Greenhouse Gas Emissions from Sewage Treatment Plants Based on Sequential Batch Reactor in Maharashtra

Vipin Singh, Harish C. Phuleria and Munish K. Chandel

Abstract Wastewater treatment systems contribute significantly to anthropogenic greenhouse gas emissions. The main greenhouse gases emitted during the wastewater treatment processes are methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). Sequential batch reactor (SBR) is a type of an activated sludge process, and due to its high efficiency, currently, this is the preferred technology for the construction of new wastewater treatment plants (WWTPs). This study presents the estimation of greenhouse gas (GHG) emissions from SBR domestic wastewater treatment plants in Navi Mumbai, Maharashtra. We estimated direct emissions from wastewater treatment processes as well as indirect emissions due to energy usage during the treatment process. A total emission of ~ 35 kt CO_2-eq/year was estimated for six SBR-based WWTPs having combined treatment capacity of 474 MLD. All except one of these plants were well managed. In the case of not so well-managed SBR plants, significant methane production occurs during the treatment process. In the long run, if these plants are not well managed, the emission could increase by three to fourfolds for the same treatment capacity. In either case, major GHG emissions are due to CH_4 emission during the treatment process. The contribution of N_2O is negligible towards total GHG emissions.

Keywords Greenhouse gases · Methane emission · Nitrous oxide emission Emission factor · Domestic wastewater · IPCC guidelines

Abbreviation

MLD   Million litre per day
GHG   Greenhouse gas
CO_2 Carbon dioxide
CO_2-eq Carbon dioxide equivalent
WWTP Wastewater Treatment Plant

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N_2O Nitrous oxide
CH_4 Methane
GWP   Global warming potential

Introduction

Wastewater treatment systems contribute significantly to anthropogenic greenhouse gas emissions (USEPA 1997; Rittmann and McCarty 2001). The main greenhouse gases emitted during the wastewater treatment processes are methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). Carbon dioxide is formed as a result of aerobic microbial degradation and combustion of organic matter whereas methane is produced through the anaerobic degradation of organic matter. Nitrous oxide, on the other hand, is generated as a result of nitrification and denitrification processes.

This is observed that GHG emission and energy utility analysis for sewage treatment is the country wide challenge in India as their environmental impact, e.g. GHG emissions and global warming have not been assessed. According to USEPA (2014), Wastewater treatment plants (WWTPs) are the eight largest sectors that contribute to CH_4 and N_2O emissions. So in such case, the emission estimation from WWTPs could be one of the important sectors to consider along with treatment efficiency of the plant.

The sequencing batch reactor (SBR) is upgraded form of the activated sludge process (ASP). In SBR, the processes of filling, aeration, settling and decanting are consecutively carried out in the same tank. These phases constitute a cycle; during which, the fluid volume inside the reactor increases from a set working base water level. Mixed liquor is recycled into a selector from aeration zone during fill–aeration. End of the air circulation permits the biomass to flocculate and settle under at a predetermined time of the cycle. The treated supernatant is tapped after a particular setting period. The solids are isolated from the reactor amid the emptying stage. This system does not use secondary clarifier system for concentrating the sludge. The activated sludge is recycled, whereas the surplus is discarded from the basin. The BOD removal efficiency is higher in this type of treatment systems, which can be achieved up to 98% in case of BOD removal through SBR-based WWTPs (Compendium of Sewage Treatment Technologies 2009). Another study (Wakode and Sayyad 2014) in Mumbai has shown the average biochemical oxygen demand (BOD) removal of $\sim$95–97% for SBR wastewater treatment plant. According to Loganathan et al. (2012) the removal efficiency of carbonaceous fractions (e.g. BOD, COD and TSS) was achieved more than 90%, similar removal efficiencies (80–90%) were shown in another study by Iaconi et al. (2008), whereas the BOD removal efficiencies for ASP-based WWTPs were seen in the range of 77–95% in Delhi (Jamwal et al. 2009) and for UASB based WWTPs 67% in Surat (Nair and Ahammed 2015) and Seghezzo et al. (1998) reported in the range of

50–70% in Netherland for UASB treatment plant. The COD removal was reported 43–56% and 68–85% for ASP and UASB, respectively (Sperling et al. 2001).

The sequencing batch reactor (SBR) is a kind of recent wastewater treatment technology, and there are not many studies found regarding GHG emissions from these type of WWTPs. A study in Noida, India (Gupta and Singh 2012) on a 33 MLD WWTP based on SBR technology using IPCC 2006 and population equivalent data found 3027.8 CO_2-eq/year.

Due to the latest technology for wastewater treatment because of its great removal efficiency, SBR could be one of the choices of selectors for the establishment of new WWTPs in India. Considering this, the WWTPs were selected for the present study of Navi Mumbai, Maharashtra state of India, as a part of estimation of GHG emissions contributed by WWTPs sectors interestingly all plants are based upon SBR technology.

Materials and Methodology

Six differently located SBR-based WWTPs for 474 MLD capacity were selected for our research study. All WWTPs have similar design and consist of preliminary, secondary and advance treatment processes within. A schematic diagram of SBR wastewater treatment plant in Navi Mumbai has been shown in Fig. 1.

The personal visits were made to individual WWTP and required data such as Treatment Capacity and BOD were collected from individual WWTPs in Navi Mumbai. For these WWTPs the range of BOD (raw sewage) was found to be 118–164 mg/l, with an average value of 138.7 mg/l (Table 1). The data for per capita intake of protein per day was taken 52.7 gm for Maharashtra state (NSSO 2014), which is required for N_2O emission calculation. On the basis of average wastewater generation in India, the per capita generation of wastewater is taken 121 l/capita/day, which is based on the studies carried out by Central Pollution Control Board (CPCB 2009). The global warming potential (GWP) is taken as 25 and 298 for CH_4 and N_2O respectively (IPCC 2006).

Setting system boundary: The system boundary is sewage treatment plant which includes the CH_4 and N_2O emissions from sewage treatment process and
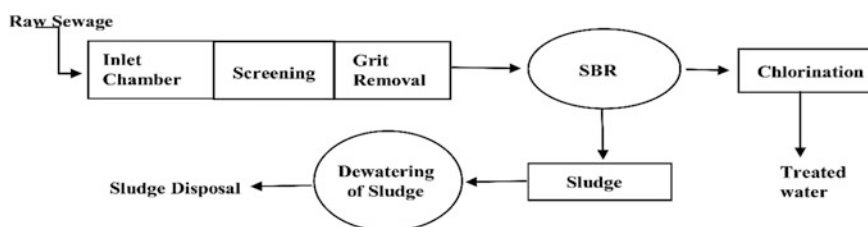

Fig. 1 Process flow diagram for SBR WWTP in Navi Mumbai

Table 1 Detail data of WWTPs in Navi Mumbai

WWTPs code	WWTP capacity in MLD	Total electricity use (KWh/month)	BOD (inlet) mg/l	Wastewater generation by population
WWTP1	100	236,170	128	723,140
WWTP2[a]	87.5	227,220	140	826,446
WWTP3	100	235,500	164	826,446
WWTP4	87.5	226,880	132	723,140
WWTP5	19	45,420	118	157,025
WWTP6	80	198,400	150	661,157
Total	474	1,169,590		3,917,355

[a]WWTP with improper management

CO_2 emissions due to use of electricity in the WWTPs. The emissions from the sludge treatment were not considered in this study due to data constraints CO_2 emissions of biogenic origin were not considered in the treatment process.

Direct and Indirect GHG emissions: There are three greenhouse gases calculated in the scope of present study, i.e. CO_2, N_2O and CH_4 using IPCC guidelines, 2006. The direct GHG emission was calculated from the generation of CO_2 by the breakdown of the organic component during the treatment process. The amount CH_4 is generated in case of improper management of WWTP which could be specific in aeration basin as there is no primary clarifier in the WWTPs considered. The N_2O emission was calculated on the basis of protein intake per capita. The Indirect GHG emission was calculated through power consumed in WWTPs. The total electrical power use in all six WWTPs was 1169.6 MWh/month for the capacity of 474 MLD wastewater treatment. The details of power uses for the operation of individual WWTP has been shown in Table 1, which was collected by the visit of WWTPs in Navi Mumbai.

The methodology for the estimation of emissions is based on IPCC guidelines for national greenhouse gas inventories (2006). Estimation of methane emissions is done using the following equation:

$$E_{CH_4} = (\text{kg BOD} \times \text{EF} \times 365) - S - R \tag{1}$$

where

E_{CH_4} Total methane emissions from waste water ($kgCH_4$)
BOD   Total organic waste load (kg BOD/year)
EF   Emission factor for wastewater type ($kgCH_4$/kg BOD)

Sludge removal and methane recovery were excluded from this study due to unavailability of required data and it has been considered zero as default as per IPCC guidelines. The Emission factor for methane was calculated as follows:

$$EF = B_0 \times MCF \tag{2}$$

where

B_0 Maximum methane producing capacity from raw sewage (default value for B_0 is 0.6 kgCH$_4$/kgBOD, IPCC 2006)

MCF   Methane correction factor (for SBR the default value of well-managed WWTP is 0 whereas it is 0.1 in case of not well-managed Pant)

Calculation of CO_2 emissions due to electricity use (IPCC 2006):

$$CO_2 \text{ Emissions from electricity use} = \text{Total Use of electricity in MWh} \times EFGE \tag{3}$$

where

MWh   Electricity consumption in megawatt hour.

EFGE Emission factor for generation of electricity in Maharashtra was taken 0.88 t CO_2/MWh from Central Electricity Authority of India (CEA 2011).

Estimation of nitrous oxide emissions is done using the following equation (IPCC 2006):

$$\text{Total}_{N_2O} = \text{Emission Factor} \times \text{Conversion Factor of kg } N_2O - N \text{ to kg } N_2O \times N_{\text{Effluent}} \tag{4}$$

where

$$N_{\text{Effluent}} = HP \times P \times F_{\text{NPR}} \times F_{\text{NON-CON}} \times F_{\text{IND-COM}} \tag{5}$$

N_{Effluent} Total amount of nitrogen in the wastewater effluent annually

HP   Population of Human being contributing to the generation of wastewater generation

Protein   Per capita protein consumption annually (kg/person/year)

F_{NPR} Nitrogen's fraction in protein (the default value = 0.16, kg N/kg protein)

$F_{\text{NON-CON}}$ Factor for non-consumed protein added to the wastewater (the value for developing countries is 1.1)

$F_{\text{IND-COM}}$ Factor of commercial and industrial co-discharged protein into the sewerage system (the default value is 1.25)

N_2O–N to kgN_2O = 1.57
Emission Factor = 0.0005 kgN_2O–N/KgN

Results and Discussion

The total estimated GHG emissions for the six SBR-based WWTPs was $\sim$35 kt CO_2-eq/year in current operation of WWTPs, whereas 83.33% WWTPs were properly managed. Where as if all plants are partially managed, the emissions will be $\sim$127 kt CO_2-eq/year (Fig. 2).

Since the SBR is an aerobic process, methane emissions are negligible. However, if the WWTP is not functioning properly, methane could be generated during the treatment process. Hence, in case of partially managed WWTPs and $\sim$87% of total GHG emission is due to the production of CH_4. In the current working conditions, where all plants, except one are well-managed, the methane emissions are estimated to $\sim$53%.

The total N_2O emissions were $\sim$3.9 kt CO_2-eq/year from all WWTPs; out of which the N_2O contribution to total GHG emissions is 11.2% in current working conditions of WWTPs and will reduce to 3.1% if WWTPs do not work well. The total emissions due to electricity consumption were 12.4 kt CO_2/year which is 35.7% (of the total GHG emissions) in the current situation and 9.7% in not well-managed WWTPs (Fig. 3).
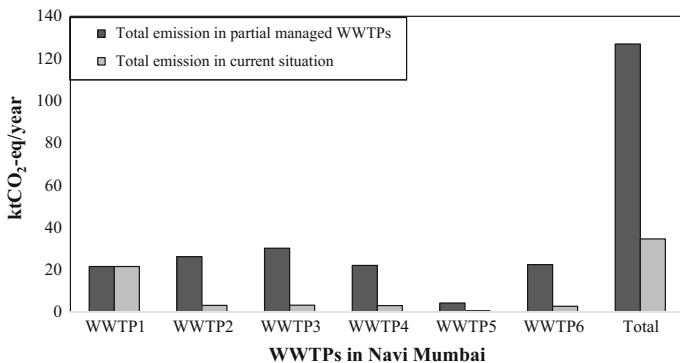

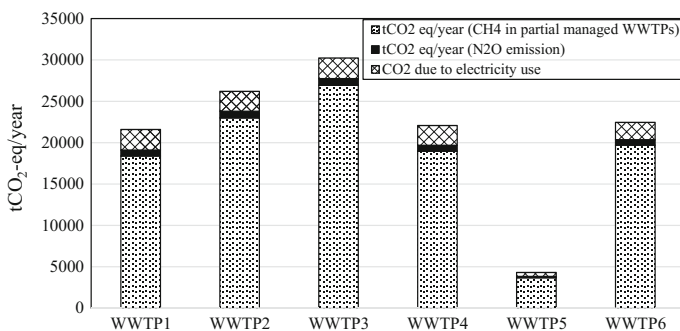**Fig. 2** Total GHG emissions from WWTPs in Navi Mumbai, Maharashtra

Fig. 3 GHG emissions from WWTPs in Navi Mumbai, Maharashtra (the individual emission of N_2O, CH_4 and CO_2 from the WWTPs has been shown in terms of CO_2-eq)

The GHG emissions data from WWTPs is very sparse in India. Gupta and Singh (2012), estimated GHG emissions from a SBR-based WWTP in Noida, India with a treatment capacity of 33 MLD. They have reported ~ 90 t CO_2/year emission from the WWTP, whereas we estimate ~ 75 t CO_2/year GHG emission for per MLD treatment of wastewater in Navi Mumbai. The slight difference in emissions could be due to the working condition of the WWTPs and efficiency of the individual units, perhaps also due to climatic conditions.

In most of the cases, it has been seen the methane generated in all WWTPs is discharged in the atmosphere and in some cases it is flared which adds to GHG concentration. The WWTPs also produce sludge during the treatment of wastewater in these WWTPs but it has been observed that there is no proper utilization or treatment of generated sludge as well as WWTPs were not equipped for capturing of generated methane. Bianchini et al. (2015) reported the energy content in sludge in the range of 12.7–15.5 MJ/kg of dry sludge. So if the produced sludge can be further utilized such as for biogas generation, then the energy could be generated and utilized in respective WWTPs. Similarly, if the generated methane in the WWTPs could be captured and utilized for energy generation. Thus, the overall GHG emission could be reduced as there will be less requirement of energy from external sources.

Conclusion

The study has estimated greenhouse gas emissions from SBR-based WWTPs in Navi Mumbai, Maharashtra for current operation as well as in case the WWTPs are not managed properly. The GHG emissions are primarily due to the treatment of sewage water and energy used associated in mechanical or electrical part of the WWTPs. Methane emissions contribute majorly in not so well-managed WWTPs, whereas the generation of N_2O and CO_2 emissions are same in both the situations, i.e. if the WWTPs functioning well or not. So if all WWTPs are partially managed, GHG emissions are estimated to be ~ 127 kt CO_2-eq/year for the whole wastewater treatment capacity available in Navi Mumbai. In this current situation, where most of the WWTPs are in proper working conditions the GHG emission is found to be ~ 35 kt CO_2-eq/year.

The recommendations could be proper management and utilization of sludge and, capturing of methane if it is produced during treatment of wastewater for generation of energy, which could be used within respective WWTP. That way, it may likely reduce energy dependency of WWTP and plants can be self-sustained to some extent. It would also help in reduction of environmental burden in terms of overall GHG emissions.

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