml/g for the TSSBR. After three months of operation, there was an overgrowth of filamentous bacteria inside the NOSBR reactor, while the morphological characteristics of the sludge inside the TSSBR reactor indicated a better and homogenous growth of filamentous bacteria.

1. Introduction

The continuing increase in industrial activities worldwide, is having an adverse impact on the environment. If not committed to protective government regulations, industrial plants can discharge highly toxic wastewater consisting of environmentally noxious materials, this constituting a serious threat to both the environment and humans [1]. There are a significant number of technologies available for the treatment of industrial wastewater; biological treatment is no exception. The latter is considered one of the most convenient technologies for the treatment of industrial wastewater due to its manufacturing and operational cost requirements. In addition to cost considerations, biological treatment has proved to be an effective technology for removing high concentrations of pollutants.

One of the common biological technologies is the activated sludge process (ASP), used worldwide for the treatment of domestic and industrial wastewater [2]. It consists of several reactors in which microorganisms degrade incoming wastewater and in doing so, grow and produce new microorganisms. After degradation is achieved, these microorganisms are separated from the treated wastewater by sedimentation. In order to sustain an active and high concentration of solids for the reaction treatment, some sediment solids should be removed from the system, others recycled back into the aeration basin [3]. One of the drawbacks of ASP is that it requires a large footprint for its treatment tanks [4].

Often industries are located within cities which makes it difficult to build a treatment system containing several tanks. In this case, alternatives are available such as sequencing batch reactors (SBR). The SBR is an activated sludge process that consists of a sequence of stages which operate in one tank following a time sequence. These stages are fill, react, settle, draw and idle. It has been reported that SBRs require less area, are flexible to operate and can be operated automatically [5,6]. However, solid-liquid separation, or sludge bulking, is still one of the most problematic issues with SBRs and ASPs in general [7,8].

Researchers have reported several reasons for this problem such as difficulty in handling sudden changes in the operating parameters [9,10], microbial clustering behaviour [11], the overgrowth of filamentous bacteria [12,13], foaming [14,15], pin-point sludge [15,16], poor macrostructure [15], poor flocculation properties [17] and floc size distribution [13,18].

To overcome settling problems, researchers have been evaluating a variety of solutions, one of which is granulation technology. In specific environments, microbial self-agglomeration forms a granular biological polymer known as aerobic granular sludge (AGS) [19,20]. It has many

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Table 1
Composition of synthetic wastewater.

Chemicals	Chemical formula	Concentration
Glucose	$C_6H_{12}O_6$	500 mg/l
Magnesium Sulphate Heptahydrate	$MgSO_4{\cdot}7H_2O$	5 mg/l
Sodium Bicarbonate	$NaHCO_3$	200 mg/l
Ammonium Chloride	NH_4Cl	25 mg/l
Potassium Nitrate	KNO_3	25 mg/l
Monobasic Potassium Phosphate	KH_2PO_4	5 mg/l
Iron(III) Chloride Hexahydrate	$FeCl_3{\cdot}6H_2O$	1.5 mg/l
Calcium Chloride Dihydrate	$CaCl_2{\cdot}2H_2O$	0.15 mg/l

advantages such as high degradation abilities, significant settling velocity, a regular shape and compact structure [4,20]. However, the stability of AGS may decline after extended periods of operation [21,22]. In addition to stability loss, granulation technology has other problems such as high operation temperatures, a long acclimatisation time and inefficiency when subject to low concentrations of organic wastewater [23,24]. This means that granulation technology requires more research to address these issues. A different approach to overcoming settling problems is the addition of chemicals before the settling stage to improve the settling performance [25,26]. However, this procedure raises the cost of treatment and results in more complex and toxic residual which has a negative impact on the environment [27]. Along with granulation sludge technology and chemical conditioning, researchers have been modifying operation strategies and trialling the addition of more stages to SBR treatment cycles to improve the treatment performance without additional costs due to increased cycle time [4,28,29].

The aim of this study is to improve sludge settleability by introducing a novel, two-stage settling SBR. This system will focuses on three issues. The first is to create a shock after the first settling stage and allow small flocs to climb together, merge with large flocs and settle again in the second settling stage. Secondly, the effect of this procedure will be assessed to examine the elimination of filamentous accumulation and improvement in the settling stage. Finally, verification will be sought of whether separating the two stages of settling with a short anoxic stage enhances nitrogen removal efficiency by improving the denitrification stage.

2. Materials and methods

2.1. Activated sludge characteristics and synthetic wastewater

The returned activated sludge (RAS) used in this study was collected from a treatment plant at Sandon Docks, United Utilities, Liverpool, UK. Synthetic wastewater was prepared every week by mixing the chemicals in Table 1 [30,31] with deionized water. All reagents used in this study were purchased from Sigma-Aldrich, UK.

2.2. Experimental setup and operation of the treatment reactors

Four Plexiglas reactors were used in this study as shown in Fig. 1. The total volume of each reactor is 6.5 l, 5 l the working volume of each. For the aeration stage, an air pump was used to supply air at the rate of 1 l/m, air diffusers used inside each reactor to produce fine air bubbles. Overhead stirrers were used for each reactor to achieve the anoxic stages. Three electronic sensors (probes) were positioned in each reactor to monitor the pH, oxidation-reduction potential (ORP) and

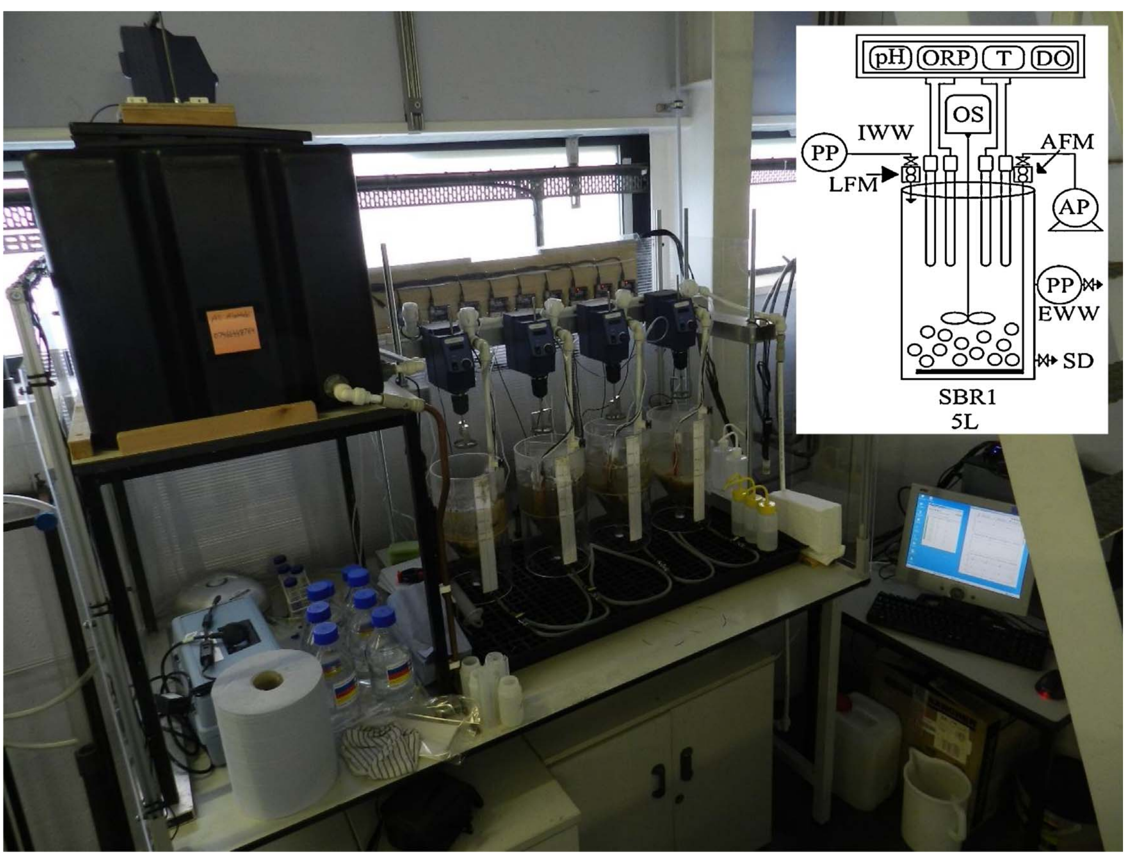

Fig. 1. The configuration of the laboratory-scale SBRs (AFM: air flow meter; AP: air pump; DO: dissolved oxygen probe; IWW: Influent wastewater; EWW: effluent wastewater; LFM: liquid flow meter; ORP: oxidation-reduction potential probe; PP: peristaltic pumps; OS: overhead stirrer; pH: pH probe; SD: sludge draw; T: temperature probe).