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Effect of intermittent aeration cycles on EPS production and sludge characteristics in a field scale IFAS reactor

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ABSTRACT

In the present study, an integrated fixed-film activated sludge (IFAS) bioreactor was subjected to dissimilar intermittent aeration (IA) cyclic operations, and its effects were investigated on extracellular polymeric substances (EPS) production, sludge characteristics, and specific power consumption. A total of three IA cycles (IA1, 150 min aeration on and 30 min off; IA2, 120 min aeration on and 60 min off; IA3, 90 min aeration on and 60 min off) were evaluated in the present IFAS reactor. Specific EPS production (mg/g of suspended solids) was found to be following the increasing trend with respect to the non-aeration to aeration time ratio, whereas, the sludge production followed the reverse trend. The amount of bound EPS was observed to be much higher (6–10 times) than soluble microbial product (SMP) in each intermittent aeration phase. During all the investigated IA cycles, the pilot was observed to be significantly affected in terms of biomass characteristics, which was also confirmed by increasing trends of sludge volume index (SVI) and filamentous index (FI) values. In-situ monitoring and measurement of reactor operation parameters such as pH, oxidation reduction potential (ORP), and dissolved oxygen (DO) was also done in all IA cycles. A maximum of 27.05% reduction in electrical energy was observed in highest non-aeration period cycle.

1. Introduction

All the biological wastewater treatment systems (suspended and/or attached) produce a complex mixtures of high-molecular-weight substances i.e. polymers secreted by microorganisms, produced from cell disintegration, and adsorbed substrate from wastewaters [1], which are known as extracellular polymeric substances (EPS). These materials play a consequential role in enhanced settling of biomass, and helps them to form the microbial clusters in a wastewater treatment system. The prime components of EPS mixture include macromolecules such as carbohydrates and proteins, which exerts influence on bio-chemical characteristics of microbial consortium [2]. Furthermore, the two forms of EPS exist at outer surface of microbial cells which can be categorized as bound EPS and soluble EPS [3,4]. As the classification term implies, the bound EPS are closely attached with microbial cells, whereas soluble EPS are those compounds which are either loosely bound with cells or dissolved into the mother solutions [5]. In spite of significant research on EPS, many other factors play important role which could influence the composition and production rate of EPS in environmental systems. This quantitative as well as qualitative variation in constituents of the extracted EPS may be attributed to various factors such as type of wastewater, biomass conditions, operational parameters, bioreactor type, and extraction method etc. [3]. Among the various important operational parameters of bioreactors, solid retention time, shear rate or aeration intensity, and aerobic or anaerobic conditions were found to be affecting the EPS production and composition as well. However, the results published in literature are slightly contradictory as some reported increasing trend while others observed the decreasing trend of EPS production with similar change in operating conditions [5,6–9]. To date, although ample amount of literature is published about EPS quantification methods but more studies are required to investigate their roles in the biological wastewater treatment systems under different operational conditions. Therefore, to gain confidence about the fate of EPS it is important to conduct more studies under stressed conditions to investigate the behaviour of biomass with respect to EPS production.

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In last two decades, various operational strategies such as intermittent aeration and variable dissolved oxygen mode have been investigated for biological wastewater treatment systems [10–13]. Among these operational stresses, intermittent aeration (IA) strategies, also called alternating anoxic/oxic process, have been proved very efficient in removal of the biodegradable components (organics, solids, and nutrients) of wastewaters in continuous as well as in batch reactors. During the times of 1980–1990, a good number of plants were built to operate under same operational conditions, and data on treatment performance and energy consumption were reported [14–17]. More advantages of alternating anoxic/oxic process are well documented in our recently published studies [12,13]. This type of operational strategies also gives a major reduction in electric energy consumption as well as in operational costs associated with aeration [18–23].

The integrated fixed-film activated sludge (IFAS) systems, which were introduced in 1994, emerged as one of the most encouraging alternative in decentralized context [24–26]. These systems have been proved efficient in developing as well as in developed countries for the municipal and/or industrial wastewater treatment [12,27–31]. To date, some studies have been reported the role and impact of various intermittent aeration strategies on organics and nutrient removal in natural and aerobic wastewater treatment systems [32–35]. However, the sludge characteristics of these systems are still unexplored, and very limited studies are available revealing the role of EPS, and nature of sludge produced in biological wastewater treatment systems [36]. Until now, very limited published literature is available reporting the effect of intermittent aeration strategies on the EPS quantity produced, and biomass characteristics in an IFAS and/or biofilm reactor [37]. Therefore, this study was carried out to investigate the effects of different IA cycles on the EPS production and sludge characteristics in an IFAS reactor.

2. Material and methods

2.1. Description of experimental set-up

All the experiments were conducted on a pilot-scale fixed media based IFAS reactor (Table 1). The whole body of reactor was made up of stainless steel including fixed media holding frame. The fixed media curtains (a loop knitted polypropylene fabric in a rectangular geometry), placed within the aerobic zone of system, and mounted within a detachable frame assembly which can be simply lifted out from the aeration tank for maintenance or inspection, whenever required. Necessary aeration in the IFAS reactor was provided by using an automated blower supplying requisite air to the highly efficient membrane diffusers, installed at the bottom of the fixed media holding tank. The actual municipal wastewater was pumped from the sump well of the sewage pumping station, and settled activated sludge along with raw municipal wastewater flowed over a weir into the aeration chamber by using centrifugal pumps. The typical characteristics of wastewater fed to pilot were equivalent of medium strength sewage, and the values of main parameters are noted in the range of 400–600; 240–350; 200–360; 40–65; and 3–10 for COD, BOD, TSS, TN, and TP, respectively. The daily wastewater feeding rate was adjusted to yield a hydraulic retention time (HRT) of 11.1 h. The schematic diagram of experimental setup used in this study is shown in Fig. 1.

Table 1
Technical design details of pilot plant.

Parameter	Unit	Value
Dimension of aerobic tank (L × W × H)	m	3 × 2 × 3.34
Volume of aeration tank	m^3	20
Volume of settling tank	m^3	4.2
Media packing (by volume)	%	0.5
No. of media pieces (curtains)	–	64
Dimension of each curtain (L × W)	m	2.7 × 0.96

2.2. Start-up and experimental methodology

The start-up of pilot plant was done according to our previous study [12], and results of treatment performance analysis and changes in microbial diversity are presented in our recent studies [12,13]. The overall experimental campaign was divided into four phases: three intermittent aeration (IA) runs, and one continuous run. Each of the IA phase lasted for around three weeks with an interval of one week between two consecutive phases. The operational parameters for the pilot are presented in Table 2. The aeration was controlled by using an automated timer in the blower unit with fixed time periods of aeration and non-aeration.

2.3. Analysis and measurement

During the entire experimental period, the influent, effluent, and sludge samples were placed in an icebox and brought to environmental engineering laboratory at IIT Roorkee, until analysis could be performed. Selected in-situ operational parameters and reactor conditions such as pH, dissolved oxygen (DO), HRT, waste activated sludge (WAS) rates, and return activated sludge (RAS) rates were monitored and measured on each sampling day, while oxidation reduction potential (ORP) was monitored in batch mode. The major treatment performance parameters such as 3-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), and total phosphorus (TP) were measured according to Standard Methods [66]. The mixed liquor suspended phase biom HRT, waste activated sludge (WAS) rates, and return activated sludge (RAS) rates were monitored and measured on each sampling day, while oxidation reduction potential (ORP) was monitored in batch mode. The major treatment performance parameters such as 3-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), and total phosphorus (TP) were measured according to Standard Methods [66]. The mixed liquor suspended phase biomass samples were collected from the IFAS reactor and characterized by mixed liquor suspended solids (MLSS) and sludge volume index (SVI) measurements by following the procedure as presented in Standard Methods [66]. The electrical energy consumption was calculated by considering the rating and running hours of blower unit.

2.4. EPS quantification

In order to examine the physiochemical condition of the suspended biomass in IFAS reactor, the total concentration of EPS, termed as EPS_T, was measured in present study. The soluble (termed as soluble microbial products, SMP) and bound EPS concentrations were determined according to Zhang et al. [38], Di Bella et al. [39], Di Bella and Torregrossa [40]. The total EPS (both bound and soluble) concentration was calculated as the sum of the above two described fractions, according to the below equation:

$$EPS_T = EPS_b + SMP = (EPS_{bp} + EPS_{bc} + (SMP_p + SMP_c)$$

Where EPS_b = bound EPS; SMP = soluble microbial product.

Here subscripts 'p' and 'c' indicate the content of proteins and carbohydrates in the EPS_b and SMP, respectively.

In order to measure the contents of proteins and carbohydrates in bound and soluble EPS, Lowry's Folin method [41] and Anthrone's method [42] were used, respectively.