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Estimation of Biomass Composition and Biological Sludge Production in SBR Plants of India

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Abstract: ***This study focuses on estimating biological sludge production in the Sequencing batch reactors (SBR) based wastewater treatment plants of India. It includes the different criteria for analyzing the specific sludge production in nine pre-anoxic selectors attached SBRs of India. The parameters generally vary with the geographical distribution of WWTPs (including living standard of the nearby population, its size, and working background), and also system's Solids Retention Times (SRT) play a significant role. The plants could perform biological nutrient removal (BNR), along with organic matter and suspended solids removal by satisfying the new NGT standards for COD, BOD, and TSS exceptionally. Biomass composition of the sludge in the treatment plants presented that the highest heterotrophic biomass and inert fraction were observed in the Varanasi SBR, 34%, and 58%, respectively. However, the range of heterotrophic biomass, cell debris, nitrifying biomass, non-biodegradable VSS, and Inert fractions were found 20-34%, 2-3%, 1-2%, 3-45%, and 28-58%, respectively in all the treatment plants. Wastewater characterization was also performed and showed that rbCOD/ COD range in the treatment plants varied from 8-32%. The readily biodegradable portion of COD is effective in denitrification and phosphorus release mechanisms of BNR processes of the pre-anoxic selector attached SBR plants.***

Keywords: Endogenous decay, Inert, readily biodegradable COD, Sequencing batch reactor, Sludge

1. Introduction

Sludge handling and maintenance are becoming major issues in dealing with wastewater treatment plant management. The high cost for treatment and disposal of excess sludge has increased up to 50-60% of the total operation costs [18], and this often results in improper disposal of sludge. Still, it has been observed as an ignored or disregarded issue in these treatment plants. A comprehensive investigation program is required to maintain the sludge production record based on the critical control design parameters of influent wastewater. Sludge handling and maintenance are becoming major issues in dealing with wastewater treatment plant management. There is also inadequate information regarding daily sludge production in the WWTPs; neither the wastage is recorded systematically, nor it is to be provided by the operators of these plants (if recorded), as it is generally conducted manually. The economy is the most crucial driver for the development and operation of WWTPs (Wastewater Treatment Plants) [1, 12].

In the case of a highly populated country, China, to achieve minimal unit sludge production, it can be concluded that membrane bioreactor can be the best candidate (0.390 kg/m3). And if we are looking for small- and large-scale WWTPs (<5 x 10^4 m3/day and 10–20 x 10^4 m3/day) biological filters are a good option, whereas sequencing batch reactor is suitable for medium-scale and super large-scale WWTPs (5–10 x 10^4 m3/day and >20 x 10^4 m3/ day) and oxidation ditch is not appropriate for large scale WWTP [7, 8, 15]. A definite positive correlation between COD reduction and sludge production was also observed in the study of China. In rapidly populated country India also, the case might be the same in terms of sludge generation and treatment efficiencies from different technologies applied for wastewater treatment [18].

It is also fundamental to implement new technologies to minimize sludge production as much as achievable. Some technologies have been developed, including metabolic uncouplers addition, sonication–cryptic growth [21], sludge predation [13], and other derivative technologies [17]. For the treatment plants, it was observed that the use of extended biological processes (i.e., constructed wetlands, extended aeration systems) produces lesser sludge as compared to WWTPs that opt for traditional ASPs or use physicochemical methods for phosphorus removal [14].

Systematic treatment and disposal of the excess sludge generated from these treatment plants are very essential. Agricultural use of raw sludge or other composting practices is encouraged by national authorities as to the best way for recycling, while incineration is considered the worst [16, 20]. Compost is an excellent soil conditioner as it includes major plant nutrients, i.e., TN, TP, and TK, plant micronutrients, i.e., Cu, Fe, and Zn, and organic matter which develop soil properties by ascending soil aeration and water holding potential [3, 5, 6].

The different processes for sludge treatment are: 1) Sludge Pasteurization, 2) Mesophilic Anaerobic Digestion, 3) Thermophilic Anaerobic Digestion, 4) Composting (Windrows or Aerated Piles), 5) Lime Stabilization of Liquid Sludge, 6) Liquid Storage and 7) Dewatering and Storage by using any of these technologies that are Centrifuge, Belt Press, Screw Press, Filter Press or Sludge Drying Beds [1,4].

The objectives of the study:

1) To estimate sludge production (as per daily) from full-scale municipal wastewater treatment plants based on various technologies established across India, running

efficiently by satisfying NGT effluent standards water quality in terms of TN, TP, COD, BOD, and TSS.
2) To estimate specific sludge production based on influent wastewater parameters in terms of Kg TSS/ Kg BOD removed, Kg VSS/ Kg BOD removed, Kg TSS/ Kg COD removed and Kg VSS/ Kg COD removed.
3) To evaluate and observe excess sludge production in plants and to compare it with existing prediction models described in equation (1).
4) To judge the percentage of composition of various types of biomass present in sludge production. Generally, the inert portion i.e., Q ($TSS_{influent}$- $VSS_{influent}$), is found quite higher than others because of unpaved areas, intersection, and diversion of open drains to sewage systems in India.

The key aim is to go into detail for actual wastewater in a long term study and actual sludge production in Indian wastewater contexts because they have a lower VSS/TSS ratio (0.5-0.7) as compared to extended aeration systems with a ratio ~0.8 and explore on various feasible sludge handling ways

2. Material and Methods

2.1 Study sites and design parameters

Nine SBR plants were analyzed for this study (Table 1). All the SBRs have proper automated systems governed by the programmable logic controller (PLC) and DO/ OUR control systems. A thorough study was done, and the results were shown in table 2 and these plants were found efficient in removing the nutrients (TN and TP), suspended solids, and organic matter up to the NGT effluent discharge standards [11]. In all of these plants, the tertiary treatment/ final polishing of the biologically treated effluent was carried out by chlorination and UV Disinfection.

Table 1: Design parameters of SBR plants

Location	Designed Flow (MLD)	Actual Flow (MLD)	Volume (m^3)	HRT	Cycle duration (h)	SRT (d)	Sludge recirculation (%)	VSS/ TSS
Roorkee (Uttarakhand)	3 (0.2 MLD recycle)	1.80	2414.5	18.1	4	15.2	25	0.54
Gharaunda, Karnal (Haryana)	7	2.94	5214	17.9	3	13.5	25	0.52
Near Indra Chakrawati, Karnal (Haryana)	10	2.52	5986	14.4	3	13.2	21	0.70
Haridwar (Uttarakhand)	27	27.7	12476	11.1	3	13.5	22	0.56
Rajkot (Gujarat)	56	19.6	35112	15.05	3	12.4	18	0.55
Ahmedabad (Gujarat)	60 (1.14 MLD recycle)	43.3	38390.4	15.07	3	14.5	25	0.62
Koparkhairane (Mumbai)	87.5	36.3	52424	14.4	3	12.0	35	0.50
Airoli (Mumbai)	80	33.0	44000	13.2	3	12.0	-	0.53
Varanasi (Uttar Pradesh)	120	22.3	71911	14.00	3	10.4	18	0.55

2.2. Physicochemical parameters and wastewater characteristics

The operational parameters were observed regularly in the treatment plants along with the parameters like COD (total, filtered, and other fractions), BOD5 (total and filtered), TN, TKN, Ammonia, Nitrate, Orthophosphate, and Total Phosphorus according to *Standard Methods* [2] and rbCOD by Floc-filtration method [19] (Table 1 and 2). EBPR was calculated as TP removed more than ~2.7% of PO4-P uptake as VSS in the sludge. It can be seen in figure 1 that parameter ratios like COD/BOD are unusually higher compared with design parameter and pure domestic sewage parameter ratios which confirms either the presence of industrial effluent or mixing of drain water including sand, silt, and clay in the domestic sewage.

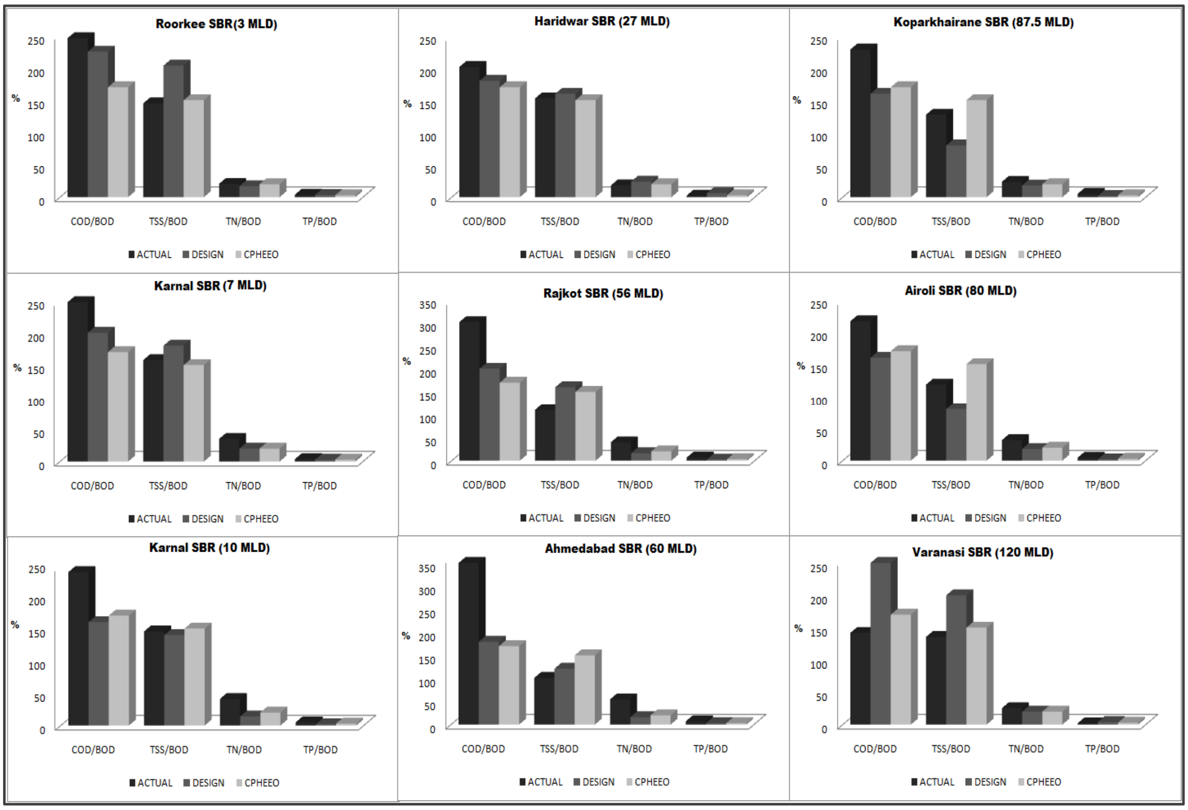

Figure 1: Parameter ratios for actual, design & CPHEEO parameter values are compared in the SBR plants

2.3 Biomass yield estimation

The sludge production was calculated by the method as described by [9]:

$P_{X,\,TSS}$ = A/0.85+ B/0.85+ C/0.85+ D + E (1)

Where,
A=Heterotrophic biomass
B=Cell Debris
C=Nitrifying bacteria biomass
D=Non-biodegradable VSS
E=Inert TSS

$Yield\ coefficient\ (Y) = 0.5, Endogenous\ decay\ (Kd) = 0.06,\ fd = 0.15,\ Yn = 0.12,\ Kdn = 0.08$, TSS_O= Influent TSS (mg/L), and VSS_O= Influent VSS (mg/L).

3. Results and Discussion

3.1 Performance evaluation in SBR plants

All the plants were able to meet desired stringent effluent standards of NGT in terms of COD, BOD, and TSS [11]. In the SBR plants with capacity 10 MLD, 60 MLD, 87.5 MLD, and 80 MLD, the total nitrogen in effluent got slightly beyond the standards (10 mg/L). TP removal was observed highest in 87.5 MLD SBR plants, and 120 MLD SBR.

Table 2: Average overall performance evaluation of SBR plants (influent and effluent parameters)

Plant capacity (MLD)	COD		BOD		Ammonia		Nitrate		TN		TP		TSS	
	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)
3	401	18	163	6.0	21.8	0.7	0.9	5.6	33.6	9.7	6.1	3.6	237	9.4
7	398	31	161	5	34	1	0	5.5	56.3	9.3	5.8	4.7	254	8
10	401	29	169	4	45.2	1.9	0	6	69.4	13.5	8.2	6.9	246	4
27	324	16	161	7	15	0	2	5	29.2	6.9	3.9	2.4	246	10
56	265	26	88	2.9	29	1.5	0.8	3.6	35	8	5.7	3.9	97	12
60	301	16	86	3.1	36	0.4	0.4	7.6	47	12	6.1	4.1	87	8
87.5	290	35	127	10	24.5	5.8	1	3	30	10.5	6.4	1.5	162	20
80	212	30	98	9	23.2	1	1	5	31	10.6	4.4	3.7	116	18
120	326	18.2	230	2.7	43.7	1.6	1.1	3.7	58.3	10	4.5	1.1	312	8

3.2 Wastewater characterization

The COD is an important parameter for determining the potential of wastewater in organic carbon sources for proceeding BNR in WWTPs. The fractions are also important in determining theoretical sludge production (equation 1) and specific sludge production analysis. The total COD of wastewater, divided into fractions, can be calculated in a simplified way: Total COD = Readily Biodegradable COD (RBCOD) + Non-Biodegradable Soluble COD as soluble effluent COD (NBSCOD) + Slowly Biodegradable COD (SBCOD) + Non-Biodegradable

Particulate COD (NBPCOD) [10]. The readily biodegradable portion of COD is effective in denitrification and phosphorus release mechanisms of BNR processes of the pre-anoxic selector attached SBR plants. Also nbVSS fraction of biomass requires biodegradable particulate COD (bpCOD), particulate COD (pCOD), soluble BOD (sBOD) and soluble COD (sCOD) in detail. The sCOD/COD (%) and sBOD/BOD (%) varied from 29-54% and 24-69%, respectively, in the SBR plants. The rbCOD/COD% of 17%, and 32% helped in gaining 83%, and 65% TN removal and 76%, and 77% TP removal, respectively in 120 MLD and 87.5 MLD SBR plants when other parameters were also up to the mark. The non-biodegradable particulate COD in total COD illustrates the part of COD consumed in sludge production and the range belongs to 3-52% in these SBR plants (Figure 2).

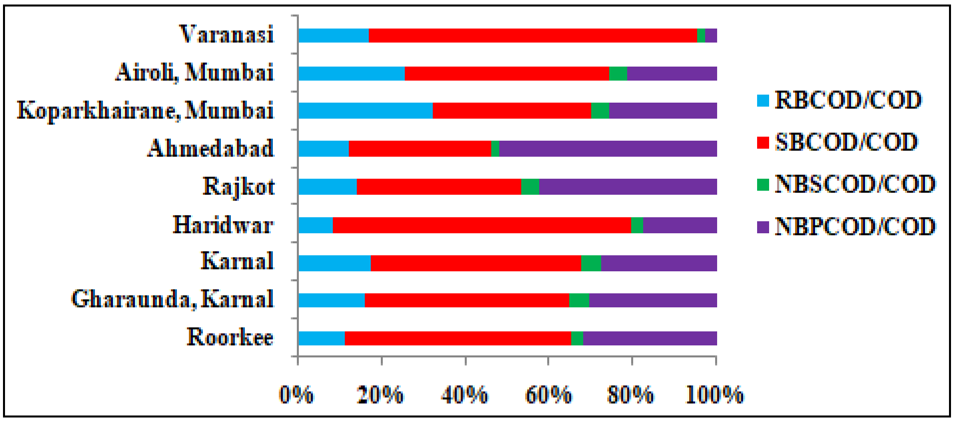

Figure 2: Wastewater characterization (based on COD fractions) in the SBR plants

3.3 Sludge production

The sludge production was constituted of five biomass fractions as suggested in Metcalf and Eddy, Inc. 2003. The estimation is based on equation (1) dedicated to suspended growth systems, i.e., ASP, A_2O, SBR, etc. However, all the biomass fractions rely on their independent terms i.e., heterotrophic biomass for heterotrophic biomass growth, cell debris from endogenous decay, nitrifying biomass for nitrifying bacteria biomass, non-biodegradable volatile suspended solids for VSS that is not biodegradable, and inert for inorganic solids in the influent wastewater can be used to estimate sludge production (Metcalf and Eddy, Inc. 2003). The inert part coming either from drains or broken sewers or wastewater collection systems includes primarily sand, silt, clay which remains as it is during the treatment process and can also harm the system if present in great amounts. Sludge production estimation of the SBR plants shown in Table 3. The 120 MLD Varanasi, 87.5 MLD Mumbai, 80 MLD Mumbai, and 60 MLD Ahmedabad SBRs were having >50% inert content in their biomass composition whereas, the remaining plants were having 38.6 ± 9.0%. Heterotrophic biomass was constituted of only 24.8 ± 4.3% of total biomass and the least role in biomass composition was observed of nitrifying biomass (1.2 ± 0.5%) after the complete sludge production estimation of all the SBR plants (Figure 3). Similarly, specific sludge production estimation (Kg TSS/ Kg BOD removed) was least observed in 120 MLD Varanasi and 80 MLD Airoli SBR which shows that these plants are reduced sludge producing plants and lesser cost for sludge treatment, handling and disposal will be required compared to other plants (Table 4).

Table 3: Sludge production and biomass composition in the SBR plants

Sludge Production							
Plants	(A) Heterotrophic Biomass (Kg/d)	(B) Cell Debris (Kg/d)	(C) Nitrifying biomass (Kg/d)	(D) nbVSS (Kg/d)	(E) Inert (Kg/d)	$P_{(X, TSS)}$ (Kg/d)	$P_{(X, VSS)}$ (Kg/d)
(Location)	QY(S0-S)/ (1+Kd*SRT)	fd*kd*QY(S0-S)*SRT/ (1+Kd*SRT)	QYnNOx/ (1+Kdn*SRT)	Q*(1-bpCOD/pCOD)* VSS	Q*(TSS_0-VSS_0)	A/0.85+B/0.85 +C/0.85+ D+E	
Roorkee	73.9	10.1	2.1	113.7	196.7	411.8	221.7
Gharaunda, Karnal	126.5	15.4	5.6	215.5	361.6	750.7	387.1
Karnal	115.9	13.8	6.4	198.9	186.5	545.5	381.4
Haridwar	1177.4	143.0	24.1	971.5	2961.4	5514.8	3116.0
Rajkot	479.1	53.6	32.5	966.3	864.6	2495.9	1363.7
Ahmedabad	959.8	125.3	85.6	2285.9	1428.9	5092.1	3160.6
Koparkhairane (Mumbai)	1234.6	133.3	41.6	1188.8	2940.3	5787.4	2893.7
Airoli (Mumbai)	853.8	92.2	44.9	654.6	1815	3635.3	1911.7
Varanasi	1560.6	146.1	61.5	159.0	3122	5361.2	2955.5

Table 4: Specific sludge production in the SBR plants

Plants location	P(TSS) KG/D	P(VSS) KG/D	KG TSS/ KG BOD Removed	KG TSS/ KG COD Removed	KGVTSS/ KG BOD Removed	KG VSS/ KG COD Removed
Roorkee	411.8	221.7	1.5	0.6	0.8	0.3
Gharaunda, Karnal	750.7	387.1	1.6	0.7	0.8	0.4
Karnal	545.5	381.4	1.3	0.6	0.9	0.4
Haridwar	5514.8	3116.1	1.3	0.6	0.7	0.4
Rajkot	2495.9	1363.7	1.5	0.5	0.8	0.3
Ahmedabad	5092.1	3160.6	1.4	0.4	0.9	0.3
Koparkhairane (Mumbai)	5787.4	2893.7	1.4	0.6	0.7	0.3
Airoli (Mumbai)	3635.3	1911.7	1.2	0.6	0.7	0.3
Varanasi	5361.2	2955.5	1.1	0.8	0.6	0.4

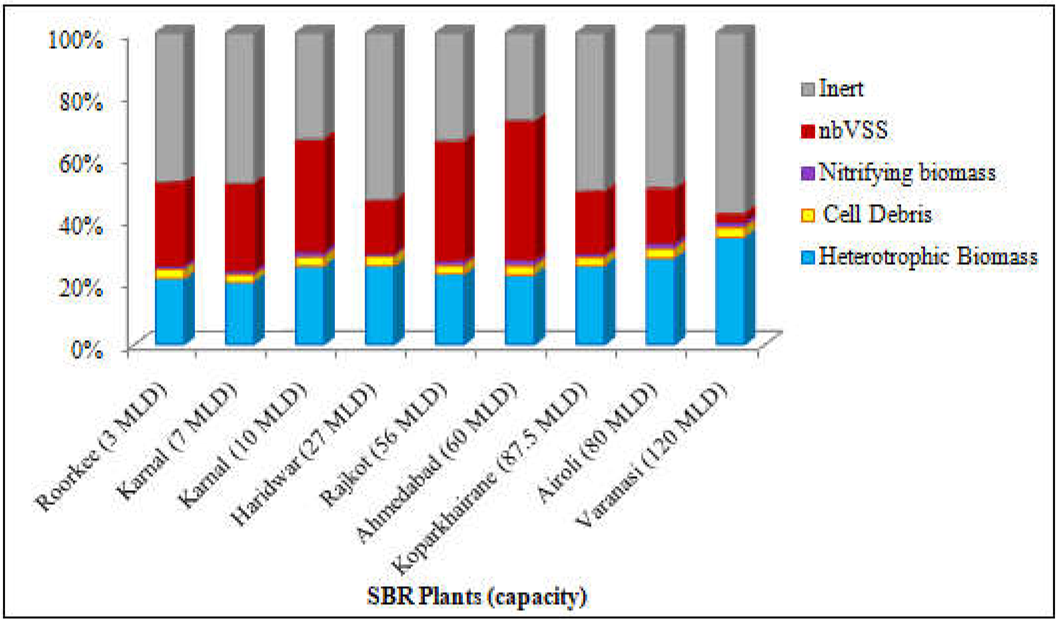

Figure 3: Percentage fractions of different biomass composition

4. Conclusion and Future Scope

Sludge production estimation is one of the most important tasks after the biological treatment process. Still, it has been observed as an ignored or disregarded issue in these treatment plants. This study gives insights into different factors responsible for biological sludge production. The following points have been highlighted in the study: (a) In the Indian wastewater context, heterotrophic biomass constitutes (24.8 ± 4.3%), nbVSS (26.1 ± 12.9%), the inert fraction (45.1 ± 10.2%) and rest ~4.0% included in cell debris and nitrifying bacteria biomass. (b) The rbCOD fraction in COD was found essential in the BNR process. (c) The rbCOD fraction in COD only covers an average of 16.9% whereas; sbCOD content covers the highest portion of COD, i.e., 51.4%. (d) The least specific sludge production was found in 80 MLD and 120 MLD SBR plants. The present study can help assess and develop proper sludge management, treatment, and disposal techniques based on the estimated excess sludge generation and composition of the biomass, which has become one of the significant issues in the total cost estimation of WWTPS feeding with domestic wastewater.

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