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Review Paper on: UASB Bioreactor for Sewage Treatment

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ABSTRACT: *The Up-flow Anaerobic Sludge Blanket (UASB) is a low cost and high rate of treatment process that can produce more bio-energy benefits in terms of biogas production. The UASB treatment process cannot completely remove the organic matter and pathogenic microorganisms. Therefore, a post-treatment process is required for UASB effluent before discharge to the environment to be reused and recycled for agricultural irrigation. The post-treatment of UASB effluent may be an aerobic process, such as a Final Polishing Ponds Unit system (FPU); Trickling Filters (TF); Rotating Biological Contactor (RBC); Bio-Filter (BF); Sand Filter; Sequence Batch Reactor (SBR) and Down-flow Hanging Sponge System (DHS). Alternatively, the post-treatment of UASB effluent may be an anaerobic process such as Anaerobic Bio-film Fluidized Bed reactor; Anaerobic Sludge Thickening and Digestion Process; Anaerobic Hybrid Reactor (AHR); Anaerobic Filter Process (AF) and Dissolved Air Flotation system which are not performed well for the treatment of sewage. Among the systems for treating UASB effluent, Down-flow Hanging Sponge System (DHS) is the best combination process. It reduces significantly the organic load and pathogenic microorganisms. It produces less excess sludge and a final effluent with higher level of dissolved oxygen.*

KEYWORDS: *Sewage; UASB Bioreactor; Post-treatment; Anaerobic Vs. Aerobic Digestion; Standard Effluent*

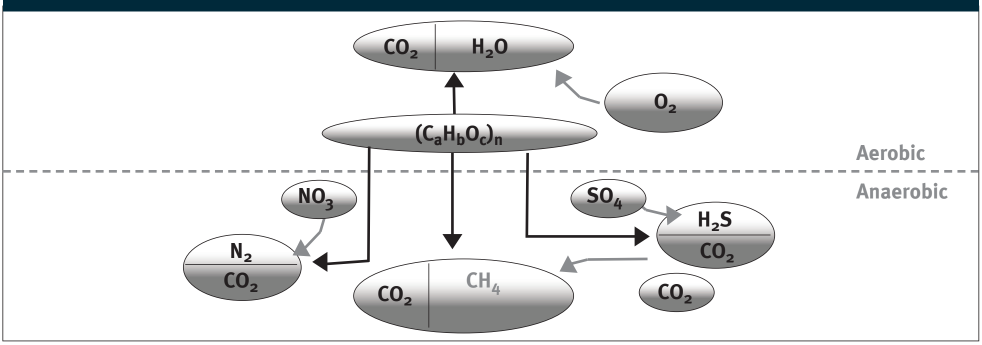
INTRODUCTION

Sewage is wastewater, primarily generated from toilets. It is easily biodegradable organic waste with solids and microorganisms that settle easily. The settled materials are referred to as sludge. Before it can be discharged to the environment, the high oxygen-demanding waste, suspended solids, ammonia, phosphates and a high load of pathogenic microorganisms (Coliform group) must be removed by an advanced sewage treatment process. Most urban areas in developing countries are facing severe deterioration of aquatic environment, due mainly to direct discharge of municipal sewage, which in turn is due to a lack of low-cost treatment technologies. Karn& Harada (2001) reported that rivers in urban areas of Nepal, India and Bangladesh are severely polluted due to direct discharge of urban waste and wastewater. Initially, the main drawback of anaerobic treatment was that the hydraulic retention time (HRT) treatment process required a long retention time. Today, the UASB system is widely used in mesophilic temperature conditions with shorter retention times. Relative to HRT, UASB systems are more reliable and simpler for high-rate anaerobic processing of sewage (Seghezzo *et al.*, 1998; Van Haandel and Lettinga 1994). Sewage treatment using a UASB reactor generates effluent containing a high count of fecal microorganisms. It is not ready for direct discharge to the environment (Sperling *et al.*, 2000; Augusto *et al.*, 2000; Goncalves *et al.*, 1999). It is necessary to undertake post-UASB treatment of the effluent. This review paper critically analyzes the efficiency of low-cost treatment systems for UASB effluent in the context of developing countries.

Significance of Combined Process for Sewage Treatment

Microorganisms play a key role in biological wastewater treatment processes. Basically, bacteria metabolize the organic matter, as shown in Figure 1. Under aerobic condition, oxygen is used as an electron acceptor during the degradation of organic matter. Under anaerobic conditions, in the absence of oxygen, organic matter is oxidized with inorganic electron acceptors such as nitrate

Figure 1: Biodegradation mechanisms of organic matter under aerobic and anaerobic process



(denitrification), sulphate (sulphate reduction), carbon dioxide (methanogensis).

Under both anaerobic and aerobic processes, bacteria have a beneficial effect in minimizing the organic load and pathogenic microorganisms in UASB effluent (Torres and Foresti, 2001; Augusto *et al*., 2000).

Characteristics of Raw Sewage

The major components of raw sewage in some selected developing countries are shown in Table1. The composition of sewage is similar in these countries. The volume of raw sewage generation in different countries differs from place to place due to climatic conditions and economic aspects. The raw sewage composition in developing countries is low-strength, which is suitable for anaerobic digestion. The suspended solids (300-600 mg/l), CODt (210-740 mg/l) are suitable for anaerobic treatment (Henze *et al*., 2000). Therefore, depending on the characteristics of the raw sewage, anaerobic treatment is required for treatment for remaining high concentrations of COD, BOD, nutrients and pathogens (Mahmoud *et al.,* 2004).

Conventional Processes for Sewage Treatment

Most developing countries do not undertake any sewage treatment for sewage; some follow traditional methods, such as stabilization ponds for municipal sewage (de Sousa *et al*., 2001; Melo *et al*., 2000). Raw sewage remains in the ponds for many days for auto bio-degradation processes to operate. Van Der Steen *et al.*, (1999) reported that sewage treatment in a stabilization pond is low-cost but has some disadvantages:

- Extensive land area is required
- Spreads a noxious odor and affects air pollution

Table 1: The characteristics of raw sewage in selected developing and high-income countries

Country	Temp	pH	COD mg/l	BOD mg/l	TSS mg/l	NH_4-N mg/l	F.Coli. MPN/100ml	Ref.
Bangladesh	20-30	7.0	--	200	200	--	2.5×10^5	1
Brazil	24-26	7.6	727	368	429	34	4×10^7	2
Colombia	24-27	7.2	267	95	215	17	---	3
Egypt	17	---	527	--	---	49	8.5×10^6	4
India	25.68	7.1	256	150	223	22	7.3×10^6	5
Indonesia	22-29	---	230	100	159	---	1.4×10^6	6
Nepal	--	--	798	360	220	41	8×10^7	7
Palestine	--	--	1586	---	736	80	--	8
Netherlands	20	---	528	---	----	48	----	9
Spain	--	7.8	693	360	226	20	---	10

- Creates a potential breeding field for mosquitoes.

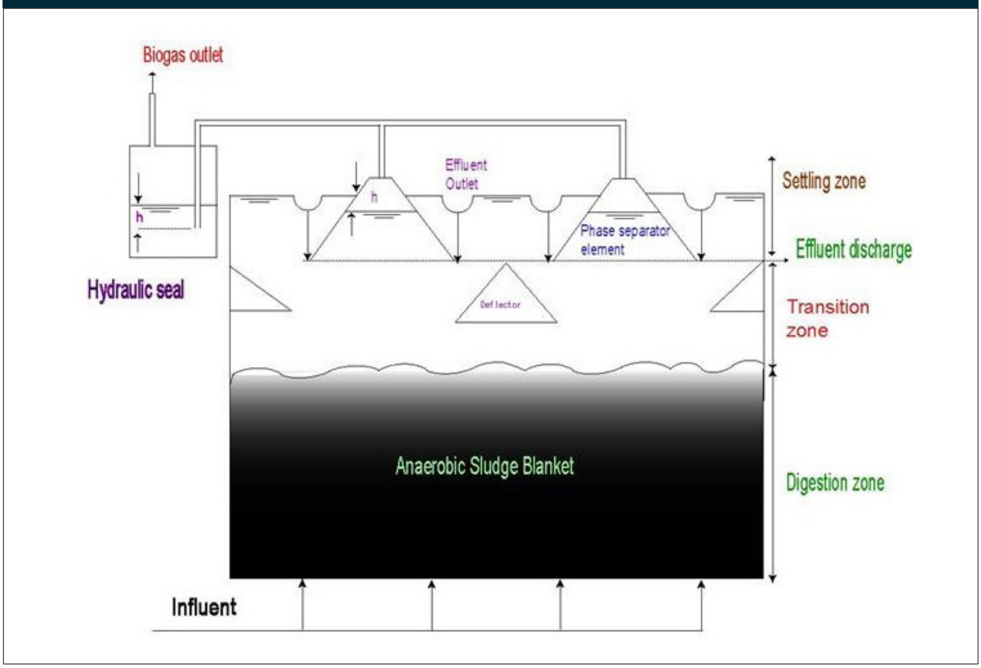
An alternative to stabilization ponds is the septic tank process. It is simple; it is the oldest digestion process.

Concept on UASB Treatment Process

UASB is an anaerobic granular sludge bed technology. It is a special kind of reactor with "High Rate" anaerobic treatment of wastewater. The UASB treatment system was developed by a research group in the Netherlands in the 1970s (Lettinga and Vinken 1980). UASB reactors have operated successfully at lab-scale, pilot-scale and full-scale sewage treatment plant (Monroy *et al.*, 2000). The application of UASB systems has increased for sewage treatment in developing countries in tropical and subtropical regions, such as Brazil, Colombia, China, India, and Mexico (Ciftci and Oztiirk 1995). The UASB reactor achieves higher methanogenic activity under mesophilic temperatures.

The UASB reactor is not only extensively used for sewage treatment but also for various types of wastewater treatment (Kato *et al.,* 2003). The UASB system is a bottom-feeding mode reactor. The sludge is in contact directly with raw waste water and substrate-microorganisms (Lettinga *et al.*,1993). The schematic diagram of the UASB process is shown in Figure 2. The sludge contained at the bottom and dense sludge do not require

Figure 2: Schematic Diagram of the UASB Process



to washout even more high dense flocculated sludge enhanced for good treatment system at high organic loading rate (Kato *et al.*, 2003). The benefits of the UASB process are the following:

- It has a high-rate anaerobic treatment potential
- UASB bio reactors perform well under mesophilic conditions
- UASB reactors can treat high organic strength waste water
- It is a relatively simple low operational cost technology
- It has high organic removal efficiency
- It potentially can generate a benefit through bio-gas capture
- Sludge production is much less than under aerobic treatment systems

Post-Treatment of UASB Effluent

There are many systems combining UASB and either aerobic or anaerobic post-UASB effluent treatment systems.

Combination of UASB and Aerobic Systems

- UASB/FPU/SP (Final polishing ponds / Stabilizing ponds)
- UASB/TF (Trickling filters) process
- UASB/RBC (Rotating biological contractor) system
- UASB/BF (Aerated Bio-filter)
- UASB/SF (Sand filter)
- UASB/SBR (Sequencing Batch reactor) process
- UASB/FFB (Fluidized & fixed-bed reactors
- UASB/DHS (Down-flow hanging sponge) system

Combination of UASB and Anaerobic systems

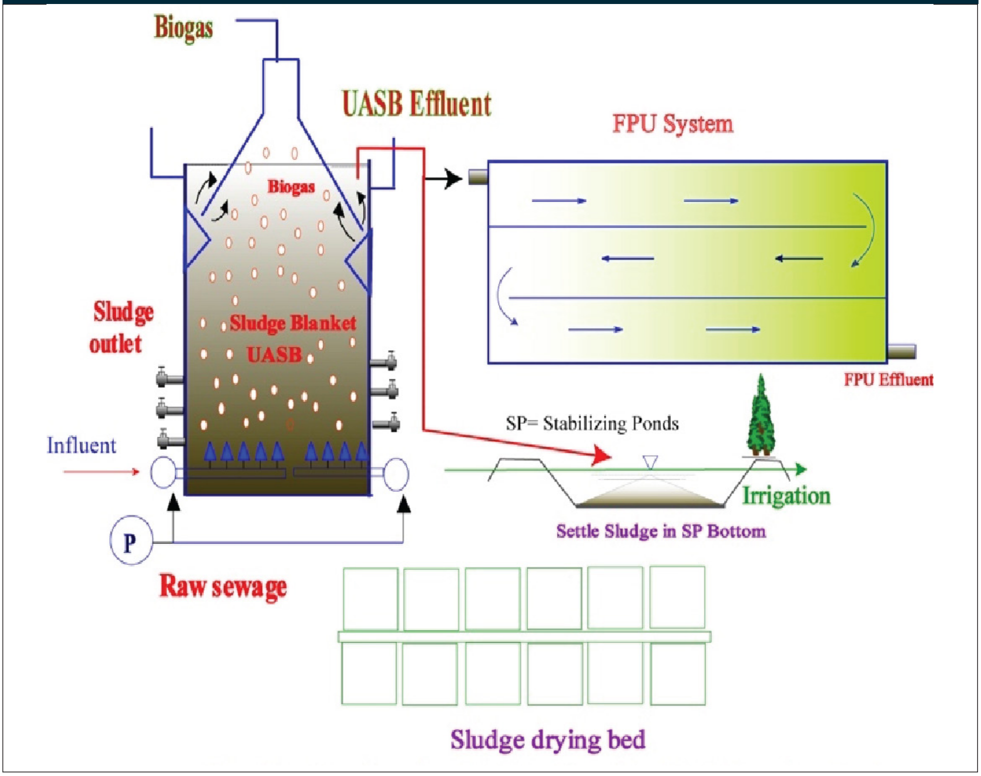
- UASB/ASTD (Anaerobic sludge thickening and digestion) process
- UASB/ABFBR (Anaerobic bio-film fluidized bed reactor)
- UASB/AH (Anaerobic hybrid) process
- UASB/AF (Anaerobic filter) process
- UASB/UASB-digester system
- UASB/EGSB (Expanded granular sludge bed reactor)
- UASB/DAF (Dissolved-Air Flotation) process

Post-treatment of UASB Effluent Using a Final Polishing Pond Unit (UASB/FPU) System

Final polishing ponds are more effective in warmer than in colder climates due to algal growth (Cavalcanti *et. al.*, 2001). The photosynthetic activity accelerates the pH and dissolved oxygen, which reduces bacterial pathogens (Curtis *et al.*, 1992). The bi-sulfide ions present in the UASB effluent are oxidized in the FPU ponds, which reduces bad odors. A flowchart for the post-treatment of UASB effluent with a FPU unit is shown in Figure 3.

Problems arise with post-treatment of UASB effluent in a FPU system. The final effluent from FPU does not fulfill the effluent quality standards due to a high fecal coliform

Figure 3: Post-treatment of UASB Effluent Under FPU System (Cavalcanti *et. al.*, 2001).



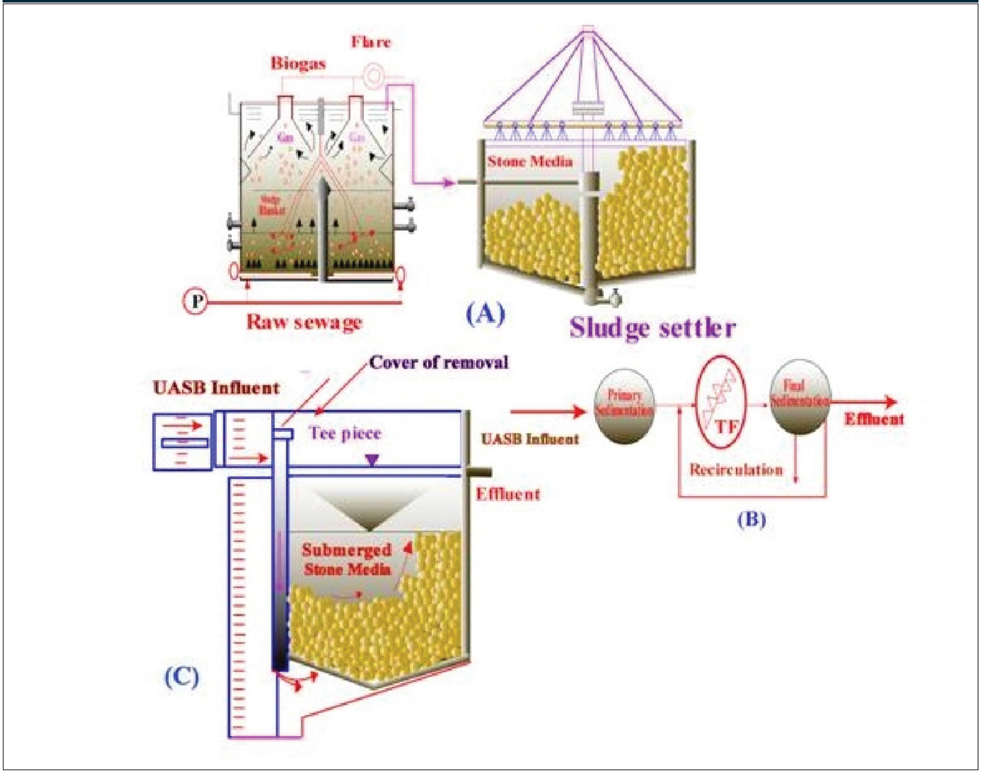
($10^{5.8}$ MPN/100 ml) presence even when the HRT of a FPU system is maintained at 24 hours. The post-treatment of UASB effluent by the DHS filtration technique is more suitable than the FPU system (Okubo *et al.*, 2005).

Post-Treatment UASB Effluent Using Trickling Filter Process (UASB/TF)

In the trickling filter process, microorganisms form a microbial film on the surface of the filter medium. The trickling filter is a packed-bed, fixed film reactor where beds materials are used in a circular tank is shown in Figure 4. The bed materials are different sizes of stones, but recently stones are being replaced by plastic materials. The influent sprays over the packed materials by using mechanically rotated distributor arms.

This process creates some problems, such as excess sludge and bio-film of microbial growth. Due to the higher abundance of microorganisms in the trickling filter, it showed good performance for removing the pollution parameters (Augusto *et al.*, 2000). But the

Figure 4: UASB process with Trickling Filter Process (TF)

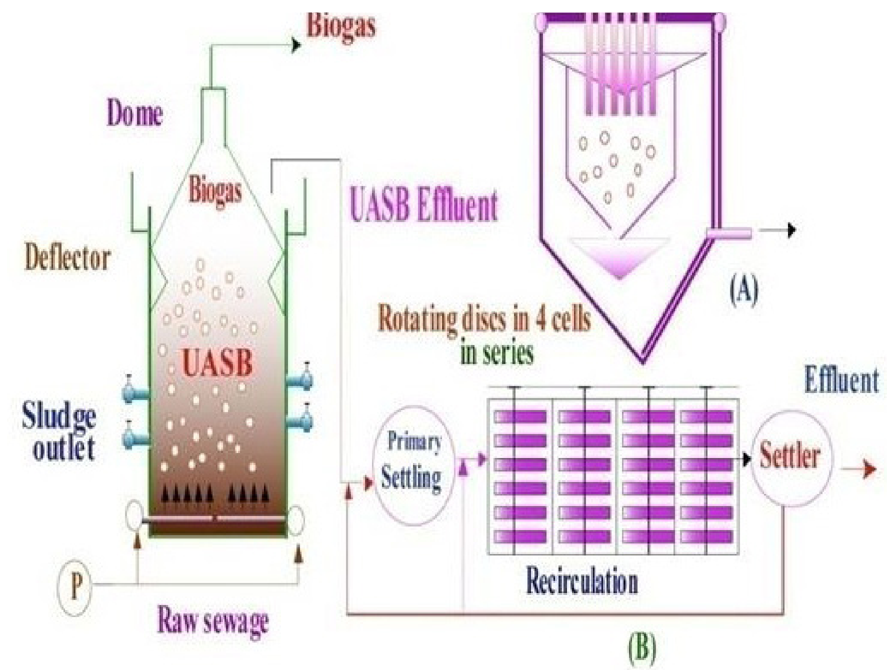


presence of pathogenic microorganisms in the final effluent was more, which is a major drawback for this TF process. There are numerous trickling filter processes which have been developed in developing countries for treating the sewage.

Post-Treatment of UASB Effluent by Using Rotating Biological Contractor (UASB/RBC)

The RBC process is designed with circulation process. The packing matters are used to grow more microorganisms in the RBC bio-reactor. The most common type of RBC is made up circular shaped high-density plastic packing materials. It should be usually less than 10 meters in length. The circulation of RBC is maintained by electric motor (Castillo *et al.*, 1999). The attached biomass can take oxygen due to rotation and can grow more biomass on the film. The attached bacterial biomass helps to treat the wastewater under the biological process. Two-stage RBCs were used for the post-treatment of UASB effluent. Most of the COD is removed at the first stage RBC, and in the second stage RBC the nitrification process occurs (Tawfik *et al.*, 2002). But there was

Figure 5: Schematic diagram of UASB process and Rotating Biological Contractor



a major drawback, the RBC was frequently blocked due to suspended materials and excessive growth of bacterial biomass. The schematic diagram of RBC process is shown in Figure 5.

Post Treatment of UASB Effluent by Using Submerged Aerated Bio-filter (UASB/BF)

Rocher *et al.*, (2012) studied an Aerated Bio-filter (BF) process. The BF is totally submerged, comprising polystyrene spheres with 3 mm diameter, 1200 m^2/m^3 specific surface and 0.5 m height. The air was injected in the BF bottom. The combined treatment capacity of UASB and BF was tested at various HRTs. The granule was also formed at the BF system. The UASB/BF combined system can be considered as a viable alternative post-treatment of UASB effluent, but the presence of pathogenic microorganisms of fecal coliform in the BF effluent was much more than the acceptable level. This is a disadvantage of the UASB/BF system. UASB reactor and post-treatment of UASB effluent in submerged aerated bio-filter (BF) were operated by Newman *et al.*, (2005), as shown in Figure 6.

Figure 6: Schematic diagram of post treatment of UASB effluent in submerged aerated bio-filter (BF)

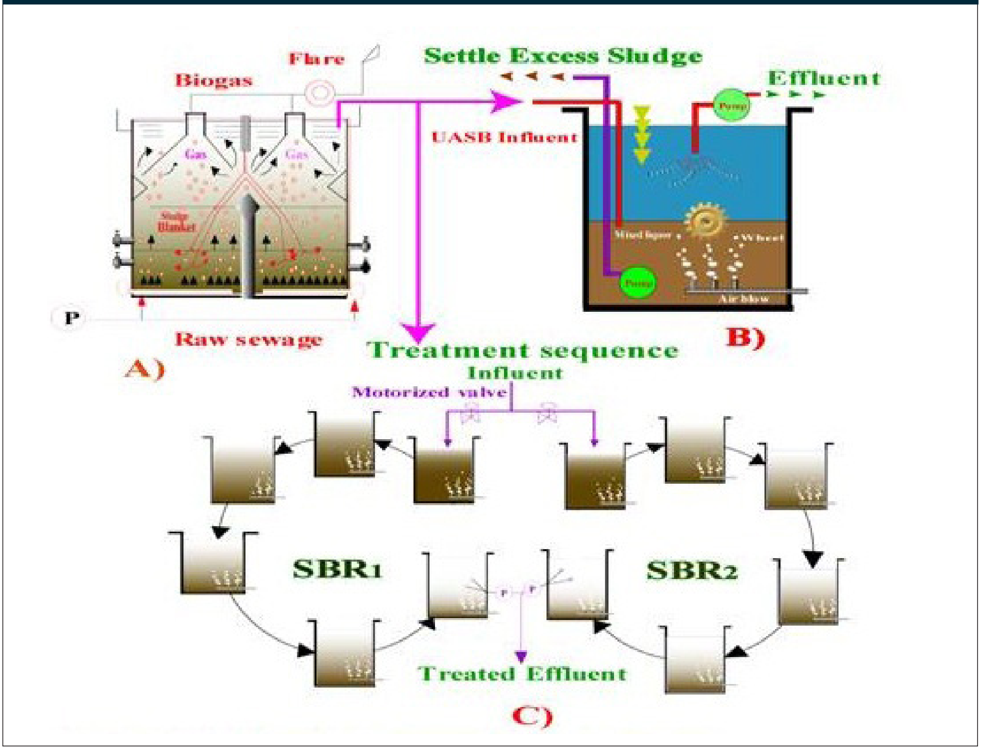
Post-Treatment of UASB Effluent by Using Down-Flow Sand Filter Process (UASB/DSF)

The preliminary post-treatment of UASB effluent by using Down-flow Sand Filter (DSF) was invested by Ghangrekar and Kahalekar (2003). The total volume of sand filter reactor was 2.3 L with HRT 2.5 h at in India. According to their observations, they concluded that the properly operated UASB reactor and post-treatment of UASB effluent by using sand filtration combination could meet the effluent standard for disposal to the environment. The cost analysis of UASB and DSF has also showed the economic aspects.

Post-Treatment of UASB Effluent by Using Sequence Batch Reactor (UASB/SBR)

Sousa and Foresti (1996) were the first to investigate the post-treatment of UASB effluent by using SBR system. SBR refers to the wastewater under cyclic and aerated system. Torres and Foresti (2001) studied domestic sewage using UASB and aerobic sequencing batch reactor (SBR) system. Under their study the UASB system was operated under a constant HRT (6h) while the SBR cycle duration was 24, 12, 6 and 4 h with corresponding aeration time. Significant reduction of COD, TSS,

Figure 7: Schematic diagram of post treatment of UASB effluent in Sequence Batch Reactor (SBR)

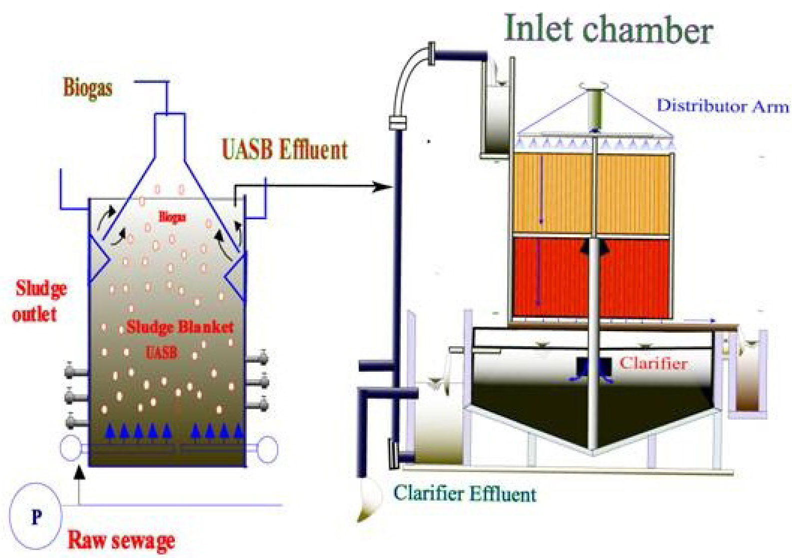


TKN and phosphate was achieved. Aparna Dutta and Sudipta Sarkar (2015) also studied a UASB/SBR combined system for sewage treatment. Under this combined system, UASB/SBR did not satisfy the reduction of pathogenic microorganism and effluent standard quality. The schematic design of SBR is shown in Figure 7.

Post-Treatment of UASB Effluent by Using Down-flow Hanging Sponge System (UASB/DHS)

The novel UASB/DHS system was developed for the post-treatment systems of UASB effluent in Japan (Uemura *et al*., 2002; Tanduker *et al*., 2003. and Okubo *et al.,* 2005). Under this combined process, the nitrogen level was removed from UASB effluent through the nitrification and de-nitrification process under DHS system (Tanduker *et al*., 2003). The UASB/DHS combined system has successfully been operated as a simple low-cost technology suitable for sewage treatment in developing countries (Machdar*et al.,* 1997). Relative to other systems, the DHS system also produced less excess sludge and does not require external aeration. The DHS effluent contains less fecal coliform (<10^4 MPN/100 ml). The UASB/DHS

Figure 8: Schematic diagram of post treatment of UASB effluent in Down Flow Hanging Sponge System (DHS)



combined system has economic advantages in irrigation purposes because it requires minimum chlorination (Okubo *et al.*, 2005). A schematic diagram of UASB/DHS system, as operated in India for the post-treatment UASB effluent, is shown in Figure 8.

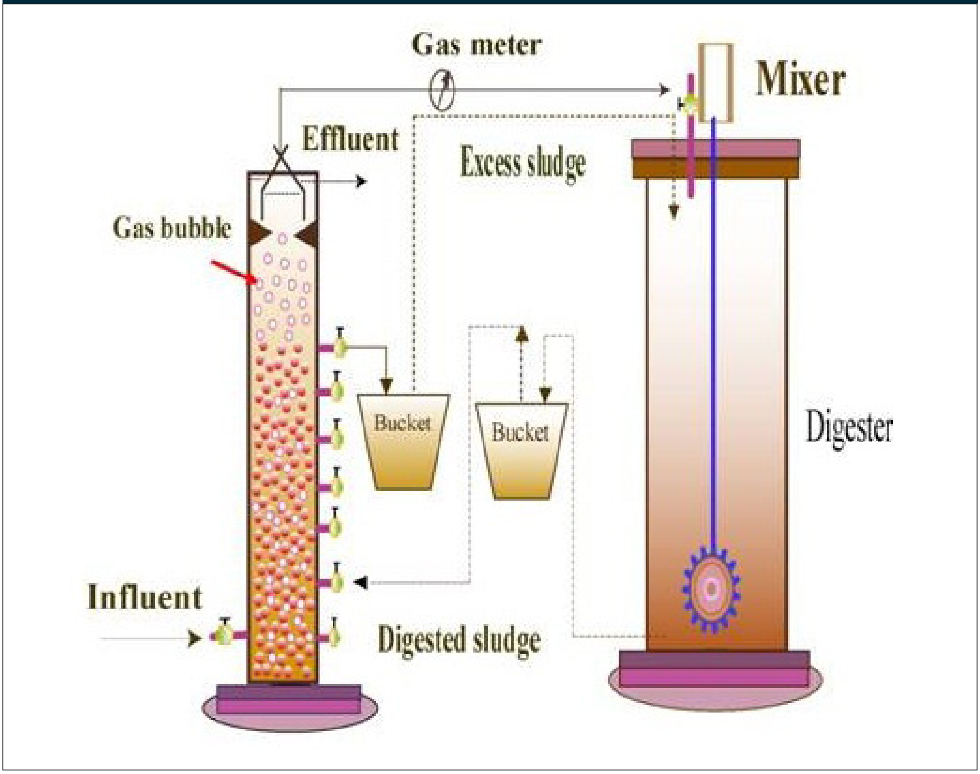
Post-Treatment of UASB Effluent by Using UASB Digester (UASB/ASTD)

The UASB digester is mainly placed for re-digestion of daily washed sludge from UASB system. This system operated two UASB processes -- first time UASB at 15°C and for second time UASB at 35°C in Netherlands (Mahmoud *et al.*, 2004). The re-circulated washed sludge from the UASB effluent contributed to an additional 20% methane production in the UASB digester system. The sludge production is very low, contains little water and is stabilized. In this system, the focus is mainly on sludge digestion and reduction of excess sludge volume produced by the UASB system. The schematic diagram of the UASB-digester process is shown in Figure 9.

Post-Treatment of UASB Effluent by Using Expanded Granular Sludge Bed (EGSB) Bio-reactor

The EGSB reactor using flocculent sludge was evaluated for the post-treatment of effluent from a UASB reactor treating domestic sewage. Kato *et al.* (2003) investigated a pilot-scale 157.5 L capacity EGSB reactor for 331 days. Seed granular sludge was needed to start up

Figure 9: Schematic diagram of post treatment of UASB effluent in UASB Digester

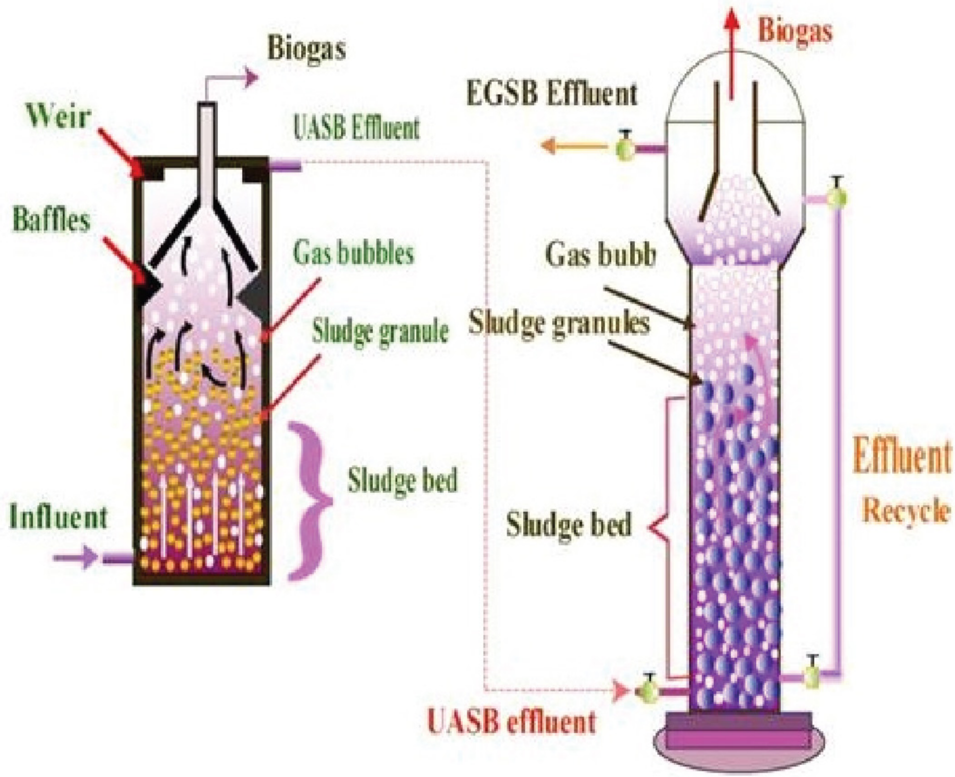


the EGSB reactor. The EGSB system uses high flow velocity in a tall reactor. The low-strength soluble wastewater (less than 1-2 g COD/l) is good for EGSB system. The EGSB system was also developed in Netherlands, by Lettinga in 1970s. Based on granular sludge the EGSB reactor was operated by applying of high-flow liquid velocity. The combination of UASB/EGSB showed good treatment efficiency. The granular sludge showed that the smaller size granule sludge had more methanogenic activity than the larger size granules (Reback *et al.*, 1997). The small sludge granules can also improve the filtration and entrapment mechanisms for removal of CODs. The combination of UASB/EGSB system is shown in Figure10.

Post-Treatment of UASB Effluent by Using Anaerobic Hybrid Reactor (UASB/AH)

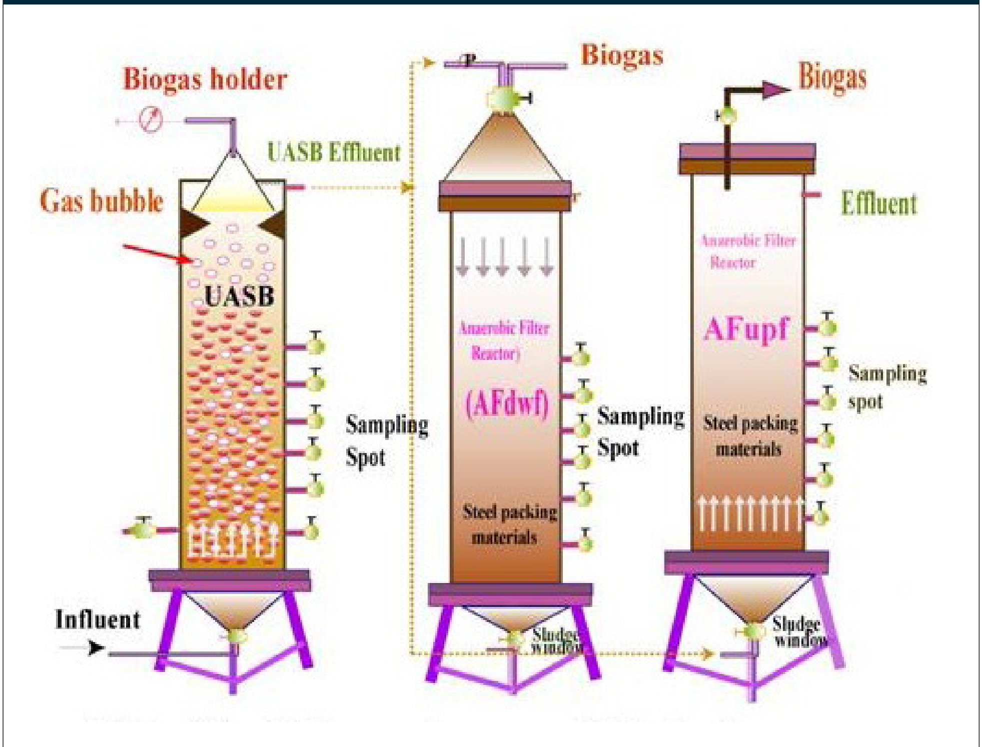
Elmitwalli *et al.*, (1999) studied the post-treatment of UASB effluent with three reactors -- one is UASB and two are AH reactors with small sludge granules with an average diameter of 0.73 m at low temperature (13°C). The experiment took place in Netherlands. The AH reactors were placed vertically with

Figure 10: Schematic diagram of post treatment of UASB effluent in EGSB



polyurethane foam sheet and the HRT was 8 h. The removal and degradation of colloidal particle from sewage appear to be limited in UASB reactors at low temperature (Mergaert *et al.*, 1992). In the UASB/AH reactors, used the smaller size granules were used to obtain higher degradation effect and recover more COD. The polyurethane foam (PF) appeared as an excellent colonization matrix for filtration. The results with the combination system of UASB/AH performed significantly for the post-treatment of UASB effluent. A disadvantage of the reactor is the need to back wash the reactor. The combination of UASB/AH system is shown in Figure 11.

Figure 11: UASB reactor and post-treatment of UASB effluent in the Anaerobic Hybrid Reactor (AH)



Discussion

The post-UASB technology discussed is more acceptable for many reasons, such as lower capital cost, less land area required, simple operation techniques, more reliable, locally available reactor materials, longevity of the reactor and the fulfillment of the standard effluent quality. Among the post-treatment technologies, the DHS system could be considered as the best reactor for post-treatment of UASB effluent, because it required low land area, has a simple operation technique, uses locally available materials with low prices (sponge materials are cheap and universally available). It is a low-cost technology and the DHS effluent fulfilled the standard effluent quality with minimum chlorination. Therefore, the DHS effluent could be useable for irrigation purpose, which may significantly affect the economic aspects of developing countries. Comparison of effluent characteristics of post-treated UASB effluent is shown in Table 2.

Table 2: Effluent Characteristics of Post-treated UASB Effluent by Using Various types of Bio-Reactors

Primary treatment	Post-treatment reactors	pH	COD (mg/l	BOD (mg/l)	SS (mg/l)	F.Coli. MPN/100ml	References
UASB	FPU/SP	7.3	145 88-112	41 32-64	74 52-120	$10^{5.8}$ 1.1×10^6	Okubo *et al.*, (2005) Cavalcanti *et al.*, (2001)
UASB	Trickling Filter (TF)	--	60-120	⇢67	⇢30	Not Done	Chernicharo & Nascimento (2001)
UASB	Rotating Biological Contractor (RBC)	---	61-76	...	...	6.5×10^5	Tawfik *et al.*, (2002)
UASB	Submerged Aerated Biofilter (BF)	---	49	19.0	10	Not Done	Goncalves *et al.*, (1998)
UASB	Sequencing Batch Reactor (SBR)	7.4	94	---	26.0	Not Done	Torres &Foresti *et al.*, (2001)
UASB	Fluidized and Fixed-bed reactor (FFB)	---	45	30	---	Not Done	Colliviganarelli *et al.*, (1991)
UASB	Down-flow Hanging Sponge System	7.9	33	5	10	10^4	Okubo *et al.*, (2005)
UASB	Expanded Granular Sludge Bed (EGSB)	--	87	---	32	Not Done	Kato *et al.*, (2003)
UASB	Anaerobic Hybrid (AH) reactor	---	67	---	----	----	Elmithwalli*et al.*, (1999)
UASB	Anaerobic filter (AF) process	---	60-79	31-34	9-21	Not Done	Chernicharo& Machado (1998)
UASB	UASB-digester	7.4	460	ND	-----	Not Done	Mahmoud *et al.*, (2004)
UASB	Dissolved air flotation (DAF)	5.1-7.6	50	-----	8	Not Done	Penetra*et al.*, (1999)

Conclusions

Sewage contributes directly to environmental pollution. The UASB treatment process can provide bio-energy from sewage treatment. In this review paper, various post-treatment processes of UASB effluent have been analyzed for their ability to fulfil the quality standards of UASB effluent in developing countries. The combination of UASB and DHS system is more convenient and economic than others, because UASB and DHS systems produce less excess sludge and the final effluent has a higher level of dissolved oxygen (DO) and less fecal coliform ($<10^4$/100 ml). This system satisfied the WHO standard. Therefore, the DHS effluent can be reused in irrigated fields and aquaculture industry with minimum chlorination, which simultaneously reduces environmental pollution and significantly contributes to economic development.

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