THE CLOGGING OF SEWAGE LAGOON AERATORS

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ABSTRACT

The Lagoon method of waste water treatment was introduced into Canada in the mid 1950's. At present, of the 2019 waste water treatment systems in Canada, 1163 are Lagoon systems and 265 of these include aeration equipment.

Continuing difficulties associated with the plugging of the aerators have led to a study of this maintenance problem.

Physical factors have been identified as the major cause of the plugging of large bubble aerators; whereas chemical solution and deposition under high algal growth conditions have been set forward as the causes of fine bubble aerator plugging.

Selected field investigation data collected indicate that the proposed push-pull system of precipitation of calcium carbonate and silica dioxide may in fact be responsible for the plugging of fine bubble aerators with these materials.

KEYWORDS
Lagoons; waste water; aeration; aerators; plugging; calcium carbonate deposition; silicon dioxide deposition.

INTRODUCTION

Canada, which claims sovereignty over more than 3,850,000 square miles, had a 1986 census population of 25,116,102 (Anon. 1987). The majority of this population is located along the southern border of the country.

Even in the most populous Central regions the centres of population, especially the smaller ones, are fairly well removed from others. In the less populous Western and Eastern regions the population centres are considerably removed from others. On the prairies of the Western region the distance between small centres is usually 10 to 20 kilometers, and between large centres is frequently 100 to 200 kilometers.

With such vast areas available between small population centres, it is understandable that large area, low cost maintenance, low cost operation, wastewater treatment facilities would evolve and predominate.

Prior to 1955 the few waste water treatment plants in existence were of conventional design employing activated sludge or trickling filters. These plants were often plagued with maintenance and operational problems associated with empirical design and lack of skilled
operation. In 1955 the concept of "sewage lagoons" (sewage ponds, oxidation ponds) was introduced into Western Canada from the northern tier of the United States. These units had been transferred northward, with very little modification, from the hot, arid south western United States where they had been initially employed in industrial waste treatment and storage.

By 1958 the use of "lagoons" was widespread in Western Canada and data was being collected on their treatment efficiency, operations and inherent problems (Higo, 1965). Major among these was odor. Under the severe winter conditions of this region the lagoon would become ice covered (except perhaps for a small area around the inlet) by about the first of December. The ice cover increases to three or four feet in thickness before thawing temperatures are reached in April or May. During the six months of winter the lagoons act as very large septic tanks. The majority of the organic matter accumulates during this period as little anaerobic digestion takes place. The organic removal efficiency is therefore similar to a sedimentation unit.

In the spring when thawing occurs, the lagoons are said to "turn over". The accumulated solids begin to decompose more rapidly, the gases of decomposition are liberated to the atmosphere and accompanied by intense odors. The facility begins to move towards an aerobic state. This change from anaerobic to aerobic operation gave rise to the local use of the term facultative lagoons. The only time a lagoon operates as a double process system is when it is turning over and the aerobic process is becoming established from the surface layer downwards. This turn over period may last from several days to several weeks and is accompanied by intense odors.

Once an aerobic condition has been established it is maintained until the next period of ice cover. The extremely high insolation (10000 ft - candles) and the length of sunlight (up to 16 hours) and the length of daylight (up to 20 hours) insures intense algal growth.

The intense odor problem and poor treatment capability during winter has, among other reasons, spawned the use of aerated lagoons (Ross, 1980; Smith, 1983; Townsend, 1986).

In 1986 there were 2019 waste water treatment systems in Canada treating the waste of 11,671,000 persons (46% of total); of these, 1163 were lagoon systems, and of these, 265 were aerated systems (Anon. 1987).

**AERATED LAGOONS**

The general types of aeration equipment available may be classified as in Table 1.

<table>
<thead>
<tr>
<th>Surface Spray</th>
<th>Submerged</th>
<th>Fine Bubble Diffusers</th>
<th>Coarse Bubble Airlift Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Ceramic</td>
<td>Baffled Flow Guns</td>
<td></td>
</tr>
<tr>
<td>Floating</td>
<td>Metal</td>
<td>Pulsed Flow Guns</td>
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<td></td>
<td>Elastic</td>
<td>Aspirators</td>
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<td></td>
<td>Split Tube</td>
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</table>

Severe icing problems during winter in a large part of Canada mediates against the use of spray aeration devices, usually leaving engineers with the option of fine or coarse bubble submerged aeration devices.

**Aerator Plugging**

A serious problem with all submerged lagoon aeration devices is the tendency for them to become plugged. The short term remedy is often perceived to be to increase the air pressure in an attempt to increase the air flow and thus the aeration. This in turn may lead to blow-outs of the air lines requiring further corrective maintenance.

**Mechanical Plugging**

Plugging in the air-lift pump type may be mechanical in the baffled flow pumps or may be mechanical and/or chemical in the pulsed flow or 'burp-gun' airlift pump systems.
Mechanical plugging may be initiated when a branched weed, or string of rags, or similar object enters the aeration device and is unable to pass all the baffles. It then acts as a screen and accumulates other particles which would normally pass through the pump barrel. This retained material may include synthetic fibre reinforced cloth, plastic, and grease balls. Eventually the pump barrel becomes completely blocked, resulting in the entry of the air into the lagoon in an unconstrained manner. This situation persists until the unit is serviced or replaced at the next lagoon drawdown and maintenance period. These are often scheduled one year apart.

Mechanical plugging of aeration devices may thus be explained in a simple straightforward manner. The explanation of chemical plugging is somewhat more complicated.

Chemical Plugging

Over the years the authors laboratory has been called on many times to express opinions as to the cause of plugging of submerged diffusers and coarse bubble air lift pumps. Analysis of the deposited material has proven it to be, in the main, calcium carbonate with a small but significant quantity of silicon dioxide. Some of the basic considerations which will be put forward below underlie the solution and deposition of some minerals in lagoon and natural waters which are subjected to unusual chemical stresses, due to high photosynthetic and respiration activity. Selected data from field investigations are discussed in light of the theory presented.

Natural waters and waste waters have chemical characteristics which reflect their prior exposure to the hydrologic cycle and to modifications brought about by additions and depletions due to municipal or industrial use. The past history of a waste water has resulted in the water having reached a 'reasonable' state of equilibrium with respect to the distribution of the carbon containing species. The term, "reasonable", indicates that the system can be described in approximate terms, and that the approximations may be suitable from an engineering standpoint.

Theoretical Considerations

The pH of water is by definition a function of the \( (H^+) \) ion concentration and thus the \( (OH^-) \) ion concentration. The -Log form of the Water Ionization Equilibrium Equation is given after Stimm and Morgan (1970).

\[
\text{-Log} (H^+) - \text{Log} (OH^-) = -\text{Log} K_w = 14
\]  

(1)

The pH of a water may be considered to be influenced by the presence of dissolved species of the carbonate equilibrium system. Thus the pH is influenced by the relative concentrations present of carbon dioxide, \( (CO_2) \), bicarbonate ion \( (HCO_3^-) \), and carbonate ion \( (CO_3^{2-}) \). All the species above shown in curved brackets ( ) may be classified as forms of alkalinity. Rigorously, alkalinity may be defined as the arithmetic sum of the concentrations of all the negative species in the water. For predominantly bicarbonate waters, alkalinity may be operationally defined as follows (Butler, 1981).

\[
\text{Alkalinity} = (HCO_3^-) + 2(CO_3^{2-}) + (OH^-) - (H^+)
\]

Thus alkalinity, ion product of water, and the concentration of dissolved carbonic species are inter-dependent, and the analytical determination of two of the inter-dependent terms results in the third being mathematically obtainable.

The two dissociations of carbon dioxide in water are given in equations (2) and (3) together with the values of Margolis (1966).

\[
\frac{(H^+)(HCO_3^-)}{(CO_2)} = -\text{Log}K_1 = 6.35 \\
\frac{(H^+)(CO_3^{2-})}{(HCO_3^-)} = -\text{Log}K_2 = 10.33
\]  

(2)  

(3)
Mathematical manipulation of the equilibrium expressions (2) and (3) can give rise to the concentration of a specific species as a function of pH if the total concentration of all carbonic species \((C_T)\) is known (Kern, 1960).

Figure 1 shows the pH vs-Log Concentration diagram for a solution which is \(2 \times 10^{-3}\) Molar in carbonic species (alkalinity = 100 mg/l as CaCO₃) in which the changes in concentration of each species, for equilibrium conditions, is graphically presented after the method of Butler, (1981), and Weber, (1963). Any other solution with a different total concentration of carbonic species would have an identical distribution, however, the level at which it would be located on the ordinate would be dictated by the total concentration of carbonic species.

The use of term H₂CO₃, presented in keeping with current practice (Stumm and Morgan, 1970), denotes CO₂ gas and dissolved CO (H CO₃⁻) in equilibrium. As the ratio of the gas to the hydrated form is of the order of \(\frac{1}{400}\) to \(\frac{1}{1000}\) to one, the gas form of CO₂ can be selectively used (Fair, 1968, and Garrels, 1965).

Figure 1 also shows the concentration of Ca²⁺ ion, for higher pH values, which will satisfy the solubility product constant of CaCO₃ for the solution under consideration \((2 \times 10^{-3}\) Molar CT) which is isolated from sources of CO₂ and CaCO₃. This line is obtained as a plot of equation (4) in conjunction with the equilibria equations (2) and (3).

\[-\log (Ca^{+2}) - \log (CO_3^{--}) = 8.3\]  \hspace{1cm} (4)

An increase of 1 pH unit in the pH range 7 to 10 could result from a shift in the carbonate equilibria resulting from a 10-fold decrease in the CO₂ concentration, and result is a 10-fold increase in the CO₃²⁻ concentration (yet the HCO₃⁻ concentration will remain about the same). If the water was at the CaCO₃ saturation point, then the increase in CO₃²⁻ would be accompanied by a precipitation of CaCO₃, and the Ca²⁺ concentration would therefore be lowered to one tenth its former value. If the pH was decreased within the specified range, the reverse of the above would occur if the pH was decreased within the specified range. Disturbing the carbonate equilibrium would in turn give rise to a change in pH as the systems are interrelated.

![Figure 1](https://iwaponline.com/wst/article-pdf/21/6-7/669/100428/669.pdf)
Some Chemical Reactions in a Sewage Lagoon

A. Precipitation and Solution of CaCO$_3$. If a volume of lagoon liquid open to the atmosphere and contained by a natural soil boundary is considered, physical and chemical reactions taking place in this volume may be a combination of the following:

1. **Bacterial Respiration.** Under aerobic or anaerobic conditions, bacteria liberate CO$_2$ and other gases into the water when decomposing organic matter.

2. **Gas Transfer.** At the surface of the liquid, gas transfer is taking place. Oxygen and carbon dioxide may be diffusing into or out of the liquid under their own concentration gradients independent of other gases, and/or may be undergoing air stripping. Under non-turbulent conditions the amount of gas transferred will be small due to the small concentration gradient between successive layers of liquid. Carbon dioxide transfer into the liquid is further restricted in most waters, due to over saturation, with respect to the atmosphere, of CO$_2$ derived from the carbonate equilibrium. The slow hydration of CO$_2$ to H$_2$CO$_3$ further hinders gas transfer. Thus under normal conditions, it may be assumed that the liquid in a standing lagoon body is isolated from the atmosphere, and that appreciable gas transfer does not take place.

3. **Photosynthesis.** This process of the production of organic compounds, principally carbohydrates from carbon dioxide and inorganic materials by chlorophyll under the influence of light energy with the simultaneous liberation of oxygen, may be shown simplified as follows:

$$ 6CO_2 + 6H_2O \rightleftharpoons C_6H_{12}O_6 + 6O_2 $$

The photosynthetic activity of algal cells can cause a dramatic lowering of the CO$_2$ concentration in the immediate vicinity of the cell, and subsequently, be reflected throughout the body of the liquid. This disruption of the carbonate equilibrium could result in markedly increased pH values and CO$_2$ concentration. (See Fig. 1) which could (if the Ca$^{2+}$ concentration was high enough to bring about a supersaturated condition with respect to CaCO$_3$) result in precipitation of crystals of limestone throughout the body of the liquid (Vaughn, 1961).

4. **Respiration of Algae.** This process which produces CO$_2$ and H$_2$O from the aerobic breakdown of cellular material may be simplified as:

$$ C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 $$

Under conditions of no light, if sufficient oxygen was available, it is possible for respiring algae to generate a sufficiently high CO$_2$ concentration in the vicinity of the cell, and ultimately in the body of liquid, to reverse the equilibrium produced by photosynthesis. The system could become undersaturated with CaCO$_3$ and the deposited and other limestone would tend to dissolve to re-establish the equilibrium.

As solution rates are usually much slower than precipitation rates, and as the number of hours of photosynthesis in summer is greater than the period of dark during the operation of an aerobic sewage lagoon, it would be expected that equilibrium would not be established before the next period of photosynthesis, and that CaCO$_3$ deposition would be cumulative.

A complicating situation exists due to the solubility of silica.

5. **Solution and Precipitation of Silica.** The second most abundant element is silica which, as silicon dioxide or in combination with other oxides, constitutes about 60% of the rock mantle of the earth (Iler, 1955). As all natural bodies of water are contained in more or less water-tight basins, the silicous materials are subjected to the chemical stresses of the confined liquids.

Nearly impervious soils (clay) preferred for engineering purposes are composed of particles of 2 microns or less, which themselves are composed of building blocks of dimensions which can reach down to 25 Angstrom units (Grimm, 1953). The silica content of most clays ranges from 40 to 67% depending upon type (Keller, 1963).
Data for the solubility of silica from all soils and combinations of soils are not available; however, data for the least soluble form of silica (quartz), and the most soluble form (amorphous), should encompass this missing data and give an indication of the magnitude and form of a general soil solubility diagram (Polzer, 1967).

Utilizing the solubility equilibrium data presented by Stumm and Morgan (1970) a solubility diagram for silica was prepared, and is shown in Figure 2.

![Figure 2 pH-SOLUBILITY DIAGRAM FOR SILICA](image)

It is apparent that silica is soluble in the pH range where CaCO$_3$ may be depositing, and is insoluble in that range where there may be a tendency for CaCO$_3$ to dissolve. Whether these counteracting solubility systems are in fact operating, and for what time period, presents a whole area of possible investigation.

The solubility of silica is dependent at low temperatures upon, among other factors:

1. Particle Size - The smaller the particle, the greater the rate of solution.

2. Presence of Salts and Bases - It has been reported that the presence of sodium, potassium, and carbonates greatly increase the formation of soluble silicates from colloidal silica. Aluminum, calcium and magnesium depress the solubility of silica (Iler, 1955).

**LAGOON STUDY RESULTS**

Table 2 contains some selected data from 24-hour continuous investigations conducted on lagoons under mid-summer conditions. Definite diurnal patterns of pH and dissolved oxygen (D.O.) are evident indicating the influence of photosynthesis on both aerated and unaerated lagoons. Samples evolving a gas during laboratory D.O. determinations and the values of which indicated a supersaturated condition with respect to oxygen, are recorded as S. Samples taken from these and other waters after storage showed a drop in both the pH and the carbonate ion concentration. The maximum pH drop was two units.

In all cases the silica content of the lagoons was much lower than the theory would predict if the liquid was in contact with a source of silica. It has been suggested that silica solution from the soil is most easily accomplished when soil particles are first exposed to the water and the solution becomes more difficult as the more available atoms are removed. Laboratory investigations on silica sand would indicate this to be the case.
It has also been suggested that the deposition of CaCO₃ and the deposition and subsequent decay of organic material in the lagoon bottom may shield the soil from exposure to the high pH liquid. Experimental work is continuing to elaborate on the preliminary findings on the solubility and precipitation of minerals in natural waters.

**TABLE 2 Selected Data from Lagoon Studies**

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</tr>
</thead>
<tbody>
<tr>
<td>12 Noon</td>
<td>10.0</td>
<td>Ss</td>
<td>8.2</td>
<td>3.0</td>
<td>9.5</td>
<td>12</td>
</tr>
<tr>
<td>4 p.m.</td>
<td>10.2</td>
<td>Ss</td>
<td>8.3</td>
<td>3.2</td>
<td>9.7</td>
<td>12</td>
</tr>
<tr>
<td>8 p.m.</td>
<td>9.7</td>
<td>Ss</td>
<td>7.9</td>
<td>2.4</td>
<td>9.4</td>
<td>10.1</td>
</tr>
<tr>
<td>12 midnight</td>
<td>8.8</td>
<td>8.3</td>
<td>7.8</td>
<td>2.0</td>
<td>9.1</td>
<td>8.4</td>
</tr>
<tr>
<td>4 a.m.</td>
<td>7.8</td>
<td>7.2</td>
<td>7.8</td>
<td>1.5</td>
<td>8.7</td>
<td>7.4</td>
</tr>
<tr>
<td>8 a.m.</td>
<td>8.7</td>
<td>Ss</td>
<td>8.1</td>
<td>2.8</td>
<td>9.3</td>
<td>7.6</td>
</tr>
<tr>
<td>12 Noon</td>
<td>9.7</td>
<td>Ss</td>
<td>8.2</td>
<td>3.8</td>
<td>9.5</td>
<td>11</td>
</tr>
<tr>
<td>After Storage</td>
<td>8.5</td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silica (ppm)</td>
<td>0.01</td>
<td>0.005</td>
<td></td>
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</tr>
</tbody>
</table>

Aerated 1 = First cell of 2 cell aerated lagoon.
Aerated 2 = Second cell of 2 cell aerated lagoon.
Ss = Super saturation

**REMEDIAL ACTION**

Unplugging of chemically plugged aeration devices is a complicated procedure which can take place during the operation period and also during the normal (annual) maintenance period.

When it becomes evident that fine bubble diffusers are plugging or mechanical coarse bubble diffusers are becoming sluggish, it is possible to provide an internal acid bath.

Either chlorine gas or hydrogen chloride gas can be introduced under pressure to the aerator headers either with or without the normal flow of air. These gases when exiting the bubbler will form acids which will dissolve the deposited calcium carbonate.

This is not an effective remedy on diffusers which are completely plugged and of course has no effect on removing the silica deposited in the aerators. Such completely plugged aerator must undergo maintenance during the prescribed maintenance period.

It is often necessary to physically crush the split tube type of aerators between rollers to free them of mineral deposits, while the mechanical "burp gun" type of aerator requires being removed from the system and being subjected to immersion in an acid bath.

The diurnal patterns of pH and DO in the unaerated lagoon supports the theory that intensive algal activity is occurring and producing large quantities of oxygen, utilizing and extracting such large quantities of carbon dioxide that the pH is elevated into the area of calcium carbonate deposition.

Aeration of lagoons flattens out the magnitude of the diurnal swings of pH and DO in the bulk liquid in a lagoon. The values of the two measured parameters and the carbon dioxide values immediately adjacent to the aerator orifices were not determined, however, the aerated lagoons have had a CaCO₃ SiO₂ plugging history in the more than 20 years since they were commissioned. It must be assumed that the conditions at the aerator outlets are extremely rigorous, as these units in both lagoon cells require cleaning at least yearly.
CONCLUSIONS

The use of aeration systems in waste water treatment is increasing in Canada in order to provide a more acceptable effluent from this type of facility.

Plugging of the aeration devices presents a constant and continuing problem.

Plugging may be of a mechanical nature and calls for unplugging or replacing the unit during the normal maintenance period.

Plugging of submerged fine bubble aerators is usually of a chemical nature and may be overcome by the feeding of an acid gas through the air lines to dissolve the calcium carbonate precipitated during the times of intense algal activity. Silicon dioxide, which may be precipitated during periods of no algal activity, does not appear to be prone to removal by basic chemical washing and must be removed physically by scraping or crushing.

REFERENCES


