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### AERATED LAGOONS FOR THE TREATMENT OF INDUSTRIAL WASTEWATERS IN DEVELOPING COUNTRIES

Stabilization ponds must constitute the principal technique involved in the prevention of surface water pollution in most developing countries. Their simplicity allied with their efficacy and low cost ensures that they are always the initial system to be considered for the purification of wastewaters.

On occasions, however, local factors can prevent the employment of stabilization ponds. Generally these factors might be summarized as

- (i) a shortage of land, or the high cost of the available land;
- (ii) the high strength of the received wastewater, particularly when mixed with some industrial wastewaters. This factor becomes of importance if an anaerobic lagoon cannot be used for environmental reasons;
- (iii) the necessity to protect the purity of groundwater supplies, in which case it might be essential to line the pond bottoms;
- (iv) the need to produce an effluent which is not heavily laden with algae.

Should the employment of stabilization ponds not be practicable it is of importance to resist the extreme alternative of moving to conventional wastewater treatment technology which is not only expensive in construction and operation but which also necessitates a high degree of technical control. As an appropriate alternative to stabilization ponds, that does not require either highly sophisticated plant or a high level of technical control, aerated lagoons must be considered. At their simplest aerated lagoons are stabilization ponds which are uprated by the installation of an aeration system. This might be either a mechanical surface aerator or a bubble-type of aerator. Particularly aerated lagoons can be justified for the treatment of many industrial wastewaters. In the industrial situation not only is land availability frequently limited, but also some technical expertise is usually employed in the industry.

#### TYPES OF AERATED LAGOON

Aerated lagoons can be conveniently divided into three groups (1):

- (i) Aerated stabilization ponds
- (ii) Facultative aerated lagoons and
- (iii) Completely-mixed aerated lagoons.

#### AERATED STABILIZATION PONDS

These represent a simple means of uprating existing stabilization ponds. The aerator (or mixer) is employed more to mix the water than to aerate it. The aerator merely brings the oxygen demand in the deeper water into contact with the oxygen source near to the surface. It is a means of overcoming the difficulties associated with stratification. The majority of oxygen utilized is derived not directly from the aerator, but either from direct surface adsorption through the undisturbed surface or as a result of the photosynthetic action of the algae present. Settlement of an organic sludge will still be expected as will the anaerobic stabilization of this sludge, if the temperature is warm enough. No final settlement lagoons is required and the effluent produced will still be heavily laden with algae.

It has been suggested (2) that a simple aerator positioned close to a stabilization pond inlet will not only satisfy any large, immediate oxygen demand but will also assist in the even spread of sludge over a wide area of pond bottom.

#### FACULTATIVE (OR PARTIALLY SUSPENDED) AERATED LAGOONS

With these much of the required oxygen will be adsorbed directly as a result of the action of the aeration system. There will still be a substantial amount of sludge settlement together with anaerobic sludge digestion, but there will also be an appreciable suspension of active solids (20 - 80 mg/l) assisting in the aerobic stabilization of the organic waste. As the water in the lagoon is continually turned over and because of the attenuation of its light transparency by the partial suspension of active solids, the algal content is far less than with stabilization ponds. Again, it is unusual to require an additional settlement lagoon following the limited turbulence of a facultative lagoon.

The installed power required for this type of lagoon is usually accepted as being between 1.0 and 2.0 w/m<sup>3</sup> of lagoon volume (3,4) although one authority (5) suggests as much as 4.0 w/m<sup>3</sup>. 1.0 w/m<sup>3</sup> represents the power required to hold about 20 mg/l of solids in suspension, although an MLSS of 50 to 80 mg/l has been suggested as being necessary (6). If an effluent with only a low suspended solids content is essential it is a relatively simple matter to create a quiescent settlement zone near to the effluent discharge point, protected by baffles above and below the surface.

As a result of the settlement of much of the organic suspended material, and of its subsequent anaerobic stabilization when the temperature permits, there is frequently found to be a substantial seasonal feed-back of the partial breakdown products to the aerobic water layer. Appreciable anaerobic digestion only occurs as the sludge temperature exceeds about 18°C (7,8). For this reason there is only settlement of organic solids during cold-weather periods followed by an intense period of enhanced anaerobic activity as the temperature rises seasonally. During hot weather the extra load - seasonal feed-back - resulting from the leachage of organic acids and alcohols from the digesting sludge can impose an additional 50% load onto the aerobic zone.

#### COMPLETELY-MIXED (FULLY SUSPENDED) AERATED LAGOONS

As the name implies there is no settlement in these lagoons and consequently all the solids are in suspension. The vast majority of the required dissolved-oxygen is supplied by the aeration device and because of the continual turbulence and high opacity of the suspension no algae are produced.

These are in fact embryonic activated sludge systems but in which there is no sludge-return system and in which the concentration of suspended solids is perhaps only 0.2<sub>3</sub> to 0.4 kg/m<sup>3</sup> instead of the 2.0 to 6.0 kg/m<sup>3</sup> required by the conventional process. Because there is no sludge-return it is essential that the nominal retention period should be sufficient to allow the rate of new sludge production in the unit to balance the loss of sludge with the effluent. As a result there is a critical retention period (trc) for each particular unit below which the activity will quickly drop as the concentration of active solids falls. This is suggested (9) as being

$$trc = \frac{1}{0.33.Y.K.Li}$$

The power required is suggested as being about 6w/m<sup>3</sup> (3)<sub>3</sub> but others (5) raise this to as high as 20 w/m<sup>3</sup>. The lagoon depth is usually between 3 and 5 m although they can be as deep as 6.0 m. Since there is no sludge settlement there is no seasonal feed-back to moderate the increased hot weather efficiency and as a result the design should be for the coldest month. Nominal retention periods are normally in the range of 1.0 to 2.0 days.

#### AERATORS

Aerators can either be mechanical surface aerators or one of the systems employing compressed-air and air-bubbles.

The original mechanical surface aerators were normally vertical-spindle rotating cone devices mounted on a transverse bridge. The development of anchored, floating aerators has resulted in simpler designs and the use of larger lagoons. Generally these aerators are 'low-speed' aerators operating at 3.0 to 6.0 rpm and resulting in both a high oxygenation efficiency and in a substantial mixing effect for the lagoon contents. Much higher speed floating aerators employing smaller impellers at up to about 2500 rpm are also available. These tend to be cheaper but neither in their oxygenation efficiency nor in their mixing effect (10) do they compare with the lower speed aerators. All vertical-spindle mechanical aerators require an erosion-resistant concrete slab, at least three times the diameter of the impeller (10), set below the aerator. Kessener-type, horizontal spindle aerators can also be employed set either against the lagoon bank or mounted on pontoons.

Compressed-air systems are of three types. There is the minimum-submersion, coarse bubble aeration grating of the Inka process. There is also the conventional diffused-air system relying on fine-bubble diffusers set on the lagoon floor. Thirdly, there is the coarse-bubble diffuser of the Polcon process in which the emitted bubbles pass upwards through a 'helixor' to provide extended air/water contact time. This latter system has been employed successfully for the treatment of beet-sugar wastewater in the UK. The beneficial effect of the warm compressed air has resulted in an appreciably higher-than-normal mixed-liquor temperature and consequently in increased biological activity. Conversely, surface aerators have been found to create a beneficial cooling effect which can moderate the temperature of over-hot industrial wastewaters without resorting to a specific cooling system. It is suspected that the Polcon system only rivals the efficiency of other aeration systems in the deeper lagoons.

#### REQUIRED REACTOR VOLUMES

Various authors have suggested a variety of approaches to the determination of reactor volume requirements. Some authors (11,12) have employed the first-order biological rate approach for complete-mix reactors conventionally used for the systematic design of stabilization ponds. This has been modified by Thirumurthi (13) who assumed that the reaction-rate decreases as the reaction progresses. This led him to employ the rate equation  $\frac{dc}{dt} = KC^n$

in which he suggests the factor n as being between 1.076 and 1.115.

However, since the operation of the aerated lagoons depends upon the suspension of an appreciable concentration of active solids it is justified in assuming that the rate of reaction depends not only on the concentration of biodegradable material remaining but also on the concentration of active solids in suspension. This approach has been accepted by several authorities (3, 6, 14, 15, 16).

The rate of removal of BOD is assumed to be directly proportional to both the lagoon BOD ( $Le$ ) and the concentration of active solids ( $X$ ) hence  $\frac{dL}{dt} = k.X.Le$  (i)

With a material balance of

$$\begin{aligned} \text{Biodegradable material entering} &= \text{Rate of biodegradable decay} + \text{Biodegradable material leaving} \\ Q.L_i &= V.\frac{dL}{dt} + Q.L_e \end{aligned} \quad \text{(ii)}$$

substituting (i) into (ii) and rearranging

$$Le = \frac{l}{1+k.X.V} = \frac{l}{1+k.X.t_r} \quad \text{(iii)}$$

$$\text{and } t = \frac{L_i - L_e}{k.Le.X} \quad \text{(iv)}$$

$$\text{and } A = \frac{Q}{D.k.X} \left( \frac{L_i}{Le} - 1 \right) \quad \text{(v)}$$

The concentration of active solids,  $X$ , can be obtained from a cell balance (16), assuming that the input of cells in the crude sewage is negligible.

Rate of change of biomass in system = cell synthesised during reaction - Endogenous respiration - Cell loss in effluent

$$V.dX = Q.Y.(L_i - L_e) - b.X.V - Q.X. \quad \text{(vi)}$$

as at a steady state  $\frac{dX}{dt} = 0$

$$X = \frac{Y(L_i - L_e)}{1 + b.t_r} \quad \text{(vii)}$$

These equations can be applied both for a completely-mixed lagoon and for a facultative lagoon as the reaction rate constant  $k$  is the same for both being independent of the concentration of micro-organisms.

Tikhe (16) has developed a further expression to give the minimum total retention period for a completely-mixed lagoon followed by a facultative lagoon. (This system requires no final settlement pond.)

$$t_T = \frac{1}{Y.k.Le-b} + \frac{Le-L_f}{X_f.k.L_f} \quad \text{(viii)}$$

In this only  $Le$  is variable and by differentiating (viii) w.r.t.  $Le$  the size of  $Le$  to produce the minimum  $t_T$  can be determined as

$$Le = \frac{b}{Y.k} + \left( \frac{X_f.L_f}{Y} \right)^{\frac{1}{2}} \quad \text{(ix)}$$

One has to beware of expressions giving the BOD of the pond effluent  $Le$ .  $Le$  is only the so-called soluble fraction of the remaining

BOD which, in addition, possesses a fraction due to the concentration of active solids in the effluent.

Hence total BOD of effluent =  $Le + 0.54X$ . In addition for a facultative pond there will also be a major contribution to the effluent BOD from any algal cells involved.

#### LAGOON LINING

Unlike stabilization ponds aerated lagoons are frequently lined. The necessity to prevent seepage maybe one of the reasons that lagoons have been selected, or the lining may, more usually, be employed to prevent erosion.

Polyethylene sheeting, PVC sheeting or butyl-rubber sheeting have all been widely employed. With these materials it is essential that the lagoon bed be cushioned with a layer of sand before the membrane is installed. Lagoon walls have to be stable and can be strengthened by polyester or fibre-glass underlays. The membrane itself is vulcanised or welded together from broad strips of the material and is loaded with a layer of gravel to prevent uplift. The edges are usually anchored into a trench and secured with concrete slabs.

Soil cement lining has been extensively employed in some parts of the world (17). For this the soil is loosened to a depth of 50 mm. and allowed to dry. Then portland cement is added at about 8 kg/m<sup>2</sup>, thoroughly mixed, then compacted with a light roller before the addition of the minimum required amount of water.

Asphalt-crumb rubber water-proofing has also been successfully experimented with (18). This is a mixture of asphalt-cement mixed with crumb-rubber (granulated from old tyres) which is sprayed onto the prepared lagoon. This is a tough, relatively homogenous mixture with excellent elastic and impact resistant properties. Its additional advantages include the elimination of seams, simple repairs by hand-spraying, ease of application, conformation with any slight subgrade irregularities and the fact that it adheres to the subgrade.

#### SYMBOLS

$Y$  - Yield coefficient (kg cells produced per kg BOD destroyed) - 0.6 to 0.8 kg/kg

$L_i$  - Influent BOD concentration (g/m<sup>3</sup>)

$L_e$  - Lagoon and effluent BOD concentration (g/m<sup>3</sup>)

$t_r$  - Nominal retention period (days)

$V$  - Lagoon volume (m<sup>3</sup>)

$Q$  - Flow rate (m<sup>3</sup>/d)

$A$  - Surface area (m<sup>2</sup>)

$D$  - Lagoon depth (m)

$k$  - Reaction rate constant (l.mg<sup>-1</sup>.d<sup>-1</sup>) - about 0.015 l mg<sup>-1</sup>.d<sup>-1</sup> at 20°C for domestic wastes.

This rate constant increases with temperature, up to a maximum of about 35°C, according to  $k_{(T)} = k_{(20)}(1.097)^{\frac{T-20}{10}}$

- X - Concentration of micro-organisms in lagoon ( $g/m^3$ ). Although a measurement of ATP is perhaps more realistic this is commonly accepted as being the MLVSS.
- b - Endogenous respiration rate ( $d^{-1}$ ) - 0.18 to 0.24  $d^{-1}$

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