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Septic tanks, baffled facultative ponds and aerated rock filters: a high-efficiency low-cost wastewater treatment system for small communities up to ~500 p.e.

ABSTRACT

A low-cost high-efficiency wastewater treatment system for small communities up to ~500 p.e. is described. The treatment process comprises a septic tank, a secondary facultative waste stabilization pond and an aerated rock filter. For a wastewater flow of 200 litres per p.e. per day and a BOD contribution of 50 g per p.e. per day the expected final effluent quality is ~5 mg BOD, ~5 mg SS and ~4 mg ammonia-N per litre. The overall land area requirement is ~6 m^2 per p.e., although in southern Europe it would be less (~5 m^2 per p.e.). The cost of such a WWTP in the UK, including the cost of the land, is around GBP 375 (approx. EUR 600) per p.e.

KEYWORDS: Aeration; Baffles; Facultative ponds; Rock filters; Septic tanks; Small communities; Waste stabilization ponds; Wastewater treatment

INTRODUCTION

Wastewater treatment for small communities of a few hundred people is often both expensive and problematic. Natural treatment systems, such as waste stabilization ponds (WSP) and constructed wetlands (CW), which use little or no electrical energy are generally more appropriate than energy-intensive processes, such as activated sludge, as they are cheaper to construct, operate and maintain (Tables 1 and 2) and they also have the additional advantage of requiring the removal of well-mineralised excess sludge only intermittently.

The purpose of this short technical note is to draw together the results of recent research into WSP and rock filters to provide a coherent set of recommendations for the design of a low-cost high-performance natural wastewater treatment plant (WWTP) serving up to ~500 p.e. There are many communities of below this size in Europe and many of these have no (or inadequate) wastewater treatment facilities.

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THE PROPOSED TREATMENT SYSTEM

The WWTP proposed for up to ~500 p.e. comprises a septic tank, a baffled secondary facultative pond and an aerated rock filter. If the local environmental regulator does not specify an effluent standard for ammonia-nitrogen, then the rock filter need not be aerated.

Table 1: Capital and O&M costs of various wastewater treatment processes for a population of 1000 in France in 1996 [2]

Treatment process	Capital costs (FFR p.e.$^{-1}$)[a]	O&M costs (FFR p.e.$^{-1}$ year^{-1})[a]
Activated sludge	1490	75
Trickling filter	1165	45
Rotating biological contactor	1420	45
Aerated lagoon	835	40
Vertical-flow CW[b]	1250	35
Waste stabilization ponds	765	30

[a] Average exchange rates in 1996: FFR 1 = 0.16 ecu = GBP 0.12 [19].
[b] Two-stage vertical-flow constructed wetland receiving raw wastewater.

Table 2: Capital and O&M costs of various wastewater treatment processes for a population of 500 in Germany in 1996 [6]

Treatment process	Capital costs (DEM per person)[a]	O&M costs (DEM per m^3)[a]
Activated sludge	2,000	2.00
Trickling filter	1,500	1.70
Aerated lagoon	1,200	1.70
Horizontal-flow CW	1,500	1.30
Vertical-flow CW	1,200	1.50
Waste stabilization ponds	700	1.20

[a] Average exchange rates in 1996: DEM 1 = GBP 0.43 = 0.53 ecu [19].

Septic tank

Primary treatment in a septic tank is both efficient, with ~40 percent BOD removal and ~60 percent suspended solids (SS) removal, and inexpensive. The technology is well understood and sludge removal at approximately yearly intervals is straightforward. In the UK prefabricated cylindrical septic tanks are available in sizes up to 72,000 litres.[2] These will serve different populations depending on national septic tank codes. For example, the UK code [4] gives the following design recommendation for the volume of a septic tank (V, litres) depending on the population or population-equivalents (p.e.) served (P):

$$V = 180P + 2000 \qquad (1)$$

Equation 1 assumes that the wastewater production is 180 L p.e.$^{-1}$ d^{-1}. However, British Water [5] now recommend a design value of 200 L p.e.$^{-1}$ d^{-1}, so equation 1 can be rewritten and rearranged as follows:

$$P = \frac{V - 2000}{200} \qquad (2)$$

Thus a 72,000-litre septic tank followed by one of 36,000 litres (i.e., effectively a two-compartment septic tank, with the first compartment having twice the volume of the second compartment, as recommended in most septic tank codes) can serve a population of:

$$P = \frac{(72\,000 + 36\,000) - 2000}{200} = 530 - \text{say, } 500$$

Baffled facultative pond

Facultative ponds are designed on the basis of a surface BOD loading rate (λ_S, kg ha^{-1} d^{-1}), the design value for which is a function of temperature (T, °C), usually taken as the mean temperature of the coldest month, as follows [12]:

$$\lambda_S = 350(1.107 - 0.002T)^{T-25} \qquad (3)$$

For design temperatures of ≤8°C a value of λ_S of 80 kg ha^{-1} d^{-1} is used [1, 7, 13]. The mid-depth area of the pond (A, m^2 p.e.$^{-1}$) is given by:

$$A = \frac{10C_{BOD}}{\lambda_S} \qquad (4)$$

where C_{BOD} is the BOD contribution in g p.e.$^{-1}$ d^{-1}. Thus in northern Europe, assuming a BOD contribution of 50 g p.e.$^{-1}$ d^{-1} and 40 percent BOD removal in the septic tank, the mid-depth area of a secondary facultative pond is given by:

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[2] *Titan Pollution Control, West Portway, Andover, Hampshire SP10 3LF, UK (www.titanpc.co.uk).*

$$A = \frac{10(0.6 \times 50)}{80} = 3.75 \text{ m}^2 \text{ p.e.}^{-1}$$

Despite the definition in the Urban Waste Water Treatment Directive [8] of 1 p.e. as 60 g BOD p.e.$^{-1}$ d^{-1}, a BOD contribution of 50 g p.e.$^{-1}$ d^{-1} is actually conservative for small communities. In rural France, for example, it has been found to be 35−40 g p.e.$^{-1}$ d^{-1} [22].

Baffling the pond with two or four baffles, each with a length equal to 70 percent of the pond width, improves pond performance considerably [3, 24], so at least two baffles should be provided.

Aerated rock filter

Rock filters have been used to 'polish' maturation pond effluents in the United States for over 30 years [17, 18, 20, 23, 25]. Rock filters should be considered an integral part of a WSP system, just as secondary sedimentation tanks are considered an integral part of an activated sludge system, since they both serve the same purpose: the removal of biomass produced in the preceding biological treatment stage (bacteria in the case of activated sludge and algae in the case of WSP).

BOD and SS removals in rock filters are good and related to the hydraulic loading rate on the filters (HLR, m^3 of pond effluent per m^3 of rock filter volume per day − i.e., d^{-1}), as follows (based on the data in [23]):

$$R_{\text{BOD}} = 72 - 109(\text{HLR}) \tag{5}$$

$$R_{\text{SS}} = 97 - 137(\text{HLR}) \tag{6}$$

where R_{BOD} and R_{SS} are mean percentage removals of BOD and SS, respectively. However, ammonia removal is essentially zero as the rock filters rapidly become anoxic. To permit ammonia removal by nitrification Mara & Johnson [16] developed an aerated rock filter to polish the effluent from a primary facultative pond (rather than a maturation pond) in the UK; the HLR on the filter was 0.3 d^{-1} (equivalent, for a wastewater depth in the filter of 0.6 m, to 1 m^2 p.e.$^{-1}$). Aeration achieved good removal of ammonia-N (>50% *vs.* −150−50% in the unaerated filter), and also significantly improved BOD and SS removals (>75% and >80%, respectively, *vs.* 0−75% and 25−80% in an unaerated rock filter; equations 5 and 6 predict 40% and 56%, respectively, for the latter operated at an HLR of 0.3 d^{-1}). Subsequent work [10, 11, 14, 15] has demonstrated that aerated rock filters outperform subsurface horizontal-flow CW and maturation ponds in terms of BOD, SS and ammonia-N removals in both winter and summer.

The expected mean effluent quality from the aerated rock filter is ~5 mg BOD, ~5 mg SS and ~4 mg ammonia-N L^{-1}, so that the proposed system is able to comply with an effluent quality requirement of ≤10 mg BOD, ≤15 mg SS and ≤5 mg ammonia-N L^{-1}, which has been set in England, for example, by the environmental regulator, the Environment Agency, for some small WWTP [9]. It also complies with the D4 requirement in France [2].

Footprint

The 72,000-litre and the 36,000-litre septic tanks are 15 and 8 m long, respectively, and both have a diameter of 3 m, so they occupy an area of ~70 m^2 − i.e., 0.14 m^2 $p.e.^{-1}$. The areas of the secondary facultative pond area and the rock filter are 3.75 and 1 m^2 $p.e.^{-1}$, respectively. Thus the total area is 4.9 m^2 $p.e.^{-1}$. Allowing for space between the reactors, the pond embankments and access, the overall land area requirement for this WWTP for 500 p.e. is ~3000 m^2 (~6 m^2 $p.e.^{-1}$). In southern Europe, where winter temperatures are higher and correspondingly higher BOD loadings can be applied to the facultative pond, the area will be slightly less − for example, in Cyprus the mean temperature of the coldest month is 11°C, so a loading of 110 kg BOD ha^{-1} d^{-1} would be used and the area would be 2.73 m^2 $p.e.^{-1}$; thus the overall area of the whole WWTP for 500 p.e. would be ~2500 m^2 (~5 m^2 $p.e.^{-1}$).

Costs

Land costs are low − for example, in the UK the cost of 'bareland' (i.e., farmland with no buildings on it) is around GBP 7500 (approx. EUR 12,000) ha^{-1}, so the land cost for the WWTP (6 m^2 $p.e.^{-1}$) is only GBP 4.50 (approx. EUR 7.20) $p.e.^{-1}$ [21]. The UK cost of the two-tank (76,000 and 36,000 L) septic tank system, including delivery and installation, for a village of ~500 people is around GBP 75 (approx. EUR 120) $p.e.^{-1}$ [13]. The construction cost of a secondary facultative pond and an aerated rock filter in the UK is around GBP 300 (approx. EUR 480) $p.e.^{-1}$ [14]. Thus the total cost of the WWTP is around GBP 375 (approx. EUR 600) $p.e.^{-1}$.

CONCLUSIONS

The wastewater from small communities of up to ~500 p.e. can be treated to a high standard at low cost by using a treatment system comprising a septic tank, a baffled secondary facultative pond and an aerated rock filter. The overall land area requirement is ~6 m^2 $p.e.^{-1}$.

Aeration of the rock filter permits the removal of ammonia-nitrogen by nitrification, but it uses electrical energy and so increases operational costs. However, much less land is needed than would be required for maturation ponds (5 m^2 $p.e.^{-1}$ in France [7]), and the process works well both in summer and in winter [16]; so it is likely in most circumstances to be a price worth paying. Aeration is not required if the local environmental regulator does not set a standard for effluent ammonia.

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