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Anaerobic and aerobic sewage treatment plants in Northern India: Two years intensive evaluation and perspectives

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HIGHLIGHTS

- Different STP based on various aerobic and anaerobic processes were monitored extensively for two years.
- Removal of organics and nutrient were studied.
- Methane generation under various operating conditions were investigated.

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ABSTRACT

The present study investigates the long term treatment performance of seven different sewage treatment plants located in different cities of north India for over a period of two years; two treatment technologies based on intensive aerobic processes — sequencing batch reactor (SBR) and moving bed bio-film reactor (MBBR) and; three combination of Up-flow Anaerobic Sludge Bed (UASB) reactor followed by aerobic processes — Polishing Ponds (PP), Aeration + PP and Down-flow Hanging Sponge (DHS). Effluent quality was not in accordance to the surface water disposal standards, Ministry of Environment, Forest and Climate Change Govt. of India, for UASB followed by PP and by Aeration +PP. However, a high effluent quality was observed in UASB followed by DHS; SBR and MBBR systems. In the last cases, NH_4-N and PO_4-P removal was higher than 85 and 60%, respectively; with a final effluent concentration of 20 mg BOD_5/L, 50 mg COD/L, 20 mg TSS/L, 10 mg NH_4-N/L and 5 mg PO_4-P/L. Although strictly intensive aerobic systems showed a better performance, UASB followed by simple aerobic systems, such as the DHS process is a promising technology, especially in India to reach required BOD level for water reuse at low costs.

1. Introduction

Water quality of surface water bodies receiving the treated effluents from STPs in India is deteriorating continuously despite the implementation of several environmental laws; resulting in municipality commissioners and working engineers to evaluate the performance of existing sewage treatment plants (STPs) and, come up with constructive plans to improve or even dismantle these plants (Bhardwaj, 2005). The primary concern of the policy makers, politicians and researchers has been eutrophication and toxicity in water bodies — accumulation of nitrogenous and phosphorus compounds. In consequence, in the last couple of years new, expensive and more advance STPs based on advance treatment technologies were built to reduce the pollution load on rivers/surface water bodies.

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Table 2.1
Details of monitoring STPs

Place	Ludhiana (Bhattian)	Ludhiana (Balloke)	Saharanpur	Agra	Gurgaon	Faridabad	Hathin
Type of Technology	UASB + Aeration + PP	UASB + Aeration + PP	UASB + PP	UASB + DHS	SBR	SBR	MBBR
Capacity (MLD)	111	152	38	78	119	20	4.5
HRT (h)	UASB-8 h Aeration-10 min	UASB-9.24 (h) Aeration-10 min	8 h (UASB reactor), 24 h (PP/FPU)	8–12 h	6 h	5 h	5 h
Effluent Disposal	Discharge in river Sutlej	Discharge in river Sutlej	Discharge in river Dhamola	Discharge in river Yamuna	Discharge in river Yamuna	Discharge in river Yamuna	Discharge in river Yamuna

During late 1980s most of the STPs were based on high rate anaerobic systems, mainly the UASB process due to its many advantages: low power requirement, capital cost and sludge production; together with energy (biogas) generation, relatively low foot print and lower operation and maintenance costs (Uemura and Harada, 2000; Dhoble and Ahmed, 2018). Most of the UASB rectors were installed with effluent polishing ponds (PP) in order to improve effluent quality in accordance to international standards before final discharge (Khan et al., 2012). However, these UASB systems followed by PP or any of short aeration system were not able to meet the discharge standards, mainly due to the short hydraulic retention time (HRT) of the PP system, shorter than 24 h (Sato et al., 2007; Khan et al., 2012). The solution would be to increase the HRT, with an increase in reactor area, which is not feasible in crowded areas such as New Delhi, India.

The treatment efficiency of the different STPs depends on HRT, solids retention time (SRT), Food to Microorganism (F/M) ratio and dissolved oxygen (DO), between others. Nevertheless, conventional activated sludge (CAS) processes are well known for their good treatment performance — high effluent quality. Moreover, numerous research and review papers have been published on the description of design criteria, treatment performance in terms of organics removal and application of variety of post treatment processes for anaerobic effluent treatment but scanty information was found on fate of nutrients removal and its comparison with aerobic based STPs (Chong et al., 2012; Khan et al., 2011; Chan et al., 2009).

In 2013 a new and more stringent disposal standards for discharging treated sewage into surface water bodies especially in river passed and, most of the UASB systems became either dysfunctional or were upgraded. Despite the efforts, in the last couple of years' pollution load increased significantly rather than being reduced. Since then different new technologies for nutrient removal were developed keeping in mind the financial costs of traditional wastewater treatment technologies together with the poor treatment efficiency for nutrient removal.

In order to address the challenges of up gradation/or retrofitting existing STPs, especially UASB based processes, long term monitoring of STPs having different treatment processes is necessary. Therefore, in this paper the long term performance of seven existing STPs for domestic wastewater treatment using five different treatment technologies in Northern India were studied, two based on intensive aerobic process: sequencing batch reactor (SBR) and moving bed bio-film reactor (MBBF) and; three based on Up-flow Anaerobic Sludge Bed (UASB) followed by polishing ponds (PP), aeration and PP or down-flow hanging sponge (DHS). The results helped to propose the possible concept for sewage treatment to the required disposal standards.

2. Material and methods

2.1. Location of STPs, treatment capacity and process technology

Seven different STPs located in different towns of North India-Ludhiana [(111 MLD Capacity, UASB + Aeration + PP) and (152 MLD, UASB + Aeration + PP)]; Agra (78 MLD Capacity, UASB + DHS ~5 MLD); Saharanpur (38 MLD, UASB + PP); Gurugram (119 MLD, SBR); Faridabad (20 MLD, SBR) and Hathin (4.5 MLD, MBBR) were monitored monthly for a period of over 2 years (Fig. 2.1). The average yearly ambient temperature in these STPs is around 25 ^{0}C. The design criteria of the process of the STPs and effluent disposal standards were summarized in Table 2.1.

2.2. Analytical procedure

Samples were collected from points at each STP: inlet, after primary biological treatment (UASB, MBBR and SBR) and the final effluent. The collected samples were kept in an ice box and immediately brought to the Research Laboratory, Environmental Engineering Group Labs, Department of Civil Engineering at the university. The collected samples were analysed in triplicate for BOD, COD, NH_4-N, PO_4-P, pH and TSS according to standard method (APHA, 2005).

Specific Methanogenic Activity (SMA) tests were conducted with sludge obtained from the sludge bed of different UASB reactors according to the method described by Khan et al. (2015) (Gaur et al., 2017). Glucose and sodium acetate were used as substrate (COD around 500 to 2500 mg/L) in batch tests for SMA analysis. The experiments were carried out in 500 mL glass bottles with an initial sludge VSS concentration of 2000 mg/L, kept in an incubator for 72 h at a constant temperature of 35 °C. Methane gas generation was recorded at intervals of 8 h.

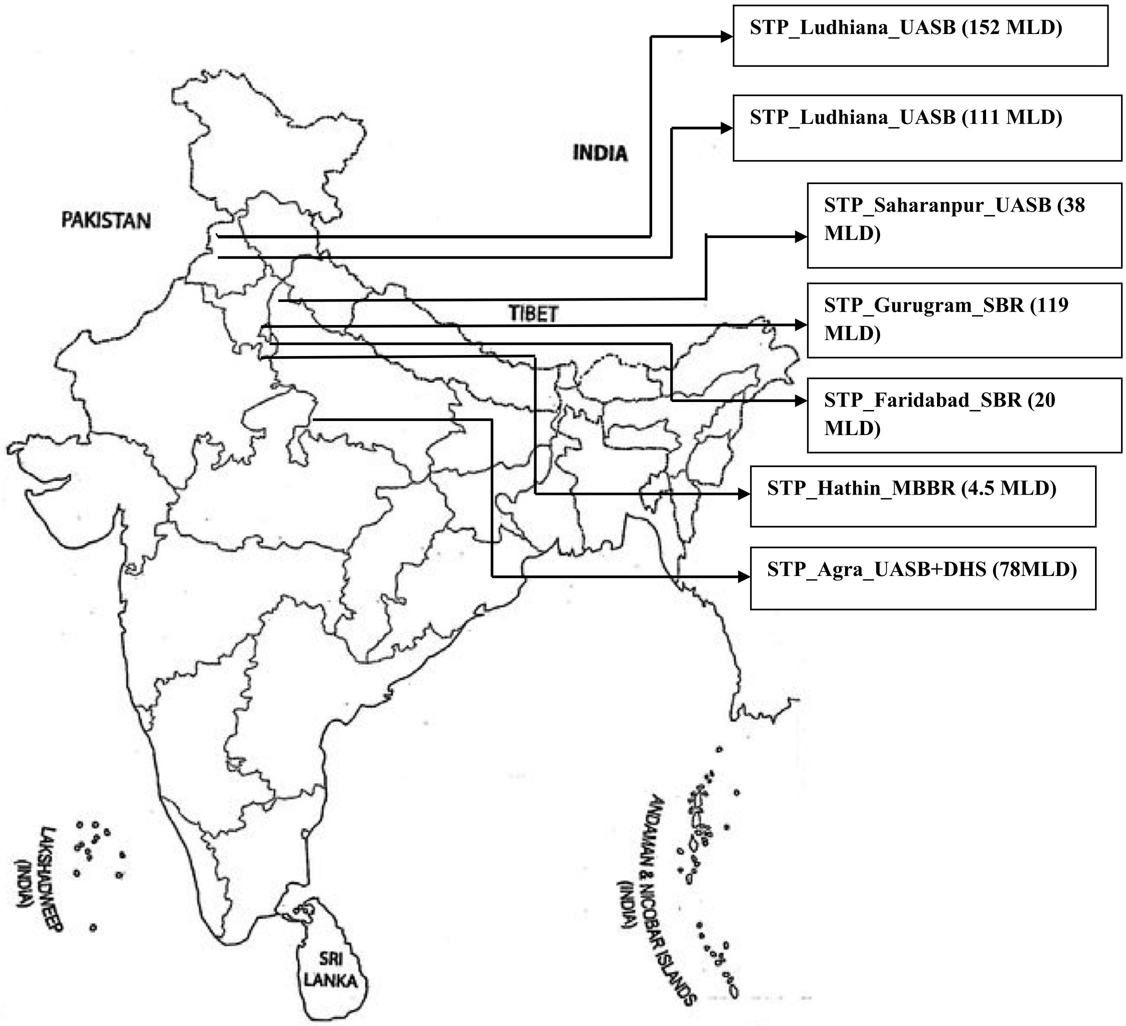

Fig. 2.1. Location of sewage treatment plants (STPs).

3. Results and discussion

3.1. BOD removal

BOD influent concentration (Fig. 3.1) did not have a significant variation between STPs, around 200 mg BOD/L. Still, minimum and maximum values of 140 and 320 mg BOD/L were observed at 4.5 MLD MBBR Hathin and 119 MLD SBR Gurugram, respectively. The highest calculated BOD removal was observed at 119 MLD SBR Gurugram, 95%, which is high and similar results were also observed by Prokopov et al. (2013) for sequencing batch process.

The average effluent BOD ranged 12–44 mg/L at all STPs. MBBR — STPs presented the lowest average effluent BOD concentration, 12 mg/L, which is still higher than the 10 mg BOD_5/L according to the latest guidelines of Central Pollution Control Board of India (CPCB, 2013) for disposal of treated effluents in surface water bodies. All the STPs were designed to produce BOD_5 according to standards, not more than 30 mg/L. However, STPs with UASB systems showed a higher effluent BOD concentration than STPs with intensive aerobic systems, even with the effluent polish systems. In UASB followed by post treatment plant, the effluent BOD concentration was around 39 $\pm$ 4 mg/L; whereas in the intensive aerobic systems 12 $\pm$ 1 mg/L, 14 $\pm$ 2 mg/L and 31 $\pm$ 2 mg/L at 4.5 MLD MBBR Hathin, 119 MLD Gurugram and 20 MLDFaridabad SBR plants, respectively. The lower effluent BOD concentration observed in the intensive aerobic systems in comparison to UASB followed by polishing systems can be explained by the fact that aerobic bacteria have a higher oxidation rate for organic carbon and in these systems high bacteria concentration was observed (MLSS $\sim$3000–5000 mg/L). On the other hand, anaerobic treatment systems, such as UASB have low degradation rate of organic carbon and, some organic matter are highly persistent for degradation at anaerobic conditions, making it hard to reach low BOD concentrations (Khan et al., 2014).

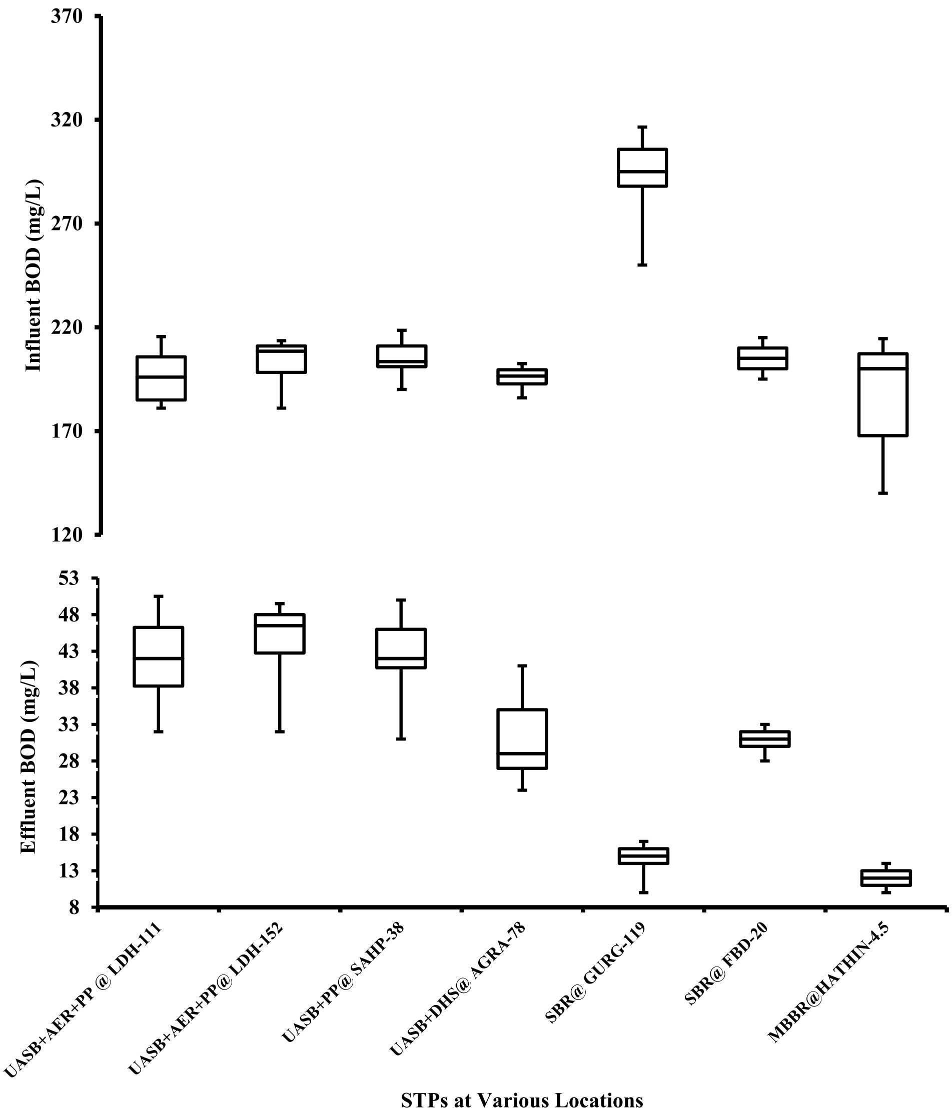

Fig. 3.1. BOD influent and effluent concentrations at the different STPs.

3.2. COD removal and its mass balance

Influent and effluent COD concentration at different STPs are shown in Fig. 3.2. Also influent COD concentration did not vary between the different STPs, with an average value of 355 ± 40 mg/L. Only 119 MLD SBR Gurugram showed at some periods of high fluctuations in influent COD concentration, around 552 ± 20 mg/L and that is probably caused by disposal of industrial effluents. Almost all STPs were situated in the vicinity of industrial area, which influenced influent quality and characteristics. In Ludhiana, the sewage colour changed sometimes to red–brown due to the industrial effluents. Sometimes, during Holi, festival colour dyes were also responsible for increasing the COD concentration of sewage and affected the treatment performance of the STP.

In order to overcome these issues, industries are advised to treatment its effluent within their premises by an effluent treatment plants (ETPs) or disposal their effluent to Common Effluent Treatment Plants (CETPs) to treat up to some degree prior to discharge it into the municipal sewer so that it could not hamper the treatment efficiency of the STPs.

On the other hand, 4.5 MLD-MBBR Hathin plant received the sewage with the lowest COD influent concentration, 299 ± 27 mg/L, reaching sometimes 240 mg/L. The lower concentration of COD in the influent was probably due to the rural population and dilution due to discharge of surface runoff. The town lacks the facility of combined sewer facility and overflowing of open storm water channels drains the runoff into the sewer due to poor manhole/damage of manholes.

Effluent COD concentration ranged from 83 ± 4 to 136 ± 4 mg/L in the UASB based STPs and, from 50 ± 4 to 78 ± 4 mg/L in the intensive aerobic STPs. The UASB based STPs effluent COD concentration was not in accordance to discharge

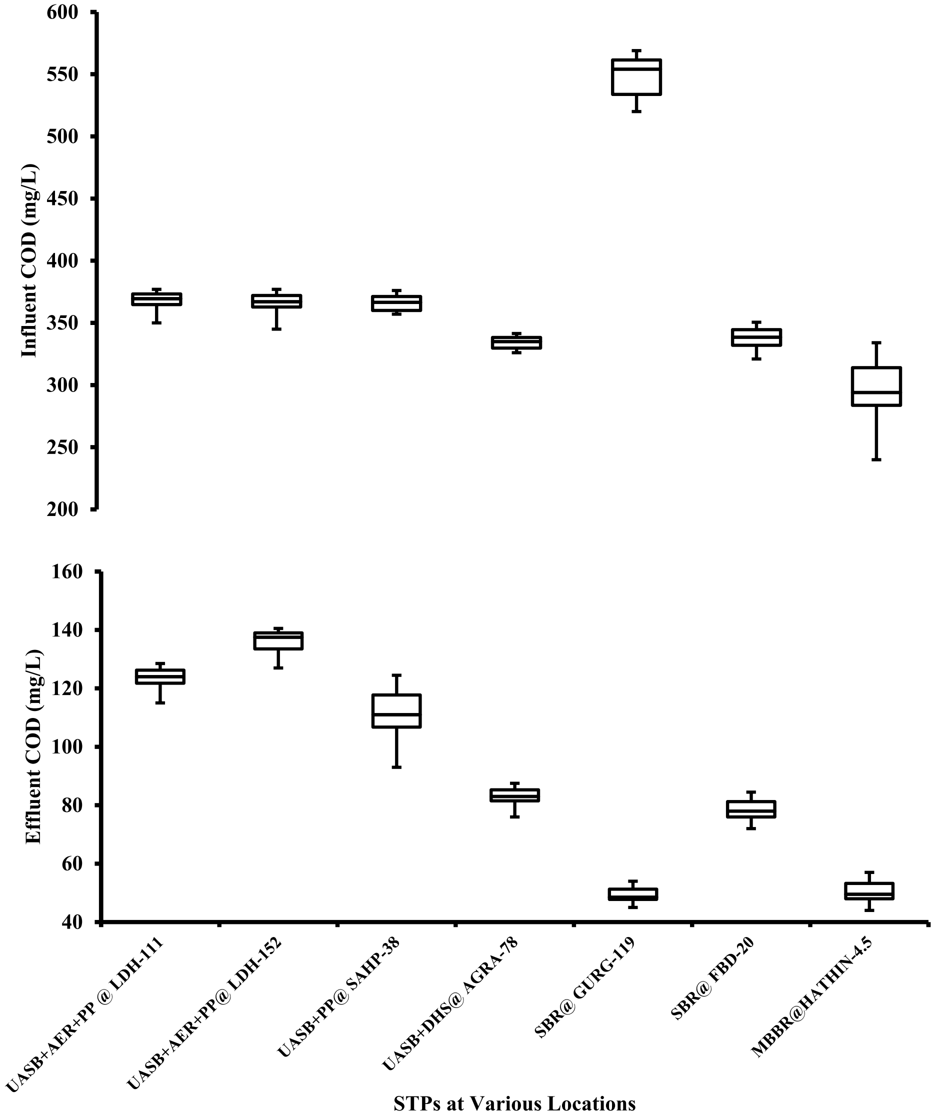

Fig. 3.2. COD influent and effluent concentrations at the different STPs.

standards and the reason maybe the high influent COD concentration due to the industrial effluents, poor treatment performance and wash out of the suspended solids with the effluent.

The lowest effluent COD concentration in an UASB based STP was observed for the UASB + DHS system, 83 ± 4 mg/L. It is important to notice that the influent COD concentration in this case was similar to the other UASB based STP systems. Still, this effluent COD concentration was similar to the highest one observed for intensive aerobic STPs; 78 ± 4 mg/L in the 20 MLD SBR-STP at Faridabad, which also do not comply with effluent standards. The failure in achieving removal performance might be due to maintenance and operation during the constant power failures. Effluent COD concentration in the SBR-STP at Gurugram and MBBR-STP at Hathin were in accordance to effluent standards, lower than 50 mg/L; with a COD removal higher than 80%.

To determine the COD fate in the UASB based STP systems, COD balance was performed on 111 MLD STP at Ludhiana on the basis of the average COD mass entering to UASB reactor, leaving the UASB reactor as effluent and converted to biogas (taking in consideration the measured biogas and the assumed biogas that left the system dissolved in the effluent), Fig. 3.3. The unaccounted COD in the mass balance was assumed to be due to sludge generation (influent solids precipitation and accumulation and bacterial growth) and withdrawal, leakages and sulphate reduction. The inferences drawn from the carbon flow in UASB reactor was 21% of COD leaving as effluent, 20% of COD becoming biogas (generated and leaving the system dissolved in the effluent) and 49% recorded for unaccounted.

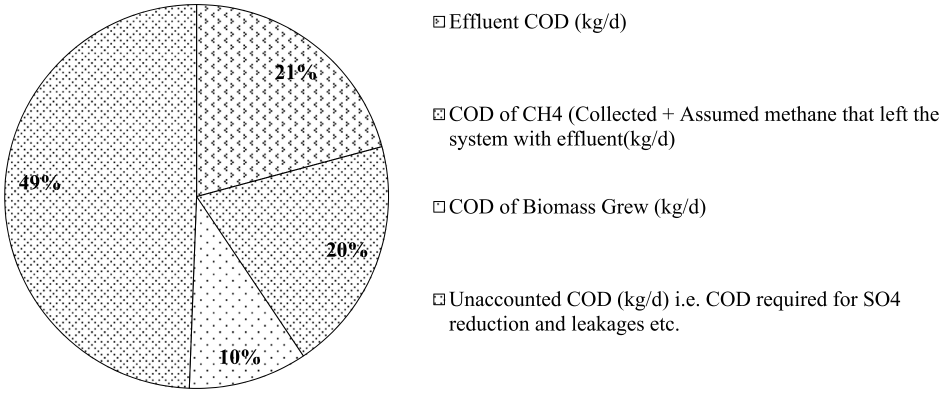

Fig. 3.3. Mass flow of COD in UASB based STP (111 MLD)

3.3. TSS removal

Influent and effluent TSS concentrations are shown in Fig. 3.4. Influent TSS concentration showed no significant differences between the different STPs, with an average of 195 ± 11 mg/L. Maximum and minimum TSS concentrations were observed in 111 MLDUASB based STP at Ludhiana, 240 mg TSS/L and in 20 MLD SBR based STP at Faridabad, 181 mg TSS/L, respectively. The disposal of industrial effluent into domestic sewer did not influence TSS concentration. Effluent TSS concentration was observed in accordance to the disposal standards in SBR STP at Gurugram and MBBR STP at Palwal, with a TSS removal higher than 90%. On the other hand, average effluent TSS concentration in the UASB based STPs were high, 58 mg TSS/L and, also the SBR STP at Faridabad showed similar results. Again, in Faridabad, the failure in achieving removal performance might be due to maintenance and operation during the constant power failures.

3.4. NH_4-N removal

Influent and effluent ammonia (NH_4-N) concentrations are showed in Fig. 3.5 The influent ammonia concentration was very similar in all STP studied and it varied from 37 ± 3 mg/L at 20 MLDSBRSTP at Faridabad to 53 ± 3 mg/L at 152 MLD UASB based STP Ludhiana. These values are in accordance to medium to highly concentrated sewage (Metcalf and Eddy, 2003).

Effluent ammonia concentration in the UASB based STPs was higher than in the influent, except for the UASB + DHS system. This increase is due to hydrolysis of organic nitrogen in the UASB reactor. In the polishing of the UASB effluent i.e. PP or aeration + PP, ammonia was removed/incorporated by algal growth. However, algal death released the ammonia back to the liquid phase.

In the MBBR, SBR and UASB + DHSSTPs, ammonia removal was higher than 85%. Effluent concentration of 5 ± 1.3 mg/L was observed at both UASB followed by DHS STP, 78 MLD at Agra and 4.5 MLD at Hathin and; 9 ± 1.1 mg/L was observed at 20 MLD SBR STP at Faridabad. High rate aeration system and combined UASB + DHS system can be good options to attain ammonia removal through nitrification, since high oxygenation is accomplished in these systems.

3.5. PO_4-P removal

Influent and effluent phosphate (PO_4-P) concentration is shown in Fig. 3.6. Influent phosphate concentration ranged from 6 ± 0.4 mg/L at 152 MLD UASB based STP at Ludhiana and 8 ± 0.7 mg/L at 4.5 MLD MBBR based STP at Hathin.

Effluent Phosphate concentration was higher than in the influent for the UASB followed by PP system and by Aeration + PP system STPs. Similarly to the ammonia case, this increase is due to hydrolysis of organic phosphate in the UASB reactor. Phosphate removal is only possible through bacteria assimilation when moving between aerobic/anoxic zones, with medium to high BOD concentration. These conditions did not happen in the UASB reactor followed by PP or by aeration + PP.

A decrease of phosphate concentration was observed for the UASB + DHS systems and in the intensive aeration reactors; a removal of 60%–75% was observed with an average effluent phosphate concentration of 2 ± 0.41 mg/L as PO_4-P. In the UASB + DHS STP, the effluent from the UASB reactor flows downward in the DHS, assimilating oxygen from the air. The high sponge porosity also helps for air flow. However, due to the relatively high UASB effluent BOD concentration, the bacteria in the sponges are sometimes under aerobic conditions and sometimes under anoxic conditions, depending on the flow, BOD concentration, air temperature, humidity, etc. This situation of aerobic/anoxic promotes phosphate assimilation by the bacteria.

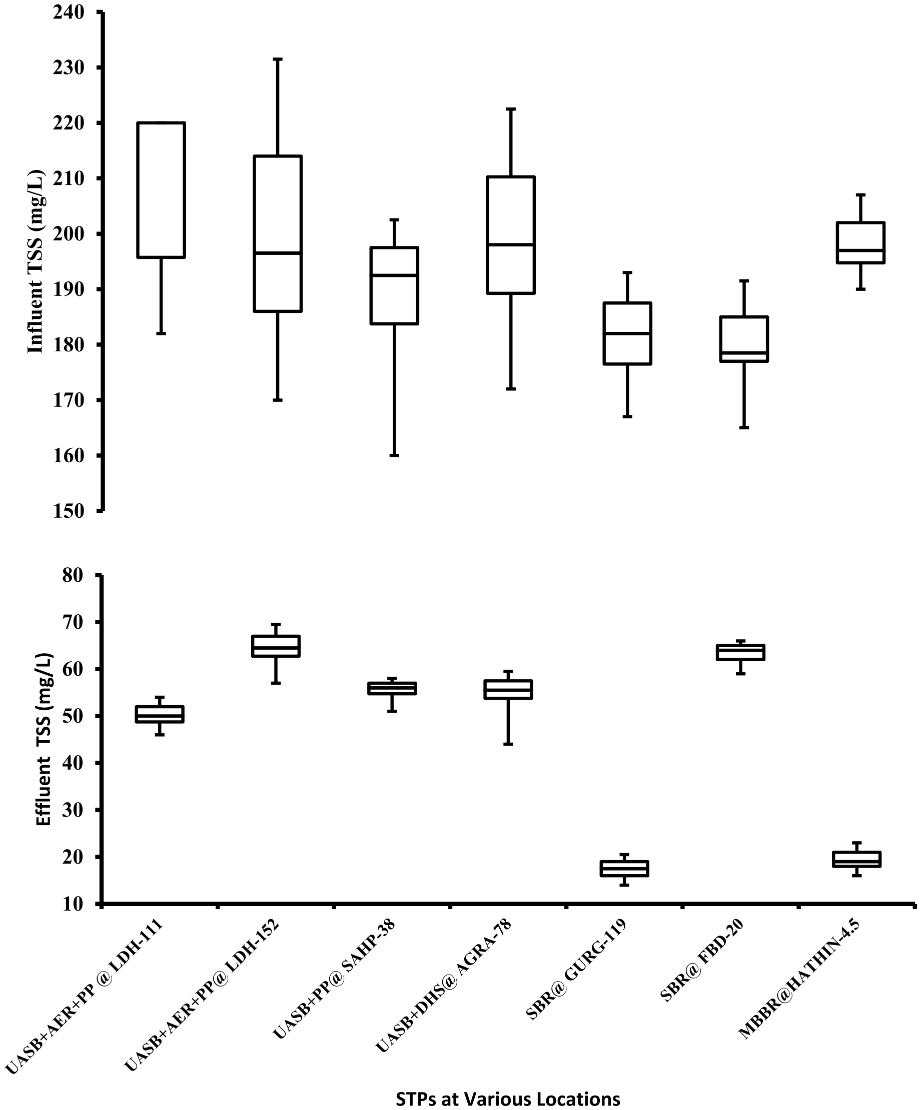

Fig. 3.4. TSS influent and effluent concentrations at the different STPs

For the MBBR and SBR processes, bacteria go through anoxic/aerobic cycles. The MBBR system consists of an aeration tank with special plastic carries that provide a surface where a bio-film could grow. Anoxic/aerobic conditions change in the bio-film due to aeration rate, BOD concentration, temperature, plastic carrier position in the reactor, etc. The SBR reactor operates in stages: wastewater fill (anoxic), reactor aeration (aerobic), sludge settling and effluent removal. Since, sludge is almost not removed from the reactor, bacteria goes several times through the anoxic (wastewater fill) and aerobic (reactor aeration) cycles.

3.6. Biogas generation potential

The biogas generation was monitored regularly at each UASB reactor and the recorded average biogas produced was 300 m^3/h, with the maximum being 389 m^3/h at 111 MLD STP at Ludhiana, and the lowest value recorded around 210 m^3/h at Agra. Biogas yield (biogas produced per COD removed) ranged 0.17 to 0.23 m^3/kg COD removed; which is low in comparison to the theoretical value of 0.35 m^3/kg COD removed; however, similar values were observed by Khan et al. (2014). This low biogas yield indicates biogas losses in the system and emission to atmosphere, probably methane is dissolved in the effluent.

Methanogenic activity batch tests were conducted with sludge collected from the different UASB reactors with glucose and sodium acetate as substrate. The Specific Methanogenic Activity (SMA) from the sludge collected at the different UASB

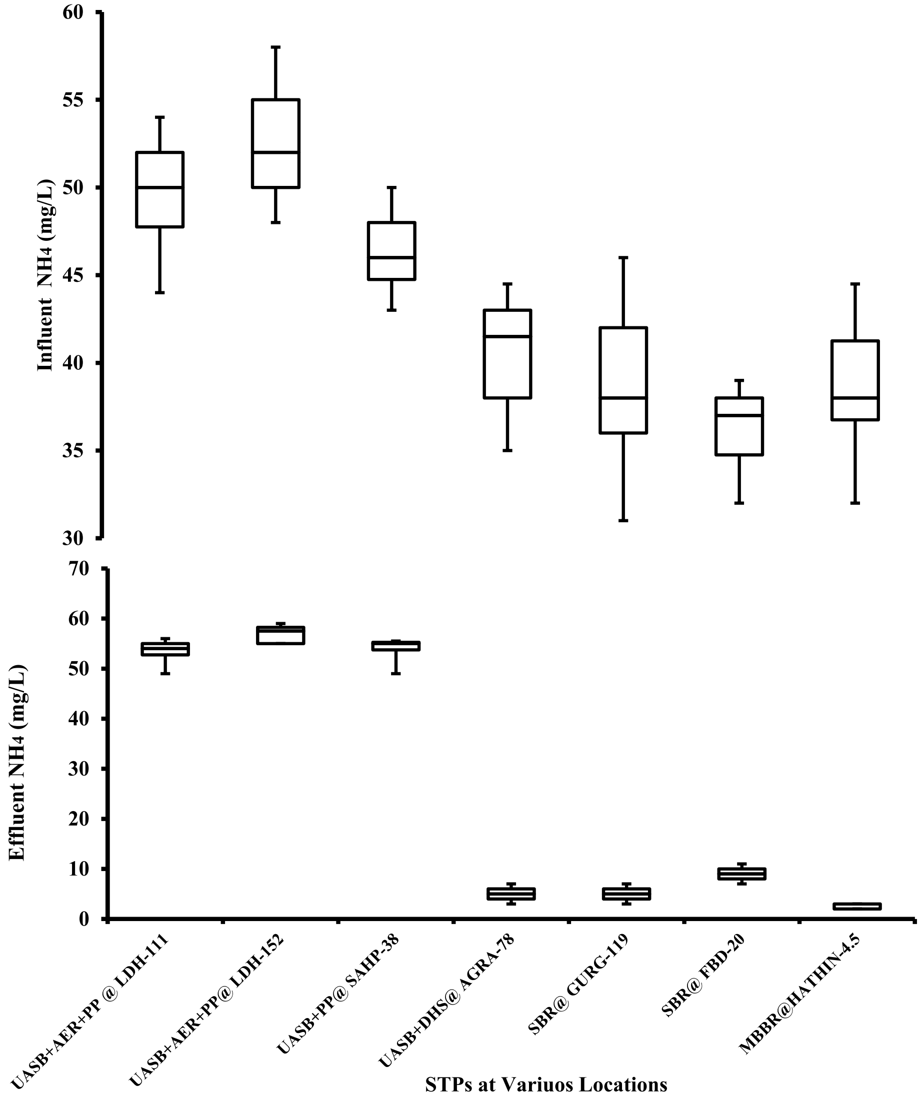

Fig. 3.5. NH_4-N influent and effluent concentrations at the different STPs

reactors range from 250–280 mL CH_4/g VSS/d. The maximum value 280 mL CH_4/g VSS/d was observed 111 MLD STP at Ludhiana.

4. STPs performance variation

The treatment performance of every STP greatly varied even between STPs with the same treatment process (Table 4.1). Based on the results of this study, it was observed that most of the STPs were not well maintained and were poorly operated, with no constant grit removal, screen cleaning and improper/poor sludge wasting. The poor pre-treatment, non-degradable and high organic load reaching the biological reactors might be a reason for poor treatment performance. In some STPs, bar screen was non-operational due to technical fault. Also, scum layer and foaming were observe don the biological reactors due to presence of insoluble substances such as fats and oil in the sewage. Together with that, power failure was a constant in all STPs and there was no proper operation of the backup technology in situ to produce electricity, such as generator, solar photovoltaic panels, wind turbine or gas fired fuel cell; except in Gurugram and Ludhiana. Gurugram (119 MLD) and Ludhiana (111 MLD) STPs are well operated and maintained. Gurugram STP is monitored remotely and has fully automated mechanized system. The biogas produced at these STPs is used for electricity generation. The generated electricity is used for the STP operation and, the excess electricity produced sale out to power grid houses.

Another problem observed at these STPs was the inflow of industrial wastewater without previous pre-treatment. There is a need to identify all the sources of the STP raw sewage and its characteristics before treatment and, all

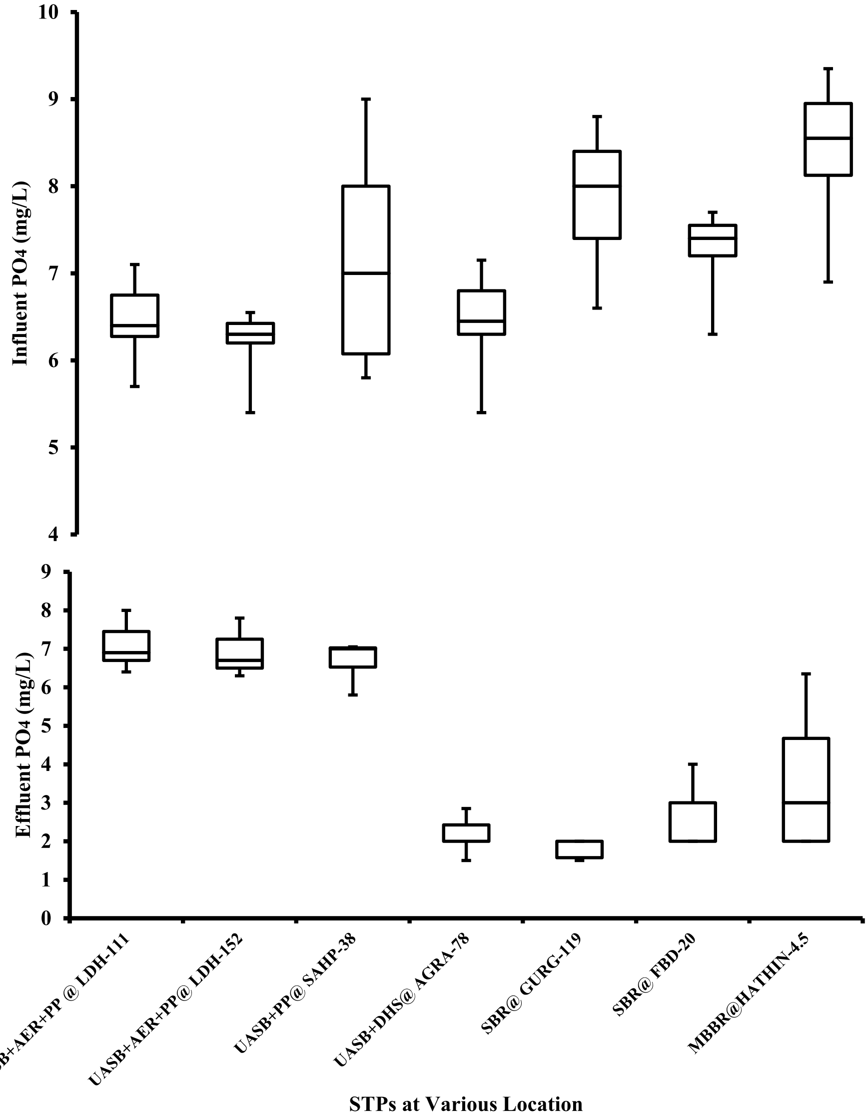

Fig. 3.6. PO_4-P influent and effluent concentrations at the different STPs

Table 4.1
BOD, COD, TSS, Ammonia and Phosphate removal (in %) at the different STPs.

STP/Parameter	UASB + PP (Ludhiana)	UASB + Aeration + PP (Ludhiana)	UASB + PP (Saharanpur)	UASB + DHS (Agra)	SBR (Gurugram)	SBR (Faridabad)	MBBR (Palwal)
BOD	78	79	79	85	95	85	94
COD	63	66	69	75	91	77	83
TSS	68	76	70	72	90	65	90
NH_4–N	[a]	[a]	[a]	88	86	76	93
PO_4–P	[a]	[a]	[a]	66	76	66	60

[a]Insignificant removal and increase/or decrease in values from initial values

chemical and physical characteristics of the sewage must be in ranged according to Metcalf and Eddy (2003) for domestic wastewater treatment. Also, during some months/period of the year, mostly during rainy season the STPs were operated beyond treatment plant capacity due to rain water being piped together with sewage. A complete separation of sewage transportation is necessary for proper and optimum running of the STPs.

5. Economics of the different technologies

According to the CPCB report 2013 on performance evaluation of STPs under NRCD, the treatment cost per cubic metre of SBR, MBBR and UASB systems followed by extended aeration system was $0.043, 0.047 and 0.004 respectively up to secondary treatment. Although, the SBR and MBBR based STPs shows better treatment performance for pollutant removal and effluent quality, the treatment cost incurred was quite high compared to anaerobic–aerobic combined treatment process based STPs.

6. Conclusions

Seven different STPs for domestic wastewater treatment located in Northern India were evaluated for over two years. Five different treatment technologies were studied: SBR; MBBR; and UASB followed by DHS, PP or aeration + PP:

- Only the STPs based on SBR, MBBR and combined UASB + DHS, based processes produces an effluent quality required for the disposal into surface water bodies.
- The BOD, COD and TSS removal efficiencies were ranged 63%–95% for all STPs irrespective of the treatment technology used.
- The NH_4-N and PO_4-P removal were more than 85 and 60%, respectively, for SBR, MBBR and UASB + DHS based STPs. However, for UASB followed by PP or Aeration + PP, an increase in nutrients concentration was observed from influent to effluent.
- Present study indicates that all STPs should require proper operation and maintenance. The costs to produce an effluent required to achieve the disposal standards is lowest one between the technologies studied, only 10% higher costs incurred on intensive aerobic processes compared to operated UASB followed by PP or UASB followed by aeration + PP, which produces an effluent not according to standards.

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