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Sustainability of Wastewater Treatment in Subtropical Region: Aerobic Vs Anaerobic Process

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ABSTRACT:- Sustainable wastewater treatment technologies are gaining attention of policy-makers and industries for meeting the required pollution guidelines laid down by the regulators of the countries and conservation of natural resources. In both developing and industrial countries adoption of sustainable and economically viable sewage treatment systems are necessary for optimum treatment, recovery and its utilization. This paper provides a comparative analysis of technologies used and latest applications of technological developments in wastewater treatment for subtropical climate. The paper mainly focuses on anaerobic and aerobic treatment of domestic wastewater in subtropical climate. It is recommended that, where region is semi-urban or rural area and land is available, natural treatment technologies or DEWATS like system may be utilized. In urban region, it is recommended that UASB followed by suitable post treatment conforming to the effluent standards, may be adopted.

Keywords: aerobic, anarobic, sustainable, treatment

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I. INTRODUCTION

Growing population load and more industrial output demands have catalyzed pollution load on the environment. It needs appropriate environmental management to reduce pollution from soild, liquid and gases resulting from industries, etc. All this demands to develop environmental friendly, economically viable, and socially acceptable wastewater treatment technologies for sustainability. Sustainability, can be assessed through energy analysis, life cycle assessment (LCA) and economic analysis. Historically, provisions for sewage handling can be traced from fourth century B.C. in 'Athenian Constitution' [93]. Most common way to handle the domestic wastewater especially in developing countries and rural areas is the direct discharge in an environment. Stabilization pond in developing countries is commonly used wastewater treatment system because of availability of land at reasonable cost and less requirement of skilled labour[38]. Due to urbanization, more sustainable treatment option is required. Here, treatment of domestic wastewater limited only to secondary treatment focusing on biological methods available for the treatment suitable for subtropic region where average temperature for eight months of the year is at or above 10 $^{\circ}$ C and coldest months temperature remains between 2 and 13 $^{\circ}$ C is discussed.

The characteristics of the domestic wastewater may vary from place to place and mostly depends on the social, economical, climatic conditions. Table 1 of composition of municipal wastewater indicates, high concentration which is due to low water consumption or infiltration and low concentration which is due to high water consumption or dilution of wastewater by storm water. The wastewater may also have heavy metals in their decreasing order as aluminium, zinc, copper, lead, nickel, chromium, silver, cadmium, lead, mercury and the major microorganisms like E. Coli, coliforms, fecal Streptococcae, Cl. perfringens, campylobacter, Staphylococus aureus, coliphages, enterovirus mostly comming from human excreta or food [35]. Domestic wastewater can be considered having low COD concentrations, high of suspended solids and fluctuating organic loading. It is generally considered as low strength wastewater.

Table 1: Composition of municipal wastewater with minor contribution of industrial wastewater [35]

Parameter	High	Medium	low
COD Total	1200	750	500
BOD	560	350	230
VFA (as acetate)	80	30	10
N Total	100	60	30
Ammonia-N	75	45	20
P Total	25	15	6
Ortho-P	15	10	4
TSS	600	400	250
VSS	480	320	200

Aerobic treatment technology is about 100 years old. Commonly used technique for sewage treatment was to spread wastewater on land. As the volume of sewage increased, the treatment technologies were developed from trickling filter treatment to "activated sludge" [6, 70]. Presently, the technological advancement have evolved the use of particular microbiological consortium in aerobic wastewater treatment to decompose the waste of particular characteristic to achive desired results. Conventional activated sludge process, which is aerobic, is widely adopted for treating low strength wastewater like municipal wastewater where strength is 1000 mg COD/L. This system requires energy due to the high aeration requirement which increases the cost of its operation and also produces about 0.4-0.5 g dry weight/g COD removed of sludge. Sludge generated is required to be treated and disposed off.

On the other hand, anaerobic process is found to be economical, wherein instead of energy requirement, some energy can be produced by means of methane gas production as well as anaerobic treatment generates less amount of sludge than the aerobic treatment. It is found to be an better option for treating municipal wastewater in the sub-tropical and tropical regions [57]. Table 2 provides comparison of aerobic and anaerobic treatment. Tropical regions where sewage temperature generally exceed 20 C anaerobic treatments are preferred over aerobic treatment [82]. In low-strength domestic sewage presence of suspended solids including fats contribute to 50% of chemical oxygen demand which may block fixed beds [68, 37], and cannot be retained in anaerobic reactors at high up-flow velocities [54].

Table 2: Comparison of Aerobic and Anaerobic treatment [15]

Features	Aerobic	Anaerobic
Organic removal efficiency	High	High
Effluent Quality	Excellent	Moderate to Poor
Organic Loading rate	Moderate	High
Sludge Production and Nutrient requirement	High	Low
Alkalinity Requirement	Low	High to certain Industrial waste
Energy Requirement	High	Low to moderate
Temperature sensitivity	Low	High
Startup time	2-4 weeks	2-4 months
Odour	Less opportunity for odours	Potential Odour problem
Bio-energy and nutrient recovery	Not possible	possible
Mode of treatment	Total (depending on feedstock characteristics)	Essentially pretreatment

Table 3: Advantages and Disadvantages of Anaerobic treatment

Advantages	Disadvantages
High efficiency and can be applied to large and small scale	Long start up
Simplicity, Low space requirment	Necessity of post treatment
Low energy consumption	Low pathogen and nutrient removal
Low nutrient and chemical requirment	Possible bad odours due to Generation of Hydrogen Sulfide

Aerobic or anaerobic, except in case of stabilization pond performance of the system gets severely affected by the presence of pathogens [87]. Therefore, anaerobic reactors is required to be combined with other technologies for treatment. Since both aerobic and anaerobic wastewater treatment have been upgraded due to technological advancement, how they complement to each other is required to be seen. Advantages and disadvantages of anaerobic treatment in Table 3 indicates that anaerobic treatment is useful over aerobic due to low sludge production and energy recovery but requires long startup period. Research has shown that, high as well as low strength industrial wastewater can be treated through anaerobic systems such as the upflow anaerobic sludge blanket(UASB) [10, 9], anaerobic sequencing batch reactor (AnSBR) [79, 91] and anaerobic filter (AF) [16]. The anaerobic process alone would not be able to produce an effluent of a quality that meets typical secondary effluent standards. Post-treatment will therefore be required. However, the size of the aerobic system required for the integrated anaerobic - aerobic treatment processes would be reduced because the wastewater has been pretreated by the anaerobic system and hence it becomes cost-effective for treating wastewater by reducing the aeration requirement and sludge production while achieving secondary effluent standards. Combination of anaerobic treatment with proper post treatment provides a sustainable and better quality of effluent from domestic sewage. Such treatment plan is being used successfully in tropical region [17, 14, 34].

II. AEROBIC TREATMENT

Aerobic treatment can be termed as economical in design, operation and having end product stable which is able to handle all kind of wastewater with variable composition and toxic pulses. 20% of aerobic treatent system do not meet the required discharge standards [11]. Aerobic wastewater treatment generates relatively low density of sludge in the reactor due to poor settling, which can be improved by allowing the biomass to attach to carrier like sand particles and operate in up-flow fluidized bed. However, Fluid bed treatment increases the complexity in monitoring and requires intensive control over the conventional systems.

Online monitoring of aerobic treatment processes can be done through use of parameters like oxidation reduction potential (ORP) or redox potential [64], Oxidation and pH. Oxidation is a measure of an activity of electrons in the oxidation-reduction reaction whereas, pH corresponds to microbial reactions. ORP and log of DO have a Linear relationship with each other. ORP, pH and DO parameters if monitored properly could provide stability in wastewater treatment system.[62]. Aerobic treatment can be improved by increase in metabolic activity by more diverse microbial community either by immobilized or by free floating organisms. Some of them are the addition of polyurethane foam sponges [26], addition of powdered activated carbon [77] or by combining trickling filter directly to the activated sludge process [32].

Activated sludge comprises of heterotropic bacteria, autotrophic bacteria, fungi and protozoa [52]. Other then cultural techniques, molecular biological techniques such as denaturing gradient gel electrophoresis of polymerase chain reaction (PCR-DGGE), fluorescent in-situ hybridization (FISH) helps in understanding microbial ecology in wastewater treatment systems [50] and has helped in designing the required consortium for the treatment of the wastewater. Natural treatment systems like wastewater Stabilization ponds (WSP), facultative ponds, lagoons and constructed wetland(CW) are adapted in developing countries for treating municipal and industrial wastewater primarily due to low socio-economic conditions, long retention time and for removing parasites from urban wastewaters [28]. WSP system may be in series or parallelly arranged either alone or in combination with anaerobic, facultative and maturation pond. Anaerobic and facultative ponds are used to remove BOD and maturation pond is used for removal of pathogens [65]. Advantages and disadvantages of WSP as shown Table 4 indicates that WSP is low on expenditure but requires large land area and performance of different type of ponds as shown in Table 5 indicates that ponds can be used as secondary treatment option and the effluent quality is also within the desired limits. CW using Phragmites australius after ASP showed encouraging results wherein average removal efficiency for TSS, BOD, TC and FC were 81, 89, 97 and 99% respectively and has been recommended as tertiary (polishing) unit in subtropical climatic conditions[4].

Table 4: Advantages and Disadvantages of WSP

Advantages	Disadvantages
Simplicity in design and constructions	Odour Problem if not designed properly.
Low capital, operational and maintenance cost	Large land requirement
Low production of biological Sludge	Higher sludge accumulation in cold climatic conditions
Can take shock loading and better treatment efficiency	Difficult to control ammonia level
Robust and reliable	Mosquitoes/insects can breed if not maintained properly

Table 5: Performance of different type of Natural Treatment System [65] [4]

Technology	Treatment Type	climate	D. Time (days)	Depth (m)	Organic loading (kg/ha.day)	Effl Char (mg/l)
Oxidation pond	Secondary	Warm	10-40	1-1.5	40-120	BOD=20-40; TSS=40-100
Facultative pond	Secondary	None	25-180	1.5-2.5	22-67	BOD=30-40; TSS=40-100
Partial mixed Aerated pond	Secondary, polishing	None	7-20	2-6	50-200	BOD=30-40; TSS=30-60
Storage pond, HCR pond	Secondary, storage, polishing	None	100-200	3-5	22-67	BOD=10-30; TSS=10-40
CW	Tertiary	Warm	3-5	-	1-2	TSS=81.02%; BOD=88.93 %
Root zone Treatment, Hyacinth pond	Secondary	Warm	30-50	< 1.5	< 30	BOD < 30; TSS < 30

2.1 Advanced Aerobic Treatment

To improve the settlability, aerobic granular sludge technology is used. It was used primarily for anaerobic systems during 1980's. Aerobic granular sludge can be classified as a type of self-immobilized microbial consortium, consisting mainly of aerobic and facultative bacteria and is distinct from anaerobic granular methanogenic sludge. Aerobic granules have been cultured mainly in sequenced batch reactors known as Granulated Sequenced Batch Reactor (GSBR) under hydraulic selection pressure [27]. GSBR provides stability in operation, treatment of large organic loads, removal of toxins and better quality effluents than conventional process [2].

For example, Low-strength municipal wastewater of 200 mg/L of COD was treated in sequencing batch reactor (SBR) having aerobic granulation of activated sludge. Volume exchange ratio and settling time were found to be an important factors in granulation. After operation of 300 days, it was observed that, concentration of mixed liquor suspended solids in SBR reached 9.5 g/L and had 85% granular sludge [63].This technology is developed from the laboratory-scale to pilot scale applications, but full-scale applications for municipal wastewater treatment are yet to be published. In recent studies, operational cycle length of biofilm membrane bioreactor (BF-MBR) was found increased by around 7 days due to 35% higher rate of fouling in the conventional membrane bioreactor, while no significant difference in organic matter removal was observed. [78].

III. ANAEROBIC TREATMENT

In early days, anaerobic treatment and Imhoff tank proved to be poor for removal of soluble BOD due to stricter effluent standards for municipal wastewater treatment. In mid of 1980s, anaerobic reactors such as anaerobic filter, anaerobic fluidized bed and UASB were published. Till the end of the 19 century household wastewater was treated in septic tanks. Design of high rate reactors such as UASB, due to its compactness and performance had given wide acceptance to the anaerobic treatment in the treatment of municipal wastewater treatment. The loading potential of anaerobic reactors are dependent on wastewater characteristics, the amount of viable biomass that can be retained by the system, and degree of mixing of methanogenic sludge and

wastewater. Anaerobic reactors conventionally are operated at mesophelic (30 to 40 C) or at moderate thermophilic (50 to 60 C) temperature to yield higher biomethane, some researchers even demonstrated anaerobic digestion possible at 80 C. Thermophilic reactors require energy input and are highly unstable. However, biosoilds produced are pathogen free and increased degradation rate [47]. Neutral pH is suitable for anaerobic digestion. However, researchers are able to run anaerobic process at pH level of 4.5 to 5 [49].
In anaerobic degradation sequent organisms are involved. Synergistic action of micro-organisms helps in conversion of complex substrate. The partial pressure of hydrogen and the thermodynamics of the system play an important role in anaerobic degradation.[80].

Identification and characterization of new species of their physiological behavior and their contribution in the treatment, has been possible due to research advancement in the biotech sector. Substrate affinity of both hydrogenotrophic and acetotrophic methanogensis are important factor, the first remove hydrogen down to ppm levels and the second has low substrate affinity. Aaerobic digestion is sensitive to toxicants, therefore while designing a capacity of the treatment system compostition of wastewater, type of micro-organisms involved in a system, rate of its chemical conversion, pH and temperature are considered. Anaerobic treatment gives less sludge and hence lower sludge handling cost. Further, low energy is required due to no aeration requirement. Methane is produced as a byproduct of the treatment process. However, to meet the final effluent discharge quantity standards the post treatment is required.

3.1 Advanced Anaerobic Treatment

Technological advancement in anaerobic treatment provides higher concentration of biomass, which can be achieved through auto flocculation and gravity settling by UASB reactor, by attachment to a static carrier as in case of anaerobic filter or by mobile carrier as in case of fluidized bed. Anammox bacteria can be applied for autotrophic nitrogen removal for nitrogen concentration 100 mg N/L and temperature < 20 C at a municipal wastewater treatment plant. This is found to be an energy-efficient treatment process [33]. Anaerobic treatment of wastewaters at low temperatures (8-25 C) has been made possible. Lower temperature limit for domestic wastewater treatment with anaerobic treatment lies between 8 and 4 C and threshold for relaible operation is 8 C [13]. In the future, seeding of a desirable organism (cold adopted biomass) and the time required for that organism for sewage treatment would help in better treatment such as low temperature anaerobic digestors (LTAD) for energy-sustainable wastewater treatment. LTAD is now being used on a pilot scale [56].

Sulphate reducing bacteria (SRB) are more active then MPB for utilization of substrate and volatile fatty acids. SRB generates H S which is corrosive to equipment and odours. SRBs can be found in both mesophilic and thermophilic systems and in broad range pH values, this suggests temperature and pH would act as comtrolling parameter. SRB may be effectively controlled by addition of nitrates or by micro-aeration techniques [51].

3.1.1 Anaerobic Filter

Anaerobic filter produces nutrient rich, solids free effluents and has high degree of pathogen removal. Anaerobic filter has the drawback of membrane fouling, low flux, high capital and operational costs. Anaerobic filters are coupled with CSTR, UASB, EGSB, FB reactor, Hydrolization reactor, Jet flow anaerobic bioreactor, Hybrid upflow anaerobic bioreactors. Filter material used by different researchers are Polyvinylalcoholâ€“polysulfone, Polyethylene, Polytetrafluoethylene (PTFE) Teflon, PTFE laminated, Polyvinylidene fluoride, Polyether sulfone, Non-woven fabric (polythylene terephthalate), PVDF coated with a polyether block amide. Alternative cost effective membranes, its use at a particular stage by determining the characteristics of the wastewater would certainly reduce the cost of AnMBR. Recently, dynamic membrane uses meshes, fabrics as a support material instead of real membranes, which are comparatively cheaper. Table 6 shows performance of a membrane with anaerobic treatment process for municipal wastewater treatment.
Table 6: Treatment performance of a membrane with conventional anaerobic treatment process for Municipal wastewater treatment

Reactor Type	Vol. (L)	Membrane Material	Pore size (μ m)	Area of filtration m^2	Influent COD (mg/l)	HRT (h)	COD removal (%)	MLSS (g/l)	ref
CSTR-side stream	850	PTFE	0.45	1.59	637	14.4	92	-	[31]
CSTR-submerged	900	Hollow Fiber (PURON)	0.05	30	445	6-21	87	6-22	[29]
UASB-side stream-tubular	34	Poly-acrylonitrile	0.2	185.6	5.5-10	77-81	12-32	-	[5]
UASB-submerged -flat type	45	Dacron mesh (Dynamic membrane)	61	-	302.1	8	57	5.9-19.8	[94]
Hydrolyzation reactor-membrane -FB bioreator	1000	Polyethylene	0.1	54	2187	-	98	-	[43]
Jet flow anaerobic bioreator-side stream	50	Ultra-filteration	100	1	685	15-60	88	0.5-10	[69]
Hybrid Upflow anaerobic Bioreator-submerged	17.7	Polyethylene	0.03	0.3	97.5-2600	4-6	97	16-22.5	[89]

3.1.2 Uasb

Earlier only used in high strength industrial wastewaters, UASB has found its application in domestic wastewater treatment. However, some studies under cold climatic conditions showed conventional UASB technology using granular sludge as seed material as not attractive enough for treating very dilute and very septic sewage [21]. Wide range of factors (process conditions) influence the performance of anaerobic digestion [22]. The important factors are temperature, pH, hydraulic retention time, organic loading rate, sludge granulation, seed sludge, sludge aging, degree of mixing, nutrient requirements, ammonia sulfide control, and the presence of toxins in the influent [12]. Efficiency of an anaerobic process is dependent on reactor temperature as it influences the rate of the process and is deciding factor in degradation [12, 24]. The rate of degradation of organics is enhanced at elevated temperatures (mesophilic conditions). The mesophilic temperature varies between 30-40 C. However, the effect of temperature is mainly governed by various physical, chemical, and biological processes taking place in the reactor [24]. It is found that, there is 78% decrease in the gas production rate when the temperature is lowered from 27 C to 10 C, while it has been reported that, an increase in methane production with a gradual increase in temperature [11]. A sharp drop in methane generation appears as the reactor temperature exceeds 45 C because of bacterial decay at higher temperatures ranging from 45 to 65 C. 1 m of biogas with 75% methane content provides 1.4KW-h electricity [40]. The effect of temperature on the efficiency of the anaerobic process is governed by the reactor type as well.

The pH of an anaerobic reactor in the range of 6.3 7.8 appears to be most favorable for methanogenesis. The optimum pH range for all methanogenic bacteria is 6.0 8.0, but the most appropriate pH for the group on the whole is close to 7. On the other hand, acidogenic bacteria are less sensitive to pH variations so at lower pH acid fermentation may predominate over methanogenic activity. The HRT is defined as the amount of time for which the wastewater is retained in the reactor for digestion (treatment) and is computed by dividing the volume of the reactor by the influent flow rate. The UASB reactor gives high COD removal at very short HRT. However, it is a function of effluent characteristics, which vary from industry to industry. High sulfate concentration in sewage does not affect the performance of the UASB [42].

Upflow velocity also influences the physical characters and specific activity of granules and a correlation exists between upflow velocity and size of the sludge granules. The effect of upflow velocity is more significant in operation of an upflow anaerobic reactor without gas-liquid solid separator. The increase in upflow velocity demonstrates a significant decline in removal efficiency of the system. It is found that, UASB reactor can be used as a first step for the organic matter removal and further treatment i.e. post treatment would be required to attend effluent discharge standards.

Better contact between the immobilized organisms and the influent wastewater by increasing height/diameter ratio, and recirculaing effluent helps in improving the performance. The expanded granular sludge bed (EGSB) reactors has better contact and has shown better removals of soluble pollutants, due to which EGSB has become good option for treating cold and low strength wastewater. Thus, UASB performance can be increased by increasing the contact between the wastewater and organisms.

Table 7 shows treatment Performance of a UASB reactors for Municipal wastewater treatment in some subtropical region wherein removal efficiency of COD, BOD and TSS falls in the range of 60 to 70, 70 to 80 and 65 to 75 respectively, which requires post treatment of UASB effluent.

Table 7: Treatment Performance of a UASB reactors for Municipal wastewater treatment in some subtropical region

Place	Volumn (m^3)	Temp (^{0}C)	Influent Conc. (mg/l) (COD;BOD;TSS)	HRT (h)	Removal Efficiency (%) (COD;BOD;TSS)	Period (months)	Ref
India	6000	18-32	404;205;362	8	62-72; 65-71; 70-78	11	[81]
India	12000	18-32	1183; 484; 1000	8	51-63; 53-69; 46-64	13	[81]
India	1200	20-30	563; 214; 418	6	74; 75; 75	12	[23]
Brazil	120	18-28	188-459; 104-255; 67-236	5-15	60; 70; 70	24	[85]
Brazil	106 L	20	495;195;188	4	60;69;69	-	[41]
Brazil	67.5	16-23	402; 515; 379	7	74; 80; 87	14	[86]
Mexico	0.110	12-18	465; NP; 154	12-18	65; NP; 73	12	[58]
South Africa	0.008	20	500; 148; NP	24	90; 49; 60-65	1	[66]

3.1.3 Post Treatments to UASB effluent

An anaerobic upflow reactor does not prove to be so effective in colour and pathogen removal from treated wastewater within permissible limits.UASB effluent contains dissolved sulphides, phosphate, nitrates, reduced organics and inorganics. Therefore, post treatment seems to be essential to bring anaerobically treated effluent to the level of recommended quality. Post treatment techniques include final polishing unit(FPU), shallow polishing ponds, overland flow process (OFP), submerged aerated biofilter, trickling filter(TF), aerated filter (AF), dissolved air floatation (DAF), activated sludge process (ASP), constructed wetland (CW), ozonation, rotating biological contactor (RBC), expanded granular sludge bed reactor (EGSB), down flow hanging sponge process (DHS), aerobic fixed bed reactor, biofilters, zeolite Ion exchange [60]. In addition to these systems, advanced oxidation processes (AOPs) are the emerging post treatment options. The main advantages of AOPs include a lack of byproducts of environmental concern, high process rate, and efficiency [92, 30, 3]. Trickling filters after UASB treatment is adopted where effluent standards require removal of TKN [90]. else a UASB system, followed by a polishing pond, is a used which is relatively simple and manageable treatment system.

FPU, OFP or maturation ponds helps in setting of the stabilized suspended matter of the UASB effluent. Table 3.1.3 shows economics of UASB based STP with post treatment. UASB + SBR has the lowest land requirement, but it has high capital cost requirement and moderate operation and maintenance cost. However, it has high percentage of BOD, COD and TSS removal but no biogas generation. UASB + CW has the highest land requirement 3-5 m / inhabitant, however it has lowest capital 20-30 US $/inhab and O & M cost 1-1.5 US $/inhab/year and its performance is dependent on the temperature, hydraulic load and use of plant species. UASB + PP also has low capital cost and low O & M cost i.e. 2.75 US $/inhab/month, but high land requirement 1.5-2.5 m /inhab and also it rarely attain required effluent discharge standards. However, it has a BOD, COD and TSS removal of 75-85%, 70-85% and 70-85% respectively and no biogas generation. UASB + MBR has moderate land requirement 800 m /mld and provides highest BOD, COD and TSS removal from 95-100%, but it has high capital, O & M cost and no biogas. UASB+TF may require the pumping as UASB reactors are constructed one half underground [40].

UASB+MBR provides a effluent that meets the discharge standard but requires high capital O & M cost. DHS as well as RBC requires costly growth media like sponge and discs, which requires maintenance cost but is able to reduce the BOD and coliform to required discharge standards.

Table 8: Economics of UASB based STP with post treatment [60]

UASB + post treatment	Construction cost/capital cost	Land Requirement	O and M cost
UASB + PP	30 US $/inhaba	1.5-2.5 m^2/inhab	33 US $/inhabyr
UASB + FPU	32.5 L/mld	0.18 m^2/Ml/d	2.45 US $/Ml/d
UASB + Ponds	27.9-85.6 US $/$M^3$ /d	1.70-1.98m^2/m^3/d	-
UASB + OFP	35 US $/Ml/d	1.5-3 m^2 /inhab	30 US $/inhab/d
UASB + TF	31.5 US $/PEb	0.64 m^2 /PE	0.53 US $/PE
UASB + AF	30 US $/Ml/d	-	-
UASB + DAF	35 US $/Ml/d	0.05-0.15 m^2 /inhab	5 US $/inhab
UASB + SBR	400 US $/inhab	-	5.5 US $/Ml/d
UASB + CW	20-30 US $/inhab	3-5 m^2 /inhab	1-1.5 US $/inhab/year
UASB + ASP	30-45 US $/inhab	0.08-2 m^2 /inhab	2.5-5 US $/inhab/Year

IV. PERFORMANCES OF STP IN SUB-TROPICAL REGION

4.1 India

India, with 16% of the world population is having only 2.4% and 4% of land area and water resources respectively. In India, 234 Sewage treatment plants are present, out of them 59.5 % are oxidation pond and activated sludge process, 26% of them uses UASB and rest of them uses waste stabilization pond. Normally, in India, FPU is used to treat UASB effluent [40]. As per the CPCB report of 2005 the total cost on the establishment of entire domestic wastewater treatment system was 1260 million US Dollars. also the another report of CPCB in 2007 observed that many of the treatment plants are poorly managed due to lack of skilled manpower, frequent power failures and improper sludge management [38]. Performance of wastewater treatment plants in India are shown in Table 9.

Table 9: Performance of wastewater treatment plants in India

Region	System	BOD Removed (%)	COD Removed (%)	Ref.
Dal Lake, Kashmir Valley	Fluidized aerobic bioreactor	64%	52%.	[36]
Varthur lake, Bangalore	Sewage aerobic/anaerobic lagoon	70% (Filterable)	-	[53]
SangholDistt. Fatehgarh Sahib, Punjab	High rate algal pond system	15-83%	52-93%	[45]
India	Anaerobic and facultative treatment	71.93%	73.19%	[73]
Noida and Ludhiana, India	UASB	53- 59%	41 to 55%	[42]
Jaipur	Activated sludge with gravity thickening and digestion	effluent contained <10mg BOD5/L	-	[67]
Bhopal, India	Sewage Anaerobic and Facultative ponds	-	68 -72.9	[46]
Haridwar, India	Conventional ASP	88	86.8	[75]
Rishikesh, India	Waste stabilization Pond	83.5	78.8	[75]
Saharanpur, India	UASB and final Polishing Unit	82.9	72.8	[75]
Delhi, India	Extended Aeration	90.7	89.4	[75]
India	UASB and detention ponds	50%	-	[88]
Surat, India	UASB	55	43	[83]
India	Anaerobic baffled reactor	> 90%	> 90%	[44]

4.2 Brazil

Domestic sewage is the main source of pollution of water resources in Brazil, as only 39% of the sewage is treated which leading to deterioration of water quality in many urban areas with economic and social consequences to some rivers. The national sanitation plan released in 2013 aims to provide domestic sewage collection and treatment for 93% of homes in urban area by 2033 [1].

The Brazilian Engineering Standards considered the use of septic tanks in 1963. The subsequent standards (NBR 7229/1982 and 1993) emphasized the need for reducing the organic content remaining in effluents from septic tanks by means of upflow anaerobic filters. The combination of septic tanks with upflow anaerobic filters (STANF) is considered as a temporary solution for wastewater treatment in low density urban areas. However, the reality of sanitary infrastructure in the country did not allow adoption of more efficient systems. Probably this is why septic tanks combined with anaerobic filters (STANF) became a widespread community system for domestic wastewater treatment in Brazil [19]. Presently, the UASB along with activated sludge process, submerged aerated filter or stabilization pond is used to treat many types of wastewater. Performance of wastewater treatment plants in Brazil are shown in Table 10.

Table 10: Performance of UASB wastewater treatment plants in Brazil [72]

volumn m^3	BOD Removed (%)	COD Removed (%)
0.120	78	74
120	70	60
477	-	68
67.5	80	74
9	74	79
810	73	75
1.5	-	79

4.3 Mexico

According to the National Water Commission of Mexico, in 1995 only 20 % of municipal wastewater is treated with low efficiencies. In order to increase the capacity of treatment plants in the country investment plans in environmental projects, financing mechanisms, incentives and penalties were introduced. In Mexico, anaerobic digestion has grown but not at the required rate. 228,551 m of wastewater was treated anaerobically in the year 2000, out of which 74% was treated used UASB reactors and most of them were provided by their national companies [59]. The UASB technology is found economical than facultative ponds and oxidation ditches for treating sewage both in tropical and subtropical countries [12, 84, 7]. Performance of wastewater treatment plants in Mexico is shown in Table 11 wherein COD removal efficiency have reached from 70 to 95 %.

Table 11: Performance of wastewater treatment plants in Mexico [59]

Region	System	COD Removed (%)
CooporativoTelevisa Santa Fe, Mexico City	UASB followed by anoxic and aerobic Submerged filters, fast filtration, chlorination	95
NEPSA, Mexico City	UASB followed by rapid sand filter	80
Ixtepec, Oaxaca	UASB followed by secondary settler, chlorination	70
Esperanza, Sonora	UASB followed by secondary settler, chlorination	70
Conj. urbanco, Mexico	UASB followed by chlorination	70
Cuautitlan, Ciudad Juarez, Chih	Hybrid	87.65

4.4 South Africa

The government of South Africa had adopted a green drop certification for municipal wastewater treatment and till May 2011, 32 out of 1237 municipal wastewater treatment plants were certified by the authorities with green drop. 449 wastewater treatment plants were assessed in 2009, 7% were classified as excellently manage, 38% were classified as performed within acceptable standards [55].

Wastewater treatment technologies currently deployed in South Africa for the treatment of municipal sewage which includes WSP or oxidation ponds (OP), activated sludge plants (ASP), bio-filtration (BF), biological nutrient removal (BNR), constructed wetlands (CW) [55]. Performance of wastewater treatment plants in South Africa are shown in Table 12 wherin COD removal efficiency is found in the range of 70 to 90 %.

Table 12: Performance of wastewater treatment plants in South Africa

Region	System	COD Removed (%)	Ref
South Africa	Integrated algae pond systems (IAPS)-Combined anaerobic and aerobic bio-processes	Treated water COD 72.2 mg/L	[55]
South Africa	Anaerobic baffled reactor	70-80	[20]
Kingsburgh wastewater treatment plant, South Africa	ABR (anaerobic baffled reactor)	2-80	[48]
South Africa	UASB	90	[71]

Sustainability Of Domestic Wastewater Treatment

Sustainable development as per the world commission on environment and development (WCED, 1987): ‘Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs’. Sustainability of domestic wastewater treatment can be assessed by human health, functional, economic, environmental, and social-cultural aspects. Some of the indicators are hard to quantify and depends more on weighted analysis. Sustainability indicators are quantified through mass and energy balances and cost-benefit analysis [8]. The impact analysis is the decision making process and is the final step towards knowing the sustainability of technology. The literature of sustainability assessment of wastewater treatment system indicates a weightage assigned to minimise cost, energy use, land area requirement, nutrients, waste production and to maximise clean water, bio-gas, biomass, fertilizer, compost, etc.

Burden to Capacity Sustainability Assessment (B2C SA) has emerged recently as a result of extensive research where influence of sustainability indicator’s impact and influence is enhanced in decision making related to designing, implementing and operating a sanitation programme [61].

Table 13: Sustainability Assessment of treatment plants

Indicator	Assessment parameters
Technical/functional	System robustness, complexity of construction, Operational and Maintenance aspects, capacity, Flexibility, adaptability, Know how/knowledge of implementation and management
Environmental	Percentage removal of TSS, BOD, COD, Energy Consumed/Water treated, N, P in discharged water, Sludge produced
Human Health	Risk of waterborne infections, Sewerage connections
Social Acceptance	Remotely placed, odor, birds and flies nuisance, public awareness, public approval for the installation of Treatment Plant
Economic	Manpower cost, chemical cost, land cost, power cost, gas and fertilizer produced, Wastewater Transport cost, Operational and Maintenance cost

Several technologies are available for the treatment of the domestic wastewater as can be seen from the studies done on some subtropical countries. Technologies used were activated sludge process (ASP), trickling filter (TF), waste stabilizing pond (WSP), UASB with final Polishing Unit (FPU), UASB with extended aeration system (EAS), UASB with other post treamtent options, moving bed bioreactor (MBBR), sequencing batch reactor (SBR), memberane bioreactor(MBR). some other technologies are solid immobilised biofilter (SIBF), multiple stage filtration (MSF), Ecosan (UDDT), decentralized wastewater Treatment System (DEWATS) with anaerobic baffled reactor (ABR).

Table 14: Evaluation of Natural Treatment System [76]

Parameter	Facultative Pond	Facultative Aerated lagoons	Septic Tank-Anaerobic filter	Rapid Infiltration	WSP	CW
Overall HRT (Days)	15-24	3-9	1-2	-	8-15	3-5
BOD Removal, %	35-40	75-90	70-90	86-98	75-85	85-95
N Removal,%	10-25	30-50	10-25	10-80	-	45-55
P Removal,%	10-20	20-60	10-20	30-99	-	45-55
Coliform Removal,%	30-40	60-96	60-90	> 99	upto 4 < 5 log unit	90-99
Land Required,(m^2/PE)	0.03-0.05	0.25-0.5	0.2-0.4	1-6	0.97	0.75-2
Construction Cost US$/PE	20-30	10-25	30-80	5-15	2.63	30-50

Table 15: Evaluation of different treatment processes [39][74]

Parameter	ASP	TF	UASB with FPU	UASB with EAS	MBBR	SBR	MBR	DEWATS (ABR)
Overall HRT (Whole system)	12-14 Hrs	13-14 Hrs	1.33-1.5 days	14-18 Hrs	8-12 Hrs	14-16 Hrs	12-14 Hrs	1-2 days
BOD Removal,%	85-95	80-90	80-88	80-95	85-95	90-95	95-98	88.7
COD Removal,%	80-90	85-90	80-85	80-90	80-90	88-96	95-100	88.5
TSS Removal,%	85-90	75-85	80-85	85-90	85-95	90-96	98-100	99.9
FC Removal, log unit	upto 3 < 4	upto 2 < 3	upto 1 < 2	upto 2 < 4	upto 2 < 4	upto 2 < 4	upto 6 < 7	97.5%
Average Area Required,(m^2/PE)	0.221	0.196	0.218	0.176	0.054	0.036	0.097	0.092
Capital Cost US$/PE	6.88	6.075	6.58	6.88	8.74	11.74	17.21	-
Biogas Generation, m^3	55-70	55-70	35-50	35-50	Nil	Nil	Nil	0.2 m^3 CH_4/Kg COD
Annual O&M maintenance costs US$/PE	1.55	1.44	0.435	0.662	2.14	2.34	5.60	-
Net present worth of Investment US$/PE	31.24	18.20	10.59	12.74	26.29	28.89	49.18	-

It is found that, anaerobic treatment especially offers very attractive prospects for developing countries because of its several merits such as high efficiency, cost-effective, simple in construction and operation, both in tropical and subtropical regions. Modern anaerobic processes are successfully applied to the treatment of municipal wastewaters because of their advantages like high nutrient removal and retenting of active sludge within the reactor.[18]. Natural turbulence at the inflow and bio-gas production also helps in imrproving biomass contact in lesser reactor volume.

Table 16: Type of reactors used in subtropical region [25]

Reactor	Number
UASB	793
Anaerobic Contractor	112
Anaerobic Filter	104
Anaerobic pond	66
Internal Circulation	50
EGSB	50
Hybrid	33
Fluidized Bed	21

1200 anaerobic treatment plants are installed worldwide and out of which 40% of them are in subtropical regions [25]. The application of anaerobic treatment in subtropical region is in agro-industries, chemical industries, landfill leachate and municipal wastewater [25]. Table 16 describes the number of installation of technology for the treatment of wastewater anaerobically. It can be seen that UASB followed by anaerobic contractor & Anaerobic Filter are used mostly in sub-tropical countries. The literature of sustainability assessments of wastewater treatment systems lists indicators as shown in Table 13. Evaluation of treatment processes on the basis of cost, land requirment and the qualitity of treatment are shown in Table14 and Table15. Based on above factors it would be possible to identify technology that would be sustainable. It is observed that, MBR is best on the removal of COD, BOD and TSS but is not good on capital cost and O&M cost. Whereas, WSP is not so good on COD, BOD and TSS removal but is better on capital cost and O&M cost. However, due to stringent norms of effluent discharge a cost effective technological solution is required that would meet the local requirement. UASB with post treatment or system like DEWATS offers a cost effective as well as better treatment of the domestic wastewater [74].

IV. CONCLUSION

Sustainable wastewater treatment technology is chosen by systematic evaluation of the technical, environmental, societal, and economic indicators and incorporating local parameters such as characteristics of wastewater, climatic conditions, investment requirement. Adoption decision is done based on cost, energy use, land area requirement, loss of nutrients, waste production and maximize biogas generation and meeting the required permissible discharge standards. It is observed that, composition of raw municipal wastewater largely and ranges from 500-1200 mg/L of COD and 230-560 mg/L of BOD. The wide variation requires a technology which can handle shock loads and has the capacity to treat large volumes of waste and it can also manage shock organic loading but drawbacks are high aeration costs, nutrient requirement, sludge handling, large footprint and odour which makes it unsustainable. However, this technology can be efficiently utilized after anaerobic treatment as a post treatment option.

Another option is to use natural treatment technologies such as oxidation ponds, facultative ponds, partially mixed aerated ponds, constructed wetland treatment wherein the operational and maintenance cost is low, but requires large foot print area. In semi urban and rural areas availability of land relatively is not a problem, can be suitably adopted in subtropical regions where the BOD loading is moderate or low. However, it has been observed that the major drawback is large detention time which may be overcome by providing multiple ponds in series or in parallel or by converting those ponds into lagoons. Anaerobic treatment such as UASB, AF, AnSBR, EGSB, has been most sought after technology. UASB has been tried with several permutations and combinations of post aerobic treatment like polishing ponds, ASP, trickling filters, SBR, DHS, RBC, MBR, constructed wetland, overland flow and advanced oxidation processes. Anaerobic treatment has the advantage of high efficiency, simplicity, low space requirement, low energy consumption, and generation of energy. Though, it is more sensitive towards temperature fluctuations, pH variation and requires close monitoring of operational parameters. It also requires high startup time from 2 to 4 months. But stand-alone anaerobic treatment do not conform to the standards of discharge, therefore further treatment is necessary for acceptable effluent.

Economics related to UASB and various post treatment options suggests that the UASB+SBR has the lowest land requirement, but it has high capital cost requirement and moderate operation and maintenance cost. However, it has high percentage of BOD, COD and TSS removal but no biogas generation. UASB+CW has the highest land requirement 3-5 m /inhabitant, but it has lowest capital 20-30 US$/inhab and O&M cost 1-1.5 US$/inhab/year. UASB+PP also has low capital cost and low O&M cost 2.75 US $/inhab/month, but high land requirement 1.5-2.5 m /inhab. It has a BOD, COD and TSS removal of 75-85%, 70-85% and 70-85% respectively and no biogas generation. UASB+MBR has moderate land requirement 0.097 m /PE and yields highest BOD, COD and TSS removal from 95-100%, but it has high capital, O&M cost and no biogas.
In subtropical developing countries such as India, Brazil, South Africa and Mexico it has been observed that stabilization ponds and ASP are mostly used to treat domestic wastewater. Recent trend is towards anaerobic treatment particularly UASB. Moreover, more than 50% of the waste remains untreated and most of the treatment plants installed do not conform to the defined environmental guidelines which conclude either to upgrade existing one or to install new one for compliance of environmental guidelines. It is recommended that, if the region is semi-urban and rural area where land is available, natural treatment technologies or DEWATS like system may be utilized. In urban region, it is recommended that UASB followed by suitable post treatment, which conform to the effluent standards, may be adopted.

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