

## Waste Stabilization Ponds in India<sup>1</sup>

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### INTRODUCTION

Many of the communities in the underdeveloped countries of the world do not have modern sanitary facilities, due to lack of funds. Thus, they have to cling to the old conservancy system which is hazardous to human health. Labor is inexpensive in these countries, whereas technicians are quite scarce and demand high wages. The conventional types of sewage-treatment plants are, therefore, prohibitive. Thus, even after construction of sanitary sewerage systems, many communities cannot afford to operate them. Recently, waste-stabilization ponds have been developed to meet the needs for sewage purification with low construction and operation costs and with a minimum of maintenance.

Various design criteria and operational methods have been developed for waste-stabilization ponds in the USA. Such ponds, designed and operated on these criteria, cannot give satisfactory results in geographic locations having extremely different climate and human culture. It is possible to design waste-stabilization ponds for such locations by studying the climate and human culture in the desired area and then modifying the design criteria and operational methods developed in the USA accordingly.

This paper has been directed toward developing design criteria for waste-stabilization ponds in India. Initially, a survey was made of the work done thus far in the USA on the waste-stabilization-pond method of sewage treatment.

Some of the design criteria and operation principles were modified for the design of waste-stabilization ponds in India, according to the climatic conditions and human culture. The changed conditions due to climate have been considered broadly and are typical of northern and central India. They are representative of climatic conditions in many parts of India. In actual practice the climate may differ slightly for a particular area and some modifications in the design and operation may have to be made, as a result of experience from operation of local waste-stabilization ponds.

Only those aspects of design and operation which are affected by the change in geographic location or human culture have been considered and studied.

### DISPOSAL OF WASTE MATTER IN INDIA

For dealing with the waste matter, particularly of domestic excremental nature, the water-carriage system is best. All of the waste products are rapidly flushed by the force of water into sewers and carried away to a place for final disposal or treatment. Most of the cities and towns in India (particularly with population below 50,000) have conservancy or dry systems. Night soil and other waste matter is collected in pails or baskets and carried away by sweepers for final disposal. The conservancy system is a potential danger to public health. Some of the cities have recently constructed sanitary sewers. In the absence of treatment plants, these cities dump their wastes directly into streams, rivers, or ditches. Thus, the water-pollution problem is on the increase.

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The lack of money is the chief cause for not having sewage-treatment plants. As the situation stands, India cannot afford to have conventional treatment plants such as digesters and trickling filters in many of the cities and towns, and especially not in the villages or rural areas. Machinery, mechanical or electrical equipment, and technicians are very costly, whereas labor is very cheap and easily available.

Waste-stabilization ponds can be constructed and operated at a comparatively low cost, since land and labor are normally cheap in small cities and towns. In India, the earthwork type of construction is done by manual labor using shovels and spades. A person can be hired at the rate of 2.00 to 2.50<sup>1</sup> (\$0.27 to 0.34) Rupees a day. A technician such as a motor repairer or a crane operator will cost about 5.00 Rupees (\$0.68). Most of India enjoys a suitable climate for the satisfactory operation of the waste-stabilization ponds. Effluent from the stabilization ponds can be used for the irrigation of the crops wherever possible.

*Climatic Conditions and Habits of People*—Before designing the treatment plant it is necessary to know the climate and the habits of the people. In India the average winter and summer temperatures are much higher than in USA. The average temperature during winter is 60 F. In summer the average temperature is 80 F (Hammond, 1962). The temperature during the summer often reaches as high as 110 or 115 F. Except on mountains, snowfall is not known. For most of the year the weather is clear. Cloudy to partly cloudy weather appears during the rainy season or in the later part of the year. For most of the year the sunshine is very bright. Normally, summer months are very dry with hot winds and gales. The average rainfall is about 20 to 40 inches (Hammond, 1962).

The annual surface evaporation for central and northern India is about 130 inches (Sharma, 1946b). Average seepage rate is about ¼ inch/day. Thus, the total annual losses may be taken as 18.5 ft.

The habits of the people of India are different from those in the USA. Water consumption per capita is low. In towns where water supply has been provided and industries are growing, the consumption is gradually increasing.

Pots and pans are normally cleaned by ash or sand (Deshpande, 1951). The quantity of settleable solids thus increases, as part of it may go down the drain, even with all precautions. The net digested sludge may be taken as 3,650 ft<sup>3</sup>/1,000 persons/year. In a stabilization pond of 1.5 acres, this will mean a sludge build-up of 0.05 ft./year. Most people use water instead of toilet paper for ablution. The B.O.D. of the average sewage may be 360 ppm (Deshpande, 1951).

#### DESIGN FORMULATIONS

Probable values of available light energy can be predicted from Table I and photosynthetic efficiencies estimated. The quantity of oxygen that can be produced for a given efficiency may be found from the formula (Oswald et al., 1957)

$$WO_2 = (F \times S \times D \times A) / 3.68$$

where  $WO_2$  is the weight of oxygen in milligrams,  $S$  the amount of visible solar energy which penetrates a smooth water surface in cal/cm<sup>2</sup>/day,  $F$  the efficiency of light-energy conversion to chemical energy (expressed in decimal), 3.68 represents the energy needed in calories to produce 1 mg

<sup>1</sup>The dollar value for Indian currency is approximate and is based on current exchange rate. The comparison here, made on an international basis, is not realistic because of the different purchasing power at the local level.

of oxygen through photosynthesis, and  $D$  is the detention time in days. Since  $V = QD$ , where  $Q$  is the flow / day expressed in the same units as  $V$ , the pond volume  $V$  may be expressed in liters and the area  $A$  in square centimeters. The surface area for 1 liter of volume is then  $1,000/d$ , where  $d$  is depth in centimeters. Hence

$$WO_2 = (1000 \times F \times S \times D) / (3.68 \times d)$$

The actual photosynthetic efficiency attained by the pond is different from the theoretical photosynthetic efficiency. The theoretical efficiency is that which is necessary to provide sufficient oxygen to meet the total B.O.D. loading to be stabilized by photosynthetic oxygenation. It is thus termed as the critical efficiency. The actual photosynthetic efficiency is approximately equal to the calories of energy in the algal cells produced per unit volume per day divided by the amount of visible solar energy received by the pond per unit volume each day. The ratio of the actual photosynthetic efficiency is termed the "oxygenation factor," and values of 1.2 to 1.8 are considered essential for continuous maintenance of aerobic conditions. An oxygenation factor above 1.8 will cause excess algal growth, which results in the increase of pH in the pond and thus retards bacterial oxidation.

The Joint Committee of the Water Pollution Control Federation and the American Society of Civil Engineers gave the formula

$$d/D = (70 \times F \times S) / L, \quad (\text{Anon., 1959})$$

where  $d$  is the pond depth in inches,  $D$  the detention period in days,  $S$  the visible light energy penetrating the water surface in cal/cm<sup>2</sup> (obtained from published data),  $F$  the efficiency of light energy conversion to chemical energy by algae, and  $L$ , the B.O.D. in mg/l. The constant 70 includes a factor of safety such that the amount of light energy,  $S$ , will produce about two times as much oxygen as is required to oxidize 85% of  $L$ . The formulation does not include oxygen absorbed from the atmosphere at the pond surface, which, although normally negligible, would be useful in cloudy weather. The loading factor,  $d/D$ , as formulated, is in inches of depth per day. The lb./acre/day applied can be computed from the loading factor and B.O.D. of the waste.

#### DESIGN AND OPERATION

An attempt will be made to design a waste-stabilization pond for a small community in India, based on the literature study carried out in the preceding paragraphs and modifications made for Indian conditions. It is planned to use the stabilization pond effluent for crop irrigation.

In small cities or towns, the average water consumption is about 25 gal / capita/day (Anon., 1960-1961). Approximately 75% (18.6 gal/capita/day) of the water consumed reaches the sewers (Deshpande, 1951).

The quantity of infiltration water depends upon the season, length of sewer, quality of joints, soil permeability, and topographical conditions. In a tropical country like India, owing to the constant evaporation from the ground surface by capillary attraction in the heat of the sun, the sub-soil water table is low (Deshpande, 1951) and infiltration minimal, probably zero. It is possible that in the rainy season some water infiltrates into sewers. A provision ranging from 0 to 5% of dry-weather flow is made for infiltration. Thus the sewage flow may be taken as 20 gal/capita/day. The B.O.D. per capita =  $360 \times 20 \times 8.34/10^6 = 0.06$  lb./day. For the purpose of a design illustration, a population of 2,000 people is assumed. The total B.O.D./day will be  $2,000 \times 0.06$  or 120 lb. The volume of inflow/day will be 0.123 acre-ft.

The common design criteria of waste-stabilization ponds in the USA in terms of B.O.D. loading and average depth is 30 lb./acre/day and 4 ft respectively (McKinney, 1962). If the above design criteria are adopted in India, then the required area of the stabilization pond will be 4 acres. The volume of the stabilization pond will be  $4 \times 4$  or 16 acre-ft. Annual evaporation and seepage losses will be 10.9 ft + 7.6 ft or 18.5 ft. It is thus seen that the total annual loss is greater than the annual inflow and the waste-stabilization ponds designed on the basis of the above criteria will fail in India.

Design parameters of waste-stabilization ponds can also be determined by means of a loading factor,  $d/D = (70 \times F \times S)/L_s$ , (Anon., 1959), where  $d/D$  is called the loading factor, in inches of depth/day.  $S$  (average) =  $S_{\min} + (S_{\max} - S_{\min}) p$  (Oswald and Gotaas, 1957), where  $p$  is the total hours of sunshine / total possible hours of sunshine.

India is situated around latitude  $22^\circ$ . Available light energy is minimal during winters, and so the stabilization ponds designed for winter light energy will be satisfactory for the summer period, as available light energy is maximal during this period.

TABLE I. PROBABLE VALUES OF VISIBLE SOLAR ENERGY AS A FUNCTION OF LATITUDE AND MONTH (OSWALD AND GOTAAAS, 1957).

North Lat.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
0	max	255*	266	271	266	249	236	238	252	269	265	256	253
	min	210	219	206	188	182	103	137	167	207	203	202	195
10	max	223	244	264	271	270	262	265	266	266	248	228	225
	min	179	184	193	183	192	129	158	176	196	181	176	162
20	max	183	213	246	271	284	284	282	272	252	224	190	182
	min	134	140	168	170	194	148	172	177	176	150	138	120
22	max	174	206	241	270	286	286	285	273	248	218	183	172
	min	123	132	162	167	193	152	173	176	170	143	128	110
30	max	136	176	218	261	290	296	289	271	231	192	148	126
	min	76	96	132	141	184	163	178	166	147	113	90	70
40	max	80	130	181	181	286	298	288	258	203	152	95	66
	min	30	53	95	125	162	173	172	147	112	72	42	24
50	max	28	70	141	210	271	297	280	236	166	100	40	26
	min	10	19	58	97	144	176	155	125	73	40	15	7

\*Values of  $S$  in cal/cm<sup>2</sup>/day.

To determine the average value of  $S$ ,  $S_{\text{average}} = S_{\min} + (S_{\max} - S_{\min}) p$  in which  $p = \text{total hr of sunshine} / \text{total possible hr of sunshine}$ .

For Latitude  $22^\circ$ :  $p = 46\%$  in December;  $p = 51\%$  in April.

During Winters:  $S_{min} = 110$ ,  $S_{max} = 172$ ,  $p = 0.46$  (Table I);  $S_{average} = 110 + (172-110) 0.46 = 138$  cal/cm<sup>3</sup>;  $F$  may be taken as 0.04 (Oswald, 1960);  $d/D = (70 \times 0.04 \times 138)/360 = 1.072$  inches or 0.0894 ft.

Thus, the pond may be hydraulically loaded at the rate of 1.072 inches of depth/day.

The area required = 0.123 acre-ft/0.0894 ft = 1.38 acres.

The B.O.D. loading = 120/1.38 = 87 lb./acre/day.

Before choosing the depth, the following points must be considered:

- a) Generally waste stabilization ponds in the USA are constructed to operate between the depths of 3 to 5 ft (average 4 ft). Some of the stabilization ponds have been constructed with greater depths, like the one at Mojave, California, (Merz, Merrell, and Stone, 1957) which has a depth of 9 ft and has been operating successfully.
- b) Deeper stabilization ponds will provide more effluent for irrigation. In the event of a dry season, additional discharge of effluent can be obtained by lowering the depth of operation, which can be restored during favorable weather.
- c) During winter, the surface water cools faster than that near the bottom and, having greater density, sinks and mixes with the lighter, warmer water. This process, more pronounced in deeper waters and aided by wind action, tends to maintain aerobic conditions.
- d) Mixing is mainly dependent upon wind currents (Oswald et al., 1957). A shallow pond with large surface area will generally have better mixing than a deep pond with a small surface area.
- e) India has more favorable climate than the USA for deeper ponds, specially with regard to temperature and sunlight.

From the above considerations, it is clear that waste-stabilization ponds with depths of more than 4 ft can be advantageously operated in India. In spite of the example of the 9-ft-deep stabilization pond at Mojave, California, it will not be desirable to construct a 9-ft-deep stabilization pond in the beginning, unless proved by experimental operation for a particular area. Mixing by wind action may not be as satisfactory as in a comparatively shallow pond and may increase the extent of anaerobic decomposition in the pond bottom.

While 9 ft seems too deep to begin with, a depth of 4 ft will be too shallow. The sludge will build up at the rate of about 0.1 ft/year. A 4-ft-deep stabilization pond will need frequent cleaning to keep the desirable liquid depth. Also, no additional effluent will be available for irrigation during dry weather. Theoretically, a stabilization pond depth somewhere between 4 and 9 ft seems reasonable. A depth of 7 ft will be favorable under Indian conditions and need cleaning once in about 20 years, because a sludge build-up of about 2 ft will occur during this period. About a 3-ft depth of water can be obtained for irrigation in addition to normal effluent flow. In case of dry weather the operating depth can be lowered, and the effluent used. The normal depth of 7 ft can be restored during the rainy or winter season. The available depth of water will be reduced as sludge build-up occurs.

The 7-ft depth has been selected from theoretical considerations. In practice, the stabilization pond may have to be operated at slightly lesser or greater depths, depending upon local climatic conditions and the manner by which the effluent is to be disposed. It will be desirable to use deeper ponds, where found practicable by experience, particularly where

the effluent is to be used for irrigation.

The oxygen production by photosynthesis (Oswald et al., 1957)  $WO$ ,  
 $= (1,000 \times .04 \times 138 \times 1)/(3.68 \times 7 \times 12 \times 2.54) = 7.1 \text{ mg/l/day}$ .

About 40% of the above oxygen produced will be consumed by respiration of the microorganisms present in the waste-stabilization pond (Bartsch and Allum, 1957). Thus, the net oxygen available for the stabilization of wastes will be 4.25 mg/l/day. In a 7-ft-deep pond about 80 lb./acre/day of oxygen will be available. For each pound of 5-day B.O.D., the ultimate B.O.D. exerted is 1.32 lb. Thus, 62 lb./acre/day of 5-day B.O.D. can be satisfied. The average dissolved oxygen concentration on a 24-hr basis is  $(4.25-3.2) = 1.05 \text{ mg/l}$ .

So far surface aeration has not been considered. Surface aeration is given by the formula:  $R \text{ (lb./acre/day)} = 0.0271 b \lambda D$ , where  $b$  is the daily reaeration as percentage of constant oxygen deficiency,  $\lambda$  is water depth in feet, and  $D$  is oxygen deficiency (Imhoff and Fair, 1940). An average value of  $b$  may be taken as 15.

The maximum probable temperature in a stabilization pond is 30 C (Pipes, 1960). At this temperature water will hold about 7 ppm of oxygen (Imhoff and Fair, 1940).  $R = 0.0271 \times 15 \times 7 \times (7-1.05) = 17 \text{ lb./acre/day}$ . Thus, the surface aeration will further satisfy about 13 lb./acre/day of 5-day B.O.D.

It is seen that the waste-stabilization ponds can be loaded at the rate of 75 lb. B.O.D./acre/day and not at the rate of 87 lb./acre/day as indicated by the formula (Anon., 1959). The area of the stabilization pond  $= 120/75 = 1.6$  acres. The volume of the stabilization pond  $= 11.2$  acre-ft. The detention time  $= 11.2 \text{ acre-ft}/0.123 \text{ acre-ft per day} = 90$  days. The depth of inflow in 90 days  $= 11 \text{ acre-ft}/1.6 \text{ acre} = 6.8$  ft. The average loss of water depth as a result of evaporation and seepage in 90 days  $= 4.7$  ft. The pond will maintain its depth against heavy losses and there will be 2.1 ft in depth of effluent flow.

The above design is broad-based and may have to be slightly varied according to the local climatic and soil conditions and also local elevation above sea level.

**Structures**—Inlet and outlet structures may be similar to those used in the USA, with minimal mechanical devices to reduce the cost. A simple inlet with valve for opening or closing the flow will serve the purpose. The inlet should discharge in the center of the pond over a concrete splash plate to prevent erosion of the pond bottom. For the outlet, stop planks of creosoted lumber slipped into grooves at each end will serve the purpose. The planks will be provided with hooks to facilitate removal or to slip in the planks to regulate the level of the stabilization pond.

Dikes may be kept 7 to 8 ft wide to enable movement of maintenance vehicles on the dikes. The permissible bank slopes will vary with the type of the soil. Kushlani (1954) gave permissible slopes for common Indian soils (Table II). Banks subject to leakage due to rat or rabbit holes, if provided with sand and puddle-core fill, will not have this trouble (Sharma, 1946a). The sand collapses and fills the rat or rabbit holes and the leakages stop, as shown in Figure 1.

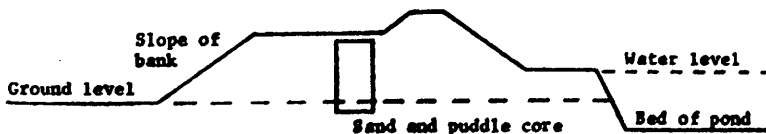


Figure 1. Sand and Puddle Core

**Pond Bottom**—In places where there is seepage and danger of water contamination, clay puddle will be effective and cheap for sealing the pond bottoms. The only material needed is suitable clay. The selected soil is allowed to weather and then pugged thoroughly after saturating with water. The pugged clay is then put in position and covered with about one inch of silt. This reduces the seepage by about 80%.

**Maintenance**—The maintenance will be similar to that required in America, except that it has to be done at different periods. All the grass on the inner slopes, particularly on the slopes of the banks near the water level, should be removed by mowing before the rainy season starts, in June, and soon after it is over, sometime in October. This will reduce the mosquito breeding. Repairs to the banks will be needed in October and February, after summer and winter rains respectively. Rainfall in central and northern India is not heavy. Experience with canal banks has shown that no particular protection from rains is needed, except the seeding of the banks with grass and effecting repairs after rains (Sharma, 1946b). The stabilization pond dikes also will not need any particular protection like riprap. The eroded portion of the dikes can be repaired by filling and compacting the earth brought from the outside.

TABLE II. RATIOS FOR PERMISSIBLE BANK SLOPES RECOMMENDED FOR INDIAN SOILS (KUSHLANI, 1954).

Types of soil	Horizontal to Vertical		
Firm rock	1¼	:	1
Soft or fissured rock	1¼	:	1
Gravelly soil	1¼	:	1
Firm gravelly or clay soil	1½	:	1
Average gravelly loam or loam	2	:	1
Loose sandy loam	2½	:	1
Very sandy loam	3	:	1

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