ESTABLISHING THE BASIS FOR A WASTEWATER TREATMENT PLANT DESIGN[1]

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ABSTRACT

This paper presents basic concepts that must be considered if a biological system in chosen to stabilize organic pollutants commonly found in many industrial wastewaters. The important equations describing the kinetics of a microbial process are presented, the basic design concepts of aerobic, anaerobic and facultative biological systems are discussed.

To establish a sequential approach to conceiving, designing, constructing, operating and maintaining a wastewater treatment plant, it is necessary to throughly characterize the waste. These treatability data are neeeded to provide a definition of the wastewater in terms of meaningful design parameters. Basic design criteria can best be formulated from bench or pilot-scale studies. It is much more economical to explore the many technical variables in well-established test programs than it is to modify full-scale operations.

Worldwide emphasis on environmental preservation, human health, food and conservation has placed increased emphasis on wastewater treatment. Human wastes and pollution resulting from man's need for material things continue to accumulate at an alarming rate and now seriously impact on the usability of diminishing available resources. Since the elimination of wastes at the source is not always practicable, it is therefore necessary that human and industrial wastes be treated before release to the environment to the extent required. Frequently, the most cost effective treatment method

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available for stabilizing organic pollutants involves an engineering adaptation of natural occuring biological processes.

This paper will focus on an analysis of the microbial processes for waste stabilization. The processes of microbial growth and energy utilization are similar under most wastewater treatment concepts, although bacteria function differently under anaerobic, faculative or aerobic environments. With known technology, it is possible to develop mathematical expressions which describe the basic parameters of biological waste treatment processes. Furthermore, much can be gained from transferring knowledge from one treatment process and using this information to guide, design and operate significantly different processes.

A unifying parameter such as biological solids can be related to microbial growth, substrate assimilation and process efficiency. For example, the parameter such as sludge age in highly mechanized aerobic systems is synonymous to hydraulic detention time in less complex systems such as facultative waste stabilization ponds or even more sensitive operations typical of anaerobic digesters.

Basic Kinetic Equations

Basic to wastewater treatment plant operations are: a) microbial growth and substrate utilization; b) process design and control parameters; and c) process performance. The net rate of growth and substrate utilization is of importance, but of equal significance is the relationship of the substrate utilization both to the concentration of microorganisms in a treatment basin and to the concentration of substrate surrounding the organisms. These concepts have been described very well by Monod, van Uden, and more recently by Lawrence and McCarty.[1-3] Equations 1 and 2 provide basic mathematical expressions.

$$\frac{dx}{dt} = Y \frac{dF}{dt} - bx \qquad (1)$$

In which $\frac{dx}{dt}$ represents the net growth rate per unit volume of reactor, mass per volumne - time; Y, the growth yield coefficient, mass per mass; dF/dt, the rate of microbial substrate utilization per unit volume, mass per volume - time; b, the microorganism decay coefficient, per time; and x, the microbial concentration, mass per volume. Furthermore, the rate of microbial substrate utilization can be related to a number of important parameters, Equation 2.

$$\frac{dF}{dt} = \frac{kSX}{K_s + S} \qquad (2)$$

in which k represents the maximum rate of substrate utilization per unit weight of microorganisms, per unit of time; S, the concentration of substrate surrounding the microorganism, mass per volumen, and K_s the half-velocity coefficient, equal to the substrate concentration when $dF/dt = 0.5$ k, mass per volumen. When S is large with respect to K_s, $dF/dt = kX$ and this represents a zero order reaction with respect to substrate concentration. Conversely, if $S << K_s$, the equation is a first order reaction.

These empirical relationships are useful in developing designs for wastewater treatment units. For example, the operational parameters of significance for an activated sludge treatment unit are: a) the process loading factor, also called the substrate removal velocity, or food to microorganism ratio; and b) the sludge age, also referred to as mean cell retention time or biological solids retention time. These two parameters are defined in Equations 3 and 4. The latter can be measured more easily and is therefore the parameter most frequently used as a control measure.

$$\text{Process Loading Factor} = \frac{\left(\frac{\Delta F}{\Delta t}\right)_T}{X_T} \qquad (3)$$

$$\text{Sludge Age} = \frac{X_T}{\left(\frac{\Delta X}{\Delta t}\right)_T} \qquad (4)$$

in which $(\Delta F/\Delta t)_T$ is the waste used by the microbial culture, X_T during a specified time, and $(\Delta X/\Delta t)_T$ is equal to the total quantity of active microbial mass withdrawn or lost daily.

Ultimately the process efficiency can be related to the specific removal of some soluble substrate or the combined removal of biochemical oxygen demand of all forms, Equation 5.

$$E = \frac{100\ (S_o - S_e)}{S_o} \qquad (5)$$

in which E represents the percent removal; S_o, the influent waste concentration, mass per volume; and S_e the effluent waste concentration, mass per volume.

Aerobic Biological Systems

Aerobic Systems commonly include aerated lagoons, which are flow through systems with no recycle of biological cells, and the continuous activated sludge process which does utilize recycled biological cells. Because of the complexities of most modern wastewater treatment problems, it is desirable to conduct laboratory and pilot-scale treatability studies and thereby establish design parameters. A typical characterization of liquid wastewaters is shown in Figure 1. Emphasis herein is directed to the organic analyses, oxygen demand and those aspects of the problem that may influence microbial growth.

Ben scale biological reactors may be of the continuous-flow or batch variety, Figures 2 and 3.[4] These may be used in the laboratory to assess biological treatability of the waste and predict the process kinetics of various aerobic systems. The batch analysis approach is usually limited to screening tests, biological seed acclimation, and estimates of organic removal rates. Continuous-flow tests are usually conducted after batch tests have been undertaken. The data provided by continuous operations are necessary for evaluating process kinetics and establishing design criteria. Most of the pilot-plant operations, however, are continuous-flow systems.

For example, the significant aspects of an aerobic system must include an evaluation of substrate removal, sludge production, and oxygen requirements. An activated sludge model usually considers a completely mixed biological system which means the soluble biochemical oxygen demand (BOD) in the effluent is equal to that in the aeration tank. For this case, a material balance can be expressed by Equation 6.

$$Q\ S_o - Q\ S_e = V \frac{ds}{dt} \qquad (6)$$

in which S_o represents the raw waste, chemical oxygen demand (COD) or biochemical oxygen demand (BOD); V, the tank volume; S_e, the effluent COD, BOD; t, the detention time; and Q, the flow. Substituting the simplest form of ds/dt in terms of a retardent equation yields Equation 7.

$$\frac{S_o - S_e}{X_a t} = kS_e^{n} \qquad (7)$$

in which X_a represents the volatile suspended solids (VSS) undergoing aeration; k, the substrate (BOD or COD) removal rate; and n, the exponent (for a first order approximation, n = 1). The total oxygen requirements by the biological system will be the sum of the oxygen consumed for cell synthesis and endogenous respiration. This assumes that oxygen must be supplied to provide oxygen for: a) biological organic removal ($a'S_rQ$); b) endogenous respiration ($b'X_aV$); and c) chemical oxidation as measured by the immediate oxygen demand (k^oQ). This total oxygen requirement is shown in Equation 8.

$$R_rV = a'S_rQ + b'X_aV + K^oQ \qquad (8)$$

in which R_r represents oxygen utilization per day; V, the volume of aeration basin; a′, the fraction of substrate (BOD or COD) used for oxidation; S_r, the substrate (BOD or COD) removed; Q, the flow; b′, the fraction per day of volatile suspended solids (VSS) oxidized (oxygen basis); X_a, the average mixed liquor volatile suspended solids (MLVSS) in an aeration tank ;and k^o, the chemical oxygen demand coefficient (as measured by immediate oxygen demand). This expression is most applicable for the activated sludge process. The oxygen requirements for the aerated lagoon system might be estimated according to Equation 9.

$$R_rV = 1,2\ (S_o — S_e)\ Q \qquad (9)$$

The accumulation of biological sludges resulting from the biological oxidation of wastewaters can be computed using a similar approach. Such a mathematical relationship would include: a) increase in sludge attributable to influent SS (QX_i); b) increase in sludge due to cellular synthesis (aS_iQ); c) decrease in sludge due to cellular oxidation or endogenous respiration (bX_aV); and d) decrease in sludge due to effluent suspended solids (QX_e). The sludge production relationship can be expressed by Equation 10.

$$\Delta x = QX_i + aS_rQ[bX_aV + QX_e] \qquad (10)$$

in which ΔX represents sludge production per day; V, the volume of aeration basin; Q, the flow; a, the fraction of substrate (COD or BOD) converted to new cells; S_r, the substrate (BOD or COD) removal; b, the fraction per day of volatile suspended solids (VSS) oxidized (sludge basis); X_a, the average mixed liquor volatile suspended solids (MLVSS) in aeration tank; X_i, the influent suspended solids (SS); and X_e, the effluent SS.

A graphical solution for determining the design coefficients can be obtained by varying organic loadings to the bench or pilot-scale units and measuring the parametric responses. The substrate removal rate as predicted by Equation 7 can be estimated by plotting the response data in accordance with Figure 4A. If a non-removable COD or BOD persists as shown in Figure 4B, then Equation 7 must be modified to substrate an amount y, Equation 11.

$$\frac{S_o - S_e}{X_a t} = KS_e - Y \qquad (11)$$

The system oxygen requirements can be estimated by rearranging Equation 8 and producing Equation 12.

$$\frac{R_r}{X_a} = \frac{a'S_r}{X_a t} + b' \qquad (12)$$

where $t = \frac{V}{Q}$ and k^oQ is neglected assuming this oxygen demand is satisfied prior to testing. The coefficients, a′ and b′, represent the slope and are taken as the intercept, respectively, when plotting the data as shown in Figure 5.

The synthesis sludge production is predicted by rearranging Equation 9 and neglecting or accounting for the influent and effluent suspended solids:

$$\frac{\Delta X}{X_a} = \frac{aS_r}{X_a t} - b \qquad (13)$$

the "a" and "b" coefficients are taken as the slope and intercept values, respectively, of the plot shown in Figure 6.

Anaerobic Digesters and Ponds

When anaerobic treatment processes are used, it is necessary to create an environment in which complex wastes are first hydrolized and then fermented to organic acids. This process can be accomplished in modern digesters or open ponds. The efficiency, particularly as related to anaerobic digesters, can be described by Equation 4. This relationship implies that if the sludge is concentrated, the same efficiency can be maintained, although the digester volume is reduced. The limiting step in a typical anaerobic process is rate or fermentation of the organic acids to methane.[5–6] Of these acetic, propionic, and long-chain fatty acids (palmitic and stearic) are the most limiting.

Anaerobic fermentation is a sequential process. First, facultative organisms hydrolyze complex organic compounds into simpler organic molecules, primarily organic acids. Secondly, the anaerobic methane forming bacteria transform the organic acids into methane and carbon dioxide. Both processes may take place simultaniously and synchronously in a well-buffered system. The facultative acid producing bacteria also can use molecular oxygen during metabolism and protect the anaerobic methane forming bacteria from dissolved oxygen which may be introduced or generated in a wastewater treatment system. These facultative organisms can also tolerate a wide variation in pH ranging from a $pH=5.5$ to about $pH=8.4$. Also, temperature affects the rate of acid fermentation; however, these organism are active over a temperature range of approximately 5°C to in excess of 60°C. During acid fermentation almost no net reduction in the chemical oxygen demand or biochemical oxygen demand occurs. Carbohydrates such as cellulose and starch are converted to simple sugars which, in turn, are broken down to organic acids, aldehydes, and alcohols. Lipids, fats, and oils are converted to glycerol and fatty acids which subsequently are broken down into alcohols ,aldehydes, and organic acids. Proteins are degraded to amino acids which, in turn, are converted to organic acids, mercaptans, and amines. During this conversion step some carbon dioxide, ammonia, and hydrogen sulfide gas may be released. The principal intermediate compounds released during acid fermentation are the short chain carboxylic acids (volatile acids) primarily acetic, propionic, and butyric acids; however, smaller quantities of formic, valeric, isovaleric, and caprioc acids frequently are found in anaerobic systems. These volatile acids are converted by the methane forming bacteria into methane and carbon dioxide.

The conversion of the volatile acids by the methane forming bacteria results in a marked reduction in the amount of biodegradable material (COD, BOD) in the system. The amount of organic material stabilized during methane fermentation is directly proportional to the amount of methane produced.

A schematic diagram of the mechanicsm of anaerobic degradation of organic wastes is presented in Figure 7. The environmental factors which affect methane fermentation are summarized in Table 1. Initially there is a decrease in pH accompanied with an increase in the volatile acid concentrations of volatile acids and BOD or COD decrease accompanied by a rapid increase in the quantity of methane in the off gas. The ultimate oxygen demand (BOD_u or COD) stabilized or removed from the system during methane fermentation is equal to the ultimate oxygen demand of the methane formed. Therefore, the amount of methane gas produced can be predicted by estimating the degree of waste stabilization achieved, or conversely, the

TABLE 1

ENVIRONMENTAL FACTORS FOR METHANE FERMENTATION

Variable	*Optimum*	*Extreme*
Temperature (°C)	30-35	25-40
pH	6.8-7.4	6.2-7.8
Oxidation-Reduction Potential (millivolts)	-520 to -530	-490 to -550
Volatile Acids (mg/1 as acetic)	50-500	2000
Alkalinity (mg/1 as $CaCO_3$)	2000-3000	1000 to 5000

amount of methane gas produced can be used to determine from the quantity of COD stabilized in the system. Methane can be expressed in terms of equivalent oxygen as shown in Equation 14.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad (14)$$

Therefore, one mole of methane is equivalent to two moles of oxygen or for 16 grams of methane produced and released from the system, 64 grams of oxygen equivalents (COD or BOD_u) are removed from the waste.

Methane formation is precluded by sulfate reduction where sulfate concentrations are high. However, once the sulfates are reduced to H_2S, methane fermentation procedes, provided the other environmental conditions are appropriate. The H_2S produced diffuses into the upper layers of the digester or pond and may cause odor problems if released into the atmosphere. The reduction of sulfate by organisms such as *Desulfuvibrio* requires a dissolved oxygen concentration of less than 0.16 milligrams per liter (mg/1), and thus, is practically restricted to anaerobic regions of open anaerobic ponds.[7] Temperature should be greater than 15°C. The optimum oxidation-reduction potential (ORP) for this organism is -100 to -300 millivolts (mv) at pH 7.0. Growth is inhibited at ORP greater than +27 mv.

Sulfides can be toxic to bacteria in anaerobic systems at concentrations in excess of 200 mg/1 at a pH near neutral. However, at concentrations between 50 to 100 mg/1, sulfides are tolerated with little or no acclimation. On the other hand, this anion will react with soluble heavy metal ions to form a metal sulfide precipitate which is relatively insoluble at pH near neutral. Approximately 1.8 to 2.0 mg/1 of heavy metals are precipitated as metal sulfides by 1.0 mg/1 of sulfide ($S^=$). This phenomenon offers an attractive alternative for the treatment of industrial wastewaters which contain heavy metals.

The alkalinity of the anaerobic system provides the buffering capacity to the system; and this is essential for proper pH control. Alkalinity primarily in the form of bicarbonate ions, is derived from the breakdown of organics. This relationship between alkalinity and the carbon dioxide in the gas is pH dependent and may be illustrated by Equations 15 and 16.

$$CO_2 + H_2O \rightarrow H_2CO_3 \qquad (15)$$

$$H_2CO_3 \rightarrow H^+ + HCO_3^- \qquad (16)$$

The hydrogen ion concentration and eventually the pH of the system may be calculated from the following equilibrium equation for the ionization of H_2CO_3, Equation 17.

$$[H^+] = k_1 \frac{[H_2CO_3]}{[HCO_3^-]} \qquad (17)$$

At values of pH between pH=5.6 and pH=7.4 and at normal carbon dioxide content in the gas, namely, 30 to 40 percent by volume, the bicarbonate alkalinity will range between 1,000 and 5,000 mg/1. Concentrations of alkalinity of about 3,000 mg/1 are generally preferred rather than attempting to operate the system at the extreme values.

Ammonia also is closely related to the alkalinity in the control of the anaerobic process. Ammonia reacts with the carbon dioxide and water resulting in ammonium carbonate which is available to react with the free volatile resulting in the formation of volatile acid salts. These reactions may be written as Equations 18 and 19.

$$NH_3 + CO_2 + H_2O \rightarrow NH_4HCO_3 \qquad (18)$$

$$NH_4HCO_3 + RCOOH \rightarrow RCOONH_4 + H^+ + HCO_3^- \qquad (19)$$

A portion of the alkalinity appears as "volatile acid salts" alkalinity. At low volatile acid concentrations, the bicarbonate alkalinity represents approximately the total alkalinity; however, as the volatile acids concentration increases, the bicarbonate alkalinity is much lower than the total alkalinity.

Reductions in BOD of 70 percent have been reported for anaerobic pons treating wastewater. The recommended depths for anaerobic ponds are 2 to 4 meters. The advantages of the deeper ponds are :a) more efficient land utilization; b) protection of the anaerobic methane bacteria from changes in the environment and from exposure to dissolved oxygen; and c) adequate storage for sludge deposits. Increasing depths tend to promete thermal stratification which helps in preventing the intrusion of oxygen into the deeper layers of the pond. However, the average temperature lapse rate in a stabilization pond may be as high as 3°C per meter during periods of stratification. When the temperature decreases from 20°C to 15°C near the bottom of the pond, there may be a five-fold decrease in methane production.[8]

The hydraulic detention time for anaerobic ponds need only be sufficient to settle the solids or completely biodegrade the soluble organics anaerobically. In some cases, detention periods of 5 days based on liquid volumen are adequate but sludge storage must be available to compensate for anaerobic decomposition of solids. The detention-temperature-biodegradation relationship must be established by laboratory and pilot-scale studies. A useful laboratory device is shown in Figure 8. The minimum loading rate necessary for anaerobic conditions in open ponds is usually between 200 and 600 kilograms of BOD per hectare per day based on the volumetric loading and geographical location.

Facultative Biological Systems

Facultative organisms may exist in some of the previously discussed systems, but unique to the wastewater treatment processes are facultative waste stabilization ponds (FWSP). Such ponds, subject to the hydraulic and organic loadings, can be designed to serve as mostly anaerobic, mostly aerobic or predominantly facultative systems.[9]

All of the previously discussed design and control parameters also relate to waste stabilization ponds; however, in this case, the bacterial population is dispersed, the detention time is great and aeration is largely due to photosynthetic organisms. Consequently, laboratory and field data are of particular importance to establishing design criteria for pond systems.

A facultative waste stabilization pond (FWSP) provides an aquatic environment in which photosynthetic and surface oxygenation provides an aerobic bottom layer. This type of pond may be designed to operate separately; follow an aerobic waste stabilization pond (AWSP), a mechanically aerated pond (MAP), or various types of biological treatment units. Also, an FWSP can provide pretreatment for a polishing waste stabilization pond (FWSP).

Table 2 provides a comparison of how various influent variables and plant operating characteristics are reflected in the performance of an FWSP and an activated sludge unit. Although FWSP produce acceptable effluents as based on soluble organics, the effluents contain relatively high amounts of biological solids (algal cells). The cost of these facultative pond systems is usually less than the other conventional forms of biological waste treatment.

TABLE 2

WASTE TREATMENT PLANT COMPARISONS AFFECTING DESIGNS AND OPERATING BUDGETS

	Relative Sensitivity		
Variable	*FWSP*	*Activate Sludge*	*Remarks*
Influent Characteristics			
Oil Removal	less	more	Assuming preteatment
Toxicity	less	high	
pH	less	more	
BOD	less	more	
N	less	more	N can be recycled in pons and scavenged from the air
PO_4	less	more	P can be recycled
Equalization	lesss	high	
Energy & Resource			
Electric	low	high	Basis: Aeration, Sludge pumping
Fuel	low	high	Basis: Sludge Disposal
Chemical	neg	high	Basis: Sludge Handling
Land	high	low	
Effluent Characteristics			
BOD removals	good	good	
COD removals	good	Less	
Nutrient removals	less	more	Assuming no algae removal; however, ponds require less oxygen
Operating Characteristics			
Manpower	much less	more	
Plant upsets	some	more	Assuming some pretreatment controls

A facultative pond typically contains abiotic substances, producer organisms, consumer organisms, and decomposer organisms. The major biological reaction which occur in waste stabilization ponds include: a) oxidation of carbonaceous organics by aerobic and facultative bacteria; b) nitrification of nitrogenous material by bacteria; c) reduction of carbonaceous organics by anaerobic bacteria living in benthal deposits and bottom liquids, and d) oxygenation of surface liquids by algae.

The algal forms may be blue-green algae, non-motile green algae (either unicellular or multicellular), pigmented flagellates and diatoms. Photosynthetic algae basically require water, inorganic substrate and simple carbon compounds (mostly carbon dioxide).

Typical of the green algae in facultative waste stabilization ponds are *Chlamydomonas, Chlorella,* and *Scenedesmus*. Blue-green algae common to waste stabilization ponds are *Oscillatoria, Phormidium, Anacystis,* and *Anabaena* In the operation of a pond, *Chlamydomonas* and *Chlorella* are usually the first planktonic genera to appear. Blue-green algae mats frequently develop when detached patches of benthic algae such as *Phormidium,* begin to accumulate. *Euglena* shown a high degree of adaptability to various pond conditions and are present during all seasons and under most climatological conditions. Probably next in adaptability are *Chlamydomonas, Micractinium, Ankistrodesmus Scenedesmus,* and *Chlorella.* Frequently *Euglena* and *Chlamydomonas* tend to dominate during the cooler weather, while the various *Chlorococcales* are most numerous during summer months. This latter grouping is an order under the division Chloraphyta containing *Chlorella, Ankistrodesmus, Schenedesmus,* and others.

Unicellular algae, in particular, will react fairly rapidly to changes in the environment. Therefore, it is of importante to examine critically those factors that affect the growth rate.

The amount of oxygen utilized by the bacteria and algae, and the rate at which this oxygen can be supplied by the algae, are critical elements in the design of facultative waste stabilization ponds. There must be sufficient surface area and light available to accommodate the required production of photosynthetic oxygen. Similarly, the detention requirements must accommodate the rate of oxygen utilization. Significant variables and controlling parameters are listed in Table 3.

The overall performance of an FWSP system, as in other biological waste treatment systems, is highly temperature dependent. Sludge deposits will be degraded by anaerobic bacteria, and throughout most of the pond depth the soluble BOD will be biodegraded by faculative bacteria. Thermal stratification of the pond liquid is partially responsible for maintaining separate aerobic and anaerobic zones for extended periods of time. Thus, designs reflect the relatively slower biodegradation rates of anaerobic-facultative systems in contrast to the more rapid rates exhibited by truly aerobic-facultative systems. The van't Hoff-Arrhenius equation aids in describing the detention-temperature relationships, Equation 20.

$$\frac{t}{t_o} = d^{C'[T_O - T]} = \Theta^{[T_O - T]} \qquad (20)$$

in which t represents the reaction time required at any temperature T, days; T_o, the temperature for t_o, days; and $C' = 0.0693$. The useful range is 5°C to about 35°C, the lower limit being due to retardation of bacteria and algal activity. Anaerobic bacteria are not very active below 15°C. The upper limit (i.e., 35°C) is imposed by inactivation of many green algal species, and the resultant oxygenation due to photosynthesis.

The required surface area is the critical parameter. This area is related to availability of light, temperature, biodegradability and other factors. Therefore, the effective depth used to establish the surface area must be minimal,

TABLE 3

Significant variables and controlling parameters

Item	Algae	Bacteria	Remarks
1. Nutrient	$106\,CO_2 + 90\,H_2O$ $+ 16\,NO_3^- + PO_4^{-3} + \text{Light} \longrightarrow$ $C_{106}H_{180}O_{45}N_{16}P_1 + 154\frac{1}{2}O_2$	$C_aH_bN_cO_dP_e + (a + \frac{b}{4} - \frac{d}{2} + \frac{3c}{2} + 2e)O_2$ $a\,CO_2 + \frac{b}{2}H_2O + CNO_3 + e\,PO_4^{-3}$	Theoretically 750 gms of dissolved O_2 are produced per pound of algae synthesized For each 6 moles of CO_2 reduced about 6 moles of O_2 and one mole of carbohydrate are produced
2. Light	Optimum 400 - 600 ft. candles (1 ft. cd. = 10 Lux) Inhibition 1000 - 4000 ft. cd.		Overall eff. of photosynthetic conversion of solar energy to algal energy about to 5 %
3. Temperature	5°C - 40°C	10°C - 40°C (Aerobic) 5°C - 45°C (Facultative) 15°C - 40°C (Anaerobic) 45°C - 65°C (Anaerobic)	Optimum for green algae about 20-35°C
4. Oxygen Production	1 gm cell $\cong$ 1 gm O_2 1 gm ash $\cong$ 1.35 gm O_2 2.6 to 13.0 mg O_2/hr.		1 mg O_2 req. 3.58 cal. of radiation ash incl. organic ~85% of cell
5. Growth rate coefficients	0.2 to 2.0 / day	2.0 to 6.0	Protozoa (1.0 to 4.0)

but sufficient to achieve desired results. Additional depth, not to be included in the depth used to calculate the surafce area, is usually needed for sludge storage, particularly if seasonal temperature variations occur. Equation 21 presents an empirical approach for the design of a facultative waste stabilization pond.

$$V = 3{,}5 \times 10^{-5}\, Q\, L_a\, [\Theta^{[35-T]}]\, f\, f' \qquad (21)$$

in which V represents pond volume (cubic meters); Q, the flow (liters per day); L_a, the ultimate influent BOD_u (mg/1) or COD; f, the algal toxicity factor, $f=1$ for domestic wastes and many industrial wastes;[10] f′, the sulfide or other inmediate COD, $f'=1$ for SO_4 equivalent ion concentration of less than 500 mg/1;[7] and Θ, the temperature coefficient.

The BOD removal efficiency can be expected to be 80 to 90 percent. The efficiency based on unfiltered effluent samples can be expected to vary unless a maturation pond is used as a follow-up unit.

The detention times provided by the above equations are given in Figure 9. Added detention times may be provided by increasing the depth, but this depth must not be used to calculate the surface area.

The recommended minimum depth of a faculattive pond is one meter. Additional depth to compensate for sludge storage is desirable. The minimum depth of one meter is required to control potential growth of emergent vegetation. If the depth is too great, there will be inadequate surface area to support photosynthetic action. Deep ponds tend to stratify during hot periods. The following design guidelines for depths are suggested as design guidelines for municipal wastewaters and industrial wastes having similar treatability characteristics.

Case	*Depth*	*Related Conditions*
1	1 meter	Generally ideal condition, uniform temperature (tropical to subtropical), minimum settleable solids and possibly preceded by anaerobic ponds.
2	1.25 meters	Same as above, but with modest amounts of settleable solids. Surface design based on one meter depth and 0.25 meters used for reserve volume. (For wastes contining considerable amounts of biodegradable, settleable solids the FWSP should be preceded by an anaerobic pond.)
3	1.5 meters	Same as Case 2 except for significant seasonal variation in temperature, major fluctuations in daily flow. *Surface design based on one meter of depth.*
4	2 meters and great	For soluble wastewaters that are slowly biodegradable and retention is controlling.

Laboratory-scale ponds can be very useful in evaluating the performance of pilot-scale or full-scale units. While there are no precise relationships for the scale up factors, experience has shown that the unit in Figure 10 is very functional. The fluorescent light over the facultative unit should provide about 600 foot candles (6000 lux) at the surface of the pond, assuming the water depth of the pond to be about 30 cm. With these units it is possible to study the detention, temperature, BOD removal relationships. Care must be taken to maintain water levels, scum free surfaces and well seeded units.

Conclusions

It is apparent that each wastewater treatment facility presents its individual problems, and therefore, characterization and treatability investigations are necessary prerequisites to the design and operation of water pollution control facilities.

Once the design information has been developed, the economic aspects of several alternate treatment and disposal plans may be investigated with the final results being the construction and operation of the waste treatment facility.

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