Waste Stabilisation Ponds

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Table of Contents

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Direct links to more detailed explanations and documented experiences of critical aspects of the topic on the world wide web

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Waste Stabilisation Ponds Technology overview

Introduction

Waste stabilization ponds (WSPs) are usually the most appropriate method of domestic and municipal wastewater treatment in developing countries, where the climate is most favourable for their operation WSPs are low-cost (usually least-cost), low-maintenance, highly efficient, entirely natural and highly sustainable. The only energy they use is direct solar energy, so they do not need any electromechanical equipment, saving expenditure on electricity and more skilled operation. They do require much more land than conventional electromechanical treatment processes such as activated sludge – but land is an asset which increases in value with time, whereas money spent on electricity for the operation of electromechanical systems is gone forever).

WSP systems comprise one or more series of different types of ponds. Usually the first pond in the series is an anaerobic pond, and the second is a facultative pond. These may need to be followed by maturation ponds, but this depends on the required final effluent quality – which in turn depends on what is to be done with the effluent: used for restricted or unrestricted irrigation; used for fish or aquatic vegetable culture; or discharged into surface water or groundwater.

Many wastewater treatment plants (WwTP) of all kinds in developing countries do not function properly. Parr and Horan (1994) found that there are three principal reasons for WwTP failure: a lack of technical knowledge; failure to consider all relevant local factors at the pre-design stage; and inappropriate discharge standards. As a result, wrong decisions are often made and inappropriate unsustainable treatment processes are selected and implemented This is then exacerbated by the absence of any real incentive to operate the WwTP correctly once it has been commissioned. It is therefore essential for the long-term sustainability of WwTP that simple efficient technologies such as WSPs are always considered at the pre-design (or feasibility) stage. An honest comparison of the cost-effectiveness of wastewater treatment technologies will almost always favour the selection of WSPs in warm-climate countries (see Section WSP Costs).

Wastewater treatment in WSPs

WSPs are one of the main natural wastewater treatment methods. They are man-made earthen basins, comprising at any one location one or more series of anaerobic, facultative and, depending on the effluent quality required, maturation ponds. WSPs are particularly suited to tropical and subtropical countries since sunlight and ambient temperature are key factors in their process performance.

Prior to treatment in the WSPs, the wastewater is first subjected to preliminary treatment − screening and grit removal − to remove large and heavy solids. The design of this preliminary treatment stage is the same as that used for conventional electromechanical

WwTP, but for WSPs the simplest systems are generally used (i.e. manually raked screens and manually cleaned constant-velocity grit channels).

The wastewater treatment processes that occur in anaerobic, facultative and maturation ponds are described in detail in Section 3 of the Design Manual for WSPs in India (see also Section 3.1). Basically, primary treatment is carried out in anaerobic ponds, secondary treatment in facultative ponds, and tertiary treatment in maturation ponds. Anaerobic and facultative ponds are for the removal of organic matter (normally expressed as "biochemical oxygen demand" or BOD), Vibrio cholerae and helminth eggs; and maturation ponds for the removal of faecal viruses (especially rotavirus, astrovirus and norovirus), faecal bacteria (for example, Salmonella spp., Shigella spp., Campylobacter spp. and pathogenic strains of Escherichia coli), and nutrients (nitrogen and phosphorus).

Due to their high removal of excreted pathogens, WSPs produce effluents that are very suitable for reuse in agriculture and aquaculture. The reuse of WSP effluents is discussed in Section Reuse of WSP effluents.

The process design of anaerobic, facultative and maturation ponds is detailed in Section 4[1] of the India Manual; the physical design of WSPs is detailed in Section 5[2], and WSP operation and maintenance (which is very simple, but essential) in Section 6[3]. Each is described briefly here and in Box 1. More detailed information on the microbiological processes in WSPs is given in the specialized literature listed in TOP Resources/References of this TOP.

Anaerobic ponds

Anaerobic ponds are the smallest units in the series. They are sized according to their "volumetric organic loading", which means the quantity of organic matter, expressed in grams of BOD_5 per day, applied to each cubic metre of pond volume. Ponds may receive volumetric organic loadings in the range of 100 to 350 g BOD_5/m^3 day, depending on the design temperature.

[1] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc4.pdf
[2] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc5.pdf
[3] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc6.pdf

Box 1. Design equations for WSPs

1. Anaerobic ponds

The volumetric BOD loading (λ_v, g/m^3 d) is given by:

$$\lambda_v = L_i Q / V_a$$

where L_i is the BOD_5 of the raw wastewater (mg/l = g/m^3), Q is the wastewater flow (m^3/d) and V_a is the anaerobic pond volume (m^3).

The permissible range of λ_v is 100 g/m^3 d at temperatures ≤10°C, increasing linearly to 300 g/m^3 d at 20°C, and then more slowly to 350 g/m^3 d at 25°C and above. The design temperature is the mean temperature of the coldest month. Once the temperature is known, the value of λ_v is determined and the value of V_a calculated. The anaerobic pond area is then determined by dividing V_a by the pond depth (e.g., 3 m).

BOD_5 removal is 40% at temperatures ≤10°C, increasing linearly to 70% at 25°C and above.

2. Facultative ponds

The surface BOD_5 loading (λ_s, kg/ha d) is given by:

$$\lambda_s = 10 L_i Q / A_{af}$$

where L_i is the BOD of the anaerobic pond effluent (mg/l) and A_f is the facultative pond area (m^2).

The value of λ_s depends on the design temperature (T, °C), as follows:

$$\lambda_s = 350(1.107 - 0.002T)^{T-25}$$

The value of λ_s is determined for the design temperature and the value of A_f calculated.

3. Maturation ponds

These are designed for *E. coli* and helminth egg removal as shown in Section 1.5 on the reuse of WSPs effluents in agriculture and/or aquaculture **[LINK]**.

4. Minimum retention times

The mean hydraulic retention time (θ, days) in an individual WSP is given by:

$$\theta = V/Q \text{ (or } AD/Q\text{)}$$

where V is the pond volume (m^3), Q the wastewater flow through the pond (m^3/d), A is the pond area (m^2) and D is the pond working liquid depth (m).

The minimum design retention time is one day in anaerobic ponds, four days in facultative ponds, and three days in maturation ponds. If the calculated value of θ in the latter is less than this minimum value (θ_{min}), then the pond volume or area is recalculated from:

$$V = Q\theta_{min}$$

$$A = Q\theta_{min}/D$$

These high loadings produce a strict anaerobic environment throughout the pond volume (i.e., there is no dissolved oxygen present and the redox potential is negative). The depth of anaerobic ponds is in the range 2−5 m; the precise value depends on the ground conditions and local excavation costs (which increase with depth) − depths are often 3−4 m.

Anaerobic ponds work extremely well in warm climates: for example, a properly designed pond will achieve around 60 percent BOD_5 removal at 20°C and over 70 percent at 25°C and above. Organic matter removal in anaerobic ponds is governed by the same mechanisms that occur in all other anaerobic reactors (Mara et al., 1992; Peña, 2002). A retention time of one day is sufficient for wastewaters with a BOD_5 ≤300 mg/l at temperatures above 20°C.

Odour nuisance from anaerobic ponds, typically due to hydrogen sulphide, has always been a concern for design engineers. However, odour is not a problem provided that the anaerobic pond is properly designed and the sulphate concentration in the raw wastewater is less than 500 mg SO42-/l.

Facultative ponds

These ponds are of two types: primary facultative ponds that receive raw wastewater (after screening and grit removal) and secondary facultative ponds that receive settled wastewater from the primary stage (usually the anaerobic ponds effluent). Facultative ponds are designed for BOD_5 removal based on their "surface organic loading". The term refers to the quantity of organic matter, expressed in kilograms of BOD_5 per day, applied to each hectare of pond surface area; thus the overall units are kilograms of BOD_5 per hectare of facultative pond surface area per day − i.e., kg BOD_5/ha d. A relatively low surface organic loading is used (usually in the range of 80−400 kg BOD_5/ha d, depending on the design temperature) to allow for the development of an active algal population. The depth of facultative ponds is in the range 1−2 m, with 1.5 m being most common.

The maintenance of a healthy algal population is very important as the algae generate the oxygen needed by bacteria to remove the BOD_5 (see Figure1). The algae give facultative ponds a dark green colour. Ponds may occasionally appear red or pink, due to the presence of anaerobic purple sulphide-oxidising photosynthetic bacteria (Mara and Pearson, 1986). This change in facultative pond ecology occurs due to slight BOD_5 overloading, so colour changes in facultative ponds are a good qualitative indicator of pond function. The concentration of algae in a well-functioning facultative pond depends on loading and temperature. It is usually in the range 500−1000 μg chlorophyll-a per litre (algal concentrations are best expressed in terms of the concentration of their principal photosynthetic pigment). The photosynthetic activity of the algae results in a diurnal variation of dissolved oxygen (DO) concentration and pH. The DO concentration can rise to more than 20 mg/l (i.e., highly supersaturated conditions) and the pH to more than 9.4 (these are both important factors in the removal of faecal bacteria and viruses; Curtis et al., 1992).

BOD_5 removal in primary facultative ponds is about 70 percent on an unfiltered basis and more than 90 percent on a filtered basis (filtering the sample before BOD_5 analysis excludes the BOD_5 due to the algae in the sample; this "algal BOD_5" is very different in nature to ordinary wastewater BOD_5 or "non-algal BOD_5"). Some regulators specify effluent BOD_5 requirements for WSPs in terms of filtered BOD_5 − for example, in the European Union WSP effluents are required to achieve ≤25 mg filtered BOD_5/l (Council of the European Communities, 1991). Other regulators should be encouraged to apply similar standards.

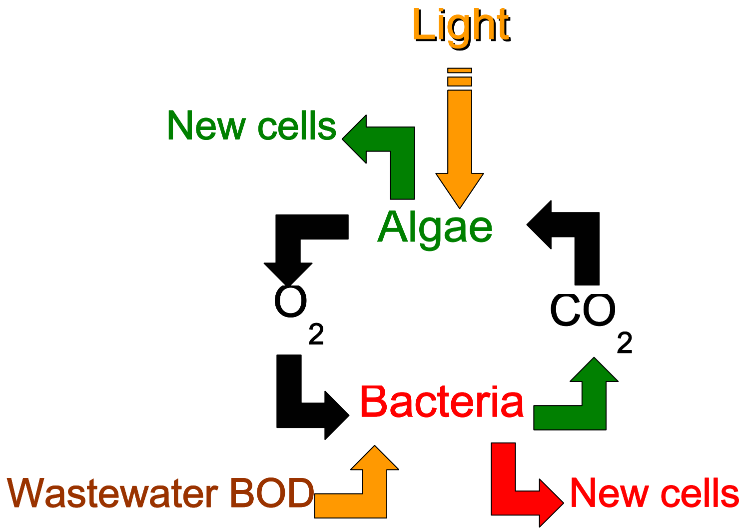

Figure 1. Mutualistic relationship between the algae and the bacteria in facultative and maturation ponds

Maturation ponds

Maturation ponds receive the effluent from the facultative ponds and their size and number depends on the required bacteriological quality of the final effluent. They are shallower than facultative ponds with a depth in the range 1−1.5 m, with 1 m being optimal (depths of less than 1 m encourage rooted macrophytes to grow in the pond and so permit mosquitoes to breed). Because of the lower organic loadings received by maturation ponds, they are well oxygenated throughout their depth. The algal populations are much more diverse than that in facultative ponds; algal diversity increases from pond to pond along the series.

The main mechanisms of faecal bacterial and viral decay are driven by algal activity along with photo-oxidation. Further details on the removal mechanisms in maturation ponds can be found in Curtis et al. (1992). Maturation pond design for E. coli removal is outlined in Section 1.5 [LINK].

Maturation ponds only achieve a small additional removal of BOD_5, but they make a significant contribution to nitrogen and phosphorus removal. Total nitrogen removal in a whole WSP system is often above 80 percent and ammonia removal is generally more than 90 percent (these figures depend on the number of maturation ponds included in the WSP system). Phosphorus removal in WSPs is lower (usually about 50 percent). Examples of WSP series (anaerobic ponds + facultative ponds + maturation ponds) are shown in Figures 2−4.

Figure 2. WSP system at Ginebra in southwest Colombia (population 9,000; wastewater flow 27 l/s) comprising an anaerobic pond and a facultative pond. The WSP effluent is used for the irrigation of sugar cane.

Figure 3. WSP system at Fortaleza in northeast Brazil comprising an anaerobic, a facultative and three maturation ponds (Influent flow 10,000 m3/day). Around half the flow is from local textile factories.

Figure 4. Phase I of the WSP system at Dandora serving Nairobi, Kenya (design flow 30,000 m^3/d) comprising two series with a facultative and three maturation ponds. [Phase II comprises a further six series to the right of the Phase I series (design flow 80,000 m^3/d), and Phase III will add an anaerobic pond as the first stage in the eight series (design flow about 160,000 m^3/d).]

Construction of WSPs

Full details of the physical design of WSPs can be found in Section 5 of the India Manual[4], and in Wastewater and Evaporation Lagoon Construction[5] published by the Environment Protection Agency of South Australia (EPA SA, 2004). A brief introduction to WSP construction is given below.

The site selected for WSPs should be at least 500 m downwind of the nearest housing. Ideally it should have a reasonably flat topography and the soil should have an in situ coefficient of permeability of less than 10−7 m/s (WSP construction costs increase with increasing site gradients, and soils with a coefficient of more than 10−6 m/s require the ponds to be lined). The principal construction activity is earthmoving (Figure 5) and there should be a good balance between cut and fill. Embankments should be made from the local soil compacted in 250 mm layers to 90 percent of its maximum dry density, such that its coefficient of permeability is less than 10−7 m/s. Internal embankment slopes are commonly 1 in 3 (i.e. 1 m vertically per 3 m horizontally) and external slopes 1 in 2. Slow-growing grass is planted on the embankment to improve slope stability. Embankment protection is provided at top water level to prevent erosion due to wind-induced wave action (Figures 6 and 7).

[4] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc5.pdf
[5] http://www.environment.sa.gov.au/epa/pdfs/guide_lagoon.pdf

Pond lining, if required, is normally a plastic membrane covering the entire pond base and the embankments. Membrane joints need to be watertight. Alternatively the ponds can be sealed with a 250 mm layer of clay.

Pond inlets and outlets should be constructed carefully and located in diagonally opposite corners of the pond to minimize hydraulic short-circuiting (see Shilton and Harrison, 2003). Inlets to facultative ponds and maturation ponds should be provided with a "scum box" (Figure 8) to minimize the amount of scum on the pond surface, and outlets should be provided with a simple scum guard to prevent any scum or duckweed that may be growing on the pond surface from leaving the pond (scum and duckweed removal is an essential WSP maintenance requirement; see Section Operations and Maintenance of WSPs (Figure 9).

WSP start-up procedures are explained in Section 1.6.

Figure 5. WSP construction − earthmoving is the main activity.

Figure 6. Embankment protection with in situ concrete slabs.

Figure 7. Embankment protection with stone rip-rap.

Figure 8. Pond inlet with scum box.

Figure 9. Pond outlet weir with integral scum guard.

WSP Costs

Case study in Sana'a, Yemen

A rigorous economic analysis was undertaken for a hypothetical large WSP system for the city of Sana'a in the Yemen (Arthur, 1983) (Table 1). The overall cost of each of four alternative treatment systems (WSPs, aerated lagoons, oxidation ditches and biological filters) is given as a net present value (NPV), which is a figure that combines construction costs with future operational costs discounted to their present value.

This least-cost analysis found that WSP costs are dictated by the cost of land, the discount rate used and the value of the land at the end of the project life (taken in this study as 25 years). WSPs were found to be the least-cost solution for land prices in the range US$50,000−150,000 per hectare, depending on the value of the discount rate used (5−15%). These land prices refer, of course, only to the conditions of Arthur's case study. However, they do indicate that WSPs are very competitive even at high land costs.

Arthur's study highlights an extremely important and universal aspect of WSP economics, which is that their main capital item (land) is recoverable. Furthermore, since land is an appreciating capital item, it can appear as such in company accounts. Including the end-of-project value of the land dramatically alters the net present values in favour of WSPs − their NPV decreases by nearly 90 percent (Table 2). Consideration of the end-of-project value of land used for WSPs is not just a hypothetical or academic exercise − for example, it has been extremely profitable in California, where WSP land in the city of Concord increased in real terms by US$270,000 (1975 dollars) per ha during the 20-year period 1955−1975 (Oswald, 1976).

Table 1. The 25-year costs in millions of 1983 US dollars at a 12% discount rate of alternative wastewater treatment systems for a population of 250.000 at a design temperature of 20oC and for an effluent concentration of ≤10.000 faecal coliforms/100 ml.

System	Capital Costs	Annual Operating Costs	Income*	Net Present Value
Waste stabilization ponds	**5.68**	0.21	0.73	**5.16**
Aerated lagoons	6.98	1.28	0.73	7.53
Oxidation ditch	4.80	1.49	0.43	5.86
Biological filters	7.77	0.86	0.43	8.2

* From the sale of final effluent for crop irrigation and fish culture.

Table 2. The 25-year costs in millions of 1983 US dollars for the systems in Table 1 but with the end-of-project value of the land included.

System	Net Present Value
Waste stabilization ponds	**0.57**
Aerated lagoons	2.55
Oxidation ditch	3.89
Biological filters	5.73

Arthur's study was done in 1983 and did not include treatment technologies such as up-flow anaerobic sludge blanket (UASB) reactors and constructed wetlands. Also, the effluent quality used (≤104 faecal coliforms/100 ml) would now be better taken as ≤1.000 faecal coliforms/100 ml, the WHO (1989) guideline for unrestricted irrigation (see Section 1.5).

Despite these criticisms, the basic cost-comparison methodology used by Arthur remains the best available and its continued use is highly recommended to derive transparently honest cost comparisons between competing treatment options for any given location.

Box 2. WSP construction costs in Brazil

Costa and Medri (2002) give the following functions for the construction costs of WSPs in south Brazil:

(a) Cost of land (taken as the twice the pond area to allow for embankments and access − hence the factor 2 in the equation):

$$C_{Li} = 2P_LA_i$$

where C_{Li} is the cost of the land for pond number i (US$); PL is the local cost of land (US$/m^2); and A_i is the volume of pond *i* (m^2).

(b) Cost of construction:

$$C_{ci} = 5.514V_i^{0.678}$$

where C_{ci} is the construction cost of pond *i* (US$).

(c) Pond lining cost (using a PVC liner):

$$C_{li} = 18.592V_i^{0.732}$$

where C_{li} is the cost of lining pond *i* (US$).

The costs are calculated for each pond in turn and the total cost for the system is then determined by summing the costs of the individual ponds.

Caveat emptor − let the buyer be aware!

It is not uncommon for manufacturers of electromechanical wastewater treatment equipment to denigrate WSPs, often by exaggerating their land area requirements, claiming that they can be expected to have serious odour problems, or even saying that they are too low-tech for the 21st century, especially for "large, modern cities". Don't believe it! WSPs are used for "large, modern cities" − for example, Melbourne, Australia; Amman, Jordan; and Nairobi, Kenya (details are given in Mara, 2004). Of course, WSPs are not always the best option for large cities, but they should not be dismissed out of hand, especially on the advice of equipment salesmen.

Reuse of WSP effluents

WSPs produce effluents of high microbiological quality that permit them to be used for crop irrigation and/or the cultivation of fish and aquatic vegetables. WSP effluent reuse for these purposes is described in detail in Section 10 of the India Manual[6].

Agricultural reuse

Crop irrigation is divided into two broad categories: restricted crop irrigation, meaning irrigation of all crops except salads and vegetables eaten uncooked; and unrestricted irrigation which includes those crops). The World Health Organization has different guidelines for the microbiological quality of treated wastewaters used for these two categories of irrigation. These guidelines were originally published in 1989 (WHO, 1989) and they are currently under revision (see Blumenthal et al., 2000). The revised guidelines, due to be published in 2005, will be as follows:

a) Restricted irrigation
   ≤105 E. coli per 100 ml, and
   ≤1 human intestinal nematode egg per litre, reduced to ≤0.1 egg per litre when children under the age of 15 are exposed (by working or playing in wastewater-irrigated fields).

b) Unrestricted irrigation
   ≤1000 E. coli per 100 ml, and
   ≤1 human intestinal nematode egg per litre, reduced to ≤0.1 egg per litre when children under the age of 15 are exposed locally by their field-worker parents bringing home food crops eaten uncooked.

Faecal coliforms may be substituted for E. coli. The intestinal nematodes are Ascaris lumbricoides (the human roundworm), Trichuris trichiura (the human whipworm) and Ancylostoma duodenale and Necator americanus (the human hookworms). Details of these nematodes can be found in Sanitation and Disease[7].

[6] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc10.pdf
[7] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/watsan/sandis/sandis.html

As a general rule (but there are exceptions), a WSP system comprising only anaerobic and facultative ponds produces an effluent suitable for restricted irrigation (or for discharge to a stream, river or lake). Maturation ponds are needed if the effluent is to be used for unrestricted irrigation or if there are special requirements in terms of microbiological quality for the receiving water body (bathing waters, for example). However, in all cases the appropriate design calculations must be done to determine whether or not suitable effluents will be produced.

These calculations are detailed in Section 4 of the India Manual. They are briefly described in Box 3:

Box 3. Removal of nematode eggs and E – coli in WSPs

Removal of human intestinal nematode eggs

The design equation of Ayres *et al*. (1992) is used:

$$R = 100[1 - 0.41\exp(-0.49\theta + 0.0085\theta^2)]$$

where R is the percentage egg removal in a single pond, and θ is the retention time in the pond (days).

The equation is applied first to the anaerobic pond, then to the facultative pond, to calculate the number of eggs per litre of the facultative pond effluent, as follows:

$$E_{fac} = E_{rw}(1 - r_{an})(1 - r_{fac})$$

where E_{fac} and E_{rw} are the number of eggs per litre of facultative pond effluent and the raw wastewater, respectively, and $r = R/100$ with the subscripts 'an' and 'fac' referring to the anaerobic and facultative ponds.

If E_{fac} is >1 (or >0.1 if children under 15 are exposed), then the facultative pond effluent requires further treatment in a maturation pond (usually a single 3-day maturation pond is sufficient, but this must always be checked).

Removal of *E. coli*

The equations of Marais (1974) are used:

$$N_{fac} = N_{rw} / [(1 + k_{B(T)}\theta_{an})(1 + k_{B(T)}\theta_{fac})]$$

where N_{fac} and N_{rw} are the number of *E. coli* per 100 ml of facultative pond effluent and the raw wastewater, respectively; and $k_{B(T)}$ is the value of the first-order rate constant for *E. coli* removal at T °C (day^{-1}), given by:

$$k_{B(T)} = 2.6\,(1.19)^{T-20}$$

If N_{fac} is >10^5 per 100 ml, then further treatment in one or more maturation ponds is necessary.

Aquacultural reuse

The fish most commonly grown in wastewater-fed fishponds are carp and tilapia (see Figure 10). Details of wastewater-fed fishponds in metropolitan Kolkata, India are given in Section 2 of the India Manual[8].

The revised WHO microbiological quality guidelines for aquacultural reuse will be:

> $\leq 10^4$ *E. coli* per 100 ml of fishpond water (or aquatic vegetable pond water), and
> zero detectable human trematode eggs per litre of treated wastewater.

Faecal coliforms may be substituted for *E. coli*. The human trematodes are *Schistosoma* spp. (human blood flukes) *Clonorchis sinensis* (oriental liver fluke) and *Fasciolopsis buski* (giant intestinal fluke). Details of these trematodes are given in Sanitation and Disease[9].

Wastewater-fed fishponds are designed to receive facultative pond effluent on the basis of a total nitrogen loading on the fishpond of 4 kg N/ha d. Checks are then made to determine whether the *E. coli* count in the fishpond is $\leq 10^4$ per 100 ml and whether the free ammonia (NH_3) concentration in the fishpond is ≤0.5 mg N/l (higher concentrations are toxic to fish).

Figure 10. Harvesting carp from one of the wastewater-fed fishponds in Kolkata, India.

[8] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc2.pdf
[9] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/watsan/sandis/sandis.html

Methane recovery from covered anaerobic ponds

Biogas (methane and carbon dioxide) can be profitably recovered from anaerobic ponds if they are covered with a floating plastic membrane. This is done at the Western Treatment Plant in Melbourne, Australia, where the three large WSP systems each receive a wastewater flow of 120,000 m^3/day. Half of the anaerobic section of the first pond is covered (Figure 11) and the biogas collected is used to generate 6,000 kW of electricity 8–16 hours per day, 365 days per year, which is worth about US$ 1 million per year (DeGarie et al., 2000). The cover has three layers: a high-tensile UV-resistant geo-membrane for biogas recovery at the top; a 12.5 mm polyfoam insulation and flotation layer in the middle; welded to a base layer of high-density polyethylene. The cover measures 171 × 200 m (an area of 3.4 ha).

So, biogas recovery from anaerobic ponds is obviously feasible at large WSP sites, but it has also been done at smaller sites − for example, at Arad (population 22,000) in the Negev desert, Israel (Shelef and Azov, 2000). Biogas recovery is especially feasible if high-rate anaerobic ponds are used (see Peña, 2002).

Figure 11. Covered anaerobic pond at the Western Treatment Plant in Melbourne, Australia.

Operation and maintenance of WSPs

WSP start-up

Before commissioning a WSP system, any vegetation growing in the empty ponds must be removed. The facultative ponds and maturation ponds are commissioned before the anaerobic ponds so as to avoid odour release when the anaerobic pond effluent discharges into empty facultative ponds. The facultative ponds and maturation ponds should ideally be filled initially with fresh surface water or groundwater to permit the development of the required algal and heterotrophic bacterial populations. If freshwater is not available, then the facultative pond can be filled with raw wastewater and allowed to rest in batch mode for 3−4 weeks to allow the microbial populations to develop. Some odour release may be expected during this period.

Once the facultative ponds and maturation ponds have been commissioned, the anaerobic ponds are filled with raw wastewater and, if possible, inoculated with active biomass (sludge seed) from another anaerobic bioreactor. The anaerobic ponds are then loaded gradually up to their design load over a period of 2−4 weeks (the time depends on whether the anaerobic pond was inoculated with an active sludge seed or not). The pH of the anaerobic pond has to be maintained at around 7−7.5 during the start-up to allow for the methanogenic archaeal populations to develop. If the pH falls below 7 during this period, lime should be added to correct it.

Routine maintenance

Once the ponds have started functioning in steady state, routine maintenance is minimal but essential for good operation. Full details are given in Section 6 of the India Manual[10]. The main routine maintenance activities are:

- Removal of screenings and grit from the preliminary treatment units
- Periodically cutting the grass on the pond embankments
- Removal of scum and floating macrophytes from the surface of facultative ponds and maturation ponds. This is done to maximise the light energy reaching the pond algae, increase surface re-aeration, and prevent fly and mosquito breeding
- If flies are breeding in large numbers on the scum on anaerobic ponds, the scum should be broken up and sunk with a water jet
- Removal of any material blocking the pond inlets and outlets
- Repair of any damage to the embankments caused by rodents or rabbits (or any other burrowing animals)
- Repair of any damage to fences and gates.

As a rough guide one full-time operator is required at WSPs receiving wastewater flows up to about 1,000 m^3/d, two operators for wastewaters flows up to about 2,500 m^3/d and pro rata for higher flows (Arthur, 1983). A foreman/supervisor is required at sites treating more

[10] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc6.pdf

than 5,000 m^3/d; and should also keep a record of all maintenance activities, measure and record the wastewater flow and carry out routine effluent sampling.

All WSP operators should receive adequate training so that they understand what they have to do and how to do it correctly. If, for example, the pond operators have not been told to remove scum from facultative ponds and maturation ponds, they will not know that it should be removed. As a result, scum can cover a substantial part of the pond, algal photosynthesis becomes impossible, and the pond turns anoxic (Figure 12).

Figure 12. A facultative pond with a high accumulation of scum.

Anaerobic ponds need to be desludged when they are around one-third full of sludge. This occurs every 2−5 years, but it is operationally better to remove some sludge every year (as a task to be done every February, for example, has a better chance of being done on time than one which has to be done every few years). The sludge removed from anaerobic ponds can be dewatered on sludge drying beds (Figure 13). Facultative ponds store any sludge for their design life, which is a significant operational advantage.

When the travel time in the sewers is long (more than a day), the wastewater arriving at the WSP site may be highly septic, and that can cause odour from the preliminary treatment works.

Figure 13. Sludge drying beds at a WSP site in Colombia.

WSP effluent quality monitoring

The quality of the final effluent should be regularly determined at all WSP sites. For large systems this should be done monthly, and for small systems serving just a few thousand people at least every three months. Samples should be analysed for those parameters for which the effluent standards have been set by the local environmental regulator (usually BOD_5, suspended solids, pH, possibly also ammonia; and, if the effluent is reused in agriculture, E. coli or faecal coliforms and helminth eggs).

It is important to take representative samples: 24-hour flow-weighted composite samples are required for BOD_5, suspended solids, ammonia and helminth eggs; and grab samples for pH and E. coli/faecal coliforms. Details are given in Section 7 of the India Manual[11] (see also Pearson et al., 1987). This is an important stipulation because if the samples taken are not truly representative, the analytical results will not be meaningful and could lead to inappropriate design criteria being developed.

Problems encountered with WSPs

WSPs are essentially a simple technology, but some common problems tend to occur regularly. These are generally the results of mistakes made during design, construction and operation.

Design and construction

WSP design is often poor as too many designers do not understand the microbiological processes occurring in them. They may think that, because ponds are "simple", it is not strictly necessary to follow the correct design procedures. Either they do not know what

[11] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc7.pdf

these are, or they apply design criteria from temperate climates to the design of WSPs in the tropics). Some are also unaware of the basic principles for the physical design of WSPs.

The result of this regrettable ignorance is that many WSPs have been "designed" with inappropriate BOD_5 loadings. Inappropriately high loadings lead to odour and pond failure; inappropriately low loadings, especially on anaerobic ponds, lead to under-performance and overall costs are increased as the land area used is greater than necessary. Inlets and outlets are often incorrectly located (Figures 14 and 15) − indeed pond hydrodynamics is rarely considered. In some cases, there is no provision for preliminary treatment (screening and grit removal), which adversely affects the ponds because of too much scum and a higher rate of sludge accumulation. Pond failure or poor performance is also caused by inadequate attention being given to geotechnical aspects during the physical design of WSPs (Bernhard and Kirchgessner, 1987; Mantilla et al., 2002).

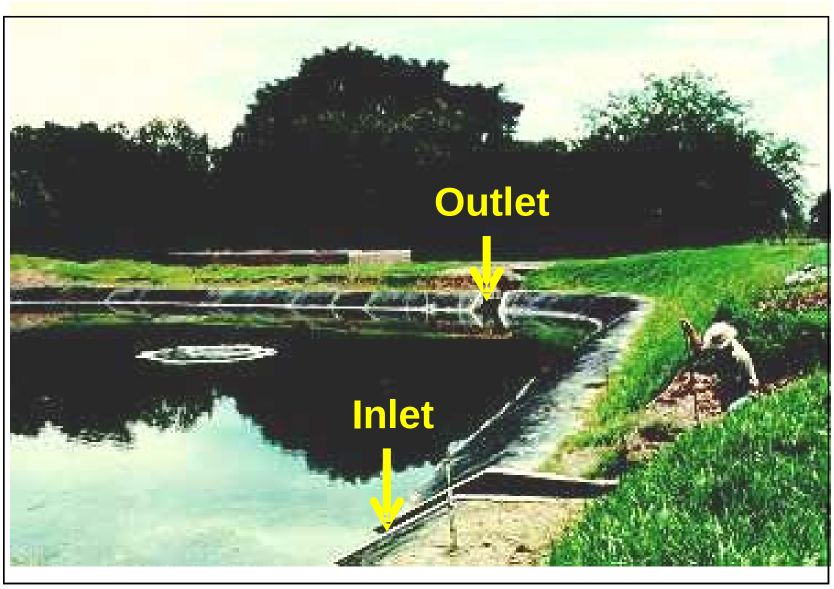

Figure 14. An example of poor inlet and outlet arrangements in an anaerobic pond. They are located in adjacent corners of the pond rather than in diagonally opposite corners, leading to hydraulic short-circuiting.

Figure 15. An example of poor inlet and outlet arrangements in a facultative ponds and a maturation ponds. They are all located directly opposite each other in the centre of the pond width (rather than in diagonally opposite corners), so maximizing hydraulic short-circuiting.

Lloyd et al. (2003) studied 14 WSP systems in Mexico: all produced poor quality effluents. The reasons for under-performance included gross under-design, adverse environmental conditions, a very high degree of hydraulic short-circuiting, and very poor operation and maintenance. The main adverse environmental conditions were the large diurnal variations in temperature in winter (from −4°C to +30°C) and very high wind speeds (peaks of more than 8 m/s), both of which were major factors in the excessive hydraulic short-circuiting. In one pond the dead space was 80 percent of the pond volume).

Another common problem is that, despite the loading rates being correctly selected by the designer, based on reasonable values of the key design parameters, such as population, per caput wastewater flow and BOD_5 contribution, the actual influent loads are different. The actual loading at the start may be much lower than the design value used, leading to critical underloading in the anaerobic ponds; or it may increase at a greater rate than predicted in the design, so leading to early critical overloading in the anaerobic and facultative ponds.

Inappropriate changes made during construction can also adversely affect pond performance. For example, it has been found in Colombia that contractors sometimes decide to change the pond length-to-breadth ratio and/or increase the depth, or fail to install the lining material correctly. They do this in the misguided belief that WSPs are just holes in the ground and everything will be fine as long as the pond volumes are more or less correct. They get away with it because their site work is not adequately supervised by the designer or an independent civil/environmental engineer.

Routine maintenance

The simplicity of routine WSP maintenance is sometimes mistakenly interpreted as "low maintenance equals no maintenance". As a result, routine preventive maintenance is often not done, or not done correctly, and the WSPs are "maintained" only when a serious problem has developed − for example, odour, mosquito breeding, excessive sludge accumulation in anaerobic ponds, or excessive vegetation growth in facultative ponds and maturation ponds (Figure 16).

Figure 16. An example of a WSP system suffering from total maintenance neglect.

Training

Professional staff involved in WSP projects include design and construction engineers, engineers responsible for operation of the WSPs once commissioned, and chemical and microbiological laboratory managers and analysts. Financial analysts and sociologists may also be involved at the pre-design and design stages. It is now becoming more common for the local community to be involved at these stages; among other things, local residents may need reassurance that WSPs will not cause odour problems, etc. All the professionals require appropriate training. Ideally, this is best done at a university or technical college, but that requires specialist lecturers who teach up-to-date curricula, and this is not so common in many universities and colleges. Few local professional institutions, such as national environmental engineering associations, take continuous professional development (CPD) seriously, yet CPD is necessary to keep professionals up to date in their specialism.

Other type of ponds

Sections 1.1−1.8 have dealt with conventional free-surface WSP systems. Some other types of pond systems merit discussion:

Wastewater storage and treatment reservoirs (WSTR)

WSTR were developed in Israel to store the effluent from a WSP system during the non-irrigation period, so that the whole year's treated wastewater could be used in the irrigation season, permitting a much greater area to be irrigated and more crops produced (Juanicó and Shelef, 1991). WSTR are especially suitable in arid and semi-arid areas where the value of treated wastewater for irrigation is high. Current practice is to treat the wastewater in an anaerobic pond and discharge the effluent into a single 5−20 m deep WSTR with a retention time equal to the length of the non-irrigation season (Figure 17a). This is perfectly satisfactory if only restricted irrigation is practised.

If unrestricted irrigation is intended, three or four sequential batch-fed WSTR are required to achieve the WHO guideline for unrestricted irrigation (Mara and Pearson, 1992) (Figure 17b). These sequential batch-fed WSTR are operated on a cycle of fill, rest and use, such that the E. coli count in a reservoir at the end of its rest phase (i.e., just before it is used for irrigation) is less than 1000 per 100 ml.

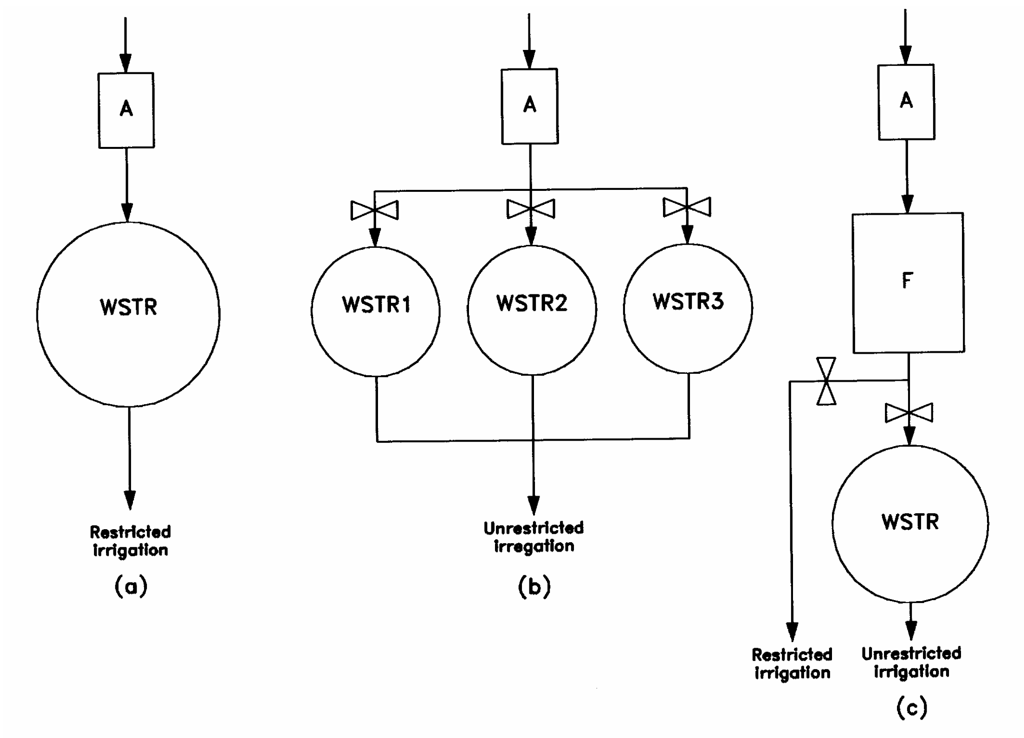

Figure 17. Wastewater storage and treatment reservoir systems: (a) single WSTR for restricted irrigation; (b) sequential batch-fed WSTR for unrestricted irrigation; and (c) hybrid WSP–WSTR system for both restricted and unrestricted irrigation. A: Anaerobic pond; F: Facultative pond.

Hybrid WSPs−WSTR systems provide treated wastewater for both restricted and unrestricted irrigation (Mara and Pearson, 1999) (Figure 17c).

- Floating macrophyte ponds
  These ponds contain plants that float on the water with their leaves close to the surface and their roots hanging down into the pond water column to absorb nutrients. Some plant types commonly used are Eichhornia sp. (water hyacinth), Lemna sp. (duckweed), Pistia sp. (water lettuce or water cabbage) and Cyperus sp. (papyrus). The plants shade out the algae, so reducing effluent BOD_5 and suspended solids; however, this has the disadvantage that disinfection is reduced, with the result that effluent E. coli numbers are higher. This suggests that floating macrophyte ponds should only be used as a final treatment stage (for nutrient and algal removal) after conventional maturation ponds have reduced E. coli numbers to the required level. However, if the final effluent is used for crop irrigation, nutrient and algal removal is unnecessary and floating macrophyte ponds are therefore not required.

  A major disadvantage with floating macrophyte ponds is that they encourage mosquito breeding. Culicine mosquitoes, the vector of Bancroftian filariasis, are the principal problem, but Eichhornia ponds permit the breeding of anopheline mosquitoes, the malaria vector, as well.

- Septage and nightsoil ponds
  Septage is the sludge removed from septic tanks; it also contains much of the wastewater fraction in the septic tank as this is generally also pumped out during septic tank desludging. The sludge fraction is highly mineralized, so treatment in anaerobic ponds is not required. The BOD_5 of septage is very high, often 3,000−5,000 mg/l. Treatment is in several facultative ponds in parallel, designed on the basis that evaporative losses in the coolest month equal the inflow and no effluent is produced. The BOD_5 surface loading on the facultative ponds should not exceed the value for the temperature of the coolest month (Box 1). Make-up water is added in other months to maintain the pond depth, which means that septage ponds should be located near a reliable source of water.

  Nightsoil ponds are not very common, as bucket latrines are increasingly being replaced by more appropriate sanitation technologies. Nightsoil treatment ponds (anaerobic ponds + facultative ponds) are designed in the normal way (Box 1) for a BOD_5 contribution of about 20 g/person day. Suitable arrangements have to be made for the nightsoil tankers to discharge their loads into the anaerobic ponds. Tanker wash water is also discharged into the anaerobic ponds.

- Advanced integrated pond systems (AIPS)
  AIPS were developed from high-rate algal ponds (HRAPs) (Oswald, 1991, 1995). They comprise "advanced" facultative ponds with a submerged anaerobic digestion pit, paddle-stirred HRAP, algal sedimentation ponds and one or more maturation ponds. The original purpose of HRAPs was to maximize the production of algae to recover and use the algal protein (algae are 50−60 percent protein and HRAPs can produce up to 80 tonnes of algal protein/ha year). However, with AIPS no attempt is made to recover the algal protein. HRAPs, which are the key component of AIPS, are complex and sensitive reactors which are much more difficult to operate correctly than conventional WSPs (and indeed activated sludge processes). In the real world of wastewater treatment in developing countries, AIPS are too complicated a technology to be considered a viable and sustainable treatment option.

Lessons learnt

Experience from around the world has shown that WSPs are very often the most cost-effective wastewater treatment method. However, both the process design and the physical design of WSPs have to be carried out very carefully by competent design engineers since WSPs are more than just holes in the ground.

Effluents from WSPs can achieve stringent discharge standards that make them highly suitable for reuse in agriculture and/or aquaculture. This puts WSPs at the forefront of wastewater reclamation technologies.

Despite more than 50 years of continued research into different aspects of WSPs, there is still much work to do on topics such as hydrodynamic improvement, ecological modelling and enhancement of removal rates (i.e., organic matter, nutrients and pathogens). Such research should be aimed at developing efficient WSP systems that require less land.

Training is needed to ensure that practising engineers properly understand WSP technology and so are able to design new WSPs and upgrade existing WSP systems correctly.

Good operation and maintenance by adequately trained operators is fundamental to guarantee the long-term sustainability of WSPs systems.

Research perspectives

Recent research has shown that it should be possible to improve the performance of all types of WSPs (i.e. anaerobic ponds, facultative ponds and maturation ponds). For example, the recent development of high-rate anaerobic ponds has shown that it is possible to reduce the retention time to 12 hours, yet still achieve average BOD_5 removals of 70 percent at 25 ºC (Peña, 2002). Future research should investigate high-rate facultative ponds and maturation ponds to treat the effluents from both high-rate anaerobic ponds and UASBs.

Mechanistic modelling of the microbiological and biological processes occurring in WSPs is probably the most difficult area of research, especially in relation to nutrient (N and P) removal. However, the combination of high-power computing, computational fluid dynamics packages, molecular biology and ecological engineering techniques is likely to help the development of both more rational design procedures and dynamic models to predict WSP performance under changing conditions. There are already promising results showing that simple engineering interventions such as the intelligent incorporation of baffles and flow deflectors can greatly improve WSP performance. Shilton and Harrison (2003) show that this opens new perspectives for the improvement of the physical design of WSPs.

Case studies

The following are case studies the reader may find useful since they are from different regions in the world where WSPs have been successfully implemented.

- Middle East: Section 4 of Design Manual for WSPs in Mediterranean Countries[12].
- North Africa: Section 5 of Design Manual for WSPs in Mediterranean Countries[13].
- Europe: Section 3 of Design Manual for WSPs in Mediterranean Countries[14].
- India: Section 2 of India Manual[15].

[12] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/med/emedwsp.pdf
[13] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/med/wspna.pdf
[14] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/med/wspmed.pdf
[15] http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/IPDMc2.pdf

TOP Resources

TOP Books

Design Manual for Waste Stabilization Ponds in India, by Duncan Mara (Lagoon Technology International, Leeds, United Kingdom, 1997).
http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/india.html
A full description of WSPs, their process and physical design, including the design of wastewater-fed fishponds; contains case studies of WSPs systems in Greater Kolkata.

Guidelines for the Hydraulic Design of Waste Stabilization Ponds, by Andy Shilton and Jill Harrison (Massey University, Palmerston North, New Zealand, 2002).
http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/nzealand/nzealand.html
A detailed description of hydraulic aspects of WSPs design, including the effect of baffles in improving pond performance.

Advanced Primary Treatment of Domestic Wastewater in Tropical Countries: Development of High-rate Anaerobic Ponds, (PhD Thesis), by Miguel Peña Varón (University of Leeds, UK, 2002).
http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/theses/penavaron.html
A doctoral thesis covering the performance of anaerobic ponds in southwest Colombia and the development of high-rate anaerobic ponds which are shown at pilot scale to be more efficient than conventional anaerobic ponds but at half the retention time of the latter.

Sanitation and Disease: Health Aspects of Excreta and Wastewater Management, by Richard Feachem, David Bradley, Hemda Garelick and Duncan Mara (John Wiley & Sons Ltd, Chichester, United Kingdom, 1983).
http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/watsan/sansis/sandis.html
A comprehensive treatise on the subject with separate chapters for each of the major excreta-related human pathogens.

Design Manual for Waste Stabilization Ponds in Mediterranean Countries, [i.e., including the Eastern Mediterranean and North Africa], by Duncan Mara and Howard Pearson (Lagoon Technology International, Leeds, United Kingdom, 1998).
http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/med/medman.html
A full description of WSPs, their process and physical design, including WSPs effluent reuse; contains case studies of WSPs systems in the Middle East, North Africa and Mediterranean Europe.

Pond Treatment Technology, edited by Andy Shilton (IWA Publishing, London, 2005; not available on-line – see publisher's webpage for this book).
http://www.iwapublishing.com/template.cmf?name=iwapcatalogue
A state-of-the-art review of all aspects of WSPs written by a number of experts in the field.

Domestic Wastewater Treatment in Developing Countries, by Duncan Mara (Earthscan Publications, London, 2003; not available on-line – see publisher's webpage for this book).
http://www.earthscan.co.uk/asp/bookdetails.asp?key=4094
A textbook for undergraduate and graduate students; includes comprehensive didactic material on WSPs and wastewater reuse.

Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries, by Jim Arthur, World Bank Technical Paper no. 7 (The World Bank, Washington, DC, 1983).
http://www-wds.worldbank.org/sevlet/WDS_IBank_Servlet?pcont=detail&eid=000178830_98101904165457
This report contains the recommended financial methodology for comparing competing wastewater treatment technologies in terms of their net present values.

Wastewater Treatment and Use in Agriculture, by M. B. Pescod, FAO Irrigation and Drainage Paper No. 47 (Food and Agriculture Organization, Rome 1992).
http://www.fao.org/docrep/T0551E/T0551E00.htm
A comprehensive review of the subject.

Biological Wastewater Treatment in Warm Climate Countries, by Marcos von Sperling and Carlos A. de L. Chernicharo (IWA Publishing, London, 2004; not available on-line – see publisher's webpage for this book).
http://www.iwapublishing.com/template.cmf?name=isbn1843390027
A comprehensive guide to wastewater treatment in warm climates; includes basic principles, WSPs, anaerobic reactors, sludge treatment and disposal.

TOP Conference proceedings

Selected proceedings of the following WSP conferences of the International Water Association are available on-line in the following issues of the IWA Journal Water Science and Technology[16]:

- Second international conference (Berkeley, USA, 1993): vol. 31, no.12.
- Third international conference (João Pessoa, Brazil, 1995): vol. 33, no. 7.
- Fourth international conference (Marrakech, Morocco, 1999): vol. 42, no. 10−11.
- First Latin American regional conference (Cali, Colombia, 2000): vol. 45, no. 1.
- Fifth international conference (Auckland, New Zealand, 2002): vol. 48, no. 2.

The proceedings of the first international conference (Lisbon, Portugal, 1987) are in Water Science and Technology, vol. 19, no. 12; this issue is not available on-line.

[16] http://www.iwaonline.com/wst/toc.htm

TOP Web sites

Sanitation Connection

Sanitation Connection Wastewater Treatment Technologies
http://www.sanicon.net/titles/topicintro.php3?topicId=6
This site lists many publications on WSPs (including links to the IWA WSP Conference Proceedings listed above) which are all available on the Internet.

For publications on WSP effluent reuse in agriculture and aquaculture, go to Sanitation Connection Wastewater Reuse.
http://www.sanicon.net/titles/topicintro.php3?topicId=3

For publications on low-cost sewerage (i.e. how to get wastewaters to WSPs), go to Sanitation Connection Low-cost Sewerage.
http://www.sanicon.net/titles/topicintro.php3?topicId=8

Tropical Public Health Engineering

http://www.leeds.ac.uk/civil/ceri/water/tphe/tphehome.html
University of Leeds, UK – This site has many on-line publications on WSPs, including:

- Design Manual for WSPs in India
- Design Manual for WSPs in Mediterranean Countries
- Advanced Primary Treatment of Domestic Wastewater in High-Rate Anaerobic Ponds
- Sanitation and Disease: Health aspects of excreta and wastewater management

World Health Organization

http://www.who.int/water_sanitation_health/en/
The revised Guidelines on Wastewater Use in Agriculture and Aquaculture will be available in mid-2005 via the WHO site on Water, Sanitation and Health.

IWA Publishing

Water Science and Technology (index to all issues published since 1995 which are available on-line)
http://www.iwaponline.com/wst/toc.htm

TOP Who's who

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Electronic network

wsponds@jiscmail.ac.uk – to join send an e-mail to jiscmail@jiscmail.ac.uk; leave the subject line blank, type in the message “join wsponds your-first-name your-last-name” (please use your own actual names – e.g., “join wsponds Joseph Smith”); and on the next line type -- (i.e., two hyphens/dashes). You will then receive a few automatic e-mails with full instructions. To e-mail all members of the Network (or List, as it is generally called), simply send an e-mail to wsponds@jiscmail.ac.uk (if you are not a registered member of the List, your e-mail to this address will simply bounce back).

Feedback on specific issues of WSPs may be obtained from the contacts in the list of Who’s Who, via the e-network and from the resources listed in the previous sections. Additionally, opportunities for research placements, specific training courses, field visits and other types of collaborative activities can be discussed directly with any of the contacts given in the previous sections.

TOP Information

Most of the up-to-date resources available in the field of WSPs are listed in Sections 3 and 4. In addition, the web pages of the following IWA specialised groups are excellent sources of scientific, technical and practical information:

- Waste Stabilization Ponds
  http://www.iwahq.org.uk/template.cfm?name=sg16
- Small Water and Wastewater Systems
  http://www.iwahq.org.uk/template.cfm?name=sg28
- Use of Macrophytes in Water Pollution Control
  http://www.iwahq.org.uk/template.cfm?name=sg13
- Water Reuse
  http://www.iwahq.org.uk/template.cfm?name=sg14

TOP Research facilities

Research on WSPs and related technologies are currently being carried out at the following facilities in South America and Asia:

- The research station on wastewater treatment located in Campina Grande, Paraíba, Brazil − Estação Experimental de Tratamentos Biológicos de Esgotos Sanitários (EXTRABES), Universidade Federal de Campina Grande.
- The research facilities at pilot-scale at the Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil.
- The research station on wastewater treatment and reuse located in Ginebra, Valle del Cauca, Colombia − Estación de Investigación en Tratamiento de Aguas Residuales y Reuso, Acuavalle S.A. ESP and Instituto Cinara, Universidad del Valle, Cali.
- The research facilities at pilot- and full-scale located at the Instituto Mexicano de Tecnología del Agua (IMTA), Jiutepec, Morelos, Mexico; and
- The research facilities at pilot- and full-scale at the Asian Institute of Technology, Klong Luang, Thailand.

TOP Past and future events

The most important past events related to WSPs technology are listed in the section about 'Conference Proceedings'. Two more recent events are:

The International Seminar on Natural Wastewater Treatment, Cartagena, Colombia, 1−3 October 2003. The selected proceedings of this event, including papers on WSPs technology in South America, are due to be published in 2005 in the Water and Environmental Management Series of the International Water Association.

The Sixth International IWA Conference on Waste Stabilization Ponds, Avignon, France, 27 September − 1 October 2004. The selected proceedings of this event will be published in Water Science and Technology in 2005.

Details on future IWA Conferences on WSPs will be available at www.iwahq.org.uk (click on 'Events').

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About IRC

IRC facilitates the sharing, promotion and use of knowledge so that governments, professionals and organisations can better support poor men, women and children in developing countries to obtain water and sanitation services they will use and maintain. It does this by improving the information and knowledge base of the sector and by strengthening sector resource centres in the South.

As a gateway to quality information, the IRC maintains a Documentation Unit and a web site with a weekly news service, and produces publications in English, French, Spanish and Portuguese both in print and electronically. It also offers training and experience-based learning activities, advisory and evaluation services, applied research and learning projects in Asia, Africa and Latin America; and conducts advocacy activities for the sector as a whole. Topics include community management, gender and equity, institutional development, integrated water resources management, school sanitation, and hygiene promotion.

IRC staff work as facilitators in helping people make their own decisions; are equal partners with sector professionals from the South; stimulate dialogue among all parties to create trust and promote change; and create a learning environment to develop better alternatives.

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