SPECIFIC OPTIONS IN BIOLOGICAL WASTEWATER TREATMENT FOR RECLAMATION AND REUSE

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Contents

Summary

This chapter focuses on a number of specific biological treatment technologies as options to wastewater reclamation with specific reference to concepts, treatment processes and configurations and its performance. These biological technologies will be classified and discussed in two main categories of non-membrane biological and membrane biological treatment systems.

1. Introduction

1.1 The World's Worsening Water Crisis

All living organisms are composed of cells that contain at least 60 percent water because organisms can only exist where there is access to adequate supplies of water. Water is also a unique and essential for life on Earth because it has remarkable physical properties. We need water everyday for our basic physiological needs, for food and cleaning, for energy, and most important, for sustaining our global ecosystems. Worldwide water demands roughly tripled. Agriculture now accounts for about 70% of world water use, industry for about 22% and towns and municipalities for 8% (Worldwatch Institute, 2004). However, during the last half century the scale and pace of human influences on freshwater systems has accelerated rapidly with population and consumption growth and our usable water supplies have been exhausting due to both human and natural factors. Today, 1.1 billion people lack safe drinking water and 2.4 billion lack access to basic sanitation. The United Nations estimates that it costs $30 billion a year to meet current drinking water supply and sanitation needs, and that between $14 and $30 billion more per year would be needed to meet global water and sanitation targets. If people continue with business as usual, two-thirds of the world's population will be living in moderate to severe water stress by 2025 (Skirble, 2003).

1.2 Wastewater Reclamation and Water Reuse

It is important to understand the terminology used in the arena of water reclamation and reuse. *Wastewater reclamation* means the treatment or processing of wastewater to make it reusable whilst *water reuse* is the use of treated wastewater for beneficial purposes such as agricultural irrigation and industrial cooling. *Reclaimed water* is a treated effluent suitable for an intended water reuse application. In addition, *direct* water reuse requires the existence of pipes or other conveyance facilities for delivering reclaimed water. *Indirect* reuse is discharge of an effluent to receiving water for assimilation and withdrawals downstream. In contrast to direct water reuse, *water recycling* normally involves only one use or user and the effluent from the user is captured and redirected back into that use scheme. In this context, water recycling is predominantly practiced in industry (Metcalf & Eddy, 1991). A conceptual comparison of the extent to which water quality changes through municipal applications is shown in Figure 1 (Asano, 2001). Water treatment technologies are applied to produce high quality drinking water for domestic water supply. Conversely, municipal and industrial water use tends to degrade water quality by introducing chemical or biological contaminants. The dashed broken line represents an increase in treated water quality as necessitated by water reuse. Ultimately, as the quality of treated water approaches that of unpolluted natural water, the practical benefits of water reclamation and reuse are evident. As more advanced technologies are applied for water reclamation, such as carbon adsorption, advanced oxidation, and reverse osmosis, the quality of reclaimed water can exceed conventional drinking water quality by most parameters, and it is termed repurified water (Asano, 2001).

To solve the worlds worsening water crisis, the need and benefits of water reclamation and reuse from sewage are assessed. Water reclamation and reuse are being considered as an unavoidable stage not only for alleviating the contradiction of growing water demand in connection with limiting water resources, but also for protecting existing water sources being polluted. Water reclamation and reuse provides a unique and viable opportunity to augment our water supplies. As a multi-disciplined and important element of water resources development and management, water reuse can help to close the loop between water supply and wastewater disposal (Asano, 2001).

Water reuse accomplishes two fundamental functions: (i) the treated effluent is used as a water resource of beneficial purposes, and (ii) the effluent is kept out of streams, lakes and beaches; thus, reducing pollution of surface water and groundwater. The foundation of water reuse is built upon three principles: (i) providing reliable treatment of wastewater to meet strict water quality requirements for the intended reuse application, (ii) protecting public health, and (iii) gaining public acceptance. Whether water reuse is appropriate for a specific locale depends upon careful economic considerations, potential uses for the reclaimed water, and the relative stringency of waste discharge requirements.

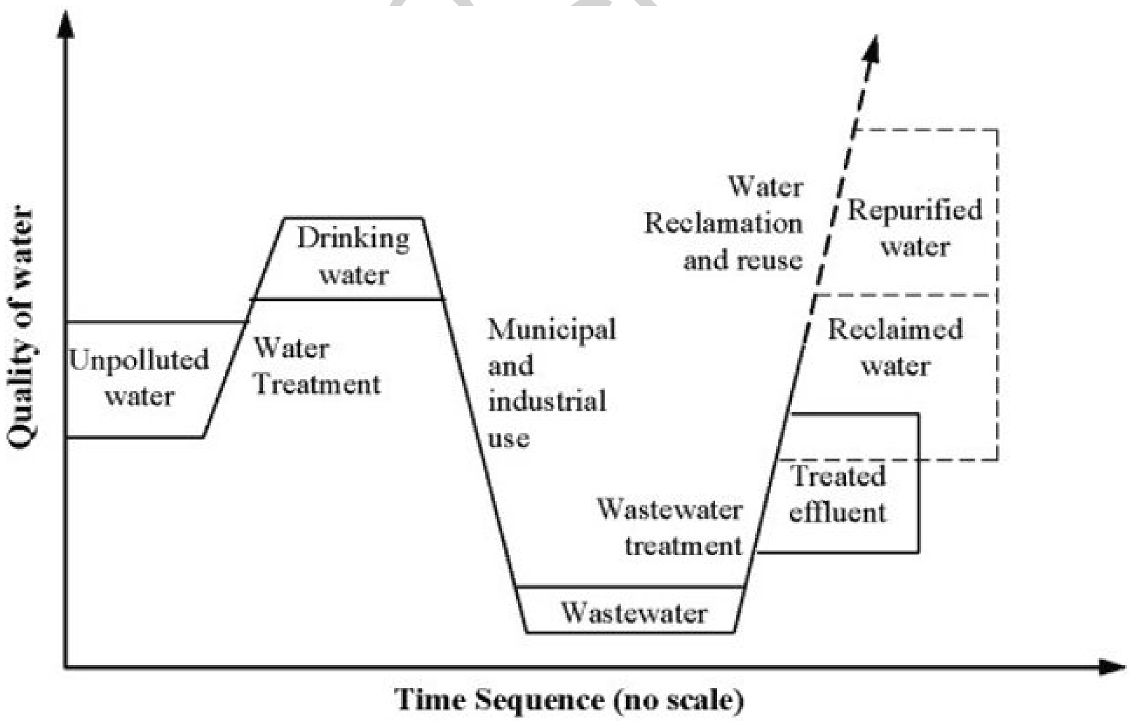

Figure 1 Water quality changes during municipal uses of water in a time sequence

The dominant applications for water use include agricultural irrigation, landscape irrigation, groundwater recharge, industrial reuse, environmental and recreational uses, non-potable urban uses, and indirect or direct potable reuse. The relative amount of water used in each category varies locally and regionally due to differences in specific water use requirements and geopolitical constraints (Asano, 2001).

1.3 Biological Wastewater Treatment

The application of biological treatment can be traced back to the late nineteenth century. By the 1930s, it was a standard method of wastewater treatment (Rittmann, 1987). There are two major biological wastewater treatment processes, which are known as aerobic and anaerobic processes. In aerobic process, dissolved oxygen is required as an electron acceptor, while the existence of oxygen is not permitted in anaerobic process.

The microbial population could be carbonaceous wastes in sewage, or introduced from the soil as the wastewater flows through the drains, or from the microbial spores carried by the wind. The microorganisms which are important in wastewater are yeast, fungi, bacteria, algae and protozoa. The microorganisms may be dispersed in the wastewater or they could aggregate to form flocs or slimes. They support microbial growth in treatment processes and in distribution systems. Bacterial slimes in distribution systems may also facilitate corrosion of pipes; produce taste, odor, and color in the treated water; and increase the amount of chlorine needed to maintain a residual throughout the distribution system. Extremely low concentrations of biodegradable organic matter can be utilized by oligotrophic microorganisms. Ammonia, iron and manganese remaining in the product water are also suitable growth substrates for certain bacteria. Consequently, biodegradation of assimilable organic carbon (AOC) is one approach to achieving a product water that is biologically stable and offers limited opportunity for regrowth (Ouano, 1981; Bouwer and Crowe, 1988).

Aerobic degradation of organic wastes could be generalized by the following reaction:

Bacterial cell + organic matter + oxygen + nutrient CO_2 + H_2O + more bacterial cells (2.16)

Anaerobic degradation could be generalized by a two stage symbiotic reaction:

Acid forming bacteria cell + organic matter + nutrient organic acids + CO_2
+ more acid forming bacteria cells (2.18)

and

Methane forming bacteria cell + organic acids + nutrient CH_4 + CO_2
+ more methane forming bacteria cells (2.19)

During the biological wastewater treatment process, organic matter, mainly insoluble form, is converted into H_2O, CO_2, NH_4^+, CH_4, NO_2^-, NO_3^- and bacteria cells. Although the end products vary depending on the presence or absence of oxygen, bacteria cells are always an end product. They go through the following five stages, Figure 2, (Ouano, 1981; Benefield and Randall, 1980; Visvanathan et al., 2000, Tchobanoglous and

Burton, 1991):

1. Lag phase: When a bacterial culture is introduced into a solution containing carbonaceous substances, the sells adjust their enzymatic system to suit the food available. The growth rate at this stage is very low. This phase of growth is known as lag phase or acclimatization stage.
2. Exponential growth phase: After the bacterial cells have been acclimatized, they grow and multiply rapidly at a growth rate that is exponential in nature. This period of rapid growth is known as log phase or exponential growth phase.
3. Stationary growth phase: When almost all the food is used up, a balance is established between the bacterial population and the food supply and the growth rate remains close to zero. This period is known as stable growth phase.
4. Death phase: When the food is used up, the bacterial cells start to consume the stored cellular reserves. The bacterial cells stop reproducing and they lose weight. This phase is known as endogenous phase.
5. Equilibrium phase: Where nutrients are being constantly fed through the system, the bacterial mass will reach a state of equilibrium. That is, the rate of growth of cells will be proportional to the rate at which nutrients are being fed into the system.

In the planning and implementation of water reuse schemes, the degree of biological wastewater treatment required and the reliability of treatment processing and operation are governed by the reuse applications. In principle, wastewater or any marginal quality waters can be used for any purpose as long as adequate treatment is provided to meet the water quality requirements for the intended use.

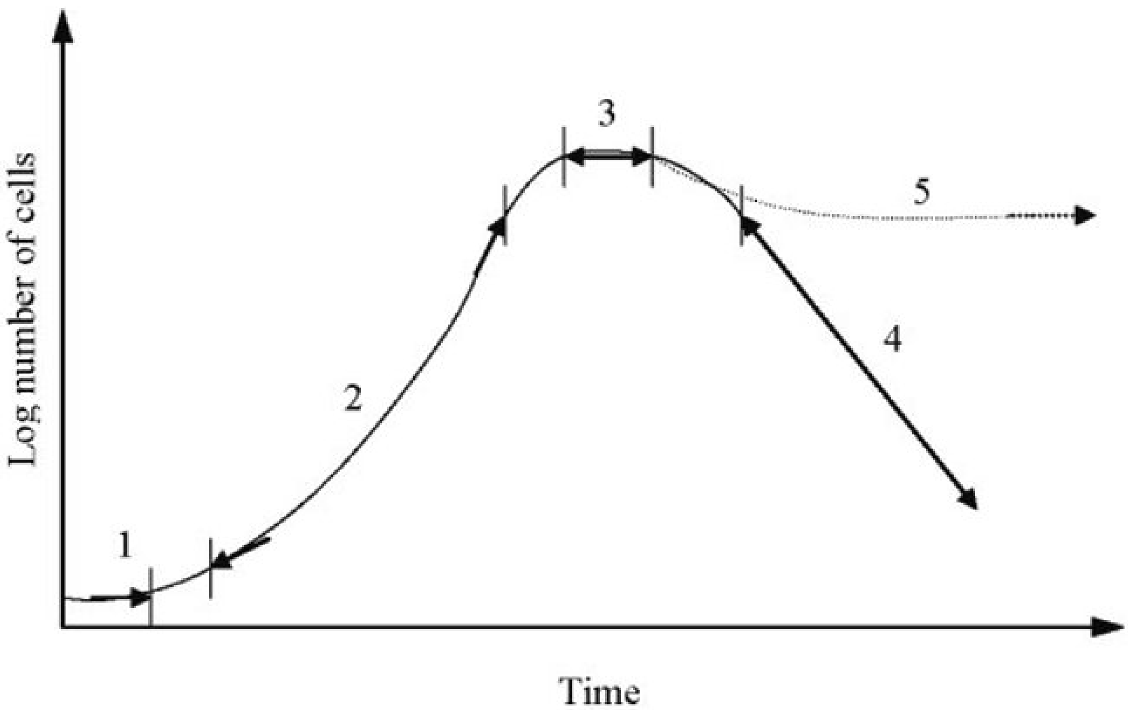

Figure 2 Typical Growth Patterns of Biomass

2. Specific Non-Membrane Biological Processes

2.1 Biological Filtration

2.1.1 Introduction

Biofiltration is distinguished from other biological wastewater treatment by the fact that there is a separation between the microorganisms and the treated water. In biofiltration the microbial biomass is static – immobilized to the bedding material, while the treated fluid is mobile – it flows through the filter. The activities of immobilized microbes determine the performance of biological filtration even though the separation is not complete and biomass to a certain extent leaches into the treated fluid (Cohen, 2001).

The immobilization of microorganisms to the bedding material can be divided into two main immobilization processes: (1) the self-attachment of microorganisms to the filter bedding material, which is defined as 'attached growth on filter media', (2) the artificial immobilization of microorganisms to the bedding material. During biofiltration, the pollutants may be adsorbed from the wastewater by microbial film or the bedding material. The main way of pollutant removal in biofiltration systems is the biological degradation of the organic matters in wastewater. In this way, the contaminants are incorporated into the microbial biomass or used as energy sources (electron donors or electron acceptors), therefore available nutrients sources in feed wastewater is essential for their development (Cohen, 2001; Yang et al., 2001).

The filter media and factors related to the development of microorganisms will influence the performance of biological filters. While filter media influence to the attachment process of microorganisms, the growth of microbiological community in biofilter is effected by influent characteristics and temperature. In addition, operational conditions such as backwashing technique, empty bed contact time etc. will also affect the effectiveness of biological filtration in wastewater treatment. Moreover, biological filtration is economical and safe for environment. Therefore, biofilter is more suitable than other treatment methods in terms of removing organic matter. As the success of a biofilter depends on the growth and maintenance of biomass on the surface of filter media, it is necessary to understand the mechanisms of biological attachment, growth and detachment on the surface of the media (Chaudhary et al, 2003).

2.1.2 Biological Mechanisms of Attachment

The attachment of microorganisms onto surface of filter media to form biofilm is a complex process. It was studied by many methods such as scanning confocal laser microscopy, microbalance applications, microelectrode analysis, high resolution video microscopy, atomic force microscopy and scanning electron microscopy. Bacteria generally range in size from 0.05 (nanobacteria) to 4 μm in length or diameter, with slow-growing and starved cells dominating at the smaller end of the range and fast-growing cells, especially in nutrient rich environments, at the larger end. Although bacteria commonly bear a negative charge with the initial interactions between bacteria and surfaces of media, the fact that bacteria are living entities and capable of changing themselves and their environment through active metabolism and biosynthesis must not be overlooked. With the use of the electron microscope, researchers have identified the presence of microorganisms enclosed in an extracellular polymeric substance (EPS) which are associated with surfaces (Percival et al., 2000; Van Loosdrecht et al, 1989).

Figure 3 describes the attachment of microorganisms to the surface of supported media, (Percival et al., 2000). The attachment of microorganisms to the surface of bedding materials can be divided into five steps (Percival et al., 2000):

1. Development of a surface-conditioning film,
2. Those events which bring the organisms into the close proximity with the surface (transportation of cells to a surface).
3. Adhesion (reversible and irreversible adhesion of microbes to the conditioned surface),
4. Growth and division of the organisms with the colonisation of the surface, microcolony formation and biofilm formation.
5. Detachment.

Compared to suspended microorganisms, attached microbial film has several advantages in the degradation of pollutants, such as higher biomass concentrations, higher metabolic activity, greater resistance to toxicity and better sludge properties (Cohen, 2001). There are several elements that take part in microbial attachment to a surface in which the strength of the attachment relies on environmental conditions, type of micro organisms, surface properties and fluid characteristics.

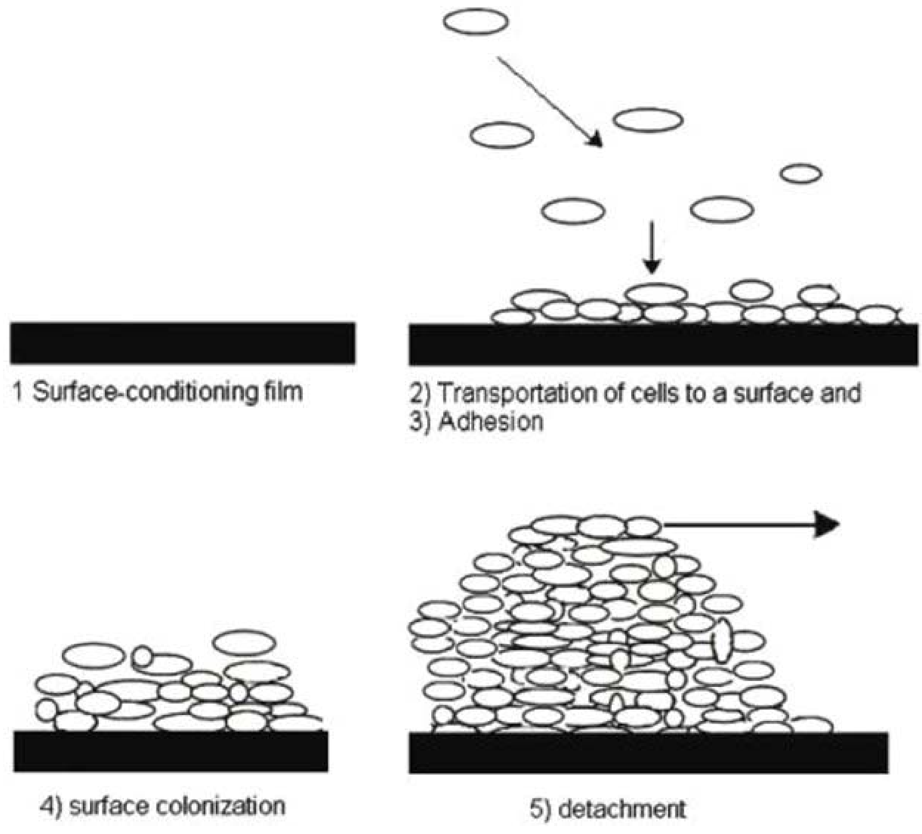

Figure 3 Diagram to show biofilm formation

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Biographical Sketches

Wenshan Guo is working as UTS Chancellor's Postdoctoral Research Fellow and her research focus is on the innovative water and wastewater treatment and reuse technologies. Her expertise and practical experience cover the areas of water and wastewater engineering such as membrane technologies (e.g. membrane bioreactor, microfiltration, membrane hybrid system, and PAC-submerged membrane bioreactor etc.), advanced biological wastewater treatment technologies (e.g. suspended growth reactors and attached growth reactors), and physical/chemical separation technologies as pretreatment or post-treatment (e.g. adsorption, column, and flocculation). She also has strong ability to work in solid waste management, life cycle assessment, and desalination.

Huu Hao Ngo is an academic and senior environmental research engineer with more than twenty five years' professional experience in Australia and in Asian countries. He is now working as Associate Professor of Environmental Engineering and Manager, in-charge of Environmental Engineering R & D Laboratory, School of Civil and Environmental Engineering at University of Technology, Sydney (UTS). He is also serving as a core member (Team Leader of advanced water and wastewater treatment materials based technology group and Project Investigation of membrane based technology in the theme of Urban Water Management) of the Institute of Water and Environmental Resource Management at UTS. Assoc. Prof. Ngo is internationally known for his activities in the development of innovative water, wastewater treatment and recycling technologies, and is a recognised authority on the flocculation and filtration process, biofiltration and membrane hybrid technology. He has been involved in more than 50 research projects and published more than 200 technical papers including two books and several book chapters. He is also a reviewer for more than 20 international journals.