ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)

Vol 4, Issue 3, March 2017

Biological Wastewater Treatment Principles

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Abstract— Natural receiving waters including rivers, streams, and tidal areas sustain a background population of microorganisms including bacteria, fungi, and algae. These organisms require energy for respiration and organic carbon food sources in order to synthesize new cells using the following general equation: In the above equation, the microbes occur naturally and consume organic food sources that are naturally present in the water. Some of the carbon matter in the food is biodegraded to release energy that drives the reaction. Energy is released through the biodegradation process by combining part of the organic food source's carbon compounds with oxygen. The by products of this reaction are additional microbial cells and carbon dioxide. Nutrients, primarily nitrogen and phosphorus, complete the reaction and are needed as part of the building blocks used to form new microbial cell tissue. In a clean water environment, the amounts of available organic food supplies are limited. This places a restriction on how fast the above reactions proceeds and also on how many microbes are able to grow. In general, the population of microbes in a clean water environment is restricted to a low background level by the limited amount of organic food that is present. While periodic fluctuations in the food supply may cause brief periods of population swings or declines, the number of microbes in the ecosystem will achieve an equilibrium condition over time that is based on the steady state amount of organic food present. If an artificial organic food supply is allowed to enter the ecosystem, the number of microbes that can be sustained will increase in response to the added food. If the amount of additional food is large, the population of microbes may increase exponentially and will continue to grow up to the point that the amount of food again becomes limiting for the elevated population. Raw sewage contains a high organic carbon content that provides an excellent supply of food for waterborne microbes. If raw sewage is discharged into receiving water, the bacteria population will become elevated in response to the new addition of food. This causes the above biodegradation reaction to proceed rapidly and, in the process, to create larger amounts of new microbes and carbon dioxide. This requires that more oxygen be available for use by the microbes. If sufficient extra food is added by the sewage discharge, the population of microorganisms and the resulting oxygen consumption may proceed so rapidly that all of the receiving water's oxygen is depleted.

I. INTRODUCTION

The maximum amount of dissolved oxygen present in receiving water is a function of temperature, atmospheric pressure, elevation, the solids content of the water, and salinity. In any case, the saturation value of dissolved oxygen.. At sea level and 0°C, the maximum amount of dissolved oxygen that can be saturated into solution is 14.6 mg/l. This value decreases to only 7.6 mg/l at 30°C. For this reason, there is less dissolved oxygen available in the summer when water temperatures are warmer than during the cold winter months. Unfortunately, high water temperatures will also stimulate microbial activity which will cause biodegradation reaction rates to increase and oxygen depletion to occur faster. This makes summertime the most critical period for maintaining dissolved oxygen conditions in receiving waters. As receiving water becomes higher in chlorides, less oxygen can be dissolved into the water.

If free dissolved oxygen is present, the ecosystem is considered to be aerobic. If excess raw sewage is discharged to receiving water, the available food supply may result in a large microbial population that fully depletes all of the dissolved oxygen. This results in the system becoming anoxic or anaerobic. Since most fish and aquatic species require a minimum dissolved oxygen level of at least 5.0 mg/l to survive, the depletion of all the dissolved oxygen is a serious environmental concern. Septic conditions also present a variety of other environmental problems including odder 30 Oxygen is the oxidizing agent of choice in microbial biodegradation because it results in high energy yields and harmless by products. Nitrate results in nearly the same energy yield, but produces nitrogen gas that can float solids in receiving waters or treatment systems. Sulphur or carbon dioxide compounds can be used to biodegrade organic matter under septic conditions; however, extremely low energy yields result and hydrogen sulphide or methane gas is produced. These gases are odorous, corrosive, explosive, and toxic. They contribute to acid formation and pH reductions as well as unsafe environmental conditions. Bacteria in the ecosystem will always use oxygen 31 first if it is available and, in doing so, will avoid the types of adverse by products. Should all of the oxygen be depleted, the ecosystem will continue to biodegrade the organic food supply by converting to an anoxic or anaerobic environment. In these cases, adverse environmental effects will be created.

The discussion on microbes up to this point has focussed on naturally occurring bacteria and other microorganisms that are simply biodegrading organic compounds. It is important to note that raw sewage discharges into a receiving water also present additional problems from harmful human enteric microbes, called pathogens that can spread waterborne diseases to humans. The wastewater discharge from a community will contain a representative sampling of all diseases that exist within the general population of sewer users. The presence of these diseases is usually assessed by measuring the amount of E. coli or fecal coli form bacteria that are present in the raw sewage. These organisms serve as indicators of upstream human waste contamination. If the indicator organisms are present, it can be assumed that harmful disease causing pathogens are also present. Given the possibility of downstream human contact or shellfish contamination, the presence of pathogens in a raw sewage discharge represents a serious environmental health concern.
As previously discussed, wastewater discharge licenses limit the amount of pollutants that can be discharged into the environment. Maximum discharge limits are established for total suspended solids (TSS), biochemical oxygen demand (BOD) and E. coli.

II. BIOLOGICAL NITRIFICATION AND DENITRIFICATION

The processes for biological nitrogen removal can be incorporated or retrofitted into both activated sludge and percolating filter plants. The overall mechanism follows the route of nitrification (oxidation of ammonia to nitrite and nitrate) and denitrification (reduction of nitrate sequentially to nitrite, nitric oxide, nitrous oxide and nitrogen). In modifying an existing plant for nitrification, up to 25% additional oxygenation and volumetric capacity may be required. On lowly loaded plants, nitrification can occur automatically due to the capacity remaining after carbonaceous oxidation. Their slower growth rate and susceptibility to shock loads and hydraulic washout mean that nitrifiers require more stable conditions and longer hydraulic and solids retention times than heterotrophic carbonaceous bacteria. Denitrification is an anoxic process which takes place in the absence of dissolved oxygen. The nitrate and nitrite produced during nitrification become the oxygen source for heterotrophic bacteria which utilise the available BOD. In essence, what is required are: bacteria, oxidised nitrogen as the oxygen source and a carbon source. In percolating filter processes, these conditions will be provided in a separate reactor which may precede or succeed the biofilters themselves. Conventionally, if the reactor precedes the biofilter, settled sewage is used as the carbon source and recirculated nitrified biofilter effluent (either settled or unsettled, depending on the nature of the reactor) provides the nitrate. This is termed pre-denitrification and is illustrated.

If the reactor succeeds the biofilter , nitrified effluent again provides the nitrate but the carbon source is provided by dosing a carbon rich chemical such as methanol (CH3OH). Such dosing processes are controlled to avoid excess methanol getting into the effluent stream, thereby increasing its BOD. Submerged unaerated reactors are generally used and good results have been achieved at high hydraulic and organic loading rates. Simultaneous nitrification and denitrification is possible on some proprietary submerged filters .Sludge production is high when operated at high loading rates. In the activated sludge process, denitrifying conditions are provided in a separate anoxic zone at the front end of a nitrifying plant. Organic carbon from the incoming waste water and nitrate provided in the RAS are utilised by the microorganisms. Anoxic zones can occupy 25-40% of the total capacity of an activated sludge lane and can therefore provide significant savings in the energy required for aeration. In utilising the oxygen contained in the RAS to satisfy incoming BUD, the actual organic load carried forward to the aerated section of a plant is reduced. This allows for more complete treatment of an effluent or improved nitrification downstream. Anoxic zones may have the added benefit of improving the settleability of mixed liquor and of helping to control bulking and filamentous bacterial growth, particularly in plug flow tanks. Anoxic zones are low dissolved oxygen areas or tanks with weir or baffle overflows to the aeration lanes.

Mechanical mixers are generally required to keep the mixed liquor in suspension. Biological denitnfication processes generally recirculate nitrified effluent as a source of nitrate. This means that 100% removal can never be achieved. Only the nitrate contained in the recirculated

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ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)
Vol 4, Issue 3, March 2017

stream will be removed; thus, if the recycle ratio is 1:1, then a maximum 50% NO3 removal is possible, i.e. only half of the flow is recirculated. If the recycle ratio is 3:1, then a 75% removal is possible. Obviously, the recycle ratio becomes limiting due to hydraulic constraints on the plant and allowances must be made for periods of high flow. As many plants are designed for a throughput of no more than 3 DWF, there are practical limitations on the amount of NO3 removal possible.

III. THE PURPOSE OF THESE LIMITS IS TO ACCOMPLISH THE FOLLOWING PRINCIPLES

- Limit the amount of available organic matter that is discharged to the receiving water to avoid over stimulating the growth of microorganisms in the environment.
- Limit the amount of dissolved oxygen that the discharged organic matter will deplete in the environment as it is biodegraded by naturally occurring bacteria.
- Disinfect the wastewater discharge to protect human health by reducing the number of pathogens in the water.

Wastewater collection systems are designed to convey raw sewage to a central location for treatment. Wastewater treatment plants are designed to process the raw sewage prior to its discharge to reduce its organic content, oxygen demand, and pathogenic content. This is accomplished by utilizing treatment processes that remove the waterborne pollutants directly (primary treatment) or that convert them into bacterial cells (secondary treatment). With biological treatment processes, organisms that occur naturally in the environment are grown under controlled conditions in the treatment plant. They are allowed to eat the organic portion of the incoming sewage which leaves clean water behind. Clean water is then discharged into the environment and the plant's excess cells, called sludge's, are disposed of in an environmentally acceptable manner. By the time that the treated effluent is discharged, it has lost its ability to serve as a food supply for the receiving water's microbes.

A wastewater treatment plant consists of a series of unit processes that receive polluted raw sewage directly from the sewer system and progressively clean it to a point that it can be safely discharged to receiving water. Raw sewage first enters the head works of the plant and is treated in several preliminary treatment processes that remove debris and make the water easier to treat in subsequent downstream processes. Primary treatment follows preliminary treatment and includes sedimentation processes that allow the water to be held under quiescent conditions. Settle able pollutants fall to the bottom of the primary treatment reactors and form sludge’s. The clarified primary effluent then flows into secondary treatment where microbes are grown to biodegrade non-settle able organic pollutants. Effluent from the secondary treatment system is further treated in a disinfection process to remove pathogens. Sludge residuals that form in each unit process must also be treated and properly discharged of at licensed sludge processing facilities.

IV. PRELIMINARY TREATMENT PROCESSES

Preliminary treatment systems encompass all unit processes in the headworks of a treatment plant prior to primary treatment. The purpose of these processes is to refine the incoming wastewater’s characteristics to make the water more conducive to treatment in downstream processes. Preliminary treatment is also designed to remove undesirable pollutant constituents and debris from the influent to prevent it from interfering with downstream treatment systems and to protect subsequent equipment from damage. Typical preliminary treatment processes include screening, shredding, grit removal, equalization, and pH neutralization. Screening and shredding processes either remove or refine incoming wastewater solids to achieve a uniform particle size which can be more efficiently handled by downstream treatment systems. Poor screening or shredding may lead to plugging problems in downstream processes, pumps, or piping. Grit removal systems remove abrasive substances from the wastewater such as sand and gravel. Inadequate grit removal can lead to excessive pump and impeller wear, equipment abrasion, pipe deterioration, and loss of available treatment tank volumes. Equalization is used to reduce the variability of erratic waste loads by providing upstream storage of influent flows. Effective equalization can dampen influent flow, TSS, and BOD fluctuations, Variability's impacts on the treatment plant, and result in controlled loadings to the downstream processes. Where influent loadings exhibit a high degree of hydraulic or pollutant variability, inadequate equalization can result in unstable downstream performance, particularly in biological treatment systems. Neutralization processes are used to chemically alter the influent pH by the addition of acid or alkaline compounds and is required when the pH of wastewater is highly variable or outside a required regulatory or process range. Inadequate neutralization can result in pH swings in downstream processes effecting their efficiency and performance. In addition to these systems, preliminary treatment processes also include other typical head works functions such as flow measurement and wastewater sampling equipment. These systems are used to monitor the incoming waste's characteristics for regulatory and process control purposes.

While preliminary treatment processes are conceptually simple in function and operation, the important role that these processes play in overall treatment plant optimization is often ignored. Since the sole purpose of preliminary treatment is to make the wastewater easier to treat, marginal process performance of existing preliminary systems, or the omission of critical preliminary treatment processes from a plant's headworks, almost always results in a loss of downstream process efficiency and stability. Preliminary treatment processes are relatively simple to operate.

V. KEY FACTORS IN KEEPING TYPICAL PRELIMINARY TREATMENT EQUIPMENT OPERATING AT MAXIMUM EFFICIENCY INCLUDE:

- Grit systems should be adjusted in response to changes in the incoming flow rate. Higher wet weather flows will tend to produce more grit than lower dry weather flows. The aeration rate into an aerated grit chamber should be adjusted in response to changing flow rates and grit production amounts. Once settled, grit should be removed from the system frequently to prevent it from becoming compacted or septic.
- Grinder equipment should be kept in a well maintained condition. Cutter and shredder blades should be kept sharp.
- Flow metering equipment should be frequently checked and calibrated to make sure that it is providing accurate readings.
- Sampling equipment should be properly maintained, frequently calibrated, and cleaned often to prevent the fouling of sample tubing that can lead to contaminated, false samples and test results which are not representative.
- All debris removed from the head works area, such as gravel, sand, screenings, and other materials should be disposed of frequently to prevent odours and nuisance conditions from forming in the plant.

VI. CONCLUCTION

As discussed, excess sludge's must periodically be removed from the primary clarifiers and the activated sludge process to keep the plant's F/M, MCRT, and MLSS levels at an optimal equilibrium. When wasting sludge, only the solids content or mass of microbes wasted has an impact on the process. Unfortunately, this waste mass is often contained in large volumes of water. Even the thickest waste activated sludge is seldom more concentrated than a 1% solution. This means that 99% of the waste sludge volume is water. As a result, the plant operators must remove, convey, and transport large volumes of water in order to remove small volumes of actual sludge mass. This is often problematic in treatment plants with poorly conceived sludge handling systems. Many treatment plants perform poorly because operators choose not to waste as much sludge as they should because of the costs and nuisance conditions associated with its removal.

Wastes sludge's also have a high volatile solids or organic content. This means that they will continue to biodegrade once removed from the plant. This can lead to odor generation issues and the creation of nuisance conditions. It is important to properly operate plant processes that help to reduce the organic content of the waste sludge. A sound sludge management strategy should include the consideration of both water volume reduction methods and organic content reduction approaches.

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)
Vol 4, Issue 3, March 2017

Finally, a sludge dewatering process is often used to further reduce the volume of the sludge by removing excess water. Drying beds, belt presses, and centrifuges are often used to dewater sludge's.

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