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Importance of Granulation to Promote Clean Energy Production and Effluent Treatment in the Anaerobic Hybrid Reactor (AHR)

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Abstract: **Anaerobic reactors have acquired a new relevance in recent years due to their ability to generate methane from biodegradable wastewaters—thereby producing clean energy. Methane capture in this way prevents the outflow of the greenhouse gas to the air, which otherwise occurs when anaerobic conditions develop in drains and outfalls carrying wastewater. About 80% of the world's anaerobic wastewater treatment systems are estimated to be based on the UASB technology. The performance of a UASB reactor revolves round its sludge bed which gets expanded as the wastewater is made to flow vertically upwards through it. It is the micro flora attached to the sludge particles which acts upon the sewer water. Hence the quality of bio-fuels sported by the sludge particles, and the tightness of the sludge–wastewater contact are the factors which, principally, govern the success of a UASB reactor. Early in the development of UASB technology, it was realized that granular sludge of appropriate particle size, particle density, and microfilm characteristics enhances the reactor efficiency in terms of the rate as well as the extent of wastewater treatment.**

1. INTRODUCTION

With the coming of industrialization there is an enormous production in wastes and wastewater, thereby with due course of time it has been concentrated increasingly in low fields. Many open water has transferred into an open sewer system. As surface water serves various purposes, so wastewater treatment is gaining popularity and many industries is opting for this form of treatment. The benefits of anaerobic treatment system has been restricted to sludge and slurry digestion for a long period, only the evolution of systems based on biomass retention such an anaerobic filter has passed out the applicability of anaerobic systems to wastewater streams. Initially this arrangement was not acceptable, but high energy prices during energy crisis have made the focus of a very attractive characteristic of anaerobic wastewater treatment, i.e.low energy requirement & ability to generate biogas as a usable fuel. Breakthrough of anaerobic wastewater treatment resulted from the evolution of the Upflow Anaerobic Sludge Bed (UASB) reactor [8]. Successful application of the UASB to many different types of wastewater have been described [34].The Anaerobic Hybrid reactor implements both the benefits of attached and suspended growth. Today the small excess sludge production of anaerobic treatment systems compared to conventional aerobic wastewater treatment systems is one of the most significant benefits of anaerobic systems. From an economic point of view, the granular sludge produced in UASB reactors is certainly not a case of waste rather a saleable by-product. Though granular sludge is not essential for wastewater treatment using UASB reactors, but today almost all full-scale reactors are started up using granular seeding sludge in order to reduce the start-up. The other benefits of granular sludge of anaerobic treatment help it to become feasible for the waste water. The granular sludge can be stored unfed over a long period without serious deterioration [34] therefore anaerobic granular sludge will be viewed more and more as a valuable raw material which is necessary for wastewater treatment.A key organism in anaerobic sludge granulation is Methanosaeta concilii. Most studies cited use its synonym Methanothrix soehngenii.

2. ANAEROBIC DIGESTION PROCESS: A BRIEF REVIEW

The digestion is initiated with the hydrolysis step; it involves a wide range of depolymerization and solubilization processes mediated by facultative and obligate fermentative bacteria which facilitate the hydrolysis of the initial proteins and polysaccharides, including the suspended organics present in the wastewater, to monomeric sugars, amino acids, long chain fatty acids and alcohol [2-3].

In the next – acidogenesis – step, further fermentation of the monomeric products of these, and other non-hydrolytic fermentative bacteria, results in the contemporaries of a broad sort of fermentation end products including acetate, formate, methanol, H_2 and CO_2 [6].

The products of acidogenesis are further oxidized to acetate, hydrogen, and carbon dioxide, in a step called acetogenesis

[20-21]. It is brought nigh by the obligate hydrogen producing acetogens (OHPAs). Normally, the oxidation of substrates such as butyrate, propionate or ethanol to acetate, hydrogen, and format; or acetate, hydrogen/Formate and carbon dioxide; are an endergonic reaction. Just when the hydrogen partial pressure gets lowered, for instance due to the presence of hydrogen or format-utilizing methanogens, the reaction becomes exergonic. Therefore, it is necessary that OHPA bacteria should always grow in syntrophy with hydrogen utilizing methanogens, sulfate-reducing bacteria (SRB), or homoacetogens, this process serves to facilitate interspecies hydrogen transfer and gain energy from growth in the acidogenesis phase [20&6] In this manner OHPAs serve as a nexus between the initial fermentation stages and the ultimate methanogenic phase. The last form is defined by methanogens which are strict anaerobes and have a highly diverse cell morphology, ranging from regular and irregular coccoidal cell shape to short rods and long filaments. They may either be hydrogenophilic or hydrogenotrophic species, which form methane by the reduction of H_2/CO_2 or acetoclastic or autotrophic species, which generate methane by acetate decarboxylation. Of the two, the acetoclastic methanogens are of greater importance as 70% of the total methane generated during anaerobic digestion is via their mediation[11].

3. THE IMPORTANCE OF GRANULATION IN UASB REACTORS

The anaerobic sludge which provides anchorage to microflora is the principle component of a UASB reactor. It is the continuous interaction of wastewater with the microflora attached with the sludge particles which brings nearly the treatment achieved in a UASB reactor. Hence the energy of the microbial films on one hand, and the shape, size, and compactness of the sludge particles on the other, together, control the efficacy of wastewater treatment in a UASB reactor. The formation of sludge granules becomes exceedingly important because not only do granules support active biofuels, but also provide the buoyancy and the stability necessary to enable very vigorous granule–liquid contact with the reactor. Anaerobic granules are particulates enveloped by biofilms, which are formed spontaneously in a UASB reactor by the auto immobilization of anaerobic bacteria. Granules are dense particles, consisting of an intertwined mixture of symbiotic anaerobic microorganisms. Each granule is a functional unit in itself, comprising of all the different micro-organisms necessary for the methanogenic degradation of organic matter. A typical granule is a veritable microecosystem harbouring millions of organisms per gram of biomass. Nevertheless, none of the individual species in these micro-ecosystems are capable of completely degrading influent wastes [11], and tie-ups between the component micro-organism is needed [12, 13, 14 and 15]. A layered structure for the granule has also been proposed, in which a central core of acetoclastic methanogens is supposed to be surrounded by a layer of hydrogen- or formate-producing acetogens and hydrogen- or formate-consuming methanogens. Once a UASB reactor is seeded with anaerobic sludge and wastewater is made to fall in the upward direction through the sludge, granule formation can slowly take place under appropriate conditions of substrate and nutrient availability, pH, alkalinity, upflow velocity, and so on by-and-by different scientific groups come in concert to form roughly spherically shaped clusters as depicted by McHugh et al [33]. These clusters have come to be called granules. The granules may range from 0.1 to 5 mm in size and possess higher shear strength than flocculated sludge[19]. Granulated sludge has better settling property than normal sludge which allows higher hydraulic loading rates, hence higher reactor efficiency. Granules also reduce inter-species mass transfer limitation between syntrophic groups. Moreover granules can withstand high gas and liquid shear stress without disintegrating; and provide increased immunity to process shocks and toxins compared to disperse microorganisms. Ideally a granule should contain concentric layers of near spherical biofilms possessing different bacterial trophic groups. Among the microflora, the methanogen, Methanosaeta concilii, is thought to act as a central part in setting up granulation, where the lumps formed by the development of these filamentous microorganisms function as nucleation centers that initiate granule development [9].McHugh et al. have proposed the following list of advantages that the phenomena of granulation offer towards the overall efficiency of the UASB bioreactors:

1. More efficient microbial proliferation.
2. Access to resources and niches that cannot be utilized by isolating cells.
3. Internal physicochemical gradients within the aggregates.
4. Collective defence against antagonists that eliminate isolated cells.
5. Optimization of population survival by differentiation into distinct cell types.
6. Continuous operation of reactors beyond normal washout rates.
7. Generation of a reactor effluent with low suspended solids.
8. Manipulation of biomass in a single phase.
9. Manipulation of growth rates independent of the dilution rate.

4. FACTORS WHICH EFFECT GRANULATION: GENERAL

In broad terms the components which play a role include:

- Operating conditions[23 and 24]
- pH and alkalinity[10, 25, 22, 26].
- Temperature[27 & 28].
- Intensity level and composition of wastewater [29, 33 and 31].

- Reactor hydrodynamics [10, 28]
- Presence of metal ions and trace metals [11]
- Presence of polymers[32]

5. ROLE OF SPECIFIC FACTORS IN THE FASHIONING OF GRANULES

5.1. pH and alkalinity

A stable pH value close to neutrality and a high partial pressure of hydrogen are needed to obtain good-quality granulated sludge. The pH values inside a granule have been found to be lower than the bulk liquid. Given that an acidogenic population is significantly less sensitive to pH fluctuations compared to methanogens, which require pH to be in the close range of 6.3–7.8, acid formation prevails over methanogenesis when pH is low, resulting in accumulation of volatile fatty acids (VFAs) in the reactor. The pH may also shift if the un-ionized volatile fatty acid concentration exceeds the buffering capability of the reactor content, this status is aggravated due to much more brisk activity of acidogenic bacteria than of the methanogens at lower pH. These conditions can lead to the disintegration of the granules because the methanogens may die. Alkalinity bestows buffering capacity to a UASB reactor, thereby providing a hedge against sharp changes in pH. Alkalinity, also helps in neutralizing fluctuations in VFA concentration which often rise due to variation in organic loading. Thus, the interplay between alkalinity and chemical oxygen demand (COD) has an influence on granulation [10 and 22].

5.2. Organic loading rate

Organic loading rate (OLR) may very either due to variation in influent COD at a constant flow-rate or variation in flow rate with a constant COD. An OLR at levels beyond its optimum range leads to decrease in pH due to increase in the concentrations of the VFAs. But the methanogens gradually recover and stabilize, consuming the extra VFAs to make the pH rise up once more till it stabilizes. Low OLR, on the other hand, may starve the microflora and cause other sorts of mass transfer limitation leading to the adjournment of the larger granules. OLR and hydraulic retention time (HRT) can also affect the microbial ecology of granules. An increase in OLR may lead to a shift of Methanothrix to Methanosarcina in the granules.

5.3. Nitrogen and phosphorous

Nitrogen, phosphorus, and potassium have been also been shown to buffer the effect of impact loading and prevent the flotation of granules [33].Merely, there are also reports of inhibition of the process of granulation at higher concentrations of these nutrients. Methanogens utilize ammonia as a source of nitrogen, and ammonium-rich substrates can be successfully treated in UASB reactors. The concurrent presence of high sulfide concentrations in a UASB may support denitrification; at high sulfide levels ammonium may even pretend as an electron donor for N2 production. These aspects notwithstanding, accumulation of ammonium ions can alter the intracellular pH and the activities of methane-synthesizing enzymes may be inhibited by free ammonia.

5.4. Multivalent cations

The UASB granules have a high porosity and a large internal surface area on to which metals can get absorbed at specific sites or just get lodged as insoluble compounds. From the latter form, metals can become labile when pH gets lowered. The presence or absence of several metals, and the concentrations in which they are present, can stimulate a heavy impact on granule formation. Multivalent cations condense the diffused double layers and facilitate flocculation due to van der Waals forces.

5.4.1. Calcium

Ca2+ is one of the nutrients essential to the growth of several strains of microorganisms. It has likewise been found to be effective in speeding up granulation and extensively accumulates in microbial aggregates.Ca^{2+} assists granulation, it has been suggested by Schmidt and Ahring that the anaerobic granulation process follows the four-step model for biofilm formation:

- Transport of cells to the surface of other cells or uncolonised inert material
- Initial reversible adsorption by physico-chemical forces to the substratum
- Irreversible adhesion of the cells to the substratum by microbial appendages and/or polymers
- Propagation of the cells and maturation of the granules

Calcium accelerates these steps:

i) Calcium being a component of extracellular polysaccharides may be helpful in the adsorption and linking operations. As calcium precipitates serve as inert supports during granulation, Ca2+ might be carrying on an important role in the initial adsorption.

ii) Calcium may also be promoting adhesion by acting as a link between cells and polysaccharide and between polysaccharide molecules. As bacterial surfaces are normally negatively charged, the presence of divalent cations, like Ca2+, is adopted to negate the charge and serve as a liaison between constituents.

iii) The presence of calcium can also be associated with the multiplication of cells, in terms of facilitating cell–cell bridging and also indirectly promoting the growth of granules.

5.4.2. Iron

The beneficial consequence of iron is also emphasized in two recent works exploring the use of zero-valent iron. Iron aids in better granulation. COD removal rate was higher when zero-valent iron was added to the reactor.

5.4.3. Aluminium

Al^{3+} has also been reported to induce a positive effect on sludge granulation. They found that granules began to come out earlier, and matured faster, in aluminium spiked reactors. Al^{3+} seemed to improve biomass retention and enabled a higher rate of COD removal. The addition of AlCl3 played an important role only in the initial level of granulation and its result was decreased after the growth of mature granules.

5.4.4. Heavy metals other than iron

Copper, manganese, zinc, cobalt, molybdenum and nickel, besides iron, have been shown to stimulate methane production in anaerobic digesters. Lack of one or the other of these trace metals has been found to severely restrict the overall anaerobic conversion process as well as granulation. All these findings suggest that several heavy metals are essential for the success of anaerobic digestion.

6. SUMMARY AND CONCLUSION

The agents that determine it and the impact of granules on treatment efficiency reveals the following:

- Composition of granules in a UASB reactor strongly depends on the operating temperature as different species achieve optimum growth rates at different temperatures. Sudden temperature changes could result in granule disintegration in the reactor.
- Optimum alkalinity is essential to keep the reactor pH and buffer significant fluctuations in the VFA concentrations.
- The high partial pressure of hydrogen and neutral pH favor granulation. Changes in OLR and HRT influence these parameters, but the optimum range of OLR and HRT can only be determined after taking the influent characteristics and other operating conditions.
- The granule microstructure, especially the layer geometry, is dominated by the substrate type and strength.
- The presence of adequate concentrations of bioavailable nutrients and certain metals is essential for granulation.
- Calcium and iron may enhance granulation, but are as well capable of causing mass transfer limitations when present in large quantities. The import of calcium is influenced by phosphate.

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