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

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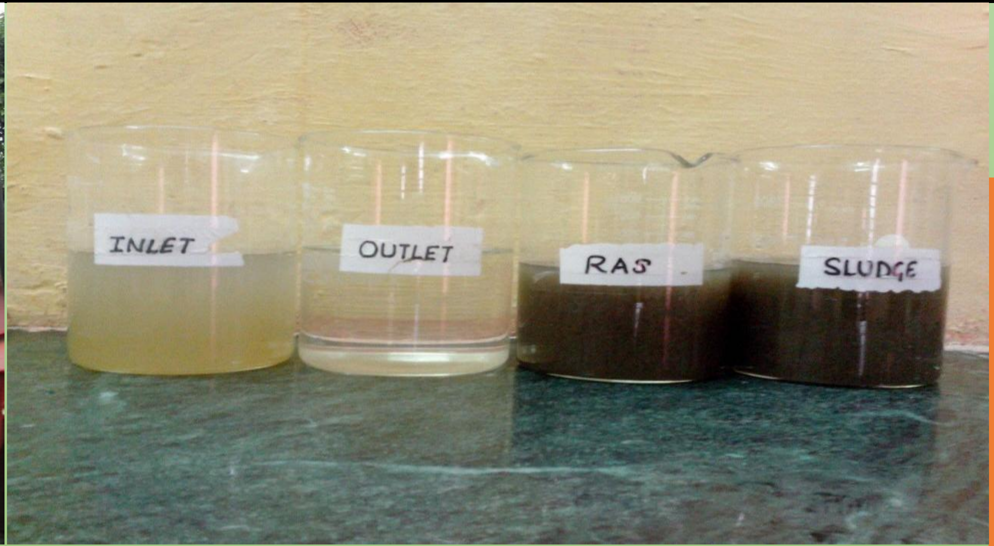

Nitin Kumar Singh
PhD scholar
Civil Engineering Dept.
Indian Institute of Technology, Roorkee

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.

- Centralized systems require intricate technologies and skilled manpower for satisfactory performance, while on the other side, as an alternative, decentralized wastewater treatment systems are more suitable for growing demand and provides a “build-when-you-need” or “well-timed” treatment solutions.

- Literature review revealed that various treatment technologies are 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.

- 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.

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

S. No.	Carrier	Study	Filing fraction (%)	Country	References
1	Plastic net	Lab scale	30	India	Seetha et al., 2010
2	Ringlace	Lab scale	NR	USA	Sen et al., 1994
3	Foam (sponge)		10-15		
4	Non-woven fabric carrier	Lab scale	50	China	Duan et al., 2013
5	Bioweb	Pilot scale	NR	Thailand	Sriwiriyarat et al., 2008
6	Accuweb	Pilot scale	NR	USA	Sriwiriyarat and Randall, 2005a
7	Ringlace	Full scale	1	USA	Randall and Sen, 1996
8	Ringlace & Biomatrix	Full scale	NR (Length reported)	Canada	Jone et al., 1998
9	Polyurethane plastic	Lab scale	8.6	China	Li et al., 2012
10	Bioweb media	Pilot scale	NR	Thailand	Sriwiriyarat and Randall, 2005b
11	Bioweb media	Pilot scale	NR	Thailand	Sriwiriyarat et al., 2008

- **Bearing these considerations in mind, present study had been undertaken to assess the performance of a fixed media based IFAS system, exposed to real wastewater under actual field conditions.**

2. Material and Methods

2.1 Schematic of pilot plant

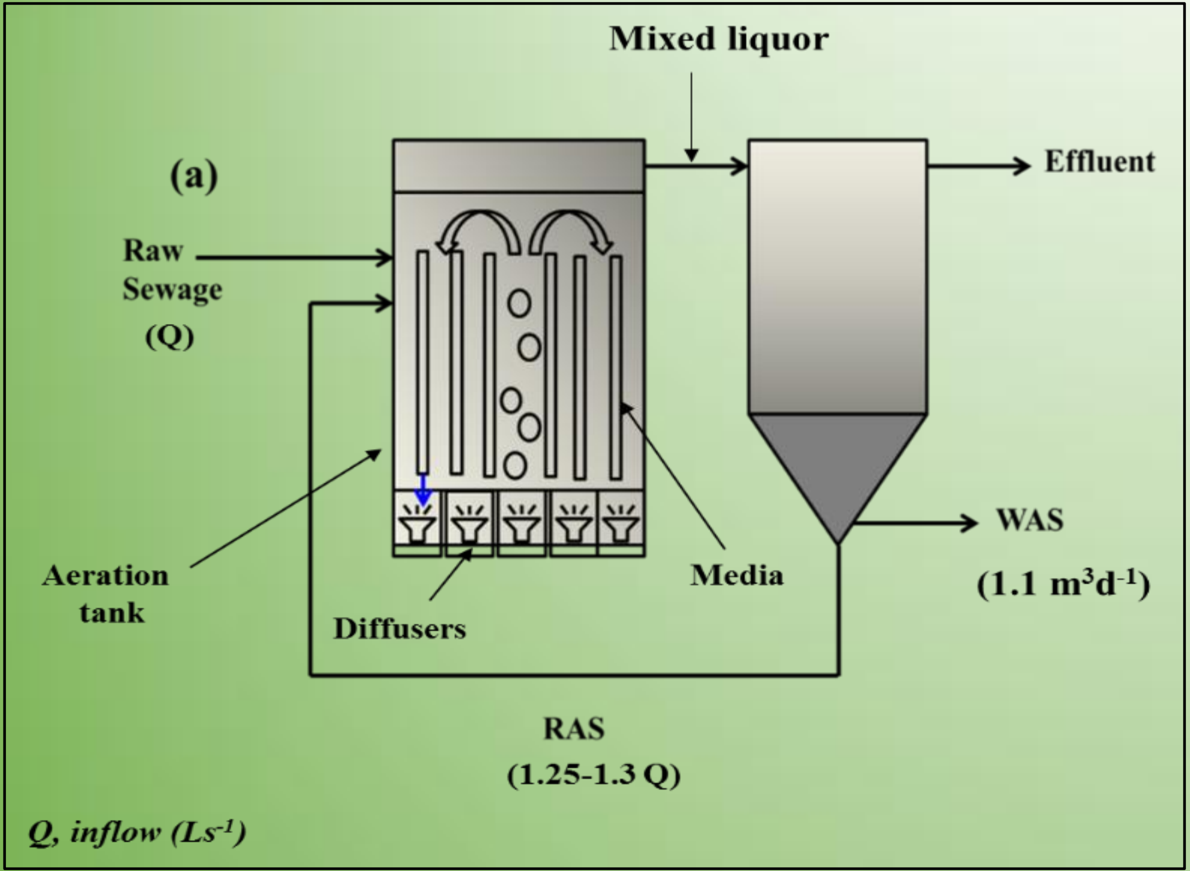

Fig. 1 Schematic of pilot scale IFAS (along with media) unit installed at SPS, Rishikesh (Uttarakhand), India

- 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.
- Municipal wastewater was pumped from the sump of SPS to pilot and settled activated sludge along with raw municipal wastewater flowed over a weir into the aeration chamber by using centrifugal pumps.

Table 2 Technical design details of pilot scale IFAS 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
Foot print	m^2	6
No. of fixed media (curtains shape)	-	64
Dimension of each curtain (L×W)	m	2.7×0.96

2.2 Start-up Methodology

- **The pilot plant was operated for a period of approximately 4 months, during which various operational problems were encountered and resolved to set a pragmatic solution for decentralized communities.**

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
D.O. (mgL^{-1})	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 (Ls^{-1})	0	0	0	0.5	1	1	1	1.25	1.25	1.3	1.3	1.3	1.4
WAS (m^3d^{-1})	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 continuous flow of municipal wastewater started;* [b]*Patches of floating sludge were observed*

- **At steady state conditions, the operational parameters were set as HRT, 6.9 h; RAS, 160-175%; WAS, ~1.1 m^3d^{-1} and detailed performance assessment of plant was performed with respect to removal of organics, solids, nutrients, and bio-indicators (coliforms and pathogenic bacteria).**

- **Start-up and optimization of pilot was done as per our previous study (Singh et al., 2015).**

2.3 Analysis and Measurement

- **During whole experimental period, the analysis of influent and effluent samples was conducted by considering essential water quality parameters according to Standard Methods (APHA, 2005).**

- **At regular intervals, the attached biomass on fixed media was quantified gravimetrically to estimate the total concentration of attached biomass in the reactor (Marques et al., 2008).**

3. Experimental Results

- The reactor was started at HRT of 27.7 h which was further optimized to 6.9 h. Besides, RAS and WAS rates were optimized to achieve requisite quality of effluents.

- The average concentration of mixed liquor suspended solids in IFAS reactor was recorded as 1598 mgL^{-1} and varied between 820-2713 mgL^{-1} corresponding to changes in operational parameters.

- The results of present investigation indicated that during start-up and optimization of IFAS, low COD and BOD effluent values were observed even after huge variation of influent concentration, as its COD recorded as 147-513 mgL^{-1} while BOD observed as 130-298 mgL^{-1}.

- At optimized conditions, the plant was able to guaranteed low effluent BOD and COD, which were quantified as 27.1 mgL^{-1} and 45 mgL^{-1} , respectively.

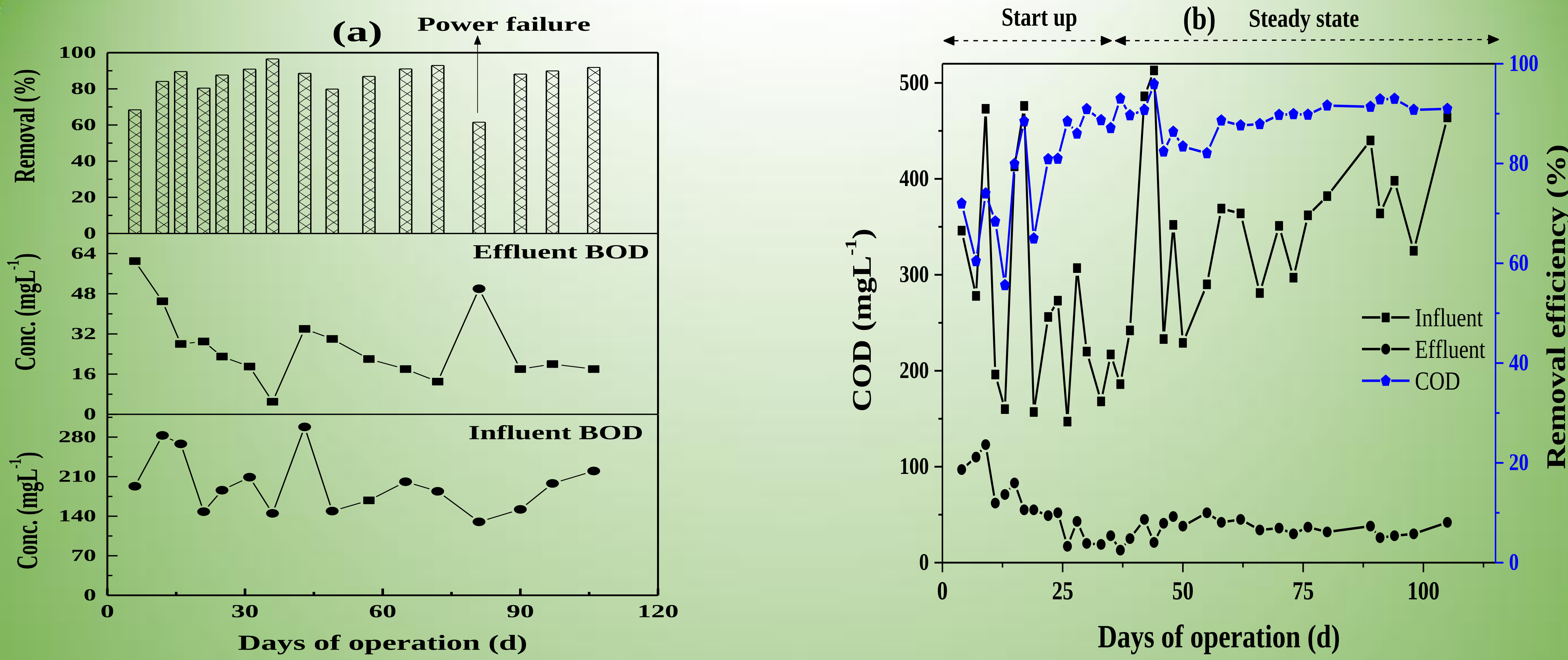

Fig. 2 Time series plot of **a)** BOD, **b)** COD; and corresponding removal efficiencies during experimental period

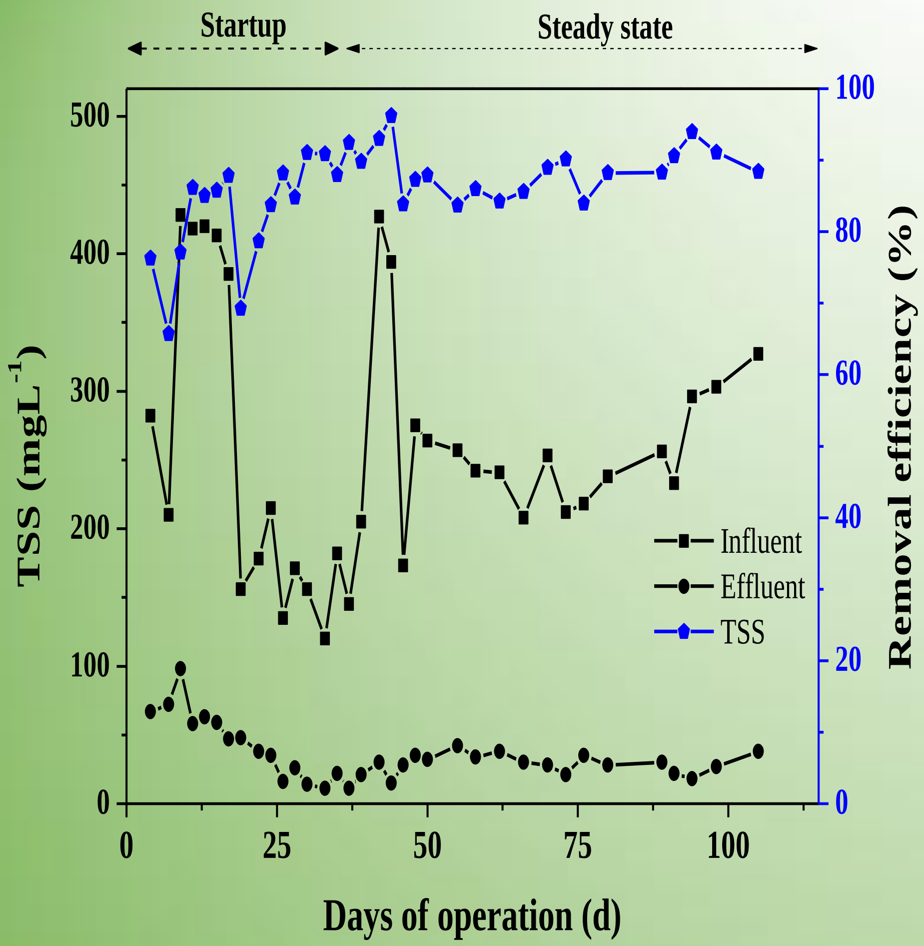

Fig. 3 TSS removal profiles throughout the study period

- The maximum COD and BOD removal efficiencies (95.9 and 96.5 %) were observed at an organic loading rate of 1.786 kg COD m^3d^{-1} and 0.504 kg BOD m^3d^{-1}.

- The average TSS and VSS concentrations in the effluent at PSS were amounted as 26.8 and 18.2 mgL^{-1}, respectively.

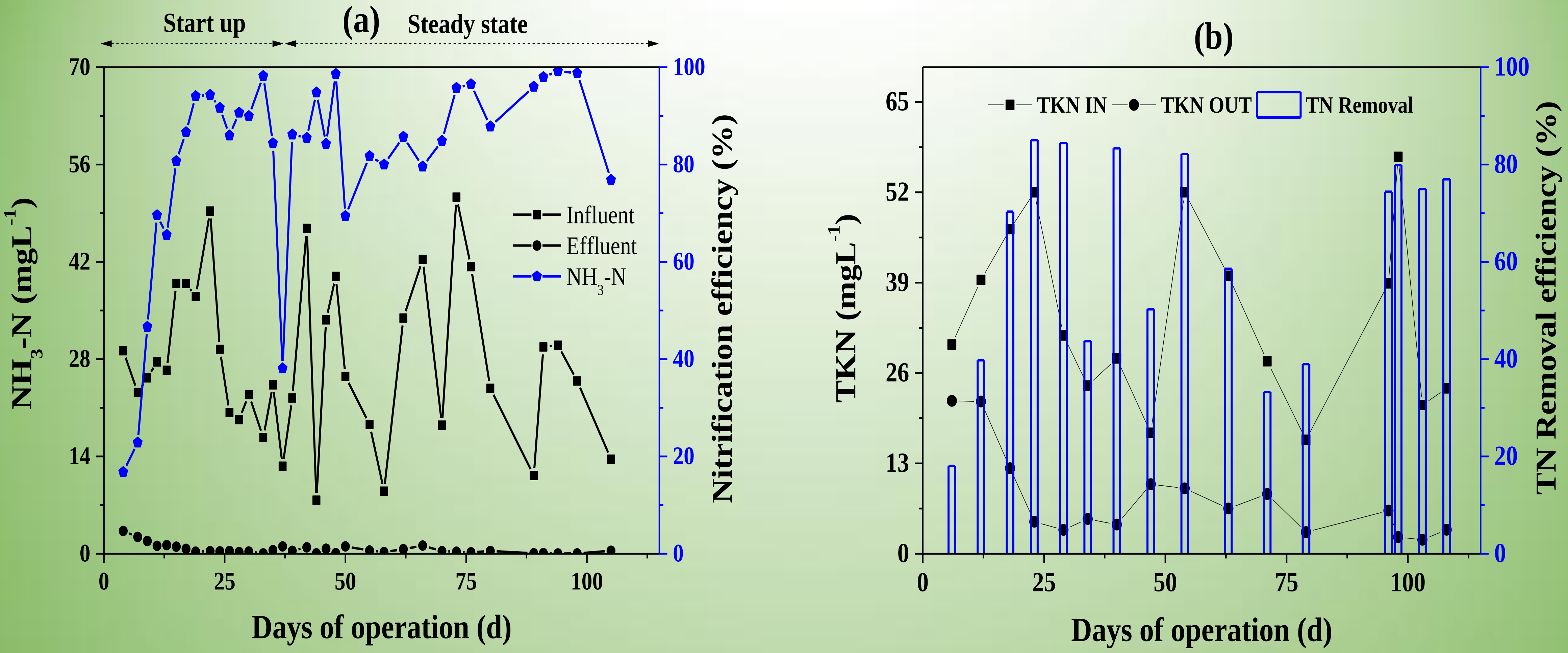

Fig. 4 Time series plot of influent and effluent **a)** NH_3-N concentration and corresponding removal efficiencies, **b)** TN removal efficiencies and TKN concentrations profiles in IFAS reactor

- The average concentration of ammonia nitrogen was reduced up to 3.1 mgL^{-1} from its initial influent concentration of 25.6 mgL^{-1} at PSS condition.

- The average denitrification in IFAS was found to be 71.4% and reached up to 96%. On an average about 74.9 % of NO_3-N was denitrified at PSS in the absence of insignificant nitrite accumulation.

- During the start-up period, the average total nitrogen (TN) concentration in the IFAS effluent was 18.4 mgL^{-1}, corresponding to 59.1 % TN removal. Similarly at PSS, the average effluent TN was recorded as 11.2 mgL^{-1}, which showed that IFAS had been enriched with denitrifying bacteria.

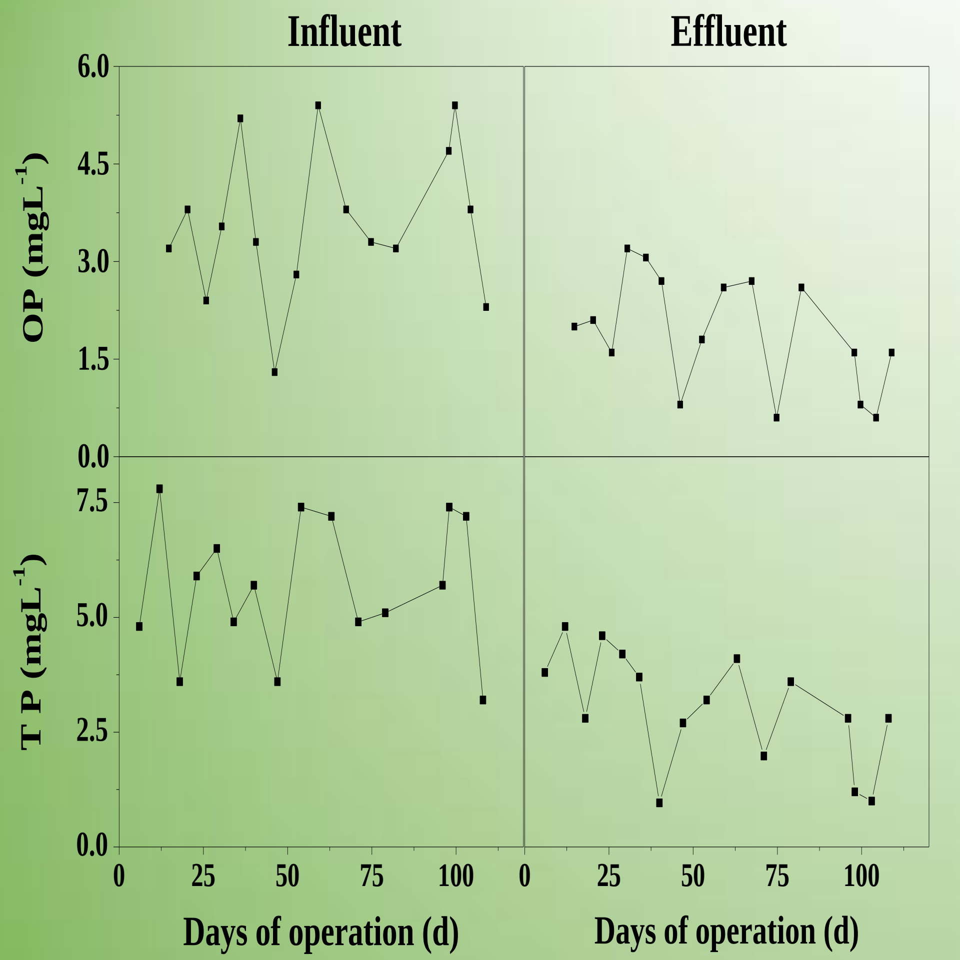

Fig. 5 Concentration profiles of soluble and total phosphorus components of influent and effluent in IFAS reactor

- Total phosphorus removal was observed as 27.7 ± 8.4 and 50.4 ± 26.1 %, respectively with influent TP concentrations of 5.7 ± 1.6 and 5.6 ± 1.5 mgL^{-1} for the start-up and PSS condition, respectively.

- The orthophosphate and total phosphorus present in the effluent were amounted as 5.68 and 3.01 mgL^{-1} throughout this study, respectively.

Table 5 Data on SVI values observed during experimental campaign

SVI	Start-up period (Day 1 –Day 33)	PSS (Day 33 onwards)	Entire experimental period
Average	77.85	92.89	89.49
Maximum	96	135	135
Minimum	42	40.7	40.7
S.D.	17.3	22.23	21.9

Table 6 Average percentual removals of pathogenic bacteria and indicator microorganism by IFAS reactor (without any chemical addition)

Microorganisms	Average log removal (min-max)	Average removal efficiency (%) (min-max)
TC	1.98 (0.46 - 3.08)	94.63 (65.22 - 99.92)
FC	1.36 (0.25 - 2.46)	89.29 (43.75 - 99.65)
E. coli	2.59 (2.06 - 3.82)	99.53 (99.12 - 99.99)
Salmonella spp.	1.22 (0.51 - 1.92)	90.22 (68.97 - 98.80)
Shigella spp.	0.82 (0.37 - 1.39)	79.95 (57.33 - 95.92)
HPC	2.03 (1.19 - 2.58)	98.34 (93.48 - 98.34)

- The average removal of TC and FC by plant was found to be 2.2 (99.4% removal) and 2.4 log unit (99.6% removal), respectively.

- The highest prevalence of E. coli was observed in influent as compared to the other studied pathogens and accordingly high removal efficiency (~99 %) was achieved in present system.

Conclusions

- The reactor is proved to be a compatible, efficient and appropriate wastewater treatment solution for small communities under actual field conditions.

- IFAS reactor allowed the efficient treatment of municipal wastewater with average removal rate of 92% for COD, 91% for BOD and 88% for TSS, under hydraulic retention time of 6.9 h.

- Reactor lacked the efficiency in phosphorus removal. Further coagulant addition may improve the phosphorus removal.

- High percentage removals of micro- biological parameters have been achieved during present study.

- Present study proved that fixed media based IFAS system are equally capable to treat the municipal wastewater under actual field conditions.

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Thank You

Results of study (Characteristics of effluent)

Parameter	Start up –I*	Steady state (DO ~ 2.5 - 3)	Start up –II*	Intermittent aeration –I @ 3 DO	Intermittent aeration –II @ 4.5 DO	Variable DO	Intermittent feeding (6 h on/off)
pH	7.25	7.38	7.30	7.1-7.5	7.2-7.6	6.9-7.5	7.15-7.45
COD (mg/L)	49	38	58	33[a] 29[b] 42[c]	28[a] 42[b] 54[c]	80[d] 62[e] 25[f]	34[m] 40[e]
BOD (mg/L)	23	22	26	17[a] 13[b] 18[c]	13[a] 23[b] 26[c]	45[d] 30[e] 8[f]	17[m] 19[e]
TSS (mg/L)	35	27	38	17[a] 13[b] 15[c]	15[a] 20[b] 33[c]	55[d] 38[e] 15[f]	18[m] 22[e]
Fecal coliforms (MPN/100 ml)	300	318	415	430[a] 13[b] 11[c]	45-318	247-413	512-674

**Minimum values achieved; [a] 2.5 h on/0.5 h off, [b] 2 h on/1 h off, [c] 1.5 h on/1 h off; [d] 0.5 mg/L; [e] 2.5 mg/L; [f] 4.5 mg/L; [m] morning shift; [e] evening shift*

Parameters	HYSAF Performance - Normal Condition*	Optimized HYSAF Performance**	Indian Effluent Standards 2006	River Ganga Effluent Standards	Latest Indian Effluent Standards 2016	Remark
pH	6.5-7.5	6.5-7.5	6.5-9			Can Satisfy IS 2016
BOD	< 30	<10	30	20	10	Can Satisfy IS 2016 by additional sand/cloth media filtration
COD	<50	<50	-		50	Can Satisfy IS 2016
TSS	<50	<20	100	30	10	Can Satisfy IS 2016 by additional sand/cloth media filtration
NH_4-N	<5	<5	-		5	Can Satisfy IS 2016
T-N	<20	<10			10	Can Satisfy IS 2016 by additional sand/cloth media filtration
Fecal Coliforms (After Cl_2)	<230	<230		<1000	<230	Can Satisfy IS 2016 after chlorination
PO_4-P (With Coagulant)	<2	<1			2	

**Flow: 0.75 l/s or 65 m3/day, DO: 2.5-3 mg/L; ** Flow : 43 m3/d. DO: 4.5, Intermittent Aeration 2h –ON, 1 h-OFF*

Results of study (Characteristics of effluent in different operational phases)

Parameter	Start up –I*	Steady state (DO ~ 2.5 - 3)	Start up –II*	Intermittent aeration –I @ 3 DO	Intermittent aeration –II @ 4.5 DO	Variable DO	Intermittent feeding (6 h on/off)
pH	7.25	7.38	7.30	7.11	7.23	7.5	7.15-7.45
COD (mg/L)	49	38	58	29[1]	28[2]	25[3]	34[m] 40[e]
BOD (mg/L)	23	22	26	13[1]	13[2]	8[3]	17[m] 19[e]
TSS (mg/L)	35	27	38	13[1]	15[2]	15[3]	18[m] 22[e]
Fecal coliforms (MPN/100 ml)	300	318	415	13[1]	45	247[3]	512[m] 674[e]

****Minimum values achieved;*** [1] ***2 h on/1 h off,*** [2] ***2.5 h on/0.5 h off ;*** [3] ***4.5 mg/L;*** [m] ***morning shift;*** [e] ***evening shift***

Standards →

	BOD	TSS	pH	COD	NH3-N	PO4-P	FC
IS standard	30	100					
NRCD	30	50	5.5-9.0				1000
New standard	10	10	6.5-9.0	50	5	2	