Environmental performance of an integrated fixed-film activated sludge (IFAS) reactor treating actual municipal wastewater during start-up phase

Nitin Kumar Singh, Absar Ahmad Kazmi and Markus Starkl

ABSTRACT

The present study summarizes the start-up performance and lessons learned during the start-up and optimization of a pilot-scale plant employing integrated fixed film activated sludge (IFAS) process treating actual municipal wastewater. A comprehensive start-up was tailored and implemented to cater for all the challenges and problems associated with start-up. After attaining desired suspended biomass (2,000–3,000 mg/L) and sludge age (~7 days), the average biological oxygen demand (BOD) and chemical oxygen demand (COD) removals were observed as 77.3 and 70.9%, respectively, at optimized conditions, i.e. hydraulic retention time (HRT), 6.9 h; return sludge rate, 160%. The influent concentrations of COD, BOD, total suspended solids, NH_3-N, total nitrogen and total phosphorus were found to be in the range of 157–476 mg/L, 115–283 mg/L, 152–428 mg/L, 23.2–49.3 mg/L, 30.1–52 mg/L and 3.6–7.8 mg/L, respectively, and the minimum effluent concentrations were achieved as ~49 mg/L, 23 mg/L, 35 mg/L, 2.2 mg/L, 3.4 mg/L and 2.8 mg/L, respectively, at optimum state. The present system was found effective in the removal of pathogenic bacteria (*Escherichia coli*, 79%; *Salmonella* spp., 97.5%; *Shigella* spp., 92.9%) as well as coliforms (total coliforms, 97.65%; faecal coliforms, 80.35%) without any disinfection unit. Moreover it was observed that the time required for the stabilization of the plant was approximately 3 weeks if other parameters (sludge age, HRT and dissolved oxygen) are set to optimized values.

Key words | India, integrated fixed-film activated sludge, municipal wastewater, optimization, start-up performance

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INTRODUCTION

In the last two decades, the role of biological processes in municipal wastewater treatment has increased considerably. Although the inevitable need of a new wastewater treatment plant is to prove its feasibility and to operate flawlessly from the first day of start-up within some constraints, it is also important to mention and accept that this has probably never happened (Sarioglu 2012; Tang *et al.* 2012; Khalili *et al.* 2013; Singh *et al.* 2015). That is why the start-up methodology of a wastewater treatment plant (WWTP) is one of the most important stages of successful operation and always requires special attention. However, the start-up methodology differs from one treatment facility to another but a similar kind of treatment system may adopt the same guidelines for start-up of the plant. Because of an inappropriate start-up, aimed objectives in the establishment of a wastewater treatment system would not be achievable and the system would be ineffective (Van Hulle *et al.* 2005; Gali *et al.* 2006; Jubany *et al.* 2008).

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Since 1994, there has been increasing concern in the development of integrated fixed-film activated sludge (IFAS, also known as a hybrid biological reactor) systems due to their advantages, such as smaller reactor sizes, ease of operation, less sludge production, and the increased specializations of attached biomass (Ødegaard 2006; Regmi *et al.* 2011; Trapani *et al.* 2013; Piculell *et al.* 2014). These systems render combined features of suspended and attached growth processes by incorporating specially designed biomass carriers, on which the biomass attach and populate, in the aeration basin of WWTPs (Seetha *et al.* 2010; Chen *et al.* 2014). Like other treatment systems, they are constructed either as prefabricated units known as 'package plants' or individually built on site (Ødegaard *et al.* 1994; Randall & Sen 1996). There are basically two types of IFAS module reported in literature. In one module, part of the biomass is suspended while the remainder is supported on fixed biocarriers. In another module the active biomass is mainly supported on the moving biocarriers along with the suspended phase (Sen *et al.* 1994; Seetha *et al.* 2010; Duan *et al.* 2012). However, various laboratory-scale studies have been carried out on moving media systems using mainly synthetic wastewater, with a common goal of assessing process performance (Fouad & Bhargava 2012; Sriwiriyarat & Randall 2005a; Seetha *et al.* 2010; Chu & Wang 2011; Chen *et al.* 2014; Zhang *et al.* 2014) but very limited experience exists about the fixed biocarriers-based IFAS systems employing actual wastewater as feed and under real treatment conditions, especially in developing countries (Randall & Sen 1996; Jones *et al.* 1998; Sriwiriyarat *et al.* 2008a; Seetha *et al.* 2010; Li *et al.* 2012).

Bearing these considerations in mind, the present study was aimed at discussing the results of the start-up phase and the necessary actions and modifications that have to be made to overcome the operational challenges and lessons learned during the start-up of an IFAS reactor. Various operational changes were made throughout the start-up and optimization period. Moreover, the authors also intended the present system to be flexible, operationally easier and adaptable to complex conditions in the decentralized locations of India. Confronting and overcoming these operational challenges has been a gratifying experience for the authors. The results of this study would be helpful in the implementation of IFAS systems in developing countries such as India.

EXPERIMENTAL PROGRAMS

Description of the pilot-scale IFAS reactor

The experiments were conducted on a pilot-scale fixed media IFAS reactor operated in conventional activated-sludge process configuration (aeration tank followed by settling tank), which was located at the sewage pumping station, Rishikesh, Uttarakhand, India. The IFAS reactor's body was made of stainless steel. 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 which can be easily lifted from the aeration tank for maintenance or inspection whenever required. The technical specifications of the pilot plant are presented in Table 1.

Table 1 | Technical design details of pilot plant

Parameters	Unit	Value
Dimension of aerobic tank (L × W × H)	m	3 × 2 × 3.34
Hybrid stage (aeration tank) volume	m^3	20
Setting tank volume	m^3	4.2
Footprint	m^2	6
Fixed media filling fraction	%	0.5
No. of fixed media (curtains)	–	64
Dimension of each curtain (L × W)	m	2.7 × 0.96

Necessary aeration was achieved using fine-bubble membrane diffusers (Hydrok Aquaconsult AEROSTRIP®), mounted at the bottom of the aeration tank. For this purpose, the blower was constantly operated at maximum power (3 kW) and generated a constant airflow of 24 and 38 Nm^3/h (specific airflow was 20 and 31.6 $Nm^3/(h.m^2)$) at average and peak load conditions (2.07 and 2.96 kg O_2/h). Influent wastewater and settled sludge from the secondary clarifier were pumped directly into the splitter box of the reactor, from where both streams flowed over a weir to the bottom of the aeration tank. Treated liquor and excess biomass overflowed from the aeration tank to the secondary clarifier for the separation of biosolids. The schematic diagram and actual experimental setup (IFAS reactor) used in this study is illustrated in Figure 1.

Sample collection and analysis

In situ operational parameters, such as dissolved oxygen (DO) in aeration basin, oxygen uptake rate (OUR), hydraulic retention time (HRT), return activated sludge (RAS) and waste activated sludge (WAS) rates, were closely monitored and recorded during the experimental period. Grab samples were collected and analysis of feed, effluent and biomass samples was conducted as proposed by *Standard Methods for the Examination of Water and Wastewater* (APHA *et al.* 2005). All values were reported as average values of the duplicate measurements. During the field campaign, samples were collected three times a week and analysed for pH, temperature, conductivity, alkalinity, turbidity, chemical oxygen demand (COD), total suspended solids (TSS), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), suspended solids (SS), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), and sludge volume index (SVI).

Influent and effluent samples were also examined for the determination of biological oxygen demand (BOD; 3 days), soluble BOD, soluble COD, volatile suspended solids (VSS), ortho and total phosphorus (OP and TP), total Kjeldahl

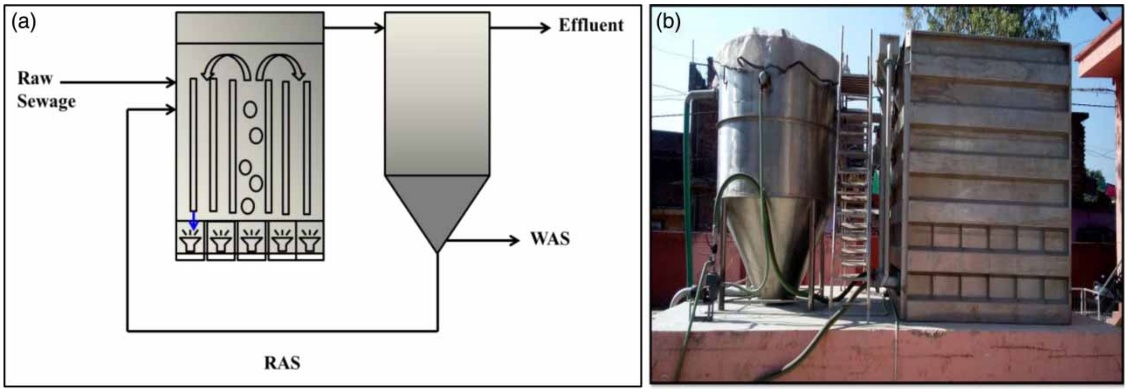

Figure 1 | (a) Schematic diagram of pilot-scale IFAS unit, (b) actual experimental setup installed at sewage pumping station, Rishikesh (Uttarakhand), India.

nitrogen (TKN), total coliforms (TC) and faecal coliforms (FC) on every fifth day. Samples for the determination of soluble components were filtered using a 0.22 μm filter paper and the process was the same as for the raw samples' measurement. The concentrations of metals were quantified in liquid and biomass samples on a monthly basis. The content of heavy metals (Cd, Fe, Mn, Cu, Co, Ni, Zn and Pb) in influent, effluent and biomass samples was determined using the acid digestion method by atomic absorption spectrophotometry as described in previous studies (Brown *et al.* 1973; Yoshizaki & Tomida 2000). The most common pathogens (*Escherichia coli*, *Shigella* spp. and *Salmonella* spp.) found in treated and untreated wastewater were determined three times each month by using different selective media (MF027Fs, *E. coli*; MF020Fs, *Salmonella* spp.; M1326, *Shigella* spp.) procured from Hi Media, India. The experimental protocol was followed as described in the specification sheet provided by the manufacturer.

Attached biomass quantification and measurement

At regular intervals (every 10 days), the attached biomass on the fixed media was quantified gravimetrically to estimate the total concentration of attached biomass in the reactor (Marques *et al.* 2008). For this purpose, two separated fixed-media sample pieces of the same known area were used and, out of these two, one was placed inside the aeration tank (fully submerged into the mixed liquor) and the other was considered as a reference for the suspended sample piece. Routinely, the sample frame was taken out and by weight difference attached biomass was determined according to the procedure as described in *Standard Methods for the Examination of Water and Wastewater* (APHA *et al.* 2005).

To determine the volatile fraction of attached biomass, the sample media was separated from the frame and rinsed in a known amount of distilled water by water pressure washing several times. This allowed the transfer of maximum biomass in the distilled water. Then the total and volatile attached biomass was calculated based on the biomass density (g/m^2) and the total surface area of the media in the aerobic zone. The total attached biomass inventory in the IFAS zone was then quantified as the multiplied value of surface area and biomass density. The attached biomass was then converted to biomass concentration (mg VSS/L) according to Equation (1):

$$X = (m * A)/V \quad (1)$$

where m (g VSS per unit area) is the amount of the biomass attached per unit area; A is the total available area (m^2); and V is the volume of the reactor. Each measurement was made in triplicate, and the average of three independent measurements was presented.

Instrumentation

Bulk liquid DO concentration, pH and conductivity were measured using a portable DO meter (Hach, Model OX-2P), a pH meter (Cyberscan 510 digital) and a conductivity meter (HQ14d portable conductivity meter, Hach), respectively. Turbidity readings were recorded with a pocket turbidimeter from HACH (Model 52600-00). All colorimetric analysis such as NH_3-N, NO_3-N, COD, OP and TP were accomplished using a UV-visible spectrophotometer procured from Hach Co. Ltd. (DR-6000™). TKN was measured according to the digestion method using a Hach kit (models 23130-20, DOC316.53.01091). The analysis of metals was carried out by an atomic absorption spectrophotometer (Thermo Scientific, iCE™ 3500 AAS).

Start-up, optimization and operational methodology

The preliminary test, applied before the start-up of the IFAS system, was hydraulic testing of the reactor, which was necessary to ensure the leakproofness of the system (USEPA 1973). In order to obtain a requisite amount of attached and suspended biomass in the reactor, the pilot plant was inoculated with 200 kg of dewatered activated sludge, which was brought from another full-scale sludge blanket reactor plant (Haridwar, India). The basic characteristics of the inoculum used were: MLSS, 20%; MLVSS, 7.8%; total nitrogen (TN), 0.91%; TP, 0.75%, on a dry weight basis of dewatered sludge. After seeding, the culture was incubated in the already added wastewater for approximately 72 h to encourage microbial growth and adhesion on the fixed media. Bulk liquid aeration was also started just 6 h before the seeding, and DO levels were maintained in the range of 6–7 mg/L. At the time of inoculation, aggressive foaming was observed, which reduced to a negligible extent at a later stage. After 3 days, wastewater was fed to the reactor continuously. Typical characteristics of the influent wastewater are shown in Table 2.

During the initial days of start-up, no sludge was wasted from the reactor. Different operational parameters (HRT, RAS and WAS rates) were chosen to optimize the process, enabling the best overall treatment performance of the reactor. Table 3 shows a summary of the several changes made in operational parameters during start-up and optimization of the IFAS reactor.

Table 2 | Characteristics and composition of influent wastewater fed to pilot plant (based on average values of experimental period)

Parameter	Unit	Average (min–max)
pH	–	7 (6.3–7.9)
Temperature	°C	30.3 (26.5–34.4)
Conductivity	µS/cm	713.2 (534–824)
Turbidity	NTU	84.9 (43.4–144)
Total alkalinity[a]	mg/L	264.2 (160–320)
BOD	mg/L	198.8 (115–283)
Soluble BOD	mg/L	54 (30–95)
COD	mg/L	295.7 (157–476)
Soluble COD	mg/L	84.2 (55–122)
TSS	mg/L	275.5 (152–428)
NH_3-N	mg/L	31.6 (23.2–49.3)
TKN	mg/L	39.1 (30.1–52)
TP	mg/L	5.5 (3.6–7.8)

[a]Expressed as $CaCO_3$.

RESULTS AND DISCUSSION

Preliminary examination and process optimization

During the early start-up days, HRT was kept high to enrich and acclimatize microorganisms in the aeration basin (Khalili *et al.* 2013). Changes made/observed during the experimental period in various operational parameters, such as MLSS, MLVSS, HRT, and OUR, are shown in Figure 2. Initially, the HRT of the reactor was decreased gradually from 27.7 to 4.4 h, and then increased again up to 6.9 h to maintain the required sludge age (~7 days) according to Equation (2) (Larsen 2010). Sludge age was calculated on the basis of total biomass in the aeration basin:

$$\text{Sludge age (d)} = \frac{\text{Total biosolids in aeration tank (kg)}}{\text{TSS in aeration tank effluent (kg/d)}} \quad (2)$$

Biomass enrichment for a biological wastewater treatment is an important issue during the first few weeks of start-up (Khalili *et al.* 2013). That is why no wasting was allowed until the 16th day and the developed sludge was returned to the aeration basin as much as possible to help in developing the active biomass (see Table 3). After about

Table 3 | Changes made in operational parameters during start-up and optimization of pilot

Day	4[a]	6	10	13	15	17	19[b]	22	24	26	28	30	33
HRT (h)	27.7	11.1	7.4	7.4	7.4	5.5	5.5	4.4	4.4	5.5	7.4	7.4	6.9
DO (mg/L)	6.5	5.3	3.8	2.4	2.3	3.5	2.9	2.5	2.7	2.6	2.6	2.7	2.8
RAS (L/s)	0	0	0	0.5	1	1	1	1.25	1.25	1.3	1.3	1.3	1.4
WAS (L/s)	0	0	0	0	0	0	200	300	300	500	650	750	1100

[a]Inoculation was followed by 72 h of aeration for culture growth and then continuous flow of municipal wastewater was started; [b]patches of floating sludge were observed.

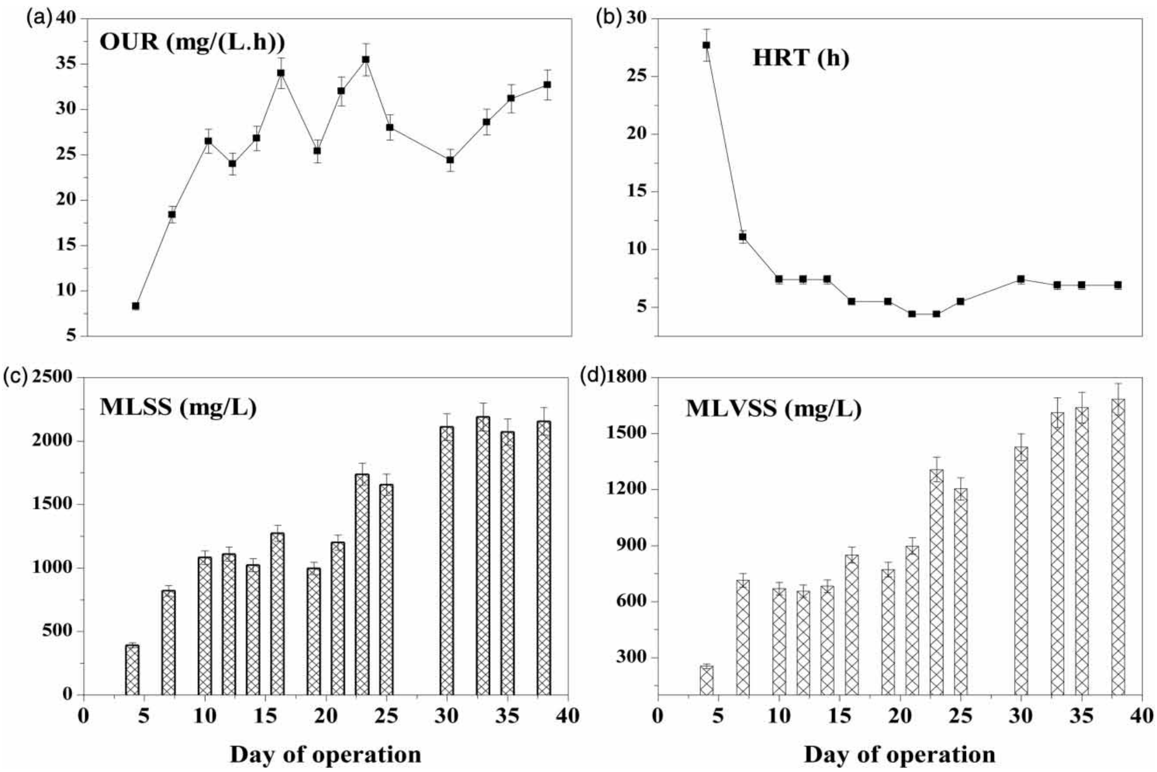

Figure 2 | Time series plots of (a) OUR, (b) HRT, (c) MLSS and (d) MLVSS in IFAS during start-up.

18 days of start-up, total biomass (both suspended and attached) of the whole system rose quickly to ~3,000 mg/L (suspended, 1,298 mg/L; attached ~1,700 mg/L) and it started to waste sludge. On the 30th day, the reactor attained significant biomass to provide acceptable results. During this study, it was evidenced that an MLSS concentration of ~2,100 mg/L was obtained after approximately 30 days while total biomass concentration reached around ~5,300 mg/L at the end of the start-up period. Quantification of attached biomass revealed that biofilm grew relatively better, as evidenced by biofilm solids (~3,200 mg/L) on day 30, suggesting that the IFAS system was very easy to get started. During the whole experimental period SVI varied in the range of 42–130 with an average value of 82 g/mL, presenting good settling characteristics (Sarioglu 2012).

Organics and solids removals

Figure 3 shows the time series plots of major performance parameters of the IFAS system, i.e. COD, BOD, and TSS. The results depicted that effluent concentrations of performance parameters decreased gradually and optimized after maintaining the required sludge age (~7 days). Following the reach of steady state conditions (DO ~3 mg/L; HRT ~6.9 h; WAS ~1.1 m^3/d), the COD, BOD, and TSS values were found to be in the range of 40–50, 20–30, and 35–45 mg/L. These results are comparable with other reported studies based on the performance of fixed media IFAS systems (Sen *et al.* 1994; Randall & Sen 1996; Sriwiriyarat *et al.* 2008a; Seetha *et al.* 2010). However, in these studies the treatment configuration, type of media, media packing ratio and type of wastewater were different than in the present study. It took approximately 30 days to reach steady state conditions and completion of the start-up phase. The removal efficiency increased to about 80% in the first 16 days following the inoculation but it took another 2 weeks to become stable again due to operational problems. Soluble forms of COD and BOD in the effluent were observed with an average value of ~20.8 and 9.7 mg/L, ranging from 14–30 and 4–14 mg/L, respectively. TSS and VSS values also followed the same trend as COD and BOD. The values of TSS and VSS were reduced significantly in effluent with minimum values of 35 and 16 mg/L, respectively. This indicates that the wastewater had a significant fraction of non-biodegradable COD (Metcalf & Eddy, Inc. & Tchobanoglous 1991).

With regard to COD, the influent concentration varied mostly from 157 to 476 mg/L. A sharp increase in the influent concentration was observed around day 7 and day 16, but its

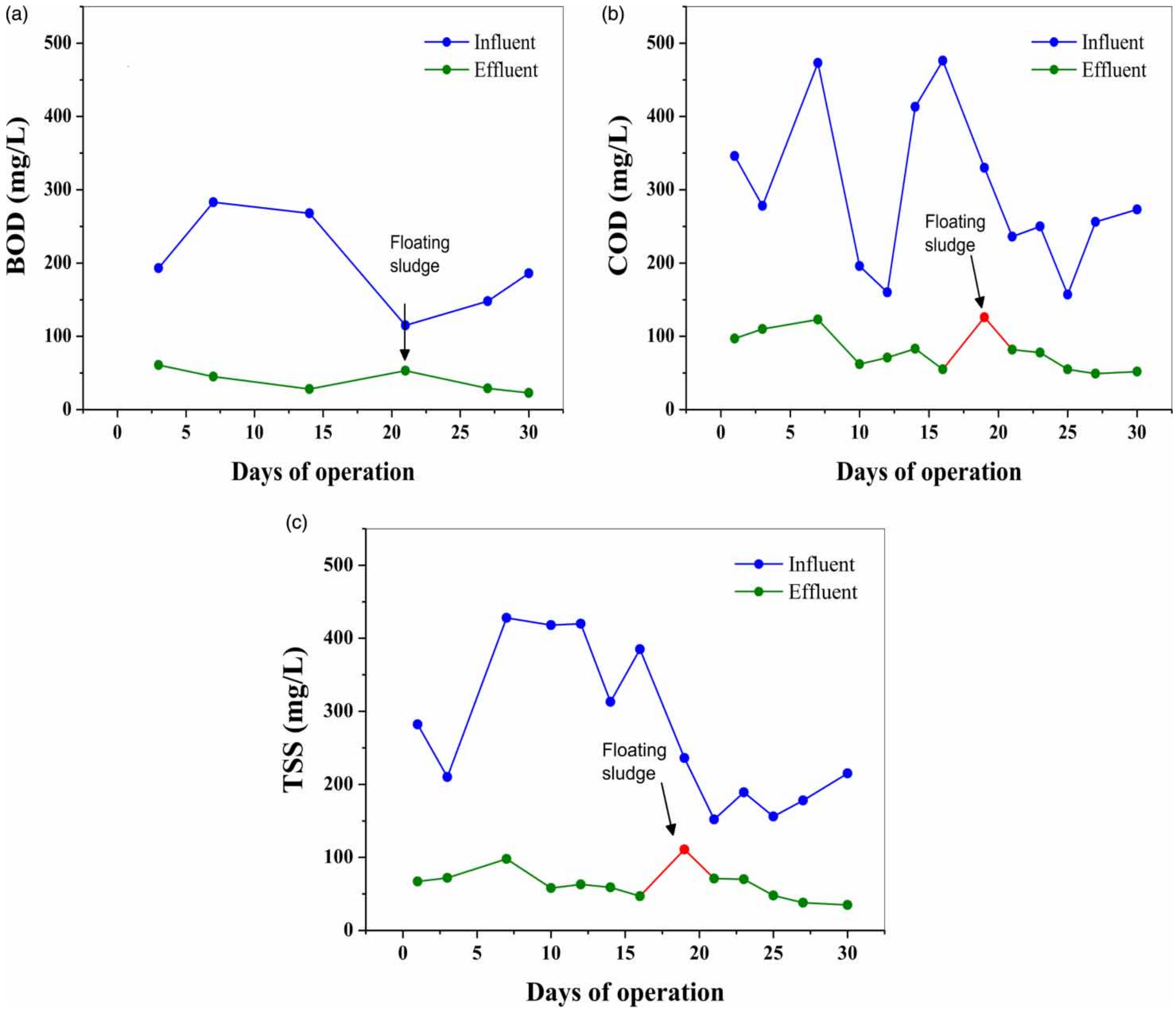

Figure 3 | Time series plots of (a) BOD, (b) COD and (c) TSS during the experimental campaign.

duration was short and the increased loading did not appear to have affected the COD removal. Initially the effluent concentration was approximately 100 mg/L, and this gradually decreased except for the duration of the rising sludge phenomenon observed. The effluent COD as well as BOD decreased to approximately 50 and 25 mg/L respectively, as microorganisms became acclimated to the wastewater. Overall, the IFAS system showed its potential for achieving a maximum of approximately 88.4 and 89.6% COD and BOD removal efficiency, which is consistent with the published findings on IFAS systems treating similar wastewater (Sriwiriyarat & Randall 2005a; Trapani *et al.* 2011, 2013). The performance of these kinds of systems can be enhanced by incorporating the appropriate primary treatment unit. Around day 21, rising sludge in the clarifier led to an increase in effluent COD to approximately 126 mg/L. The anaerobic condition was also evident during this period, through the production of a noticeable sulphide odour from the settling tank (Metcalf & Eddy, Inc. & Tchobanoglous 1991). This event led to diminished performance of the system in terms of organics as well as nutrient removal. As a corrective measure, the influent flow rate decreased (sludge age increased according to Equation (2)) and the effluent COD concentration gradually returned to the earlier level, showing the resilience of the system (Qasim 1999). In totality, the system exhibited a stable performance with low effluent concentrations and high removal efficiencies, even though there was a fluctuation in the influent concentration.

Nutrient removal

Figure 4 shows the plots of influent and effluent nutrient parameters of the pilot. The first signs of nitrification were exhibited approximately on day 3 during start-up, when the NO_3-N concentration was observed as 8.2 mg/L, and approximately 18 days later the concentration of NH_3-N was observed to be below the concentration of 3 mg/L (Figure 4(a)). A gradual increase in nitrification capacity occurred as expected. It was experienced that the time required to achieve nitrification did not appear to be significantly impacted by the volume of activated sludge inoculum utilized (Di Bella *et al.* 2010; Kim *et al.* 2010; Maillard *et al.* 2014).

In the last two decades, many authors have investigated simultaneous nitrification and denitrification (SND) in IFAS systems (Sriwiriyarat & Randall 2005b; Sriwiriyarat *et al.* 2008b; Lu & Chandran 2010; Jenkins & Sanders 2012; Zeng *et al.* 2014). The evidence of SND in the present IFAS system was also examined and confirmed through the determination of influent and effluent nitrate content (Figure 4(b)). During start-up time it was observed that nitrate concentrations in effluent decreased gradually, ranging from 1.4 to 15.1 mg/L, and revealing signs of denitrification. Further reduction of nitrate content (<1 mg/L) in effluent is very dependent upon the quantity and type of biodegradable matter present in wastewater, as reported in a previous study (Rusten *et al.* 1995). Similar findings were reported earlier by Sriwiriyarat & Randall (2005b). The average denitrification efficiency in IFAS was found to be 71.4% during this period and reached up to a maximum level of 96%. This may be associated with inner anoxic regions of biofilm formed at the fixed carrier material (Regmi *et al.* 2011).

Figure 4(b) shows the removal efficiencies of TN in the pilot during the start-up period. During the start-up period, the average TN concentration in the IFAS effluent was 18.4 mg/L and offered 59.1% TN removal, correspondingly. The TN concentration of effluent also followed the trend of COD, as expected. The degradation rate of TN increased from 26.1 to 91.2% on day 30.

Figure 4(c) shows the time series plots of phosphorus concentration in influent and effluent in the IFAS reactor during the process optimization phase, to provide precise information about the phosphorus removal potential. The results revealed that the tendency for phosphorus removal in the present system was insignificant as compared to nitrogen removal. This can be further improved by repetitive cycling of microorganisms between anaerobic and aerobic environments. The system showed an average phosphorus removal of ~24.7% and varied in the range of 9.5–38.5%. These values of removal efficiencies at start-up were lower than the previous studies on similar systems operated at steady state conditions (Sriwiriyarat & Randall 2005a; Kim *et al.* 2010). The addition of coagulant, as a supplemental treatment, at steady state conditions may be an effective step for removal of total phosphorus so that it could meet the discharge limits (TP < 1 mg/L) of the concerned area.

Metal removal

In the present study, pH values for samples of raw and treated wastewater did not interfere with the removal of metals; their concentrations remained stable at a pH range between 6.0 and 8.0 (Metcalf & Eddy, Inc. & Tchobanoglous 1991). The levels of Cd, Fe, Cu, Mn, Zn, Pb, Ni, and Co were determined in influent and effluent samples of the reactor. Suspended and attached biomass samples were also investigated to determine their individual role in overall removal of metals during the treatment process. The levels of Fe, Cu and Zn showed significant differences before and after treatment, while the difference between the other tested metals in raw and treated sewage was not significant. It must be noted that, in the present study, Hg was not determined, as in the concerned area its concentrations were in trace amounts and it was assumed that this would not cause a health risk in the study area. Moreover, according to the industrial and social activities of this tourist area, a negligible release of Hg was expected in municipal wastewater.

In biological systems, the removal of metals occurs by biosorption and bioaccumulation processes (Zabochnicka-Swiatek & Krzywonos 2014). This bioaccumulation takes place by the extracellular polymeric substance (EPS) content of suspended and attached microorganisms. The concentrations of different metals, selected in this study, are presented in Table 4. Results revealed that the removal of these selected metals was dominated by attached biomass as compared to suspended biomass. This can be attributed to the high production of anionic exopolymers by microbial biofilms as compared to the suspended biomass. In general, the removal efficiency of a metal depends on to what extent the metal is attached to biomass or a microorganism–EPS matrix. This matrix can act as a direct web for dissolved metal ions (Pagnanelli *et al.* 2009; Schaechter 2009). The density of EPS components basically determines the overall metal removal in a biological system (Pepper *et al.* 2014).

Removal of bacterial indicators of pollution

The occurrence of bacterial indicators and pathogens in treated wastewater increases the risk of epidemics among animals and humans handling such wastewater. A high level of pathogens in

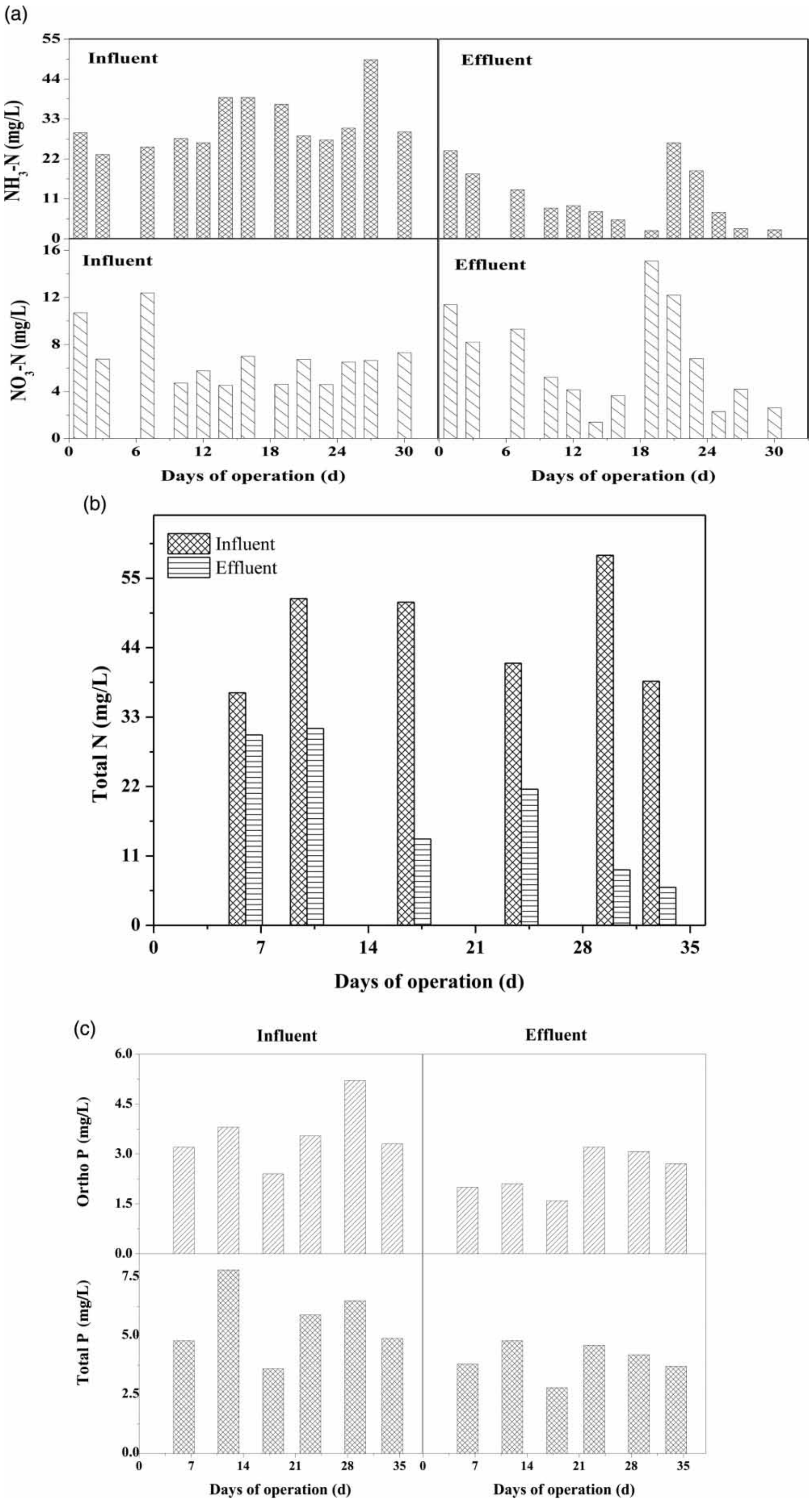

Figure 4 | Influent and effluent concentrations of (a) NH_3-N and NO_3-N, (b) TN, and (c) OP and TP throughout the study period.

Table 4 | Concentrations of various metals in wastewater and biomass samples

Sample[a]	Influent (mg/L)	Effluent (mg/L)	In suspended biomass (mg/kg)	In attached biomass (mg/kg)
Cd	0.0066	0.0059	1.18	1.78
Fe	1.146	0.599	7026.26	7460.3
Cu	0.1063	0.033	261.68	334.4
Mn	0.0522	0.0421	184.58	257.36
Zn	0.2837	0.1735	702.44	768.12
Pb	0.047	0.043	4.36	5.82
Ni	0.0015	0.001	2.63	4.45
Co	0.003	0.0012	3.21	3.97

[a]Analysis performed at the end of the start-up phase.

the effluent can also be risky for the food chain of humans and animals if discharged without any post treatment (Oron *et al.* 1999; Wen *et al.* 2009; Mungray & Patel 2011; Tonani *et al.* 2011; Dubber & Gill 2014). The detection of these microorganisms in treated and untreated wastewater should not be neglected because the survival of these pathogens and bacteria in environments is long (Jepsen *et al.* 1997; Ogden *et al.* 2002; Mahgoub *et al.* 2015). In this regard, two groups of microorganisms, including selected indicators (TC and FC) and pathogens (*E. coli*, *Salmonella* spp., and *Shigella* spp.), were considered during investigation.

The influent concentrations of TC and FC were found to vary between 5.3–7 log units and 3.2–4.4 log units, respectively. Almost similar concentrations of indicator organisms were observed in raw sewage by various researchers (Bahlaoui *et al.* 1997; George *et al.* 2002; Bitton 2005; Kazmi *et al.* 2008). In the treated wastewater, TC and FC values were encountered in the range of 3.3–5.4 log units and 2.4–3.4 log units, respectively. The average removals of TC and FC by the IFAS system were found to be 1.9 log (97.65%) and 0.9 log (80.35%), respectively. It is important to mention here that the process was entirely biological (no disinfectant was used).

The inlet concentrations of *E. coli*, *Salmonella* spp., and *Shigella* spp. ranged from 4.1×10^3 to 2.2×10^4, 9.5×10^2 to 4.8×10^3, and 49 to 71 MPN/100 mL, respectively. The IFAS system was found to be effective in reducing selected pathogens, i.e. *E. coli*, 0.77 (79%); *Salmonella* spp., 1.35 (97.5%); and *Shigella* spp., 0.94 (92.9%) log (percent) removal, respectively. This can be attributed to the adsorption of pathogens on suspended as well as on attached biomass of the IFAS system. Also in the literature, it has been evidenced that biofilm-based systems adsorb and filter out many pathogens such as *Leptospira interrogans* (Gerardi & Zimmerman 2005). Also, the coating of secretions from attached microorganisms changes the surface charges of pathogens, making them amenable to adsorption to floc particles and biofilm (Gerardi & Zimmerman 2005; Cheng *et al.* 2012). These results confirmed the potential of the IFAS system for the removal of indicator organisms and pathogens, even without any disinfection of effluent.

CONCLUSIONS

Mostly foreseen and expected operational challenges have occurred during the start-up period of the pilot-scale IFAS plant for municipal treatment. These challenges have been overcome using technical knowledge, consistent communication and timely decisions and corrective measures. The important lessons learned include:

- Extensive laboratory testing and data collection is important for accurately estimating start-up conditions and optimum process parameters, confirming influent and effluent characteristics, and monitoring performance of the IFAS for a successful start-up.
- By adding dewatered activated sludge as a seed, biomass growth speeded up and the desired biomass (suspended as well as attached) was developed in the system within 1 month of start-up. Attached biomass has been found to be more capable of removing metal as compared to suspended biomass.
- The IFAS unit removed organics and solids (COD, 70.9%; BOD, 77.3%, TSS, 74.2%) during the start-up phase except on some operational days, without a primary settling unit. A grit chamber along with appropriate screening may also enhance the overall performance of this system.
- Nitrification and denitrification were established in 1 month and removal of TN by the IFAS reactor appeared to be more sensitive to operating conditions than COD removal. IFAS has produced average effluent concentrations of TN and TP of approximately 12.3 and 4 mg/L, respectively, since the completion of start-up testing. Increased removal of TP can be achieved by incorporating a coagulation system in the future while much better simultaneous nitrification denitrification efficiency can be achieved by intermittent aeration.
- An overall reduction of TC and FC without any disinfection process (1.9 and 0.9 log) in the IFAS system has been found to be significant. The removal efficiency of *E. coli* was found to be low as compared to other pathogens considered in the present study.

In general, the start-up was successfully achieved using available resources, and the IFAS system proved to be sufficiently resilient in nature. As a result, the operation team has benefited by gaining expanded knowledge and experience in addressing various issues related to the start-up of IFAS reactors. The results of this study are helpful and can be used for similar types of future projects.

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