

Cost-Effective Treatment Technology for Small Size Sewage Treatment Plants in India

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Received 29 February 2016; revised 17 October 2016; accepted 27 December 2016

The present paper discusses cost effective wastewater treatment technologies for small size Sewage Treatment Plants (STPs) in India. Wastewater treatment technologies are gaining importance for an attention of policy-makers and industries for meeting the required pollution control guidelines as laid down by the regulators of the countries and to make the wastewater fit for desired usages resulting in conservation of water resources. This article provides an analysis of technologies commonly used in this sector in terms of cost assessment and footprint requirement for selecting its suitability in Indian climate. Various aerobic treatment technologies viz. Moving bed biofilm reactor (MBBR), Membrane bioreactor (MBR), Sequencing batch Reactor (SBR), Extended Aeration (EA), Submerged aerobic fixed film (SAFF), suitable for treating wastewater have been considered for comparative analysis which includes operation and maintenance (O & M) cost also. The study suggests SBR as most cost-effective treatment technology and MBR most expensive among various available treatment options.

Keywords: Sewage Treatment Plant, Cost Effective Technology, Wastewater

Introduction

A cost effective treatment technology would definitely save the huge quantity of water by reusing the treated water¹. The study is focused on treatment technologies upto secondary level using biological methods which are appropriate for subtropical regions. Available statistics reveals that India inhabits 1/6th of the total world's population on 1/50th portion of the land and just with 1/25th of the total water resource². This depicts the need to treat and reuse wastewater by taking effective measures for sustainable development. The Figure 1 depicts the water usage in the year 2010 and the expected usage predicted for years 2025 and 2050 respectively. The annual per capita utilizable surface water has gone down from 1911 m³ in year 1951 to 575 m³ in year 2011, mainly because of ever rising population.³ Presently, the annual consumption by this sector is 42 km³. This is expected to increase exponentially to 90 km³ by year 2050 which would account to 9% of the total water consumption of that time^{4,5}. Sewage generation is growing with rapid urbanisation. The trend of sewage generation and treatment facility is

shown in Figure 2. Total sewage generated in 2011 from Class I and II cities 43.0 BLD while the treatment capacity of the installed STPs is only 14.5 BLD^{4,6}. In other words India currently has only facility to treat 33% of total sewage generated. It is estimated that by 2050, sewage generation quantity would be 132 BLD that can meet around 10% of total irrigation water demand^{7,8, 10}. The challenge for next decade is not only to bridge this huge gap in treatment capacity but also to develop suitable and cost-effective treatment facilities for not only wastewater treatment but its recycling also.

Methodology

The study includes wastewater treatment plant being operated in northern India. The maximum capacity of STPs in this sector is 1 MLD and most of the plants are in range of 200 to 500 KLD. All the STPs selected, are based on aerobic biological treatment process. To carry out the cost effectiveness the data of 36 small sewage treatment plants has been collected. The STPs selected are equipped up to tertiary level so that the BOD and Suspended Solids are less than 30 and 50 mg/l respectively for its reuse in non-potable purposes. An analysis of the technologies employed in these treatment plants have been enumerated in the Table 1.

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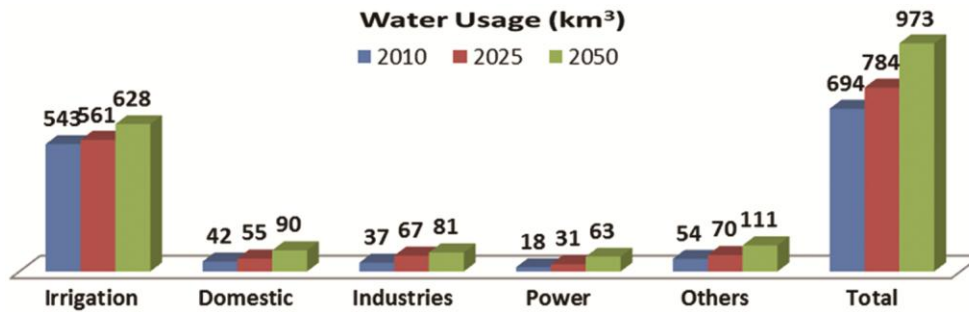
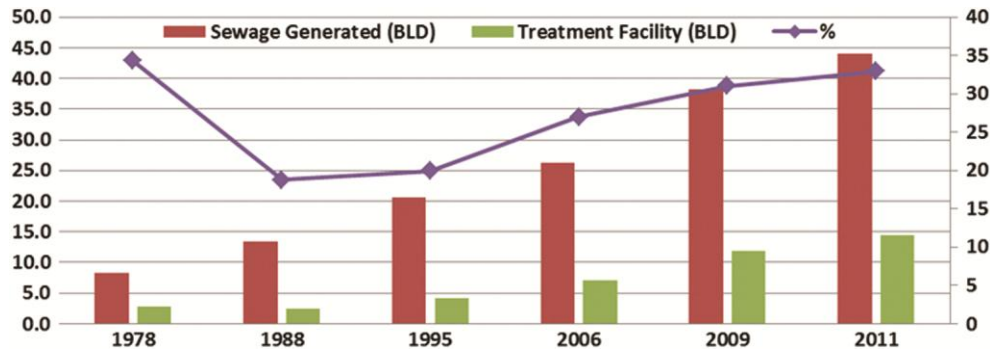
Fig. 1—Broad annual water usage pattern for India (Km³) [Source:4]

Fig. 2—Wastewater generation and treatment capacity in India [Source:3 & 9]

Cost definition

The capital cost of STP is evaluated as per Detailed Schedule of Rate (DSR) - a Central Government Guidelines (CPWD)¹¹ for estimation of construction project. The capital cost is bifurcated between civil and electro-mechanical cost.

The land cost is not considered as it varies with and within the cities. The area of requirement of STP has been analyzed to determine the footprints area of the STPs required for various technologies¹². The fixed cost includes civil construction cost of various STP units i.e equalization tank, screen, grit chamber, settling and biological reactor tanks, supernatant water tank and treated water tank for reuse and electro-mechanical cost such as piping, screen, tube media, FAB Media, MBR tubes, motor, pumps, sludge dewatering system, air blower, fine and coarse air diffusers, electrical panel, flow meter, pressure filter, activated carbon filter, disinfection system, etc. The O&M costs are based on cost of electricity, chemicals, salary of manpower and maintenance of electro-mechanical parts only. The energy cost is calculated at the rate of 10.45 Rs/kWh. Repair and maintenance for mechanical and electrical equipment are estimated on annual basis as certain percentage i.e 5% (extended aeration), 6 % (MBBR, SAFF, SBR) and 7% (MBR). The effective life of the mechanical and electrical equipments is

Table 1—Details of different treatment technologies considered for the study

Name of the Technology	Number of Plants	Plant Capacity Range (KLD)
Membrane Bioreactor (MBR)	5	50-280
Moving Bed Biofilm Reactor (MBBR)	11	50-600
Submerged Aerobic Fixed Film (SAFF)	9	40-750
Extended Aeration (EA)	5	60-750
Sequencing Batch Reactor (SBR)	6	230-600

considered as 10 years. The replacement cost was included in the repair cost. The service lives of small STP were considered as 20 years. Since all the cost was estimated as per DSR for year 2015 therefore, the price conversion for different STPs was not required. The concept of capital recovery factor present worth (PV) cost per KLD for O&M of 20 years is calculated using following equation¹³

$$PV = O\&M \times \left[\frac{1 - (1+i)^{-n}}{i} \right] \quad \dots (1)$$

Where PV is present worth cost of recurring expenditure, O&M is annual operation and maintenance cost per KLD, i is interest rate and n is service life of STPs. Total investment cost per KLD was calculated as follows

$$TIC = FC + PV \quad \dots (2)$$

Where TIC is Total investment cost per KLD, FC is fixed cost (initial capital cost) per KLD

Result and Discussion

Capital cost

Figure 3(a) shows the relationship between unit capital cost, civil cost and electromechanical cost and treatment volume for various treatment technologies. Many researchers such as Molinos¹³ Balmer¹⁴, Tsagarakis¹⁵, Nobuyuki¹⁶ and Li¹⁷ have used power equation for expressing capital cost and O & M cost of STPs,

$$\text{Cost per unit discharge} = a * (x)^b \quad \dots (3)$$

Where a, b are constant and x is capacity of STP in KLD. Therefore Eq 3 is also used in this study and the cost is worked out in Indian rupees per KLD. The capital investment cost relationship appears as

$$\text{Total capital Cost} = 2445x^{-0.33} \quad (R = 0.884) \quad \dots (4)$$

$$\text{Electro - Mechanical Cost} = 1806x^{-0.38} \quad (R = 0.787) \quad \dots (5)$$

$$\text{Civil Cost} = 721.7x^{-0.26} \quad (R = 0.833) \quad \dots (6)$$

The ratio of civil/EM cost has been found to linearly increase with the increase in capacity, for smaller STPs (50KLD) the observed value is 0.69 and for 750 KLD capacity value is observed as 1.15. The increase in the ratio clearly shows that electromechanical component of the cost decreases with the increase in the capacity. The following equation can best describe this relationship

$$\frac{\text{Civil}}{\text{Electro-Mechanical}} \text{ Cost} = 0.0005x + 0.351 \quad \dots (7)$$

The annual operation and maintainance cost

Figure 3 (b) shows relationship between annual O & M cost and Electricity cost for the treatment sewage through various STPs of this study. The following equations describe O & M cost and annual electricity cost as function of treatment capacity.

$$\text{Annual O \& M Cost} = 61359x^{-0.49} \quad (R = 0.9381) \quad \dots (8)$$

$$\text{Electricity Cost} = 4476x^{-0.23} \quad (R = 0.737) \quad \dots (9)$$

The O & M cost is the annual operation and maintenance cost per KLD. It is found to be highly sensitive in smaller capacity of STP. The annual

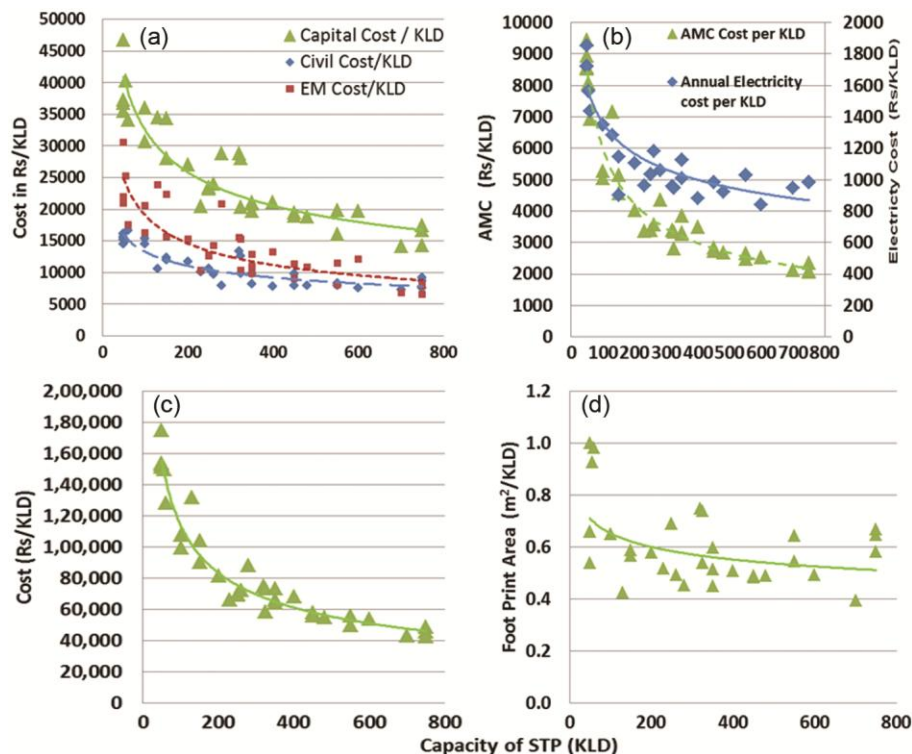


Fig. 3—Capacity of STP and various cost parameters (a) Relationship between unit capital cost, civil (b) Relationship between unit Annual O & M cost and cost and electro-mechanical cost and treatment Capacity Electricity cost and treatment Capacity of STP (c) Relationship between unit Total Investment Cost (d) Relationship between Foot print area and treatment and treatment Capacity of STP

treatment cost varies from INR 8900/KL to INR 2100/KL. The O & M cost almost decreases by 3.25 times with the increase in the STP capacity from 50 KLD to 750 KLD. The treatment cost per KLD is found to be varying exponentially in smaller range i.e. should be from 50 to 200 KLD. Annual electricity cost is found to vary from 1855 to 1063 INR per KLD. The energy cost per KLD becomes stable on STP capacity of 300 KLD and above.

Total investment cost

The variation of total investment (capital cost and present worth of annual O & M cost) is shown in Figure 3 (c). The total investment cost per KLD for the treatment of sewage varies from INR 175,000 to INR 40,000 from 50 KLD to 750 KLD capacities.

Foot print area

The foot print area requirement per KLD of discharge in m² is shown in Figure 3 (d), it is evident that the foot print area requirement varies from 1 m²/KLD to 0.48 m²/KLD. It is important to mention here that these STPs are very compactly designed therefore the foot print area is much less than the conventional municipal sewage treatment plants requirement i.e. 4 to 1.1 m²/KLD^{18,19}. All STPs have facilities up to tertiary treatment level including pressure filter, activated carbon filter and treated water storage tank. The following equation depicts the Foot print area requirement of the STPs

$$\text{Foot Print Area} = 0.867x^{-0.14} \quad \dots (10)$$

It is found that the foot print area per unit discharge becomes nearly constant with the capacity above 200 KLD. The STPs under study are small therefore the land for buildings such as warehouse, administrative building and other structures is not required.

Selection of cost effective technology

The footprints area of STP, cost of installation and O & M cost for effective life of plant are major concerns in selection of small wastewater treatment technology^{20, 21}. It was found that the variation of average footprint area for various aerobic sewage technologies was not significant less than 15%. The maximum value observed was 0.65 m² per KLD and minimum value was 0.48 m² per KLD for (MBBR, SAFF & EA) and for MBR respectively. gives a summary of average value of various types of cost per KLD for different treatment technologies. One time cost of installation is bifurcated into civil and

electromechanical. Effective life of plants is considered 20 years for calculation of the present investment requirement to meet the O & M. The maintenance cost is further trifurcated into electricity cost; cost of manpower and cost of maintenance is given in cost definition section. Highest unit cost for civil structure was found for EA and lowest cost is associated with MBR technology. Similarly, the highest unit cost of electromechanical component of STPs is associated with MBR and lowest cost is for SBR. If complete installation cost per KLD is considered then the cheapest is SBR and most expensive is MBR. The cost per KLD of MBR was around 20% higher than SBR. SBR is also found as the most energy efficient technology in comparison to others where MBBR comes out to be the least energy efficient technology. However, the energy variation is not very significant i.e. around 5% only. Operation of MBR requires more skilled and continuous monitoring in comparison to other methods. The cost of manpower is observed maximum for MBR i.e. INR 38653 per KLD. The man power cost is the least for EA i.e. INR 30042 per KLD. While comparing maintenance cost, it is found MBBR requires the least and MBR requires the highest maintenance and in terms of percentage, this 7026 difference is around 80% which is a significant value. On the basis of the overall O & M cost, MBR is most expensive to operate with a cost of INR 69763 per KLD and EA is the cheapest with a cost of INR 39110 per KLD. The cost of installation cum O & M for the effective life of STPs is also analyzed and the cost wise hierarchy found is: MBR < SAFF < EA < SBR < MBBR. The figure 4 shows the percentage wise ratio of various components of STPs cost. Minimum share of civil cost is found for MBBR whereas maximum share in terms of percentage is for MBR. Similarly, for electromechanical, minimum value is again reported for MBBR and maximum value is for MBR. In terms of initial investment all the technologies have almost

Table 2—Average value of various types of cost per KLD for different treatment technologies

Cost per KLD(INR)	MBBR	MBR	EA	SAFF	SBR
Civil	11419	9720	11510	11215	10714
Electro-Mechanical	13088	18916	14025	15610	13044
Electricity	15900	15686	15472	15771	15126
Manpower	33256	38653	30042	31720	31107
Maintenance	8398	15424	8996	10607	8864
Total Investment Cost	82062	98399	80045	84924	78856

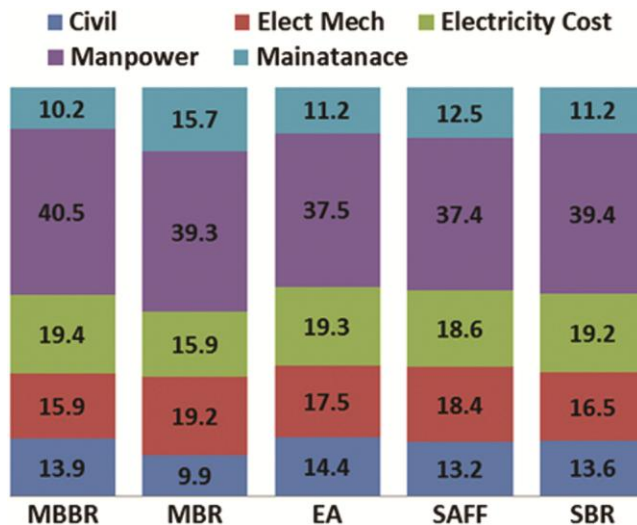


Fig. 4—Percentage wise ratio of various cost components of STP

same share varying from 29.1% to 31.9% thus, variation is not very significant.

Conclusion

The paper has evaluated low cost treatment process for discharge varying from 50 to 750 KLD and that is the range of capacity of most of the small STPs in India. Various variant of aerobic technologies such as MBBR, MBR, EA, SAFF and SBR are employed for comparative cost analysis in terms of capital and O & M. The cost-effective wastewater treatment technology has been driven by systematic evaluation of installation cost and present value of operation and maintenance cost. The present value of annual O & M cost is considered for 20 years as effective life of STPs with 5 % interest rate. The footprint area, capital cost and O & M cost per unit discharge (KLD) are expressed as the first order equation as done by most of the researchers working in the same area. MBR requires the least foot print i.e. 0.48 m² per KLD, therefore, if area is major constraint then it could be a better option. It is found from this analysis that average cost of treatment of sewage in small STP is around Rs 13 per KL. In terms of overall investment including initial investment and O & M for effective life of STP, it has been found that SBR is the most economical and MBR is most expensive. MBR as a treatment option would be 25% more expensive than SBR. As the treatment quality of effluent from SBR is superior to the rest of the variants and comparable to MBR, SBR is recommended as the most cost-effective technology for the biological treatment of sewage in India.

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