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A Life Cycle Cost Approach for Evaluation of Sewage Treatment Plants

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***Abstract*— Sewage treatment plants based on different technologies are in practice. Varied claims are being made on their performance efficiency as suitability. In most of the situations, these claims are made on the basis of evaluation of different plants in isolation. A uniform or rational basis for comparison of these plants is yet to evolve. In this study an attempt was made to evaluate the performance of the treatment plants based on UASBR, SBR and MBBR, operating under similar conditions. It was also aimed to apply the Life Cycle Cost analysis technique in making a comparative evaluation of the treatment plants. LCC analysis could be used as a potential tool for comparative evaluation of sewage treatment plants. LCC supports UASBR as the most suitable technology for sewage treatment followed by MBBR and SBR.**

***Keywords*— Life Cycle Cost; Sewage Treatment; Efficiency; SBR; UASBR; MBBR**

I. Introduction

Sewage Treatment planning is not always an easy task to accomplish. In the developing nations where ecological issues couldn't be given due importance because of budgetary imperatives, open bodies need to reconsider before making significant speculations for the same. Over the course of the years, treatment related issues are additionally getting to be lavish in light of the fact that accentuation is being given to regard wastewater as well as its reuse and reuse is likewise turning into a vital angle. Residues and by-products resulting from the treatment process are additionally being incorporated in the general wastewater administration framework. On the other hand, emphasis is also being given to clean technologies to minimize waste production [1].

A standout amongst the most essential and challenging aspects of a sustainable sewage treatment design is the examination and determination of the treatment procedures and technologies equipped for meeting the prerequisites. The procedure is to be chosen in view of obliged nature of treated water. While treatment expenses are critical, different components ought to additionally be given due thought. For instance, effluent quality, process unpredictability, process dependability, environmental issues and area necessities ought to be assessed and weighted against expense contemplations [2].

Different technologies for sewage treatment are in practice and varying claims on comparison of performance have been reported. Various studies have been carried out for comparison of different sewage treatment technologies. Singh and John had carried out comparison of UASBR and SBR technologies for sewage treatment by studying different parameters which included BOD, COD, TSS, pH and temperature. SBR showed better results than UASBR as per the treatment performance. But consideration of other factors such as power consumption and land requirement led authors to conclude that any of the two technologies can be used as per requirements and resource availability [3]. CPCB published a report with comparison of different technologies. ASP, MBBR, UASBR, SBR and WSP based STPs. SBR had shown slightly better performance, followed by MBBR and UASBR [4]. Khalil et al. had made comparison of various STPs based on technologies which included ASP, TF, WSP, UASBR, MBBR, SBR and MBR. BOD, COD, TSS and FC were parameters considered for performance evaluation. It was observed that removal of different parameters was almost comparable and was not significantly varying [1]. Tripathi and Singhal analyzed performance of two STPs based on UASBR and FAB technologies. BOD, COD and TSS were parameters considered for carrying out performance evaluation. FAB showed high TSS and BOD removal that UASBR, while higher COD removal was observed for UASBR [5].

Life Cycle Cost analysis has evolved as one of the measures for determining the suitability for use of a particular type of wastewater treatment technology. Different treatment processes can be used for any particular type of wastewater generated from any source. Most of the times the efficiency or the degree of treatment for a treatment technology may be almost similar to other technology or the difference may not be much significant. In such cases, Cost analysis may come of use as to determine which treatment process can be preferred over other. Life Cycle Cost analysis helps to evaluate the cost of a treatment technology over its design period to help determine the most suitable one. This is particularly helpful in areas where selection of wastewater treatment technology may be restricted due to financial constraints.

Among the different new wastewater treatment technologies presently in use, UASBR has risen as most practical. In numerous nations, UASBR has been used for treatment of high quality wastewater, yet in India, it has been utilized for the treatment of residential wastewater. India is one of the main nations as far as the measure of sewage volume treated by the UASBR process. It has been perceived as a standout amongst the most financially savvy and suitable sewage treatment procedure considering the natural necessities in India. At present about 37 number of sewage treatment plants based on the UASBR [4] are in operation in India.

The present study was carried out with a view to propose a rational basis for comparative evaluation of different sewage treatment processes based on different technologies. It was achieved by monitoring and comparing the performance of the STPs, evaluating and comparing the total cost involved in each of the treatment process and applying LCC analysis technique to rationalize the comparative evaluation of STPs.

II. MATERIALS AND METHODS

Chandigarh has a well planned underground network of pipes for the disposal of sewage generated in the city. As the city has same social base, quality of sewage generated is almost similar. Three sewage treatment plants based on Upflow Anaerobic Sludge Blanket (UASBR), Sequencing Batch Reactor (SBR) and Moving Bed Biofilm Reactor (MBBR) technologies were selected for the study. The treatment plants based on UASBR and SBR are located at 3BRD, while as MBBR based plant is located at Diggian, Mohali. The details of the treatment plants are specified in Table I.

Wastewater samples were collected from three treatment plants on a weekly basis during the period of study. Samples were collected in plastic bottles, preserved and taken to the laboratory as per procedures described in Standard Methods [6].
Physical and Chemical analysis of both treated and untreated wastewater was performed in accordance with procedures detailed in Standard Methods [6].

Table I
Wastewater Treatment Technologies under consideration

S.No	Location of STP	Capacity	Technology
1	Sewage Treatment Plant, 3 BRD	22.7 MLD	UASBR Based Technology
		45.4 MLD	SBR Based Technology
2	Sewage Treatment Plant, Diggian, Mohali	136 MLD	MBBR Based Technology

Life Cycle Cost

For Life Cycle Cost analysis, the cost data for different technologies was collected from the respective treatment plants. This included initial cost comprising of construction cost and equipment setup, land required and its cost, net operation and maintenance cost including electricity charges, replacement works, manpower involved, maintenance works, etc.

The total annual cost is calculated by using the following equation [1],

$$TAC = (CRF \times IC) + OMC \qquad (1)$$

Where,
TAC = Total Annual Cost, CRF = Capital Recovery Factor, IC = Initial Cost (e.g., for Capital, Land), OMC = Operation and Maintenance Cost

The economic life of STP and annual rate of interest have been considered as 30 years and 12 % respectively
Life Cycle Cost for n years can be calculated by using following equation

$$F = A\left[\frac{(1+i)^n - 1}{i}\right] \qquad (2)$$

Where,
F = total cost at end of n years, A = Uniform Annual Cost, n = design period in years, i = annual rate of interest

III. RESULTS AND DISCUSSION

The performance of the Sewage Treatment Plants was evaluated over a period of 4 months. The various parameters which were monitored included BOD, COD, Total Suspended Solids, Nitrates and Coliform Reduction. The removal efficiencies in respect of the mentioned parameters for each of the treatment plant were calculated and analyzed on a weekly basis.

A. Characteristics of Influent

The variation in the characteristics of influent with respect to BOD, COD and Total Suspended Solids for the three STPs is depicted in table II. It was observed that the influent for all the three plants had almost similar characteristics. The variation in BOD ranged from a maximum of 310 mg/L to a minimum of 210 mg/L and the COD varied from 950 mg/L to 420 mg/L. The pH varied from 6 to 8, while suspended solids varied from 400 mg/L to 150 mg/L.

Table II
Variation of BOD, COD and TSS in influent

	Influent BOD (mg/L)			Influent COD (mg/L)			Influent TSS (mg/L)		
Weeks	**SBR**	**UASBR**	**MBBR**	**SBR**	**UASBR**	**MBBR**	**SBR**	**UASBR**	**MBBR**
1	259.3	241.26	211.14	640	720	500	310	320	260
2	280.4	240.4	255.4	800	720	592	220	250	270
3	283.23	285.1	275.1	576	680	512	200	280	320
4	248.92	301.2	301.2	816	740	740	220	310	280
5	270	265	275	704	640	500	210	290	290
6	285	253.01	307.22	760	800	580	240	260	260
7	295	280.2	270.2	730	780	640	400	375	265
8	303.25	283.13	240.96	720	660	540	240	290	200
9	289.45	270.3	211.14	800	608	416	210	330	150
10	259.03	283.13	210.84	592	840	420	210	220	246
11	289.15	240.96	246.98	870	900	800	270	170	140
12	278	260	260	940	950	940	260	160	220
13	284.15	310	303.35	752	940	890	240	120	260

B. Process Efficiency

The process efficiency of the entire system was evaluated by comparing the characteristics of the influent and effluent from the plant. The process efficiency was evaluated based on the following monitoring parameters:

1) *Biochemical Oxygen Demand*: BOD percentage removal was calculated for the three STPs during the period of study. Table III shows the percentage removal of BOD for all STPs. The average removal percentages were 88.58%, 81.58% and 79.32% for SBR, UASBR and MBBR respectively.

2) *Chemical Oxygen Demand*: Table III shows the variation of percentage removal for COD in three treatment plants during the course of study. The average removal percentages were 71.75%, 69.2% and 74.36% for SBR, UASBR and MBBR respectively.

3) *Total Suspended Solids*: Table III shows the percentage removal for TSS in three treatment plants during the study period. The average percentage removal was 88.74%, 91% and 90% for SBR, UASBR and MBBR respectively.

Table III

Percentage removal of BOD, COD and TSS for three STPs.

	BOD Removal			COD Removal			TSS Removal		
Weeks	**SBR**	**UASBR**	**MBBR**	**SBR**	**UASBR**	**MBBR**	**SBR**	**UASBR**	**MBBR**
1	85.223	88.57	74.28	57.5	77.77	77.6	89.09	94.37	92.3
2	89.048	83.44	80.26	60.5	64.44	77.02	86.358	90	93.33
3	88.075	89.59	80.13	77.773	77.05	73.43	88	92.5	93.43
4	87.068	86.42	81.38	81.125	71.35	76.75	89.428	92.9	93.92
5	88.858	87.76	79.48	75.28	75	79.2	86.783	91.37	91.03
6	89.18	84.19	82.09	77.1	71.5	83.44	87.915	91.92	88.46
7	89.73	82.79	81.42	75.89	79.23	80	90.63	94.93	86.41
8	90.875	77.1	73.09	69.69	76.96	77.77	88.328	93.44	91
9	89.89	68.5	64.69	64.33	51.31	61.5	86.66	95.75	92

10	84.84	75.98	70.59	65.198	61.9	58.09	88.45	93.18	87.02
11	86.97	78.41	75.7	69.513	57.55	73.33	92.67	93.52	90.71
12	86.155	78.84	73.68	77.015	66.31	74.46	91.05	87.5	86.36
13	95.635	79.03	75.45	81.9	69.23	74.19	88.32	84.16	84.61

4) Total Coliform: Coliform reduction efficiency of the sewage treatment plants was determined by calculating log reduction by comparing coliforms present in influent and effluent. Table IV shows the log reduction of Total Coliforms in different sewage treatment technologies.

Table IV

Performance of Sewage Treatment Plants- Coliform Reduction

	SBR	**UASBR**	**MBBR**
Inlet	3×10^8	2×10^8	3×10^8
Outlet	9×10^4	3×10^5	2×10^4
Log Reduction	3	3	4

5) *Nitrates:* Table V shows the influent concentration of nitrates and removal efficiency for STPs. For SBR, average percentage removal of nitrates is 46.56%, while as for UASBR and MBBR it is 39% and 61.77% respectively.

Table V

Nitrate removal for all STPs

	Influent Nitrate (mg/L)			**Nitrate Removal (%)**		
Weeks	**SBR**	**UASBR**	**MBBR**	**SBR**	**UASBR**	**MBBR**
1	4.8	6.2	6.9	43.75	38.7	66.66
2	4.9	5.9	6.2	51	38.98	58.06
3	5.4	6	6.3	44.44	35	58.73
4	5.1	6.1	6.6	47.05	40.9	63.63

In the present study, the BOD removal efficiency varied in the order SBR > UASBR > MBBR. The COD removal was in the order MBBR > SBR > UASBR. The TSS removal efficiency followed the order UASBR > MBBR > SBR. The nitrates removal efficiency was in the order MBBR > SBR > UASBR. Therefore, it is implied that comparison of removal efficiencies of the individual parameters in these reactors may not yield reliable information for decision making. As such, choice of the suitability of these reactors cannot be made solely on the basis removal efficiencies in respect of individual parameters.

C. Life Cycle Cost Analysis

As mentioned, the performance evaluation is not alone sufficient for the comparison of different sewage treatment technologies. Life cycle cost (LCC) analysis has been largely applied as a tool to evaluate the best cost effective alternative among various alternatives to achieve the lowest long term cost of ownership. The net worth investment cost analysis was done on actual existing plants based on the available information. This analysis was followed by LCC analysis to determine life cycle cost for each of the STP on the basis of standard requirements of each technology.

Table VI presents the net worth investment cost for three technologies per MLD basis for business as usual conditions of the STPs.

Table VI

Net worth Investment per MLD of the STPs

S No	**Parameter**	**Unit**	**SBR**	**UASB**	**MBBR**
1	Land Area used	acres/MLD	0.12	0.48	0.09
2	Capital Cost	crores/MLD	0.7	0.26	0.21
3	Biogas Generation	m^3/d	-	312	-
4	Annual Power Cost	crores/MLD	0.0312	0.0052	0.019
5	Annual O&M cost (including recurring, chemical, manpower costs, etc.)	crores/MLD	0.6	0.203	0.6
6	Total Annual O&M cost	crores/MLD	0.63	0.208	0.6
7	Average Land cost (per acre)	Crores	11	11	11

8	Cost of Land	crores/MLD	1.32	5.28	0.99
9	Unit Capital cost including land	crores/MLD	2.02	5.54	1.2
10	Annual Interest	Percent	12	12	12
11	Economic Life	Years	30	30	30
12	Capital Recovery Factor (CRF)		0.124	0.124	0.124
13	Total Annual cost	crores/MLD	0.88	0.894	0.74
14	Present Discount Factor		8.06	8.06	8.06
15	**Net Present Worth of Investment Cost**	**crores/MLD**	**7.09**	**7.2**	**5.96**

It is observed that the present net worth investment cost of UASBR is the highest among all the reactors, which is in contradiction to previous studies ([1],[2],[4],[7]). The highest cost of UASB can be attributed to the fact that per MLD land provided in the present case was very high as compared to standard requirement as prescribed by CPCB [4] The LCC analysis for the three technologies per MLD basis is done as per standard area requirements as proposed by the CPCB [4] using the formula explained in (1) above. Table VII presents the LCC analysis.

Table VII

LCC per MLD basis as per standard area requirements

S No	Parameter	Unit	SBR	UASB	MBBR
1	Average Area Required	acres/MLD	0.13	0.26	0.13
2	Capital Cost	crores/MLD	0.7	0.26	0.21
3	Biogas Generation	m^3/d	-	312	-
4	Bio energy Generation*	kWh	-	187	-
5	Annual Power Cost	crores/MLD	0.0312	0.0052	0.019
6	Annual O&M cost (including recurring, chemical, manpower costs, etc.)	crores/MLD	0.6	0.203	0.6
7	Total Annual O&M cost	crores/MLD	0.63	0.208	0.6
8	Average Land cost (per acre)	crores	11	11	11
9	Cost of Land	crores/MLD	1.43	2.86	1.43
10	Unit Capital cost including land	crores/MLD	2.13	3.12	1.64
11	Annual Interest	percent	12	12	12
12	Economic Life	years	30	30	30
13	Capital Recovery Factor (CRF)		0.124	0.124	0.124
14	Total Annual cost	crores/MLD	0.89	0.59	0.8
15	Present Discount Factor		8.06	8.06	8.06
16	**Net Present Worth**	**crores/MLD**	**7.17**	**4.75**	**6.44**
17	**Life Cycle Cost for 30 years**	**crores/MLD**	**214**	**142**	**193**

*$1m^3$ CH_4 can generate about 0.6 kWh of electricity [1]

D. Discussion

It is observed that on the basis of prevalent conditions and actual area provided, the UASB based treatment plant shows highest cost requirement per MLD as compared to SBR and MBBR based plants. However, it is in contradiction to previous studies which have shown UASB as more cost effective than the other two technologies. Khalil et al. had compared different sewage treatments plants based on ASP, WSP, UASB, MBBR, SBR and MBR on the basis of LCC. It was observed that among UASB, SBR and MBBR, lowest cost requirement was shown by UASB, followed by MBBR and SBR [1]. NGRBA prepared a report comparing treatment costs of various treatment plants including UASB, MBBR and SBR. The results showed that UASB based STP had least cost requirements, followed by SBR and MBBR [2]. CPCB indicated the following order in case of life cycle cost for STPs: UASB < SBR < MBBR [4].

In the present study also, when the standard conditions, especially the land area required for each of the process, were used in the calculation, it was found that the UASB based plant showed least cost required per MLD, which is in accordance with the prevalent studies.

The land area in use for SBR and MBBR based treatment plants is almost equal to that prescribed as standard requirements. It is also observed that a certain portion of energy requirements is fulfilled in case of UASB process due to bio gas generation. This is another factor contributing to lower the operation costs for UASB process.

IV. CONCLUSIONS

In this study, attempt was made to generate a rational basis for comparison of STPs based on SBR, UASBR and MBBR. The performance of all the STPs in respect of removal of different monitoring parameters such as BOD, COD and TSS was almost comparable and were not significantly varying. As such, comparison of the treatment efficiencies in respect of the removal efficiencies of routine monitoring parameters may not provide sufficient information which will facilitate their selection or choice.

LCC could be considered as a potential tool for the comparison of the STPs under similar working conditions. In the study area, due to larger land area provided to the UASB reactor, it was found to be having the highest net worth investment cost. Life Cycle Cost analysis based on the standard land area requirement for all the technologies indicated the cost comparison as UASB < MBBR < SBR.

On basis of the results of the study, it can be concluded that UASB is the most suitable technology for sewage treatment for given conditions, followed by MBBR and SBR.

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