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WATER, SANITATION AND HYGIENE: CHALLENGES OF THE MILLENNIUM

Waste stabilization ponds – design guidelines for Southern Pakistan

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Introduction and methodology

In Southern Pakistan, comprising the whole province of Sindh and southeastern parts of Baluchistan province, the treatment of municipal wastewater has, traditionally, been carried out in three feet shallow oxidation ponds. Official records show that 83 urban and 208 rural wastewater treatment plants based on this traditional method are in operation in this region. But, due to lack of proper design guidelines and poor maintenance, these ponds, at many places, are not serving with full efficiency.

Waste Stabilization Ponds, due to their simple but very effective treatment mechanism, are getting increasingly popular especially in tropical and subtropical countries. In Southern Pakistan, this system can also prove to be successful if greater attention is paid at design stage. Because, where properly maintained, the above mentioned traditional method of wastewater treatment, has proved to be very successful in BOD reduction of up to 80% with the retention time of 7 days.

This study was conducted to establish proper design guidelines for installation of Waste Stabilization Pond System in southern parts of Pakistan. For this purpose a typical representative town was selected for establishing design parameters for the whole region considering its climatic conditions, groundwater level, population growth rate and socio-economic conditions. After collection of all the required data, the study ultimately led to a very practicable design procedure for the installation of an efficient waste stabilization pond system in the southern parts of Pakistan.

Waste stabilization pond system

Waste Stabilization Ponds System consists of a series of anaerobic, facultative and maturation ponds; in which there is a continuous in and out flow of wastewater. In this system wastewater is treated by natural process based on the activities both algae and bacteria. Ponds in this system are classified according to the relative dominance of two processes i.e., anaerobic digestion and aerobic bacterial oxidation by which organic material (BOD) suspended solids and bacteria are removed.

Anaerobic ponds operate under heavy organic loading rates and rely totally on anaerobic digestion to achieve organic removal. Facultative ponds operate under a lighter organic load enabling algae to develop in the surface layer and an oxy-pause to form. Below the oxy-pause anaerobic conditions persist, whereas, above the oxy-pause aerobic bacterial oxidation occurs in the symbiosis as shown in figure-1. Both the anaerobic and aerobic processes are highly temperature dependent, increasing logarithmically with a linear increase in temperature (Oswald, 1968). In maturation ponds, faecal indicator bacteria and pathogenic bacteria are removed mainly due to starvation and hostile environment. Detention time is the key factor in these ponds. Some other factors such as temperature, UV irradiation and oxidation also play their part (Arthur, 1983).

Pond design factors

The factors, which govern the size and layout of a pond system, are:

i) The volume of sewage to be treated
ii) The strength of sewage to be treated
iii) The desired quality of the final effluent from pond system
iv) The climate
v) The number of ponds

The volume of sewage depends firstly on the estimated population to be served at the end of the design life of the system and secondly on the quantity of water used by each person.

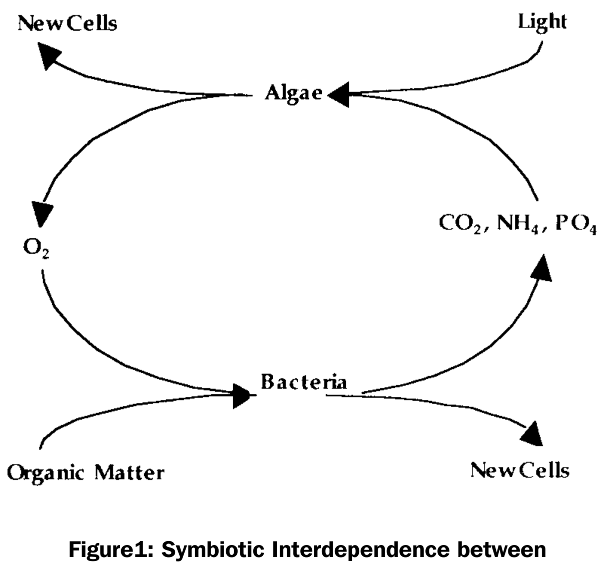

Figure1: Symbiotic Interdependence between Algae and Bacteria

The strength of sewage depends on the content of the organic material and is measured in terms of BOD. The BOD in the sewage varies according to the diet and how much food waste is disposed off through the sewers. In most tropical countries it is taken roughly as 40 gm per person per day (Mara, 1978). Table-1 shows the strength of wastewater with respect to BOD.

The desired quality of the final effluent from the pond system depends on the use to which effluent is to be put or how it is to be disposed off. The quality of effluent is judged in terms of BOD, suspended solids and number of faecal coliforms per 100 ml of effluents. However, the usual effluent standards are:

i) BOD ≤ 25 mg/litre
ii) Suspended solids ≤ 30 mg/litre
iii) Faecal Coliforms ≤ 100/100 ml

Climate plays a major role in the treatment of waste in the pond system. Temperature and sunlight are essential for algal growth, which in turn due to photosynthesis, consumes CO_2 from decomposed organic matter and produce oxygen thus reducing BOD. Wind also plays a role by creating a vertical mixing in ponds, which ensures uniform distribution of algae and dissolved oxygen. Excessive wind, on the other hand, may take all the algae to accumulate on one side, which may affect the BOD removal efficiency.

Number of ponds depends upon the quantity of wastewater. However, in a well designed system these are at least two anaerobic ponds followed by one or two secondary facultative ponds and one or more maturation ponds. The number of maturation ponds may increase depending upon the degree of pathogen removal required.

Table 1: Strength of Wastewater with respect to BOD

Strength	BOD (mg/l)
Weak	200 or less
Medium	350
Strong	500
Very Strong	750 or more

General features of Southern Pakistan

Location

As already mentioned, the Southern Pakistan comprises mainly the province of Sindh, which lies between the 23rd and 29th North latitudes and the 67th and 70th parallel east longitude. Except for the narrow coastal strip of about 240Km in the southwest along the Arabian Sea, the region is surrounded by land all sides. In the south, is the border of Rann of Kachh and the Gujrat state of India, the eastern boundary extends towards Rajasthan (India), while Punjab and Baluchistan provinces of Pakistan lie in the north and west respectively.

Climate

Being located in the sub-tropic belt, the climate of the area is predominantly warm i.e., ideal for waste stabilization pond system. Monthly mean temperature varies from 35°C maximum to 19°C minimum. The predominant season is summer while rains fall during the months of July to mid September.

Population

According to 1998 census, the population of Sindh Province is 30.44 millions out of which 45% people lived in urban and 55% in rural areas. The density of population per square kilometer is about 200 persons.

Position of Ground Water Table

The data (WAPDA,1991) shows that only 2.87% of the total area has water table at depth equal or less than 90 cm. While 19.32% of area has water table at depth between 90 to 150 cm below ground surface. The remaining 77.81% of area have water depth below 150 cm. These values indicate that the pond system will have no difficulty in working in this region.

Beside this, ample sunlight, windy conditions, availability of cheap land, construction material and expertise and high demand of effluent water for irrigation are the added factors, which may make the pond system the most appropriate, economically viable and technically sustainable system of wastewater treatment in this region.

Design Guidelines for Southern Pakistan

Since Southern Pakistan is a very vast area, separate design guidelines for each town or village is very difficult to formulate. However, in order to explain pond design guidelines and their applicability in the region, a typical town was selected from the centre of the region considering its population growth rate matches with other parts of the region, its climate represent the major portion of the area, and its socio-economic conditions and groundwater level matches with the regional average. For designing purposes the following parameters were identified of the selected town:

Temperature (T)

The pond design is made by considering the minimum mean monthly temperature. In regions subjected to prolonged cloud cover and high temperatures, special considerations are made. The average monthly mean temperature of the town selected for this study varies from 20.25°C minimum to 35.5°C maximum. Since, for the larger period, hot climate persists, a conservative value is taken as,

$$T = 25^{o}C$$

Population (Pe)

According to 1998 census, the population of selected town was 37500 persons, with a growth rate of 2.33%. Since, waste stabilization pond system is usually designed for 20 years period, the expected population for next twenty years will be:

$$Pe = 60{,}000.$$

Wastewater Contribution Per Capita per Day (Wwc)

This should be measured very carefully because the size of pond system i.e., the cost, is directly proportional to the flow. A moderate value of wastewater contribution per capita per day including infiltration losses, for this study is assumed as,

$$Wwc = 70 \text{ Litres / Capita/ Day}$$

BOD Contribution Per Capita Per Day (BOD)

The values of BOD, usually, vary between 30 and 70gm per person per day, depending on type of diet. For this particular region and selected town it is taken as,

$$BOD = 40 \text{ gm/capita/day}$$

Total Organic Load (B)

Total organic load can be calculated as,

$B = Pe \times BOD$ **Eq-1**

Putting the above given values of Pe and BOD, Total organic load B will be,

$$B = 2400 \text{ Kgs/day}$$

Total Influent BOD Concentration (Li)

Total influent BOD concentration (Li) can be calculated from the following equation (Mara, 1978),

$Li = B/Q$ **Eq-2**

or $Li = B / (Wwc \times Pe)$

Putting the given values of B, Wwc and Pe,

$$Li = 571 \text{ mg/l}$$

Volumetric Loading (λv)

The design of first pond in the series i.e., anaerobic pond is based on the volumetric loading, which normally ranges between 100 (at temperatures below 12°C) and 400 gm/ m^3/day (at temperatures above 25°C). But for this particular study the following relationship was obtained with the help of the graph drawn by Mara (1978) i.e.,

$\lambda v = [300(T-12)/18] + 100$ **Eq-3**

Putting the value of T in above equation,

$\lambda v = 316.66 \text{ gm/m}^3\text{/day}$

Influent Bacterial Concentration (Bi)

Bacterial concentration in an influent ranges between 10^7 to 10^9 faecal coliforms per 100 ml. Geldreich (1970) proposed a conservative value of this as,

$$Bi = 1 \times 10^8 \text{ faecal coliform per 100 ml}$$

Required Effluent Standards

It is assumed that the effluent will be consumed for unrestricted irrigation. Therefore, the following effluent standards are required:

i) Faecal coliforms in effluent; $Be \leq 100$ FC/100 ml

ii) Effluent BOD; $Le \leq 25$ mg/litre

Design of Anaerobic Ponds

The volume of the anaerobic ponds (**Va**) in m^3 is computed by using the formula of Mara and Pearson (1987) i.e.,

$Va = (Li\ Q)\ \lambda V$ **Eq-4**

Putting the values in Eq-4, **Va** will be,

$$Va = 7573.42 \text{ m}^3$$

The retention time is normally taken as two days and depth 2.5 meters. Desludging may be needed in 2 to 5 years, therefore, two ponds are often arranged in parallel to allow one pond to be taken out of service for desludging.

Detention Time t*a	$=Va/Q \cong 2$ days
No. of ponds, na	=2 (say)
Volume of each pond	=Va/2
	$=3786.71$ m^3
Assuming depth of each pond	=2.5 m

Therefore, the area of each anaerobic pond will be:

$\cong 1515$ m^2 (say)

Also provide one extra pond to be used during repair/ desludging. Thus,

Total no. of anaerobic ponds	= 3
Total area of anaerobic ponds	=4545 m^2

BOD removed in anaerobic ponds can be calculated from the following relation:

% BOD removal	= 2T+20
i.e.,	=70%
To be conservative, say	=55%

Design of Facultative Ponds

These ponds are usually designed by considering the maximum BOD load per unit area at which the pond will still have a substantial aerobic zone, because, biological activity is dependent on the temperature. McGarry and Pescode (1970) has given the following equation for this areal or surface BOD loading (1S):

$\lambda S(max) = 60.3\ (1.099)^{T-20}$ **Eq-5**

Where $\lambda S(max)$ is maximum surface BOD loading in Kg/ha/ day and T=Minimum monthly mean temperature. Eq-5 was modified by Mara and Silva (1979) as,

$\lambda S = 20T - 120$ **Eq-6**

Eq-6 was further changed by Arthur (1983) especially for hot climates i.e.,

$\lambda S = 20T - 60$ **Eq-7**

Putting the value of T in Eq-7,

$$\lambda S = 440 \text{ Kg/ha/day}$$

Assuming 55% BOD removal in anaerobic ponds, influent BOD to facultative ponds will be 45% i.e., 45% of Li or $Li = 0.45 \times 571$

$$Li = 257 \text{ mg/litre}$$

The mid-depth area of the facultative ponds (Af) in m^2 may be calculated by using the following formula (Mara and Pearson, 1987)

Af=(10 x Li x Q) / λS **Eq-8**
Putting the values in Eq-8,

$Af=24532\ m^2$

Assuming mid-depth = df=1.75 m, the volume of facultative ponds Vf will be 24532 x 1.75
i.e., ***$Vf=42931\ m^3$***

Detention time t*f = Vf/Q ≅ 11 days

The rate of removal of BOD in facultative ponds is generally between 70% at tropical conditions, i.e.,

70% of incoming 45% i.e., about 31.5%.
Therefore, the cumulative BOD removal is,
55 + 31.5 = 86.5%

No. of facultative ponds nf =2, therefore,
Area of each pond = 24532/2 = 12266 m^2
Volume of each pond= 42931/2 = 21465.5 m^3

Design of Maturation Ponds

The number and size of maturation ponds in a system depend upon the bacteriological quality required of the effluent. The number of faecal coliform bacteria per 100 ml of the effluent (Be) can be estimated by the following equation (Mara and Pearson, 1987):

$Be = Bi / (1+K_{B(T)}t^*)$ **Eq-9**

Where Bi=Bacterial concentration in no. of FC /100 ml of influent, t* = Detention time and $K_{B(T)}$ =First order FC removal rate constant in T°C per day and is computed as,

$K_{B(T)} = 2.6\ (1.19)^{T-20}$ **Eq-10**

By putting the value in Eq-10, the first order FC removal rate constant T°C per day will be,

$K_{B(T)} = 6.2$

The number of faecal coliforms per 100 ml can be calculated for the effluent from each pond in the series with the help of Eq-9, but the number of faecal coliforms in the effluent from the last pond of the series can be found from the following equation (Mara and Pearson, 1987)

$Be=Bi/(1+K_{B(T)}t^*a)(1+K_{B(T)}t^*f)\ (1+K_{B(T)}t^*m)^n$ **Eq-11**

Where t*a, t*f and t*m are the detention times of the anaerobic, facultative and maturation ponds respectively and n is the number of maturation units in the series.
Assuming 2 six-day-retention maturation ponds,
t*m = 6 days and nm = 2 ponds
Bacterial concentration in No. of FC/100ml of effluent can be calculated from Eq-11, i.e.,

Be= 73.90 FC/100 ml

(This is better than the required)
Volume of each pond Vm=Q xt*m=25200 m^3
Total volume **Vm**= 25200 x 2

$Vm = 50400\ m^3$

Assuming depth of ponds = 1.5 m
Area of maturation ponds= Vm/1.5=16800 m^2
Total Area Am= 16800 x 2

$Am= 33600\ m^2$

Probable cumulative BOD removal at higher temperatures is 96% after maturation ponds, therefore, effluent BOD i.e., Le = 4% of 571 mg/litre. I.e., ***Le= 23 mg/l***

This is even lower than the required.

Effluent Re-use

Since the pond effluent satisfies the standards for unrestricted irrigation, it can be used to grow crops like sugarcane, wheat, vegetables etc. The discharge quantity of 4200 m3/ day can approximately irrigate 125 hacters. Also, this water can be used for fish farming.

Physical Design and Operational Guidelines

Certain physical and geo-technical considerations are very important to be kept in mind during planning, designing and construction of a pond system. Such as proper pond location, thorough soil investigation, appropriate pond embankment, stable and strong pond base and well designed geometrical parameters of the pond system. Similarly after construction, well-planned start-up, proper and reliable monitoring and adequate maintenance are very essential for the smooth operation of the pond system.

Conclusions

The above study has yielded the following three main conclusions:

1) Traditional wastewater treatment plants in southern Pakistan, which are malfunctioning, due to poor design, operation and maintenance can be replaced by waste stabilization ponds.
2) Waste Stabilization Ponds may prove to be the appropriate wastewater treatment option in the southern parts of Pakistan due to cheap land, ideal climatic conditions, low construction costs, easy operation and maintenance, no or very little need of power and spare parts.
3) If proper design guidelines are followed, good quality effluent can be achieved for unrestricted irrigation such as sugarcane, wheat, vegetables etc. and fish farming. This will also help to overcome partly the current shortage of irrigation water in the region.

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