UASB TECHNOLOGY FOR SEWAGE TREATMENT IN INDIA: EXPERIENCE, ECONOMIC EVALUATION AND ITS POTENTIAL IN OTHER DEVELOPING COUNTRIES

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ABSTRACT

It's nearly two decades since UASB (Upflow Anaerobic Sludge Blanket) concept for sewage (municipal wastewater) treatment was started in India and today it has taken an edge over the other developing countries having similar climatic conditions in the use of this technology. At present, about 23 full-scale UASB plants are in operation at various places in India with total installed capacity of about 9,85,000 m^3/day (985 *mld*) and about 20 number are in pipeline which are likely to be commissioned within next 3-4 years. With financial assistance from international funding agency, the National River Conservation Directorate (NRCD) under the Ministry of Environment & Forests (MoEF), Government of India (GoI), formulated and launched a comprehensive action plan project for conservation of the river Yamuna under which 16 UASB sewage treatment plants (STPs) were commissioned in the period of 1999-2002. Experience shows that the present UASB reactor design and construction is quite different from the very first module of 5 *mld* treatment capacity that was constructed as a demonstration plant at Kanpur, India under the Ganga Action Plan (GAP) in late 80's. The discrepancies in the initial UASB plants were recorded and now a new breed of UASB reactor is available with respect to the design, operation and maintenance, and materials of construction. Initially, most of the UASB plants were provided with final polishing ponds as post-treatment unit, but now other options for the same are being explored to meet the stringent regulations. This paper reviews the overall implications of UASB technology in India. Institutional and technical aspects with special reference to the Yamuna Action Plan (YAP) are presented. It also presents the potential of UASB technology in other developing countries with its future within India as well based on the evaluation of life cycle cost (LCC). Other sewage treatment technologies were also included while evaluating LCC. The LCCE can be used as a tool for selecting appropriate technology under similar climatic and economic conditions in other developing countries. LCC supports that UASB as one of the most favourable methods of wastewater treatment from all aspects.

Keywords: UASB, Anaerobic Process, Sewage Treatment, India

List of Notations

AF	Anaerobic Filter
ASP	Activated Sludge Process
BIOFOR	Biological Filter Oxygenated Reactor
BOD	Biochemical Oxygen Demand
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CRF	Capital Recovery Factor
DJB	Delhi Jal Board
DO	Dissolved Oxygen
EAS	Extended Aeration System
EGSB	Expanded Granular Sludge Blanket
FAB	Fluidized Aerobic Bed
FAB	Fluidized Aerated Bed Reactor
FPU	Final Polishing unit
FRP	Fibre Reinforced Plastic
GLSS	Gas Liquid Solids Separator
GAP	Ganga Action Plan
GoI	Government of India
H_2S	Hydrogen Sulphide
IC	Initial Cost
JBIC	Japan Bank for International Corporation
LCC	Life Cycle Cost
MBR	Membrane Bioreactor
MBBR	Moving Bed Bioreactor
Mld	Million litres per day
MPN	Most Probable Number
MoEF	Ministry of Environment & Forests
MBR	Membrane Bioreactor
MCD	Municipal Corporation of Delhi
NRCD	National River Conservation Directorate
O&M	Operation & Maintenance
PIAs	Project implementing Agencies
PHED	Public Health Engineering Department
RCC	Reinforced Cement Concrete
R&D	Research & Development
Rs.	Indian Rupees
SBR	Sequencing Batch Reactor
SAFF	Submerged Aeration Fixed Film Reactor
STPs	Sewage Treatment Plants
TSS	Total Suspended Solids
TAC	Total Annual Cost
TF	Trickling Filter
UPJN	Uttar Pradesh Jal Nigam
UASB	Upflow Anaerobic Sludge Blanket

VSS	Volatile Suspended Solids
WSPs	Waste Stabilization Ponds
YAP	Yamuna Action Plan

1. INTRODUCTION

Sewage treatment is not a cheap proposition. Public bodies have to think twice before making substantial investments particularly in developing countries where environmental issues could not be given due priority due to financial constraints. Over the years, treatment related issues are becoming expensive as governments are not only giving emphasis to treat wastewater in order to protect their resources but the concept of reuse & recycling is also becoming an important aspect. Not only this, residues emanating there from, and other treatment by-products are also being included in the overall wastewater management system. On the other hand, emphasis is also being given to clean technologies to minimize waste production. However, in countries like India, the treatment issue is dominant and receiving due attention these days.

During the past two decades, several new sewage treatment technologies have been developed and are being adopted in many developing countries particularly in the South-East Asian region including India. Some of the technologies are Fluidized Aerobic Bed (FAB), Anaerobic Filter (AF), Expanded Granular Sludge Blanket (EGSB), Sequencing Batch Reactor (SBR), Membrane Bioreactor (MBR), Fluidized Aerated Bed Reactor (FAB), Submerged Aeration Fixed Film Reactor (SAFF), BIOFOR (Biological Filter Oxygenated Reactor), Upflow Anaerobic Sludge Blanket (UASB) process etc. Every technology has its pros & cons and therefore has to be applied in accordance to the local conditions.

In India, where the government has felt a need to prevent pollution of its rivers and preserving natural resources, a major action plan has been formulated under which a good number of towns and cities have been identified by the National River Conservation Directorate under the Ministry of Environment & Forests (MoEF), Government of India. The objective of river action plan is to conserve the river water bodies. Within this framework, the Ganga Action Plan (GAP) was incepted and implemented in mid 80's. After the implementation of GAP in few states, Yamuna Action Plan (YAP) was formulated in early 1990 for the states of Uttar Pradesh, Haryana and Delhi where major part of Yamuna River flows. The YAP was funded by JBIC (formerly OECF, Japan) under a soft loan bilaterally agreed arrangement. The total expenditure incurred under YAP Phase I and II was Rs. 6820 million, under which a sewage treatment capacity of 753 *mld* has been created (MoEF, 2006).

In many countries, UASB has been applied for the treatment of high strength wastewater, but in India, it has been employed for the treatment of domestic wastewater (Lucas Seghezzo *et al* 1998). Brazil and Columbia are the other two countries in the world where this technology has been used (Lucas Seghezzo *et al*

1998). It is now being used and gaining popularity in other countries like in Ras-Al-Khaimah (UAE), Angola, Indonesia etc.

With respect to the application of UASB technology, the experience gained in India is unique and diverse. India is one of the leading countries in terms of the amount of sewage volume treated by the UASB process (Sato *et al*, 2007). It has been recognized as one of the most cost effective and suitable sewage treatment process considering the environmental requirements in India. At present about 23 number of sewage treatment plants with total installed capacity of 985 mld (MoEF, 2005, 2006) based on the UASB are in operation and about 20 number are in pipeline which are likely to be commissioned within next 3-4 years. These plants have come up under different national plans during the last 20 years under various river catchments, i.e., GAP from Himalayan region to the Bay Bengal, Sabarmati in the state of Gujarat, Godavari in the states of Maharasthra and Andhra Pradesh, Sutlaj in the state of Punjab, Khan in the state of Madhya Pradesh and YAP. However, the present study focuses on the Yamuna action plan. In this study, efforts have been made to present the experience to treat 985 mld sewage wastewater using UASB with respect to its design, operation and maintenance, material of construction, effluent quality, post-treatment options etc. and its potential in other developing countries having similar climatic conditions.

2. INSTITUTIONAL FRAMEWORK FOR YAMUNA ACTION PLAN

The Yamuna River Basin (Fig. 1) is one of the major tributaries of the river Ganga, contributing about 40% basin area of Ganga River and 10% of the total landmass of India. The catchment of the Yamuna River System covers parts of the states of Uttar Pradesh, Himachal Pradesh, Haryana, Rajasthan and Madhya Pradesh and the entire State of Delhi.

YAP project was started in 1993 with a restriction to only 15 cities in the Yamuna catchment. A central nodal agency, National River Conservation Directorate (NRCD) under the Ministry of Environment & Forests (MoEF) was made responsible for the overall implementation, coordination and monitoring of river action plans in India including YAP since 1993. One of its key roles is to channelise Central Government funds to the concerned State governments for the implementation of the river conservation schemes. At the state levels (i.e. in Uttar Pradesh, Haryana and Delhi), designated state agencies known as the Project implementing Agencies (PIAs) were given the responsibility for implementing the YAP project. They were:

- In Haryana, Public Health Engineering Department (PHED) under the state Government of Haryana;
- In UP, Uttar Pradesh Jal Nigam (UPJN), an autonomous organization under the Department of Urban Development of Government of UP;
- In Delhi, Delhi Jal Board (DJB) and Municipal Corporation of Delhi (MCD).

The institutional linkages for the implementation and operation of the YAP are shown in Fig. 2.

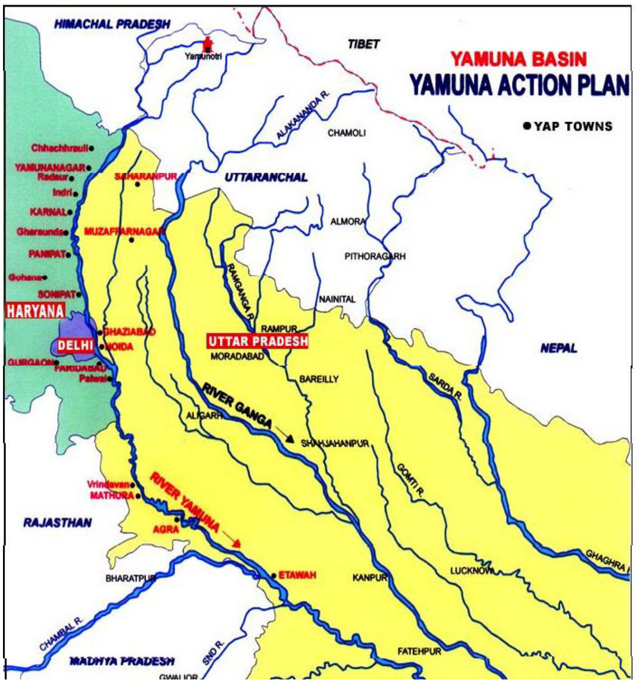

Figure 1: Yamuna Basin and towns under YAP

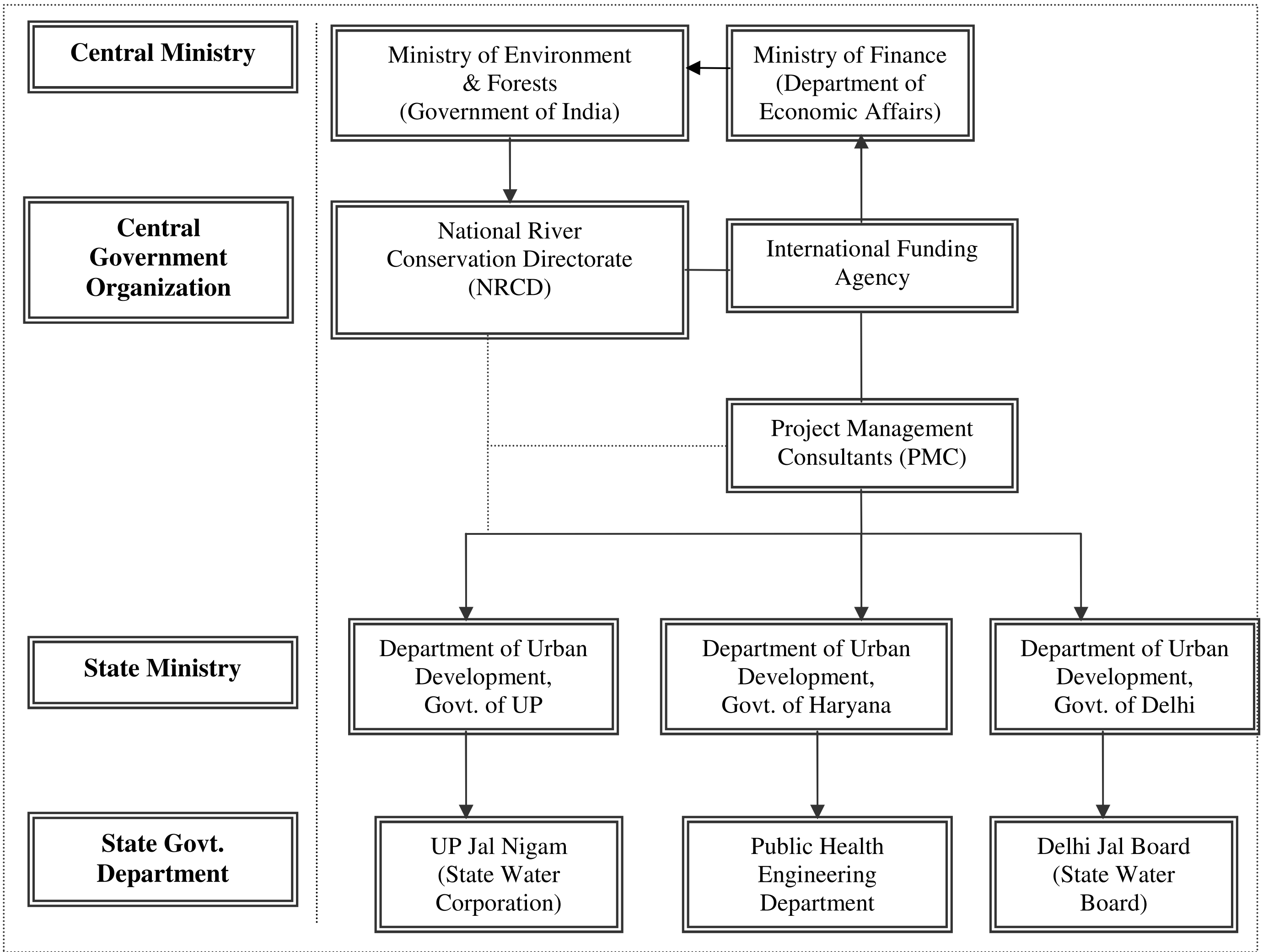

Figure 2: Institutional Framework for YAP

3. UASB TECHNOLOGY EXPERIENCE IN INDIA

3.1 Historical Developments of UASB Technology

Worldwide presently over 200 full-scale UASB plants are in operation for the treatment of both domestic and industrial wastewaters. However, in India the UASB Process is being widely adopted for domestic wastewater and it can be claimed that 80% of total UASB reactors worldwide for domestic wastewater treatment is in India. The basic approach towards selection of technology for sewage was low capital costs, low energy requirements, low O&M costs and sustainability aspect. This was derived from the experience of Ganga Action Plan (Kanpur- Mirzapur). Based on the successful results of 5 mld demonstration plant was constructed at Kanpur, Uttar Pradesh. The experience GAP was mixed in terms of efficiency of treatment versus energy consumption and cost of operation and maintenance. Drawing lessons from GAP, the YAP opted for energy neutral and energy recovery technologies like anaerobic processes for the sewage treatment. Conventionally, anaerobic processes are to be used for the treatment of high strength organic wastewaters. However, typical hydro-dynamics of UASB coupled with its unique characteristic of holding high granular biomass (Sunny *et al,* 2005), made it possible to apply the anaerobic processes for the treatment of low strength wastewaters.

After studying the performance of the demonstration plant for a few years, a full scale UASB plant of 14 MLD was constructed at Mirzapur for treating the domestic wastewater (Draaijer *et al*, 1992.) In view of the fact that the USAB effluent does not meet discharge standards, the plants were used in conjunction with a settling pond called 'final polishing unit' to achieve desired BOD and suspended solids reduction. These being pilots and experimental plants, their performance were varied. However they were found to be promising in terms of energy consumption, biogas yield and reduced requirements for sludge disposal.

The key factors that influenced selection process against the conventional aerobic systems were their high energy requirements, unreliable power supply situation in the states, and higher O&M costs; while those in favour of UASB were their robustness, low or no dependence on electricity, low cost of O&M. Moreover, the possibility of resource recovery from biogas and aquaculture respectively also influenced the selection process. Among the large capacity plants under YAP, in all 28 STPs comprising 16 UASBs, 10 Waste Stabilization Ponds (WSPs) and 2 BIOFOR technology STPs with aggregate capacity of 722 MLD were constructed. UASBs accounted for an overwhelmingly high 83% of the total created capacity.

The state of Haryana almost entirely opted for UASB technology where 10 out of the 11 large plants were based on this. On the other hand in the state of UP there was a balance in terms of numbers of STPs based on UASB and WSP technologies. Generally for larger flows UASBs were considered while for smaller flows WSPs were adopted. Summary of technology distribution of various STPs created under YAP are presented in Table 1.

Table 1: Technology Wise Distribution of STP Capacity Created under YAP

Technology	No. of plants	STP Capacity, mld	% of total in YAP
UASB	16	598	83
WSP	10	104	14
BIOFOR	2	20	3
Total	**28**	**722**	**100**

(Source: MoEF, 2005 and 2006)

Preference for WSPs in UP could be attributed to State's experience with complex and energy intensive activated sludge process based plants during GAP-I as well as with the pilot UASBs at Kanpur.

3.2 Design Considerations

The most important feature is the modular approach adopted for the design of UASB reactors. This facilitates in having more flexibility in the operation of the STP. The major treatment units, which includes UASB reactors and Final Polishing unit (FPU) has been provided in modules of same capacity. Each reactor operation is independent of each other and during trouble shooting in one reactor the flow can be suspended and diverted to the other reactors for its maintenance without disturbing the operation of the STP. Final Polishing units (FPU) also have been provided in modules. The basic assumptions and design criteria derived over the years experience that have been adopted in most of the UASB reactors in India are presented in Table 2.

The design of UASB reactors for domestic wastewater is mainly based on hydraulic principles and the incoming wastewater composition. A top view and sectional views of UASB reactor are shown in Figure 3.

Table 2: Basic Assumptions and Design Criteria adopted for UASB Reactors

Parameter	Value/Range	Unit
Ambient Temperature	18-42	*°C*
Temperature of Sewage	20-25	*°C*
Bacterial Yield Coefficient	0.06-0.08	*kg VSS/kg COD*
Sludge Retention Time (SRT)	32-38	*Days*
VSS Destruction in Reactor	50	*%*
Maximum Sludge Bed Height	80-85	*% of height to gas collector*
Sludge Bed Concentration	65-70	$kg\ TSS/m^3$
Upflow Velocity at Average Flow	0.52-0.58	*m/h*
Maximum biogas loading	1.0	$m^3.m^{-2}.h^{-1}$
HRT (Hydraulic Retention Time)	8-12	*Hours*
Maximum Aperture Velocity	5	*m/h*
Volumetric Loading Rate	1.15-1.25	$kg\ COD/m^3/day$
Biogas production	0.08-0.11	$m^3.\ kg^{-1}\ COD\ rem.d^{-1}$
Methane Content in Biogas	60-65	*%*
Gas Hood Width	0.44-0.50	*m*
Settling Zone Surface	75	*%*
Angle of Gas Collector	50	*Degrees*
Angle of Deflector	45	*Degrees*
Feed Inlet Density	0.25	*m2*
Overlap of gas collector over deflector beam	0.15-0.20	*m*
Centre to centre distance between gas domes	4.0	*m*
Clear distance between gas domes	3.0	*m*
Feed pipe velocity	1.0	*m/s*
COD removal efficiency	75-80	*%*
BOD removal efficiency	65-70	*%*
TSS removal efficiency	75-80	*%*

(Source: Urban Plan Consulting & Engineering Pvt. Ltd, Aligarh, India, 2007)

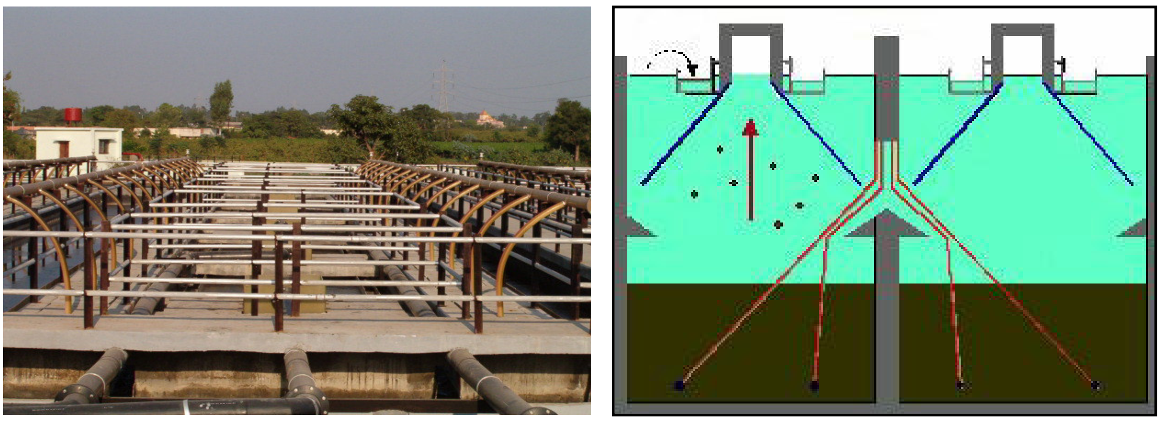

Figure 3: Top and Sectional Views of UASB Reactor

3.3 Material of Construction of UASB Reactors

From the time of introduction of UASB concept in India in late 1980s and till date, there have been significant modifications in the material of construction of UASB reactors, which has significantly resulted in lowering capital costs. The modifications incorporated in the 14 MLD UASB plant at Mirzapur constructed in 1989 over that of 5 MLD UASB plant at Kanpur under GAP were in the selection & introduction of Fibre Reinforced Plastic (FRP) (bisphenol resin) to rectify corrosion problems and resulting in longer durability. Simpler wastewater feed inlet system in the UASB reactors is adopted to take care of choking, operation and maintenance problems surfaced at 5 MLD plant. But, in the ten UASB STPs designed for YAP in Haryana and recently in other UASBs, further necessary improvements were incorporated, such as, improvement in fixing of FRP Feed inlet boxes, Gas Liquid Solids Separator (GLSS), change in design of deflector beam, selection of most appropriate material with respect to durability and costs etc.

In the present scenario, the main structure of UASB reactor being constructed at various places in India is with RCC (Reinforced Cement Concrete) since concrete is easily available and has been used in most of the developing countries for construction works. The inside surface was coated with epoxy paint as a protective layer to avoid corrosion due to formation of H_2S and CO_2. FRP of Isothelic resin class gas hoods and domes have been provided in the GLSS (gas-liquid-solid separation). The purpose of use of FRP was because of easy construction, light weight, anti-corrosion and simple maintenance. The feeding boxes, effluent gutters, baffle plates and gas collection pipes are also constructed with FRP material. For feeding pipes, HDPE (High Density Polyethylene) pipes are being used to distribute the wastewater uniformly over the surface of the reactor. For sludge discharge, CI (Cast iron) pipe is being generally used. However, further R&D shows that the reactors can be constructed fully in FRP using Isothelic resin instead of RCC for small flows provided modular approach is adopted.

3.4 Operation and Maintenance (O&M) and Performance of UASB Reactors under YAP

The O&M responsibility of UASB STPs created under YAP is not uniform. In the state of Uttar Pradesh, the O&M of STPs comes under UPJN (Uttar Pradesh Jal Nigam) while in the state of Haryana where 10 UASB STPs were constructed responsibility lies with PHED (Public Health Engineering Department). However in Delhi, it is upto (DJB) Delhi Jal Board which looks after O&M.

The major operational activity associated with UASB plants is monitoring of sludge and its profile inside the reactor. There has to be balance in sludge ash content, VFA to alkalinity ratio and routine sludge discharge. Maintenance includes cleaning of screen chambers, grit chambers, checking of valves, weirs, the effluent gutters, gas collectors, feeding boxes, de-choking of feeding pipes and time-to-time checking of pumps and electrical items. The cost involved in the operation and maintenance of UASB plants is less than 1% of capital cost per year. It has also been estimated that the annual operation and maintenance cost of the UASB plant is approximately 30 % of the ASP based plants.

The performance results of 5 plants, i.e., Faridabad (45 MLD & 50 MLD), Gurgaon (30 MLD), Ghaziabad Trans Hindon (56 MLD) and Ghaziabad Cis Hindon (70 MLD) are presented with respect to the removal of BOD, COD, and TSS in Table 3. All the plants have a typical flow scheme comprising screens, grit chambers, UASB reactors, ponds as polishing units (ponds), sludge drying beds, gas holder and duel fuel generators. The UASB section of the plant comprises modular reactors, which typically have capacity varying in between 5 to 15 MLD.

Table 3: Summary of Performance of few UASB STPs under YAP

Location	*Capacity, MLD*	*Removal Efficiencies (%)*					
		BOD		COD		TSS	
		UASB[1]	Total[2]	UASB[1]	Total[2]	UASB[1]	Total[2]
Faridabad Zone-II	45	45-57	70-77	58-67	72-81	57-69	64-77
Faridabad Zone-III	50	51-67	65-78	66-73	69-83	71-78	70-84
Ghaziabad Cis	70	53-66	64-76	69-78	65-88	64-73	67-78
Ghaziabad Trans	56	57-64	65-72	58-79	66-81	59-70	64-81
Gurgaon	30	61-69	62-72	61-68	63-81	66-73	67-80

(Source: MoEF, 2005 and 2006)
[1] Percent removal by UASB only.
[2] Percent removal by the plant, which includes UASB and post treatment (final Polishing Pond having retention time of 24 hours having a water depth of 1.25 m).

4. EVALUATION OF LIFE CYCLE COST

A good number of sewage treatment plants under various river action plans have been created over the past two decades. Numerous technologies like activated sludge process, trickling filter, waste stabilization ponds, UASB and other new technologies have been applied. Based on the reliable source of data available and experience of authors, an attempt has been made to evaluate the life cycle cost (LCC) of different sewage treatment technologies operated in India with an objective to compare and forecast the future prospects of UASB. The LCC can be used as a reference for selecting an appropriate technology for future STP projects in India and other countries having similar economies. UASB with Final Polishing Unit (FPU), and Extended Aeration System (EAS) and other common technologies being used in India such as activated sludge process (ASP), Trickling Filter (TF), Sequencing Batch Reactor (SBR), Moving Bed Bioreactor (MBBR) and Membrane Bioreactor (MBR) have been considered for LCC.

Data on capital costs, O&M costs, land price etc. were collected from various reliable sources. The total annual cost was calculated by using standard equation, TAC = CRF x IC + OMC, where TAC is the total annual cost, CRF the capital recovery factor, IC the initial cost (e.g., for capital, land), OMC the operation and maintenance cost (e.g., manpower, power, repair, replacement of E&M items, chemicals). The economic life of STP and annual rate of interest have been considered as 30 years and 12% respectively. The base year is taken as 2010 and the land cost is assumed for the ultimate demand upto 2040. The cost is given in Indian Rupees (1 US $ = ~ Rs. 40). Table 4 presents the life cycle cost evaluation and net worth investment costs for different technologies on per MLD basis.

On the basis of figures given in Table 4, net worth investment cost has been evaluated for different technologies assuming a flow of 50 MLD as a case study. The land cost has been assumed as Rs. 200 Lacs per hectare, which may be the prevailing rate in many cities and towns of India having population more than 1 million such as Agra where YAP is being implemented. The results are as presented in Table 5.

It can be seen from Tables 4 and 5 that the net present worth of investment for WSP is lowest followed by UASB with FPU. Although WSP option is lowest but it cannot be considered due to large area requirement for places where large vacant land may not be available. It can be applied where land is cheap and easily available which could be possible for small flows in other. After WSP, UASB in combination with FPU gives better proposition in terms of investments as compared to other technologies. Experience of Trickling Filters has not been very good in India and therefore it is not recommended anymore. The SBR and MBR offer good effluent quality but their investment and O&M costs are very high. The second best option is UASB with EAS. Its investment and O&M costs are not high vis-à-vis the effluent quality is better as compared to UASB+FPU. In a nutshell, UASB with FPU or EAS still has a better future in India as compared to other technologies.

Table 4: Evaluation of Life Cycle Cost and Net Worth Investment on Per MLD basis in Indian Rupees

S.No.	Item/Parameter	ASP	TF	WSP	UASB+FPU	UASB+EAS	MBBR	SBR	MBR
1.	Overall HRT (Whole System)	12 - 14 hrs	13 - 14 hrs	8 - 15 days	1.33 - 1.5 days	14 - 18 hrs	8 - 12 hrs	14 - 16 hrs	12 - 14 hrs
2.	BOD Removal, %	85 - 95	80 - 90	75 - 85	80 - 88	80 - 95	85 - 95	90 - 95	95 - 98
3.	COD Removal, %	80 - 90	85 - 90	70 - 85	80 - 85	80 - 90	80 - 90	88 - 96	95 - 100
4.	TSS Removal, %	85 - 90	75 - 85	70 - 85	80 - 85	85 - 90	85 - 95	90 - 96	98 - 100
5.	Faecal coliform Removal, log unit	upto 3 < 4	upto 2 < 3	upto 4 < 5	upto 1 < 2	upto 2 < 4	upto 2 < 4	upto 2 < 4	upto 6 < 7
6.	Average Area required (m^2/mld)	1,820	1,620	8,000	1,800	1,450	450	300	800
7.	Capital Cost, Rs. Lacs per MLD	34	30	13	32.5	34	42	58	85
8.	Biogas Generation m^3	55 - 70	55 - 70	Nil	35 - 50	35 - 50	Nil	Nil	Nil
9.	Bio - Energy Generation (kWh)	25 - 35	25 - 35	Nil	20 - 30	20 - 30	Nil	Nil	Nil
10.	Annual Power Cost	4.2	3.56	0.17	0.25	1.51	5.29	4.70	5.61
11.	Annual Civil, E&M maintenance Costs, Rs. Lacs Per MLD	1.36	1.20	0.13	1.30	1.36	1.68	1.89	13.60
12.	Annual Recurring Costs (Chemicals etc.), Rs. Lacs	2.10	2.40	0.25	0.60	0.40	3.60	3.60	0.00
13.	Annual Non-Recurring Costs (7 yrs for E&M items)	1.94	0.86	0.09	1.63	2.19	3.60	4.97	8.50
14.	Total Annual Manpower O& M cost, Rs. Lacs per MLD	0.32	0.28	0.23	0.30	0.32	0.32	0.33	0.34
15.	**Total Annual O&M Costs, Rs. Lacs per MLD**	9.96	7.43	0.79	2.45	3.58	10.89	10.51	19.55
16.	Total Annual Resource Recovery, Rs. Lacs per MLD	0.334	0.344	0.064	0.254	0.254	0.014	0.144	0.144
17.	Avg. Land Cost Assumed (Per m^2), Rs. Lacs	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220
18.	Cost of Land, Rs. Lacs per MLD	40.04	0.03	0.00	0.03	0.03	0.04	0.04	0.30
19.	Unit Capital Cost including Land, Rs. Lacs per MLD	74.04	30.03	13.00	32.53	34.03	42.04	58.04	85.30
20.	Annual Interest in %	12	12	12	12	12	12	12	12
21.	Economic Life in Years	30	30	30	30	30	30	30	30
22.	Capital Recovery Factor, CRF	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124
23.	Total Annual Cost, Rs. Lacs per MLD (38x 9 + 28)	19.15	11.16	2.40	6.49	7.81	16.11	17.72	30.14
24.	Present Discount Factor, DR	8.060	8.060	8.060	8.060	8.060	8.060	8.060	8.060
25.	Net Present Worth of Investment, Rs. Lacs per MLD	154.384	89.968	19.347	52.305	62.925	129.830	142.793	242.925

(Source: MoEF, 2004, 2005 and 2006, UPJN 2006, N. Sato et al. 2006, N. Khalil et al. 2006, EPA USA 2000, Urban Plan Consulting & Engg. Pvt. Ltd., New Delhi, 2007)

1. Disinfection through Chlorination technique is considered for all the technologies except where not required. Land required is also included.
2. Manpower requirement varies from technology to technology. Annual cost for each category is taken as per the NRCD norms.
3. O& M costs capitalization is done assuming constant annual expenditure over the life of the plant.
4. In case of WSP, cost of bed lining is not included. In case included, capital cost of WSP could be doubled.
5. Sludge Drying Beds considered for dewatering of sludge wherever required.

Table 5: Evaluation of Net worth Investment for 50 MLD capacity STP

ITEM	ASP	TF	WSP	UASB+ FPU	UASB+ EAS	MBBR	SBR	MBR
Assumed Capacity (2025), MLD	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Assumed Ultimate Demand (2040), MLD	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0
Land Required, in Hec./MLD	0.18	0.16	0.80	0.18	0.15	0.05	0.03	0.08
Cost of Land, Rs. Lacs/Hec.	200	200	200	200	200	200	200	200
Capital Recovery Factor, CRF	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Total Annual Cost (TAC), Rs. Lacs	1,011.94	604.10	124.88	339.51	412.40	872.76	950.80	1,626.48
Present Discounted Cost Factor, DR	8.06	8.06	8.06	8.06	8.06	8.06	8.06	8.06
Net Present Worth of Investment, Rs. Lacs	8,156.28	4,869.06	1,006.55	2,736.43	3,323.96	7,034.43	7,663.43	13,109.40

5. POTENTIAL OF UASB TECHNOLOGY IN OTHER DEVELOPING COUNTRIES

In most of the developing countries, sewage treatment technologies that can provide effluent standards at minimum cost are generally preferred. The concept of centralized sewage treatment methods is very common in these countries. The most widely used treatment systems are stabilization ponds, activated sludge process, trickling filters, extended aeration system etc. The performance of wastewater stabilization ponds in achieving the goals for developing countries appears to be satisfactory in many cases (Amelia K. Kivaisi, 2001).

Conventional sewage treatment processes (like the activated sludge process) require high capital investment, excessive consumption of energy, and high maintenance costs (Nobuyuki Sato *et al*, 2006). As a result, efforts to implement these methods in developing countries for water pollution control have been seriously impeded. During the last two decades, the use of anaerobic treatment systems particularly the UASB process in an outstanding position has increased significantly for sewage treatment in countries having warm climatic conditions like in Brazil, India, and Columbia (C. A. L. Chernicharo, 2006). In spite of their great advantages, anaerobic reactors hardly produce effluents that comply with usual discharge standards established by environmental agencies. Therefore, the effluents from anaerobic reactors (UASB) usually require a post-treatment step as a means to adapt the treated effluent to the requirements of the environmental legislation and protect the receiving water bodies.

In contrast to developed countries, emphasis is given more in developing countries to remove organic pollutants, solids and pathogens to some extent only. The ideal situation for sewage treatment in these countries would be the complete removal of pathogens (health protection) and the highest removal of COD (environmental protection) with recovery of energy (methane or hydrogen) and compounds of interest: nitrogen (as NH_4^+, NO_2, and NO_3), phosphorus (as phosphate) and sulfur (as S^0). As such, in terms of sustainability the use of UASB reactors as the core unit of sewage treatment facility is most suited for this purpose. In addition to the removal of organic matter with low energy consumption and with a net production of methane gas, the presence of phosphate, nitrogen and sulfur reduced compounds in the effluent opens the opportunity for the development of economically feasible processes to recover these compounds of interest. In fact, the development of post-treatment units of anaerobic reactors is not only important to improve the effluent quality for environmental protection, but also to achieve the recovery of resources (Eugenio et al., 2006).

6. CONCLUSIONS AND RECOMMENDATIONS

Historical evolution of the application of the UASB based STPs in India and subsequent modifications over the years with respect to the design, material of construction, operation and maintenance have given a new dimension to this technology. Reduced capital costs, increased durability of the reactors and simple operation and maintenance are some of the features of these modifications. Over the last 20 years, more than 23 STPs have been designed and constructed using UASB technology in India under various national level river conservation projects and it can be claimed that India is market leader in the world in UASB application for sewage treatment. There has been complete know-how & knowledge transfer in the design & implementation of UASB reactors indigenously over the years.

Performance of these plants has been satisfactory. UASB efficiency can further be enhanced if adequate measures related to process operations are taken. There is need to augment the existing plants, since more stringent standards for biological quality (including nitrogen) cannot be met out by the existing plants.

There are a number of issues which emerged from the 2 decades of experience of operation and running of UASB based sewage treatment plants in India which has been outlined as under:

- Sustainability
- Policy matter and regulatory aspects
- Institutional framework
- Monitoring of assets and Training
- O&M aspects
- Water quality aspects

Out of these, the regulation regarding indicator organism (faecal matter) is considered to be the most serious (Pant et al., 2002) as it has emerged recently apart from sustainability, monitoring and O&M issues. Besides the typical quality parameters of

BOD, suspended solids and DO which have a direct impact on the quality of receiving water body/environment, the pathogens are known to have a direct impact on the public health. The intestinal pathogens and coliform are obligate anaerobes and unlike in an activated sludge plant, their die off rate in UASB environment is low. Recognizing this aspect and in view of wider application of the anaerobic technology, the Ministry of Environment and Forests has proposed inclusion of Faecal Coliform as one of the quality parameters in the national discharge standards for STP effluents. The suggested desirable and maximum permissible limits for Faecal Coliform are 1000 and 10,000 MPN/100 ml respectively. However, adequate post-treatment removing faecal matter (Pant and Mittal, 2004) and residual organic & solids load has always been an issue, which needs to be attended. Other post-treatment options like constructed wetlands, newly developed attached growth aerobic system (Okubo et al 2004), lagoons are to be investigated for their suitability after UASB.

Institutional strengthening and involvement of local urban minor bodies for the operation of assets is another important issue. The engineers of ULBs and Jal Sansthans (operating agencies under YAP) have little prior experience or knowledge of the STPs created under the project. The agencies are plagued by institutional and financial crisis, barely managing the current services. Ideally a project such as YAP would provide an opportunity for strengthening the ULBs and integrating sewerage and sanitation, thereby providing a basis for long-term institutional sustainability. There was a need for comprehensive and systematic training for specific target groups under YAP. Assessment of the training needs, type and its level is to be carried out to ascertain either the content or structure of the training module to be imparted.

Based on the life cycle cost evaluation of sewage treatment technologies, it can be concluded that UASB in combination with adequate post-treatment option like FPU or EAS still offers best proposition compared to other treatment systems in India. The potential for application of anaerobic treatment systems in the developing world is enormous. The use of UASB reactors as a core unit can improve the sustainability of sewage treatment system in these countries. Most of the developing countries have warm tropical and subtropical climates that are conducive for higher biological activity and productivity, hence better performance of anaerobic systems (UASB).

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