WASTEWATER STABILIZATION PONDS (WSP) FOR WASTEWATER TREATMENT

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Contents

Summary

Many industrialised countries have achieved high levels of wastewater treatment technologies most of which are too mechanized and automated and beyond the affordability of the poor and developing nations. Technologies that are appropriate to the developing nations are required since two third of world's population live in developing countries.

This review focuses mainly on those technologies appropriate to the developing countries. Appropriate technology should be affordable (capital cost), have low O&M cost (sustainability), effective in meeting the discharge standards, at least nuisance (public acceptability) and is environment-friendly.

Many low cost technologies are being developed but the choice of the most appropriate technology depends on a proper evaluation of all the factors such as economic, political, social, availability, etc. Wastewater Stabilization Ponds (WSP) have been extensively used worldwide because of the simplicity in design and construction, the low capital and operating cost, are very reliable and are a sustainable technology.

Constructed wetlands not only treat wastewater but have other functions such as habitats for animals and birds, recreational areas for the visitors, etc. Other low cost technologies appropriate to developing countries such as land treatments, filtration techniques, attach growth, aeration, baffled reactor and chemically enhance primary treatment are also discussed.

1. Introduction

Wastewater Stabilization Ponds (WSP) or facultative ponds or lagoons are used to treat municipal and industrial wastewater all over the world. WSP are often thought of as being suitable only in the developing countries yet there are about 2500 pond systems in France, 1100 in Germany and 39 in UK (Mara, 2003).

The technology associated with lagoons has been in widespread use in the United States for at least 90 years, with more than 7,000 facultative lagoons in operation today (US EPA, 2002b).

WSP are suitable for low-income countries because of its low cost and where conventional wastewater treatment is not suitable due to the lack of resources. Further, the advantage of these systems, in terms of removal of pathogens, is one of the most important reasons for its use.

WSP systems consist of single series of anaerobic, facultative and maturation ponds, or several series in parallel. The pond system can be used alone but usually they are used in combination with each other. Figure 1 (Pescod and Mara, 1988) shows different pond combinations.

Anaerobic and facultative ponds are mainly designed for BOD removal and maturation ponds mainly for pathogen removal (Mara and Pearson, 1998). In many cases anaerobic ponds and facultative ponds are enough for wastewater treatment but depending on the destination of effluent the maturation ponds are provided for further polishing purposes.

In some cases facultative ponds are provided without anaerobic ponds. In general maturation ponds are required only when the treated wastewater is to be used for unrestricted irrigation and has to comply therefore with the WHO guideline of <1000 faecal coliforms per 100 ml, and when stronger wastewaters (BOD >150 mg/l) are to be treated prior to surface water discharge (Mara and Pearson, 1998).

Restricted irrigation refers to the irrigation of industrial crops, such as cotton and sunflower, and food crops that are processed or cooked prior to consumption, such as wheat, potatoes and many other vegetables. Unrestricted irrigation covers food crops eaten uncooked, such as salad crops.

Usually there are odour problems associated with the anaerobic ponds but its inclusion substantially reduces the land area required for facultative ponds. Odour problem can be reduced if properly taken into account during the design stage.

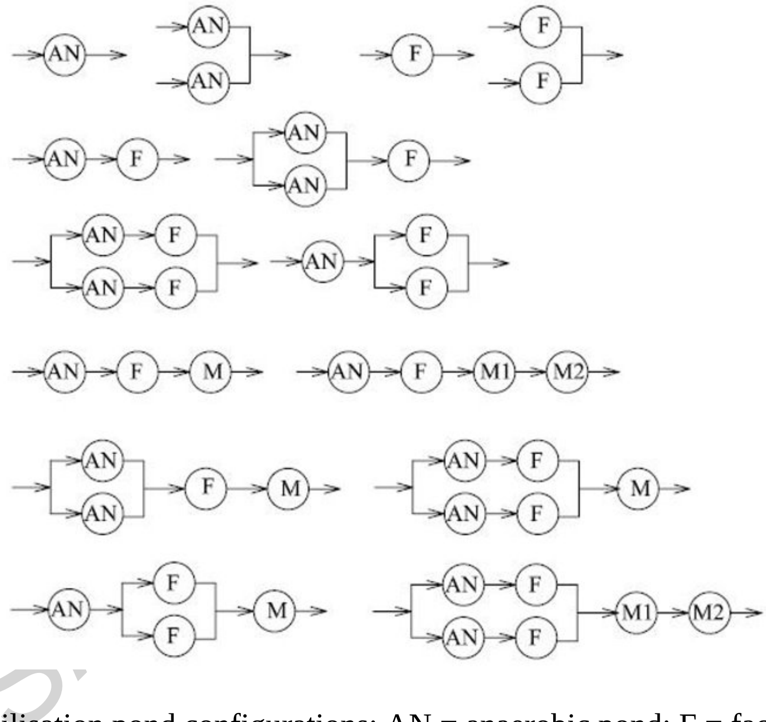

Figure 1: Stabilisation pond configurations: AN = anaerobic pond; F = facultative pond; M = maturation pond

2. Advantages and Disadvantages of WSP

The advantages of WSP include:

- Simplicity in design and construction
- Low production of biological sludge
- Low capital, operation and maintenance cost

- High treatment efficiency if properly designed
- Robust and relatively reliable
- Less sensitive to shock loading

The disadvantages of WSP include:

- Large land requirement for the ponds
- Sludge accumulation will be higher in cold climates due to reduced microbial activity (US EPA, 2002b)
- Mosquitoes and other insects can breed if vegetation is not controlled
- If not designed properly may cause odour problem
- Difficult to control or predict ammonia levels in effluent (US EPA, 2002b)

A comparison of WSP with other technologies is given in Table 1(Ramadan and Ponce, 2003)

3. Types of WSP

The ponds are classified as:

- Anaerobic ponds
- Facultative ponds
- Maturation ponds
- Fully aerated ponds
- Partially aerated ponds
- Controlled discharge ponds
- Complete retention ponds
- Hydrograph controlled release

Anaerobic, facultative and maturation pond are more commonly adopted and are generally not aided by any mechanical devices. These three are described in detail. The design features are presented in Table 2 (Reed *et al.*, 1995).

	Criteria	Package plant	Activated sludge plant	EAAS	Biological filter	Oxidation ditch	Aerated lagoons	WSP system
Plant performance	BOD removal	Fair	Fair	Fair	Fair	Good	Good	Good
	SS removal	Fair	Good	Good	Good	Good	Fair	Fair
	FC removal	Poor	Poor	Fair	Poor	Fair	Good	Good
	Helminth removal	Poor	Fair	Poor	Poor	Fair	Fair	Good
	Virus removal	Poor	Fair	Poor	Poor	Fair	Good	Good
Economic factors	construction simplicity & cost	Poor	Poor	Poor	Poor	Fair	Fair	Good
	Land requirement	Good	Good	Good	Good	Good	Fair	Poor
	Operational simplicity	Poor	Poor	Poor	Fair	Fair	Poor	Good
	Maintenance costs	Poor	Poor	Poor	Fair	Poor	Poor	Good
	Energy demand	Poor	Poor	Poor	Fair	Poor	Poor	Good
	Sludge removal costs	Poor	Fair	Fair	Fair	Poor	Fair	Good

BOD: Biological oxygen demand, FC: Faecal coliform, SS: suspended solids, WSP: Wastewater stabilization ponds, EAAS: Extended aeration activated sludge

Table 1**:** Advantages and disadvantages of various wastewater sewage treatment systems.

3.1 Anaerobic Ponds

In anaerobic ponds large concentration of organic and inorganic solids in wastewater is stabilized and the biological activity occurs in the absence of oxygen and in the process produce methane gas and sulphur containing malodrous gases. The anaerobic ponds are the smallest of the series and are used as a primary treatment process and not necessarily to produce the high effluent quality. The BOD and solids concentration in the raw wastewater are reduced by sedimentation and anaerobic digestion. Since anaerobic pond is devoid of oxygen, it functions much like open septic tanks (Mara, 2003). Anaerobic digestion occurs in the sludge at the bottom of the pond which results in converting organic load to methane and carbon dioxide and releasing some soluble by-products into the water column (eg. organic acids, ammonia). Anaerobic treatment is more suited to wastewater with high BOD (IETC-UNEP, 2002) and therefore useful at reducing high concentrations of BOD and SS from agricultural and food processing wastewater. The chemical reactions occurring in the anaerobic ponds can be represented by the following equations (Crites *et al.*, 2006).

$$5(CH_2O)_x \rightarrow (CH_2O)_x + 2CH_3COOH + \text{Energy}$$

$$2CH_3COOH + 2NH_4HCO_3 \rightarrow 2CH_3COONH_4 + 2H_2O + 2CO_2$$

$$2CH_3COONH_4 + 2H_2O \rightarrow 2CH_2 + 2NH_4HCO_3$$

A properly designed anaerobic pond can achieve around 60% BOD removal at 20° C and one-day hydraulic retention time is sufficient for wastewater with a BOD of up to 300 mg/l and temperatures higher than 20° C (Mara, 2003).

At temperatures below 15^oC, the digestion processes slows down and the dominant process is thought to be sedimentation (Mara and Pearson, 1998). Anaerobic ponds are usually more than 2 m deep for sludge storage capacity. The hydraulic retention time depends on the volumetric BOD loading required ($g/m^3.d$) and can be up to 20 days (WEF, 2006). They reduce the problems associated with sludge accumulation and solids feedback in a following facultative pond. The high efficiency of BOD removal combined with the partial mineralisation of organics experienced in an anaerobic pond allows for smaller subsequent ponds thereby reducing the overall land requirements (Mara and Mills, 1994). The major problem of anaerobic ponds are the odour and the increase in ammonia and sulphide concentrations caused by the anaerobic processes (Mara and Pearson, 1998; Crites *et al.*, 2006). Besides BOD, COD and SS removal, anaerobic pond is efficient in the removal of *Vibrio cholerae* due to their high sulphide concentrations (Mara *et al.*, 2001). WSP system can be constructed without anaerobic ponds (Reed, 1995; US EPA, 2002b; Crites *et al.*, 2006) but their provision not only stabilizes the organic concentrations of wastewater but also reduces the land area required for the facultative ponds (Mara *et al.*, 2001).

3.2 Facultative Ponds

Facultative ponds are either primary facultative ponds that receive raw wastewater or secondary facultative ponds that receive settled wastewater effluent from anaerobic ponds. They are designed for BOD removal on the basis of a relatively low surface loading (100-400 kg BOD/ha d at temperature between 20°C and 25°C) to permit the development of a healthy algal population as the oxygen for BOD removal by the pond bacteria is mostly generated by algal photosynthesis (Mara and Pearson, 1998). The appearance of dark green colour in the ponds indicates the presence of algae (such as *Chlamydomonas*, *Pyrobotrys* and *Euglena*) but sometimes they may appear red or pink due to the presence of anaerobic sulphide-oxidizing photosynthetic bacteria. Facultative pond is the most common type used in the US and in different terms such as oxidation pond, sewage lagoon and photosynthetic pond (Reed *et al.*, 1995). The water layer near the facultative pond surface contains dissolved oxygen due to atmospheric reaeration and algal respiration, a condition suitable for aerobic and facultative organisms. The sludge deposits at the bottom of the pond support anaerobic organisms while the intermediate anoxic layer, termed as facultative zone ranges from aerobic near the top to anaerobic at the bottom. These layers may persist for long periods due to temperature-induced water density variations (US EPA, 2002b). Inversions can occur in the spring and fall when the surface water layer may have a higher density than lower layers due to temperature fluctuations. This higher density water sinks during these unstable periods, creates turbidity, and produces objectionable odours (US EPA, 2002b).

The presence of algae in the aerobic and facultative zones is essential for the successful performance of facultative ponds (US EPA, 2002b). In sunlight, the algal cells utilise CO_2 from the water and release O_2 produced during photosynthesis. The oxygen, produced by algae and surface reaeration, is used by aerobic and facultative bacteria to stabilise organic material in the upper layer of water. As a result of the photosynthetic activities of the pond algae, there is a diurnal variation in the concentration of dissolved oxygen. After sunrise, the dissolved oxygen level gradually rises, in response to photosynthetic activity, to a maximum in the mid-afternoon, after which it falls to a minimum during the night when photosynthesis ceases and respiratory activity consumes oxygen. The position of the oxypause (the depth at which the dissolved oxygen concentration reaches zero) similarly changes, as does the pH since at peak algal activity carbonate and bicarbonate ions react to provide more carbon dioxide for the algae, so leaving an excess of hydroxyl ions with the result that the pH can rise to above 9 which kills faecal bacteria (Mara and Pearson, 1998). This also creates conditions favourable for ammonia removal via volatilisation (US EPA, 2002b).

Anaerobic fermentation occurs at the bottom layer of the lagoon. In cold climates, oxygenation and fermentation reaction rates are significantly reduced during the winter and early spring and effluent quality may be reduced to the equivalent of primary effluent when an ice cover persists on the water surface (US EPA, 2002b). Figure 2 (Metcalf and Eddy, 1995) and Figure 3 (Mara and Pearson, 1998) shows the schematic representation and mutual relationships within the WSP systems of treatment.

Technology	**Treatment goal**	**Climate needs**	**Detention Time (days)**	**Depth (m)**	**Organic Loading (kg/ha. day)**	**Effluent Characteristics (mg/l)**
Oxidation pond	Secondary	Warm	10-40	1 - 1.5	40 – 120	BOD=20-40

						TSS=80-140
Facultative pond	Secondary	None	25-180	1.5 - 2.5	22 – 67	BOD=30-40 TSS=40-100
Partial mixed Aerated pond	Secondary, Polishing	None	7-20	2 - 6	50 – 200	BOD=30-40 TSS=30-60
Storage pond, HCR pond	Secondary, storage, polishing	None	100-200	3 - 5	22 – 67	BOD=10-30 TSS=10-40
Root zone Treatment, Hyacinth pond	Secondary	Warm	30-50	<1.5	<30	BOD <30 TSS <30

Table 2: Design features and expected performance for aquatic treatment units

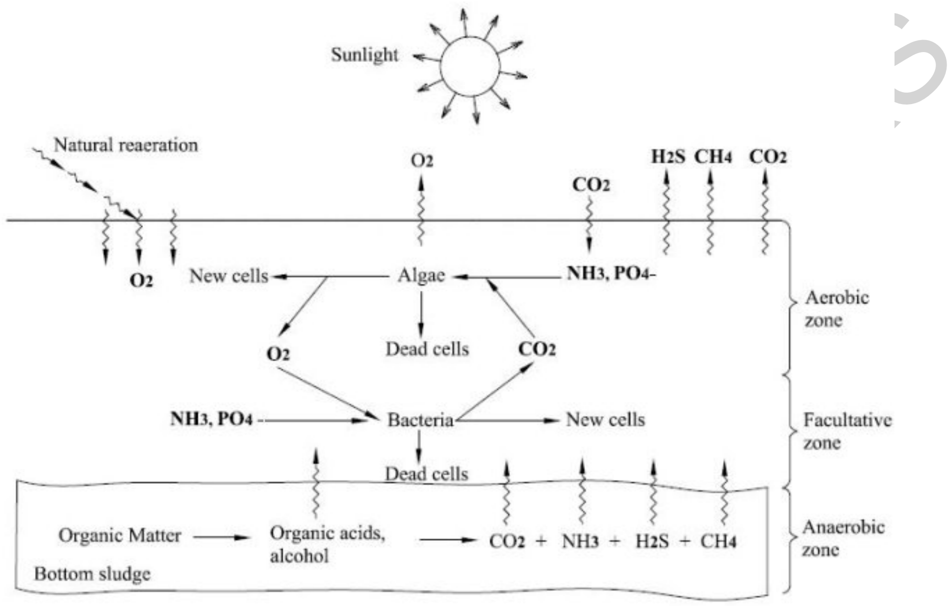

Figure 2: Schematic representation of facultative Ponds

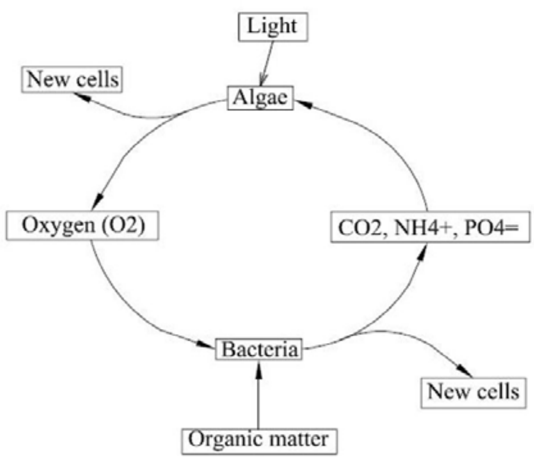

Figure 3**:** Mutual relationship between pond algae and bacteria

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Dr H.K. Shon is currently a UTS Chancellor’s postdoctoral research fellow since 2006. His research interests include membrane processes and new analytical methods for wastewater treatment and reuse. He has made significant contributions to the understanding of membrane fouling in wastewater treatment processes. He has published over 100 technical papers since 1999. His research activities on membrane fouling are documented in leading Journals such as Environmental Science and Technology, Critical Review in Environmental Science and Technology, Water Research, Journal of Membrane Science, Desalination and American Institute of Chemical Engineers Journal. He received Best Paper/Presentation Awards on four different occasions related to environmental fields. His paper published in Journal of Membrane Science in 2004 (Shon et al., vol. 234, pp. 111-120) was selected as Top 25 Hottest Articles in the field of chemical engineering. In 2006, he was awarded the winner of the Water Environment Merit Award (WEMA), given to a corporate member of the Australian Water Association (AWA) who has made a significant contribution or has been responsible for a major project of benefit to the industry, community or environment. In 2007, he has been awarded ‘The Chancellor’s Award’, for the most outstanding PhD thesis at University of Technology, Sydney.

Dr S. Vigneswaran has been working on water and wastewater treatment and reuse related research since 1976. During the last twenty years, he has made significant contributions in physico-chemical water treatment related processes such as filtration, flocculation, membrane-filtration and adsorption. His research activities both on new processes development and mathematical modeling are well documented in reputed international journals such as Water Research, American Institute of Chemical Engineers Journal, Chemical Engineering Science, Journal of American Society of Civil Engineers, and Journal of Membrane Science. He has also been involved in a number of consulting activities in this field in Australia, Indonesia, France, Korea, and Thailand through various national and international agencies. He has authored two books in this field at the invitation of CRC press, USA, and has published more than 230 papers in journals and conference's proceedings. Currently a Professor of the Environmental Engineering Group at the University of Technology, Sydney, he was the founding Head of and the founding Co-ordinator of the University Key Research Strength Program in Water and Waste Management. He is coordinating the Urban Water Cycle and Water and Environmental Management of the newly established Research Institutes on Water and Environmental Resources Management and Nano-scale Technology respectively.

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