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Environmental performance and microbial investigation of a single stage aerobic integrated fixed-film activated sludge (IFAS) reactor treating municipal wastewater

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ABSTRACT

Due to exhausting natural and conventional water resources, it is necessary that the existing wastewater management practices should introduce small-scale treatment technologies. In this purview, technical assessment of a single stage integrated fixed-film activated sludge (IFAS) reactor, treating municipal wastewater, was carried out at optimized operating conditions i.e. dissolved oxygen (D.O.), ~3 mg L^{-1}; hydraulic retention time (HRT), 6.9 h; return activated sludge (RAS) rate, 160–175%; waste activated sludge (WAS) rate, 1.1 $m^3 d^{-1}$; sludge age, ~7 d. The start-up period for the reactor was 33 days and after this, the reactor was run for three months. The suspended and attached biomass worked together to maintain an average removal rate of ~92% for chemical oxygen demand (COD), ~91% for biological oxygen demand (BOD), ~90% for total suspended solids (TSS), ~88% for total nitrogen (TN) and 50% for total phosphorus (TP), respectively under optimized conditions. Almost two times of the suspended biomass was observed in attached phase, which provided high treatment performance of the system with respect to overall pollutants removals. Scanning electron microscope observation of suspended and attached microbial community showed that biofilm was more homogeneous and porous than the suspended biomass. Microbial results revealed 2.2 and 2.4 log reduction of total coliforms (TC) and faecal coliforms (FC), respectively. *E. coli* was found to be achieved higher removal efficiency (>99%) among all the selected pathogens (*E. coli*; *Salmonella* spp. and *Shigella* spp.). Respirometric characterization of biomass showed that attached biomass was found to be dominating in the overall removal of pollutants.

1. Introduction

Effective wastewater management in small, medium sized and isolated communities is of crucial importance and has drawn attention of many scientists and sanitary engineers [14]. Various efforts have also been made to set up affordable wastewater disposal systems in small communities of developing countries [1]. At this juncture, the final selection of an appropriate system always depends upon site specific conditions as well as adaptability by local authorities [2,3].

Since last three decades, two well-known wastewater treatment approaches i.e. centralized and decentralized treatment (onsite and cluster) are in practice, but the centralized approach is the preferred method [4–6]. These systems paid much attention in last 30 years, as it has become technically out-dated and adoption of these systems keeps much capacity idle until the demand grows into it [4,7]. Centralized systems require intricate technologies and skilled manpower for satisfactory performance, while on the other side, as an alternative, decentralized wastewater treatment systems (DEWATS) are more suitable for growing demand and provides a “build-when-you-need” or “well-timed” treatment solutions [5,8,9]. Also DEWATS have been represented its potential in developing countries as compared to developed countries [10–12]. These systems reported appreciable performance for those areas which are devoid of sewerage systems [1,13,14].

In actual practice, the developing countries, who are already facing financial problems, cannot afford vast investment in construction & operation of centralized systems, while DEWATS allows major advantages over these issues [10,15,16]. Various DEWATS have been implemented at full/demonstration scale with various conventional and advanced treatment technologies such as anaerobic baffle reactor (ABR), rotating biological contactor (RBC), sequential bioreactor (SBR), and septic tanks (ST) etc. [10,17]. Literature review revealed that various treatment technologies are

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available for decentralized wastewater management at lab and pilot-scale level but their applications at the full-scale level are still in its infancy, especially in developing countries [6].

Since 1994, integrated fixed-film activated sludge (IFAS, also known as hybrid biological reactor) technology emerged as trailblazing option which can provide a sustainable solution for small and isolated communities. The IFAS system combines the features of suspended and attached growth processes by incorporating the specially designed biomass carriers, on which the biomass attach and populate, in bioreactors. This addition of biomass carrier increases the biomass inventory subsequently treatment capacity of reactor [18–25]. It could be an effective option for municipal as well as industrial wastewater treatment [26,27]. The main feature of IFAS process includes high surface area for microbial growth that leads to enhanced nitrification rates along with being capable to bear organic as well as hydraulic shock loads. The IFAS systems are categorized into two types of modules depending upon the arrangement of biocarriers inside the bioreactor. Accordingly, two modules of IFAS systems are being practiced: moving bed biofilm reactor (MBBR) in which carrier moves freely inside the reactor and another is fixed media activated sludge systems in which carrier is fixed inside the reactor [20,21].

A detailed literature review has been compiled regarding fixed media based IFAS systems (lab-scale, pilot-scale and full-scale). The data found in literature, as presented in Table 1, was analyzed critically to draw insight and came with following outcomes:

1. Fixed media based IFAS systems have been successfully implemented at lab, pilot and full-scale level in developed countries but its implementation in developing countries such as India is still in infantry phase.
2. Applications of real wastewater based IFAS systems are very limited.

The inventory presented in Table 1 demonstrated that in last 20 years the IFAS systems have gained much attention all over the world, but very limited applications are demonstrated using actual wastewater and fixed biocarriers, especially in developing countries.

Similar to fixed media based IFAS systems, MBRRs also have potential applicability in wastewater treatment but the packing ratio of these systems is still on a higher side (60–70%) which ultimately lowers the hydraulic capacity of MBBR systems [26,33]. Contrary, fixed media based IFAS systems possess very low packing ratio as compared to MBBR systems. Thus, it was supposed that fixed media IFAS systems may be more capable to work against the accelerated hydraulic loads. These fixed media based IFAS systems are capable to accomplish nitrification throughout the year and have high potential for treatment due to increased biomass inventory and sludge retention time.

Bearing in mind all these considerations, the present study had been undertaken to assess the performance of a fixed media based IFAS system, exposed to real wastewater under actual field conditions. In this paper in particular, the results of a field gathering campaign on a single stage fixed media based IFAS system are presented and discussed. Start-up experiences (performance and operational problems along with counter measures) of this system are published in our recent study [34]. The broad objectives of this paper are:

(i) To investigate the feasibility of single stage IFAS reactor as decentralized treatment option under real treatment conditions.
(ii) To optimize the system to achieve the best possible results in terms of effluent quality and to identify the operational problems and challenges during operation and its control.
(iii) To determine the role of suspended and attached biomass regarding organics and nitrogen removal using respirometric techniques.
(iv) To assess the capability of system for removing bio-indicators and pathogenic bacteria also.

The results obtained in present study may also aid in the design of full-scale processes.

2. Material and methods

2.1. Description of the IFAS reactor

All experiments were conducted on a single stage fixed media based IFAS reactor operated in conventional activated sludge process mode (aeration tank followed by settling tank) using actual domestic wastewater as a feed. The whole body of reactor was made up of stainless steel sheets including fixed media holding frame. The fixed media (Biotextil Cleartec®, Hydrok, UK) was placed within the aerobic zone of system, occupying approximately 0.5% of the gross tank volume. The Cleartech® media is a loop knitted polypropylene fabric in a rectangular geometry. The fixed media curtains were mounted within a detachable frame assembly which can be simply lifted from the aeration tank for maintenance or inspection, whenever required. The treatment system was installed at the sewage pumping station (SPS), Rishikesh, Uttarakhand, India so that the continuous feeding of municipal wastewater could be ensured. Technical specifications of accessories employed in system are illustrated in Table 2.

The municipal wastewater feed was pumped from the sump of SPS to plant and settled activated sludge along with raw municipal

Table 1
Inventory of different fixed carrier based IFAS bioreactors installed at lab/pilot/full scale across the world.

S. No.	Carrier	Study	Type	Filing fraction (%)	Country	References
1	Plastic net	Lab scale	Fixed	30	India	[23]
2	Ringlace	Lab scale	Fixed	NR	USA	[28]
3	Foam (sponge)		Fixed	10–15		
4	Non-woven fabric carrier	Lab scale	Fixed	50	China	[29]
5	Bioweb	Pilot scale	Fixed	NR	Thailand	[26]
6	Accuweb	Pilot scale	Fixed	NR	USA	[30]
7	Ringlace	Full scale	Fixed	1	USA	[21]
8	Ringlace & Biomatrix	Full scale	Fixed	NR (Length reported)	Canada	[31]
9	Polyurethane plastic	Lab scale	Fixed	8.6	China	[19]
10	Bioweb media	Pilot scale	Fixed	NR	Thailand	[32]
11	Bioweb media	Pilot scale	Fixed	NR	Thailand	[33]

NR: not reported.