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DESIGN, DEVELOPMENT AND ECONOMIC EVALUATION OF SMALL AND DECENTRALIZED WASTE WATER TREATMENT SYSTEM

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Abstract: Rapid urbanization, population growth and limited land availability increased the global issue of water crises and wastewater disposal method. In the present study, Fluidized Aerobic Biological treatment (FAB) system based sewage treatment plant was designed scientifically and installed in the 50 sites of 7 tsunami affected districts of Tamil Nadu, India using modular design principle. FAB is an advanced technology which is a combination of attached and suspended growth process and fluidized condition is maintained in the reactor by providing diffused aeration from the bottom of the reactor. The installed STP consists of high rate FAB reactor and tube settler forms heart of the treatment system to remove organic and suspended solids. The STPs were designed in 8 modules of capacity 55, 75, 100, 150, 200, 250, 300, 450 KLD based on standard design criteria and engineering consideration of the sites. The total area requirement varied 0.64-0.746 m^2/KLD which is 6 times lesser than conventional methods. Economic evaluation was done for all the installed modules in 50 sites so as to access and validate the cost effectiveness of the FAB reactor. The cost and economic analysis indicated that capital cost, recurring cost and total cost of treatment per KLD varied Rs.13, 620-23,980, Rs.384-880 and Rs.14, 094-24,575 respectively. The civil, electro-mechanical and operation and maintenance cost contributes to 50-72%, 26-50% & 2-4% of the total treatment cost respectively. The performance evaluation of installed STP at these 50 sites indicated the removal efficiencies of TSS, BOD & COD varied 83-85%, 92-93% and 74-80% respectively. A computer aided design package was designed and developed for cost estimation and performance evaluation of the mathematical model formulated to predict the STP cost using statistical analysis. The models formulated indicated that the accuracy was good (99%) and the error was less for electro-mechanical cost model (0.017 lakhs) followed by civil cost model (0.529 lakhs).

Key words: Fixed-film biological reactor, Moving bed biological reactor, Conventional treatment methods, Performance evaluation, Modular design, Lamellar flow tube settler, Tube settler, Design package, Mathematical cost model

INTRODUCTION

Safe water supply and hygienic sanitation facilities are the two basic essential amenities the community needs on a top priority for healthy living. Wastewater generation in India is increased from 7,000 MLD in 1978 to 35,558 MLD in 2008 in class I cities (CPCB, 2009). As of 2003, it was estimated that only 30% of India's wastewater was treated and the rest 70% finds its way to local rivers and streams contributing to water pollution. In addition to this, occurrence of natural disasters also contributes to sanitation problem and environmental pollution. Providing environmentally safe sanitation to millions of people in India is a significant challenge, especially in the world's second most populated country.

Tsunami a natural disaster hit the southern Indian Ocean on December 24, 2004, affecting the entire coastal area of Tamil Nadu (1076 km). About 154,000 houses were damaged of which 80% belonged to fishers (ADB, 2005). In order to overcome the sanitation issue and to safe guard the coastal area from environmental pollution, Government of Tamil Nadu scientifically designed a cost effective and sustainable Fluidized Biological Reactor (FAB) based Decentralized Wastewater Treatment (DWWT) system in 8 modules of capacity 55, 75, 100, 150, 200, 250, 300, 450 m^3/day (KLD) to treat the sewage generated from the tsunami affected 50 sites covering the 7 districts of Nagapattinam, Cuddalore, Villupuram, Kancheepuram, Tirunelveli, Kanniyakumari and Toothukudi (Fig. 1). The STPs were designed to meet the effluent discharge standards to effectively utilize the treated effluent thereby reducing the water crises.

There are many conventional wastewater treatment methods but they require relatively large capital investment, large area, power intensive and require a lot of monitoring (Helen, 2008). Since, the sites were along the coastal area there was a need for compact, low cost and efficient treatment method which could be achieved through decentralized approach defined as collection, treatment, and disposal/reuse of wastewater at or near the point of waste generation. In addition, decentralized treatment system and modular installation reduces the sewage transportation cost significantly (NEERI, 2008).

The objective of the study is to design a scientific, compact, cost effective and efficient STP to treat the sewage generated from housing clusters constructed for tsunami affected areas to provide a well planned wastewater management system along the coastal area with an option to reuse the treated effluent. The study also includes formulation and evaluation of a mathematical model using statistical analysis for predicting civil, electro-mechanical and operation & maintenance cost for FAB based decentralized STP to validate the cost effectives of the treatment method.

METHODOLOGY

Selection of STP capacity

The prime importance in the design of a sewage treatment plant is to estimate the capacity of the STP to be designed. The volume of sewage generated for all the 50 sites was quantified directly by a flow meter. The capacity of the STP was estimated based on the quantity of sewage generated.

Wastewater Characteristics

Assessing sewage characteristic is essential for the choice of treatment method, extent of treatment, beneficial use of the wastewater and cost of treatment required (Ross, 2000; Rao, 2007). Samples of raw sewage were collected from all the 50 sites for determination of pH, TSS, TDS, TS, BOD & COD as per standard methods (APHA, 2005). Sampling was carried out in 3 stages consisting of one week for each

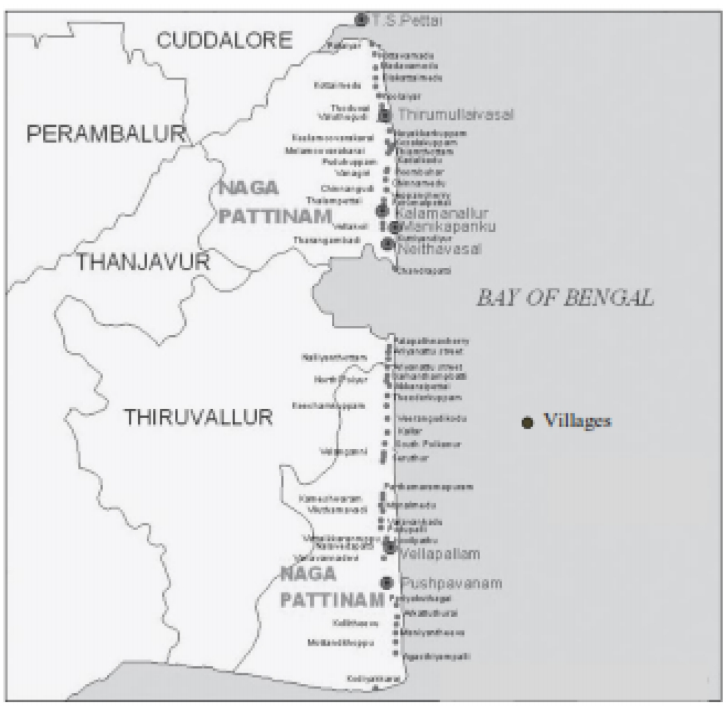

Fig. 1. Location of STP sites

stage. First stage of sampling was done for a week followed by second stage of sampling after a month interval and third stage of sampling after 2 months.

Design of STP

Once the sewage characteristic is assessed suitable cost effective and economical treatment method must be chosen for designing a STP. Since all the 50 sites in the study were distributed along the coastal area, it was decided to go in for DWWT method. DWWT method is preferred as compared to conventional centralized treatment system, since it enhances sewage treatment near the points of generation, thereby avoiding the sewage transportation cost (Lens, 2001).

Nagapattinam district which includes 30 sites was divided into 3 clusters and each cluster was provided with one STP. The cluster installation was done to minimize the sewage transportation and maintenance cost. For all the other 6 districts each village was provided with individual STP and they were designed in modular basis since it is cost effective and self contained. Modular installations are relatively compact and transportable units and are ideal for use in remote location and require less installation. Most importantly modular design was done to optimize the organic and hydraulic loading rate of the treatment system. In addition, the prime advantage of modular design is that it can be easily added to the existing module at the time of increase in the sewage generation volume so as to achieve the maximum design efficiency in terms of organic and hydraulic loading rate.

Design of Fluidized Aerobic Biological Reactor

The raw sewage generated from the households were processed through preliminary treatments and pumped into FABR (aeration tank), using submersible sewage pumps, wherein the aerobic microbes attached to the media in the reactor utilizes the biodegradable organic pollutant in presence of oxygen there by reducing BOD/COD. The free, molecular oxygen required is provided through air grid supplied by air blower.

The dead biomass along with treated wastewater flowed by gravity into tube settler tank, wherein solid-liquid separation was achieved. Tube settlers are high rate settlers of the inclined surface or shallow settling type. The settlers use inclined tubes to divide the depth into shallower sections. Thus, the depth of all particles (and therefore settling time) was significantly reduced. These clarifiers provide a large surface area reducing clarifier size. No wind effect exists, and the flow was laminar. Tubes are circular, square, hexagonal, or any other geometric shape and were installed in an inclined position within the basin. Tubes were commonly inclined steeply (55^0) to horizontal and fabricated in modules.

The solids separated were pumped to the sludge drying bed for further volume reduction. The treated supernatant dosed with sodium hypochlorite through and was allowed to react in chlorine contact/filter feed tank prior to further polishing. The treated wastewater then pumped with filter feed pump through dual media filter & activated carbon filter prior to suitable reuse like gardening and toilet flushing. The dead biomass was separated and transferred periodically into the sludge drying bed wherein mass reduction occurs. The dried sludge was further removed periodically and used as a fertilizer for plants.

Design Criteria used for STP Design

Design criteria are guideline values used for designing new wastewater treatment facilities. Choosing the design criteria depends on the engineering conditions like topography of the area, hydraulic head, ground water depth and its seasonal variations, soil bearing capacity, type of strata expected to meet in the construction and these data are obtained from field studies. The treatment units were designed based on the standard design criteria according to the field conditions of the sites (NEERI, 2008).

Computer aided design for STP

A computer aided design for STP was developed for treatment plant design, cost estimation and detailed statistical evaluation of the model developed. It comprises of design package in excel platform for sizing the different units of STP. Design criteria, raw sewage characteristic, sewage volume, topography of the area were used as the input data.

Performance evaluation of the STP

Performance evaluation of the STP was carried for all installed STPs in the field by collecting influent and effluent samples periodically from the inlet and outlet of the constructed STP.

Cost estimation

Cost estimation was carried for justifying the cost effectiveness of the FAB based STP in terms of civil, electro-mechanical and operation & maintenance cost. The total cost of STP involves capital cost, operation & maintenance cost and recurring & non-recurring cost. Capital cost was estimated based on the dimensions of the unit processes, i.e. volume, surface area and on an estimated in place material cost. (Duggle, 2007).

Mathematical model formulation

Mathematical model was formulated for predicting the relation between cost and the capacity of the FAB based STP. The cost and treatment capacity are often expressed by the following power equation (Tsagarakis *et al.*, 2003; Guleda and Ibrahim, 2006).

$$y = ax^b$$

where, 'y' is the STP cost, 'x' is the capacity of the STP and 'a, b' are the constants.

Prediction of cost for wastewater treatment system could be influential for accessing the economic feasibility of various level of water pollution control program. This model could pave as a platform for planning and estimating the cost required for different treatment capacities.

Model performance evaluation

The evaluation of model formulated is a matter of great interest and it becomes particularly important in all those fields in which modeling is used as a decision making tool. Evaluation focuses on assessing the accuracy of the formulated model. Statistical analysis was carried out to evaluate the model performance included the calculation of observed mean $\overline{O}$, predicted mean $\overline{P}$, mean fractional bias (MFB), mean fractional error (MFE), observed and predicted standard deviation ((σ_o, σ_p), fractional bias (FB), mean square error (MSE) and its components, the mean systematic error (MSEs) and mean unsystematic error (MSEu), correlation coefficient γ, regression coefficients a, b and index of agreement 'd'. These statistical parameters along with target and model efficiency score (MES) was calculated to assess the model performance based on the field data collected from the constructed STPs in the 50 sites.

Willmot and Wicks (1980) and Willmot (1982) observed that small differences in observed O_i and predicted P_i cost would result in negative ã. Hence, they recommended the use of index of agreement d and root mean square error (RMSE), which indicates the accuracy and error involved in the prediction, respectively. For ideal model, the value of d should be equal to 1 and RMSE equal to zero.

RESULTS AND DISCUSSION

Modular design

The quantity of sewage generated was calculated as discussed in section 2.1. Since, there were 50 sites it was difficult to provide different modular capacity for each site. In order to overcome this problem, the 50 sites were grouped under 8 modular capacities of 55, 75, 100, 150, 200, 250, 300, 450 KLD based on quantity of sewage generated as given in Table 1

Maximum number of STP was installed in the module of capacity 55 KLD in 17 sites followed by 100 KLD in 10 sites, 75 KLD in 8 sites, 200 KLD in 5 sites, 150 KLD in 4 sites, 250 KLD in 4 sites , 300 & 450 KLD in one site each. The maximum quantity of sewage generated was 3450 KLD from Nagapattinam district. Among the 30 sites in Nagapattinam district the sewage generated varied 44-308 KLD. The sewage generated from Thoothukudi district was only 57 KLD.

Sewage characteristics

Physico-chemical characteristic of the sewage confirmed the sewage as medium strength as BOD varied from 208-220 mg/l. The pH value of 8.48 indicates alkaline nature of the sewage. Average BOD and COD from the 50 sites were 204 mg/l and 530 mg/l with BOD/COD ratio of 0.522 indicating that the sewage is biodegradable.

Table 1. Quantity of sewage generated and their corresponding module capacity

S. No	Name of Village	No. of houses connected	Sewage generated, KLD	Module capacity, KLD
	Nagapattinam District, Total quantity: 3450 KLD			
1.	Samanthanpettai	340	122	150
2.	Akkaraipettai	800	176	200
3.	Vailankanni	443	71	75
4.	Sathangudi	1100	300	300
5.	Perumalpattai	275	61	75
6.	Pudupattinam	1024	225	250
7.	Thirumullaivasal	470	103	150
8.	Pudupettai	225	50	55
9.	Pandagasaalai	206	55	55
10.	Arcottuthrai	369	100	100
11.	Nambiyar	600	216	250
12.	Chandrapadi	276	55	55
13.	Saveriyarkoil	602	169	200
14.	Vanagiri	550	121	150
15.	Pappakovil	255	55	55
16.	Sellur	850	187	200
17.	Poompuhar	730	161	200
18.	Thirumullaivasal	386	85	100
19.	Andanapettai	200	44	55
20.	Nambiyar Nagar	202	73	75
21.	Kizhapattinachery	796	223	250
22.	Panangudi	266	55	55
23.	Kameshwaram	210	46	55
24.	Thideerkuppam	426	94	100
25.	Vanavanmahadevi	200	44	55
26.	Vellapallm	232	51	55
27.	Chinnangudi	432	95	100
28.	Madavamedu	200	44	55
29.	Keechankuppam	800	224	450
30.	Seruthur	434	122	200
	Cuddalore District, Total quantity: 390 KLD			
31.	Devanampattinam	648	233	250
32.	Chellankuppam	436	157	150
	Villupuram District, Total quantity: 367 KLD			
33.	Eggiyarkuppam	216	60	75
34.	Panichamedu	200	44	55
35.	Koonimedu Kuppam	250	55	55
36.	Kilputhupattu	231	51	55
37.	Bommaiyarpalayam kuppam	260	55	55
38.	Chinnamudaliyarchavadikuppam	354	99	100
	Kancheepuram District, Total quantity:65 KLD			
39.	Muttukadu	202	32	55
40.	Paramankeni	202	32	55
	Tirunelveli District, Total quantity:335 KLD			
41.	Koottapanai	244	68	75
42.	Idinthakarai	450	100	100
43.	Perumanai	202	55	55
44.	Koothankuzhi	300	84	100
	Kanniyakumari District, Total quantity:400 KLD			
45.	Colachel 1	353	99	100
46.	Colachel 2	249	70	100
47.	Kadiapattinam	313	88	100
48.	Needakara	264	74	75
49.	Thengamputhoor	249	70	75
	Thoothukudi District, Total quantity:57 KLD			
50.	Mappilaiyurani	202	57	75
	Total quantity of sewage generated is 4750 KLD from 50 sites in 7 districts			

Table 2. Design criteria used for STP design

Sl.No	Parameter	Value
1.	Screen chamber (fine screen)	
	• Velocity, m/min	2.0
	• Head loss, m	0.8
	• HRT, min	3.0
	• Peak factor	3.0
2.	Grit chamber	
	• Detention time, s	60
	• Horizontal velocity, m/s	0.3
	• Diameter of the Particle removed, mm	0.15
	• Specific gravity of the particle	2.65
	• Peak factor	3
3.	Oil and grease trap	
	• HRT, min	30
	• Peak factor	3
4.	Collection tank	
	• Hydraulic Retention time, hrs	3
5.	Fluidized Aerobic biological reactor	
	• Organic loading rate, kg BOD @ 20 ºC m^3.d	1.0
	• Oxygen required, kg/kg BOD	2.5
	• Oxygen transfer efficiency, %	12
	• Specific gravity of element	0.9-0.93
	• Element required	30% of tank volume
	• Sp. gr. of air @ 30 Deg	1.165
6.	Tube settler	
	• Surface loading rate, m^3/ m^2.d	20
	• Tube inclination, degree	55
	• Tube shape	Rectangular
7.	Sludge Drying bed	
	• Area of sludge drying bed, m^2/capita	0.03
	• Sludge removal cycle, days	10
	• Depth of sludge provided, m	0.3
	• Depth of sand layer, m	0.15
	• Depth of gravel layer, m	0.2
	• Drain pipe diameter, mm	200

Design of STP

FAB based modular STP was designed based on standard design criteria listed in Table 2. The raw sewage generated from each village was processed through preliminary treatment followed by biological and tertiary treatment (Fig. 2). The dimensions of different units of STP including FAB are tabulated in Table 3.

The installed FAB was rectangular shaped with an average height of 4.5 m. The reactor was filled with polypropelene carrier media occupying 30% of the total tank volume. The carrier media used offered an effective surface area ranging 200-500 m^2/m^3 for different shaped media. The reactors were designed for 9-12 hrs HRT and fluidized condition was maintained by providing diffused aeration at the rate of 15 m/s thereby enhancing effective oxygen transfer efficiency by allowing the sewage in full contact with the media up on which the microbes are immobilized.

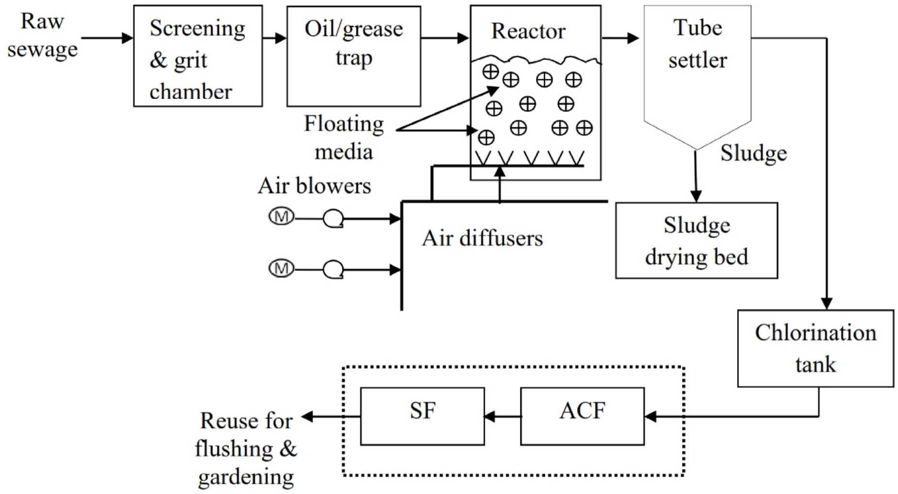

Fig. 2. Schematic diagram for FAB based STP

During fluidization operation, the carrier media expands to accommodate microbial growth. The higher the surface area for the biomass to grow higher will be the concentration of active bio-mass per unit volume of the reactor. Return sludge which is indispensable for the activated sludge process was not required enabling extremely easy maintenance control.

The total area required for FAB based STP including all preliminary units varied 6.40-7.46 m^2/KLD for 55-450 KLD, with land requirement of 0.7 m^2 per KLD. On an average, FAB reactor alone occupies an area of 0.087 m^2/ KLD and it varied 0.075-0.095 m^2/KLD. This contributes to an average of 12.6% of the total area ranging 11%-13%.The high rate tube settler occupies an area of 0.043-0.058 m^2/KLD which constitutes 7-8% of the total area required. This proves that FAB based STP requires 6 times lesser land than conventional treatment methods.

Performance evaluation of constructed STP

The removal efficiency of the FAB reactor in terms of TSS varied 83-85%, whereas for BOD 92-93% and COD 74-80% respectively. High rate of treatment efficiency within a short HRT was due to high surface area provided to the microbes, high organic loading rate and the diffused aeration provided through bottom of the STP. As compared to conventional methods FAB's efficiency is high and consistent irrespective of the climatic conditions since the system is compact and highly controlled.

Cost estimation

Cost estimation indicated the capital cost varied Rs. 1,174,360-Rs.7,046,950 and the total treatment cost varied Rs. 12,22,870-72,20,080 (Table 4). The operation & maintenance cost varied Rs. 48,500-173,130 per annum. The increase in the capacity of STP corresponds to a decrease in capital cost, annual O&M cost and total treatment cost per m^3 of sewage because of the larger STP capacity. The civil, electro-mechanical and operation & maintenance cost contributes to 50-72%, 26-50% & 2-4% of the total treatment cost for the modules of 55-450 KLD.

Mathematical model

The mathematical model formulated for cost estimation as per the procedure outlined in section 2.9 for civil units, electro-mechanical and operation & maintenance cost is given below.

Plant civil cost model

Plant civil cost model was constructed with modular STP capacity in x axis and corresponding actual civil cost in y axis as shown in Fig. 3.

$$y = 0.176\, x^{0.893}$$

where x denotes the capacity of the STP in KLD and y denotes the civil cost in lakhs.

Table 3. Computer aided design details of STP

units	Capacity of the modules, KLD							
	55	75	100	150	200	250	300	450
Screen chamber (Screening of coarse solids)								
Size, m	1.0x 0.30x 0.4 LD[a] + 0.2 FB[b]	1.1 x 0.4x0.4LD + 0.2 FB	1.2 x 0.5 x0.4 LD + 0.2 FB	1.3 x 0.3 x 0.3 LD +0.2 FB	1.2 x 0.35 x 0.4 LD +0.2FB	1.4 x 0.4 x 0.4 LD + 0.2FB	1.5x0.45x 0.5 LD + 0.2FB	1.6 x 0.5 x 0.5 LD + 0.2 FB
Grit chamber (Removal of inorganic solids)								
Size, m	2.0 x 0.25 x 0.3 LD + 0.2 FB	2.0 x 0.3 x 0.3 LD + 0.2 FB	2.4 x 0.3 x0.3LD + 0.2 FB	3.0 x 0.3 x 0.3 LD +0.2 FB	3.5 x 0.4 x 0.30 LD + 0.2FB	3.7 x 0.4 x 0.35LD + 0.2FB	4.2 x 0.45 x 0.4 LD + 0.2 FB	5.0 x 0.5 x 0.5 LD + 0.2 FB
Oil and grease trap (Removal of free floating oil & grease)								
Size, m	2.0 x 1.0 x 1.0 LD + 0.5 FB	2.0 x 1.0 x 1.0 LD + 0.5 FB	2.4 x 1.2 x 1.0 LD + 0.5 FB	3 x 1.5 x 1.0 LD + 0.5FB	3.5 x 0.4 x 0.30 LD + 0.2FB	3.0 x 1.5 x 1.5 LD + 0.5FB	2.9 x 1.4 x 2 LD + 0.5 FB	3.5 x 1.8 x 2.0 LD+ 0.5 FB
Collection tank (Collection by gravity and pumping downstream)								
Size of the tank, m	3.4 x 2.0 x3.0 LD+ 0.5 FB	3.1 x 3.0 x 3 LD + 0.5 FB	3.6 x 3.5 x3 LD + 0.5 FB	5.5 x 3.5 x3 LD + 0.5 FB	5.6 x 4.5 x3.0 LD + 0.5 FB	6.9 x 4.50 x3 LD + 0.5 FB	7.5 x 5.0 x 3 LD + 0.5FB	5.4 x 7.0 x 3 LD+ 0.5 FB
FABR (aeration tank)								
Size of the tank, m	2.6 x 2.0 x 4.0 LD + 0.5 FB	2.8 x 2.5 x 4.0+0.5FB	3.1 x 3 x 4.0+0.5FB	4.0 x 3.5 x 4.0+0.5FB	4.8 x 3.5 x 4.5+ 0.5FB	5.2 x 4.0 x 4.5 LD + 0.5 FB	5.0 x 5.0 x 4.5+0.5FB	5.6 x 6.0 x 5.0+0.5FB
Air blower capacity required, m^3/hr @ 0.5 kg/cm^2	60	80	100	149	200	250	300	440
Tube settler (Removal of fine inorganic particle)								
Size of the	1.6 x 2.0 x	1.7 x 2.5 x	1.8 x3.0 x 4.0	2.3 x 3.5	3.0 x 3.5 x 4.5	3.3x 4.0 x	3.1 x 5.0 x	3.8 x 6.0 x

settling tank, m	4.0 LD +0.5 FB	4.0 LD + 0.5 B	LD + 0.5 FB	x 4.0 LD + 0.5 B	LD + 0.5 FB	4.5 LD + 0.5 FB	4.5 LD + 0.5 FB	5.0 LD + 0.5 B
Tube modules dimension, m	1.6 x 2.0 x 0.6 ht.	1.7 x 2.5 x 0.6 ht.	1.8 x 3.0 x 0.6 ht.	2.3 x 3.5 x 0.6 ht.	3.0 x 3.5 x 0.6 ht.	3.3 x 4.0 x 0.6 ht.	3.1 x 5 x 0.6 ht.	3.8 x 6.0 x 0.6 ht.
Tube inclination, Deg.	55	55	55	55	55	55	55	55
Tube shape	Rectangle	Rectangle	Rectangle	Rectangle	Rectangle	Rectangle	Rectangle	Rectangle
Sludge drying bed								
Size, m	4.8 x 4.8 x 0.65 LD + 0.1 FB	5.6 x 5.6 x 0.65 LD + 0.1 FB	6.3 x 6.3 x 0.65 LD + 0.1 FB	7.5 x 7.5 x 0.65 LD + 0.1 FB	8.8 x 8.8 x 0.65 LD + 0.1 FB	10 x 10 x 0.65 LD + 0.1 FB	11 x 11 x 0.65LD+ 0.1 FB	13.6 x 13.6 x 0.65 LD + 0.1 FB
Mechanical and electrical equipment								
Sewage feed pump capacity, m^3/hr	2.1	3.12	4	6.25	8.3	10.4	12.5	18.75
Motor type & rating	Submersible 1 HP	Submersible 1 HP	Submersible 1 HP	Submersible 2 HP	Submersible 3 HP	Submersible 3HP	Submersible 5 HP	Submersible 5 HP
Tube pack size, m	1.6 x 2.0 x 4 LD	1.7 x 2.5 x 4.0 LD	1.8x 3.0 x 4 LD	2.3 x 3.5x 4.0LD	3.0 x 3.5 x4.5LD	3.3x 4.0 x 4.5 LD	3.1 x 5.0 x 4.5 LD	3.8 x 6 x 5 LD

a- Liquid Depth

b- Free Board

Table 4. Cost estimation of the STP using computer aided design

Units	Cost, Rupees							
Module capacity, KLD	55	75	100	150	200	250	300	450
1. Civil units								
Screen chamber	1,400	1,820	2,520	1,340	1,750	2,460	3,300	3,920
Grit chamber	1,750	2,100	2,520	3,360	4,900	5,075	9,450	12,250
Oil and grease trap	16,040	21,870	29,160	43,750	51,850	6,810	72, 910	109,380
Collection tank	168,440	229,690	306,250	459,370	612,500	750,620	918,750	1378,130
FABR (aeration tank)	162,420	221,490	295,310	442,970	583,330	729,170	875,000	1,299,380
Settling tank	102,380	133,880	173,250	252,000	367,500	455,000	542,500	885,500
Sludge digester	160,250	218,520	291,360	437,040	582,720	728,400	874,090	1,311,130
Sludge drying bed	46,230	49,760	53,630	62,310	67,410	73,520	85,530	98,960
Operator/electrical room	45,200	45,200	45,200	45,200	45,200	45,200	67,810	67,810
Total cost, Rs.	704,110	924,330	1,199,210	1,747,360	2,317,180	2,121,280	3,449,350	5,166,440
2. Electro mechanical equipments								
Raw sewage/sludge transfer pumps & Motors	62,320	81,950	158,930	121,360	143,490	170,060	190,370	249,210
Air blower and motors	67,510	88,780	172,170	131,470	155,450	184,230	206,230	269,980
Aeration grid, diffusers, strainers	27,910	36,700	71,190	54,360	64,270	76,170	85,270	111,630
Aeration tank - biomass carrier media	96,080	126,340	245,010	187,100	221,210	262,200	293,480	384,200
Settling tank - tube Packs	27,530	36,190	70,190	53,600	63,370	75,110	84,080	110,070
Electro chlorinator	51,930	68,290	132,440	101,130	119,570	141,720	158,640	207,680
filtration	60,370	79,390	153,960	117,570	139,010	164,750	184,420	241,420
Interconnecting piping/valves & Fittings	35,700	46,950	91,050	69,530	82,210	97,430	109,060	142,780
Electrical panel	22,720	29,880	57,940	44,250	52,310	62,000	69,400	90,860
Electrical cables & accessories	11,030	14,510	28,140	21,490	25,410	30,110	33,710	44,130
Instruments	7,140	9,390	18,210	13,900	16,440	19,490	21,810	28,560
Total cost, Rs.	470,260	618,380	1,199,220	915,750	1,082,750	1,283,250	1,436,500	1,880,500
3. Operating cost, Rs./month								
Electrical – operating load , kWh/d	1,860	2,790	3,720	4,420	4,880	6,050	6,980	9,310

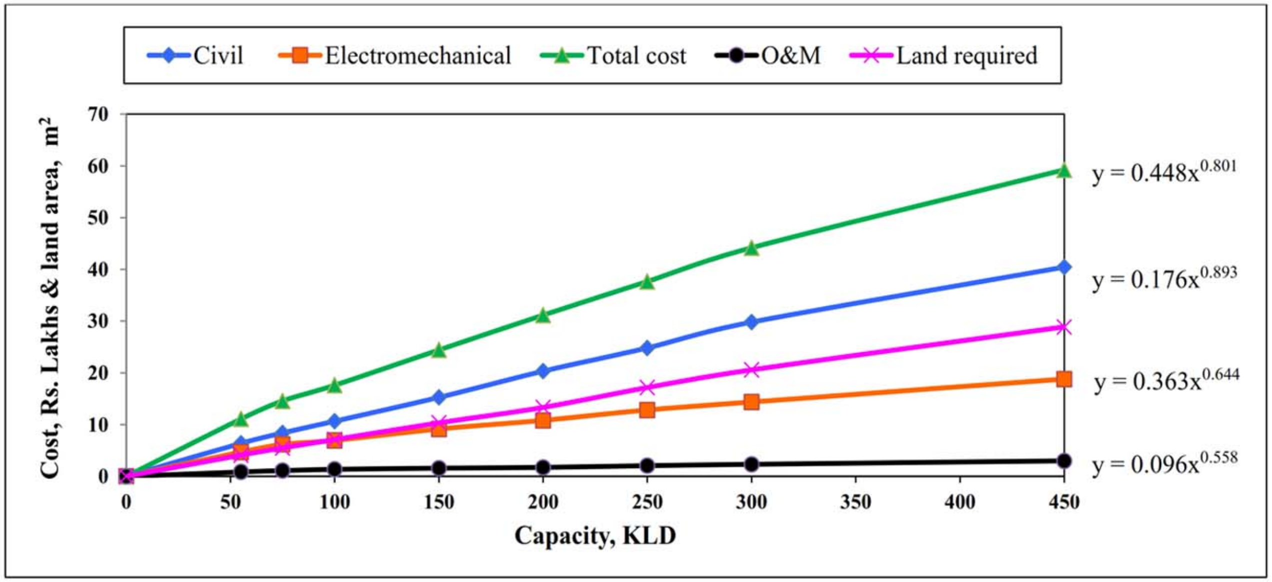

Fig. 3. Cost and land requirement for FAB technology

Manpower (operator)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Total Cost, Rs.	3,060	3,990	4,920	5,620	6,090	7,250	8,180	10,510
4. Maintenance cost, Rs/annum								
Oil & grease for lubrication and minor maintenance cost	11,760	15,460	17,390	22,890	27,070	32,080	35,910	47,010
5. Total civil and electromechanical cost	1,174,360	1,542,710	2,398,440	2,663,110	3,399,930	3,404,530	4,885,850	7,046,950
6. Operation and maintenance cost per annum (B)	48,500	63,380	59,090	90,360	73,040	119,090	134,090	173,130
8. Capital cost per KLD	21,350	20,570	23,990	17,750	17,000	13,620	16,290	15,660
9. O&M cost per KLD	880	850	590	600	450	480	450	380
10. Total treatment cost Rs per KLD	22,230	21,410	24,580	18,350	17,450	14,095	16,730	16,050

Plant electro-mechanical cost model

Plant electro-mechanical cost model was constructed with STP capacity in x axis and corresponding actual electro-mechanical cost in y axis as shown in **Fig. 3**.

$$y = 0.363x^{0.644}$$

where x denotes the capacity of the STP in KLD and y denotes the electro-mechanical cost in lakhs.

Plant operation and maintenance cost model

Plant operation & maintenance cost model was constructed using with STP capacity in x axis and corresponding O&M cost in y axis as shown in Fig. 3.

$$y = 0.096\, x^{0.558}$$

where x denotes the capacity of the STP in KLD and y denotes O&M cost in lakhs.

Plant total cost model

Plant total cost model was constructed using modular STP capacity in x axis and corresponding total cost in y axis as shown in Fig. 3.

$$y = 0.448\, x^{0.801}$$

where x denotes the capacity of the STP in KLD and y denotes the plant total cost in lakhs.

Model performance evaluation

Model performance evaluation was carried out using actual cost observed in the field and the corresponding predicted cost. The summary of the statistical analysis of the mathematical model showed that, the difference in observed and predicted mean was least for O & M cost model (0.02 lakhs) followed by electro-mechanical cost model (0.05 lakhs) and civil cost model (0.14 lakhs). The models formulated indicated that the accuracy was good (99%) and the error was less for electro-mechanical cost model (0.017 lakhs) followed by civil cost model (0.529 lakhs).

CONCLUSIONS

FAB a hybrid reactor offers the following advantage compared to conventional STP:

- Consistent and efficient removal of organic and inorganic pollutant simultaneously within short HRT in one single reaction tank there by making it more advantageous by occupying 6 times less space
- High treatment efficiency viz., TSS removal varied 83-85%, BOD removal 92-93% and COD removal 74-80%
- Return sludge and circulation of nitrifying liquid is not required, enabling extremely easy maintenance control
- Low operating cost as the tube settler employs no moving parts
- Low installation cost as it is pre assembled, light weight, skid mounted requiring minimum foundation construction
- They can operate at high hydraulic and organic loading rate
- The computer aided design package developed for FAB sizing makes it easy for computing the dimensions of the treatment units and cost estimation
- The mathematical model performance evaluation indicated that the accuracy of the mathematical model formulated is 99% and hence could be used in predicting the cost for FAB based STP

Hence, with all the above mentioned advantage, FAB proves to be an efficient, economical and sustainable sewage treatment method suitable for urban and rural areas.

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