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Chapter 10
Waste Stabilization Ponds: A Highly Appropriate Wastewater Treatment Technology for Mediterranean Countries

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Abstract This chapter describes waste stabilization pond (WSP) systems for wastewater treatment. WSP systems comprise a series of anaerobic and facultative ponds and sometimes maturation ponds. Rock filters can be used instead of maturation ponds and they can be aerated to remove ammonia and to improve biochemical oxygen demand and suspended solids removals. Effluent quality is high, and properly designed and well maintained WSP systems produce effluents that can be safely used for both restricted and unrestricted crop irrigation.

10.1. Introduction

Waste stabilization pond (WSP) systems are a high-performance, low-cost, low-energy (often zero-energy) and low-maintenance wastewater treatment process, especially suitable in warm climates.

There are three principal types of WSP systems: anaerobic, facultative and maturation (Figures 10.1 to 10.3).[1] These different types of ponds are arranged in

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[1]Other types of WSP exist; for example, high-rate or “advanced” algal ponds and macrophyte ponds, but these are not recommended for normal municipal usage (see Mara and Pearson, 1998).

Figure 10.1 An anaerobic pond in Cyprus treating wastewater from a slaughterhouse

Figure 10.2 Partial view of a facultative pond in southern France treating domestic wastewater

Figure 10.3 Maturation ponds in northern France

series; at any one site there is usually more than one series, with each series comprising an anaerobic pond followed by a facultative pond and, depending on the effluent quality required, by one or more maturation ponds. Rock filters (RFs) are a land-saving alternative to maturation ponds (Section 10.2.2).

10.1.1. WSP System Usage in Mediterranean Countries

WSP systems are widely used in France where there are more than 2,500 systems, each typically comprising a facultative pond (sized at 6 m^2 per person) and two maturation ponds (each 2.5 m^2 per person; Cemagref and Agences de l'Eau, 1997; Racault and Boutin, 2005). They are also used in Portugal, Spain, Greece, Israel, Jordan, Egypt, Algeria and Morocco (i.e., in virtually every Mediterranean country; details in Mara and Pearson, 1998). In Greece, WSP systems were found to be the cheapest treatment process up to the land price of USD 300,000 per ha (Tsagarakis et al., 2003).

10.1.2. Advantages of WSP Systems

Cost is the most important advantage of WSP systems: they are almost always the cheapest form of wastewater treatment to construct and to operate (Table 10.1 gives costs in France for WSP and five other treatment processes; see also Arthur, 1983). They are also very easy to operate and maintain: there is no electromechanical machinery and only unskilled labor is required to perform very simple tasks (see Section 10.3). The oxygen required by the pond bacteria to oxidize the wastewater BOD is supplied by the micro-algae that grow naturally and profusely in facultative and maturation ponds (Figure 10.4).

10.1.3. Perceived Disadvantages of WSP Systems

WSP systems are commonly thought (especially by those selling energy-intensive electromechanical wastewater treatment systems, such as activated

Table 10.1 Capital and operation and maintenance costs of various wastewater treatment processes for a population of 1,000 in France in 1997

Treatment process	Capital costs (ECU per person)*	O&M costs (ECU per person per year)*
Activated sludge	230	11.50
Trickling filter	180	7.00
Rotating biological contactor	220	7.00
Aerated lagoon	130	6.50
Vertical-flow constructed wetland**	190	5.50
Waste stabilization ponds	120	4.50

*Average exchange rates in 1997: 1 ECU = GBP 0.69 = USD 1.17 (www.oanda.com/convert/fxhistory).
**Two-stage vertical-flow constructed wetland receiving raw wastewater.
Note: All processes designed to produce effluents complying with French regulations (see Alexandre et al., 1997; Racault and Boutin, 2005).
Source: Alexandre et al., 1997.

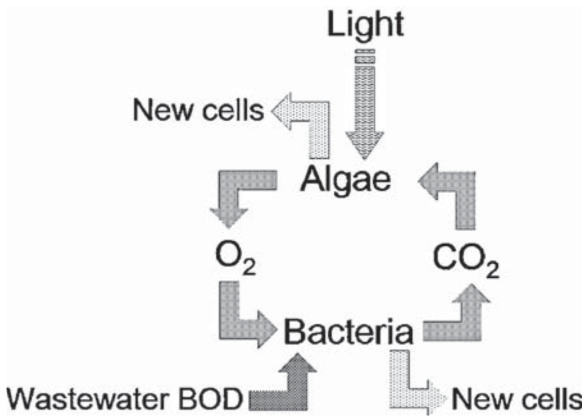

Figure 10.4 Algal-bacterial mutualism in facultative and maturation ponds

sludge) to require excessive areas of land, to be unable to produce satisfactory effluents (especially in terms of their suspended solids [SS] concentrations due to the algae present), to generate odors and to lose too much water by evaporation.

10.1.3.1. Land Area Requirements

Although it is true that WSP systems require considerably more land than energy-intensive processes such as activated sludge, this is not a disadvantage in countries with large areas of unused land (e.g., Jordan is >90% desert). Furthermore, it should be realized that land purchased for WSP systems is an investment, whereas the money spent on electricity for energy-intensive processes is money gone forever.

10.1.3.2. Effluent Quality

In the European Union, WSP system effluent requirements are 25 mg filtered BOD or less and 150 mg SS or less per liter (Council of the European Communities, 1991) This quality is achieved by a facultative pond loaded at 80 kg BOD ha^{-1} day^{-1}, which is the design loading for winter temperatures of 8 °C and below (Abis and Mara, 2003). Often, however, the local environmental regulator sets a higher standard than this and, therefore, either maturation ponds or RFs are required. Maturation ponds have lower algal biomass concentrations than facultative ponds, which decrease along a series of maturation ponds. As noted in Section 10.2.2, the effluent quality achieved by aerated RFs is very high and can be expected to satisfy even the most stringent regulator.

10.1.3.4. Odor

WSP systems, provided they are correctly designed and operated and maintained properly, do *not* cause odor. To avoid odor release from anaerobic ponds, the sulphate concentration in the raw wastewater should be less than 500 mg SO_4 L^{-1} (Gloyna and Espino, 1969); this is rarely a problem as the maximum permissible sulphate concentration in drinking water is 250 mg SO_4 L^{-1} (World Health Organization, 2003) and, although the sulphate concentration in wastewater is higher than that in the drinking water (due to sulphates being used in domestic detergents), it very seldom exceeds 500 mg SO_4 L^{-1} (however, it is always worthwhile to measure its concentration in both the local drinking water and the wastewater deriving from it).

Overloaded WSP will present odor problems, just as any overloaded wastewater treatment process does. The solution in this case is to construct an additional series of ponds to cope with the increased load.

10.1.3.5. Evaporation

WSP systems do, of course, lose water by evaporation, but commonly less than 20% of the influent raw wastewater. This is often claimed to be a serious disadvantage of WSP systems, but the real question is whether the value of the water lost is greater than the cost of the electricity that would be used for an alternative treatment process, such as activated sludge—the answer will almost always be “No.” Evaporation can be minimized by using RFs, rather than maturation ponds (see Section 10.2.2).

10.2. WSP System Design

An introduction to WSP design is given by Peña Varón and Mara (2004) and detailed in Mara and Pearson (1998) and Mara (2004). Only a brief outline of the concepts is included here. Box 10.1 gives the design equations in summary form.

Box 10.1 Pond design equations

Anaerobic ponds

The design value for the volumetric biochemical oxygen demand (BOD) loading (λ_V, g m^{-3} day^{-1}) varies with the design temperature (T, °C), taken as the mean temperature of the coldest month, as follows: at ≤10 °C λ_V = 100 g m^{-3} day^{-1}, at 15 °C λ_V = 200 g m^{-3} day^{-1}, at 20 °C λ_V = 300 g m^{-3} day^{-1}, and at 25 °C λ_V = 350 g m^{-3} day^{-1}, with linear interpolation between these values. The area (A_V, m^2) is given by:

$$A_V = \frac{L_i Q}{\lambda_V D_A}$$

where D_A is the anaerobic pond depth (m).

Facultative ponds

The surface BOD loading (λ_S, kg ha^{-1} day^{-1}) is a function of the design temperature (T, °C), taken as the mean temperature of the coldest month:

$$\lambda_S = 350(1.107\text{–}0.002\,T)^{T-25}$$

The area (A_F, ha) is given by:

$$A_F = \frac{10 L_i Q}{\lambda_S D_F}$$

where D_F is the facultative pond depth (m).

▸ ***Check effluent quality for restricted irrigation:***

Once the anaerobic and facultative ponds are designed, it is sensible to check if the facultative pond effluent is suitable for restricted irrigation (Chapter 1). The required log unit reduction of pathogens is taken to be achieved by the same reduction of *E. coli*, for which the equations of Marais (1974) are used. For a pond series comprising only anaerobic and facultative ponds these are:

$$N_F = \frac{N_i}{(1 + K_{B(T)}\theta_A)(1 + K_{B(T)}\theta_F)}$$

$$K_{B(T)} = 2.6(1.19)^{T-20}$$

where N_F and N_i are the numbers of *E. coli* per 100 mL of the facultative pond effluent and raw wastewater, respectively; $K_{B(T)}$ is the first-order rate constant for *E. coli* removal (day^{-1}); and θ_A and θ_F are the mean hydraulic retention times in the anaerobic and facultative ponds, respectively (days). The design temperature T is taken as the mean temperature of the coolest month in the irrigation season. An *E coli* reduction of 3 to 4 log units is required (i.e., for N_i = $10^7 - 10^8$ per 100 mL, N_e should be no more than $10^4 - 10^5$ per 100 mL for highly mechanized agriculture or $10^3 - 10^4$ per 100 mL for labor-intensive agriculture; see Chapter 1).

For restricted irrigation, there should be no more than one intestinal nematode egg per liter of treated wastewater. For E_i eggs per liter of raw wastewater, the number of eggs per liter of facultative pond effluent (E_F) is given by the equations of Ayres et al. (1992):

$$E_F = E_i(1-r_A)(1-r_F)$$

where r_A and r_F are the fractional egg removals in the anaerobic and facultative ponds, respectively, given by:

$$r = 1-0.41[\exp(-0.49\theta + 0.0085\theta^2)]$$

where, for $r = r_A$, $\theta = \theta_A$ and, for $r = r_F$, $\theta = \theta_F$.

Maturation ponds

Maturation ponds are designed either for *E. coli* removal or for nitrogen (N) removal, or occasionally for both.

▸ ***E. coli removal:***

Marais' (1974) equations are used, as follows:

$$N_e = \frac{N_F}{[1 + K_{B(T)}\theta_{M1}][(1 + K_{B(T)}\theta_M)^n]}$$

where N_e is the number of *E. coli* per 100 mL of the final effluent, θ_{M1} and θ_M are the retention times (days) in the first and subsequent maturation ponds, respectively, and n is the number of maturation ponds after the first maturation pond. The value of θ_{M1} is such that the surface BOD loading on this pond is 70 percent of that on the facultative pond; it is therefore given by:

$$\theta_{M1} = \frac{10 L_i D_{M1}}{0.7\lambda_F}$$

▸ ***N removal:***

For total N removal Reed's (1985) equation is used, as follows:

$$TN_e = TN_i \exp\{-[0.0064(1.039)^{T-20}][\theta + 60.6(\text{pH}-6.6)]\}$$

where TN_e and TN_i are the effluent and influent total N concentrations (mg N L^{-1}), respectively. This equation is applied to the facultative pond and then to each maturation pond in turn; it is not used for the anaerobic pond as there is no total N removal in anaerobic ponds, only partial conversion of organic N to ammonia.

(continued)

Box 10.1 (continued)

For ammonia removal one of the equations of Pano and Middlebrooks (1982) is used, as follows:

(a) for $T \leq 20\,°C$:

$$AN_e = AN_i/\{1 + [(A/Q)(0.0038 + 0.000134T)\exp((1.041 + 0.044T)(pH–6.6))]\}$$

(b) for $T > 20\,°C$:

$$AN_e = AN_i/\{1 + [5.035 \times 10^{-3}(A/Q)][\exp(1.540 \times (pH–6.6))]\}$$

where AN_e and AN_i are the effluent and influent ammonia-N concentrations (mg L^{-1}), respectively. These equations are applied to the facultative pond and then to each maturation pond in turn. The ammonia-N concentration in the influent to the facultative pond may be taken as about 75% of the total N concentration in the raw wastewater.

Rock Filters (RFs)

The RF area (A_{RF}, m^2) is given by:

$$A_{RF} = \frac{Q}{HLR \times D_{RF}}$$

where Q is the wastewater flow (m^3 day^{-1}), HLR the hydraulic loading rate (day^{-1}; range: 0.6–1 day^{-1}), and D_{RF} the wastewater depth in the RF (0.5–1 m). This equation is valid for both aerated and unaerated filters. Currently, no design equations are available for BOD, SS, N and *E. coli* removals in aerated RFs, only the effluent quality data given in the main text.

10.2.1. Anaerobic, Facultative, and Maturation Ponds

Anaerobic and facultative ponds are designed on the basis of volumetric and surface BOD loadings (in g BOD m^{-3} day^{-1} and kg BOD ha^{-1} day^{-1}), respectively, to achieve high BOD removals, with concomitant high SS removal in anaerobic ponds. (SS removals in facultative ponds are not as high due to the growth of green algae, the cells of which are measured as SS.) Design values for these loadings depend on the design temperature, which is taken as the mean temperature of the coldest month (see Box 10.1). Depths are typically 3 m in anaerobic ponds (range 2 to 5 m) and 1.5 m in facultative ponds (1 to 2 m).

Maturation ponds are designed for the removal of excreted pathogens and nutrients such as nitrogen (N) and phosphorus (P; Box 10.1). Pathogen removal is extremely important when the effluent is to be used for crop irrigation (Chapter 1). BOD and SS removals are much lower than in anaerobic and facultative ponds. Depths are typically 1 to 1.5 m.

10.2.2. Rock Filters

RFs are subsurface horizontal-flow filters with a rock size of 75 to 200 mm. They have been used for more than 30 years in the United States to remove algal BOD and SS in maturation pond effluents (O'Brien et al., 1973; Swanson and Williamson, 1980; Middlebrooks 1995; U.S. Environmental Protection Agency, 2002; Figure 10.5). Work in Jordan on RFs composed of "wadi gravel" with a size of 30 to 230 mm has confirmed their efficiency: SS removal was about 60% at a loading of 32 to 44 g SS m^{-3} day^{-1} (Saidam et al., 1995). However, these RFs were unaerated and thus unable to remove ammonia through nitrification as they were anoxic. Recent work in England has investigated the use of aerated RFs to treat facultative (rather than maturation) pond effluents; it was found that aerated RFs effectively enabled ammonia removal by nitrification and achieved higher BOD, SS and fecal coliform removals than unaerated RF (Mara and Johnson, 2006). Mean effluent quality from an aerated RFs receiving a hydraulic loading rate of 0.6 m^3 of facultative pond effluent per m^3 of RF volume per day was about 9 mg BOD, about 7 mg SS, about 3 mg ammonia-N per liter and 10 to 1,000 fecal coliforms per 100 mL. This is a very good quality effluent indeed, which is suitable for both restricted and unrestricted crop irrigation. In fact, RFs should be considered an integral part of WSP systems, in exactly the same way that secondary sedimentation tanks are considered an integral part of activated sludge systems, since they both serve the same purpose, namely the removal of excess biomass produced in the preceding biological treatment—bacteria in the case of activated sludge and algae in the case of WSP. The area required for RFs is very much less than that for maturation ponds: about 0.4 m^2 per person, compared with 5 m^2 per person for maturation ponds in France. RF design is detailed in Box 10.1.

10.3. WSP Maintenance Requirements

The maintenance requirements of WSP are listed in Table 10.2. It is essential that these simple tasks are done regularly to avoid operational problems. Therefore, while only unskilled labor is required, it is very important that all maintenance work is adequately supervised.

10.4. WSP Systems: A Highly Sustainable Solution

WSP systems are a high-efficiency, low-maintenance and low-cost wastewater treatment process. Land area requirements can be minimized by good design, and also by using RFs instead of maturation ponds. High-quality effluents can be produced that are suitable for crop irrigation, thereby ensuring that the valuable nutrients in domestic wastewater are not wasted.

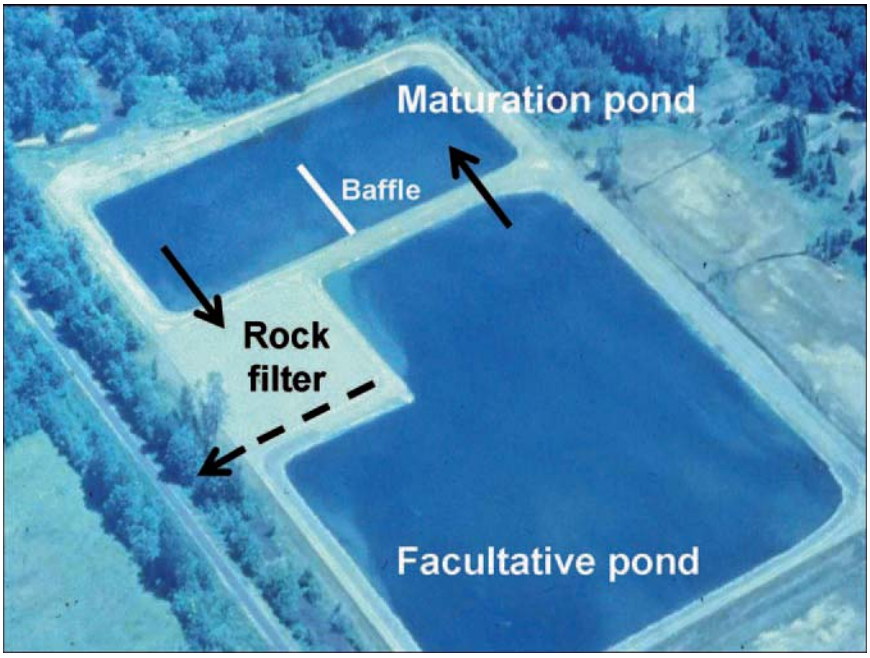

Figure 10.5 Rock filter treating maturation pond effluent at Veneta, Oregon, in the United States

Table 10.2 WSP maintenance requirements

Maintenance task	Frequency
Removal of screenings and grit from preliminary treatment processes	Daily
Cutting the grass on the embankments and removing it so that it does not fall into the pond (necessary to prevent the formation of mosquito-breeding habitats)	Monthly
Removal of floating scum and floating macrophytes, such as *Lemna* (duckweed), from the surface of facultative and maturation ponds (required to maximize photosynthesis and surface reaeration and to prevent fly and mosquito breeding)	Weekly
Spray the scum on anaerobic ponds (which should not be removed as it aids the treatment process), as necessary with clean water, pond effluent or a suitable biodegradable larvicide to prevent fly breeding	Monthly
Remove the sludge from anaerobic ponds	Annually*
Remove any solids blocking the inlets and outlets	Whenever observed
Repair any damage to embankments caused by rodents, rabbits or other animals	Whenever observed
Repair any damage to the external fences and gates	Whenever observed

*Usually done when the pond is one-third full of sludge, which takes about 2 to 4 years. However, it is better to desludge partially every year as a task that has to be done every April, for example, is more likely to be done than if scheduled for every so many years.

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