PROCESS ANALYSIS AND DESIGN OF ON-SITE AERATED WASTEWATER TREATMENT SYSTEMS

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Abstract

The collection, treatment and disposal of wastewater from single households by the use of on-site waste management systems is a prevalent feature in unsewered regions of Australia. Although simple systems such as septic tanks with trenching fields are still in use, increased environmental awareness has led to changes in the type of systems that are currently installed for on-site waste management. This paper deals mainly with one such system, i.e., the aerated wastewater treatment system (AWTS). In an AWTS, wastewater from a septic tank is further treated by bacterial populations which strive on oxygen. The types of AWTS available today are varied and can be categorised depending on how microorganisms are retained within the aeration tank. These categories are suspended growth, attached growth and hybrid systems. In a hybrid AWTS, microbial population, growing both in suspension as well on a fixed medium, is used for treating the wastewater. One of the aims of this paper is to describe and analyse various processes in an AWTS. The main emphasis of this paper however, is to present an analysis of the evaluation of parameters required for the design of the biological treatment in a hybrid AWTS. The evaluation showed that both hydraulic retention time (a design parameter of suspended growth systems), organic loading rate (of attached growth systems) and solids retention time (an operational parameter of suspended growth systems) play important roles in designing a hybrid on-site AWTS. The field data from the existing on-site systems is a rich source of performance information. These should be collected and analysed before setting up specific design criteria and standards for on-site hybrid AWTS.

Keywords

Aerated wastewater treatment systems, attached growth, disinfection, design parameters, hydraulic retention time, on-site, organic loading rate, solids retention time, suspended growth hybrid systems,

1 Introduction

In our modern society, the system of collecting wastewater from houses and treating it in a central treatment plant is well established in almost all major urban areas. History shows that this method of wastewater management first started when continuous water supply to a household made it possible to develop water closets and drainage systems to carry waste away (Van der Ryn, 1978). Wastewater collected from residences, and today also from industries, is treated by physical, biological and chemical means in centralised treatment plants before it is discharged into water ways. Recently, the reuse of wastewater and sludge, produced as a result of wastewater treatment, is becoming more common. In some parts of developed countries such as Australia, not every area is sewered and setting up a fully reticulated sewer system and a wastewater treatment plant may not always be an economical option. This is especially true if the density of human population is very low. In consequence on-site treatment and disposal of domestic wastewater from houses in rural areas or isolated communities is becoming a common feature. As the necessity to provide more on-site waste management systems grew, so did the development of a variety of systems. As Geary *et al*. (1998) indicates, almost 12% of Australian population uses some kind of on-site wastewater treatment system. In NSW currently there are over 250,000 systems (Hogan et al., 1998).

On-site treatment systems are required to collect, treat and dispose or reuse all the wastewater within the boundaries of the premises. There are numerous types of systems currently in use in Australia. Some of these are septic tanks, composting toilets, systems which use sand filters, and aerated wastewater treatment systems. The main concerns with on-site systems are their design, operation and maintenance, and disposal of treated wastewater and sludge.

Although there are many types of waste management systems, aerated wastewater treatment systems (AWTS) have become more popular in recent times in NSW, Australia. A complete AWTS is designed to divert and collect wastewater from all sections of a house, aerobically treat it and reuse it for irrigation. On-site AWTS usually follow the design of conventional systems used in large-scale treatment plants, such as activated sludge process, rotating biological filter or trickling filters. However, systems which have been modified by incorporating some changes in the biological system do not follow any particular design criteria.

The criteria for the design of most of the unit processes in an AWTS are well defined (AS 1547; 1998, Franceys, 1992; Dharmappa & Khalife, 1998). However, there are no criteria available for the design of modified biological treatment. This paper makes an attempt to tackle this problem and evaluate some design parameters which are suitable for modified biological systems. In this paper, though a description of process analysis of the whole system is given, the main emphasis is placed on the design of the biological process.

2. Aerated Wastewater Treatment Systems

Aerated wastewater treatment systems can be used to treat *all* the wastewater generated in a household. This includes blackwater (wastewater from the toilets) and greywater (wastewater from kitchen, bath, shower and laundry).

In aerated wastewater treatment systems (AWTS) wastewater is treated using a method which is a combination of different physical, biological and chemical processes. Depending on the type of pollutants removed, AWTS can be broadly categorised into (i) systems which remove organic pollutants and destroy pathogens and (ii) systems which also include the removal of nutrients (mostly nitrogen and phosphorus). In this paper, the design of the first category of system will be discussed.

2.1 Process aims

The treatment train in a typical AWTS can be divided into three stages: primary treatment, secondary treatment and tertiary treatment. Figure 1 shows a schematic of all three stages. Different stages of the system are designed to remove different pollutants (Table 1).

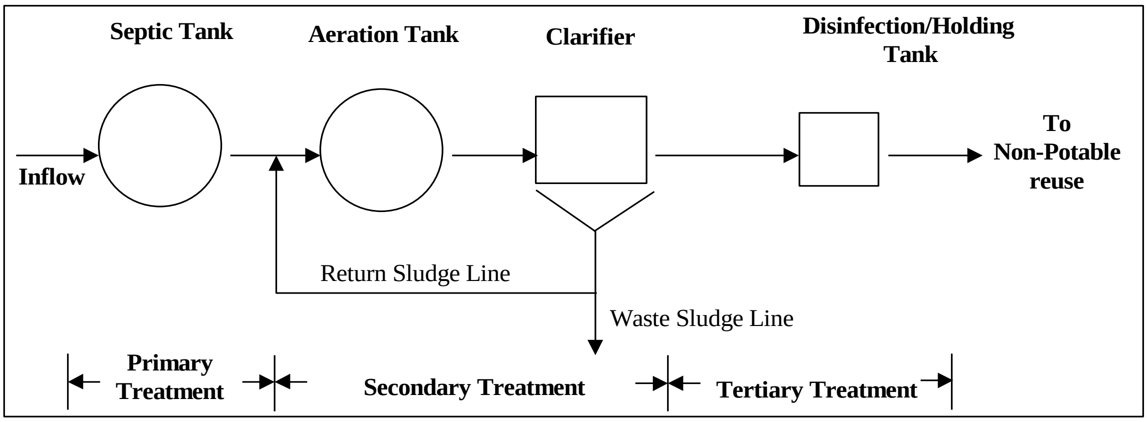

Figure 1. Schematic of processes in an aerated wastewater treatment system

2.2 Primary treatment

The raw wastewater from a household first enters the primary treatment stage and is high in solids, organic pollutants and pathogenic microorganisms. A single tank, conventionally called as a septic tank, is used for primary treatment. Though the main mechanism of treatment is sedimentation of all settleable solids, the outlet from the septic tank is designed so as to segregate and capture all floatable solids. Septic tanks are also designed to store solids for a certain period of time. As the septic tank is air tight, anaerobic bacteria grow and thrive in the accumulated solids. These anaerobic bacteria help in stabilising the sludge over a period of time. Typically a vent is provided to scrub-of the odorous gases produced during anaerobic stabilisation process.

Table 1. Process aims of different treatment steps in an on-site AWTS

Pollutant removed or altered	Primary Treatment	Secondary Treatment	Tertiary Treatment
Floatable organic solids	ŏ	ŏ	✕
Settleable organic solids	ŏ	ŏ	✕
Dissolved organic solids	✕	ŏ	ŏ
Change in pH	✕	ŏ	ŏ
Change in dissolved oxygen	✕	ŏ	ŏ
Nitrification	✕	ŏ	✕
Denitrification	✕	✕	✕
Sludge production	ŏ	ŏ	✕

2.3 Secondary treatment

After the primary treatment, wastewater, devoid of settleable and floatable solids, then undergoes secondary treatment. This stage of treatment consists of two distinct steps: biological aerobic degradation of dissolved organic solids in an aeration tank followed by the clarification of the wastewater to settle out microorganisms. The biological process of the system is aerobic; oxygen being one of the essential components. Based on the type of bacterial growth and the aeration method used in the secondary treatment, AWTS can further be divided into the following categories: (i) Suspended growth systems, (ii) Attached growth systems and (iii) Hybrid systems. Figure 2 shows a schematic of all three types of systems:

(i) Suspended growth systems: These are AWTS where air is artificially introduced into the system to both provide oxygen and keep microorganisms suspended in the wastewater. Some of the examples of these systems include the activated sludge process and the aerated lagoon systems. In an on-site system, the main advantage of using a well designed suspended growth system is its process control and the use of less land area. These systems however, cannot withstand shock loads in terms of variable flow rates. Moreover, the main operating problem associated with this system is retaining microbiological solids within the aeration tank. Often, the failure of this system is due to the washout or settlement of biological solids, which leads to decreased rates of degradation of organic matter.

(ii) Attached growth systems: These systems are designed in such a way that inert media such as rock, glass or plastic is used to support the growth of microorganisms. Here microorganisms, growing as a biomass layer on the medium, rely on the natural flow of air within the pores of the medium for their oxygen supply. Some examples of this type of system are the trickling filters used in centralised wastewater treatment plants or the intermittent or recirculating granular medium filters used in on-site wastewater treatment (Rich et al., 1995). Although it is possible to provide for the highest possible retention of microorganisms within the reactor, this system however, has been proven to yield low removal efficiency. This is due to insufficient contact provided between microorganisms and organic matter.

(iii) Hybrid systems: There are systems where bacteria are allowed to grow both in suspension and on a fixed medium. In most of the on-site AWTS currently in operation, the growth medium is usually immersed in a tank full of wastewater. For systems such as these, artificial aeration is required for two purposes: (a) to provide oxygen to the suspended microorganisms and to those growing on the support medium and (b) to aid in suspending the microorganisms in the wastewater. If designed well, these hybrid systems can combine the positive aspects of both suspended and attached growth systems while eliminating the problems associated with both suspended and attached growth systems. These systems can be designed to handle shock loads with minimum maintenance requirement.

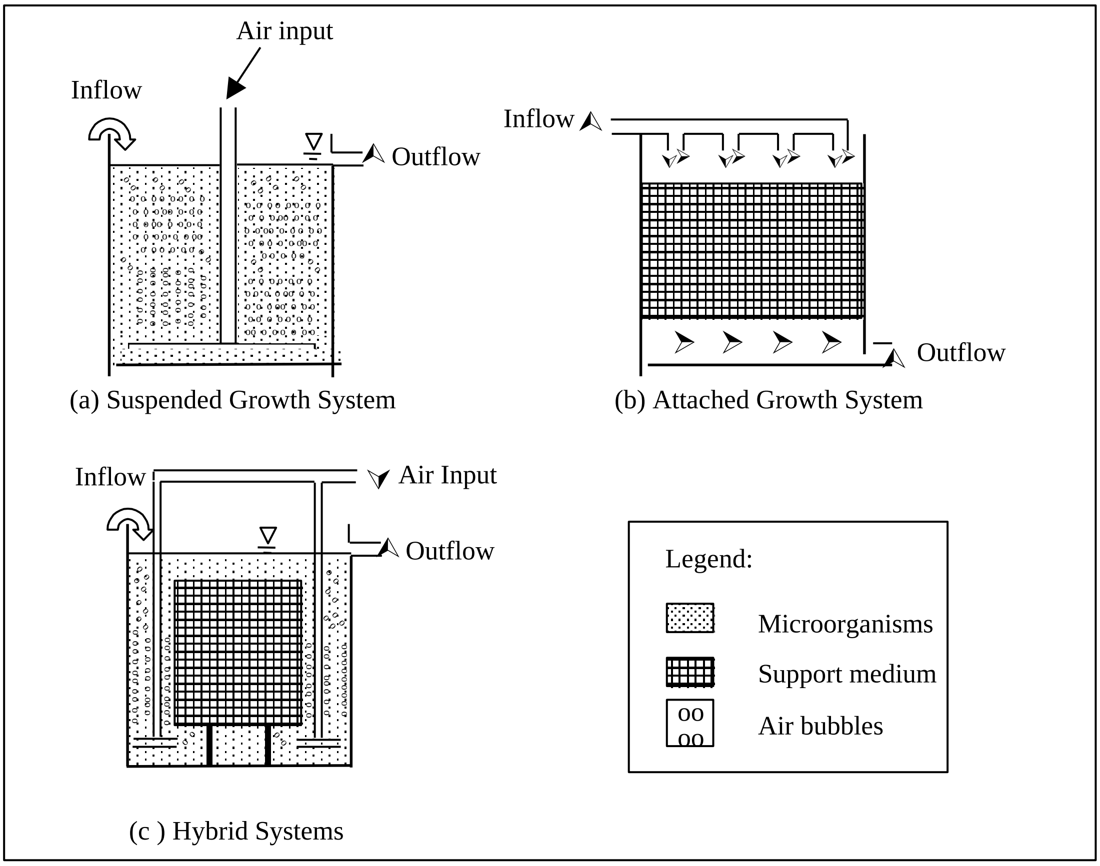

Figure 2. Schematic of different types of secondary treatment in AWTS

Design considerations:

Taking into account the design aspects of well established suspended and attached growth systems, an attempt will be made in this section of the paper to discuss the design aspects of hybrid AWTS. Relationships exist between the complex microbial kinetics and the design of biological processes. In this paper, an attempt is made to explain the design in simple and easy to understand terms.

While designing a biological process the most important parameters to consider are: the design flow, concentration of dissolved organic solids in terms of BOD_5, the concentration of microorganisms, the volume of the aeration tank and the amount of air supplied.

Design of the aeration tank for suspended growth systems:

In a suspended growth system the design principles of an extended aeration process have been adopted. In this process it is aimed to achieve a high BOD removal and as well as some level of nitrification. Here, the volume of the aeration tank is designed by taking into account two parameters: organic loading rate or food to microorganism ratio and hydraulic retention time.

The *organic loading rate* is the ratio of mass of BOD entering the tank/day to the total mass of microorganisms (as mg/L of MLVSS) in the aeration tank.

$$\text{Organic loading rate or F/M} = \frac{\text{Mass of BOD entering the aeration tanks in a day}}{\text{Total mass of microorganisms under aeration}}$$

In terms of normal design variables,

$$F/M = \frac{Q \times BOD_5}{V \times MLVSS} \qquad \text{Equation 1.}$$

where Q = total wastewater flow, L/d
BOD_5 = 5 day BOD, kg/L
V = volume of the aeration tank, L
MLVSS = mixed liquor volatile suspended solids (microorganisms concentration), kg/L

The values for typical F/M ratio range from 0.05 to 0.15 kg BOD_5/kg MLVSS.d. In this type of a system, it is very important to maintain a high concentration of microorganisms in the aeration tank. This is achieved by partially returning the settled sludge from the clarifier to the aeration tank and partially wasting the sludge. In a well designed system, the MLVSS concentration in the aeration tank should be as high as 2400 - 4800 mg/L. Recent surveys of on-site AWTS with suspended growth systems showed that the MLSS (mixed liquor suspended solids) concentrations are as low as 45 mg/L (Dharmappa & Khalife, 1998). This can lead to inefficient performance of the overall system.

Hydraulic retention time (HRT) in suspended growth systems is the ratio of volume of the tank to total flow and has a typical value of 24-36 hours for extended aeration process (Tchobanoglous, 1991). Higher retention times can lead to higher aeration tank volumes. If it is required to treat wastewater so as to allow only the biological degradation of organic matter, a lower HRT (4-8 hours) in the aeration tank would be sufficient to achieve this.

Design of the aeration tank for attached growth systems:

In an attached growth system, since the bacteria grow on a support medium it is very difficult to obtain a simple measure of total microorganism concentration or MLVSS in the system. *Organic loading rate* is therefore defined as:

$$\text{Organic loading rate} = \frac{\text{Kg of BOD/d}}{\text{Volume of media}} = \frac{Q \times BOD}{A \times H} \qquad \text{Equation 2.}$$

where Q = flow, m^3/d,
BOD = BOD value in kg/m^3,
A = surface area, m^2 and
H is the depth of the tank, m.

Typical organic loading rates are 0.5 - 1.6 kg/m^3.d .

The *hydraulic loading rate* (a ratio of flow to the cross-sectional area of the tank) is also an important parameter, which can vary from 12-70 m^3/m^2.d (Tchobanoglous, 1991). Attached growth secondary systems, though very efficient in withstanding shock loads, require very low hydraulic loading rates and large surface areas.

Design of the aeration tank for hybrid systems:

In a hybrid system, microorganisms exist in suspended and attached modes. It is therefore important to consider the design parameters of both the above systems. The following is the result of a preliminary analysis carried out to determine appropriate aeration tank volume for a known design flow. If F/M ratio of suspended growth systems is considered, it is not possible to arrive at a design volume because it is difficult to determine a value for constant biomass concentration. If the hydraulic loading rate of an attached system is considered, it would yield a very small tank volume. For example, for a design flow of 2000 L/d, considering an average HLR of 41 m^3/m^2.d and a depth of 1.5 m, the volume of the aeration tank will be only 73 L.

Other two parameters to consider are HRT of suspended growth systems and organic loading rate of attached growth systems. For a HRT of 8 hours, the design volume is 670 L. If an average organic loading rate of 1.05 kg/m^3.d is considered, for a system with an average BOD5 of 300 mg/L and a flow of 2000 L/d, the volume of the tank will be 571 L.

From the above discussion, it is apparent that HRT of suspended growth systems and organic loading rates of attached growth systems yield approximately similar values for the aeration tank volume. From this preliminary analysis it appears that these two parameters should be considered while designing the aeration tank volume. However, the surface area of the support media and the amount of biomass that can be supported, are not included in either of the above parameters. As such the design cannot depend solely on these two parameters. It is very important to develop specific design parameters which would take into account the complete configuration of a hybrid system.

For efficient operation of the system, field investigations showed that a constant biomass concentration should always be maintained in the suspended part of the aeration tank. This can be achieved by recycling viable biomass to the aeration tank. Studies conducted by Hazlewood (1999) showed that the MLVSS concentration of only the suspended growth part in a hybrid system could be as low as 60 mg/L.

Design of the clarifier for all types of AWTS:

The sedimentation tank or clarifier, which follows the aeration tank, is a part of the secondary treatment. Proper design of a clarifier is important for the overall performance of the system. The design of the clarifier should be such that:

- adequate time is provided for settling the biomass exiting the aeration tank;
- any biological activity is avoided; and
- floatable solids and other matter can be easily removed.

2.4 Tertiary treatment

In a typical sewage treatment system, disinfection is considered to be a part of tertiary treatment where additional BOD removal and disinfection are achieved. It should, therefore, be noted that tertiary treated wastewater is not potable; it can only be reused for non-potable purposes such as irrigation.

Proper disinfection should destroy all pathogenic and other harmful organisms in secondary treated wastewater. Chlorine, UV and ozone are popular disinfectant agents for on-site treatment systems. Since chlorine is cheaper and very effective in the destruction of pathogenic and other harmful organisms, it still is a popular disinfectant agent (WEF & ASCE, 1991)

Disinfection chambers are designed taking into account the following: (1) the chlorine demand of the wastewater; (2) chlorine contact time; and (3) chlorine residual concentration. Typical values for the chlorine demand of secondary treated wastewater in an on-site AWTS can be 4 - 10 mg/L (Crites & Tchobanoglous, 1998). This can leave chlorine residual concentration of 0.5 - 2 mg/L at a detention time of 15-45 minutes.

Chlorine, being a very powerful oxidising agent, oxidises the soluble organic matter still present in the wastewater after secondary treatment. Studies showed that typically 2 kg of chlorine could reduce one kg of BOD (White, 1986; Crites & Tchobanoglous, 1998). Studies conducted by Hazlewood (1999) showed that an additional 30-40% BOD removal can be achieved in the disinfection chamber of an on-site AWTS.

3 Conclusions

On-site waste management systems not only treat wastewater generated in a household, but also allow for reusing some of the wastewater for non-potable purposes such as irrigation. This, along with an increased awareness in the community for saving natural resources has made the use of on-site waste management systems become more popular. Over the years, the aerated wastewater treatment systems have taken precedence over all other types of systems. In an AWTS, the output from a conventional septic tank is further treated in a two-stage process, both to remove oxygen demanding substances and also to destroy pathogenic and other harmful organisms in the wastewater. In Australia, especially in NSW, though AWTS initially consisted of a biological system where microorganism were suspended, it quickly changed to a hybrid system where additional media is provided for supporting microorganism growth. The evolution of such systems was mainly based on the valuable experience gained through field trail and error methods. Though guidelines and criteria are well established for designing septic tanks, clarifiers, disinfection/irrigation chambers and irrigation systems, no criteria have been developed for hybrid biological treatment systems (aeration tanks).

In this paper an attempt was made to identify some variables which can be used to design aeration tanks for hybrid systems which can perform effectively. The evaluation provided is only an initial attempt to determine the design criteria for hybrid systems. The current use of different types of on-site hybrid systems presents an opportunity for collecting field data. These data are useful in correlating design criteria to the performance of each type of system. Further research and theoretical analysis will enable researchers to define specific criteria for these hybrid systems, which can then be used by regulatory authorities to set proper standards.

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