Up-Flow Anaerobic Sludge Blanket

Subjects: Engineering, Environmental

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The interest in research on up-flow anaerobic sludge blanket (UASB) reactors is growing. Although the state of research on UASB is to be considered advanced, there are still several points that will be developed in future research such as the consolidation of the results obtained on a semi-industrial or real scale, the use of real matrices instead of synthetic ones.

Keywords: anammox ; microbial community ; anaerobic digestion ; wastewater ; sewage

1. Introduction

The up-flow anaerobic sludge blanket (UASB) systems were first proposed in the 1970s and, recently, the interest in using this technology has grown [1]. In the UASB process, the biomass is not of the flock type but of granular consistency due to a phenomenon in which microorganisms formed granular groups with a more compact structure, a higher dimension, higher density and higher settling capacity than in the conventional active sludge (CAS) [2]. The process is activated using selective environmental conditions that generate a spontaneous involvement of microorganisms commonly present in CAS [3][4]. One of the most significant disadvantages is represented by the low rate of formation and growth of granular biomass that make necessary long start-up periods [5]. However, the inoculation of biomass already granulated proved to be an effective method to reduce the start-up phase [6]. Other drawbacks of this technology include the difficulty associated with the operation of the three-phases separation, the possible sludge washout and foam formation [7][8][9][10].

UASB can be operated in psychrophilic, mesophilic, or thermophilic conditions depending on the type of matrices fed. Generally, higher temperatures allowed researchers to also degrade recalcitrant chemical oxygen demand (COD), particularly in the case of industrial wastewaters (WWs) [1]. The high concentration of biomass (60 ÷ 100 kg_{VSS} m^{-3}) [11] and the high microbial diversity present in the granules allow for the rapid degradation of the organic substance. In compact reactors, the UASB process can also be applied to waste with high organic concentration [12].

One of the main advantages of UASB system is represented by the production of methane and therefore the feasibility of energy recovery. This aspect contributes to the significant widespread of these reactors in low–middle-income countries [13][14]. This is a crucial aspect since water sanitation and energy production are inserted in the Sustainable Development Goals (SDGs) of the United Nations (SDG 6 and SDG 7, respectively) [15]. The other main advantage of this system is represented by the low sludge production with respect to other types of biological treatments [5]. Additionally, this point is a very current aspect since on the one hand legislation about sludge reuse is becoming stricter [16][17] and on the other hand waste (and also sludge) prevention and minimization is strongly stimulated by regulatory bodies (e.g., [18]).

Despite the high organic substances removal efficiencies, the final effluent of a UASB process generally requires subsequent treatments to remove the residual pollutants, particularly nutrients and pathogens [5]. Many studies evaluated the efficiency of diverse post-treatment in order to increase the effluent quality. For instance, de Oliveira and Daniel [19] found 28–33 oocysts L^{-1} of *Cryptosporidium* spp. and 3177–4267 cysts L^{-1} of *Giardia* spp. in UASB effluent and obtained good removal rates (2-log) treating it with dissolved air flotation. In another case, dos Santos and van Haandel [20] used waste stabilization ponds to treat UASB effluent pointed out an acceleration of the decay of pathogens and the removal of nutrients.

2. Organic Substance Removal and Biogas Production

To degrade organic substances and produce methane, the UASB process was tested on synthetic matrices [21][22][23][24][25][26] and real feed, mainly toilet wastewater [27][28], urban wastewater [29], distillery wastewater [30], mining wastewater [31][32], leachate [32][33], brewery wastewater [34], food waste [35], soybean molasses [36], pharmaceutical wastewater [37], and pulp mill wastewater [38].

The results of the literature analysis highlighted that UASB used in the research were mainly at lab-scale with few studies conducted at semi-industrial or full-scale reactors. The few studies at full-scale concerned the optimization and/or the monitoring of the existing plant. For instance, Omine et al. [30] evaluated the minimum alkalinity supplementation to optimize COD removal from a distillery wastewater. They monitored a real UASB operating in thermophilic conditions (55 °C) for more than one year and they found that 0.045 mg_{CaCO3} $mgCOD^{-1}$ is required to obtain 87% of the COD removal rate. Monitoring two real full-scale UASB reactors, de Freitas Melo et al. [39] studied the seasonality of biogas production finding a negative correlation with the rainfall events.

Lab-scale reactors have been mainly used to investigate the effect of diverse types of matrices on UASB performance but also to simulate critical conditions. For instance, Cervantes-Avilés et al. [40] tested the effect of chronic exposure to titanium dioxide nanoparticles and their accumulation in the granular sludge demonstrating that this aspect did not affect badly the removal of organic substances (92–98%). In their study, an increase in biogas production by 8.8% was evaluated but no significant changes in terms of methane content (78–90%) were detected.

In some cases, UASB technology was also tested to produce volatile fatty acids (VFAs). For instance, Eregowda et al. [41] fed the foul condensate collected by a Kraft paper mill to a UASB reactor operating with HRT equal to 75 h and diverse temperature conditions (22 °C, 37 °C and 55 °C). Their results showed that 52–70% of the organic carbon used (42–46%) was converted into VFAs. Moreover, after more than 5 months of operational activity, Eregowda et al. [41] also found that the biomass of the UASB reactor at 55 °C exhibited the highest activity.

Recently, UASB reactors have also been tested coupled with other technologies such as polishing ponds [42], sponge filters [42][43][44][45], granular activated carbon [46], aerobic treatments [47][48]. Additionally, in this case, diverse matrices were evaluated as possible feed to UASB but very few experiments have been conducted on a larger scale while the majority have been studied in laboratories.

The aim of coupling technologies was the improvement of organic substance removal efficiency and methane yields production. For instance, Rahman et al. [49] evaluated the performance of UASB reactor, coagulation–flocculation, and aeration to remove organic substances from wastewater of rubber latex production. They found that this combined system proved to be effective by reducing total Kjeldahl nitrogen (TKN) by 68–87%, and BOD and COD by more than 80% [49].

In another study, Zhang [50] treated oilfield wastewater with a multi-system in which UASB is combined with dissolved air flotation, yeast bioreactor, and biological aerated filter, highlighting organic substance removal equals 96%.

Mazhar et al. [42] compared the performances produced by two combined systems on urban wastewater: (i) UASB + polishing with ponds and (ii) UASB + downflow hanging sponge (DHS) system. The results of their monitoring pointed out the higher removal yields on COD, BOD and TSS feasible with UASB + DHS system (92%, 82%, and 91%, respectively) compared to UASB + polishing ponds (82%, 74%, and 84%, respectively) and predicted the lower operational costs of UASB + DHS with respect to the other combination [42]. Additionally, Asano et al. [44] evaluated the coupling of UASB and DHS, in this case, to treat food wastewater. Further, in this case, their system allowed to obtained high performance in term organic substance conversion into methane: 58% of total COD was removed and 63–87% of soluble COD was converted into methane.

The coupling of UASB reactors with other treatments was also evaluated by Dohdoh et al. [48]. Based on their results, they suggested the combination of hybrid UASB and integrated fixed-film activated sludge (IFAS) as an alternative to conventional UASB + conventional activated sludge (CAS) in treating urban wastewater obtaining about 95% of COD removal after 6 h of HRT [48]. El-Khateeb et al. [51] tested the coupling of UASB reactor with a downflow reactor in which a hanging non-woven fabric made by polyethylene terephthalate (PET) is located. They demonstrated the ability of this system in removing up to 88% and 90% of COD and BOD, respectively. Moreover, their results suggested that coupling these two technologies allowed to reach high removal rates of bacteria (i.e., faecal coliforms and *E.coli*) [51].

Petropoulos et al. [52] compared the performances of two UASB reactors operating in an extreme condition of low temperature (4 °C), with and without an ultrafiltration membrane. They pointed out two interesting aspects: (i) organic substance conversion into methane occurred also in this condition with an HRT equals to 3 days, and (ii) both systems produced comparable results proving that degradation efficiency was not affected by the coupling with an ultrafiltration membrane [52].

The research has also been focused on evaluating solutions for reducing the impact of load shock. In fact, Soh et al. [53] proved that organic load shock can also stimulate the production of soluble microbial products (SMPs) and identified cyclooctasulfur as a potential indicator of reactor performance. Wang et al. [54] tested the effectiveness of biochar against high organic loading shock in up-flow anaerobic sludge blanket (UASB) reactors. They found that the addition of biochar stimulated the development of an enriched microbiota which helped the system to restore quickly maintaining high performances in terms of organic substances removal and methane production in contrast to irreversible acidification which conventional UASB reactors met [54].

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