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A REVIEW ON ORGANIC REMOVAL OF MUNICIPAL AND INDUSTRIAL WASTEWATER USING UP-FLOW ANAEROBIC SLUDGE BLANKET (UASB) AND ITS APPLICATION IN ANAMMOX PROCESS

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ABSTRACT

Anaerobic treatment processes are widely recognized as a sustainable wastewater management system for their encouraging results in treating highly concentrated wastewater (bCOD > 4000 mg/L) with low energy requirement, which is more economical than aerobic processes. High rate anaerobic reactors, particularly up-flow anaerobic sludge blanket (UASB) reactors, have been extensively employed worldwide due to their high volumetric organic capacity and less sludge yield. However, some limiting factors need to be resolved for large-scale applications. This review aims to emphasize the organic removal of municipal and industrial wastewater using UASB technology and its application in the anammox process in treating ammonia-rich wastewater.

Keywords: Anaerobic, anammox, granulation; up-flow Anaerobic Sludge Blanket (UASB)

INTRODUCTION

Historically, aerobic reactors such as trickling filters or oxidation ponds have been used to treat municipal and industrial wastewaters. Due to the dramatic rise in power costs in the 1970s, high capital cost and high energy consumption induced in aerobic treatment processes cease its attractiveness as core biological means of wastewater treatment [1]. This prompts the development of anaerobic biological treatment because it can generate methane gas as energy recovery, and no aeration is required [2].

During anaerobic treatment, there is no oxygen consumed as anaerobes utilize the energy generated from the transfer of electrons for growth. Meanwhile, low digested sludge production, which is 3-20 times smaller than in the aerobic system, was demonstrated [1]. This would reduce the sludge handling and aeration costs substantially. Chan et al. [3] further emphasizes that anaerobic systems are well suited to treat high strength sewage (biodegradable COD over 4000 mg/L) due to the high COD level biogas energy generation and reduced sludge yield.

Recently, many anaerobic systems have been built and researched. Among them, high rate anaerobic systems such as up-flow anaerobic sludge blanket (UASB), expanded granular sludge bed (EGSB), anaerobic filter (AF), and anaerobic hybrid receive a great response due to their high organic loading rate and low surplus sludge generation [2]- [4]. Chong et al. [2], Khan et al. [4] and Ratanatamskul and Siritiewsri [5] agreed that the success of high rate anaerobic digesters is due to their high loading capacity while sustaining long solids retention times (SRTs) at short hydraulic retention times (HRTs). These factors encourage useful surface contacts between wastewater and microbes at high concentrations, thus improving organic matter removal efficiency and sludge immobilization.

Despite its potential to generate biogas, low biological sludge production and low energy consumption, there are still many improvements in the anaerobic treatment technology. Long start-up processes, possible noxious odour, and inadequate organic matter removal efficiency to meet local discharge standards have been frequently cited as drawbacks of anaerobic treatment [1]-[2]. Therefore, the objectives of this review are to provide an overview of the performance of UASB technology for the organic removal of municipal and industrial wastewater and to discuss the application in the anammox process.

Anaerobic Treatment

In anaerobic treatment, complex organic materials are broken down to form methane, carbon dioxide and water through hydrolysis, acidogenesis, acetogenesis and methanogenesis without the aid of dissolved oxygen [3]. Figure 1 outlines the process of anaerobic decomposition of organic matter. The process begins with the hydrolysis of complex compounds such as carbohydrates, lipids and proteins to soluble substances (e.g., amino acids, sugar) by hydrolytic bacteria. Acidogenic bacteria will further convert the components to carbon dioxide, hydrogen, ammonia and organic acids. Hydrogen producing acetogens then digest the resulting organic acids to produce acetic acid, together with additional CO_2, CH_4 and hydrogen. Lastly, methanogenic bacteria (also known as Archaea) will transform these products into CH_4 and CO_2.

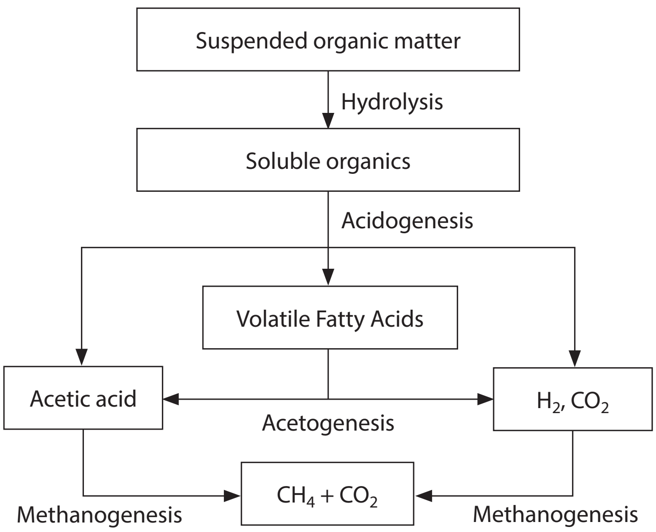

Figure 1 Process of anaerobic decomposition of organic matter [6]

In order to ensure efficient anaerobic treatment, various parameters such as pH, alkalinity, temperature, SRT and HRT are investigated. In terms of pH, the acid balance between acidification and methanogenesis should be considered carefully as methanogenic bacteria are susceptible to the extreme environment, which could inhibit their metabolism from degrading the organic matters. At high organic loading rate (OLR), the build-up of organic acids will eventually cause the failure of methanogenesis [7]. Based on the study, methanogenic bacteria work the best at pH of 6.5-7.2, whereas acidogenic microbes react in a wider range of pH between 4.0 and 8.5. Alkalinity (buffering agent) is also important to prevent changes in pH. It is generated during methanogenesis in the form of carbon dioxide, ammonia and bicarbonate to counter the pH reduction caused by volatile fatty acids (VFAs). Alkalinity should be controlled at 70 meq $CaCO_3$/L for stable operation of anaerobic treatment [6].

The temperature is also crucial because methanogenic microorganisms are very sensitive towards thermophilic conditions at around 50-60°C [8]. It was found that higher methanogenic diversity was identified in the reactors operated under mesophilic environment (37°C) compared to those with thermophilic situations (55°C) [9]. On the other hand, Zielinska et al. [10] claimed that fermentation of dairy wastewater under mesophilic temperatures (35°C) using microwaves promotes higher number and diversity of methanogenic bacteria in biomass than that under thermophilic temperature (55°C) which leads to an increase in biogas generation with a high methane content and a stable reactor performance. Although high temperature promotes biological and chemical reactions, enhances the solubility of organic matter and death rate of pathogens, it also boosts the concentration of free ammonia (FA) and growth of H_2 scavengers that outcompeted methanogenic bacteria which will eventually lead to failure in digestion process [11]-[12]. Hence, process temperature should be controlled to ensure a safe and stable operation during anaerobic digestion. At the same time, SRT should be kept for more than 10 days at a digestion temperature of 35°C for complete and stable digestion of organic compounds [6]. However, this value is established under the ideal situation of temperature, mixing and feeding, so a safety margin of minimum 2.5 should be considered when designing SRT and in practice [13].

UASB Technology

Within the realm of anaerobic treatment technologies (Table 1), up-flow anaerobic sludge blanket (UASB) reactors have been widely recognized as robust yet sustainable technology as high rate anaerobic system for wastewater treatment [14]. They have been remarkably adopted in tropical countries, such as Brazil and India [2],[4],[15]-[16]. The success of UASB theory depends on the development of dense sludge bed at the bottom of the reactor, in which all biological processes occur [1].

UASB Reactor

A schematic diagram of the UASB reactor is shown in Figure 2. The reactor comprises of two parts: (1) a cylindrical or rectangular column, and (2) a gas-liquid-solid (GLS) separator [2]. Initially, inoculum such as granular, activated or digested sludge is used to start up the UASB reactor [18]-[20]. When sludge enters through the distributor at the bottom, the incoming suspended solids and bacterial growth promote the accumulation of sludge bed. Based on selection pressure theory, light and dispersed particles will be washed out while heavier granules or flocs consisting of small microbes agglomerates, organic and inorganic matter will be formed in the inoculum under high selection pressure (dependent on sludge loading rate) [21]. After the acclimatization period, which is around 2-8 months, a very dense sludge bed (granules of 0.5 to 2 mm in diameter) with good settling properties will be established [22]. This formation enables the application of higher organic loads in small reactor sizes, thus enhancing treatment efficiency [14]. Above the sludge bed, there is a sludge blanket zone with considerable dispersed growth and lower particle settling velocities [2]. Both zones act as a medium for biological reactions. As the wastewater moved upward, the organic matters are entrapped and converted into methane, carbon dioxide and water. Natural turbulence induced by the influent flow and the biogas generation offers good wastewater-biomass contact without any external agitating force in UASB systems [1]. The mixtures of the biogas and floating sludge are then separated by

Table 1 Anaerobic treatment process technologies for wastewater [1], [14], [17]

Treatment process	Characteristics
Completely stirred tank reactor (CSTR) and anaerobic contact process	a. Has a mixer to promote contact between biomass and organic matter for digestion b. Require biomass recirculation (for contact process) to ensure sufficient amount of MLSS within the reactor c. Not suitable for rapid waste flow
Fixed film or anaerobic filter (AF) reactor	a. Dependent on media support for biomass growth b. Has the concern of biomass plugging on the support medium c. Applicable for wastewater with low organic contaminants level like chlorinated solvents
Anaerobic baffled reactor (ABR)	a. Suspended growth reactor with compartmentalized configuration b. Phase separation for acidogenic and methanogenic process which allows the buffer to toxic materials, good biomass retention and granulation
Internal circulation (IC) reactor	a. 2 stages of traditional separators with one placing midway the height of the reactor b. Provide good mixing and high shear on granules to govern the outgrowth of fermentative bacteria
Expanded granular sludge bed (EGSB)	a. Modified UASB, significantly taller, higher up-flow velocity at 6-15 m/h b. Adaptable to low temperature and low strength wastewaters c. Higher cost and particulates tend to be washed out of the sludge bed
Up-flow anaerobic sludge blanket (UASB)	a. Up-flow velocity at 1-2 m/h, simple solid-liquid-gas separator b. Encompass well-mixed features of the contact system with an internal gas separation and clarification mechanism c. Natural mixing resulted from gassing of organic degradation within the biomass bed d. Contain GLS separator for gas, liquid and solid phase separation e. Granulation happens during the operation f. Can treat both concentrated and dilute wastewater at high organic loading (40 kg/m^3 d)

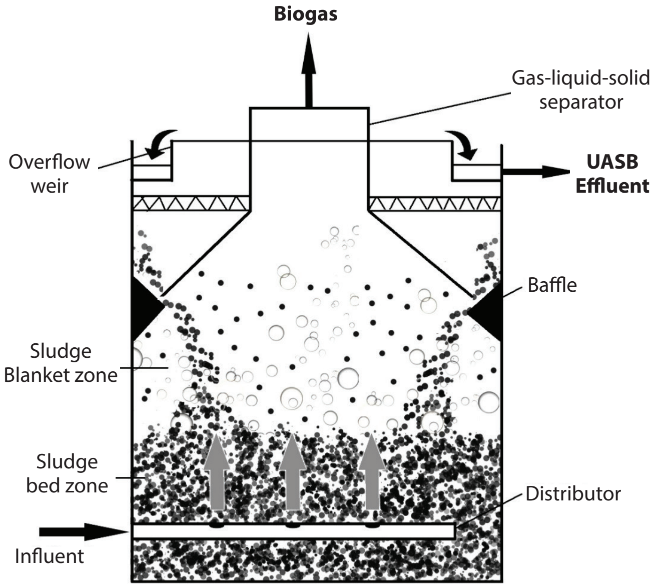

Figure 2 Typical schematic diagram of the UASB reactor [2]

GLS separator. Clarified water is released as effluent while buoyed sludge is settled back to the reaction zone via baffles and biogas is gathered at the top of the reactor [2].

Indeed, the UASB configurations meet the key requirements for a biological treatment system to be simple yet efficient. High biomass concentration (sludge bed) enables good removal of chemical oxygen demand (COD) without additional support medium. It could also accommodate high organic loading rates (OLR) and provides high stability in response to influent fluctuations [14]. Moreover, lower energy demand via methane recovery of UASB establishes more promising results for wastewater treatment, especially under colder climates as compared with aerobic treatment [23]. Lastly, blanketing zone in the UASB reactor allows the flexibility of independent control of SRT and HRT in accordance to the degradative capacity of the biomass [2].

Organic Removal of Municipal and Industrial Wastewater

In view of the robustness of UASB, the applicability of UASB process remain attractive for the treatment of different composition of municipal and industrial wastewater. UASB reactor performance can be further improved by revising the configuration such as integrating settler above GLS separator or supplementing with additional hybrid reactor operated at optimum temperature and HRT as summarized in Table 2.

LIMITATIONS AND PERFORMANCE ENHANCEMENTS

Despite the good efficiency in treating the organic matter in the wastewater, there are some challenges imposed on the anaerobic process and the UASB technology, specifically long start up and granulation, temperature restriction and poor effluent quality.

Start up and Granulation

The main issue associated with the granulation is that a long start up period is required to form the granular sludge due to long multiplying times and low cell yield of methanogenic bacteria [38]. A period of around 2-8 months was required before the system comes into operation [2]. Chong et al. [2] explained that the development of granules involves four phases, which are (1) transfer of cells to a substratum (e.g. an unpopulated inert material or other cells), (2) early reversible adhesion to the substratum by physicochemical forces, (3) irreversible adsorption of cells to the substratum by microbial appendages and/or polymers, and (4) cells multiplication and granules development. The granulation mechanism leads to the studies on the relationship between divalent and trivalent cations in accelerating the granule formation.

Chong et al. [2] highlighted that the presence of divalent and trivalent cations enhances granulation process by establishing cationic connections between bacteria to neutralize negative charges on the bacterial surface. In view of this, the addition of Fe^{2+}, Ca^{2+} and Al^{3+} for influent COD concentration of 4000 mg/L were examined and found out that granulation process is greatly enhanced but at different optimum concentrations, which were 300-450 mg/L, 150-300 mg/L and 300 mg/L, respectively. However, when Al^{3+} was added into low COD sewage (650-750 mg/L)at a concentration of 200-300 mg/L, it influenced the COD removal efficiency and growth of granules. The study implies that the addition of multivalent cations is relying on the influent COD concentration.

Table 2 Treatment performance of UASB reactors treating municipal and industrial wastewater

Type of wastewater	UASB design	pH	Temperature (°C)	Organic loading rate (kg COD/ m^3 d)	HRT (h)	COD removal rate (%)	References
Fresh leachate with high-strength organics and calcium from municipal solid waste incineration plant	UASB	7.1 ± 0.2	35 ± 1	12.5	4.5 – 8.5	82.4	[24]
Recalcitrant substrate (- 2,4 dichlorophenol)	UASB integrated with AOP system	7.0 ± 7.6	-	0.482	6	90	[25]
Organic micropollutants	UASB-hybrid aerobic MBR	7.5	20 - 22	1.7	17	95	[26]
Textile dyeing wastewater with sago wastewater as co-substrate	Two phase UASB reactor	5.7 – 7.4	28 ± 5	5.6	24	88.5	[27]
Textile effluent	UASB-submerged aerated biofilter (SAB)	-	30	UASB: 2.42 ± 1.13 SAB: 1.66 ± 0.4	21	71	[28]
Lurgi coal gasification wastewater	UASB	7.5 ± 0.4	55 ± 2	2.5	24	50 - 55	[29]
Saline sulphate wastewater	UASB	-	35 ± 0.5	-	16	52	[30]
Skim latex serum	Two-phase UASB	4.97 ± 0.21	55	38	36	62	[31]
Domestic wastewater	UASB	-	8 - 40	0.57 – 6.35	8	65 - 85	[32]
Dairy wastewater	Hybrid UASB with foam bed	8	30 ± 2	8.89	24	93	[33]
Petroleum refinery wastewater	UASB	8.48	25 - 29	1.21	40	83	[34]
Petroleum wastewater	UASB	6.5 – 8.0	36 ± 2	11.0	10	93	[35]
Saline phenolic wastewater	UASB	7.0 – 7.5	35 ± 1	-	48	95	[36]
Starch wastewater	UASB	-	35 ± 1	4.0	-	73.5 – 80.2	[37]

Other improvements can be made using selected inoculum such as granular sludge from in-operating reactors. However, the availability of quality seed material is limited, and the costs for purchase and transportation can be high [38]. On the other hand, the addition of natural polymers such as WEMOS which is water Extract of the Moringa Oleifera seeds, powdered bamboo-charcoal and synthetic polymers could decrease start up times by as large as 46% [2], [38].

Temperature Constraint

Temperature is the principal criterion altering the initial hydrolysis rate of sludge. Generally, UASB reactor works the best for tropical temperature, ranging from 20-40°C [2], [15]. This is because, at low temperature (5-20°C), the performance of the one-stage UASB reactor is restrained by slow hydrolysis of captured solids accumulated in the sludge bed when high loaded wastewater is applied. The excess sludge will increase the chances of washout, which resulted in low SRT and less stabilized sludge bed [16]. In order to fully utilize the UASB technology, various studies focus on the modifications of reactor configurations to solve the temperature fluctuations.

An alternative approach to treat wastewater at 15°C is via the application of integrated UASB-digester system [15]. The high concentrated and less stabilized solids that entrapped in the sludge bed were transported to a digester which was maintained at 35°C so that the sludge was stabilized and recirculated to UASB reactor to improve the methanogenesis and COD removal. This promising technology yielded a higher COD removal rate of 66%, compared to 44% in a UASB alone and increased the methanogenic activity by 27%. In spite of the fact that temperature increment from 15 to 35°C was needed for digester unit, the system provided less sludge yield that was well stabilized and dewatered.

Apart from that, anaerobic filter and anaerobic hybrid reactors after UASB, combined UASB-septic tank systems and incorporation of lamella settlers under GLS separator in a UASB reactor can also improve the COD removal efficiency at low temperatures [2].

Effluent Quality

Despite well-proven benefits, the effluent of UASB reactor does not comply with the international discharge standards for organic matter, pathogens and nutrients. Khan et al. [4] claimed the effluent of UASB system contained a high level of dissolved methane, which was around 23.5% of the methane gas produced, nutrients and pathogens which impact to the environment if discharged directly to the rivers or ponds. In the latter study, Khan et al. [39] expressed that BOD, COD and suspended solids of the effluent from the UASB treatment is relatively high in the absence of post-treatment, varied from 60-150 mg/L, 100-200 mg/L and 50-100 mg/L, respectively. Thus, the post-treatment system is required to polish the anaerobic effluent in order to attain the ideal effluent quality and save water bodies in the ecosystem.

There are various post-treatment systems or combination of anaerobic-aerobic systems to treat the UASB effluent. For instance, low rate natural settling systems such as overland flow system (OFS), polishing pond (PP), constructed wetland (CW) and duckweed pond (DP) [40], micro-aerobic methods such as down-flow hanging sponge (DHS) [41], trickling filter (TF) and flash aeration, high rate aerobic methods such as sequential batch reactor (SBR), activated sludge process (ASP), rotating biological contactors (RBC) [42], aerated fixed bed reactor (AFBR) [43], submerged aerated bio-filter (SABF) [44] and moving bed biofilm reactor (MBBR) [45], final polishing techniques such as membrane technology and slow sand filtration (SSF) system [46]. All post-treatment systems were capable of improving the performance of existing UASB reactor.

Amongst all post-treatment systems, integrated UASB-SBR system was found to be the best and viable sustainable option for sewage treatment and anaerobically treated effluent at low cost, low space requirement and low sludge generation [40]. Moawad et al. [47] justified this combination treatment method was competent to acquire high organic matter and nutrients removal efficiency with low BOD (97% removal), COD (94% removal), TSS (98% removal) and total phosphorus (48.4% removal). Nonetheless, the overall efficiency of the combined system was dependent on organic loading rate, SRT and aeration time. Phosphorus removal rate was higher at high loaded situations and low SRT than that of low organic loading and high SRT [48]. At the same time, intermittent aeration regime with 1 h of aeration and 2 h without aeration would significantly improve the nitrogen removal at around 90% [49].

Application of the UASB Reactor

One of the major applications of UASB reactor technology is for the development of anaerobic ammonium oxidation (anammox) process to remove ammonia nitrogen in the wastewater. UASB reactors have been demonstrated to be the most productive reactors for the cultivation of anammox bacteria. As compared to other reactors such as SBRs and membrane bioreactors (MBRs) which require biofilm to immobilize anammox bacteria to solve biomass floatation issue, UASB reactors can avoid the problem through the effective separation of gas, water and solids by GLS while compact biomass granules can be formed which greatly support biomass retention in the reactor [50]. This leads to higher nitrogen removal rates in the UASB reactor as compared to SBR and other reactors.

Anammox Process

In view of ammonia-rich wastewater such as landfill leachate, coking wastewater, nitrogen fertilizer production wastewater and other industrial wastewater, anammox process offers sustainable yet promising biotechnology due to its high capability in nitrogen removal at low operating costs as compared to conventional nitrification-denitrification biological processes [51]-[52]. It was first discovered by Mulder in 1995 in a denitrifying fluidized bed reactor [53]. In the anammox process, part of ammonium in wastewater is oxidized to nitrite by ammonium-oxidizing bacteria (AOB). Subsequently, the remaining ammonium is further oxidized by anaerobic oxidizing bacteria (anammox) to nitrogen gas using nitrite produced as the electron acceptor. Eq. (1) illustrates the reaction of AOB with ammonium and nitrite to produce nitrogen gas anaerobically [51], [54]

$$NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 2.03H_2O + 0.066CH_2O_{0.5}N_{0.15} \quad (1)$$

Ma et al. [55] remarked that nitrate is reduced to nitrogen gas with ammonium as the electron donor and with carbon dioxide as the carbon source for growth. This shows that the organic carbon source in the wastewater is not required for nitrogen removal. Meanwhile, Ma et al. [55] and Zhang et al. [54] claimed that energy usage and carbon dioxide effusions could be decreased by 60% and 90%, respectively, in a biological nitrogen removal system using anammox. Hence, this option allows for the reduction of operational costs.

Although the highest nitrogen removal rate of up to 77 kg Nm^3/d had been reached in a lab-scale anammox UASB reactor in 2011 [50]-[51], the application of anammox system in the industry is limited due to low cell growth rate and high sensitivity of anammox bacteria towards various inhibitors in the ammonia-rich wastewater and sudden change in operational variations such as reactor configuration, , physical structure of the sludge (biofilm, granular or flocculent sludge), pH, nitrogen loading rate, etc. which may cause the anammox process to halt [56]-[57]. At optimum condition (around 35°C), anammox bacteria required approximately 10-14 d to generate new cells and few months for start-up process [51], [58]. To accelerate the start-up process, different kinds of gel immobilization techniques using polyethene glycol (PEG), polyvinyl alcohol (PVA) and sodium alginate (SA) have been adopted recently to immobilize the anammox bacterial cells as it offers faster and deeper substrate transport which improves anammox activity for nitrogen removal [59].

Due to the low growth rate and yield of anammox bacteria, good biomass retention reactors are crucial for effective removal of nitrogen from the wastewater. Different reactors have been studied at laboratory scale and full scale for the anammox process under limited oxygen and anoxic environments, as shown in Table 3. Though all reactors demonstrate good ammonia nitrogen removal, UASB reactor is more tolerant and stable towards hydraulic shock and substrate concentration shock as compared with up-flow stationary fixed film (USFF), up-flow biofilter (UBF) and SBR. This could be linked with effective contact between granular sludge and wastewater in UASB [60]-[61]. Interestingly, the start-up of anammox process using membrane bioreactor (MBR) is found much effective than sequencing batch reactor (SBR) for the enrichment and growth of anammox bacteria due to high biomass retention characteristic of MBR configuration [62]-[63].

With regards to sludge structure, the physical properties of anammox flocculent biomass are substantially impacted by the presence of FA and FNA as compared with biofilm biomass at short-term exposure of ammonium and nitrate [75]. Meanwhile, the change in pH can greatly affect the anammox process attributed to the build-up of toxic substances

Table 3 Different anammox reactors

No.	Reactor	Wastewater application	Nitrogen loading rate (kg N/m^3 d)	Nitrogen removal rate (kg N/m^3 d)	Organism	References
			Laboratory scale anammox reactors			
1	UASB	Pharmaceutical wastewater	8.1-10.4	7.2-9.4	Brocadia	[64]
2	Cylindrical up-flow	Digester liquor from biogas plant	5.3	4.0	-	[65]
3	SBR	Optoelectronic industrial wastewater	0.909	0.825	-	[66]
4	UASB	Piggery waste	1.36	0.72	*Planctomycetales, Candidatus* "Kuenenia stuttgartiensis"	[67]
5	UASB-MBR-SHARON-Anammox	Landfill leachate	1.13	1.03	-	[68]
6	UASB-MBBR	Municipal wastewater	0.27	0.10	-	[69]
			Full scale anammox plants			
			Nitrogen load (kg/d)	**Nitrogen removal rate (%)**	**Location**	
1	Moving bed biofilm	Sludge liquor	100-120	70	Hattingen	[70]
2	Granular sludge	Potato wastewater and reject water	911	81	Olburgen	[71]
3	SBR	Digested sewage	625	90	Zurich	[72]
4	SBR	Reject water	340	90	Austria	[73]
5	Granular sludge	Municipal wastewater	750	89[a]	Rotterdam	[56]
6	Activated sludge	Digested industrial wastewater	427-521[b]	95	Netherlands	[74]

[a] It is measured as maximum volumetric conversion, which is around 9.5 kg N/m^3/d at V=70 m^3
[b] It is reported as 0.18-0.22 kg N/m^3 d at V=2370 m^3

which inhibits anammox activity. A pH range of 6.7-8.5 would give optimum anammox activity for avoiding the inhibition of anammox by high free ammonia (FA) and free nitrous acid (FNA) [76]. Niu et al. [51] and Zhou et al. [77] related that a low pH will result in a decrease of FA concentration but an increase in the FNA concentration and vice versa. It was shown that when the inhibition thresholds of FA and FNA were kept below 5 mg/L and 2 µg/L, respectively, at a pH of 7.5-8.5, stable long-term operation of anammox process could be maintained with high nitrogen removal [51]. Moreover, the low-temperature condition will also lead to FNA inhibition. FNA concentration increased by approximately 20-25% at 10°C as compared to 20°C [77].

Although nitrite is a substrate of anammox reaction, high concentration of ammonium (NH_4^+) and nitrite (NO_2^-) will result in stability disruption in anammox process [54]. Based on the studies from Niu et al. [51] and Zhang et al. [54], as the substrate concentrations increase, the concentration of FA and FNA will also increase. It is reported that the optimal FA concentration should be less than 20-25 mg/L to ensure stable performance of the anammox process [75]. Nonetheless, another study reveals that as long as FA concentrations were kept below the inhibitory threshold, nitrite concentrations could be increased up to 120 mg N/L to have a higher nitrogen removal rate [78].

Despite high nitrogen removal, there is only around 89% of nitrogen being eliminated as NH_4^+-N and NO_2^--N whereas 11% of nitrogen was emitted in the form of NO_3^--N [50]. Due to that, a coupling system of anammox and denitrification was suggested to achieve the goal of complete nitrogen and organics removal from the wastewater. Ma et al. [55] recommended the use of intermittent aeration with low dissolved oxygen to suppress the growth of nitrite-oxidizing bacteria (NOB) to enhance the efficiency of nitrogen removal via anammox. In short, further development of integrated anammox system is necessary to enhance the efficiency and polish the effluent water quality in meeting the effluent discharge standard.

CONCLUSION

The uniqueness of UASB in anaerobic treatments of wastewater confirms the promising performance in terms of organic matter and nitrogen removal at good stability and relative lower operational costs as compared with other technologies. The development of dense sludge bed in UASB at sufficiently long SRT promotes hydrolysis and methanogenesis for sludge degradation. The success has been proven in various wastewater treatment, e.g. petroleum wastewater, saline phenolic wastewater, starch wastewater, a few to name. Nonetheless, there are unresolved issues and limitations of this treatment process, such as facilities to collect biogas, long start up process of anaerobic bacteria and long HRT. At low temperature, the hydrolysis rate is limited due to low methanogenic activity. This will result in the accumulation of excess solid matter in the UASB reactor, leading to deterioration in microbial degradation. Although various integrated and post-treatment system has been studied, there is no ideal system applicable to all situations. Therefore, further research on the application of combined systems is necessary to meet the requirements for full-scale development.

Pertaining to long start up process for anaerobic system, further research is also required to study the relationship between cation charges, influent COD and granule development in enhancing the granulation process. Culture isolation from full-scale plants may be useful to examine the behaviour and adaptation process of the microbes.

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