REVIEW PAPER ON TREATMENT OF INDUSTRIAL AND DOMESTIC WASTEWATERS USING UASB REACTORS INTEGRATED INTO CONSTRUCTED WETLANDS FOR SUSTAINABLE REUSE

ENGIDA, T. M.[1,2] – WU, J. M. [2*] – XU, D.[2] – WU, Z. B. [1,2*]

[1]*School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan, P.R. China*
(e-mail: zewedenahomruhama@gmail.com)

[2]*State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, P.R. China*

**Corresponding authors*
e-mail (J.M. Wu): wujunmei@ihb.ac.cn;
e-mail/phone/fax (Z.B. Wu): wuzb@ihb.ac.cn/+86-27-6878-0020/+86-27-6878-0675

(Received 23rd Aug 2019; accepted 8th Feb 2020)

Abstract. The successful use of anaerobic technologies, especially up-flow sludge blanket (UASB) reactors for the treatment of raw domestic sewage and industrial wastewaters in tropical and subtropical countries opened the opportunity to substitute the aerobic processes with anaerobic reactors in removal of organic matter. Proper management of domestic and industrial wastewaters in developing nations is negligible. Even cost effective integrated green technologies like anaerobic reactor with constructed wetland technologies are not applied. Hence the objective of the present review was to assess the pollutant removal efficiency of the up flow anaerobic sludge blanket (UASB) reactor coupled with a constructed wetland (CW) in treating these wastewaters and their capability to produce quality water for sustainable reuse. To achieve the objectives, the review was organized using reputable journals, articles, and review papers. The interpretation of the result of each document was done using tables, bar graphs, Pie chart and lines. The results were reorganized again by calculating average flow rate, hydraulic loading rate, and percentage removal efficiencies. Most research results revealed that use of UASB-CW integrated treatment system is a promising technology in wastewater treatment and able to complying the effluent discharge standards. Globally, the following abatement efficiencies ranged from 79.2-93.9%, 89.2-92.9%, 87.2-96.3%, 22.6-96.9%, 33-85.9%, and 97.9-99.99% were achieved for Chemical oxygen demand (COD), Biological oxygen demand (BOD), Total suspended solid (TSS), Total Kjeldhal Nitrogen (TKN), Total phosphorus (TP) and fecal Coliforms (FC), respectively using UASB-CW treatment systems. UASB-CW technologies are effectively integrated treatment systems and can be used for resource scarce developing countries. Since, both treatment technologies are cost-effective, easy operation and maintenance and capable of meeting effluent standards. Hence, the indiscriminate disposal of wastewaters and their environmental impacts in Ethiopia can be resolved using these low-cost combined treatment technologies.
Keywords: *domestic sewage, industrial wastewaters, UASB reactor technology, constructed wetland, UASB-CW integrated treatment systems, effluent sustainable reuse*

Introduction

Ocean and river quality deterioration is primarily caused by the discharge of inefficiently treated industrial and municipal wastewater. To combat this increasing problem on aquatic environment, strict regulation on pollution discharge is being implemented by various governmental bodies, with the focus primarily of waste reduction (Chan et al., 2009). Nowadays, there are a wide range of wastewater treatment technologies in the world. However, the strategies of treating domestic, municipal and industrial wastewaters by common and aerobic processes were shifted to the anaerobic processes. Anaerobic treatment technologies were known to treat medium to high strength wastewaters. Many advanced anaerobic treatment reactors have been investigated in the past. Among the reactors, Up-flow Anaerobic Sludge Blanket (UASB) reactor is widely used as a sustainable technology to tackle the challenges faced in efficient treatment of various kinds of wastewater. The success of this reactor is due to its strong ability to remove in removal of chemical oxygen demand even at light loading rates and low temperature (Atashi et al., 2010). Besides this, anaerobic treatment of wastewater has recently gained worldwide attention due to its simplicity, low construction costs, small land requirements, plain operation and maintenance, low sludge production and low energy requirements and energy production capacity in the form of biogas compared to aerobic treatment (Bhatti et al., 2014; Kasaudhan et al., 2013; Khan et al., 2011; Airuk et al., 2010; Gomec, 2010; Tandukar et al., 2007). Earlier much attention was not given to the treatment of wastewaters and they were simply dumped into the natural sources of water. This led severe health problems by deteriorating natural water resources.

An organic waste from industries, domestics, municipalities and agricultural sector decomposes in the environment and resulting large scale contamination of land, water and air. In order to protect the environment and prevent health hazards it is necessary to provide adequate treatment for the wastewater to reduce its pollution potential (Lomte and Bobade, 2015). Similarly in Ethiopia, accelerated water quality change due to rapid growth of urbanization and industrialization becomes one of the major environmental concerns in the country. Release of large quantities of industrial wastes to the environment contributes large quantities of nutrients and toxic substances into the water bodies. The pollution of water bodies and human habitat in the major cities, rivers and lakes are one evident for enormous release of wastes (Kenatu, 2011). This rise of environmental protection issue, leads to put strict environmental regulations on the industrial pollutions in order to reduce the levels of discharge standards. To full fill the regulations, some industries begin to use anaerobic reactor technologies to handle ever-increasing complex generated wastes from their processing units (Kebena, 2014). Different investigations were carried out at pilot and full-scale levels to study the effectiveness of UASB reactor for the treatment of various industrial wastewaters like distillery, petroleum, canning industry, paper and pulp, pharmaceuticals, tannery, textile and food industries such as brewery, diary, slaughterhouse, and sugar factories (Atashi et al., 2010). However, the UASB reactor has become the most frequently used method in treating domestic and industrial wastewater and can produce two main valuable resources (i.e., methane and the effluent). The methane gas is produced during the COD removal which with a potential recovery rate of 28% to 75% and can be transformed into energy (Mutombo, 2004).

The successful use of anaerobic reactor technologies for the treatment of wastewaters was restricted in tropical and sub-tropical regions. In these regions, anaerobic reactors have been responsible for the removal of large fractions of organic matters (Foresti et al., 2006). However, despite this success, UASB reactors are usually unable to attain most of the existing effluent discharge standards due to presence of high residual COD and BOD, nutrients and pathogens (Foresti et al., 2006; Yasar and Tabinda, 2010). All these features make the UASB treatment of wastewater is a very important field of research, where improvements and new developments are needed to overcome the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

problem. Thus, additional post treatment strategy is mandatory for the anaerobic bioreactor treated effluents sustainable reuse for developing countries but also for advanced countries (Yasar and Tabinda, 2010). There are different types of post treatment configurations on combination with UASB reactor, such as UASB-Aerobic suspended growth, UASB-Aerobic attached growth, UASB-Final Polishing Units (FPU) or UASB-Polishing Ponds (PP) are some of them used at several sewage treatment plants in India, Colombia and Brazil (Von Sperling and Mascarenhas, 2005; Khan et al., 2011).

Recently, application of constructed wetlands (CW) for the treatment of wastewater has received much attention, due to their cost effectiveness and environmentally friendly approach. In this situation, application of integrated anaerobic pretreatment-constructed wetland for the removal of pollutants is promising (Jamshidi et al., 2014). Constructed wetland technologies can be effectively integrated with anaerobic processes because they require a low energy input, easy operation and maintenance, modest installation and maintenance costs, minor sludge production, and the creation of visually pleasing landscapes. However, they need a large land area. The UASB removes mainly organic matter in wastewater with low and high organic loads; while the Horizontal subsurface flow constructed wetland (HSSFCW) is capable of removing organic matter and nutrients and is commonly used to obtain secondary or tertiary effluent concentration levels. In other words, combining an anaerobic reactor with a constructed wetland brings important benefits to the constructed wetland system such as the reducing of the required planted area, reducing the hydraulic retention time and increasing their life cycle (Lopez-Lopez et al., 2015). In addition to this, for resource scarce developing countries to adopt wastewater treatment, the treatment technologies must be cost-effective and easy to adopt, requires less energy input, and maintenance costs and be capable of meeting effluent discharge standards (Kyambadde et al., 2005).

The objective of this review paper was to assess the potential use of UASB reactor followed by constructed wetland in treating domestic and industrial wastewaters to the discharge standard limit, to compare and contrast UASB-CW wastewater treatment system with other kinds of post-treatment technologies and to assess the limitation of UASB reactor technology for wastewater treatment.

Method of writing the review paper

This review paper was written using journals articles, review papers, master's and doctoral thesis downloaded from Springer Link, Science Direct, Library Genesis, Jester, and www.nap.orgsearching web pages. The interpretation of the result of each document was done using tables, bar graphs, Pie chart and lines in a Microsoft excel. Results were reorganized again by calculating average flow rate, hydraulic loading rate, and percentage removal efficiencies of the scholars for comparison. The pollutant removal rates (%) were calculated for the uncalculated wastewater parameters using the following equation:

$$R\ (\%) = \left[1 - \frac{Cf}{Ci}\right] x\ 100$$

where R is the removal rate, C_i and C_f are the influent and effluent.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

Overview of anaerobic reactors

The main anaerobic reactors types used for the treatment of wastewater can be classified as low rate or high rate treatment systems as shown in *Figure 1*. High-rate systems are characterized by retention of sludge (sludge retention time (SRT) > hydraulic retention time (HRT)) whereas most low-rate anaerobic systems have no sludge retention time (SRT = HRT) (Zhang, 2016).

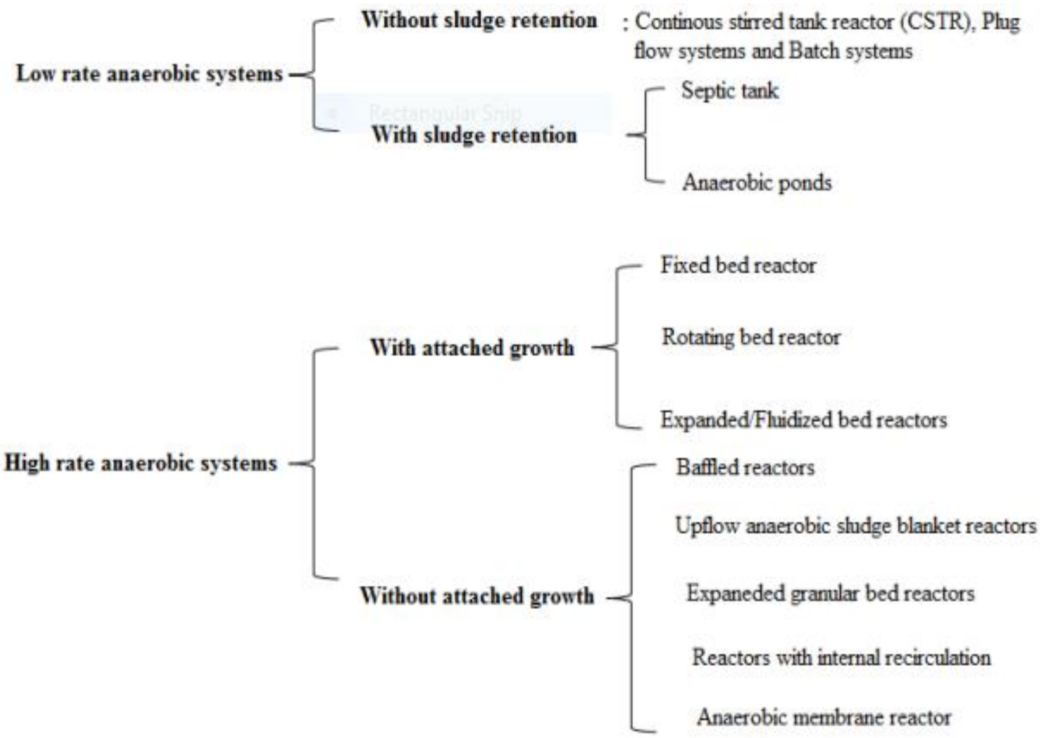

***Figure 1.** Spectrums of anaerobic reactors used for wastewater treatment*

Among the spectrums, UASB reactor is one of the most distinguished anaerobic treatment technologies developed in Netherlands. Successful construction of a UASB process is capable of affording self-granulation of anaerobic microbes. The distinguished characteristic of this reactor is the presence of active biomass at the bottom of the reactor operating on suspended growth system. In this type of bioreactor, wastewater flows upwards direction through sludge bed and sludge blanket and is degraded by anaerobic microorganisms. Small sludge granules begin to form whose surface area is covered in aggregations of bacteria. Gas produced is then separated by a gas–liquid separator and the clarified liquid is discharged over a weir, while the granular sludge naturally settles at the bottom *Figure 2* (Saleh and Mahmood, 2003). Full-scale UASB reactors are now operational in Europe, US, Japan (Bani, 2011) and Ethiopia (Kebena, 2014).

Industries discharge wastes that contain high levels of organic materials which could adversely affect the environment. To meet the discharge limits, industries prefer economical and practical treatment methods. Anaerobic treatment has gained more attentions in developing countries due to their eco-friendly, low energy input, low biomass outputs, simple and inexpensive technologies to operate (Bukhari et al., 2015).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

Several anaerobic reactor technologies have been designed and constructed for the treatment of high strength wastewater. UASB reactors have received much attention due to their ability to treat high strength wastewater at higher organic loading rate (OLR) and a lower HRT. The treatment of high strength wastewater such as brewery wastewater using anaerobic digestion has been employed throughout the world. However, anaerobic digestion has some disadvantages like bad odor, and effluent that sometimes needing post-treatment to meet the discharging standards for nutrients levels, organic matter and pathogens content.

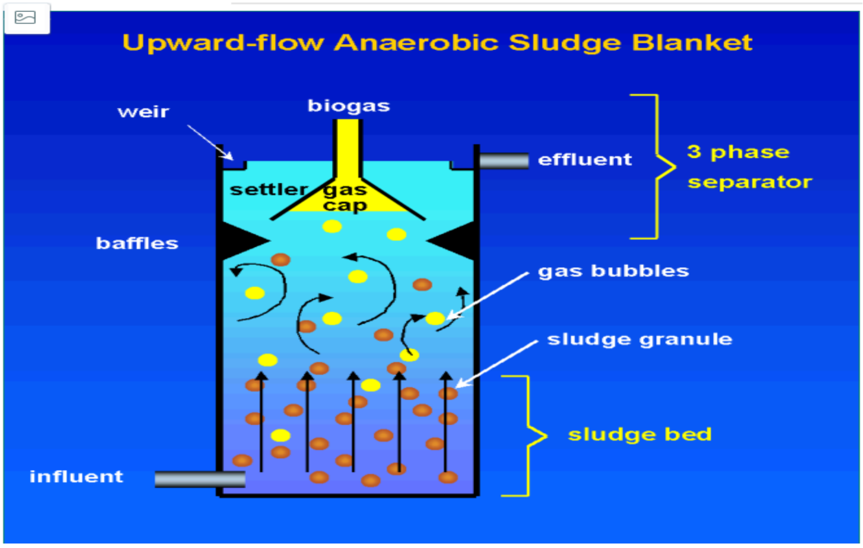

Figure 2. *Up-flow anaerobic sludge blanket reactor (UASB)*

Over the past times, different types of reactors have been developed and their installations have been commercialized. Among those, UASB reactor configuration is the most widely used high-rate anaerobic reactor for the treatment of high strength wastewater. An overview of the different anaerobic treatment systems used for different industrial wastewater pre-treatment and their proportions and types of anaerobic digestion systems that have been installed and commercialized for the treatment of industrial wastewater is presented in *Figure 3a* and *b* (Enitan, 2015).

Anaerobic reactor technologies have been widely applicable in the past decade for the treatment of various types of industrial wastewaters such as food processing, textile industry, paper and pulp industry (Pantea and Romocea, 2008). Anaerobic reactors have been used mainly for industrial wastewater treatment. This technology is also rarely applied for the treatment of municipal sewage, because municipal sewages are too weak (low BOD or COD) to maintain high biomass (i.e., in the form of granules-suspended solids or fixed film) content in the reactor. However, anaerobic wastewater treatment plants for municipal wastewater have been successfully operated in tropical countries such as Mexico, Colombia, India and China, the process until now has not been applied in countries with moderate and low temperatures.

According to Khan (2012) report indicates that there are 200 UASB reactors are used for municipal and industrial wastewater treatment application in India. The UASB reactor treating wastewater can produce main valuable resources (i.e., methane and the effluent) which can be recovered and utilized. Worldwide, more than 2000 anaerobic

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

systems are also in operation for the treatment of industrial wastewater and landfill leachates (IEA, 2001). At lower temperature, the removal of COD by anaerobic reactor is limited and long HRT is needed for one step system to provide sufficient hydrolysis of particulate organics (Gašpariková et al., 2005) because low temperature causes deleterious effect on anaerobic digestion through relatively longer generation time of anaerobic bacterial populations and lower biochemical activity, resulting in the decrease of biogas yield and digester failure (Singh et al., 1999).

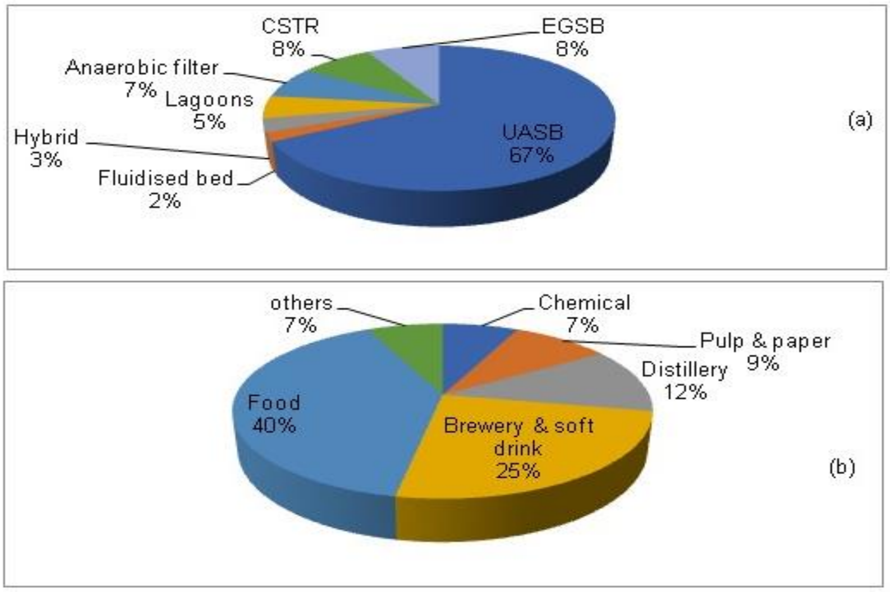

Figure 3. *(a) Proportions and types of anaerobic reactors that have been installed and commercialized for the treatment of industrial wastewater and (b) percentage of industries used anaerobic reactor technologies for wastewater treatment*

Anaerobic digestion process

Anaerobic reactors have a unique diverse group of bacteria that catalyzes the conversion of complex organic compounds to methane and carbon dioxide under a properly controlled and coordinated fashion. Degradation of organic matter in anaerobic process undergoes a complex microbial process consisting of several interdependent consecutive and parallel reactions. In this anaerobic digestion process, several groups of bacteria playing a vital role (Foresti et al., 2006) (*Fig. 4*).

Anaerobic effluents/UASB effluent characteristics

The output of anaerobic reactor indicates that the effluent contains residual organics in terms of BOD, COD, TSS and rich nutrients (N and P), microbial pathogens and reduced species such as sulfides, nitrate, ammonia, etc.

Organics and suspended solids

The concentration of BOD, COD, and TSS of anaerobic treatment system like UASB reactors in treating sewage without any post treatment system has been reported to vary from 60 to 150; 100 to 200; and 50 to 100 mg/l respectively (Foresti et al., 2006). The

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

process efficiency depends on different factors like wastewater strength and composition, temperature, pH, and others. The dissolved mineralized compounds such as ammonia, phosphate and sulfides in the effluents also varied with these factors. The performance of these treatment systems highly depends on temperature and decrease with a decrease in temperature (Elmitwalli et al., 2001; Lew et al., 2003).

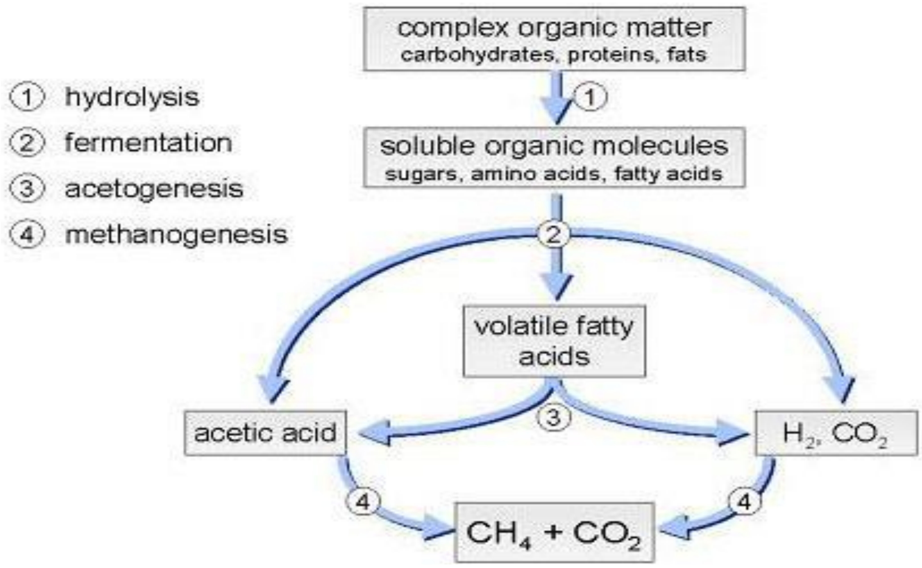

Figure 4. *The chemical reactions that occur during anaerobic digestion (Metcalf and Eddy, 2003)*

Nutrients

Insignificant or negligible removal of nutrients may be expected from anaerobic treatment systems (Foresti et al., 2006; Moawad et al., 2009). The poor removal of nutrients in anaerobic process is due to organic nitrogen and phosphorus hydrolysis into ammonia and phosphate respectively, which are not removed by this process and in consequence, their concentration increases in the liquid phase. Other highly mineralized sulfur compounds exist as sulfides in anaerobic systems effluent treating sewage. The effluent total sulfides concentration depends on the concentration of sulfates in the influents and sulfate reducing bacterial activity present in the reactor (Khan, 2012).

Indicators of microbial pathogens

The reduction of fecal coliforms is around one order of magnitude, i.e., from 108 to 107 in UASB treatment system which indicates that it is not designed for pathogenic removal, while helminth eggs removal efficiency has been reported to be 60-90% (Chernicharo et al., 2001; Von Sperling and Mascarenhas, 2005). In general, the UASB reactor effluent has a significant count of FC which is greater than the permissible limits specified by WHO (1989) for unrestricted irrigation. This indicates that the removal efficiency of UASB reactor is insufficient towards residual organics, nutrients and pathogens.

This may be due to the excessive hydraulic loading which consequently resulting higher up-flow velocities that may cause bypass of these pollutants with the final effluent without any microbial degradation. The temperature effect may be also one

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

factor, because low temperature leads to insufficient mixing and more organic matter usually remains un-degraded as a result of slow hydrolysis of volatile solids at a given HRT. Considering the intrinsic limitations associated with the anaerobic systems and the stringent discharge standards, it is imperative to include a post-treatment stage for the effluents from anaerobic reactors. Therefore, the polishing stage has the purpose to improve the microbiological quality of the effluents, in view of the public health risks and limitations imposed on the use of treated effluents in agriculture. In an environmental approach, the post-treatment needs to guarantee the effluent quality in terms of organic matter and nutrients, in view of the environmental damages caused by the discharge of these remaining pollutants into the receiving surface water (Noykova et al., 2002).

Post-treatment of anaerobic reactor effluents

The insufficient removal of nutrients in anaerobic process is organic nitrogen and phosphorous hydrolyzed to ammonia and phosphate, respectively, which are not removed by anaerobic processes. Therefore, to minimize these problems, low rate natural settling systems (polishing ponds, constructed wetlands and duckweed pond), high rate aerobic methods (chemically enhanced primary treatment, Zeolite column, sequential batch reactor) and micro-aerobic methods (down-flow hanging sponge) are used for removal of the stabilized suspended matters, nutrients and fecal coliforms (FC) present in the UASB reactor (Khan et al., 2013).

Polishing ponds (PP)

Von Sperling and Mascarenhas (2005) found that the feasibility of PP (Polishing ponds) for the post treatment of effluent of UASB reactor in Brazil. The performance of the four series shallow depth PPs (i.e., 0.4 m) for the treatment of UASB effluent at a total of 7.4 day or 1.4 to 2.5 days results the final effluent concentration of BOD and COD, 44 and 170 mg/l, respectively. The mean overall FC removal efficiency was remarkably high (i.e., 99.99996%). The high FC removal efficiency together with total nitrogen concentration of 10 mg/l in the effluent were found compatible with the discharge standards for urban wastewater from European community, 15 mg/l or 70% removal. The ammonia nitrogen concentration in effluents from combined system was 7.3 mg/l or 67% removal. However, phosphorus removal was low (i.e., 28%). Other research study done on integrated anaerobic-aerobic systems carried out in Brazil also showed that shallow ponds in series even at short HRT, are able to produce effluents complying with the WHO guidelines for unrestricted irrigation in respect to FC concentration which is lower than 1000 MPN/100 ml. In general, all polishing pond systems were able to produce a quality effluent, which is a compliance with the WHO guidelines for unrestricted and restricted irrigation (Cavalcanti et al., 2001).

Constructed wetland (CW)

Constructed wetland system is technically and economically feasible alternative for wastewater treatment for small communities (Okurut, 1999). The systems consist of a solid medium (sand, soil or gravel) used to develop a natural process under suitable environmental conditions and wetland plant species provides a substrate (roots, stems and leaves) which microorganisms can grow as they break down organic matters. These plants species have a

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

great role in utilization of the nutrients and other constituents, oxygen transfer to the solid medium and support medium for bio-films on the roots and rhizomes (De Sousa et al., 2001). According to Sousa et al. (2001) investigation, the pilot scale wetland system for the treatment of effluent of UASB reactor for the removal of residual organic matter, suspended solids, nutrients (N and P) and fecal coliforms. The 1500 L holding capacity of the UASB reactor was operated at HRT of 3 h and 6 h while the effluent of the UASB reactor was treated in four units of CW, each 10 m long and 1.0 m wide, filled with coarse sand substrate media and planted with Juncus sp. Macrophyte were planted in three CWs, whereas the other serves as a control unit without plants.

The final result revealed that the effluent COD from the four CW units had substantially constant concentration values, indicating that there was no influence of varied hydraulic load applied and presence of plant in CWs on its removal efficiency. The phosphorus removal was very efficient during the whole study periods; this removal was mainly due to the utilization by plants and microorganisms as well as adsorption and precipitation. In unplanted CW, the removal was due to precipitation and adsorption as well as assimilation by the bio-film developed on sand grains. The total nitrogen removal efficiency varied from 59 to 87% in wetlands containing macrophytes. This may be due to assimilation by plants and microorganisms present in wetlands, probably nitrification due to transport of oxygen from atmosphere by plants. The output indicated that the presence of macrophytes enhance the nitrogen removal efficiency significantly. The highest removal efficiency occurred in the unit with lowest hydraulic load corresponding to HRT of 10 day. The removal efficiency of the fecal coliforms was observed to be very high in wetlands with macrophytes. The increase in hydraulic load reduced the removal efficiency.

Duckweed pond (DP)

The aquatic macrophytes based treatment systems such as DP (Duckweed Pond) can be used to recover the nutrient and transformed them into easily harvested protein rich by products. The UASB effluents are highly rich in nutrients which should not be removed but, recovered. DP is covered by floating mat of macrophytes, which prevents light penetration into the pond resulting in shading. The high growth rates of the macrophytes permits regular harvesting of the biomass and hence nutrients are removed from the system. The produced biomass has economic value, since it can be applied as fodder for poultry and fish. El-Shafai et al. (2007) evaluated the performance of a combined UASB-DP system (3 pounds in series). The UASB reactor had a holding capacity of 40 L and run at 6 h HRT while each pond had 1 m^2 surface areas and 0.48 m depth and operated at HRT of 5 day in each pond. The duckweed ponds were inoculated with Lemna gibba, obtained from a local drain, at 600 grams fresh duckweed per m2. At the end, the system removed 93% COD, 96% BOD and 91% TSS during warm season. While residual values of ammonia, total nitrogen and total phosphorus were 98%, 85%, and 78%, respectively. The system also achieved 99.998% FC removals during the warm season. The removal efficiency of the system at the winter season was the same for BOD, COD, and TSS, but not for nutrients and fecal coliforms.

Chemically enhanced primary treatment (CEPT) and zeolite column

This treatment system was proposed by Aiyuk et al. (2004), which works in an integrated approach (i.e., coagulation and flocculation - UASB - Zeolite). In this integrate treatment system; domestic wastewater is initially treated with CEPT using

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

$FeCl_3$ as a coagulant and polymer to remove suspended material and phosphorus followed by UASB to remove soluble organics. The UASB effluent was then subjected by re-generable zeolites to remove total ammonia nitrogen. The CEPT pre-treatment on average removed 73% COD, 85% TSS and 80% phosphate (PO_4^{3-}). The coagulation/flocculation step of this integrated system produced a concentrated sludge (8.4% solids), which can be stabilized in conventional anaerobic sludge digester used as fertilizer for agricultural purposes.

After, this step, UASB reactor consequently received pre-treated wastewater with COD loading of 140 mg/l and it was operated with hydraulic loading rate of 0.4 g COD/L/day. For these conditions, the system removed about 55% COD. The zeolite removed almost 100% NH_4^+. The integrated coagulation/flocculation - UASB - Zeolite system effectively decreased the TSS and COD up to 88% and more than 90% respectively. The nitrogen and phosphorus were decreased 99% and 94%, respectively. The column of zeolite proved most beneficial due to very high removal efficiency of ammonia and the oxidation of residual organic matter. Pathogenic indicators (FC) removal is 99%. The final effluent from the system can be used for crop irrigation or discharged into surface waters.

Down-flow hanging sponge (DHS)

This treatment system is a high rate micro-aeration treatment method. Micro-aeration implies that aeration of the treated effluent for about 30 min. The role of micro-aeration is to strip off and to oxidize the reduced species such as sulfides, ferrous ions etc., which exert immediate oxygen demand and remaining easily biodegradable organic pollutants and to remove the dissolved methane gas. In this DHS reactor designed, sponge cubes diagonally linked through nylon string have been used to provide a large surface area to accommodate microbial growth under non-submerged conditions. Then the wastewater trickled through the sponge cubes supplies nutrients to resident microorganisms. Oxygen is supplied through natural draught of air in the downstream without equipment. The system provides dissolved methane gas to be recovered. The performance efficiency of combined UASB-DHS cube process, with post-denitrification and an external carbon source, 84% in average nitrogen (NO3- + NO2-) was removed with HRT of less than 1 h. The DHS reactor was capable of stabilizing TN through nitrification, which ranged from 73 to 78% (Khan et al., 2013).

Sequential batch reactor (SBR)

SBR is a fill and draw type modified activated sludge process, where four steps of fill, aeration, settle and decant takes place sequentially in a single batch reactor. The operation of SBR can be adjusted to obtain aerobic, anoxic and anaerobic phases inside the standard cycles. The performance of the system was evaluated through a bench scale set-up comprising of a 4 L volume UASB reactor followed by two SBRs of 3.6 L each. The UASB reactor was fed with partially mixed synthetic substrate in sewage while SBR received effluent of UASB reactor. The HRT of 4 h in UASB was maintained constant throughout the study while the 4 h cycles in the following sequence of fill (0.1 h), reaction (1.9 h), sedimentation (1.6 h), discharge (0.25 h), idle (0.15 h) were maintained in SBR. The combined system removed 85% TN through nitrification. The COD removal in UASB reactor was around 86% while in SBR around 65% of the remaining, thus combined systems removed 95%. The combined system was also

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

removed 96% of TSS and 98% of BOD (Khan et al., 2013). Mouawad et al. (2009) also studied the performance of the combined UASB-SBR system under different operating conditions for the treatment of domestic wastewater.

The reaction time was run for 3 h and the aeration time in the SBR cycle varied from 2 to 5 h, and then to 9 h. The observed average percentage removal for the three runs for COD, BOD and TSS was 94%, 97% and 98% respectively. Complete nitrification of ammonia was achieved after 5 h aeration in the SBR. The average percentage removal of phosphorus reached up to 65%. Increasing the HRT in the SBR from 2 to 9 h caused a significant improvement in FC removal. The overall removal efficiencies of the different post-treatment systems were mentioned in *Table 1*.

Table 1. *Treatment performance efficiency of UASB reactor integrated with different post-treatment systems in treating sewage (Khan et al., 2011)*

Treatment systems	**Removal efficiencies of pollutants**						
	BOD	**COD**	**TSS**	**NH_4 - N**	**TN**	**TP**	**FC (MPN/100 ml)**
CEPT + UASB + Zeolite	85%	91%	88%	99%	94%	94%	99%
UASB + PP	92%	79%	96%	50%	55%	-	99.999%
UASB + CWs	-	82%	79%	70%	70%	89%	99.998%
UASB + DWP	96%	93%	91%	98%	85%	78%	99.998%
UASB + DHS	96%	91%	93%	28%	40%	-	99.95%
UASB + SBR	97%	94%	98%	100%	77%	65%	-

Irrigation suitability of post-treated effluents

The UASB reactor process has been recognized as one of the environment friendly methods for treatment of urban wastewater in tropical countries due to its low capital investment, less land and energy requirements, less sludge generation, low maintenance cost and its potential to generate biogas. Effluent from this reactor, however, does not meet the disposal standards specifically in relation to organic content, suspended solids, nutrients and pathogen content. This makes the post-treatment of UASB reactor effluent necessary before its discharge into water bodies or its reuse in irrigation (Nair and Ahammed, 2013).

Domestic sewage treatment using UASB reactor is an interesting approach, provided the recovery of carbon in the form of energy-rich methane gas and nutrients. However, the effluent reusing for agriculture has some constraint because of the presence of pathogenic organisms and over nutrient dosage in the non-growing season. The UASB effluent still contain excess nutrients, salts and pathogens and is to be post-treated to remove pathogens after which the effluent can be used for irrigation and fertilization purposes. Unrestricted irrigation requires a high degree of pathogen removal and will increase the overall treatment costs. At presently, constructed wetland brings interesting results in removal of pathogens more effectively in a cost-effective way. The big advantage of this post-treatment system is its simplicity in operation, and the low investment costs when land prizes are low (van Lier et al., 2002) (*Fig. 5*).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

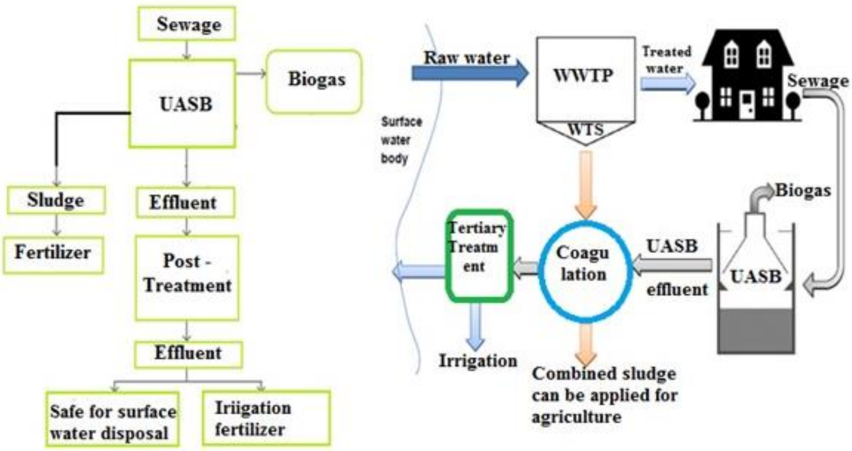

Figure 5. *(a) Post-treatment of UASB reactor domestic sewage effluents by onsite treatment options like CW for pathogen reduction and subsequent agricultural reuse (modified from van Lier et al., 1999) and (b) conceptual framework of reuse of treatment plant biosolids for UASB effluent post-treatment (Nair and Ahammed, 2013)*

Factors influencing the UASB reactors performance

The anaerobic process is a vital option for the treatment of industrial and domestic wastewater. The UASB reactor technology proved economically more attractive for treating sewage in both tropical and subtropical countries. However, a wide range of factors influence its performance efficiency. The most important factors are designing of UASB following parameters such as operational conditions (temperature, pH, organic loading rate, hydraulic retention time, and up-flow velocity), wastewater characteristics (influent concentration, influent particle size and influent particle charge), and sludge bed characteristics (particle size distribution, extra cellular polymeric substances and charge) and toxic substances should be considered as the most important factors affecting performance efficiency of UASB reactor (Sushma and Pal, 2013).

pH (potential hydrogen)

Due to the formation of different intermediates, anaerobic reactions are highly dependent on pH value particularly for methane producing bacterial ranging in 6.8-7.2. While, acid forming bacteria can survive in a more acidic condition. So, the pH of anaerobic system should be maintained between the methanogenic limits to avoid the predominance of the acid forming bacteria which may cause volatile acid accumulation. Therefore, microbial groups involved in each phase require different pH conditions for optimum growth. To achieve this, it is essential to provide buffering agents like sodium bicarbonate to neutralize any eventual VFAs accumulation. Addition of NaHCO3 is useful for supplementing the alkalinity, which shifts the equilibrium to the desired condition without disturbing the microbial population (Saleh and Mahmood, 2004).

Temperature

An aerobic occurs under a variety of temperatures depending on the species of microorganisms employed. In general, controlled anaerobic digestion is subdivided into

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

three temperature ranges, psychrophilic (10-20 ℃), mesophilic (20-40 ℃), and thermophilic (50-60 ℃). The structures of the active microbial communities at each temperature optima are quite different. For example, bacterial growth and conversion of organic materials is slower under psychrophilic conditions.

The rate of methane production increases as temperature increases until maximum mesophilic temperature ranges, 35-37 ℃, because in this temperature ranges mesophilic microorganisms are actively involved. In general, biogas production yield depends on the choice of optimal temperature conditions for microorganism activity. most conventional anaerobic digestion processes occur under mesophilic temperatures. Because, this operation conditions are more stable and requires less energy input compared to operations under thermophilic conditions, and results in a higher degree of digestion (De Mes et al., 2003). The maximum (i.e., thermophilic) and minimum (psychrophilic) temperatures explains the limits of the temperature ranges for microbial optimal growth rate. The optimum temperature ranges are suitable conditions for maximum microbial growth rate. While the microbial growth become typically low below the optimal temperature levels and in some extent, it increases its growth exponentially at higher temperatures but some while microbial growth become restricted. The temperature effects on the removal efficiency of the anaerobic reactors depend on the type of the reactor as well. For example, a decline of the removal efficiency of the UASB reactor at lower temperature is due to the decreases in biological activity (Chernicharo, 2007).

C/N ratio

Unbalanced C/N ratio is one of a limiting factors of anaerobic digestion. Substrates with high C/N ratios, such as paper and most crop residues will be deficient in nitrogen, which is an essential nutrient for microbial cell growth. Thus, anaerobic digestion of very high C/N ratios may be limited by nitrogen availability. In the case of substrates with low C/N ratios, such as some animal manure, toxic ammonia build-up may become a problem. To overcome deficiencies in either carbon or nitrogen, co-digestion of low C/N materials with high C/N materials has been proven an effective solution (Martin-Ryals, 2012).

Organic loading rate (OLRs)

Organic loading rate is defined as the number of volatile solids or chemical oxygen demand fed to the system per unit volume per time. Higher OLRs can allow for smaller reactor volumes thereby reducing the associated capital cost. However, at high OLRs there is a danger in overloading of the reactor, especially during reactor start-up. At higher OLRs, retention times must be long enough such that the microorganisms have enough time to sufficiently degrade the material. Thus, there is a balance between OLR and HRT that must be determined in order to optimize digestion efficiency and reactor volume (Martin-Ryals, 2012). Hydraulic retention time (HRT) can be defined as the amount of time that waste remains in the digester and in contact with the biomass. For easily biodegradable compounds such as sugar, the HRT is low whereas more complex compounds need longer HRTs. HRT values influences the rate and extent of methane generation and is one of the most significant factors affecting the transformation of volatile substrates into gaseous products (De Kock, 2015).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

Nutrients

Nutrient at optimal levels are important for microorganisms for cellular building blocks and ensures that the cells are able to synthesize enzymes and co-factors responsible for driving metabolic activities. These include macronutrients such as nitrogen, phosphorous and Sulphur, vitamins and trace elements (iron, nickel, magnesium, selenium, copper, and cobalt). Even though, nutrients are required in very low amounts, lack of them causes significant effect on growth of microbes (De Kock, 2015).

UASB reactor removal efficiency

The efficiency and reliability the treatment system of a domestic sewage containing of an anaerobic reactor were assessed. Considering the slight balance of the micro-biota arose following the sludge extractions and these promoted reactor imbalances. This additional took about a reduction in reactor performance and hence of the over-all sustainability of the reactor development when treating domestic sewage directly. On the other hand, the system could not eliminate the nutrients such as nitrogen and phosphorus (Aiyuk et al., 2010). For example, performance assessment of complete scale UASB reactor in India by Sharda et al. (2013) indicates that, the high BOD and COD removal efficiencies. These high elimination efficiencies of the UASB reactor might be due to the proper functioning of the reactor.

While, the TSS removal efficiency was reduced, this may be attributed due to the high volatile suspended solids resulting in the creation of granular sludge bed in the UASB reactor. Similarly, performance assessment of full-scale UASB reactor in Ethiopia shows that higher removal efficiency in terms of COD while it was limited in removal of BOD, TSS and nutrients (Kebena, 2014). *Figure 6* demonstrates that the performance competence of full-scale anaerobic reactor treating domestic and industrial wastewaters.

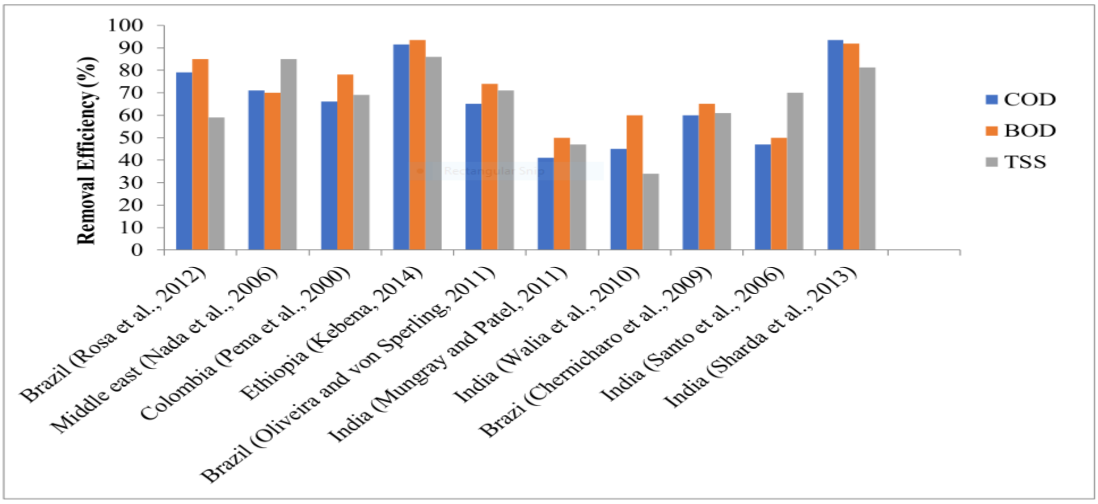

Figure 6. *Performance efficiency of full-scale anaerobic reactor treating sewage and brewery wastewater (Sharda et al., 2013; Kebena, 2014) treatment plants in different parts of the world*

The process efficiency of UASB reactor efficiency depends on diverse issues like strength and composition of wastewater, temperature and diurnal fluctuations. The

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

dissolved mineralized compounds such as sulfides ortho-phosphate and ammonia, in the effluent also varied with factors. The performance of these treatment systems highly depends on temperature and decreases with a decrease in temperature (Khan et al., 2011) The performance efficiency of pilot and complete scale UASB reactor in treating sewage and industrial wastewater at different temperature and hydraulic retention time is summarized in *Table 2*.

Table 2. *Treatment performances of laboratory and full scale UASB reactors treating sewage and industrial wastewater (Khan et al., 2011; Bula, 2014)*

	Country	**Japan**	**Japan**	**India**	**Brazil**	**Cambodia**	**Brazil**	**Netherlands**	**Ethiopia**
	Capacity	_	1148 L	5 MLD	106 L	35 m^3	106 L	6 m^3	700 m^3
	Temp. (C)	-	-	25	21-25	23-24	20	20	-
	HRT	6	6	10	4.7	5.2	4	18	17
Influent mg/l	COD	600	532	590	265	475	424	550	2676
	BOD	291	240	167	150	-	195	-	1505
	TSS	-	-	-	123	225	188	-	686
Effluent mg/l	COD	222	197	201	133	170	170	165	228
	BOD	153	79	60	59	-	61	-	98
	TSS	-	-	-	33	65	59	-	96
Removal efficiency (%)	COD	63	63	66	50	66	60	70	91
	BOD	53	67	67	61	80	69	-	93.4
	TSS	-	-	-	73	69	69	-	82.6

India is a foremost country in terms of sewage wastewater treatment by UASB development where 37 UASB grounded sewage treatment plants (STPs) is already operating. It has been requested that 80% of total UASB reactors installed worldwide for sewage treatment are in India. The straightforward approach towards the selection of this technology for sewage treatment is due to its low capital cost, low energy requirements, small operation and maintenance costs and sustainability aspect. The performance of three STPs at Agra, Surat and Ludhiana (i.e., 78, 100, and 48 MLD) was greatest and the removal of COD, BOD and TSS was 45-48%, 29-43% and 40-51% respectively. The reason for poor performance was improper operation and maintenance and lack of screening control, grit removal and sludge wasting. The performance of 27 and 152 MLD at Noida and Ludhiana reactors was observed relatively good with the BOD, COD and TSS removal efficiencies of 53-59; 41-55 and 49-59%, respectively (Khan et al., 2014) (*Fig. 7*).

These results indicated that UASB reactor requires post treatment in order to obey with the removal standards. The monitoring of 10 STPs of diverse cities of India was agreed out in order to investigate their performance. The primary objective of research was to evaluate the treatment performance of full-scale UASB reactors and diverse post treatment systems. The general performance of these STPs was extended from 66 to 95% for BOD, COD and TSS removal (*Fig. 8*). However, three UASB reactors at 78, 100 and 48 MLD STPs at Agra, Surat and Ludhiana revealed minor treatment efficiency due to poor operation and maintenance (Khan et al., 2014).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

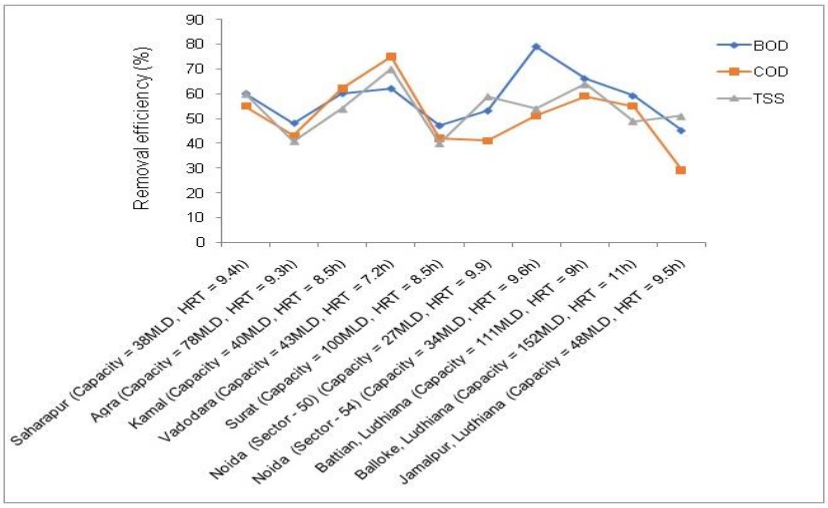

Figure 7. *Performance efficiency of full scale UASB reactor in treating sewage at different cities of Indian towns*

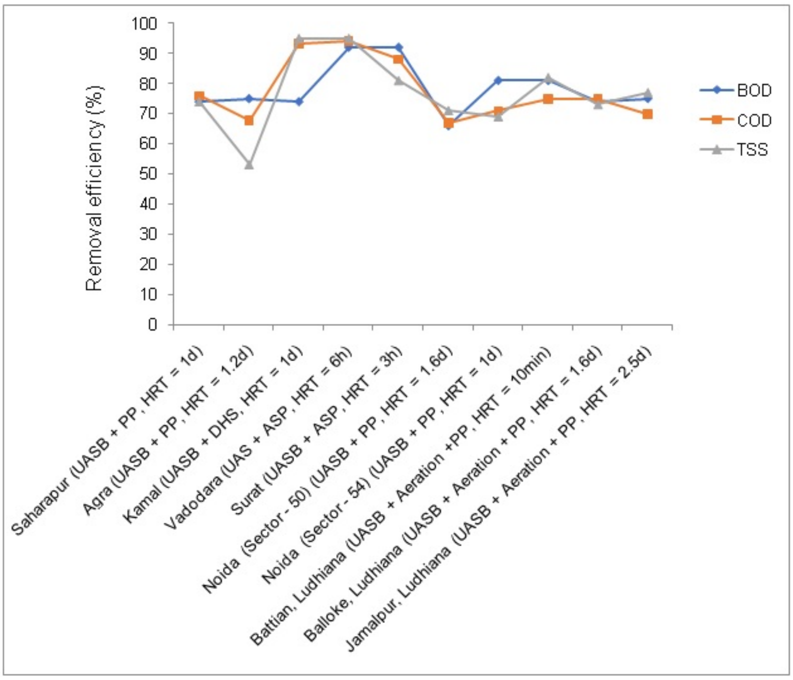

Figure 8. *Removal efficiency of the full-scale UASB reactor integrated with different post-treatment systems in different cities of India*

According to Mahmood et al. (2013) investigation, the laboratory scale UASB reactor performance for the treatment of original wastewater of COD concentration of 474 mg/l was reduced to 297 mg/l with 37.3% removal efficiency. Similarly, the TSS, BOD, NO_3 - N, and NH_4 - N were reduced from 1400 mg/l, 84.8 mg/l, 16 mg/l and 82 mg/l to 115 mg/l, 18.5 mg/l, 16 mg/l and 10 mg/l with removal efficiency of 91.7%, 78%, 88.9% and 87.8% respectively. Similarly, Khan et al. (2011) pilot scale of UASB reactor in treating sewage indicated that the performance efficiency of BOD, COD, and

TSS was 66.3%, 60.1% and 62%, respectively. The indicators of pathogens that is FC in UASB reactor was reduced to 10%. The removal of reduced species like NH_4 - N, NO_3 - N and PO_4 - P were insignificant in both pilot and full scale UASB reactors. The performance efficiency of pilot scale and full scale UASB reactors operated at OLR of 60 L and HRT of 8 h in removal organics, nutrients and pathogens were shown in *Figure 9a* and *b*.

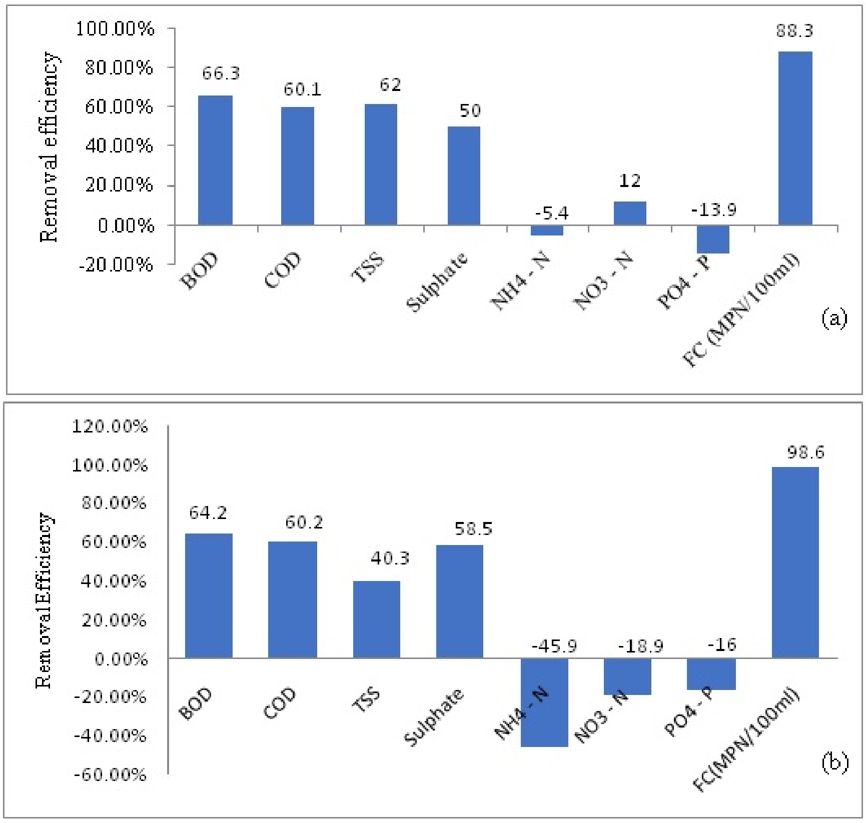

Figure 9. *Performance efficiency of UASB reactor at (a) pilot scale and (b) full scale levels in treating sewage wastewater*

The performance of the 111 ML/day full scale UASB reactor was also evaluated by Khan et al. (2011). The performance of full- and pilot-scale UASB reactors at ambient temperature (from 9 to 39 °C) was comparable. The percentage COD, TSS and BOD removal efficiency in the full-scale UASB reactor varied between 55 and 65%, whereas the removal in pilot scale ranged from 60 to 70%. The indicator of pathogens, which is FC in UASB reactors, was decreased to 10%. The removal of NH_4 - N, NO_3 - N and PO_4 - P were insignificant in both UASB reactors; the effluent pH remained within the optimal working range for anaerobic digestion (6.9-7.9). The research results were consistent with other UASB reactors investigated by El-Khateeb and El-Bahrawy (2003), i.e., the concentrations of COD, BOD, and TSS were decreased by 67.7%, 71.4% and 65.5%, respectively.

On the other hand, the TKN and TP were also reduced by removal efficiency of 11.3% and 23% respectively including fecal coliform removal efficiency of 96.7%. This high removal efficiency of COD, BOD and TSS is mainly attributed due to the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

relatively high sludge residence time (HRT = 38.1 days), which improves the hydrolysis and biodegradation of organic matter of wastewater content. Whereas the UASB reactor removed only the particulate nutrients by sedimentation and filtration and therefore, it had relatively low nutrient removal efficiency (El-Khateeb and El-Bahrawy, 2013).

Removal efficiency of UASB-CWs

Up-flow anaerobic sludge blanket (UASB) proved to be a cost-effective pretreatment system for wastewater. In addition, constructed wetlands provides a low-cost alternative for wastewater treatment in developing countries mainly in the arid and semi-arid regions. According to El-Khateeb et al. (2009) investigation, UASB reactor was used as a mainly treatment step followed by a horizontal subsurface constructed wetland for the treatment of grey municipal wastewater. The HRT and organic loading rate of the UASB reactor was 6 h and 1.88 Kg COD/m^3/day respectively. Within these operating conditions, the COD removal efficiency of the UASB reactor was 60%. Further enhancement of the quality of the treated wastewater was attained after the application of HSSFCW. The overall removal efficiency of the complete systems for COD, BOD and TSS were 87.7%, 89.5% and 94%, respectively (*Fig. 10*).

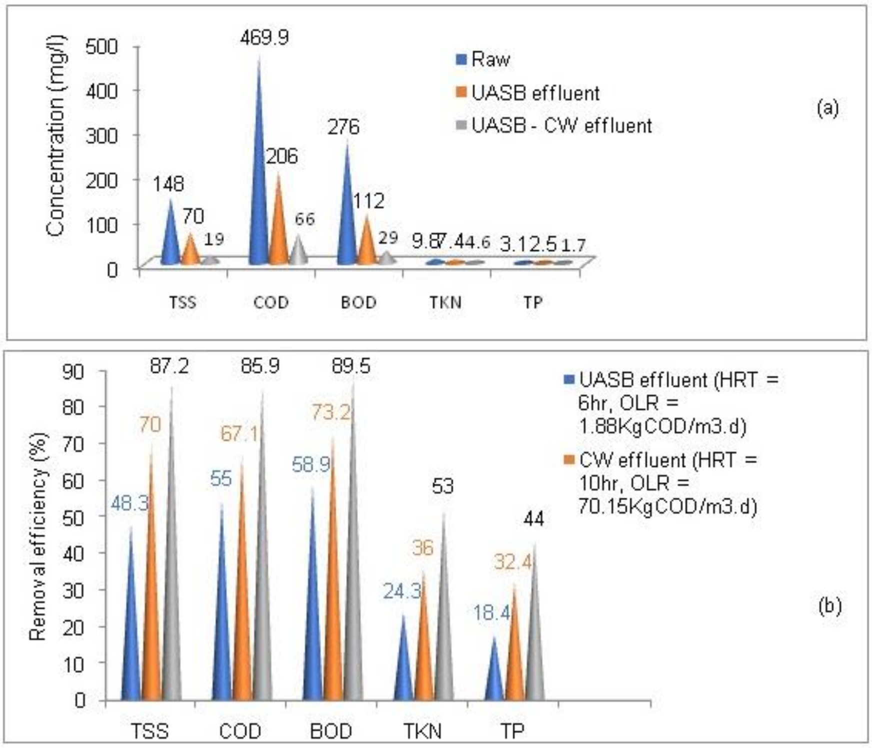

***Figure 10.** (a) Concentration of raw grey wastewater and (b) removal efficiency of UASB-CWs in treating grey wastewater*

El-Khateeb and El-Bahrawy (2003) also found that the UASB reactor was operated at wastewater temperature varying from 15 °C during winter time to 30 °C during summer time. The UASB reactor efficiency at 8 h HRT was quite satisfactory. Average removal of COD and TSS were 63.2% and 66.5% respectively. The removal of FC in

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

the reactor was 86%. After post-treatment with SSF CW COD reduction of 78%, BOD reduction of 78%, TSS and TP reduction of 78% and 79% were obtained respectively. The comparison of the removal competence of UASB reactor and its SSF CW integrated system in removal of COD, BOD, TSS, NH_4 - N, TKN, TP and FC are indicated in *Figure 11*.

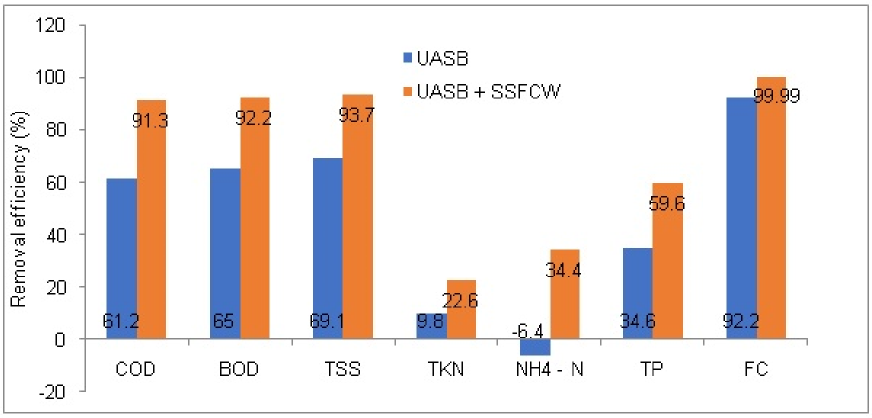

Figure 11. *Comparison between UASB reactor and UASB-SSFCW in removal of pollutants from sewage wastewater*

The likelihood of using treatment schemes consists of a UASB reactor tracked by subsurface flow constructed wetland for the treatment of sewage water is an effective system. The UASB reactor was designed at operating conditions of HRT (6 h), HLR (4 m^3//day), and OLR (2.45 Kg/m^3/day). The performance of this reactor for the treatment of raw sewage indicates that the concentration of COD, BOD, TSS, TN and TP were reduced by 67.7%, 71.4%, 65.5%, 11.3% and 23% respectively. The bacterial count was reduced to 96.7%. *Figure 12* shows that the performance of SSF wetland unit integrated with UASB reactor. The concentration of ammonia also greatly decreased in the final effluent of SSF unit. This may be due to aerobic conditions adjacent the root section of the plant in the CW unit (El-Khateeb and El-Bahrawy, 2013).

Research studies indicated that nitrogen and phosphorus elimination by plant uptake is not a significant mechanism for the removal of these elements in wetlands receipt moderately treated municipal wastewater because nitrogen and phosphorus are taken-up and free in the cycle of plant growth and death. In El-Khateeb and El-Bahrawy (2003) finding, the removal of TP was initiate to be high at the beginning of the experiment. As the plant reaches the maturation state the removal was decreased and there is some release of phosphorus from the dead parts of the plant. The removal efficiency the SSF CW was increased and noted that the final effluent was complying the WHO guidelines for treated effluent reuse.

According to Cheng et al. (2010) investigation, the removal percentage of pollutants in the influent and effluent following the UASB - CW1 - CW2 treatment systems achieved a greater reduction of pollutants (i.e., COD removal of 93.9%). The result indicates that the UASB reactor is capable of removing 60-80% of total COD, 75-85% of BOD, and 70-80% of total SS from the raw sewage, while the removal efficiency of nutrients such as TN and TP are only 10-25% and 10-20%, respectively. This removal limitation of UASB reactor can be improved by utilization of some aerobic processes such as activated sludge and constructed wetlands. *Figure 15* shows changes of NH_4 -

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

N, NO_3 - N and PO_4 - P concentrations in the influent and effluent of the treatment units. From the data presented, the UASB reactor only removed 75% of NH_4 - N, 3.9% of NO_3 - N and 42.9% of PO_4 - P. However, the CWs removed almost over 85% of NH_4- N and PO_4 - P except NO_3 - N. The removal of NH_4 - N may be due to its oxidation into nitrite and nitrate–nitrogen compounds by microbial processes. Less removal of NO_3 - N may be due to the leaves of floating lettuces covered almost all the water surface in CW2 and protected direct sunlight from penetrating into the water body could suppress the growth of algae cells. As a result, the nitrogen removal capacity of the CW could be reduced. Whereas, the removal of TP levels in the UASB reactor was 42.9%, this may be achieved by metabolism of anaerobes and adsorption into the sludge. This less removal of TP can be improved by integrating with CW, in which the CW removes TP by microbial metabolism and plant uptake (*Fig. 13*).

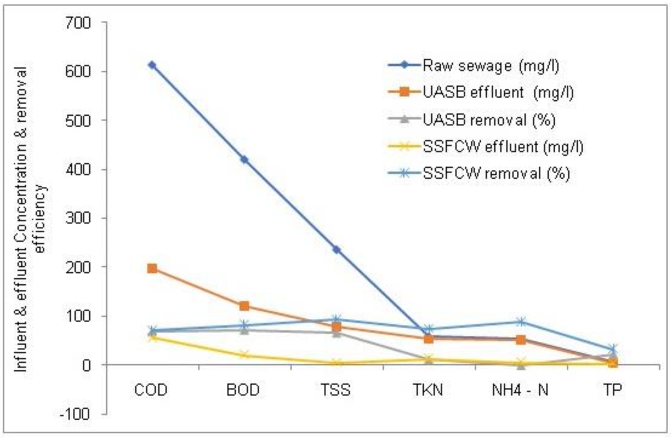

***Figure 12.** Performance of the UASB reactor alone and post treated with SSFCW of raw sewage*

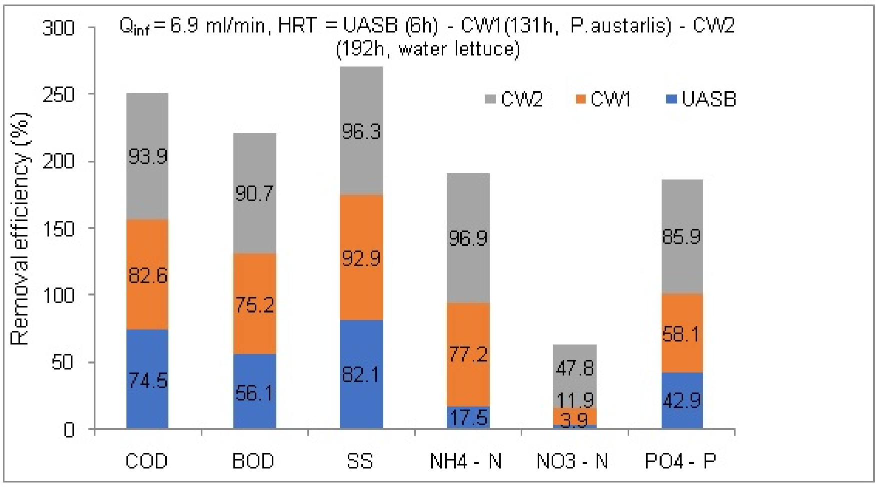

***Figure 13.** Removal efficiency of UASB-CW1-CW2 in treating mixture of raw sewage and partially treated swine wastewater*

Similar study on the use of UASB reactor followed by a HSSFCW treatment system showed an important health advantage. In specific, there were no substantial odor

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

emissions, and there was no indication of the proliferation of insects and other disease vectors. According to Raboni et al. (2015) investigations, the quality of raw sewage indicates that a high strength characteristic. Treatment of this sewage with UASB reactor results in the achievement of average removal efficiencies in the UASB reactor as high as 74% for BOD5, 71.15 for COD, and 65% for TSS. With regard to fecal indicators, the removal efficiency of UASB reactor appears low (i.e., 67.4% for fecal coliforms and 65.2% for fecal enterococci). Further treatment of UASB reactor effluents with SSFCW achieves removal efficiency of 92.9% for BOD5, 79.2% for COD, and 94% for TSS.

In addition to this, the SSFCW step concludes the removal of pathogens with an overall removal efficiency of 98.8% for fecal coliforms and 97.9% for fecal enterococci. The overall removal efficiency of the UASB reactor joint with subsurface flow constructed wetland on the removal of pollutants from raw sewage wastewater were indicated in *Figure 14*.

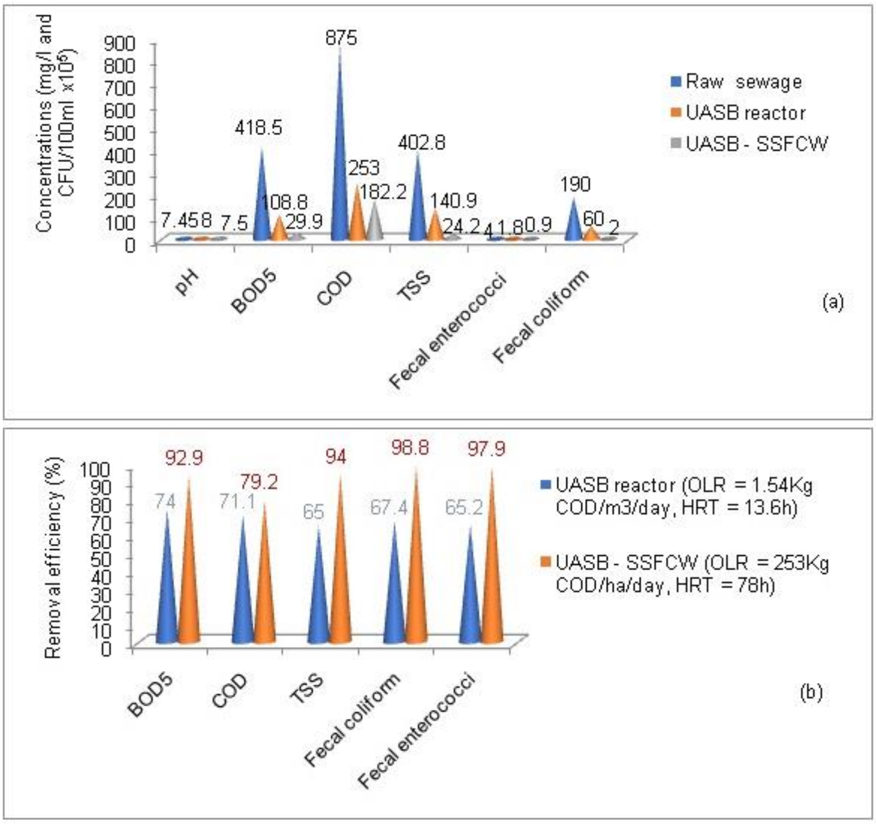

Figure 14. *(a) Concentration of pollutants in raw sewage, UASB and SSFCW and (b) removal efficiency of combined UASB-SSFCW treatment system*

It was observed that the effluent from the UASB reactor still contains significant count of fecal coliforms. These counts are larger than the permissible limit set by WHO (1989) for unrestricted irrigation. The feasibility of widespread post treatment using a horizontal subsurface flow constructed wetland for the treatment of sewage water has been studied by El-Khateeb and El-Bahrawy (2003). The result showed that the UASB-HSSFCW integrated treatment system was found to be efficient for removal of COD, BOD and TSS including nutrients and fecal coliforms. These may attribute due to the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

aerobic conditions near the root zone of the plants in the wetland units. Similarly, the water quality parameters at different sampling themes of hybrid system of UASB-CW were reduced due to through three systems. The overall removal competence of the UASB - SFCW - SSFCW was 91% for COD, 91.2% for BOD and 97.9% for TSS at applied organic loading rate in the range of 1200-6500 g BOD/m^2/day in UASB and 5-21 g BOD/m^2/day (10 g BOD/m^2/day on average for the two CW units) (de la Varga et al., 2013) (*Fig. 15*).

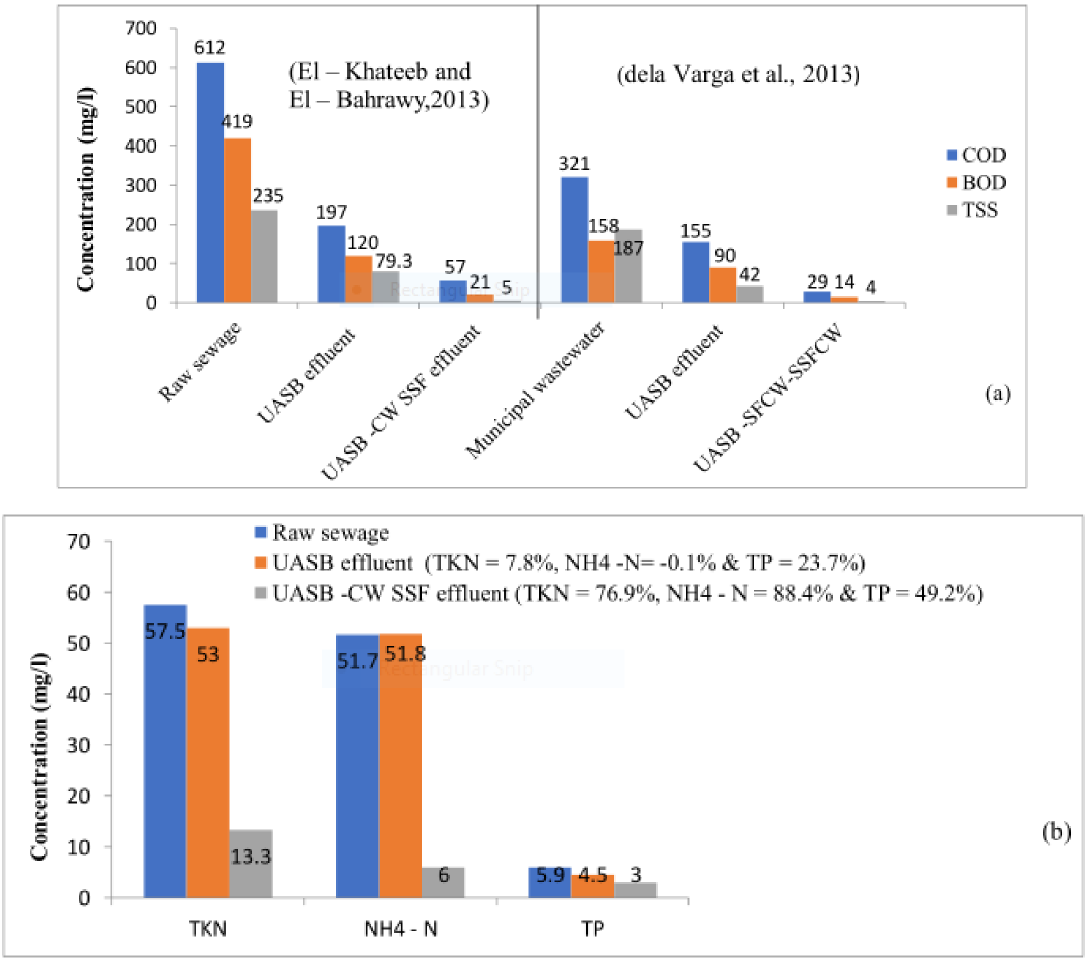

Figure 15. *Concentration of pollutants in raw sewage, UASB and SSFCW effluents and removal efficiency of combined UASB/SSFCW system (a and b)*

The anaerobic bioreactor indicates that removal of the residual concentration of organic (BOD and COD) less infective which usually exceeds the extreme permissible level prescribed by the effluent discharge standards of most developing countries. From this stand point; post treatment of anaerobic effluent is necessary to reduce the release of these contaminants to the required level. Due to this, the UASB effluent was further treated by CW at HRT of 3 days. The original wastewater fed into the UASB reactor and then post-treated by laboratory scale CW showed removal efficiencies of COD, BOD, TSS, nitrates and Ammonia were 82.4%, 78-82%, 91.7%, 88-92% and 100%, respectively (Mahmood et al., 2013). The overall results on the elimination efficiencies of the UASB-CW is summarized in *Table 3*.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

***Table 3.** Lists and comparison of the performance efficiency of UASB-CWs in treating sewage*

Parameters	**References**					
	De souse et al. (2001)	**Chernic haro et al. (2001)**	**Ma (2005)**	**Cheng et al. (2010)**	**Raboni et al. (2014)**	**Ei-khataeb et al. (2009)**
Type of WW	Sewage	Sewage	Sewage	Sewage-swine	Sewage	Gray water
HRT of UASB (h)	3-6	5.5	1-6	2-6	13.6	6
HRT of CW (day)	5-10	4-20	2.3-13.5	4.5-13.5	78	10
COD removal (%)	79-85	70-80	90	91-94	79.2	85.9
BOD removal (%)	-	70-80	93	91	92.9	89.5
TSS removal (%)	48-71	90	90	93-96	94	87.2
NH_4-N removal (%)	45-70	33	75	89-97	-	-
TP removal (%)	90	-	100	78-86	-	44
FC removal (%)	-	-	-	-	98.8	-

The performance efficiency of constructed wetland integrated with UASB reactor is comparable with other post treatment techniques. According to Sharda et al. (2013) investigation, the assessment of the performance efficiency of a full scale brewery wastewater treatment plant, UASB reactor plus aeration (holding capacity of 380 m^3 at HRT of 23 h) followed by sand and activated carbon filter (holding capacity of 15 m^3 at HRT of 1 h) for a period of thirteen weeks showed an overall percentage reduction of COD, TSS and BOD values ranges from 96-98%, 88-98%, and 99% respectively. Similarly, Gasparikova et al. (2005) investigates, characterization of real wastewater treatment plant working on the principle of anaerobic-aerobic system, there was a problem with the high organic pollution on the effluent of anaerobic-aerobic treatment system. The high COD and BOD effluent concentration as well as TSS concentration are due to the incorrect operation of the wastewater treatment plant.

Among these operation problems, the primary settling tank was full of greases which lead to failure of the process. Another problem may rise from location of the air blower that used for oxygen delivery, which is inside the plastic tank of the wastewater treatment plant. The air circulates only there and no fresh air gets inside which means that there is not adequate oxygen for the aerobic post-treatment. This operation causes the presence of filamentous bacteria in the aerated part. Another study by Sharda et al. (2013), on the general performance of the brewery wastewater treatment plant indicates a reduction in TSS, COD and BOD. During the three-month study periods of the brewery's wastewater treatment plant, the overall removal efficiencies of TSS, COD and BOD were ranges from 96-98%,88-98% and 99% respectively which may be due to the proper functioning of the remaining treatment units such as aeration tank, sand filter and activated carbon filter. The comparison of overall performance of UASB reactor followed by different post treatment techniques are indicated in *Figure 16*.

According to Bhatti et al. (2014), UASB effluent was treated with 40% H_2 O_2 in a further step. A 2 ml/l dose of H_2O_2 was originate to be very effective and shows a removal of 73% for TSS, 99.9% for COD, 84% for TN and 19.8% for PO4 3 - Post-treatment of UASB effluents using H_2 O_2 was very attractive in removal of COD and TN. Similarly, the combined UASB-DHS system was operated continuously and the result showed that UASB-DHS system performs satisfactorily even at high organic loading rate. The total removal efficiency of the COD, BOD, and TSS were 93%, 93%,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

and 98%, respectively, during the first phase and decreased by 1% and 2% during the second and third phases, respectively (Doma et al., 2016) (*Fig. 17*).

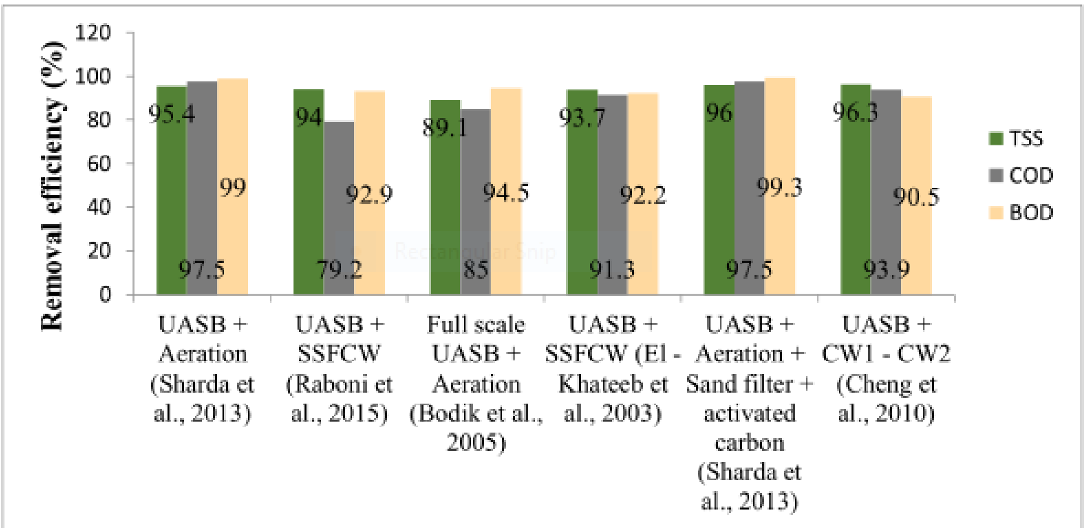

Figure 16. *TSS, COD and BOD removal efficiencies of UASB reactor integrated with different post-treatment system*

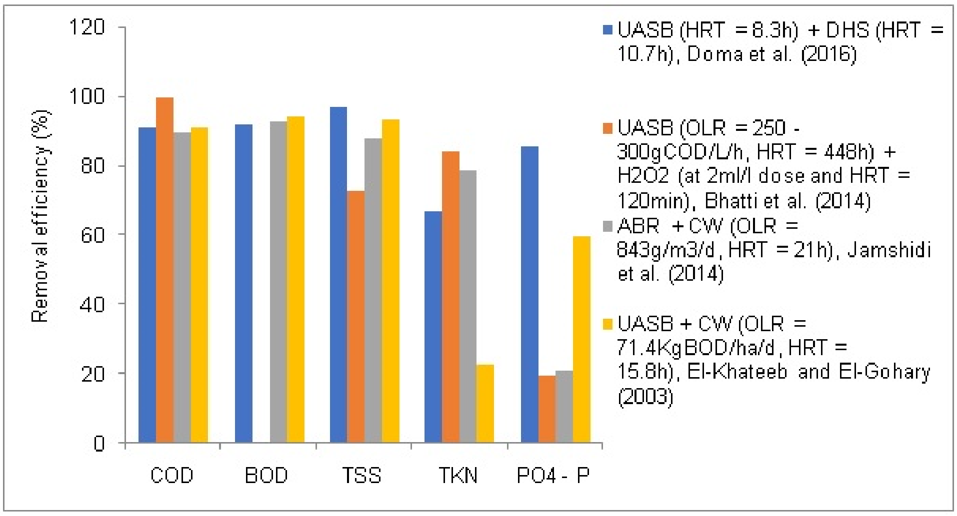

Figure 17. *Nutrient removal efficiencies of UASB reactor integrated with different post-treatment techniques*

Conclusion and recommendations

Conclusion

Now days, the strategies of treating domestic, municipal and industrial wastewaters by common and aerobic processes were shifted to the anaerobic processes. Globally, the following abatement efficiencies were achieved by UASB reactor: COD ranges from 29-92.9%, BOD ranges from 45-93.4%, TSS ranges from 40-82.6%, TKN and TP from negative values up to 74.8% and 23% and FC up to 98.6% respectively for both lab and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

full scales. Despite its success, UASB reactors are regularly unable to attain most of the present effluent discharge standards due to presence of high residual COD and BOD, nutrients and pathogens.

All these features make the UASB treatment of wastewater is a very significant field of research, where enhancements and new progresses are needed to overcome the problem. Thus, additional post treatment approach is compulsory for the anaerobic bioreactor treated effluents for sustainable reuse. At present, integrated constructed wetlands are recognized as a reliable wastewater technology because, they are low cost, simply functioned and sustained and have a strong potential for application in developing countries.

Most research investigation results revealed that use of a UASB reactor followed by a subsurface horizontal flow phytoremediation treatment system is a hopeful natural technology in the treatment of municipal or industrial wastewater. Because, the combined treatment system was found to complying with WHO (1989) standards for treated effluent reuse. Globally, the subsequent abatement efficiencies were achieved using UASB-CW treatment systems: COD ranges from 79.2-93.9%, BOD ranges from 89.2-92.9%, TSS ranges from 87.2-96.3%, TKN ranges from 22.6-96.9%, TP ranges from 33 to 85.9%, and FC ranges from 97.9 to 99.99%, respectively.

Recommendations

Enhanced water quality change due to industrial pollution is one of the great environmental concerns in the world. Most of the wastewaters in developing countries are still discharged directly to rivers, streams and open lands without adequate and comprehensive management. To reduce the indiscriminate disposal of these industrial and municipal wastewaters it is essential to provide a low-cost strategy which can bring comprehensive resource management. Literature review indicates that UASB-CW technologies are effectively integrated treatment particularly for resource scarce developing countries to adopt wastewater treatment, the treatment technologies must be cost-effective and easy to adopt, requires less energy input, easy operation and maintenance costs. Therefore, it is inevitable to adopt this technology in our country for in order to encounter effluent discharge standards with low costs.

Acknowledgments. The authors acknowledge to all authors of the original articles, books, and book chapters that we used freely for writing this reviewed article. The author also would like to thank the editor and the two reviewers for their constructive comments, which helped a lot to improve the original manuscript.

REFERENCES

[1] Aiyuk, S., Amoako, J., Raskin, L., van Haandel, A., Verstraete, W. (2004): Removal of carbon and nutrients from domestic wastewater using a low investment, integrated treatment concept. – Wat. Res. 38: 3031-3042.

[2] Aiyuk, S., Odonkor, P., Theko, N., et al. (2010): Technical evaluation of potential drawbacks in direct UASB treatment of raw domestic sewage. – 2010 International Conference on Environmental Engineering and Applications, IEEE, pp. 320-326.

[3] Atashi, H., Ajamein, H., Ghasemian, S. (2010): Effect of operational and design parameters on removal efficiency of a pilot-scale UASB reactor in a sugar factory. – World Applied Sciences Journal 11: 451-456.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129

[4] Bani, R. (2011): Wastewater Management. – In: Einschlag, F. S. G. (ed.) Waste Water: Evaluation and Management. Intechopen, London.
[5] Bhatti, A. Z., Maqbool, F., Malik, H. A., Mehmood, Q. (2014): UASB reactor startup for the treatment of municipal wastewater followed by advanced oxidation process. – Brazilian Journal of Chemical Engineering 31: 715-726.
[6] Bodik, I., Gasparikova, E., Kapusta, S., Derco, J., Kratochvil, K. (2005): Evaluation of anaerobic-aerobic wastewater treatment plant operations. – Polish Journal of Environmental Studies 14: 29-33.
[7] Bukhari, F., Rizvi, H., Ahmad, N., Abbas, H. I., Yasar, A., Ali, S., Yasmeen, T., Riaz, M. (2015): Start-up of UASB reactors treating municipal wastewater and effect of temperature/sludge and hydraulic retention time (HRT) on its performance. – Arabian Journal of Chemistry 8: 781.
[8] Bula, K. (2014): Treatment and biogas production performances efficiency of St. George Brewery full scale waste water treatment system. – Thesis. Addis Ababa (ET), Addis Ababa University.
[9] Cavalcanti, P., Van Haandel, A., Lettinga, G. (2001): Polishing ponds for post-treatment of digested sewage. Part 1: Flow-through ponds. – Water Science and Technology 44: 237-245.
[10] Chan, Y. J., Chong, M. F., Law, C. L., et al. (2009): A review on anaerobic–aerobic treatment of industrial and municipal wastewater. – Chemical Engineering Journal 155: 1-18.
[11] Cheng, L. L., Lee, Y. H., Lin, H. J., Chou, S. M. (2010): Treatment of mixture of sewage and partially treated swine wastewater by a combination of UASB and constructed wetlands. – Pract. Period. Hazard. Toxic Radioact. Waste Manage. 14: 234-239.
[12] Chernic haro, C. (2007): Anaerobic Reactors. Vol. 4: Biological wastewater treatment Series. – IWA Publishing, London.
[13] Chernic haro, C., da Silva Cota, R., Zerbini, A. M., et al. (2001): Post-treatment of anaerobic effluents in an overland flow system. – Water Science and Technology 44: 229-236.
[14] De Kock, M. (2015): Anaerobic Bioconversion of Liquid and Solid Wastes from the Winemaking Process. – Stellenbosch University, Stellenbosch.
[15] De la Varga, D., Diaze, M. A., Ruiz, I., Soto, M. (2013): Heavy metal removal in UASB-CW system treating municipal wastewater. – Chemosphere 93(7): 1317-23.
[16] De Mes, T., Stams, A., Reith, J., et al. (2003): Methane Production by Anaerobic Digestion of Wastewater and Solid Wastes. – Reith, J. H. et al. (eds.) Bio-Methane and Bio-Hydrogen: Status and Perspectives of Biological Methane and Hydrogen Production. Dutch Biological Hydrogen Foundation, Petten, pp. 58-102.
[17] De Sousa, J., Van Haandel, A., Guimaraes, A. (2001): Post-treatment of anaerobic effluents in constructed wetland systems. – Water Science and Technology 44: 213-219.
[18] Doma, H. S., El-Kamah, H. M., El-Qelish, M. (2016): Slaughterhouse wastewater treatment using UASB reactor followed by down flow hanging sponge unit. – Research Journal of Pharmaceutical Biological and Chemical Sciences 7: 568-576.
[19] El-Khateeb, A. M., El-Bahrawy, Z. A. (2003): Extensive post-treatment using constructed wetland. – Life Science Journal 10: 560-565.
[20] El-Khateeb, M., El-Bahrawy, A. (2013): Extensive post treatment using constructed wetland. – Life Science Journal 10: 560-568.
[21] El-Khateeb, S. A., Regelsberger, M. A., El-Sheikh, R. M., Shehata, M. (2009): Integrated system for the treatment of black water and grey water via UASB and constructed wetland in Egypt. – Desalination and Water Treatment 8: 272-278.
[22] El-Shafai, S. A., El-Gohary, F. A., Nasr, F. A., van der Steen, P., Gijzen, H. J. (2007): Nutrient recovery from domestic wastewater using a UASB-duckweed ponds system. – Biores. Technol. 98: 798-807.

[23] Elmitwalli, T., Zeeman, G., Lettinga, G. (2001): Anaerobic treatment of domestic sewage at low temperature. – Water Science and Technology 44: 33-40.
[24] Enitan, A. M. (2015): Microbial community analysis of a UASB reactor and application of an evolutionary algorithm to enhance wastewater treatment and biogas production. – http://hdl.handle.net/10321/1276.
[25] Foresti, E., Zaiat, M., Vallero, M. (2006): Anaerobic processes as the core technology for sustainable domestic wastewater treatment: consolidated applications, new trends, perspectives, and challenges. – Reviews in Environmental Science and Bio/Technology 5: 3-19.
[26] Gasparikova, E., Kapusta, S., Bodik, I., Derco, J., Kratochvil, K. (2005): Evaluation of anaerobic-aerobic wastewater treatment plant operations. – Polish Journal of Environmental Studies 14: 29-33.
[27] Gomec, C. Y. (2010): High-rate anaerobic treatment of domestic wastewater at ambient operating temperatures: a review on benefits and drawbacks. – Journal of Environmental Science and Health Part A 45: 1169-1184.
[28] Jamshidi, S., Akbarzadeh, A., Woo, K.-S., et al. (2014): Wastewater treatment using integrated anaerobic baffled reactor and bio-rack wetland planted with Phragmites sp. and Typha sp. – Journal of Environmental Health Science and Engineering 12: 131.
[29] IEA (2001): Biogas and More! Systems and Markets Overview of Anaerobic Digestion. – International Energy Agency (IEA), Paris.
[30] Kasaudhan, K. G., Mumtaz, N., Raj, V. (2013): Optimization of municipal wastewater treatment by UASB reactor and polishing pond. – An International Quarterly Journal of Biology and Life Sciences 1: 2000-207.
[31] Kebena, B. (2014): Treatment and biogas performance efficiency of St. George Brewery full scale-wastewater after treatment system. – Published MSc. Thesis, Addis Ababa University, Ethiopia.
[32] Kenatu, A. (2011): Evaluation of the performance of constructed wetland system for the treatment of brewery wastewater. – MSc Thesis, Addis Ababa University, pp. 1-3.
[33] Khan, A. A. (2012): Post treatment of UASB effluent: aeration and variant of ASP. – PhD Thesis. IIT, Roorkee, India.
[34] Khan, A. A., Gaur, R. Z., Tyagi, V., et al. (2011): Sustainable options of post treatment of UASB effluent treating sewage: a review. – Resources, Conservation and Recycling 55: 1232-1251.
[35] Khan, A. A., Gaur, R. Z., Kazmi, A. A., et al. (2013): Sustainable Posttreatment Options of Anaerobic Effluent. – In: Chamy, R. (ed.) Biodegradation - Engineering and Technology. – IntechOpen, London.
[36] Khan, A. A., Gaur, R. Z., Mehrotra, I., et al. (2014): Performance assessment of different STPs based on UASB followed by aerobic post treatment systems. – Journal of Environmental Health Science and Engineering 12: 43.
[37] Kyambadde, J., Kansiime, F., Dalhammar, G. (2005): Nitrogen and phosphorus removal in substrate-free pilot constructed wetlands with horizontal surface flow in Uganda. – Water, Air, and Soil Pollution 165: 37-59.
[38] Lew, B., Belavski, M., Admon, S., et al. (2003): Temperature effect on UASB reactor operation for domestic wastewater treatment in temperate climate regions. – Water Science and Technology 48: 25-30.
[39] Lomte, A. T., Bobade, V. (2015): Suitability of UASB reactor system in tropical developing countries like India. International – Journal of Science and Research 4: 801-807.
[40] Lopez-Lopez, A., Merino-Solis, L. M., Villegas, E., de Anda, J. (2015): The Effect of the hydraulic retention time on the performance of an ecological wastewater treatment system: an anaerobic filter with a constructed wetland. – Water 7: 1149-1162.

[41] Ma, J. J. (2005): Study on the treatment of sewage by a combined upflow anaerobic sludge blanket (UASB)-constructed wetland process. – Published MSc Thesis, Institute of Environmental Engineering, National Sun Yat-sen Univ., Taiwan.
[42] Mahmood, B. S., Z., Q., Jadoon, S., Pervez, A., Irshad, M., Bilal, M., Bhatti, A. Z. (2013): Combined industrial wastewater treatment in anaerobic bioreactor post-treated in constructed wetland. – Biomed Research International 8: 1-7.
[43] Martin-Ryals, A. (2012): Evaluating the potential for improving anaerobic digestion of cellulosic waste via routine bioaugmentation and alkaline pretreatment. – MSc Thesis, University of Illinois at Urbana-Champaign.
[44] Metcalf & Eddy, Tchobanoglous, G., Burton, F., Stensel, H. D. (2003): Wastewater Engineering: Treatment and Reuse. 4th Ed. – McGraw-Hill, Boston.
[45] Moawad, A., Mahmoud, U., El-Khateeb, M., et al. (2009): Coupling of sequencing batch reactor and UASB reactor for domestic wastewater treatment. – Desalination 242: 325-335.
[46] Mungray, A. K., Patel, K. 2011. Coliforms removal in two UASB + ASP based systems. – International Biodeterioration and Biodegradation 65: 23-28.
[47] Mutombo, D. T. (2004): Internal circulation reactor: pushing the limits of anaerobic industrial effluents treatment technologies. – Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference, pp. 608-616.
[48] Nada, T., Moawad, A., El-Gohary, F. A., Farid, M. N. (2011): Full-scale municipal wastewater treatment by up-flow anaerobic sludge blanket (UASB) in Egypt. – Desalination and Water Treatment 30: 134-145.
[49] Nair, A. T., Ahammed, M. M. (2013): The reuse of water treatment sludge as a coagulant for post-treatment of UASB reactor treating urban wastewater. – Journal of Cleaner Production 96: 272-281.
[50] Noykova, N., Mueller, T. G., Gyllenberg, M., et al. (2002): Quantitative analyses of anaerobic wastewater treatment processes: identifiability and parameter estimation. – Biotechnology and Bioengineering 78: 89-103.
[51] Okurut, T. O., Rijs, G. B. J., van Bruggen, J. J. A. (1999): Design and performance of experimental constructed wetlands in Uganda, planted with Cyperus papyrus and Phragmites mauritianus. – Water Science and Technology 40: 265-271.
[52] Oliveira, S. C., von Sperling, M. (2011): Performance evaluation of different wastewater treatment technologies operating in a developing country. – Journal of Water Sanitation and Hygiene for Development 1: 37-56.
[53] Pantea, E. V., Romocea, T. (2008): Thermophilic anaerobic wastewater treatment. – Protectia Mediului, Analele Universitatii din Oradea 8: 454-458.
[54] Raboni, M., Gavasci, R., Urbini, G. (2014): UASB followed by sub-surface horizontal flow phytodepuration for the treatment of the sewage generated by a small rural community. – Sustainability 6(10): 6998-7012.
[55] Rosa, A. P., Lobato, L. C. S., Chernicharo, C. A. L., Martins, D. C. R. B., Maciel, F. M., Borges, J. M. (2012): Improving performance and operational control of UASB reactors via proper sludge and scum discharge routines. – Water Practice and Technology 7. https://doi.org/10.2166/wpt.2012.046.
[56] Saleh, M. M., Mahmood, U. F. (2003): UASB/EGSB applications for industrial wastewater treatment. – Seventh International Water Technology Conference, Cairo, Egypt, 1-3 April 2003.
[57] Saleh, M. M., Mahmood, U. F. (2004): Anaerobic digestion technology for industrial wastewater treatment. – Proceedings of the Eighth International Water Technology Conference, IWTC, Alexandria, Egypt, 26-28 March, 2004.
[58] Sharda, A. K., Sharma, M., Kumar, S. (2013): Performance evaluation of brewery waste water treatment plant. – International Journal of Engineering Practical Research 2: 105-111.

[59] Singh, L., Alam, S., Ramana, K. (1999): Effect of fluctuating temperature regime on psychrophilic anaerobic digestion of nightsoil. – Defence Science Journal 49: 135-140.
[60] Sushma, P. J. (2013): Performance of UASB reactor at different flow rate treating sewage wastewater. – International Journal of ChemTech Research 5: 676.
[61] Tandukar, M., Ohashib, A., Harada, H. (2007): Performance comparison of a pilot-scale UASB and DHS system and activated sludge process for the treatment of municipal wastewater. – Water Res. 42: 297.
[62] Van Lier, J. B., Zeeman, G., Huibers, F. (2002): Anaerobic (pre-) treatment for the decentralised reclamation of domestic wastewater, stimulating agricultural reuse. – Proceedings of the VII Latin American Workshop and Symposium on Anaerobic Digestion, 22-25 October 2002, Merida, Mexico.
[63] Von Sperling, M., Mascarenhas, L. (2005): Performance of very shallow ponds treating effluents from UASB reactors. Water Science and Technology 51: 83-90.
[64] Walia, R., Kumar, P., Mehrotra, I. (2011): Performance of UASB based Sewage treatment plant in India: polishing by diffusers an alternative. – Water Science and Technology 63: 680-688.
[65] WHO (1989): Health Guidelines for the Use of Waste Water in Agriculture and Aqua Culture. – http.//apps.who int/iristhandle/10665139401.
[66] Yasar, A., Tabinda, A. B. (2010): Anaerobic treatment of industrial wastewater by UASB reactor integrated with chemical oxidation processes. An overview. – Pol. J. Environ. Stud 19: 1051-1061.
[67] Zhang, L. (2016): Anaerobic treatment of municipal wastewater in a UASB-Digester system: temperature effect on system performance, hydrolysis and methanogenesis. – Dissertation, Wageningen University, Wageningen.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_31013129