*2012 International Conference on Environmental Science and Technology*
*IPCBEE vol.30 (2012) © (2012) IACSIT Press, Singapore*

# Estimation of Environmental Footprint of Municipal Wastewater Treatment in India: Life Cycle Approach

Pradip P. Kalbar [1+], Subhankar Karmakar [1] and Shyam R. Asolekar [1]

[1]Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay, Mumbai 400 076, INDIA.

**Abstract.** Life Cycle Assessment is widely used tool for estimation of environmental footprint of products, technologies and services. In this study environmental footprint of Wastewater Treatment Plant (WWTP) based on sequencing batch reactor technology has been estimated using life cycle approach. Results show that the construction phase contributes to nearly 1% for the impacts when compared to overall life cycle impact of the plant and hence can be neglected. In the comparative assessment of WWTPs only operation phase can be considered. The results are helpful to develop a framework for assessment of wastewater treatment technologies using life cycle approach.

**Keywords:** Life Cycle Assessment, Wastewater Treatment, Sequencing Batch Reactor, CML methodology, India

## 1. Introduction

Wastewater treatment is one of the challenges faced by developing countries like India. As per the report published by Central Pollution Control Board, Ministry of Environment and Forests, Government of India, there is huge gap in the wastewater generation and available treatment capacity (CPCB, 2009). Many technological alternatives are available for wastewater treatment. Conventional wastewater treatment technologies such as Activated Sludge Process (ASP), Up-flow Anaerobic Sludge Blanket React (UASB) and other land based treatment technologies are presently used in India. However, recently Sequencing Batch Reactor (SBR) is also adopted as one of the prominent alternative which requires less land and produce better quality of effluent compared to conventional activated sludge process. Therefore there is need to evaluate this new alternative in the Indian context. Life Cycle Assessment (LCA) is best available tool to assess environmental footprint of wastewater treatment plants.

Considerable numbers of studies have been carried out worldwide addressing environmental footprint and resource consumption of Wastewater Treatment Plants (WWTPs) using LCA approach during past one decade. By and large, these studies broadly covered the municipal water and wastewater treatment plants, industrial wastewater treatment plants and water recycling facilities (Emmersion *et al.*, 1995; Tillman *et al.*, 1998; Lundin *et al.*, 2000; Karrman and Jonsson, 2000; Machado *et al.*, 2007).

This, work intends to provide the decision support to the policy makers as well as decision makers through identification of the important components that influence the life cycle impacts as well as through providing a reasonable estimation of environmental footprint of the wastewater treatment technology. In the current study an engineered designed case study of SBR has been considered for evaluation due to unavailability of the data of actual field-scale SBR plant. **Fig. 1** shows the envisaged treatment scheme of this SBR plant. 25 MLD ( ≈ 0.1 millions p.e.) capacity, SBR plant was designed for higher organic as well as nutrient removal as per the standard design procedures (Metcalf and Eddy, 2003; Arceivala and Asolekar,

[+] Corresponding author. Tel.: +912225767851; fax: +912225764650.
*E-mail address*: pradipkalbar@iitb.ac.in

2007). Based on the unit and equipment sizing the materials inventory was generated. Field visits were made to the different WWTPs to collect the actual data from field regarding equipments and civil units. Wherever primary data from field work could not be obtained; the secondary data available in literature have been used. The present effort aims at development of an LCA platform which is applicable to Indian scenarios and to quantify the environmental impact of a given wastewater treatment plant. This step might be very nascent stage on performing LCA of WWTP, but in India this is the first comprehensive effort on life cycle assessment.

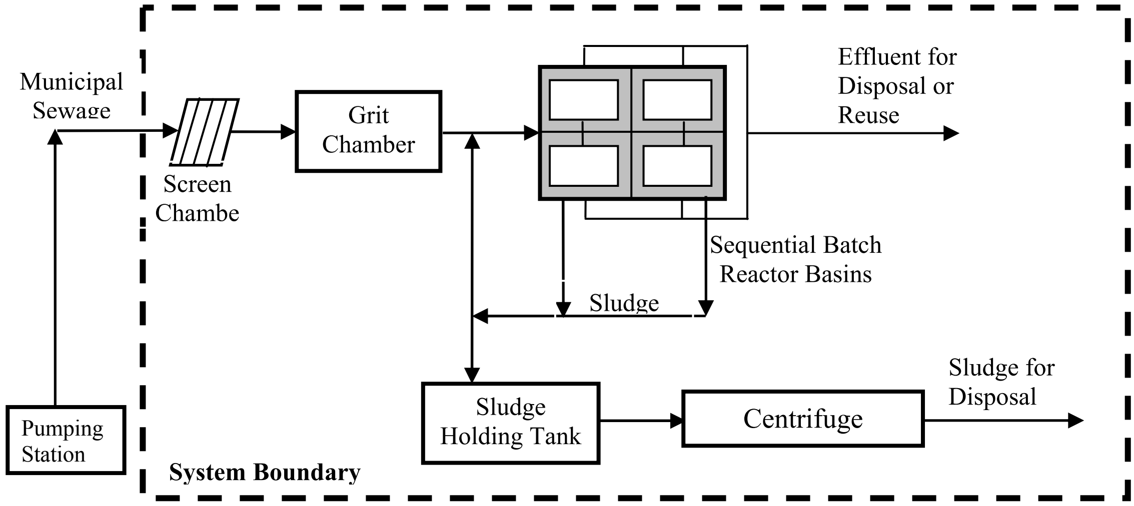


Fig. 1: Units considered in the studied wastewater treatment plant

## 2. Methodology

The LCA methodology followed in this work is as per the ISO 14040 (1997) series, which is described in operational guide to ISO 14040 by Guinee *et al.* (2002). In the present study, for evaluation of life cycle impacts, operational life of wastewater treatment plant has been considered as 50 years for both mechanical as well as civil units after consulting with water infrastructure construction companies in India. The Construction Phase (CP) and Operation and Maintenance (O&M) phase of the wastewater treatment plant have been included in the scope of present research. However, end-of-life or dismantling phase has not been included in the scope of this study since its contribution to environmental impact is typically rather low compared to overall environmental impact of the plant (Emmersion *et al.*, 1995; Tillman *et al.*, 1998; Lundin *et al.*, 2000; Karrman and Jonsson, 2000; Machado *et al.*, 2007).

LCA is subjective decision making tool in which system boundaries are defined based on personal opinion, which essentially determines transparency of the final results. In the present study manufacturing of steel and cement which are the major contributors in the CP are considered. Also, emissions associated with transportation of sand and gravel are also included assuming 100 km as transportation distance for each trip. Other emissions from the CP activities were not considered due to limitations of the data availability. In the O&M phase energy required for operation of the plant and emissions during O&M phase are considered in the present study, however, process emissions and chemicals required for operation of the plant are not taken into consideration in the system boundary. As mentioned earlier, end-of-life phase is not included in the scope of present study.

Functional unit definition is important step while conducting LCAs. In this context the functional unit for present study is chosen as p.e. (population equivalents) for a period of one year. In India one person represents 50 g of $BOD_5$ (Biochemical Oxygen Demand) load per day (Arceivala and Asolekar, 2006).

## 3. Life Cycle Inventory

The life cycle inventories have been generated from the primary data collected from studying publicly owned wastewater treatment plants based on various technologies situated in India. Generating life cycle inventories of all the units is very difficult task and since, in India no national database is available on these types of inventories. All the data related to construction of the WWTP have been collected by personally visiting the sites. The data regarding the technical specifications of mechanical units and data regarding civil units have been gathered in a standard format after reviewing daily records of construction contractors. After studying this information it has been concluded that the major materials involved in manufacturing wastewater treatment plant were steel and concrete (cement, sand and gravels) required for civil works, and steel used to manufacture mechanical equipments. Therefore, in this study only manufacturing phase of steel and cement are considered.

The O&M phase of wastewater treatment plant involves use of energy and chemicals [coagulants, carbon source, polyelectrolyte, disinfectant (chlorine) etc.]. Production of chemicals is excluded from this study due to unavailability of Indian database on production of these chemicals. Energy consumption of the wastewater treatment plant was estimated based on the equipment sizing. Appropriate efficiencies of the equipments and operation hours per day were obtained from field WWTPs. It is necessary to estimate what are the emissions from per unit of energy generation. In this study, it is assumed that all the power generation is from coal based thermal power plants.

## 4. Life Cycle Impact Assessment (LCIA)

The impact assessment phase of the LCA is comprised of mandatory elements, *viz.*, selection of impact categories, classification (assignment of the inventory data to the chosen impact category), characterization (calculation of impact categories using characterization factors), as well as optional elements viz., normalization (calculation of category indicator results relative to reference value(s), and grouping and/or weighting the results (Pennington *et al.*, 2004). Present study does not include normalization, since there are no reference values available in the context of LCA studies in India.

Life cycle impacts have been computed using Microsoft excel spreadsheet according to the CML 2 baseline 2000 methodology, developed by Centre of Environmental Science (CML), University of Leiden, The Netherlands, which gives a separate score for each type of environmental impact, is applied. Eight impact categories viz., Acidification Potential (AP), Global Warming Potential (GWP), Eutrophication Potential (EP), Freshwater Aquatic Ecotoxicity (FWAT), Human Toxicity (HT), Marine Aquatic Ecotoxicity (MAET), Abiotic Resources Depletion Potential (ADP), Terrestrial Ecotoxicity (TE), were considered to compute life cycle impacts. The results of the LCIA are given in Table 1.

## 5. Results and Discussion

Life cycle inventory in this study addresses the primary treatment as well as secondary treatment using sequential batch reactor technology. This inventory, however, does not incorporate pumping of sewage to the primary treatment facility. The total energy consumption over the life cycle of the plant has been found to be 28.21 kWh/pe-year out of which 99.7% is operational phase energy. This result is comparable with the 33 kWh/pe-year value reported by Lundin *et al.* (2000). The emissions to air, water and soil are in agreement with the findings of other researchers (Tillman *et al.*, 1998; Lundin *et al.*, 2000; Galligo *et al.*, 2008, Hospido, *et al.*, 2008).

Table 1 shows that the contribution of construction phase compared to overall impact of wastewater treatment plant is 1.33 % for GWP, 0.65% for ADP and 0.35% for AP, which can be mainly attributed to steel and cement manufacturing. In other impact categories construction phase contribution is insignificant, this result is congruent with results reported by other researchers (Karrman and Jonsson, 2008; Machado, *et al.*, 2007; Pillay *et al.*, 2002). Contribution of construction phase in the EP, FWAT, HT, MAET and TE impact categories has been found to be almost negligible compared to overall impact of the WWTP. In general it is understood that the contribution of construction phase across all the eight impact categories has been found to be nearly 1% of overall life cycle impact of the wastewater treatment plant and therefore can be fairly neglected in the ultimate analysis, which is also reported by many researchers in other parts of the world (Tillman *et al.*, 1998; Lundin *et al.*, 2000; Karrman and Jonsson, 2000; Machado *et al.*, 2007).

Table 1: Results of life cycle impact assessment of wastewater treatment plant (All the values expressed per p.e.-year)

| Impact Category | Unit | Total for WWTP | Construction Phase | O&M Phase | Construction Phase % |
|---|---|---|---|---|---|
| Acidification Potential (AP) | kg $SO_2$-Eq | 0.34 | 0.0012 | 0.34 | 0.35 |
| Global Warming Potential (GWP) | kg $CO_2$-Eq | 32.40 | 0.4315 | 31.97 | 1.33 |
| Eutrophication Potential (EP) | kg $PO_4$-Eq | 1.38 | 0.0001 | 1.38 | 0.01 |
| Freshwater Aquatic Ecotoxicity (FWAT) | kg 1,4-DCB-Eq | 62.21 | 0.0001 | 62.21 | 0.00 |
| Human Toxicity (HT) | kg 1,4-DCB-Eq | 3.42 | 0.0260 | 3.39 | 0.76 |
| Marine Aquatic Ecotoxicity (MAET) | kg 1,4-DCB-Eq | 206.15 | 0.0007 | 206.15 | 0.00 |
| Abiotic Resources Depletion Potential (ADP) | kg antimony-Eq | 0.28 | 0.0018 | 0.28 | 0.65 |
| Terrestrial Ecotoxicity (TE) | kg 1,4-DCB-Eq | 0.08 | 0.0001 | 0.08 | 0.06 |

The GWP is mainly contributed by coal combustion due to electricity production. The GWP potential was found to be 32.40 kg of $CO_2$ equivalents per pe-year. Karrman and Jonsson (2008) reported GWP potential of 12 kg of $CO_2$ equivalents per pe-year for conventional wastewater treatment plant. Eutrophication potential is directly related to nutrients discharged to water and soil environment, for which the WWTP based on sequential batch reactor studied in the present work has better nutrient removal capacity than the conventional activated sludge process. The EP for SBR was found to be 1.38 kg PO4-Eq. Gallego *et al.* (2008) reported an average value of 0.45 kg PO4-Eq for 15 WWTPs. Ecotoxicity and Human Toxicity impact categories are mostly contributed by disposal of sludge and effluent which contains heavy metals. Ecotoxicity potential is mostly dependent on the heavy metals released in the water and soil environment from the WWTP, for which in the present WWTP there is no special provision for heavy metal removal, however, removal occurs through the physico-chemical and biological processes present in the WWTP.

The wastewater treatment plant has varied impacts in each of the impact category as shown in Table 1. The contribution of construction phase is almost negligible in each of the impact category when compared to the total impact of the wastewater treatment plant. The results are helpful to develop a framework for assessment of wastewater treatment technologies using life cycle approach. For comparison of wastewater treatment technologies only operation phase can be considered and construction phase can be fairly neglected in the ultimate analysis.

## 6. Conclusions

Environmental footprint of SBR has been estimated using LCA approach. Transparent results have been obtained with the help of field data pertaining to specific case study. In Indian context, the construction phase had 1% contribution in overall life cycle environmental impact compared to impact of the total wastewater treatment plant. This study shows that for comparison of wastewater treatment technologies only operation phase can be considered and construction phase can be fairly neglected in the ultimate analysis.

## 7. Acknowledgements

Authors are thankful to the Swiss Centre for Life-Cycle Inventories, Dübendorf, Switzerland who have provided educational license to use the Ecoinvent database without which this work would not have been completed.

# 8. References


[1] Arceivala, S. J.; Asolekar, S. R. *Wastewater treatment for pollution control and reuse*, 3rd, ed.; Tata McGraw Hill, New Delhi, 2007.

[2] CPCB, Status of Water Supply, Wastewater Generation And Treatment in Class-I Cities and Class-II Towns of India Control Of Urban Pollution, Series: CUPS/ 70 / 2009 – 10. Central Pollution Control Board, Ministry of Environment and Forests, Government of India, Delhi. 2009.

[3] Emmerson, R. H. C., Morse, G. K., Lester, J. N., and Edge, D. R. The life-cycle analysis of small-scale sewage-treatment processes. *J. Chart. Inst. Water and Env. Manag.*. 1995, **9**: 317-325.

[4] Gallego , A., Hospido , A., Moreira, M.T., Feijoo ,G., Environmental performance of wastewater treatment plants for small populations. *Resour., Conserv. Recycl.* 2008, **52**: 931-940.

[5] Guinee, J. B.; Gorree, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; de Koning, A.; van Oers, L.; Wegener Sleeswijk, A.; Suh, W.; and Udo de Haes, H. Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards; Kluwer Academic Publishers: Dordrecht,; 2002, xii + 692 pp.

[6] Hospido, A., Moreira, M.T., Feijoo, G., A comparison of municipal wastewater treatment plants for big centres of population in galicia (spain). *Int. J. Life Cycle Assess.* 2008, **13**: 57-64.

[7] ISO, Environmental management - Life cycle assessment - Principles and framework: International Standard 14040. International Standards Organization, Geneva, 1997.

[8] Karrman, E., Jonsson, H., Normalising impacts in an environmental systems analysis of wastewater systems. *Water Sci. Technol.*, 2008, **43**: 203–300.

[9] Lundin, M., Bengtsson, M., Molander, S., Life cycle assessment of wastewater systems: Influence of system boundaries and scale on calculated environmental loads. *Env. Sci. Technol.* 2000, **34**: 180-186.

[10] Machado, A. P., Urbano, L., Brito, A. G., Janknecht, P., Salas, J. J., Nogueira, R., Life cycle assessment of wastewater treatment options for small and decentralized communities. *Water Sci. Technol.* 2007, **56**: 15-22.

[11] Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal, and Reuse. Metcalf & Eddy, Inc. 4th edition revised by Tchobanoglous, G. & Burton, F.L., McGraw Hill Inc. International, 2003.

[12] Pennington, D. W., Potting, J., Finnveden, G., Lindeijer, E., Jolliet, O., Rydberg, T., Life cycle assessment part 2: Current impact assessment practice. *Env. Int.* 2004, **30**, 721-739.

[13] Pillay, S. D., Friedrich, E., Buckley, C. A., Life cycle assessment of an industrial water recycling plant. *Water Sci. Technol.* 2002, **46**: 55-62.

[14] Tillman, A., Svingby, M., Lundström, H., Life cycle assessment of municipal wastewater systems. *Int. J. Life Cycle Assess.* 1998, **3**: 145-157.