TECHNOLOGIES THAT TRANSFORM POLLUTANTS INTO INNOCUOUS COMPONENTS: BIOLOGICAL METHODS

Wang Jianlong
Department of Environmental Science and Engineering, Tsinghua University, Beijing, P.R. China

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Summary

Biological treatment processes are the most important unit operations in wastewater treatment. Methods of purification in biological treatment units are similar to the self-purification process that occurs naturally in rivers and streams, and involves many of the same organisms. Removal of organic matter is carried out by heterotrophic microorganisms, which are predominately bacteria but also occasionally fungi. The microorganisms break down the organic matter by two distinct processes, biological oxidation and biosynthesis, both of which result in the removal of organic matter from wastewater. Oxidation or respiration results in formation of mineralized end-products that remain in wastewater and are discharged in the final effluent, while biosynthesis converts the colloidal and soluble organic matter into particulate biomass (new cell) which can then be subsequently removed by settlement. If the food supply, in the form of organic matter, becomes limiting then the microbial cell tissue will be endogenously respired (auto-oxidation) by the microorganisms to obtain energy for maintenance. All three processes occur simultaneously in the reactor.

The major biological processes used for wastewater treatment are typically divided into four groups: aerobic processes, anoxic processes, anaerobic processes, and a combination of aerobic/anoxic or anaerobic processes. The individual processes are further subdivided into two categories: suspended growth systems and attached growth systems according to the existing state of microorganisms.

The most commonly used biological processes are (1) the activated sludge process, (2) aerated lagoons, (3) trickling filter, and (4) stabilization ponds.

The fundamental mechanisms involved in biological treatment are the same for all processes. Microorganisms, principally bacteria, utilize organic matter and inorganic matter present in wastewater to support growth. A portion of materials is oxidized, and the energy released is used to convert the remaining materials into new cell tissue.

1. Introduction

Biological treatment processes are processes in which the removal or treatment of contaminants is brought about by biological means. The activated sludge process used for the treatment of the organic matter in wastewater is perhaps the best-known example.

The objectives of the biological treatment of wastewater are to coagulate and remove the non-settleable colloidal solids and to stabilize the organic matter.

With proper analysis and environmental control, almost all wastewater can be treated biologically. Biological treatment systems are living systems that rely on mixed biological cultures to break down waste organic compounds and remove organic matter from solution. The biological treatment processes are carried out by a diversified group of organisms. It is the bacteria that are primarily responsible for the oxidation of organic compounds. However, fungi, algae, protozoa and higher organisms all have important secondary roles in the transformation of soluble and colloidal organic pollutants into carbon dioxide and water as well as biomass, the later can be removed from the liquid by settlement prior to discharge to a natural watercourse.

Biological treatment processes are typically divided into two categories: suspended growth systems and attached growth systems. Suspended systems are more commonly referred to as activated sludge processes, of which several variations and modifications exist. Attached growth systems differ from suspended growth systems in that microorganisms attached themselves to a medium, which provides an inert support. Trickling filters and rotating biological contactors are most common forms of attached growth systems.

Two types of biological treatment process are widely used for wastewater treatment:

- Aerobic processes, in which the microbes use oxygen dissolved in the water.
- Anaerobic processes, in which the microorganisms do not have access to freely dissolved oxygen, nor to other energetically favorable electron acceptors such as nitrate ions. In such circumstances microorganisms can use the carbon in organic molecules as the electron acceptor.

A treatment unit provides a controlled environment for the desired biological process.

2. Activated Sludge Process

The most versatile of the biological treatment processes is the activated sludge process, which was developed in England in 1913 by Ardern and Lockett. It was so named because it involved the production of an activated mass of microorganisms capable of aerobically stabilizing a waste. Many versions of the original processes are in use today, but fundamentally they are all similar.

Activated sludge process is used for both secondary treatment and complete aerobic treatment without primary sedimentation. Wastewater is fed continuously into an aerated tank, where the microorganisms (activated sludge) metabolize and biologically flocculate the organic matter. Microorganisms are settled from the aerated mixed liquor under quiescent conditions in the final clarifier and returned to the aeration tank. Clear supernatant from the final settling tank is the plant effluent.

Microbial growth in the mixed liquor is maintained in the declining or endogenous growth phase to ensure good settling characteristics. Synthesis of the waste organic matter results in a buildup of the microbial mass in the system. Excess activated sludge is wasted from the system to maintain the proper food/microorganism ratio (F/M) and sludge age to ensure optimum operation.

Under conditions existing in the activated sludge process, the microbial culture grows in clumps or flocs that contain large numbers of bacteria held together by the secreted polymers that accumulate on their capsules. Maximum floc size is controlled by shear stress in the reactor, and minimum floc size in controlled by the gravity sedimentation process used to separate the culture from the treated effluent. Organisms other than bacteria (fungi, protozoa, etc.) live in or on the flocs but do not ordinarily occur in large numbers. Some free-swimming organisms such as nematode worms and rotifers are found in activated sludge also. Protozoa and rotifers feed on free-swimming bacteria and are therefore aids in producing an effluent having low turbidity.

Because the actual bacterial population is very difficult to measure, the concentration of suspended solids or volatile suspended solids in the aeration tank is used as an estimate of the cell concentration. The mixture of wastewater and suspended culture is referred to as the mixed liquor, and the respective suspended solids concentrations as mixed-liquor suspended solids (MLSS) and mixed-liquor volatile suspended solids (MLVSS).

3. Other Activated Sludge Configurations

A number of modifications of the basic activated sludge process flow sheet exist. The most important are the contact stabilization, the step aeration, the oxidation ditch, the pure oxygen, and the minimal aeration systems.

3.1. Oxidation Ditch Process

The oxidation ditch system, developed by Pasveer in Holland in 1953, is a variation of the conventional plug-flow activated sludge process in which a continuous-loop reactor is used. The wastewater and the liquor contained in the reactor are aerated, mixed, and re-circulated continuously using a brush aerator. It is a simple, single stage oxidation process with no primary sedimentation.

The influent wastewater enters the ditch upstream of the aerator ensuring maximum dilution, as well as supplying the oxygen where oxygen demand will be greatest. The mixed liquor is drawn off by displacement into the sedimentation tank and after separation most of the sludge is returned. Although oxidation ditches exhibit plug-flow characteristics, they are also completely mixed systems.

The original oxidation ditch was developed to provide low-cost treatment for small communities. The oxidation ditch is operated in the extended aeration mode (i.e., with long hydraulic retention times, high solids retention times, and low organic loading rates). Oxidation ditch needs little maintenance compared to conventional or high-rate activated sludge process and suffers less from sludge bulking or odor problems.

Three features of oxidation ditch in general are: (1) ease of operation; (2) low production of a highly stabilized sludge; (3) the ability to nitrify and denitrify within a single tank.

3.2. Tapered Aeration

Where constant aeration is provided along the length of a plug-flow system problems arise due to the decreasing oxygen demand gradient that occurs along the length of the tank. The result is under-aeration at the inlet and over-aeration at the outlet. This can be overcome by tapering the aeration according to the respiratory requirement of the mixed liquor.

While the term tapered aeration suggests a gradual reduction in the aeration along the tank, in practice it occurs as a series of steps or movements. In a tapered aeration activated sludge system, incoming wastewater is introduced into a nominally plug-flow aeration tank at several points along its length. The result is that the load is distributed over the system more uniformly.

3.3. The A-B Process

This is a two stage activated sludge system developed by B. Bohnke of the Technical University of Aachen. It also called contact stabilization, or biosorption process, adsorption and oxidation are carried out in separate tanks. Usually the process comprises two separate activated sludge plants in series; a highly loaded, or high-rate, first or A-stage, followed by a low loaded second or B-stage.

The influent wastewater enters the contact tank where it is mixed with mixed liquor with a MLSS concentration of between 2000-3000 mg/L for between 0.5-1 h. During this short contact period the organic matter present is adsorbed onto the activated sludge flocs. The mixed liquor is then settled in the sedimentation tank and the separated sludge pumped into the aeration tank where it is aerated at a high MLSS concentration of between 4000-10,000 mg/L for 5-6 h so that the adsorbed matter can be fully oxidized.

There is no primary sedimentation and the influent enters the first aeration tank after only receiving preliminary treatment. Sludge loading rates in the A-stage are high, up to 3-6kg BOD kg MLSSd^{-1}, with up to 70 percent of the influent BOD removed at this stage. The B-stage is operated at a normal sludge loading of between 0.115-0.30 kg BOD kg MLSSd^{-1}.

The A-B process does not require primary sedimentation and only requires about 60 percent of the aeration tank capacity of a conventional plant. This can result in a reduction in capital (constructional) costs of up to 30 percent, while the lower aeration costs can be in the order of up to 20 percent less than a single stage activated sludge plant.

Existing activated sludge plants can be up-rated by incorporating an A-stage, converting the plant to an A-B process.

3.4. Incremental Feeding

The same "evening-out" of oxygen demand along the length of the aeration tank achieved by tapered aeration can also be done by introducing the influent wastewater incrementally at several points along the length of the tank. The recycled sludge still introduced into the aeration tank at the inlet end. This results in a more even distribution of the BOD load and so a more even oxygen demand along the tank. With a uniform aeration system the BOD:DO should remain more constant so that ensure the efficient use of the oxygen supply. A useful advantage of this system is that the proportion of influent wastewater entering the tank at each stage can be varied according to changes in the organic or hydraulic loadings. This gives the process a considerable degree of flexibility in operation.

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Biographical Sketch

Wang Jianlong is an associate Professor in Department of Environmental Science and Engineering at Tsinghua University, Beijing, Peoples' Republic of China. He received his Ph.D degree in Environmental Chemical Engineering from Harbin Institute of Technology in 1993 and carried out the postdoctoral work in Tsinghua University. He gives a lecture on Environmental Microbiology for undergraduate students and lectures on Modern Environmental Biotechnology for graduate students. He carries out the research works in the State Key Joint Laboratory of Environmental Simulation and Pollution Control. His research interests are mainly in the following areas: (1) novel technology of biological wastewater treatment which is high efficiency, low cost and suitable for Chinese practical conditions; (2) nitrogen removal of high-concentrated nitrogen-containing industrial wastewater; (3) application of bioadsorption technique to the removal of heavy metal ions from wastewater; (4) application of bioaugmentation technique to remediation of contaminated soil and improving the removal efficiency of recalcitrant organic compounds from industrial wastewater; (5) BOD biosensor. He has done several researches on the biodegradation of refractory organic compounds by immobilized microbial cells. He was or is in charge of several projects supported by: National Natural Science Foundation of China; International Foundation for Science, National High Technology Development Plan (863 project), State Commission of Science and Technology; State Education Commission and the like. His present researches are focused on modern environmental biotechnology, such as the separation, purification and characterization of enzymes relating to the degradation of recalcitrant compounds, application of molecular biology techniques to detection and monitoring of specialized microorganisms in the bioreactor or in the field. He is also interested in environmental ethics, such as the relationship of human being and the nature. He is the author or co-author of over 100 technical papers and research reports. He has published two books and has written several chapters in other books.