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Post treatment of up-flow anaerobic sludge blanket based sewage treatment plant effluents: A review

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ABSTRACT

Biological processes are aerobic and anaerobic commonly used for wastewater treatment. Treated sewage from various wastewater treatment plants is mostly used for irrigation purposes or simply discharged into rivers. However, major drawbacks of this disposal are the input of contaminants like organics (high BOD, COD), pathogens and suspended solids into the aquatic ecosystem. This paper presents a critical review on the treatment of domestic sewage by anaerobic process and specifically in the up-flow anaerobic sludge blanket (UASB) reactor and its post treatment concept as the core. The increased removal efficiency of the UASB reactor when post treatments for UASB are used is summarized. Percent removal efficiencies of parameters, land requirement, mode of operation and operation and maintenance cost are considered for different combinations of post treatment units with UASB. Overall 16 combinations (UASB + post treatment) are taken into consideration for this review. In all combinations, ranges of 23–99%, 15–97%, and 27–97% removals were found for BOD, COD and TSS having 4–24 h and 0.3 h–24 d hydraulic residence time for UASB reactors and post treatment units respectively. Coliform removals were found from 0.3–5 log units having final concentrations from $2.1 \times 10^2 - 1.0 \times 10^6$ MPN/100 ml. From the present paper it may be recommend that UASB combination with activated sludge process and constructed wetlands are good in their performance and can be used in developing countries.

Keywords: Anaerobic treatment; Up-flow anaerobic sludge blanket reactor; Post treatment; Aerobic treatment; Municipal wastewater

1. Introduction

Municipal sewage treatment consists of an item that deserves ample documentation due to the environmental impact caused by such wastewater if directly discharged into receiving water. In addition, due to an increase in the scarcity of clean water there is a need for appropriate management of available water resources. Some of the goals of environmental protection and resource conservation concepts are the re-use of treated wastewater, residues emanating there from, and other treatment by-products [1,2]. Consequently, by implementing these concepts, a wastewater like municipal sewage, apart from being sanitized, can become an important source of re-usable water, fertilizer, soil conditioner and energy. Anaerobic digestion promises a high potential in most of the developing countries for domestic wastewater treatment, and thus is a suitable and economical solution [3]. The anaerobic process can serve as a viable alternative, compared to conventional aerobic processes [4,5], for a variety of reasons like less land requirement, less sludge generation, less energy

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requirement as no aeration is needed, and most important energy generation in the form of methane gas. The fact that the process can be carried out in decentralized mode means also that this application can lead to significant savings in investment costs of sewerage systems [6]. But the effluent coming from this has more chemical oxygen demand (COD), biochemical oxygen demand (BOD) and coliforms which generally do not meet the standards set by world health organization (WHO) for discharge of effluent in to surface water and re-use of water for agriculture purposes which causes risk to the aquatic life [7–9]. Therefore post treatment is required for the effluents which are going to be discharged in the aquatic environment from anaerobic treatment systems.

There are many post treatment processes available for anaerobic STPs which are utilizing in combinations like ozonation, activated lagoons, polishing ponds, stabilization ponds, etc. Besides percentage removal of some common parameters, some more aspects are also important, like land requirement, mode of operation, operation and maintenance cost for considering at the time of implementing the appropriate combination. Technical and non-technical parameters of the process vary for developed and developing countries. The present paper critically reviews the performance of some commonly used conventional post treatment methods used for the treatment of anaerobic effluents especially for up-flow anaerobic sludge blanket based sewage treatment plants (STPs) effluent.

2. Anaerobic treatment process

The concept of anaerobic treatment of municipal wastewater was first developed in the early 1980s from research work by Lettinga and his co-workers, who were looking at the feasibility of anaerobic treatment using UASB at ambient temperatures [10]. Since then, a considerable amount of research has been carried out on municipal wastewater treatment using various anaerobic reactor types. It is recognized as a core method for a sustainable and non-vulnerable environmental protection concept [1]. With comparison to aerobic or physicochemical treatment systems, anaerobic systems are cost effective in terms of investment and operating cost, reliability and durability. Technological point of view, for achieving high system loading rates, short hydraulic retention times should be applied, while at the same time maintaining positive net biomass retention. For maintaining biomass within the system, many reactor designs were developed [11]. Many anaerobic systems like anaerobic lagoons, anaerobic contact process, up flow anaerobic sludge blanket reactors, fixed film or anaerobic filter, fluidized bed (FB) system, hybrid systems, and expanded granular sludge bed systems (EGSB) were developed. Most popularly used UASB design, originally proposed by Lettinga, was one of the earliest to rely on the establishment of a granular biomass [12]. Due to excellent settling characteristics of this granular biomass, good sludge retention is assured because of specially designed three phase separators i.e., gas, liquid, and solid separator (GLSS). The technology originates from the Netherlands and is promoted by companies such as Biothane, Biotim (Belgium), Grontmij, Haskoning, Kurita (Japan) and Paques [11].

During anaerobic treatment, a complex microbial community [13] consisting of many interacting microbial species degrades natural polymers such as polysaccharides, proteins, nucleic acids, lipids, etc. in the absence of oxygen, into methane and carbon dioxide [14]. The unique characteristic of anaerobic treatment by methane fermentation is that no electron acceptor like oxygen or nitrate is needed for the process to work. In contrast, aerobic processes, which are widely, used for the treatment of wastewater, have at least two distinct disadvantages; viz. their relatively high energy requirement and high excess sludge production; which require handling, treatment and disposal. Anaerobic wastewater treatment is generally advantageous for removing organic matter from wastewater without consuming large amounts of electrical energy. These advantages (Table 1), associated with the favorable environmental conditions in warm-climate regions, where high temperatures prevail practically throughout the year, have contributed to establish the anaerobic systems, particularly the UASB reactors, in an outstanding position. The anaerobic treatment system is an efficient process for the removal of organic material and suspended solids. It has little effect on the concentrations of macronutrients (nitrogen and phosphorous), while pathogenic organisms are only partially removed [15]. Therefore it can be said that the high-rate anaerobic reactors, like UASB used for the treatment of domestic sewage, are a consolidated technology in some warm-climate countries, especially in Brazil, Colombia and India, with several treatment systems operating in full scale.

2.1. Up-flow anaerobic sludge blanket reactor

In the up-flow anaerobic sludge blanket reactor, the influent is distributed uniformly over the bottom of the reactor and then following an up flow path; it rises through a thick layer of anaerobic sludge, from where it is withdrawn at the top of the reactor. Thus, the contact between the influent organic material and the sludge mass in the reactor is automatically guaranteed. In order to maintain a large sludge mass, the UASB reactor has a built-in phase separator, where the dispersed solids

Table 1
Advantage and drawbacks of anaerobic sewage treatment [81]

Advantages	Drawbacks
A substantial saving in operational cost as no energy is required for aeration. On the contrary energy is produced in the form of methane gas, which can be utilized for heating or electricity production. Hence it couples the degradation of organic material from waste to the production of energy.	Need for post treatment, depending on the requirements specified for effluent standards.
The process can handle high hydraulic and organic loading rates. Thus, the applied technologies are rather compact and reduce the volume of treatment stages.	Considerable amount of produced biogas i.e. CH_4 and H_2S remain dissolved in the effluent especially for low strength wastewaters (sewage).
The technologies are low cost and simple in construction and operation.	Often it is not economically feasible to utilize CH_4 produced during anaerobic treatment of sewage for energy production.
The system can be applied at any scale enabling decentralized mode of treatment. It leads to significant saving in the investment cost.	Hydrogen sulfide is produced during the anaerobic process, especially when there are high concentrations of sulfate in the influent. Proper handling of the biogas is required to avoid bad smell.
The excess sludge production is low. In addition, the sludge is well stabilized and easily dewatered due to high solid retention time (SRT). Thus the sludge does not require excessive costly post treatment.	The start-up takes longer as compared to aerobic processes.
The valuable nutrients (N and P) are conserved which make treated effluent suitable for crop irrigation and aquaculture.	
Feasible for wide range of wastewaters, i.e. complex in composition, very low and very high in strength, and low and high temperatures.	

are retained by settling, so that an effluent virtually free from suspended solids can be discharged. The retained sludge particles will end up sliding back from the settler compartment into the digester compartment and accumulate there, thus contributing to the maintenance of a large sludge mass in the reactor. High-rate anaerobic reactors are becoming increasingly popular for the treatment of various types of wastewaters because of their low initial and operational costs, smaller space requirements, high organic removal efficiency and low sludge production, combined with a net energy benefit through the production of biogas [10]. The up-flow anaerobic sludge blanket process concept is based on the idea that anaerobic sludge inherently exerts satisfactory settling properties, provided the sludge is not exposed to heavy mechanical agitation [12]. The most important feature of the UASB system is the sludge granulation phenomenon. Operation of these reactors is based on the immobilization of high concentrations of biomass. More than 900 UASB units are currently operating all over the world [16]. Granular sludge is the prominent characteristic of the UASB reactors as compared to other anaerobic technologies. In an UASB reactor, anaerobic microorganisms can form granules through self-immobilization of bacterial cells, and the performance of the UASB system is strongly dependent upon granulation process with a particular wastewater [17]. Removal efficiencies of various UASB reactors are given in Table 2. Up flow anaerobic sludge blanket reactors are generally more resistant to toxic compounds, due to the structure of granular sludge, and have been used for the treatment of effluents containing xenophobic and recalcitrant compounds [18,19].

2.2. Need for the post-treatment

The main role of the post-treatment is to completely remove the organic matter, nutrients (N and P) and pathogenic organisms (viruses, bacteria, protozoans and helminths). The importance of the parameters depends on how the final effluent is to be used. In India, treated sewage is often used for irrigation purpose or simply discharged into rivers. Therefore, to justify these needs, effluent discharge limits for some important parameters like BOD, COD, TSS and pathogens are 30 mg l^{-1}, 250 mg l^{-1}, 100 mg l^{-1} and 10,000 most probable number (MPN) per 100 ml set by Indian Government [20]. Effluents from the UASB reactors rarely comply with

Table 2
Review of full scale UASB process removal efficiency

Place	V (m^3)	T (ºC)	Influent concentration (mg/l)			HRT (h)	Removal efficiency (%)			Reference
			COD	BOD	TSS		COD	BOD	TSS	
India	1200	20–30	563	214	418	6	74	75	75	[30]
Colombia	3360	24	380	160	240	5.0	45–60	64–78	60	[76]
India	12000	18–32	1183	484	1000	8	51–63	53–69	46–64	[83–84]
India	–	–	387	195	360	–	57	64	66	[85]
India	6000	18–32	404	205	362	8	62–72	65–71	70–78	[84], [86]
India	36000	–	1180	480	1000	–	56	61	55	[87]
Brazil	810	30.8	549	313	196	9.4	75	73	51	[59]
India	36000	–	838	398	846	–	52	50	56	[88]
India	–	–	315–403	–	162–836	4.49–5.49	45–78	–	45–76	[89]
India (15 UASBs)	10000–78000	18.8–23.8	754	258	410	8.4–10.7	46.5	49.6	7.31	[8]
India (5 UASBs)	27000–70000	–	373–452	159–175	324–419	9.4–10.3	42–55	55–69	30–43	[9]

Table 3
Various post treatment options for UASB reactor

Sr. no.	STP_s	Post treatment unit	References
1	UASB	Final polishing unit (FPU)	[8], [9], [32], [82], [90], [91]
2	UASB	Shallow polishing ponds (SPP)	[8], [85]
3	UASB	Overland flow process (OFP)	[22], [25]
4	UASB	Submerged aerated biofilter (SAF)	[39], [40]
5	UASB	Trickling filter (TF)	[41]
6	UASB	Aerated filter (AF)	[44]
7	UASB	Dissolved air floatation (DAF)	[46], [47], [48]
8	UASB	Activated sludge process (ASP)	[49]
9	UASB	Constructed wetland (CW)	[50], [51], [52]
10	UASB	Rotating biological contactor (RBC)	[55–57]
11	UASB	Expanded granular sludge bed reactor (EGSB)	[59], [92]
12	UASB	Ozonation (OZ)	[60]
13	UASB	Down flow hanging sponge process (DHS)	[61], [62], [63], [64]
14	UASB	Aerobic fixed bed reactor (AFB)	[65]
15	UASB	Biofilters (BF)	[39]
16	UASB	Zeolite Ion Exchange (ZIE)	[66]

stringent emission standards [7]. These constraints are probably the cause that has mostly limited the use of anaerobic systems (without post-treatment) for sewage treatment. Table 3 shows the combinations of post treatment units with UASB reactors. Total of 16 combinations are considered for this review paper. The discharge of nutrients into surface water bodies may cause increased algal biomass as a result of the eutrophication process. According to one estimate [21], 1 kg of phosphorous can reconstruct 111 kg of biomass in terms of green plants which approximately corresponds to 130 mg l^{-1} of COD. Similarly discharging of 1 kg nitrogen will generate 20 mg l^{-1} of COD in surface waters [22].

Anaerobic sewage treatment systems generally fail to comply with COD discharge standards as that established by Council Directive 91/271/EEC on urban waste water treatment dictated, or the guidelines proposed for unrestricted irrigation (less than 1000 fecal coliform per 100 ml, and less than 1 helminths egg per L) [23,24]. Therefore, a post-treatment step is a mandatory one in most of the cases to remove remnant COD, fecal coliform (as an indicator of pathogenic microorganisms), helminths eggs, and even nitrogen and phosphorus when direct reuse is not feasible.

The removal of helminths eggs in anaerobic reactors, particularly in UASB reactors, has been reported as amounting to 60–90% [22,25], therefore insufficient to produce effluents that may be used in irrigation. Reasons against the implementation of anaerobic processes that have been provided by some established wastewater treatment companies focus on three main points: (1) anaerobic reactors spread unpleasant odor; (2) anaerobic reactors are unstable; and (3) high performance reactors such as up-flow anaerobic sludge blanket reactors cannot cope up with high load rate variations. The performance of anaerobic reactors can deteriorate when a change in the composition of the wastewater occurs [26]. Detergents [27,28] and long-chain fatty acids [28] can cause toxicity or inhibitory effects on anaerobic treatment. The removal of suspended solids (SS) is one of the main objectives of sewage treatment. The presence of high concentrations of SS in the influent, the slow degradation of SS entrapped in the sludge bed, and the washout of incoming SS and/or biological sludge are cited as the main causes of bad effluent quality in UASB reactors treating sewage below 20 °C [29]. SS removal in UASB reactors depends on the type of sewage and the combined effect of the sludge bed height and the liquid up flow velocity in the reactor. The latter parameter is related to the hydraulic retention time (HRT) and the reactor height.

A full-scale UASB reactor has been in operation since April 1989 for domestic sewage in the town of Kanpur (India). This plant was designed to treat 5000 m^3 of raw sewage per day. Results obtained during a monitoring period of 12 months [30]. Removal efficiencies of COD, BOD and TSS were observed to be 74, 75, and 75 % respectively at a nominal HRT of 6 h. In order to meet Indian standards and to meet the guidelines of WHO [24] for discharge into surface water, post-treatment is required. Taking into consideration the intrinsic limitations associated with the UASB reactor and the need to develop technologies that are more appropriate for developing countries, it is important to include a post-treatment stage for the effluents generated from UASB reactors. Table 4 shows a review of UASB reactors removal efficiencies with the use of post treatment units. This stage has the purpose of polishing not only the microbiological quality of the effluents, in view of the public health risks and limitations imposed on the use of treated effluents in agriculture, but also the quality in terms of organic matter and nutrients. Some of the main possible combinations of UASB reactors with post-treatment systems are discussed below. Figs. 1–3 shows the removal efficiency of the UASB reactor based STP_s with the post treatments.

3. Generally used post-treatment options

3.1. Polishing ponds or final polishing units

Polishing ponds (PP) or final polishing units (FPU) are largely used for post-treatment of effluents from anaerobic reactors. These systems have an advantage of removing the pathogenic organisms present in the sewage. When an efficient anaerobic pre-treatment is applied prior to the sewage discharge into a pond, the concentrations of organic matter and suspended solids are largely reduced, and consequently only a complementary removal of these two constituents will be required, needing much lower hydraulic detention times. The UASB reactor + polishing pond configuration is a very interesting alternative from the technical–economical–environmental point of view. In addition, the problems related to odors from anaerobic ponds can be avoided in plants utilizing UASB reactor and polishing pond, since the anaerobic reactor can be installed with odor control [31,32]. This alternative is even more attractive when the effluent from the pond can be used for agricultural purposes, since the polishing ponds aim mainly at the removal of pathogenic organisms. Long term studies conducted by [33] have shown that a domestic sewage treatment system, comprising UASB reactor followed by four very shallow (0.40 m-depth) polishing ponds in series, operated with very low detention times (1.4–2.5 d in each pond), was able to achieve excellent results in terms of BOD and *E. coli* removal, and also good results in terms of ammonia removal. In relation to helminthes eggs, other studies have shown that polishing pond systems are capable of producing effluents with helminthes eggs concentrations predominantly equal to zero, and satisfying the WHO guidelines for unrestricted and restricted irrigation [22].

3.2. Shallow polishing ponds

Shallow polishing ponds (SPP) are also called polishing ponds but in present study, they are kept separate. In general polishing ponds or final polishing units have 1–1.6 d retention period, but in shallow polishing ponds it is a combination of three polishing ponds and one rock filter having HRTs 3.1 d, 3.1 d, 4.2 d, 2.0 d, respectively, which is working effectively in Brazil in terms of discharge standard guidelines [34].

3.3. Overland flow process

Sewage treatment by the overland flow process (OFP) is the one that presents the lowest relationship with the type of soil. In this method, the vegetation, associated with the top soil layer, acts as a filter, removing the nutrients and providing conditions for the retention and transformation of the organic matter contained in the sewage. Besides that, it protects the soil against erosion and creates a support layer on which the microorganisms settle. The main mechanisms through which organic matter and solids removed are biological oxidation, sedimentation and filtration [35,36]. The main

Table 4
Comparative analysis of post treatment efficiencies

Country	UASB effluent				HRT (h)	Post treatment	HRT	Effluent concentration				References
	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	Coliforms (MPN/100 mL)				COD (mg/L)	BOD (mg/L)	TSS (mg/L)	Coliforms (MPN /100 mL)	
India (FS)	183–239	53.8–75.2	184–242	—	9.4–10.3	FPU	1–1.6 d	132–161	28.7–379	108–120	4.62×10^5	[9], [91]
India (FS)	403	130	380	1×10^6	8.4–10.7	FPU	1–1.6 d	238	96	262	4.6×10^5	[8]
India (FS)	—	46	60	4.24×10^7	7.5	SPP	12.7 d	—	27	26	4.5×10^2	[90]
India (PS)	180	60	70	—	—	OFP	—	90	30	20	10^4–10^6	[22]
Brazil (PS)	88	21	30	—	4	SAF	0.3 h	49	10	10	1×10^6	[22], [40]
Ghana (FS)	340	73	—	2×10^5	—	TF	—	146	23	—	2.16×10^2	[41]
Brazil (PS)	108	55	30	—	6	AF	12 h	80	31	19	1×10^6	[22], [44]
Brazil (LS)	—	—	—	—	8	DAF	—	—	—	—	—	[47]
Egypt (LS)	1385	576	300	$\log_{10} 5.6$	24	ASP	2 h	35	7	14	8.95×10^3	[49]
Egypt (PS)	152	66.7	49.3	4.4×10^{10}	8	CW	3 d	21.4	6.4	2.6	1.6×10^2	[50]
The Netherlands (PS)	165	—	—	1.6×10^6	14–17	RBC	2.5 h	72	—	—	1.1×10^5	[57]
Brazil (LS)	156	—	123	—	—	EGSB	4 h	79	—	32	—	[59]
Brazil (PS)	126	42	51	1.2×10^6	7	OZ	0.5 h	75	21	13	1.1×10^4	[60]
Japan (PS)	178	67	47	6.2×10^7	10.7	DHS	10.7 h	43	2.3	12	2.7×10^3	[64]
Japan (PS)	103	39	26	—	24	AFB	24 h	54	11	10	—	[65]
Brazil (FS)	112	36	37	—	—	BF	—	49	9.7	10	—	[39]
Belgium (LS)	53	25	35	—	10	ZIE	—	45	32	24	—	[66]

PS — pilot scale, LS —laboratory scale , FS — full scale plants characteristic that differentiates this method from the others is the fact that the effluent flows downward on a slightly inclined vegetated ramp and the remaining water (effluent), which is neither absorbed nor evaporated, is collected downstream and directed for disposal. In relation to the microbiological quality of the final effluent, an excellent removal of helminthes eggs in the UASB reactor + overland flow process was observed, with an average counting of 0.2 egg l^{-1} in the final effluent [25,37].

3.4. Submerged aerated biofilter

A submerged aerated biofilter (SAF) consists of a tank filled with porous material, through which sewage and air flow permanently. In almost all the existing processes, the porous medium is maintained totally submerged by the hydraulic flow. The biofilters are characterized as three-phase reactors, viz:

- Solid phase: consisting of the support medium and colonies of microorganisms present in the form of a biofilm;
- Liquid phase: consisting of the liquid in permanent flow through the porous medium; and
- Gas phase: formed by the artificial aeration and, in a reduced scale, by the gases deriving from the biological activity.

Studies conducted by Goncalves and his coworkers have shown that UASB reactor + submerged aerated bio-filter systems are capable of maintaining stable operational conditions despite influent load variations and recycle of aerobic sludge discharged from the biofilter (BF) [38–40]. Submerged aerated biofilter can be installed to serve up to 3000 population equivalent (PE). Typical advantage of SAF is the guaranteed system performance which produces high quality effluent, eliminates the air and water distribution problem. SAF requires no backwash, minimum process monitoring, and eliminates the plugging potential.

3.5. Trickling filter

A trickling filter (TF) basically consists of a tank filled with a highly-permeable material, onto which wastewater is loaded in the form of drops or jets. Wastewater percolates towards the bottom drains, allowing bacterial growth on the surface of the packing material, in the form of a fixed film (biofilm). Wastewater passes over the biofilm, allowing a contact between the microorganisms and the organic matter. This association (UASB reactor + TF) may contribute significantly to the reduction of the power and operational costs of the treatment plant. Though the trickling filters have great potential in wastewater treatment systems, mainly due to the advantages of their simplicity and low operational cost, only a few units have been implemented so far with the purpose of performing the post-treatment of effluents from anaerobic reactors [34]. Modern TF is an advanced form of rock filter with cost effective treatment of both domestic and industrial wastewater [41].

3.6. Anaerobic filter

Among the high rate anaerobic reactors, anaerobic filters (AF) or anaerobic biofilter (ABR) looks promising for municipal wastewater treatment. Bachmann et al. [42] developed the first ABR, which was described as a series of UASB reactors. This design consisted of a series of vertical baffles to force wastewater to flow upwards through a series of compartments containing the mixed anaerobes as they passed from the influent to the effluent. The bench-scale ABR has been found to be effective for the treatment of high as well as low strength soluble wastewaters [43]. Nowadays, anaerobic filters, after UASB reactors, are being used in cities with population larger than 50,000 inhabitants [22]. The complementary organic matter removal achieved in the anaerobic filter occurs by:

i. The retention of solids in the anaerobic filter, reflecting on the removal of particulate matter, and
ii. The formation of biofilm on the packing medium and removal of the remaining soluble organic matter.

This association of anaerobic processes contributes greatly to the reduction of power and operational costs of the treatment plant. Chernicharo and Machado [44] have evaluated the use of pilot and demonstration scale anaerobic filters (AF) for the post-treatment of anaerobic effluents from septic tanks and UASB reactors. With HRT of minimum 8 d maximum COD removal can be obtained [45].

3.7. Dissolved air flotation

Reali et al. [46] investigated post-treatment of anaerobic effluents by dissolved-air flotation (DAF) using batch flotation test equipment. DAF units are capable of producing very high quality effluents in terms of TSS, COD and phosphorus. The DAF units are compact in nature and require less operational cost. However, the removal efficiency of ammonia, nitrogen, and fecal coliforms is poor. DAF is a high rate process, which means reduction in space requirement and in sludge thickening. DAF system offers some degree of flexibility, subject to design variations [47,48].

3.8. Activated sludge process

The activated sludge process (ASP) has been widely applied in the treatment of industrial wastewater and municipal wastewater. The activated sludge process is a suspended culture system that has been in use since the early 1900s. Name itself suggests settled sludge containing living or active microorganisms. It may be completely mixed flow or mixed flow system. The process is aerobic with O_2 being supplied by dissolution from entrained air. Activated sludge processes consist of a tank, within which the biological reaction occurs, a settling tank, a recycle pumping system and an aeration system. Classification based on loading range or the organic matter available to the microorganism is high, medium or low. Atmospheric air or pure oxygen is bubbled through primary treated sewage combined with organisms to develop a biological floc which reduces the organic content of the sewage. Among other advantages this system offers operational flexibility, an easy and quick start-up, a high efficiency, low effluent COD concentration while it enables nutrient removal [49].

3.9. Constructed wetlands

Constructed wetlands (CW), when compared to conventional system and natural systems, use less energy and require less skilled labor. CW technology is more widespread in industrialized countries due to more stringent discharge standards, finance availability and change in tendency to use on-site technologies instead of centralized system. Variety of applications for CW technologies for water quality improvement has also started to be implanted in developing countries like Kenya, Mexico, Nepal, Nicaragua, Tanzania, Uganda, India, Morocco, Iran, Thailand and Egypt. Two flow regions exist between the systems, viz: free water surface and sub surface flow. All constructed wetlands are attached growth biological reactors. Through physical, chemical and biological mechanisms CWs offer higher effluent quality than that from typical oxidation pond systems. The common removal mechanisms associated with wetlands include sedimentation, coagulation, adsorption, filtration, biological uptake and microbial transformation [50–52].

3.10. Rotating biological contactor

The rotating biological contactor (RBC) is an aerobic biological treatment system based on bio-absorption principle. It uses captive biological slimes to remove substance from the liquid wastewater by physical and biological means. Rotating biological contactor treatment design criteria is generally based on hydraulic loading [53]. The principal advantages of the RBC system lies in the fact that the interfacial area generated is very high and practically independent of the speed of rotation, unlike in the activated sludge process [54–57].

The rotating biological contactor method is not suitable for highly chlorinated organics, aliphatics, amines, and aromatic compounds. Since, heavy metals and organic chemicals may kill the microorganisms. Heavy metals and non-biodegradable organics may also concentrate in the sludge and hydrogen sulfide gas may also be released.

3.11. Expanded granular sludge bed reactor

Expanded granular sludge bed (EGSB) reactor is mainly used to control preferential flows, hydraulic short cuts and dead zones which occur in UASB reactor. The up flow velocity of the fluid in the UASB reactor is increased by expanded granular sludge bed reactor. Also the rate of production of biogas is increased with the same process. But the design part of the expanded granular sludge bed reactor requires a special attention to prevent biomass washout in the effluent, which would drop the reactor efficiency. Due to hydrodynamic characteristics in the EGSB reactor, special attention should be paid to the design of solids separator device in order to prevent biomass washout in the effluent, which would result in a drop of reactor efficiency [58–59].

3.12. Ozonation

Ozone is the triatomic form of oxygen and it is composed of three oxygen atoms. Under normal conditions, ozone is unstable and quickly decomposed to the more stable gaseous oxygen, O_2. Because ozone is unstable and cannot be stored successfully, it must be generated at the point of application. Most simply, ozone can be generated by passing oxygen, or air containing oxygen, through an area having an electrical discharge or spark. One can notice a clean smell in the air after a thunder and lightning storm. The clean smell was most likely caused by ozone formed by lightning bolts passing through the atmosphere. To generate a sufficient quantity of ozone for a wastewater treatment plant, ozonators developing a corona discharge are used. These ozonators have two large area metal electrodes separated by a dielectric and an air gap. An alternating electric current is applied to the electrodes creating an electrical discharge. At the same time air or oxygen is passed through the air gap. As the air or oxygen flows through the air gap, and the electrical discharge, a portion of the oxygen is converted to ozone. The dielectric is necessary to spread the electric discharge over the entire electrode area and avoid producing an intensive single arc. The ozonation eliminates odour, reduces oxygen demanding matter, turbidity, surfactants and removes most colors.

The disadvantages of ozonation include its high capital cost. Gasi et al., [60] applied two stage ozonation steps for the post treatment of UASB reactor effluent.

3.13. Downflow hanging sponge

Downflow hanging sponge (DHS) was developed by Harada and his research groups at Nagaka University of technology, Japan [61]. It was developed for the aerobic post treatment of the UASB reactor effluent and reached the level adequate to satisfy discharge standards at a hydraulic retention time (HRT) of only 1.5 h from the effluent of the full scale UASB in India. The UASB reactor effluent is discharged to the upper side of the DHS media, 20–30 mm polyurethane cubes and it flowed downstream through media and string, BOD in the water is effectively oxidized in the downstream by the function of urethane foam that can retain water and microorganism. Any external aeration is not required in DHS system [62] because the packing material is sponges and oxygen is efficiently supplied from air in the downstream without blower equipment. It contains 90% void space, in which solid retention time increases [63]. This technique resembles trickling filter but the performance, design parameters and driving methods of DHS are widely different from conventional trickling filters. Especially, high BOD removal ratio is obtained more than 90%. It is also found efficient for the removal of *E. coli* [64] and nitrogen [61] as post treatments for UASB reactor effluents.

3.14. Aerated fixed bed

The UASB reactor effluent is post treated by an aerated fixed bed (AFB) reactor under aerobic condition and subsequently become the final effluent after passing through the settling tank. AFB reactor is aerated from all over the bottom [65].

3.15. Biofilter

Biofilter (BF) is considered as the primary filters and is currently under use in highly dense areas of Brazil. The sludge in these biofilters is usually unstable and requires stabilization. In this mechanism low sludge formation and energy savings occurs. Also the anaerobic digestion of the sludge removed from the biofilter by backwashing. It is accomplished directly in the UASB reactors. Excellent quality of the final effluent for the domestic sewage can be obtained by UASB reactor + BF system [39].

3.16. Zeolite ion exchange

For the treatment process natural zeolite is used. After the use of zeolite in the reactor it is collected for the regeneration process and is regenerated by nitrification process. Zeolite application reduces TAN (total ammoniacal nitrogen). The reduction effect of the zeolite is due to the interstitial spaces in its lattice framework which allows the replacement of the nitrifying ions [66].

3.17. Stabilization ponds

Waste stabilization ponds (WSP) provide one of the simplest, lowest cost, and most efficient wastewater treatment technologies available. Although particularly suited to warm climates, WSPs exist worldwide. Waste stabilization ponds have been used extensively all over Tamilnadu (India) over the last few years for the treatment of municipal and industrial wastewaters. Anaerobic WSP are single stage, continuous flow, anaerobic reactors operating at ambient temperatures and low volumetric organic loading [67]. A stabilization pond is a large shallow excavation that receives sewage from a sewer system, detains the sewage so that biological process can destroy most of the disease-causing organisms, and discharges the effluent as treated sewage. Operating a stabilization pond requires the services of a trained person. Operation and maintenance cost involves starting up the pond, managing pond surface conditions, maintaining the embankment and the pond site possibly after 10–20 y.

4. Discussion

4.1. Technical aspects

The effectiveness and comparison among various post treatment methods for the removal of pollution parameters are given in Table 4. It is compiled by reviewing various post treatment options. Full scale (FS), pilot scale (PS) and sometimes laboratory scale (LS) results are also considered. Much details are covered (Total COD, Total BOD, TSS, HRTs, and coliforms) in finding the feasible post treatment unit. These data are used to find out the percentage removal in post treatment units (Table 5) and accordingly Figs. 1–4 are plotted for taking concentrations of raw sewage and final effluent for various combinations. Somewhere, raw sewage concentration was not found in the literature, UASB reactor effluent values are considered in such cases. UASB reactors performance is found to be comparatively better than conventional activated sludge process based STPs because of the production of the biogas and less land requirement. But from the findings given in Tables 2 and 4 for UASB reactor effluents, UASB reactors are showing poor effluent quality in terms of following the discharge standards (Table 7). UASB reactors are high rate reactors which have much high SRTs compared to HRTs which seem that much organic load remains un-reacted and discharged by the reactors. Removal

Table 5
Removal efficiency of UASB reactor with use of post treatment

UASB + post treatment	Parameters							Reference
	BOD (%)	COD (%)	TSS (%)	NH_3 (%)	Nitrogen-N (%)	Phosphorous-P (%)	Feacal coliform (log units)	
UASB + FPU	47	28	41.3	–13	50–65	>50	3–5	[9], [22], [90], [91]
UASB + FPU	63	68.4	36.1	–	–	–	–	[8]
UASB + SPP	88.5	–	46	–	–	–	5.7	[90]
UASB + OFP	71.4	50	66.7	35–65	<65	<35	2–3	[22]
UASB + SAF	52.4	44.3	66.7	50–85	<60	<35	1–2	[22], [40]
UASB + TF	68.5	57.1	68.8	50–85	<60	<35	1–2	[22], [41]
UASB + AF	46.6	30	36.7	<50	<60	<35	1–2	[22], [44]
UASB + DAF	83–93	83–90	90–97	<30	<30	75–88	1–2	[22], [47]
UASB + ASP	98.8	97.5	95.3	50–85	<60	<35	1–2	[22], [64]
UASB + CW	90.4	85.9	94.7	–	–	–		[50]
UASB + RBC	98.8	56.4	–	–	–	–	0.3	[57]
UASB + EGSB	90.3	50	73.9	–	–	–	–	[59]
UASB + OZ	50	40.5	74.5	–	–	–	–	[60]
UASB + DHS	96.5	75.8	74.5	–	–	–	–	[64]
UASB + AFB	71.8	47.6	27	<30	<30	75–88	1–2	[22], [65]
UASB + BF	73.1	56.3	72.9	–	–	–	–	[39]
UASB + ZIE	23.3	15.1	31.4	–	–	–	–	[66]

efficiencies of UASB reactors are well reported in literature i.e., 60–70% BOD, 55–70% COD and 65–80% TSS. But in the presently reviewed papers (Table 3), these efficiencies are lower than this i.e., 50–78% for BOD, 42–78% for COD and 45–70% for TSS (Table 2). This strongly indicates the need of the post treatment step.

One more reason for the lower efficiencies of UASB reactors is its poor operating and maintenance as it also described by Sato et al. [8] who monitored 15 UASB reactors in India. Although it was based on one time sampling that is why there is a difference among the results/performance of laboratory scale, pilot scale and in full scale reactors. Table 5 is prepared by finding removal efficiencies of UASB reactor including various post treatment options available according to Tables 2–4. Percentage removal of NH_3, nitrogen and phosphorous are also included considering that nutrients are also excessively discharged by UASB reactors and can create eutrophication as discussed earlier. Combination of anaerobic with aerobic can effectively remove nutrients.

Gasi et al. [60] utilized two stage Ozonation process in which coliforms were removed 1.1×10^4 and 84 MPN per 100 ml, respectively, in final effluents. Some more salient features of some post treatment steps are;

- Uemura et al. [61] reported that by introducing a DHS reactor as a post treatment unit removal of pathogen indicators increased and the UASB–DHS system was superior to the conventional activated sludge process in reduction of fecal Coliforms. Tawfik et al. [64] reported that by using the third generation DHS system (curtain type), better results can be obtained in regards to COD, BOD and ammonia removal.
- Insufficient land areas and high land prices in urban areas often render the use of stabilization ponds unfeasible as a post-treatment process. High investment and operational costs have limited the feasibility of established aerobic processes. In this situation the option one can use is DHS system for post-treatment, which has the more removal efficiencies.
- The AF is operated in two ways like down-flow aerated filter and up flow aerated filter. The overall performance is better in the up flow than in down flow. One possible advantage in using up flow is that it avoids the clogging problem.
- The rotating biological contactor (RBC) is operated in single stage and double stage by Tawfik et al. [57] reported that two stage RBC system is better than that of single stage RBC in case of poor quality UASB reactor effluent.
- The electro coagulation treatment has improved the effluent quality by removing up to 67% (with aluminum electrodes) and 82% (with stainless-steel electrodes) of the remaining chemical oxygen demand (COD) and 84% (stainless steel) and 98% (aluminum) of the color in the wastewater [68].
- Another technique like coagulation–flocculation treatme nt with ferric chloride and aluminum sulfate removed up to 87–90% of COD and 94–98% of

color, respectively and by addition of a high molecular weight cationic polymer enhanced both COD and color removal efficiencies [45].

Though researchers have contributed a lot for the understanding, improvement and development of post-treatment processes in the last decade, the main contributions were related to organic matter and pathogen removal. But one more contaminant that is usually present in high concentration in domestic sewage, known as anionic surfactants (AS) as linear alkyl benzene sulfonate (LAS) which generally comes from house hold laundries and cleaning process. It is widely accepted that LAS are readily degradable under aerobic conditions. Under aerobic conditions, total mineralization of LAS proceeds through degradation of the alkyl group by means of ω-oxidation, β-oxidation, desulfonation and finally degradation of the phenyl ring [69].

Biodegradation of anionic surfactants under anaerobic conditions has historically been believed not to occur. A very high concentration of 4.25–5.91 mg l^{-1} anionic surfactants as methylene blue active substances (MBAS) [9,60] is discharged from UASB reactor effluents. It is reported that LAS concentration from 0.02–1.0 mg l^{-1} can damage fish gills, cause excess mucus secretion [70]; decrease respiration in the common goby, cause reduced settling rate, and damage swimming patterns in blue mussel larva. Surfactants are also responsible for causing foam in rivers and effluents of treatment plants and reduction of water quality. A review by Venhuis and Mehrvar [70] regarding the acute effects of LAS on freshwater plankton and organisms (including bacteria to crustaceans) under field conditions reveals that LAS has a negative impact on the survival of heterotrophic nanoflagellates and ciliates at very low concentrations. Surfactants show a pronounced ecotoxicological effect on aquatic organisms. When such wastewaters having high concentration of anionic surfactants in the UASB reactor effluents are discharged to surface water, it will generate a risk to the aquatic environment. Although anionic surfactants as MBAS is not a routine parameter for the water quality that is why it is generally not been analyzed. But high concentration of AS can cause a great aquatic risk [9]. So there is a need to evaluate the post treatment systems for UASB reactor effluents.

Few researchers had worked on the post-treatment of UASB reactor effluents for removing anionic surfactants. Gasi et al. [60] used a combination of UASB reactor with ozonation for the post-treatment of UASB reactor for AS. The effluent from UASB reactor contained 4.63–5.3 mg l^{-1} of AS as MBAS. Application of ozone for 30 and 50 minutes resulted in effluent AS concentration of 1.32–0.53 mg l^{-1}, respectively. Ozone oxidized AS effectively. In a previous work by Mungray and Kumar (2008) [9], five UASB reactors with a combination of polishing ponds were analyzed for AS. At all the five locations studied, polishing ponds were found to be not effective to lower down the AS concentration in the final effluents (>3.5 mg l^{-1}).

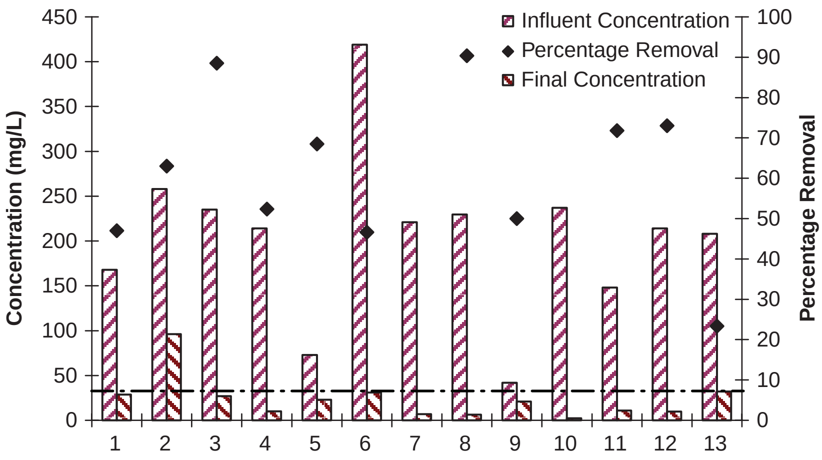
4.1.1. Comparison between various post-treatment options

For the comparison of the post treatment units, performances of the post treatment in case of the removal of total COD, total BOD, TSS and fecal coliform is considered (Table 6, Figs. 1–4). Pilot scale, laboratory scale, and full scale research data are considered for different combinations from various countries (Table 4). Figs. 1–3 are plotted by taking data from Tables 4 and 5 which indicates the percentage removal of BOD, COD and TSS among

Table 6
Economics of UASB based STP_s with post treatment

Sr no.	UASB + Post treatment	Construction cost/Capital cost	Unit	Land requirement	Unit	Operating and maintenance cost	Units	Reference
1	UASB + PP	30	US$/inhab	1.5–2.5	m^2/inhab	3	US$/inhab yr	[22]
2	UASB + FPU	32.5	L/mld	0.18	m^2/Ml/d	2.45	US$/Ml/d	[82]
3	UASB + Ponds	34.7–45.6	US$/$m^3$/d	1.70–1.98	m^2/m^3/d	–	–	[93]
4	UASB + Ponds	68.5–85.6	US$/$m^3$/d	1.1–1.7	m^2/m^3/d	–	–	[94]
5	UASB + Ponds	27.9	US$/$m^3$/d	0.64	m^2/m^3/d	–	–	[95]
6	UASB + OFP	35	US$/Ml/d	1.5–3	m^2/inhab	30	US$/inhab/yr	[22]
7	UASB + TF	31.5	US$/PE	0.64	m^2/PE	0.53	US$/PE	[95]
8	UASB + AF	30	US$/Ml/d	–	–	–	–	[96]
9	UASB + DAF	35	US$/Ml/d	0.05–0.15	m^2/inhab	5	US$/inhab	[22]
10	UASB + SBR	400	US$/inhab	–	–	5.5	US$/Ml/d	[97]
11	UASB + CW	20–30	US$/inhab	3–5	m^2/inhab	1–1.5	US$/inhab/yr	[98]
12	UASB + ASP	30–45	US$/inhab	0.08–2	m^2/inhab	2.5-5	US$/inhab/yr	[98]

Inhab = Inhabitant.

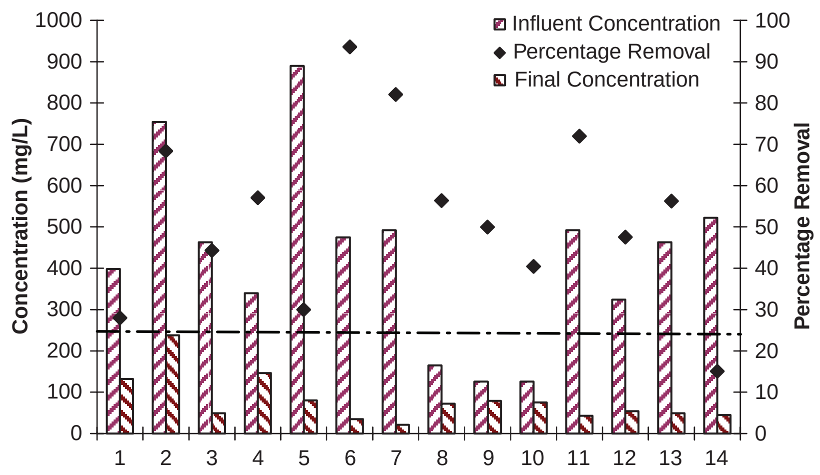


Post Treatment Units (as per references below)
1. FPU 2. FPU 3. SPP 4. SAF 5. TF* 6. AF 7. ASP 8. CW 9. OZ* 10. DHS 11. AFB 12. BF 13. ZIE

1.	Mungray and Kumar [9]	8.	Khateeb et al. [50]
2.	Sato et al. [8]	9.	Gasi et al. [60]*
3.	Sperling and Andrada [90]	10.	Tawfik et al. [64]
4.	Goncalves et al. [39]	11.	Sumino et al. [65]
5.	Awuah and Abrokwa [41]*	12.	Goncalves et al. [38]
6.	Chernicharo and Machado [44]	13.	Aiyuk et al. [66]
7.	Tawfik et al. [49]		

* *UASB effluent value is taken into consideration in place of raw sewage*

Fig. 1. BOD removals with concentration of raw and final effluents from various post treatment units.

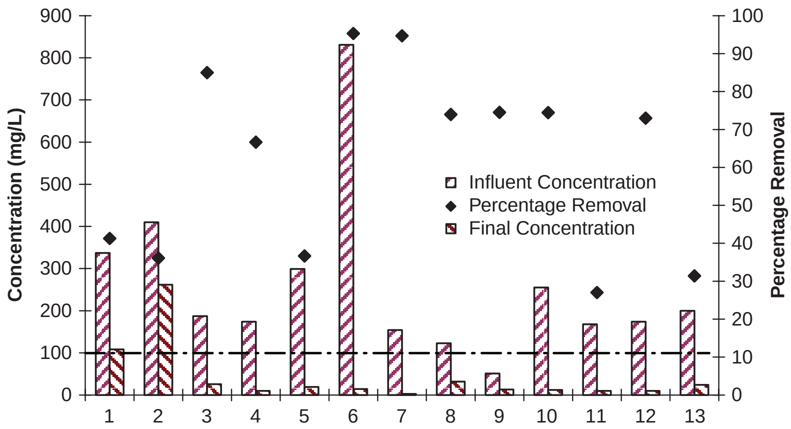


Post Treatment Units (as per references below)
1. FPU 2. FPU 3. SAF 4. TF* 5. AF 6. ASP 7. CW 8. RBC 9. EGSB* 10. OZ 11. DHS* 12. AFB 13. BF 14. ZIE

1.	Mungray and Kumar [9]	8.	Tawfik et al. [57]
2.	Sato et al. [8]	9.	Kato et al. [58]*
3.	Goncalves et al. [39]	10.	Gasi et al. [60]
4.	Awuah and Abrokwa [41]*	11.	Tawfik et al. [64]*
5.	Chernicharo and Machado [44]	12.	Sumino et al. [65]
6.	Tawfik et al. [49]	13.	Goncalves et al. [38]
7.	Khateeb et al. [50]	14.	Aiyuk et al. [66]

* *UASB effluent value is taken into consideration in place of raw sewage*

Fig. 2. COD removals with concentration of raw and final effluents from various post treatment units.

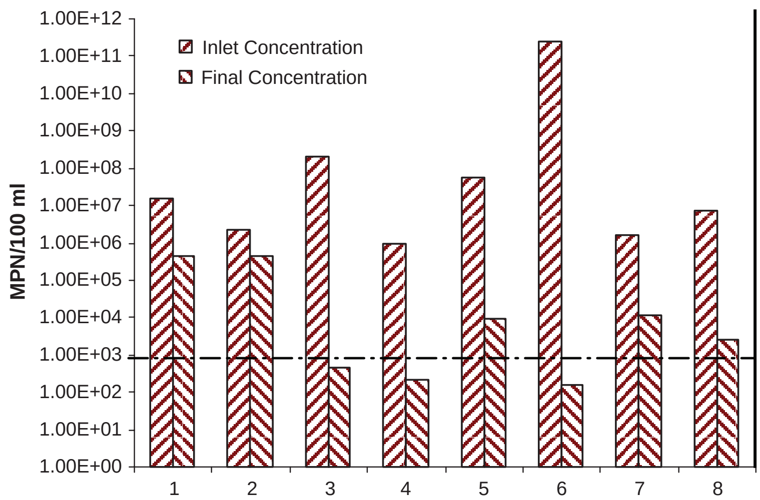


Post Treatment Units (as per references below)
1. FPU 2. FPU 3. SPP 4. SAF 5. AF 6. ASP 7. CW 8. EGSB 9. OZ* 10. DHS 11. AFB 12. BF 13. ZIE

1.	Mungray and Kumar [9]	8.	Kato et al. [58]
2.	Sato et al. [8]	9.	Gasi et al. [60]*
3.	Sperling and Andrada et al. [90]	10.	Tawfik et al. [64]
4.	Goncalves et al. [39]	11.	Sumino et al. [65]
5.	Chernicharo and Machado [44]	12.	Goncalves et al. [38]
6.	Tawfik et al. [57]	13.	Aiyuk et al. [66]
7.	Khateeb et al. [50]		

** UASB effluent value is taken into consideration in place of raw sewage*

Fig. 3. TSS removals with concentration of raw and final effluents from various post treatment units.



Post Treatment Units (as per references below)
1.FPU 2. FPU 3. SPP 4. TF 5. ASP 6. CWv 7. OZ* 8. DHS

1.	Pant and Mittal [91]	5.	Tawfik et al. [49]
2.	Sato et al. [8]	6.	Khateeb et al. [50]
3.	Sperling and Andrada [90]	7.	Gasi et al. [60]*
4.	Awuah and Abrokwa [41]	8.	Tawfik et al. [64]

** UASB effluent value is taken into consideration in place of raw sewage*

Fig. 4. Feacal coliform concentration of raw and final effluents from various post treatment units.

various post-treatment techniques along with their concentration in raw sewage and in final effluents in the overall combined systems. Dotted lines indicate the standard discharge limit value for the particular parameter. From Fig. 1, BOD removal efficiency ranges from 32–98.8%. Least BOD removal efficiency is for ZIE and highest is for ASP. Also the combinations like SPP, CW and DHS gives good BOD removal efficiency. If it is compared with standard discharge limit, only FPU, AF, and ZIE are not following while others are following. From Fig. 2, the range for COD removal is from 15.1–97.5%. For COD removal least is for ZIE and highest is for ASP. Almost all the combinations are following the discharge standards if compared with dotted line. Fig. 3 shows TSS removal in which least removal efficiency is for AFB and highest is for ASP. The only combination, FPU is not following the discharge limits. Fig. 4 is plotted by taking fecal coliform concentration in raw sewage and in the final effluents in various post treatment combinations (Table 4). Maximum final concentrations are found in almost all combinations except SPP, TF and CW.

Over all from Table 6, the only combination is CW which satisfies the discharge standard limits for BOD, COD, TSS, and fecal coliforms. CW was operated in two units with HRTs of 2 and 1 d which results in good removal efficiency. Also the OLRs for CW range from 41.40–74.50 kg BOD/ha/d for BOD and 84.50–152 kg COD/ha/d for COD which is a good working condition for this combination. But the results are based on pilot scale which needs to be justified by full scale study.

4.2. Non technical aspects

The impact of pollutants in sensitive areas is fine tuned by the developed countries. The basic stages of water pollution problems are already cleared by the developed countries while the developing countries are attempting to follow the international trends of frequently lowering the concentration limits. Also the developing countries are unable to reverse the continuous trends of environmental degradation. The pollutants concentrations in effluent for developing countries are much higher than the developed countries and also the compliance to discharge for the developing countries is much higher than the developed countries [34]. Developing countries like India, cannot afford more capital cost, operational cost and more land for fulfilling the disposal requirements. The literature provided that the DHS is a process which is simple, compact, and inexpensive [71]. The UASB reactor in association with BF resulted in a compact, efficient and low energy consumption system [39]. The UASB/AF system could become a very promising alternative resulting in very compact and low cost treatment unit with less labor costs and no energy consumption [44]. However, electro-coagulation is a complex process occurring via a series of steps and the electrochemical process is efficient in COD and color removal but it consumes more energy, depending on the operational conditions applied and the wastewater must have high conductivity (or salts must be added, increasing the costs) [68]. Wetland systems show efficient results but need more land for high retention time [50].

4.2.1. Economics

The economics of the wastewater treatment concerns with the capital cost, operation and maintenance (O & M) cost. Cost splits into investment cost and recurring cost. Investment cost covers cost of land, groundwork, electromechanical equipment and construction and recurring costs relate mainly to the paying back of loans and to the cost of personnel, energy and other utilities, stores, laboratories, repair and sludge disposal. Operation and maintenance affects the technology selection. For the annual basis expenditure of treatment and sewage collection, the costs are typically of the same order of magnitude as the depreciation on the capital investment. It requires careful exhaustive planning, trained and qualified staff, operational system which provides spare parts and other utilities, proper schedule for maintenance, management atmosphere with minimum interruptions [72].

UASB reactors with the post treatment are rarely compared with the systems without the UASB reactor and alternatives. Therefore, an economy in the conventional systems is not preceded by an anaerobic stage. The investment and the operating and maintenance cost are relatively low for the wastewater treatment plants worldwide depending on the conditions on which they are operating [73–78]. Post treatments are advantageous as they require low investment cost as the land required for their installation is very low. However in the decentralized approach the treatment system will be constructed in a close vicinity of the residential areas where flat land is scarce, and thus expensive. Another disadvantage of pond systems and overland flow system is its susceptibility for evaporation leading to loss of valuable water and a contaminant increase in the effluent salt concentration [79].

The use of post treatment consolidates anaerobic technology as the first stage treatment for domestic and municipal sewage, and also to offer a series of post treatment alternatives that take into account the social, economical and environmental aspects of most of the developing countries [22]. Institutions and policies improvement influence the use of fresh water that can reduce the cost of managing waste water. But water, supply and sanitation are institutionally and economically unconnected. Public agencies have overlapping jurisdiction that prevents optimal implementation of desirable policies. Effluent standards, taxes and tradable permits can be used to motivate improvements in water management by household and firm discharging waste water from pond sources [80].

For competition with alternative technologies the anaerobic treatment must be cost effective in terms of investment and operating cost. The system should also be compact which can reduce the cost factor [11]. In the present paper many research publications are reviewed for various combinations of UASB reactors and their post treatment options. Most of them effectively evaluated their performance in terms of removing pollutional parameters, but regarding the economic aspects, it is scarcely reported. In present paper, an attempt is being made by considering their major costs (i.e., construction cost, land requirement and operation and maintenance cost) which are supposed to be major for any STPs (Table 7). The values reported by the researchers for different combinations are very limited and differs in units.

If construction or capital cost is considered, UASB + Ponds or PPs have less compared to other combinations (27.9 US\$ m^{-3} d^{-1}). If land requirement is compared, this is minimum for the case of TF (0.64 m^2/PE) and DAF (0.05–0.15 m^2/inhabitants) and maximum for polishing ponds (1.5–2.5 m^2/inhabitants). Operation and maintenance cost is also considered for any system. Polishing ponds or final polishing ponds are found best suited in this category which requires comparatively less than other like OFP and SBR.

5. Conclusions

Several studies carried out by many researchers in full-scale, pilot scale and laboratory scale systems which demonstrated that the up-flow anaerobic sludge blanket reactor is a reliable and simple technology for treatment of domestic sewage. However, the UASB reactor effluent still contains high organic content and high counts of coliforms in the discharge. So to achieve high quality of effluents, post treatment units are required. The post-treatment units for UASB reactor effluents proved that they are feasible and efficient in reducing organic content and also pathogens at different conditions. There is a tremendous need to develop reliable technologies for the treatment of domestic wastewater in developing countries. Such treatment systems must fulfill many requirements, such as simple design, use of non-sophisticated equipment, high treatment efficiency, and low operating and capital costs. It is not easy to select one post-treatment unit which is sufficient enough to fulfill all the requirements. But UASB + CW may be a better combination which may

Table 7
Comparison of standards achieved by the UASB based STPs in various countries

Post treatment	COD* (250 mg/l) SDL	BOD* (30 mg/l) SDL	TSS* (100 mg/l) SDL	Pathogens** 1000 MPN/100 ml SDL	Countries
PP/FPU	F	F	NF	NF	India
FPU	F	NF	NF	NF	India
SPP	–	F	F	F	India
OFP	F	F	F	NF	India
SAF	F	F	F	NF	Brazil
TF	F	F	–	F	Ghana
AF	F	NF	F	NF	Brazil
DAF	–	–	–	–	Brazil
ASP	F	F	F	NF	Egypt
CW	F	F	F	F	Egypt
RBC	–	–	–	NF	Netherland
EGSB	–	–	F	–	Brazil
OZ.	F	F	F	NF	Brazil
DHS	F	F	F	NF	Japan
AFB	F	F	F	–	Japan
BF	F	F	F	–	Brazil
ZIE	F	NF	F	–	Belgium

F-Following, NF-Not following, SDL-standard discharge limit.
*Discharge standards in surface water [20].
**Standard for unrestricted irrigation [24].

satisfy the basic needs of a treatment plant for a developing country. But its implementation requires large land which increases its capital cost. Hence for the use of UASB + CW and UASB + ASP in developing countries its compactness is required so that it can be economically used. Also the post treatments such as DHS, AFB, OFP, TF and RBC shows good results and can be used as an alternative.

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