SIMPLIFIED OPTIMAL DESIGN OF THE WASTE STABILIZATION POND

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Abstract. A graphical method was applied to cost minimization in the waste stabilization pond subject to area, depth and efficiency constraints. The solution have the values of area, cost and depth at optimality. The paper also compared the optimal solutions for both plug-flow and completely-mixed flow models. Although the optimal depths for the design data considered was the same for the two models, the plug-flow model cost only one-fifth of that of completely-mixed flow model. The area occupied by the latter was found to be four times larger.

1. Introduction

The Waste Stabilization Pond (WSP) is a treatment system with many advantages over the conventional treatment systems. Such advantages among others include high treatment efficiency, low operational and maintenance cost and the ability to withstand shock loads.

However, its usefulness is greatly reduced by its large land requirement especially in the urban areas where land is scarce and costly. This problem has made some researchers consider the possibility of designing efficient ponds with larger depths (Hosetti and Patil, 1987).

Studies show that pond depth could be increased beyond the generally acceptable value of 0.9 to 1.5 m particularly in tropical countries where enough light is available (Hosetti and Patil, 1987; Oragui et al., 1987; Silva et al., 1987). Despite the small area/depth ratios of deep ponds, which induces a significant degree of short-circuiting deep ponds have achieved very high removals of BOD, excreted bacteria and viruses (Oragui et al., 1987; Silva et al., 1987). Besides, they permit rapid dispersion of the incoming wastes thus avoiding shock loading effects and minimizing the resuspension of solids from the bottom of the pond.

However, the deeper the pond, the lower the bacterial die-off rate (Sarikaya and Saatci, 1987; Sarikaya et al., 1987; Mayo, 1989) which in turn reduces the pond efficiency. Silva et al., (1987) has shown that although shallow ponds produce far better effluents than deeper ones at equal detention time, the former require a larger area to treat waste of equal strength. Hence, there is the need to always strike a compromise during design between efficiency and area needed. Such a compromise may be arrived at through an optimization technique which will not only yield a design at a minimum cost but also satisfy the constraints imposed on it by land requirement and efficiency.

This project shows how this optimal design could be achieved by a graphical
method. Not only is it simple, the graphical method illustrates with unique clarity the relationship between the various variables and allows for the imposition of constraints whose state equations are lacking.

2. Problem Formulation

The method developed here can be applied to any pond system, single or in series. However, for simplicity, consider a typical single WSP.

The mathematical formulation for the pond is shown as follows:

Minimize \( C = a_1 A^2 + a_3 Ah \)  

Subject to  

(Constraints)  

\( A \leq A_0 \)  

\( E_1 \leq N_e/N_0 \leq E_2 \)  

\( r_1 \leq L/W \leq r_2 \)  

\( h_0 \leq h \leq h_1 \)  

where \( C \) is the cost function (\$); \( A \) is the surface pond area (m²); \( N_0 \) and \( N_e \) are the bacteria number at the pond inlet and outlet, respectively; \( L, W, \) and \( h \) are the pond length, width and depth, respectively; \( A_0, r_1, r_2, h \) and \( h_2 \) are the stipulated limits; and \( a_1, a_2, a_3 \) are constants.

Equation (1), the cost function, is assumed to include capital cost, construction, maintenance and operation costs. While Equation (2) is the constraint due to area limitation, Equation (3) expresses the condition the effluent must satisfy before it is disposed off. This also is related to the efficiency of the pond. In practice this will depend on where the affluent is disposed off. The constraints in Equation (4) is imposed on the problem to achieve a better flow pattern and so reduce secondary currents. The limits on the depth are given by Equation (5).

The limits of the constraint equations are important and they are derived from theory and practice. \( A_0 \) will solely depend on land availability on the community for the project. \( E_1 \) and \( E_2 \) may be taken as 0.00007 and 0.1, respectively. The lower limit corresponds to the highest efficiency (99.99993%) attained (Mara et al., 1983). Therefore,

\[ 0.00007 \leq N_e/N_0 \leq 0.1. \]  

From the literature most FWSP have \( L/W \) ratio between 1 and 4 (Polprasert et al., 1983; Marecos do Monte and Mara, 1987; Finney and Middlebrooks, 1980) whereas for pilot-scale ponds it is between 1 and 13 (Mara and Silva, 1979; Oragui et al., 1987; Polprasert et al., 1983). For secondary facultative and maturation ponds the range of \( L/W \) is suggested to be \( 10 \leq L/W \leq 20 \) to approximate plug flow condition whereas for primary facultative and anaerobic ponds \( L/W < 3 \), to avoid sludge back forming near the inlet (Mara and Pearson, 1987). Hence, the general