ADVANCED TREATMENT TECHNOLOGIES FOR RECYCLE/REUSE OF DOMESTIC WASTEWATER

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Summary

Conventional wastewater treatment technologies improve the quality of wastewater discharged into the environment and restrain polluted waters from contaminating other available clean water resources. However, these treatment technologies do not make wastewater fit for further beneficial uses in communities closer to the points of generation. Innovative and advanced technologies that can further improve the quality of wastewater are needed to overcome this limitation of conventional technologies, and to promote widespread adoption of recycle and reuse practices. Advanced treatment processes can be biological processes, physicochemical processes, or a combination of both (hybrid processes). Biological processes to remove nutrient pollutants such as

nitrogen and phosphorus, provide the platform for further wastewater treatment to reusable quality. Physicochemical processes such as deep-bed filtration, floating media filtration, and membrane filtration, play a major role among treatment technologies for water reuse. Membrane filtration has significant advantages over other processes since they produce high quality effluent that requires little or no disinfection with minimum sludge generation. The hybrid processes attempt to obtain the benefits of both biological and physicochemical processes in one step.

1. Introduction

The continuing processes of industrialization and urbanization coupled with the natural growth of population, are exerting pressure on the planet's limited fresh water resources in particular and on the aqueous environment in general. The diminishing sources of clean water have necessitated the search for unconventional means to supplement available water resources. With the reinforcement of the concept of environmentally sustainable development after the Rio Earth Summit, 1992, recovery, recycle and reuse of natural resources have been widely accepted as appropriate norms for their conservation. Conventional wastewater treatment technologies improve the quality of wastewater discharged into the environment and contain polluted waters from contaminating other available clean water resources. However, these treatment technologies do not make wastewater fit for further beneficial uses so that it can be recycled or reused, in communities closer to their points of generation. Application of innovative and advanced technologies that can further improve quality of wastewater is required to overcome the limitation of conventional technologies to achieve the goal of resource conservation through recycle and reuse. The opportunities for reclamation of reusable quality water from domestic wastewater is huge, as only a small quantity of water supplied to households are directly consumed and so are the possibilities for a dual water supply system—a high quality supply for drinking and washing and a lower quality supply for toilet flushing and garden watering. A number of technological alternatives are available to treat wastewater to such reusable qualities. This article presents a general overview of such advanced and innovative technologies and describes some cases where they have been successfully adopted.

2. Advanced Wastewater Treatment Technologies

Advanced wastewater treatment processes can be:

- Biological processes for tertiary treatment of wastewater for nutrient removal. Intermittently Decanted Extended Aeration Lagoon (IDAL) system for nitrogen removal and Biologically Enhanced Phosphorus Removal (BEPR) system are important tertiary treatment technologies.
- Physicochemical processes such as deep bed filtration and membrane filtration.
- Hybrid processes such as a combination of physicochemical and biological processes as in membrane bioreactors.

Biological nutrient removal processes do not necessarily tend wastewater for direct reuse; however, they provide the platform for further treatment to reusable quality. The physicochemical processes play a major role among technologies for water reuse. Deep bed filtration, in modified forms, finds an important place in water reuse due to its simplicity. Membrane filtration has significant advantages over other processes since they produce high quality effluent that requires little or no disinfection requirement with minimum sludge generation. The combination of biological and physicochemical processes attempts to obtain the benefits of both the processes in one step.

3. Biological Nutrient Removal Processes

3.1. Intermittently Decanted Aeration Lagoon (IDAL) System

The IDAL system biologically removes nitrogen from domestic wastewater. Biological removal of nitrogen is a two-step process. First step is the nitrification of ammonia-nitrogen into nitrate-nitrogen by nitrifying bacteria such as nitrosomonas and nitrobacter. The second step is denitrification of nitrate nitrogen into nitrogen gas, in the absence of dissolved oxygen.

In IDAL system, biological oxidation and clarification takes place in the same tank. The three different operations namely, aeration, settling and decantation are separated in time but not in space as these operations are done in cycle. Nitrification and denitrification takes place during the aeration and non-aeration periods of the cycle, respectively. Decantation of clarified effluent is done by lowering the outlet weir of the lagoon.

The IDAL system for nitrogen removal is widely used in sewage treatment plants (STPs) in Australia. The Quakers Hill STP in New South Wales is one among them. The aeration tank of IDEAL system in this STP consists of diffused air aeration arrangement and the effluents are recirculated for ten times, once every operating cycle, during a total hydraulic retention time of 40 hr. Each operating cycle consists of 60–120 min of aeration, 30–180 min of settling and 30–90 min of decantation.

3.2. Biologically Enhanced Phosphorus Removal (BEPR) System

Phosphorus is a nutrient required for biological growth. The typical phosphorus content of biosolids from conventional activated sludge treatment process is 1.5–2% of its dry weight. Most of the bacterial populations in activated sludge mass can not survive anaerobic conditions. However, some can readily break down the polyphosphates to get energy for their metabolic growth, in the absence of oxygen. Hence, if a conventional activated sludge process is subjected to anaerobic conditions and subsequently aerated, the polyphosphate-storing bacteria out-compete other organisms, proliferate and phosphate is taken up from the wastewater to create polyphosphate stores for new bacteria. Wasting a portion of activated sludge mass, including phosphate-rich bacteria, is the basis of BEPR process.

Major advantages of BEPR systems are:

- It produces less sludge compared to chemical phosphorus removal processes.
- It reduces the chemical addition and handling, thus avoiding reliance on chemicals.

- As against chemical sludge produced in chemical removal processes, the biological sludge produced in this process is appropriate for many options of disposal.

Some of the disadvantages are:

- Operation of BEPR system requires some fairly complex analysis and process adjustments to achieve optimal results.
- It is difficult to retrofit.
- There is a potential that a breakdown can result in release of significant quantities of phosphorus in the effluent. Therefore, they may need chemical back-up facilities.

4. Physicochemical Processes

4.1. Deep Bed Filtration for Wastewater Treatment and Reuse

Deep bed (or granular bed) sand filters have been used as the final clarifying step in municipal potable water treatment since the beginning of the century. Their use is becoming important in wastewater treatment in the tertiary treatment stage as effluent standards are becoming increasingly stringent as water use is envisaged. A large number of big building complexes in Japan have their own treatment facilities to reuse wastewater as flush water for toilets, air conditioning water and floor cleaning water. Many among them have adopted various modified forms of deep bed filtration as the final treatment step before reuse. Some prominent deep bed filtration process include:

- direct filtration
- contact—flocculation filtration
- mobile bed filtration
- floating media filtration.

4.1.1. Direct Filtration (DF)

In sewage treatment, the majority of the suspended solids, and the organics contributing to biochemical oxygen demand, are removed in the primary and biological (secondary) treatment stages. Removal of the remaining solids, organics and nutrients (nitrogen and phosphorus), is important if the water is to be reused. Laboratory-scale and pilot-scale studies indicated that direct filtration with prior flocculation is one of the methods to achieve superior solids and phosphorus removal.

Direct filtration refers to the flocculation for a short period followed by filtration without the sedimentation step (Figure 1). Successful advantages in direct filtration have been attributed to:

(i) the ability to produce filterable flocs;
(ii) the wide choice of filter media available; and
(iii) the use of arrangements which permit higher solids storage capacity in “in depth” filtration without excessive headloss development.

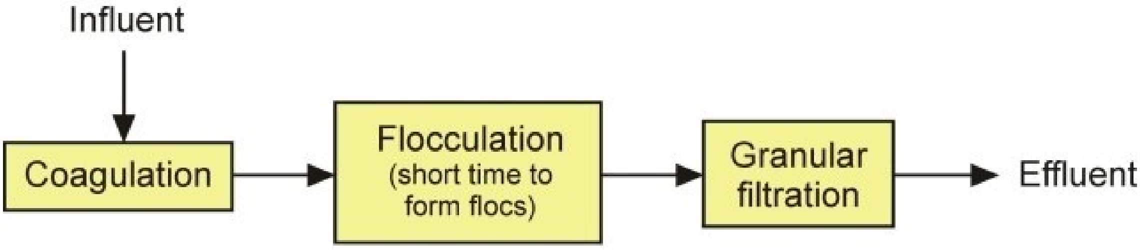

Figure 1. Process flow scheme of direct filtration

In DF, as the entire solid–liquid separation takes place in the filter itself, the floc size becomes very important. It is important to verify whether the flocs formed during the flocculation of short duration, is appropriate for filtration. In other words, one should choose the appropriate flocculation conditions (flocculation time and mixing intensity or velocity gradient) and flocculant types so that the flocs are of filterable floc size range not to clog the filter bed. Information is needed on the effects of flocculant dose, velocity gradient, flocculation time, filter medium type/size and depth, filtration velocity, and particle size and concentration in the influent with respect to floc size, density, aggregate structure and filter run.

4.1.2. Contact-flocculation Filtration (CFF)

In CFF, coagulation is followed immediately by filtration (Figure 2). In this process, both flocculation and solids separation take place directly within the filter media.

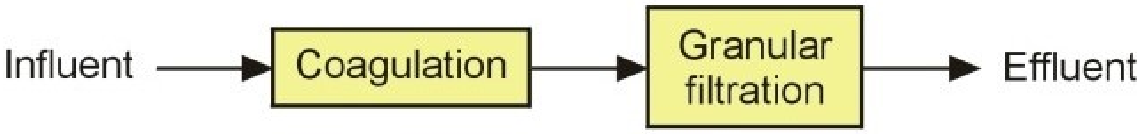

Figure 2. Process flow scheme of contact-flocculation filtration

A pilot-scale CFF study using both anthracite and granular sand as media (dual media) study conducted with the effluent from a secondary treatment in Sydney although giving reasonable removal efficiency, it led to high headloss development and significant decline in flow rate (84% after 24 hr filtration time).

Although the effluent phosphorus concentration was within standards, significant deterioration in bacteria and turbidity was observed at the end of 24 hr filtration.

Both DRF and CFF save capital costs since they eliminate most of the unit operations used in conventional treatment system. However, they suffer from the drawback that the filter becomes clogged rapidly and frequent backwashing is required.

To overcome this shortcoming, one could use either a mobile bed filter with CFF arrangement which incorporates continuous washing of sand prefilter, or a prefilter (such as a floating medium filter) with CFF arrangement.

4.1.3. Mobile Bed Filter (MBF)

Mobile bed filter normally operates on a continuous basis whereby sand media slowly falls down or moves up at an angle, depending on the filter design across which the wastewater passes (Figure 3). Wastewater flow direction can be upward or downward or radial depending on the design. As the suspended solids are removed, the sand gets dirtier until it reaches the bottom from where it is recycled by airlift or by hydraulic means, to a cleaning system at the top of the column. After washing, sand falls to the top to recommence its downward movement. In mobile bed filter, the most important operating parameters are the sand recycling and sludge withdrawal rates, which determine the removal efficiency and economy of operation of the filter.

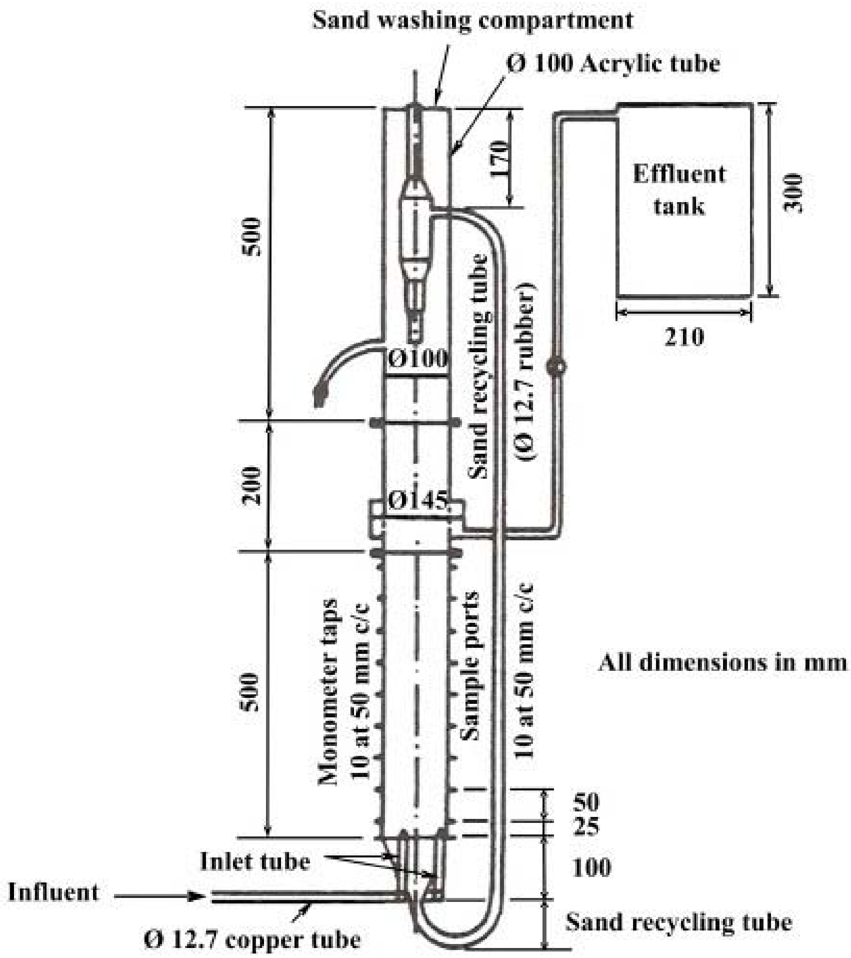

Figure 3. Sectional view of mobile bed filter

From the mobile bed filter experiments conducted, the sand recycle rate of 190 mL/min and sludge withdrawal rate of 160 mL/min were found to be the most effective giving the highest removal efficiency and steady performance. Headloss was higher for higher flow rate but still it was only 15 cm. There was no headloss development and it remained almost constant throughout the run indicating that it is economical to operate at a higher filtration rate thus saving capital cost.

Although a mobile bed filter produces an effluent of good quality with no headloss development, the use of an air compressor to recycle the sand to the top of the layer of filter medium results in an additional energy cost. Based on the results of a laboratory-scale study, a sample calculation was made to design a mobile bed filter for a small population of 250 people with per capita sewage production of 250 L/d. This calculation led to a daily energy requirement of 45 kWh per day. This cost is not high when compared to the amount of filtered water necessary for backwash in conventional sand filters (appropriately 3% of daily water production per each backwash). Further, a mobile bed filter is continuous in operation and requires very little or no supervision. A number of commercial mobile bed filtration units used in water treatment such as the Dynasand filter can be used successfully in wastewater treatment for reuse with modification.

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Biographical Sketches

H. H. Ngo is currently an Environmental Research Engineer and in charge of the Environmental and Public Health Engineering Laboratory in the Faculty of Engineering, University of Technology, Sydney (UTS), Australia. He has extensive experience in the field of water and wastewater treatment, especially in flocculation and filtration processes. He has been involved in more than 30 projects of research and consultant as a chief/co-investigator or associate investigator. He has published over 70 technical papers and authored two books and two book chapters. His research interests mainly focus on advanced water and wastewater treatment technologies, water quality monitoring and management, water environment impacts assessment and agro-waste management. In addition, Dr. Ngo worked for several years in Taiwan as lecturer/labs director and researcher, and gained experience in Thailand and Korea as visiting research fellow.

S. Vigneswaran is currently a Professor and Head of Environmental Engineering Group in Faculty of Engineering, University of Technology, Sydney, Australia. He has been working on water and wastewater research since 1976. He has published over 175 technical papers and authored two books (both through CRC press, USA). He has established research links with the leading laboratories in France, Korea, Thailand and the USA. Also, he has been involved in a number of consulting activities in this field in Australia, Indonesia, France, Korea and Thailand through various national and international agencies. Presently, he is coordinating the university key research strengths on “water and waste management in small communities”, one of the six key research centers funded by the university on competitive basis. Dr. Vigneswaran's research in solid liquid separation processes in water and wastewater treatment namely filtration, adsorption is recognized internationally and widely referred.

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