Evaluating biological methods for treating wastewater

There are many biological methods for treating wastewater. Among them the most popular processes are suspended growth processes and the boifilm also known as attached growth . Both the above mentioned processes are used to treat wastewater by different mechanisms and variations in their principle of operation for removal of carbonaceous organic matter, nutrients (i. e. nitrogen and phosphorous) and production of biorenewable methane. Attached growth or fixed-film methods are biological treatment based. In these the microorganisms convert the organic substance in wastewater to air and cell tissues are attached to some inert medium. The inert media used in attached growth process is crushed trap rock, limestone granite, wood slats clinkers, , plastic tubes, hard coal materials and corrugated plastic section over which wastewater is distributed. Biological slime layer (i. e., zoogleal slime) develops on contact media as wastewater flows over it. Because of the concentration gradient, all the organic pollutants those are dissolved in wastewater are carried into the slime layer, results in organic oxidation. Removing organic pollutants is done by microorganisms which are present in biological slime film. Rotating biological contactors, Trickling filters, packed bed reactors are the examples for aerobic attached growth process. The examples of anaerobic attached growth are anaerobic packed and fluidized bed reactors.

Suspended growth processes are the biological treatment processes in which the microorganisms convert the organic matter, nutrients in wastewater to gases and rotating devices in the liquid will keep the cell tissues in suspension cells tissues. Examples for aerobic suspended growth process treatment are municipal and industrial wastewater. Anaerobic suspended growth processes are used when there is a need to treat high organic concentration industrial wastewaters and organic sludges. Activated sludge process, aerated lagoons, aerobic digestion are the examples for aerobic suspended growth processes and anaerobic digestion and anaerobic contact are the examples for anaerobic suspended growth processes. The schematics of both the attached growth and suspended growth processes for biological treatment of wastewater are shown in Figure 1. The objective of this essay is to compare and contrast both the attached, suspended growth processes for biological treatment of wastewater in terms of their microbial ecology and review their comparative advantages and disadvantages. In addition, the essay also elaborates and discusses how these processes can be adapted to (a) remove nutrients and (b) produce biorenewable methane from wastewater by emphasising the microbiological principles involved.

2. Comparison and Contrast of Microbial Ecology of Biological Wastewater Treatment – The attached growth / Suspended Growth Processes

The first basic difference between attached growth and fixed film systems is the relative motion of contact. In attached growth system media is at rest and the sewage flows over it where as in suspended system, sewage and contact media are in relative motion. In attached growth processes, a conservative microbial slime arrangement is considered. The waste water stream is applied on the air-renewable surface. This water stream has minerals and organic substrate. This substance is then metabolized by the Micro organisms in wastewater. This is done in order to increase their population by releasing some energy. In fact, it cannot be considered as an aerobic system, but a device to do aerobic treatment. facultative micro organisms are present in it so it can be considered facultative. They are Pseudomonas, Alcaligenes, Flavobacterium, and Micrococcus. This kind of Aerobic bacteria, like Bacillus, is mostly seen in the upper, aerobic slime surfaces (McKinney 1962). In case when an anaerobic zone or anoxic is created in thick slime layer, force anaerobe Desulfovibrio and sulfur-reducing bacteria are being removed from slime-medium interface (Rogovskaya & M. F. Lazareva 1962). At this case the microbial slime system is know how to grow odours and possibly sloughing takes places because of the production of gases in these interior slimes. Fungi are nothing but aerobic microorganisms existing in the aerobic zone of the slime. These too fester the untreated substrate in wastewater. The effectiveness of fungus is important under relatively low pH situation or with unusual industrial effluents because fungus is useless to bacteria for their food under usual environmental conditions. Algae increasing on the surface of attached microbial slime are usually an unimportant element of the microorganism's population, incomplete to illuminated exteriors and they are clearly liberal to organic substances and high levels of carbon dioxide. Although algae add oxygen to the wastewater, they have been stimulated with responsibility for bed blockage and are considered to be difficult from an operational position (Hawkes 1963). The protozoa are the principally small animals with all shape from the Phytomastigophora to Suctoria are the controlling agents of bacterails population and they can't stable the waste. The free-swimming ciliates present at the slime surface, while the followed ciliates attendance is main in the lower regions of slime. Advanced animals like worms, snails and insect larvae nourish on the lower forms of microorganisms in slime system.

They also exist in the higher aerobic areas; can help to keep the bacterial population in a state of high growth or swift food use. Early learning on attached growth populations was intended at the control of the nuisance organisms (filter flies) in dribbling filters by flooding, chlorination and the use of various pesticides. A complete description of the organisms found in close growth system has been presented by Cooke (1959) and the list of a range of organisms can be found from Wang et al. (2009). Attached enlargement processes microbial slime are short term preservation plans that should not act as effective reduction devices for S. typhosa, S. paratyphi, and Mycobacteria tuberculosis and for pathogenic protozoa, such as Entamoeba histolytica (Pierce 1978). For low organic loading, attached growth system does some nitrification since of the presence of Nitrosomonas and Nitrobacter. However, for high organic loading, nitrification in a trickling filter or similar system may be absent or nominal (Shammas & Wang 2009).

In contrast to the attached growth process, the suspended growth process maintains the microorganisms responsible for treatment within the suspension in flocs. In this process, there are several microorganisms involved to treat wastewater. The suspended growth flocs contain bacterial cells, other microorganisms, inorganic and organic particles. The floc size is 1-1000 mm. Figure 2 illustrates the main microorganisms in the suspended growth microbial community. For the ATP analysis and dehydrogenase activity, the viable cells would account for 5-20% of the total cells. Some authors said that active fraction of bacteria in suspended growth flocs is only 1-3% of total bacteria (Hanel 1988).

Suspended growth floc contains prokaryotic and eukaryotic microorganisms, which can be observed with regular phase-contrast microscopy. The major genera in the flocs are Zooglea, Pseudomonas, Flavobacterium, Alcaligenes, Achromobacter, Corynebacterium, Comomonas, Brevibacterium, Acinetobacter, Bacillus spp., as well as filamentous microorganisms. The population of bacteria decrease as the floc size increase results in less oxygen level in the flocs (Hanel, 1988). Anoxic zones can happen within flocs, depending on the accessibility of oxygen attention in the tank and these zones will vanish when the oxygen concentration exceeds 4 mg/L.

The internal regions in large flocs favor the growth of anaerobic bacteria such as methanogens or sulfate-reducing bacteria (SRB). Thus, pendant growth system could be a suitable and fitting seed material for starting anaerobic reactors. Gram negative bacteria are main in suspended growth flocs. Hundreds of bacterial damage flourish in suspended growth but only small portion can be spoted by culture-based techniques. Bacteria oxidize the organic substance and change nutrient alteration and produce polymeric materials which aid in the flocculation of microbial biomass. In aerobic pendant enlargement process, the total bacterial counts in order of 108 CFU/mg of sludge. Suspended growth flocs also shelter autotrophic bacteria such as nitrifiers (Nitrosomonas, Nitrobacter), which convert ammonium to nitrate. Phototrophic bacteria such as the purple nonsulfur bacteria (Rhodospirillaceae), green sulfur bacteria are found at much lower levels and they play a minor role in carbonaceous organic matter removal in suspended growth processes. The suspended growth system does not usually favour the growth of fungi, although some fungal filaments are observed in suspended growth flocs. The predominant genera found in suspended growth system are Geotrichum, Penicillium, Cephalosporium, Cladosporium, and Alternaria, which grow under specific conditions of low pH, toxicity, and nitrogen-deficient wastes. Protozoa helps in reducing carbonaceous matter, suspended solids, and numbers of bacteria, including pathogens (Curds & Hawkes 1983). There is an inverse relationship between the number of protozoa in mixed liquor and the carbonaceous matter and suspended solids concentration in suspended growth effluents. Changes in the protozoan community reflect the food-to-microorganisms (F/M) ratio, nitrification, sludge age, or dissolved oxygen level in the aeration tank. The protozoan species composition of activated sludge indicates the carbonaceous matter removal efficiency of the process. For example, the presence of large numbers of stalked ciliates and rotifers indicate a low carbonaceous matter. The ecological succession of microorganisms in suspended growth treatment system is illustrated in Figure 3. The ciliates (free, creeping, and stalked ciliates) are used for locomotion and for pushing food particles into the mouth, which are most abundant protozoa in suspended growth systems. Stalked, Creeping ciliates ciliates are attached to the flocs. These protozoa move via one or several flagella and take up food via the mouth or via absorption through their cell wall. The role of rotifers in suspended growth system is :

They help to remove suspended bacteria, other small particles and contribute to the clarification of wastewater. They are also capable of ingesting Cryptosporidium oocysts in wastewater and thus serve as vectors for the transmission of this parasite.

They contribute to floc formation by producing fecal pellets surrounded by mucus. The presence of rotifers at later stages of suspended growth system is because of the fact that these animals display a strong ciliary action that helps in feeding on reduced numbers of suspended bacteria.

3. Advantages and Disadvantages of Attached Growth and Suspended Growth Processes of Biological Wastewater Treatment

The advantages of attached growth processes are low maintenance, low energy requirements, and, overall, less technology involved. These assets making them fit for wastewater treatment for small communities, as well as individual homes. In comparison with suspended growth process the main advantages of attached growth processes is simpler operation, no bulking problems, and better recovery from shock loads (Metcalf & Eddy 2003). An attached growth process is very effective for biochemical oxygen demand (BOD) removal, nitrification, and denitrification. A disadvantage of attached growth processes are larger area, ineffective in cold weather, and create odor problems. An unprotected attached growth plant is vulnerable to below freezing weather and its recirculation restricted during cold weather. It is less effective in the treatment of higher organic waste. Raw wastewater must be provided to primary treatment to remove the larger solids and floating debris, because these solids can clog the treatment system. The comparative advantages and disadvantages of attached growth and suspended growth processes of wastewater treatment are illustrated in Table 1 and 2, respectively.

4. Nutrient Removal by Attached Growth and Suspended Growth Processes of Biological Wastewater Treatment

Nutrients (nitrogen and phosphorous) can be removed from incoming wastewater by biological means in both the attached growth and suspended growth processes. To remove the nitrogen from, we must have to do nitrification followed by de-nitrification. Phosphorous can be removed from wastewater through assimilation of phosphorous in microbial cell.

Using nitrifying reactors nitrogen removal can be done in wastewater treatment using attached growth process based trickling. Experiments on nitrifying filters reveal that adsorption, desorption as well as de-nitrification can occur in attached growth bio-film to convert ammonium. At low organic loading the attached growth system does some nitrification because of the presence of bacteria like Nitrosomonas and Nitrobacter but at higher organic loading nitrification in a trickling filter is absent or nominal. The three-stage attached growth process can be used for carbonaceous oxidation, nitrification, and de-nitrification.

In case of suspended growth process, the flocs shelter autotrophic bacteria (Nitrosomonas, Nitrobacter), which change ammonium to nitrate. These species occur in clusters and they are in close contact in pending growth flocs and in biofilms. Fungi are also able to do nitrification and denitrification in suspended growth process. Compensation of a fungi-based dealing system are their capability to carry out nitrification in a single step, and they show great confrontation to inhibitory compounds. Molecular methods like aggressive PCR method showed that Nitrosomonas is (an ammonia oxidizing bacterium or AOB) 0. 0033% of the total bacterial population and Nitrospira is (a nitrite oxidizing bacterium or NOB) 0. 39% for NOB are present in suspended growth system. Features like ammonia/nitrite concentration, oxygen concentration, pH, temperature, BOD5/TKN ratio, and the attendance of toxic chemicals control nitrification kinetics in suspended growth system (Metcalf and Eddy 2003). The growth of a nitrifying population in suspended growth system depends on the surplus rate of the sludge and, consequently, on the BOD load, MLSS, and mean cell preservation time. The growth rate of nitrifiers is inferior in sewage and consequently a long sludge age is essential for the change of ammonia to nitrate. If the age of sludge is more than 4 days, then we be expecting nitrification. There are two processes by which nitrification can be attained in suspended growth reactors:

(i) Combined carbon oxidation-nitrification (single-stage nitrification system): this process wokrs at high BOD5/TKN ratio and has a low population of nitrifiers. The oxygen requirement is exerted by heterotrophs (Figure 4).

Nitrification must be followed by denitrification to remove nitrogen from wastewater. The rate of denitrification is independent of nitrate concentration but depends on the concentration of biomass and electron donor (e. g., methanol) in wastewater. The schematic of single sludge denitrification system is shown in Figure 6. Some more efficient methods based on suspended growth system to remove nitrogen in wastewater are Bardenpho Process (Figure 7), Sharon-Anammox Process and Completely autotrophic nitrogen removal over nitrite process.

Biological phosphorous removal can be done with the basic steps of an anaerobic zone followed by an aerobic zone. During the aerobic stage phosphorus uptake takes and in anaerobic stage it is released subsequently (Manning and Irvine 1985; Meganck and Faup 1988; USEPA 1987). The phosphorus removal processes can be divided into mainstream and side stream processes. The alternating exposure to anaerobic conditions can be accomplished in the main biological treatment process. The most popular phosphorous removal systems based on suspended growth process like A/O Process, Bardenpho Process, and UCT Process are shown in Figure 8-10, respectively.

5. Production of Biorenewable Methane by Attached Growth and Suspended Growth Processes of Biological Wastewater Treatment

Several attached growth and suspended growth processes like anaerobic digestion and microbial fuel cell are generally employed to produce biorenewable methane (CH4). A series of microbiological processes will takes place in anaerobic digestion tank to convert organic compounds to methane, carbon dioxide, and reduce the volatile solids by 35 to 60%. Bacteria and methanogens are the responsible species in stabilization of wastewater sludges and for the treatment of industrial and urban wastewaters. Anaerobic digestion produces less amounts of sludge (3-20 times less than aerobic processes). Most of the energy derived from substrate breakdown is found in the final product, CH4. Only 5% is converted into biomass under anaerobic conditions and 50% of organic carbon is converted to biomass under aerobic conditions, whereas. This biogas (mainly CH4) produced from anaerobic digestion contains about 90% of the energy of calorific value of 9000 kcal/m3, and is burned on site to provide heat for digesters.

Furthermore, synergistic interactions between the various groups of microorganisms are implicated in anaerobic digestion of wastes. The overall reaction can be written as –

Although some fungi and protozoa (anaerobic protozoa) found in anaerobic digesters, bacteria and methanogens are undoubtedly the dominant microorganisms. Large numbers of facultative anaerobic bacteria (e. g., Bacteroides, Bifidobacterium, Clostridium, Lactobacillus, Streptococcus) are used in the hydrolysis and fermentation of organic compounds. Four types of microorganisms are involved in the transformation of complex materials into simple molecules such as methane and carbon dioxide. The process for methane production through anaerobic digestion is shown in Figure 11.

6. Conclusions

The attached growth and suspended growth processes are most widely used for biological treatment of urban wastewater with respective and comparative advantages and disadvantages. The successful design and operation of attached growth and suspended growth processes for biological wastewater treatment require an understanding of microbial ecology of each process, types of microorganisms involved, the specific reactions that they perform, the environmental factors that affect their performance, their nutritional needs, and their reaction kinetics. In contrast to the microbial ecology of the suspended growth processes where the microorganisms responsible for treatment grow in suspension, the active bacteria in attached growth processes cling to some solid surface, natural or manmade, to perform the treatment. It can be inferred that the suspended growth processes are more preferable and advantageous for carbonaceous organic matter removal along with nutrient removal and production of biorenewable methane from urban wastewater in comparison to the attached growth processes.