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Treatment performance and microbial diversity under dissolved oxygen stress conditions: Insights from a single stage IFAS reactor treating municipal wastewater

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ABSTRACT

In the present study, assessment of a single stage integrated fixed film activated sludge (IFAS) reactor treating municipal wastewater and subjected to various dissolved oxygen (DO) stresses, is done in terms of treatment performance and changes in bio-chemical characteristics of activated sludge. Results obtained from experimental revealed that the DO concentrations of 0.5, 2.5, and 4.5 mgL^{-1} affected significantly the performance of IFAS reactor. The optimal DO concentrations for the efficient removals of organics, nitrification, denitrification, and total nitrogen were recorded as 4.5, 4.5, 2.5, and 2.5 mgL^{-1}, respectively. Biological phosphorus removal (BPR) efficiency of pilot deteriorated significantly at high DO (4.5 mgL^{-1}) levels. Insignificant variation in SVI values (190–245 mLg^{-1}) was observed at different DO phase experiments. The macromolecular composition) of activated sludge was also determined in terms of lipids, proteins and polysaccharides content. Moreover, activated sludge characterization results revealed that the dominance of micro fauna (ciliated protozoa) and microorganisms (gram characteristics) was different at different DO levels. Overall, the optimal DO concentration was suggested as 4.5 mgL^{-1} for the IFAS system as it not only achieved high organics removal efficiency and but also minimized the sludge production with high sludge retention time.

1. Introduction

In the last 20 years, activated sludge/biofilm hybrid system, also called integrated fixed film activated sludge (IFAS) reactor have been established as a simple-yet-robust, flexible and compact solution for municipal and industrial wastewater treatment. To date, various treatment configurations of IFAS technology such as aerobic, anoxic or anaerobic have also been documented in literature at lab, pilot and full scale levels [7,12,14,16,23–25]. Although IFAS technology based systems have shown their great potential in developed countries but its applications in developing countries are still in infantry phase either due to less practices or fear from using these technologies [1,5,6,19]. As reported by various researchers, the primary objective of IFAS systems, is to sustain under stresses conditions such as varying dissolved oxygen concentrations, flow, and organic loading rates [2,10,18]. Among the aforementioned stresses, dissolved oxygen (DO) concentration is an important operating parameter in aerobic biological treatment which determines the overall efficiency of oxidation, nitrification, denitrification, and nitrate accumulation treatment system. DO levels not only affects the removal efficiencies of pollution governing parameters, but also shows the impact on the characteristics of microbial communities [30,31,9,33,28,17].

As IFAS technology based processes involve a large amount of biomass, which require a requisite amount of DO levels in the aerobic zone, this system needs to be critically analyzed at low to moderate DO levels (0.5–4.5 mgL^{-1}). In literature, a range of 2–3 mgL^{-1} is generally suggested for IFAS systems but actual requirement must be governed by the removal of priority pollutants [21,22]. On the other side Hitherto, several lab scale IFAS systems have been investigated at low to high DO conditions in the aerobic zone to achieve the maximum capacity of the system, but it would not also be wrong to say that the results of lab scale studies are rarely applied to full scale systems. In general, literature data are contradictory and performance results are not for practical applications under low and high dissolved conditions. Finally, we hypothesize that microbial abundance and diversity are influenced by oxygen availability, which is key to understanding process resilience in future applications of IFAS system.

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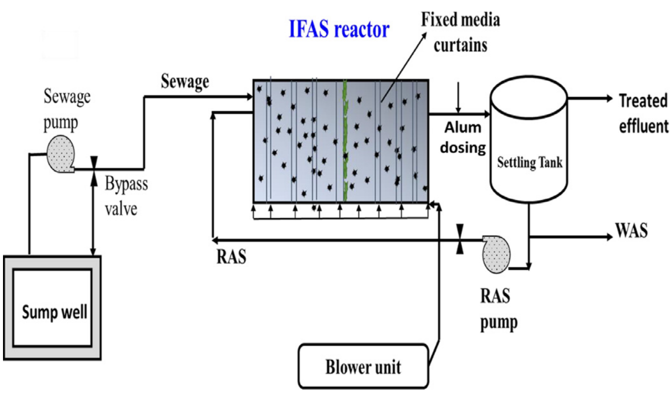

Fig. 1. The schematic of pilot scale IFAS reactor.

Table 1
Summary of reactor operating conditions at different runs.

Parameters	Run 1	Run 2	Run 3
HRT (h)	11.1	11.1	11.1
SRT (days)	8	11	22
Bulk DO (mg/L)	~0.5	~2.5	~4.5
MLSS (g/L)	2±0.2	2±0.2	2±0.2
RAS (× Q)	1.5	2.5	3

Q: Inflow (L/s).

Having these considerations in mind, the objectives of the present study were to assess the performance potential of an IFAS reactor at low to moderate DO conditions, in terms of organics and nutrient removal. Changes in sludge settling properties, macromolecular composition (polysaccharide, protein and lipid content) of activated sludge and dominancy of biological species (protozoa and bacteria) were also determined under actual treatment conditions.

2. Materials and methods

2.1. Reactor configuration and operating conditions

A pilot-scale fixed media IFAS reactor (Fig. 1), operated in conventional activated-sludge process configuration (aeration tank followed by settling tank) and located at the sewage pumping station, Rishikesh, Uttarakhand, India was investigated under different dissolved oxygen (DO) stress conditions to determine its effects on the biological treatment potential as well as on microbial communities. The pilot contains fixed curtains (Biotextil Cleartec® media) within the aerobic zone of the reactor, occupying approximately 0.5% of the gross tank volume. The Cleartec media is a loop-knitted polypropylene fabric in a rectangular geometry. The fixed media curtains and diffusers were mounted within a removable frame assembly. Aeration was provided with a fine-bubble membrane diffuser located at the bottom of aeration tank and the air flow was controlled by using a control panel. To enhance denitrification a returned activated sludge (RAS) sludge was pumped continuously from the settler to the aeration tank. Excess sludge was withdrawn daily manually from the settling tank. The operation of the IFAS system was observed for around 2 months covering the three experimental runs where the dissolved oxygen levels in the reactor gradually increased from 0.5–4.5 mgL^{-1} in Run 1, Run 2 and in Run 3, respectively. Table 1 contains a summary of operational parameters of the IFAS during different DO runs. Each run is classified according to reactor DO. The daily wastewater feeding rate was adjusted to yield a hydraulic retention time of 11.1 h. During the study, the composition of the influent wastewater varied significantly and detailed characteristics are presented in Table 2. In the mixed liquor of reactor, the pH was 7.0±0.6, the temperature was 26±4 °C and the concentration of mixed liquor suspended solids (MLSS) was 2±0.2 gl^{-1}, respectively.

Table 2
Influent wastewater characteristics at different dissolved oxygen operating conditions.

Parameters	Run 1	Run 2	Run 3	Unit
pH	7.20±0.15	7.28±0.37	7.18±0.19	–
Temperature	25–28	24–26	25–21	°C
COD_T	455.56±37.09	626.86±187.69	440.38±25.66	mg/L
BOD_T	232.78±29.82	305.71±84.41	221.63±18.44	mg/L
TSS_T	316.56±34.71	384.29±79.70	262.88±27.61	mg/L
NH_3–N	40.83±7.93	33.69±8.19	34.46±9.61	mg/L
NO_2–N	0.21±0.24	0.33±0.31	0.52±0.39	mg/L
NO_3–N	2.13±0.53	2.21±1.12	2.89±0.84	mg/L
TKN	48.57±7.56	44.21±7.10	42.49±9.59	mg/L
TP	5.60±1.96	5.93±1.50	4.65±1.20	mg/L

2.2. Physico-chemical analysis

The reactor was monitored for pH, temperature, dissolved oxygen (DO) concentration, mixed liquor suspended solids (MLSS), chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), Total Kjeldahl Nitrogen (TKN), total phosphorus (TP). Sludge settling characteristics were evaluated by the sludge volume index (SVI) values. The filtrate was analyzed for ammonia nitrogen (NH_4–N), nitrite nitrogen (NO_2–N), nitrate nitrogen (NO_3–N), using a UV–visible spectrophotometer (Hach Co. Ltd. DR-6000^{TM}). The pH and DO concentrations were measured using a pH meter (Cyberscan 510 digital) and DO meter (Hach, Model OX-2P). All experiments were performed in accordance with standard methods for the examination of water and wastewater [4]. At the end of each experimental stage, the lipid, crude protein and polysaccharide content of the suspended sludge was measured by gravimetric method [15], using Kjeldahl method [27], and the anthrone method with glucose as a standard [3], respectively. All measurement were done in triplicates and the average results are presented.

2.3. Microscopic analysis

Characterization of ciliate species was done using a light microscope (Olympus Medical Systems India Private Limited, Gurgaon, India) fitted with a photographic camera by following the procedure as per our previous study [11,22]. Ciliates counts were performed every time within 6 h of sample collection. Classical staining techniques such as gram stain were used for the examination of suspended biomass samples [8]. Binary method [13] for determining dominancy of gram positive or gram negative bacteria was used in present study in which a fragment of image is considered to be Gram-positive (respectively Gram-negative) if more than 50% of its pixels are purple (respectively pink).

3. Results and discussion

3.1. Treatment performance

3.1.1. DO to organics and suspended solids removal effect

The performance of an IFAS reactor with respect to effluent COD, BOD and TSS along with removal efficiencies at three DO conditions was investigated and is shown in Fig. 2. The experimental results indicate that there were significant differences in COD removal efficiencies at different DO concentrations. The minimum effluent COD values were achieved as 25 mgL^{-1} under condition 3 (DO ~ 4.5 mgL^{-1}), and the average removal rate attained 94.2%.