Granular Sludge Technology: A Review

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Abstract- *The formation of anaerobic granular sludge can be considered as the major reason of the successful introduction of the Up flow Anaerobic Sludge Bed (UASB) reactor concept for anaerobic treatment of industrial effluents. This granulation process allows loading rates in UASB reactors far beyond the common loading rates applied so far in conventional activated sludge processes. The resulting reduction in reactor size and required area for the treatment leads to lower investment costs in addition to the reduced operating costs due to the absence of aeration. This paper reviews different information available for sludge granule formation, its characteristics , biogas production and UASB reactor according to the removal of high COD.*

Keywords- Granular sludge , Environmental biotechnology , Chemical Oxygen Demand , Sludge bed reactor, UASB .

I. INTRODUCTION

Granular sludge technology is one of the great achievements in environmental biotechnology of the twentieth century(7).The upflow anaerobic sludge blanket (UASB) reactor, has found wide application across the world for the treatment of biodegradable wastewaters. In recent years, a new dimension has been added to the usefulness of UASB due to its ability to generate ‘captive’ methane, thereby reducing the global warming potential of wastewaters, which otherwise produce methane that goes unharnessed (1). Sludge granulation provides a rich microbial diversity,high biomass concentration, high solids retention time, good settling characteristics, reduction in both the operation costs and reactor volume, and high tolerance to inhibitors and temperature changes. However, sludge granulation cannot be guaranteed on every type of industrial wastewater. Especially in the last two decades, various types of high-rate anaerobic reactor configurations have been developed that are less dependent on the presence of granular sludge, and many of them are currently successfully applied for the treatment of various kinds of industrial wastewaters worldwide(12).

Granular sludge is the main prominent characteristic of UASB reactors as compared to other anaerobic technologies. Self immobilization of microorganisms is important in anaerobic wastewater treatment. In an UASB reactor, anaerobic microorganismscan form granules through self immobilization of bacterial cells, and the performance of the UASB system is strongly dependent upon granulation process with a particular wastewater (6). A UASB reactor is essentially a variant of the classical expanded bed reactor. In it, wastewater flows upward through a column of a sludge bed, followed by a column of less dense sludge blanket. The sludge, in turn, consists of minute biosolids or ‘granules’, each of which sports a bacterial film. The constantly expanding, settling and resuspending sludge granules bring the bacterial films in contact with the upflowing wastewater, resulting in the anaerobic digestion of the latter(1)

Hydraulic retention time (HRT) is one of the most important parameters affecting the performance of a UASB reactor when used for the treatment of municipal wastewater. The upflow velocity (Vup) is directly related with HRT and plays an important role to entrap suspended solids (4). Purification of wastewater with high concentrations of nitrogen and an unfavorable ratio of organic compounds to nitrogen (COD/N) is a current problem in wastewater treatment. The use of activated sludge technology often results in only partial ammonia removal from high-ammonia wastewater streams. This disadvantage can be overcome by the use of aerobic granular sludge systems (15).

II. OBJECTIVE

The heart of the reactor is the sludge. It should support an active biomass, and should have good settling characteristics so that it does not wash out with the inflowing liquid. It also should not be so heavy that the upflowing liquid fails to expand it. These attributes are achieved if the sludge is granular(1).

Little attention is given to the fact that granulation strongly depends of growth. This means that simply by optimising the conditions for growth granulation can be strongly enhanced (2). Granulation can proceed under mesophilic, thermophilic and psychrophilic conditions(12).

It has been observed that the sludge loading rate effects the rate of granulation (3).It should be recognized that besides the formation of sludge granules, erosion also takes place in the sludge bed under the influence of friction forces to which the sludge flocs are exposed in particular at high mixing intensities. The sludge particles would gain sufficient mechanical strength when proper environmental conditions are maintained at the start up(8). Entrapment of the suspended solids in the sludge seems to have more effect on increasing the TSS content of the reactor sludge. So, the sludge acts as a filter for removing the suspended solids from the wastewater. Low strength wastewater can lead to substrate transfer limitation and cause inhibition of granulation or can make it difficult to maintain granules (14).

The physico-chemical properties of granules largely depend upon the type of substrate on which they are grown. Granules fed with ethanol are much more compact than those developed in protein and carbohydrate-based media. Further, micro-organisms distribution in anaerobic granules also depends on the type of wastewater; granules fed with carbohydrates and proteins presented higher acidogenic bacteria colonization. Members of Methanosaetaceae are the dominant methanogens in all three types of granules, while Methanobacteriales are co-dominant in granules fed with carbohydrates and proteins (13).

III. SLUDGE GRANULE FORMATION

Activated sludge for several reasons, is a good alternative to the digested sewage sludge. First, a considerable amount of methanogenic bacteria is found in the activated sludge. Second, it is easy to obtain large amount of the sludge from activated sludge plants. Finally, the activated sludge usually contains little sand and soil and is mainly composed of biomass, thus there is no problem with either dead space or a scum layer coming from the seed material (3).Seed sludge, feed compositions and SBR operational parameters(pH, temperature, cycling time, and others) affect granulation process.In most studies, aerobic granules were cultivated with activated sludge seed.The greater the number of hydrophobic bacteria in the seed sludge the faster the aerobic granulation with excellent settle ability. Feed composition for various substrates were used to cultivate aerobic granules, including glucose, acetate, phenol, starch, ethanol, molasses, sucrose and other synthetic wastewater components. The aerobic granular process has great potential to work with anaerobic processes pre-treatment/RO processes, and others for utilizing its advantage of high biomass retention and tolerance to toxicity from substrates(10).

The occurrence of granulation can be explained as follows:

1. Proper growth nuclei, i.e. inert organic and inorganic bacterial carrier materials as well as bacterial aggregates, are already present in the seed sludge.
2. Finely dispersed matter, including viable bacterial matter, will become decreasingly retained, once the superficial liquid and gas velocities increase, applying dilution rates higher than the bacterial growth rates under the prevailing environmental conditions. As a result, film and/or aggregate formation automatically occurs.
3. The size of the aggregates and/or biofilm thickness are limited, viz. it depends on the intrinsic strength (binding forces and the degree of bacterial intertwinement) and the external forces exerted on the particles/films (shear stress). Therefore, at due time, particles/films will fall apart, evolving a next generation. The first generation of aggregates, indicated by Hulshoff Pol as ‘‘filamentous’’ granules, are quite voluminous and in fact more a flock than a granule.
4. Retained secondary growth nuclei will grow in size again, but also in bacterial density. Growth is not restricted to the outskirts, but also proceeds inside the aggregates. At due time, they will fall apart again, evolving a third generation, etc

Granulation with excellent settleability WAP (water absorbing polymer) is a resin, mainly composed of acrylic compounds and shows a complex network structure with a high specific surface for microbial attachment. It is added to the inoculated sludge. Moreover, it shows a low density (wet density of 1.0 g/ ml), which means that the contact between the particles and biomass is improved, when comparing to sand and other materials(2). Although not influencing the average granule size, the addition of WAP clearly enhanced the granulation in the lab-scale and pilot scale UASB reactors using glucose or VFA as substrates, serving as a bio-carrier to allow more biomass to attach on them. After the granules were formed, the WAP was slowly decomposed by the anaerobic bacteria.Based on the experiments performed, the authors recommended a dosage of WAP of approximately 750 mg/l of reactor volume for the enhancement of granulation.

AGS technology has attracted increased attention among scientists and engineers because of its great potential in reducing footprint and improving efficiency of municipal and industrial wastewater treatment plants. Because of the rapid and reliable cultivation of AGS, operational flexibility offered by SBR technology, majority of the researchers continued to use SBRs for advancing AGS technology. AGS reactors offer the possibilities for removing organic carbon, nitrogen (N), phosphorus (P), micropollutants such as pharmaceuticals and personal care products, recalcitrant or toxic xenobiotic compounds and metal ions. Biological removal of various xenobiotic compounds such as phenol, para-nitrophenol, chlorinated phenols, pentachlorophenol, pyridine, phthalic acids and esters, tert-butyl alcohol, methyl tert-butyl ether, chloroanilines, metal chelating agents, textile dyes, 2,4-dinitrotoluene, azo dyes and organophosphorous esters has been demonstrated.

Biological conversions involving both oxidation and reduction reactions are advantageous as real waste streams contain multitude of oxidized and reduced pollutants. These studies showed that the microbial community of AGS is capable of performing denitrification of high-strength nitrates as desired for effluents generated in fertilizer and nuclear industries. In the case of high-strength nitrate bearing wastewaters, integration of anoxic/anaerobic and aerobic conditions is necessary in the cycle of AGS reactors. Interestingly, denitrification a common biological process occurring in AGS reactors has a positive influence on granulation either through nitric oxide signalling or calcite ($CaCO_3$) precipitation (16).

The tentative guidelines for the start-up of the UASB reactor and for the cultivation of granular sludge by using activated sludge as the seed material under mesophilic conditions are suggested as follows: [1] The amount of the seed sludge be kept at approx. 15 gVSS 1-1; [2]. Incubating the seed sludge intermittently or semicontinuously for more than half a month in advance of continuous feed; [3] Increasing the COD loading rate gradually and keeping it at 0.6 kg COD kg VSS -I d -l or more; [4] Operating at a hydraulic loading rate of 0.3 m 3 m -2 h -l or more and utilizing recycling when treating high strength wastewater; [5] Providing appropriate environmental factors, i.e. pH 7.0-7.5, modest nutrients, and trace elements (3). Anaerobic granule formation is mostly observed in anaerobic bioreactors that are operated in upflow mode .However, successful granulation was also observed in anaerobic sequencing batch reactors(12). The cow dung seed sludge comprised of predominantly organic matter and heavy population of microbes. Total solids (TS) and volatile suspended solids (VSS) concentrations in the seed sludge were 50.2 and 31.5 g/L, respectively. During the acclimatization of seed sludge, nutrients (COD:Nitrogen:Phosphorus in ratio of 300:5:1) were supplied to boost sludge growth by the addition of Sucrose ($C_{12}H_{22}O_{11}$) and diammonium hydrogen phosphate $(NH_4)_2HPO_4$. The Biochemical oxygen demand (BOD)/total organic carbon (TOC) ratio was 1 . The sludge in the UASBreactor was an in homogeneous suspended mass during first three months. After that granulation started and sludge bed was stabilized in a period of 4 months and the quality of sludge was comparable with the well mature sludge of a digester (4).

Granulation of anaerobic biomass from dispersed inoculum is possible, even at sodium concentrations as high as 20 g Naþ/L, which was not reported in literature before. Moreover, calcium concentration as low as 13 mg/L is sufficient to form microbial granules at 20 g Naþ/L and is around ten times lower than the traditionally reported 100e150 mg Ca2þ/L in non-saline conditions. The granulation process at 20 g Naþ/L can be accompanied by efficient soluble COD removal, however the removal efficiency is still lower (92.8 ± 5.4% to 94.0 ± 2.2%) compared to reactors operated with the same substrate at 5 g Naþ/L (96.6 ± 3.3% to 97.2 ± 2.1%) (15).

When using aerobic granular sludge to purify wastewater of a low COD/N ratio and high-ammonia concentration, nitrogen removal efficiency may be improved by adjusting the reactor cycle by introducing alternating aeration/non-aeration phases and/or adding external organics during the reactor cycle . Alternating oxic/anoxic conditions induce a diauxic phase in bacterial cells which enables the resynthesis of denitrification enzymes and supports N removal (14).

An alternative way of sludge retention was found by applying inert support material into the bioreactor on which the anaerobic organisms can adhere. The AF (Anaerobic Filter), also called packed bed process, has been developed as a biofilm system in which biomass is retained based on the attachment of a biofilm to the solid (stationary) carrier material, entrapment of sludge particles between the interstices of the packing material, and the sedimentation and formation of very well settling sludge aggregates. AF technology can be applied in up flow and down flow reactors .Various types of synthetic packing materials, as well as natural packing materials, such as gravel, coke and bamboo segments, have been investigated in order to be used in AFs. Research results indicated that the shape, size, weight, specific surface area, and porosity of the packing material are important aspects. Also the surface adherence properties with regard to bacterial attachment are important. Applying proper support material, AF systems can be rapidly started, owing to the efficient adherence of anaerobic organisms to the inert carrier. The major disadvantage of the AF concept is the difficulty to maintain the required contact between sludge and wastewater, because clogging of the ‘‘bed’’ easily occurs. This is particularly the case for partly soluble wastewaters. These clogging problems—at least partly—can be overcome by applying a primary settler and/or a pre-acidification step. AF technology has been widely applied for treatment of wastewaters from the beverage, food-processing, pharmaceutical and chemical industries due to its high capability of biosolids retention. The experiences with the system certainly are rather satisfactory; applying modest to relatively high loading rates up to 10 kg COD m-3 day-1. The AF system will remain attractive for treatment of mainly soluble types of wastewaters, particularly when the sludge granulation process cannot occur satisfactory (12).

V. CONCLUSION

Anaerobic digestion is the classical example of a process that combines the objective of elimination of organic compounds from a waste stream with the generation of a valuable product in form of methane containing biogas. The selective pressure required to induce methane production from a waste stream containing organic compounds is very simple: Avoid the presence of an electron acceptor(e.g. Oxygen,nitrate or sulfate) or an external energy source (e.g. light)In the absence of an external electron acceptor,organic substrates can only be fermented;a process where the organic substrate is both electron donor and acceptor.The final end products of organic substrate fermentation are methane, carbon dioxide and ammonia (5). Factors influencing granulation have been identifies, including selection of pressure, at a laboratory scale with glucose containing wastewater(7). The anaerobic degradation process is effective compared to the other more conventional aerobic process and produces only 5-10% of sludge. Thid saves considerably on cost associated with the sludge disposal (8).

AGS has demonstrated superior settling characteristics, biological nutrient removal and biodegradation of toxic or recalcitrant pollutants. The knowledge accumulated thus far shows that AGS is reliably cultivated from AS in SBRs operated under a range of conditions for reactor height to diameter ratio, volumetric exchange ratio, settling time, aeration rate, anaerobic-aeration phases, substrate type and wastewater composition. AGS SBRs are a universal replacement for conventional ASP for removing nutrients, persistent pollutants and recovering water. Future research should be directed towards discovering formation mechanisms of AGS, improving AGS formation in low-strength sewage and wide-spread implementation of AGS based systems in sewage and industrial wastewater treatment (16).

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