FS-BIO-011

TECHNOLOGY FACT SHEETS
FOR EFFLUENT TREATMENT PLANTS
ON TEXTILE INDUSTRY

AERATED PONDS

SERIES: SECONDARY TREATMENTS

TITLE	**AERATED PONDS (FS-BIO-011)**
Last update	July 2015
Last revised	

UNIVERSIDADE DA CORUÑA

INDITEX

AERATED PONDS (FS-BIO-011)

Date	July 2015		
Authors	Alfredo Jácome Burgos Joaquín Suárez López Pablo Ures Rodríguez		
Revised by			
Last update	Date	Done by:	Update main topics

INDEX

1.- INTRODUCTION

The content of this technical sheet on "aerated ponds" is based primarily on the following publications:

- "Aerated Pond", compiled by Eawag (Swiss Federal Institute of Aquatic Science and Technology), Dorothee Spuhler (international Gmbh) published on SSWM (http://www.sswm.info) (2015).
- "Aerated, partial mix lagoons", Technology Fact Sheet 832-F-02-008, published by U.S. EPA (2002).
- "Principles of design and operations of wastewater treatment pond systems for plant operators, engineers, and managers", EPA/600/R-11/088, published by U.S. EPA (August 2011).

2.- DESCRIPTION

An aerated pond is a large, mixed aerobic reactor similar to facultative ponds in systems, with the difference that natural oxygenation is enhanced. Mechanical aerators provide oxygen and keep the aerobic organisms suspended and mixed with water to achieve a high rate of organic degradation. As natural oxygenation is enhanced, ponds can be deeper (thus smaller in surface) and are suited also for colder climates compared. The effluent of aerated ponds may be reused or used for recharge, but settled sludge requires a further treatment or correct disposal.

Increased mixing and aeration from the mechanical units means that the ponds can be deeper and tolerate much higher organic loads than a maturation or a facultative pond. The increased aeration allows for increased degradation. As well, because oxygen is introduced by the mechanical units and not by light-driven photosynthesis, the lagoons can function in more northern climates. Mechanical aeration enhances the treatment efficiency and reduces the required hydraulic retention time (HRT) for aerobic degradation of organics (Rose 1999, cited by U.S. EPA 2011). It also increases pathogen removal because of the favorable effect of oxygen on solar water disinfection (Curtis et al. 1992). The smaller area requirement means that it is appropriate for both rural, and peri-urban environments (Tilley et al. 2014). However, the use of aerators also increases the complexity of the systems and technical material and energy is needed (Arthur 1983).

Aerated lagoons typically are classified by the amount of mixing provided. There are two types of aerated ponds (SSWM 2015):

- Aerated facultative ponds (partial mix lagoons), when it is desired to have a more aerobic system, compacter than normal facultative ponds, or when loads for conventional facultative ponds are too high. Partial mix lagoons are commonly used to treat municipal and industrial wastewaters. This technology has been widely used in the United States for at least 40 years (U.S. EPA 2002).
- Completely mixed aerated ponds. Complete mix systems use approximately 10 times the amount of energy as partial mix systems (MPDES, August 2012).

In some cases, the initial cell in a system might be a complete mix unit followed by partial mix and settling cells. Most energy in complete mix systems is used in the mixing function which requires about 10 times the amount of energy needed for an equally-sized partial mix system to treat municipal wastes (U.S. EPA 2002).

Aerators used in partially mixed lagoons are generally placed on the lagoon surface and provide enough turbulence to satisfy the oxygen demand for aerobic oxidation, but they allow a sludge layer to form at the bottom of the pond. When energy is readily available, the water may be pumped through flow form cascades before entering the ponds for aeration. Some solids in partial mix lagoons are kept in suspension to contribute to overall treatment. This allows for anaerobic fermentation of the settled sludge. Partial mix lagoons are also called facultative aerated lagoons (SSWM 2015) and are generally designed with at least three cells in series, with total detention time dependent on water temperature (U.S. EPA 2002).

Aerators used in a completely mixed lagoon can be surface mechanical mixers or subsurface diffusers. They should provide enough energy to maintain the solids in suspension. Completely mixed aerated lagoons are in essence activated sludge units without sludge return (Arthur 1983, US-EPA 2002). As the sludge remains in suspension, effluents of completely mixed ponds require a post-treatment in a sedimentation pond. Just like for Wastewater Stabilization Ponds (WSPs), the effluent of ponds can be reused in agriculture (e.g. irrigation) or aquaculture (e.g. macrophyte or fish ponds) even though it has generally lower nutrient loads. However, the sludge which forms at the bottom of the aerated facultative lagoon or the sedimentation ponds (in the case of a completely mixed pond) needs to be dug out regularly. And before it can be reused in agriculture it requires a further treatment (e.g. through composting (compost chamber or large scale composting, anaerobic digestion or a constructed wetland).

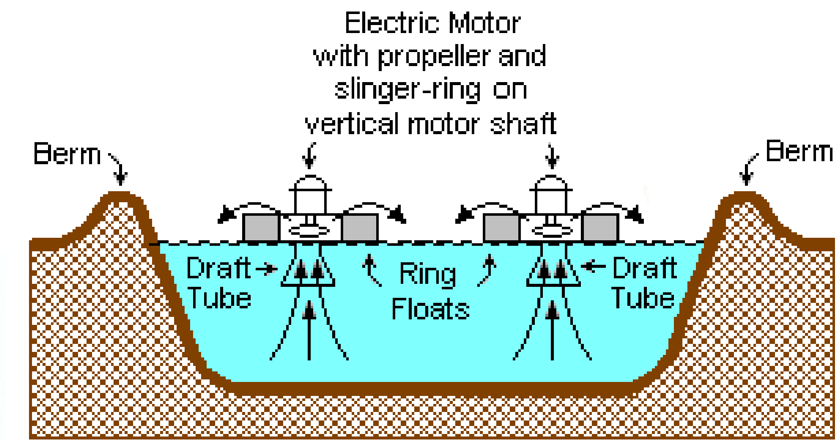

Figure.- Schematic view of a typical surface-aerated basin. Note: the ring floats are tethered to posts on the berms. (https://en.wikipedia.org/wiki/Aerated_lagoon, accessed July 22, 2015).

2.1.- Applicability

Aerated ponds are well suited for small communities and industries. They have been used to treat raw, screened or primary settled municipal wastewater, as well as higher strength biodegradable industrial wastewater.

A mechanically aerated pond can efficiently handle concentrated influent and significantly reduce pathogen levels. It is especially important that electricity service is uninterrupted and that replacement parts are available to prevent extended downtimes that may cause the pond to turn anaerobic.

Aerated ponds can be used in both rural and peri-urban environments. They are most appropriate for regions with large areas of inexpensive land located away from homes and businesses. Aerated lagoons can function in a larger range of climates than and the area requirement is smaller compared to a maturation pond. But they are also more complex from a technical and operational point of view.

Advantages

- Resistant to organic and hydraulic shock loads
- High reduction of BOD and pathogens
- No real problems with insects or odors if designed and maintained correctly
- Can treat high loads
- Less land required than for simple pond systems (e.g. WSP)
- The treated water can be reused or discharged if a secondary maturation/settling pond follows the aerated lagoon/completely mixed aerated pond

Disadvantages

- Requires a large land area
- High energy consumption, a constant source of electricity is required
- High capital and operating costs depending on the price of land and of electricity
- Requires operation and maintenance by skilled personnel
- Not all parts and materials may be locally available
- Requires expert design and construction supervision
- Sludge and possibly effluent require further treatment and/or appropriate discharge

2.2.- Estimating land area required for treatment ponds

The area estimate for a pond system depend on the effluent quality required, the type of pond system proposed and the geographic location (i.e. temperature). The land required for a community wastewater flow of 3785 m^3/d (1 mgd) is estimated below for three types of locations: a cold climate, a temperate climate and a warm climate. The allowances are made for any preliminary treatment that might be required and for unused portions of the general site area:

Table 1.- Land area estimates (in ha) for 3785 m^3/d systems (1 mgd) (Adapted from U.S. EPA 2011)

System	Cold climate	Temperate climate	Warm climate
Partial-mix aerated	20	15	12
Complete-mix aerated	2	2	1

1mgd = 1 million of gallons per day.

3.- DESIGN CONSIDERATIONS

Influent should be screened and pre-treated to remove garbage and coarse particles that could interfere with the aerators. Because the aeration units mix the pond, a subsequent settling tank is required to separate the effluent from the solids.

Equipment typically required for aerated lagoons includes the following: lining systems, inlet and outlet structures, hydraulic controls, floating dividers and baffles, aeration equipment.

3.1.- Aerated facultative ponds (partial mix lagoons)

The design of an aerated facultative pond is very similar to that of a facultative pond, with an aerobic zone close to the surface and a deeper, anaerobic zone. But there are no requirements in term of surface area as the process is independent of photosynthesis.

The two main design criteria are HRT and depth. The HRT should be adopted in order to allow a satisfactory removal of BOD (biological oxygen demand) and is usually 10 to 30 days, with 20 days the most typical (U.S. EPA 2002) for organic loads of 20 to 30 g $BOD/m^3/d$ (Sasse 1998). Pond depths range from 1.8 to 6 m, with 3 m the most typical. The shallow depth systems usually are converted facultative lagoons (U.S. EPA 2002, 2011). Aerated ponds with shallow depths are also reported to have given encouraging results (Arcievala and Mohanrao 1969).

Energy is required for the aeration devices, the amount depending on the intensity of mixing desired. Partial mix systems require between 1 – 2 W/m^3 capacity, depending on the depth and configuration of the system (U.S. EPA 2011).

3.2.- Completely mixed aerated pond

Complete mix ponds are smaller than partial mix lagoons. Completely mixed aerated/lagoons are essentially aerobic. The aerators serve not only to guarantee the oxygenation of the medium, but also to maintain the suspended solids (biomass) dispersed in the liquid medium. These systems are also called flow-through lagoons or CSTR (completely-stirred tank reactor) lagoons.

Biomass and solids from the raw sewage are maintained together in suspension. This enhances the contact between bacteria contained in the biomass (responsible for the degradation) and the raw sludge to be degraded. Hence, the efficiency of completely aerobic ponds increases in comparison to partially mixed ponds and allows a reduction in volume. Land requirements for this system are the smallest within ponds systems.

Hydraulic residence times are generally are less than 3 days except where high strength wastewaters are treated (U.S. EPA 2011). The typical HRT of a completely mixed aerated lagoon is in the order of 2 to 4 days. This time is enough for an efficient removal of the BOD5 (von Sperling 2005). A complete mix system requires about 10 times the amount of energy needed for a similarly partial mix system. For example, a HRT of 4 days, resulting in 70 to 90% BOD5 removal, requires about 20 W/m^3 of energy (Arthur 1983).

3.3.- Summary of design criteria

Table 2.- Aerated lagoons design criteria

Parameter	Partial mix lagoon	Completely mixed pond
HRT (days)	10-30 (typical 20)	2 – 4 (typical 3)
Depth (m)	1.8 – 6 (typical 3)	2 - 5
Organic load (g $BOD/m^3/d$)	20 - 30	---
Energy required (W/m^3)	1-2	Minimum 20

3.4.- Performance

According to the EPA (2002, 2011), aerated lagoons provide significant reductions, as follow:

- BOD_5: depending on the influent concentration, less than 30 mg/L is a typical effluent concentration with up to 95% removal expected
- TSS: effluent concentrations range from 20 – 60 mg/L, and reliably able to achieve TSS of less than 30 mg/L if a settling pond is in place at the end of the system.
- Significant nitrification occurs during the summer if there is adequate Dissolved Oxygen (DO).
- Where appropriate, phosphorus removal (15-25% expected).

The aerated lagoon system is simple to operate and reliable in performance for BOD removal. TSS removal can be influenced by the presence of algae in the lagoon, but generally is acceptable. The service life of a lagoon is estimated at 30 years or more.

It is also common to predict the performance of aerated lagoons using first order kinetics for BOD (or COD) reaction:

$$C_e = \frac{C_0}{[1 + (K_T)(t)/n]^n}$$

Where:

C_e = effluent BOD (or COD) (mg/L)
C_0 = influent BOD (or COD) (mg/L)
K_T = temperature dependent rate constant = $K_{20}\,\theta^{(T-20)}$
K_{20} = rate constant at 20 ºC
θ = temperature coefficient (1.036 for domestic wastewater)
T = temperature of water (ºC)
t = total detention time in system
n = number of equal sized cells in system

From the study of Shah et al. (2012) for **textile wastewater** treatment with bench scale aerated lagoon, the value of K_T came out to be 0.797 day^{-1} for BOD and 0.390 day^{-1} for COD (temperature range of study: 26 – 32 ºC).

For domestic wastewater the common value of K_{20} is 0.276 day^{-1} (U.S. EPA 2002).

If other than a series of equal volume ponds are to be employed and varying reaction rates are expected, the following general equation should be used:

$$\frac{C_n}{C_0} = \left(\frac{1}{1+\,k_1t_1}\right)\left(\frac{1}{1+\,k_2t_2}\right)\cdots\left(\frac{1}{1+\,k_nt_n}\right)$$

Where k_1, k_2, ... k_n are the reaction rates in cells 1 through n (all usually assumed to be equal without additional data) and t_1, t_2,...t_n are the hydraulic residence times in the respective cells.

Mara (1975, cited by U.S. EPA 2011) has shown that a number of equal volume reactors in series is more efficient than unequal volumes; however, due to site topography or other factors, there may be sites where it is necessary to construct cells of unequal volume.

4.- SECONDARY CLARIFICATION

Aerated facultative ponds (partial mix lagoons)
Detention times in the settling basin or portion of a basin used for settling of solids should be limited to two days to limit algae growth. The design of inlet and outlet structures should receive careful attention.

Completely mixed aerated pond
As the quality of effluent from these ponds is not satisfactory for direct discharge into the environment, completely mixed aerated lagoons should be followed by settling ponds. These may be either several short HRT ponds (i.e. 2 days), requiring frequent de-sludging (von Sperling 2005); or a single 10-day facultative pond with sufficient depth to allow long-term sludge storage.

5.- TECHNICAL CONDITIONS

To prevent leaching, the pond should have a liner. This can be made from clay, asphalt, compacted earth, or any other impervious material. A protective berm should be built around the pond, using the fill that is excavated, to protect it from runoff and erosion.

A mechanically aerated pond can efficiently handle effluents with a high concentration. But electricity service must be uninterrupted and replacement parts available to prevent extended downtimes that may cause the pond to tum anaerobic (Tilley et al. 2014).

The pond is a large expanse of pathogenic wastewater; health hazards can be caused by the aerosol effect releasing pathogens into the air (Arthur 1983); care must be taken to ensure that no one comes in contact with or goes into the water. The aeration units can be dangerous to humans and animals. Fences, signage, or other measures should be taken to prevent entry into the area.

Aerated facultative ponds (partial mix lagoons)
The depth of the pond should be planned keeping in mind the compatibility with the aeration system and the need of an aerobic layer of approximately 2 meters to oxidize the gases from the anaerobic decomposition of the bottom sludge (SSWM 2015).

The lagoons are constructed to have a water depth of up to 6 m to ensure maximum oxygen transfer efficiency when using diffused aeration. Generally designed with at least three cells in series. In most systems, aeration is not applied uniformly over the entire system. Typically, the most intense aeration (up to 50 percent of the total required) is used in the first cell (U.S. EPA 2002, 2011). The final cell may have little or no aeration to allow settling to occur. In some cases, a small separate settling pond is provided after the final cell. Diffused aeration equipment typically provides 3.7 – 4 kg O_2/kWh and mechanical surface aerators are rated at 1.5 – 2.1 kg O_2/kWh. Consequently, diffused systems are somewhat more efficient than non-aerated ponds, but also require a significantly greater installation and maintenance effort.

Even though partial mix ponds are designed using the complete mix model, it is recommended that the cells be configured with a length-to-width ratio of 3:1 or 4:1. This is because it is recognized that the hydraulic flow pattern in partial mix systems more closely resembles the plug flow condition.

One physical modification to an aerobic pond is the use of plastic curtains supported by floats and anchored to the bottom to divide existing ponds into multiple cells and/or serve as baffles to improve hydraulic conditions.

Completely mixed aerated pond
A multiple cell system with at least three cells in series is recommended, with appropriate inlet and outlet structures to maximize effectiveness of the design volume. Also, it is recommended that the cells be configured with a length-to-width ratio of 3:1 or 4:1.

Aerators should be positioned carefully to avoid dead areas where solids are able to settle out already in the aerated pond. Small aerators rather than fewer large ones provide more evenly spread mixing, and rounded pond corners also help in avoiding dead areas (Arthur 1983).

Aerated ponds have removal capabilities similar to facultative lagoons, except that nitrification of ammonia-nitrogen can be nearly completed in warm seasons, while cold weather will halt that process (U.S. EPA 2002).

6.- SPECIFICATIONS IN TEXTILE INDUSTRY EFFLUENT TREATMENT

Williams and Hutto (1961) evaluated pilot scale aerated lagoons to treat wastewater from the textile industry. The paper describe the studies and outlines the savings that will result from the construction of full-scale facilities based on the pilot plant work. The factory at which the work was done is Mooresville Mills at Mooresville, North Caroline. Dyeing at Mooresville Mills is done in both the raw stock and package form. Finishing, includes mercerization of fabric, application of various finishes, and many washing operations. The pilot lagoons consisted of two units, each 30 ft (9.1 m) long by 20 ft (6.1 m) wide at the top, with sloping sides and a net depth of 5 ft (1.5 m). The two units were arranged in series with a weir overflow from the first to the second. Baffles were placed near the inlet to each unit to prevent surface short circuiting. In order to prevent scour and to make the lagoons water-tight, the banks were lined with sheets of plastic. Flow to the lagoon consisted of 61% from package dyeing and 39% from finishing. Including raw stock dyeing and miscellaneous wastes. Aeration was performed only in the first lagoon. The second pond was used to sedimentation. After eight weeks of operation with 48 h of aeration and 48 h of settling, the aeration and settling periods were reduced to 36 h and the pilot unit was operated on this basis for two weeks.

Following this, the unit was operated for three weeks on a 24-h basis, and for one week on a 14- to 16-h basis. The removals of the five-day BOD with different detention times are shown on Table 3:

Table 3. Aerated ponds BOD_5 removal efficiencies at different hydraulic retention times

HRT (h)	BOD_5 removal (%)
14-16	33
24	48
36	71
48	81

HRT = Hydraulic Retention Time = Aeration period

Finally, pilot aerated lagoons with HRT of 48 h or more, followed by settling, have given removals of 75 to 80 percent of the BOD_5.

Applying the results of the pilot lagoon led to the construction of two concrete lined aeration ponds, each 254 ft (76.9 m) long by 112 ft (33.9 m) wide at the water line, and 12 ft (3.6 m) deep, followed by two concrete lined settling lagoons, each 122 ft (36.9 m) long by 68 ft (20.6 m) wide at the water line and 12 ft (3.6 m) deep. At a design flow of 2.0 MGD (approx. 8.000 m^3/d), holding time in the aeration lagoons is 48 h and in the settling lagoons 12 h. It has four 25-hp (18.65-kW) aeration units each with a 7.25 ft (2.2 m) diameter rotor operating at a speed of 40 rpm. Oxygen input is rated at 80 lb/h/unit (approx. 40 kg/h/unit) or approximately 2.2 lb/lb of influent BOD (approx. 2 kg/kg). It should be noted that the size of the aeration units was established by the mixing requirements in the 12-ft (3.6 m) deep lagoons, rather than oxygen requirements. An estimation, based on previous experience, was that oxygen requirements alone would be about one lb per lb (or one kg per kg) of BOD. "Authors comment: Since the ratio energy/volume was 8 W/m3 is deduced that the lagoons were designed as complete mixing systems. Partial mix systems only require between 1 and 2 watts per cubic meter (5 and 10 hp per million gallons) of capacity, depending on the depth and configuration of the system (U.S. EPA 2002)".

Opitz (1974) evaluated lagoon treatment of **combined textile and domestic wastes** from a textile finishing plant in Post, Texas. The textile waste was the major BOD contributor. Processing of both cotton and blend fibers in the textile plant involves slashing, desizing, scouring, bleaching, and finishing. The domestic sewage receives primary treatment by flowing through an Imhoff tank designed to remove settleable solids before being mixed with the textile wastewater. The combined waste then flows into the first of three lagoons: anaerobic, aerobic and maturation. The three lagoons were designed to be an anaerobic lagoon followed by two aerobic lagoons. The effluent from the third lagoon ultimately flows into a tributary of the Brazos River. Criteria for effluent discharges allow maximum concentrations of 30 mg/L and 300 mg/L for BOD and COD, respectively, with average concentrations not to exceed 20 mg/L and 200 mg/L, respectively. The objectives of this study were to evaluate the existing treatment system and to suggest a more efficient operation. Combined textile waste and domestic sewage can be treated effectively by properly designed and operated anaerobic and aerobic lagoons. The BOD, COD and SS average removal efficiencies were found to be 79.3%, 62.5% and 60.3%, respectively.

Shah et al. (2012) conducted research to assess the performance of aerated lagoon for biological treatment of textile wastewater and to determine kinetic coefficients for the design of treatment facilities. For this purpose, a bench scale model of aerated lagoon was set up and was operated continuously for 92 days by varying aeration times from 5 to 15 days. Primary treated wastewater effluent collected from Nishat Textile Mills (Lahore, Pakistan) was fed as an influent to aerated lagoon. To evaluate the performance of aerated lagoon, the suspended solids (SS), biological oxygen demand (BOD) and chemical oxygen demand (COD) for both the influent and effluent were measured at each aeration time after ensuring steady state conditions. The influent BOD was observed to vary from 540 to 355 mg/L while the effluent BOD varied from 121 to 32 mg/L during the study period. The corresponding range of influent COD was between 1813 and 1116 mg/L and for effluent COD was between 592 and 224 mg/L. The results show that the average effluent BOD at aeration time of 7 days was lower than 80 mg/L. However, the effluent COD did not meet the National Environmental Quality Standards (NEQS) limit of 150 mg/L even at the aeration time of 15 days. This indicated the presence of large amount of chemicals in the textile wastewater, for instance bleaching agents like hydrogen peroxide and sodium hypochlorite; complex dyes and pigments like chromium based dyes used for imparting color to the fabric. The fate of these chemicals varies ranging from 100% retention on the fabric to 100% discharge with effluent. Chemical coagulation, prior to primary sedimentation, by coagulants like lime, aluminum salt (especially aluminum sulphate or alum), ferric chloride and ferrous sulphate, is most commonly employed for significant removal of COD. Overall removal rate constant (K) for the present study was calculated to have a mean value of 0.79 d-1 based on BOD. Based on COD, the overall removal rate constant (K) was found out to have a mean value of 0.39 d-1. The F:M ratio for BOD ranged between 0.1 and 0.41 kg BOD/kg MLSS-d corresponding to a removal efficiency of 92.4 to 77.2%. Furthermore, the range of F:M ratio for COD varied between 0.36 and 1.30 kg COD/kg MLSS-d corresponding to a removal efficiency of 85.0 to 66.3%. The kinetic coefficients k, KS, Y and Kd determined were found to be 3.83 d-1, 1303.56 mg/L, 0.70 and 0.01 d-1 on BOD basis and 5.20 d-1, 3407.64 mg/L, 0.25 and 0.006 d-1 on COD basis. Overall removal rate constant (first-order kinetic model) (K) for wastewater of textile industry was calculated to have a mean value of 0.79 d-1 based on BOD. Based on COD, constant K was found out to have a mean value of 0.39 d-1. Average effluent BOD at 7 days aeration time revealed results conforming to NEQS in terms of BOD. Therefore, F:M ratio in the range 0.25 to 0.41 kg BOD/kg MLSS-d and a detention time of 7 days is recommended for textile wastewaters.

The WEPA (2015) has published the results of an aerated lagoon system installed in the Wastewater Treatment Plant at Kongka Textile Mill Limited Company. The process flow diagram is: equalization tank (2,016 m^3) + chemical treatment pond (2,016 m^3) + aerated lagoon (3,468 m^3) + settling pond (3,468 m^3). The daily amount of treated wastewater is 2000 m^3. Thus, total HRT is 5.484 days (1.73 days in aeration). The influent and effluent actual quality is shown in the table 4:

Table 4. Kongka Textile Mill inlet and outlet characteristics

Parameter	Influent (mg/L)	Effluent (mg/L)
SS	101	26
BOD	86	23
COD	296	233

That is, the system is efficient to remove the biodegradable organic matter (73% removal). However, it needs to improve the removal of refractory organic matter (COD).

7.- MONITORING LAGOONS

Most of this section is based on "Optimization of Lagoon Operation" published by Federation of Canadian Municipalities and National Research Council (FCM & NRC 2004) and “Principles of design and operations of wastewater treatment pond systems for plant operators, engineers, and managers”, EPA/600/R-11/088, published by United States Environmental Protection Agency (U.S. EPA 2011).

Two types of monitoring of lagoon-based systems are recommended:

- Process control monitoring provides information to the operating staff on the condition and performance of the system and allows for early warning of possible upsets or operational problems.
- Compliance monitoring is required under the operating permit or certificate of approval and reported to the regulatory agency.

Different levels of accuracy are needed for these two types of monitoring. Process control testing is intended to be used by the operating staff to make operational decisions. These tests can be done in-house using more rapid, easier test methods that do not necessarily comply with standard methods, but which provide dependable results to the operators. Compliance tests should always be done by a certified laboratory using standard methods or equivalent.

Less rigorous sampling methods, such as grab samples rather than composite samples, are often appropriate for process control measurements than are needed for compliance monitoring.

Seasonal variations in loads should also be considered in the design of the monitoring program. Regular site inspections should be conducted and the findings included in the facility operating logs and records.

7.1.- Sampling

Sampling locations usually include only the raw sewage influent to the lagoon and the effluent discharged from the lagoon. Intermediary samples collected within the lagoon cells or between the cells of multi-cell lagoon systems are not normally required by the permit. If not specified, grab samples of raw sewage and final effluent should be collected. Because of the long retention times provided by lagoons, collection of flow-proportional composite samples is not strictly necessary unless specified in the operating permit or certificate of approval.

The samples should be collected at a location that is representative of the sampled stream. Raw sewage samples can be collected at the overflow from an inlet box, in an inlet channel, or from the raw sewage pump station discharge in a turbulent, well-mixed area. Sampling from wet wells and within inlet or diversion boxes should be avoided unless the area is well mixed because solids can settle in these non-turbulent areas, affecting the result.

Similarly, effluent samples should be collected from the overflow of the outlet control structure or at a well-mixed, turbulent location in the effluent channel prior to mixing with any dilution waters such as the receiving stream waters. The frequency of effluent sampling will depend on the discharge mode.

For process control purposes, additional samples from within the lagoons and from the discharges of the individual cells should also be collected on a routine basis to assess the condition of the ponds. Pond composite samples should consist of four equal portions taken from four corners of the pond. The sample should be collected 2.4 m out from the water's edge and 0.3 to 0.6 m below the water surface or at the transfer structures between the cells if these are present. Care should be taken to avoid stirring up material from the pond bottom and should not be taken near mechanical aerators or during or immediately after high wind or strong storms, as these processes may stir solids into the water column.

7.2.- Important visual and olfactory observations

Operators' visual and olfactory observations are important pond troubleshooting tools. Color and odor can be important indicators of pond health and ability to meet discharge permit standards.

Observations of the color of the lagoon should also be made and recorded since this can provide the operator with an indication of the condition of the lagoon, as summarized in the table.

Table.- Important indicators in pond troubleshooting

Color	Odor	Interpretation
Clear	None	No problem.
Brown	Earthy	No problem; usually good operation.
Dark sparkling green	Grassy or earthy	Good conditions. Generally occurs with high pH and DO.
Dull green to yellow	Fishy	Not so good; pH and DO generally dropping. Blue-green algae beginning to predominate.
Tan to brown		May relate to brown algae, which is OK. If related to silt or bank erosion, can indicate physical problems in lagoon or collection system.
Red streaks	None or septic	Daphnia overgrowth, often after algal bloom. It is recommended increase aerator running time, recirculate.
Grey to black	Septic-sewage	Very bad. Pond is septic, virtually zero DO.

Source: Adapted from U.S. EPA (1977, 2011).

7.3.- Flow measurement

Measurement of flows into the lagoon is essential to determine hydraulic and organic loadings and to compare the loads with system design. Influent flows are also needed to determine and adjust dosage rates of chemicals used for continuous phosphorus removal. Measurement of flows out of the lagoon is essential to ensure compliance with the discharge requirements specified in the operating permit or certificate of approval.

“It is best practice to measure flows in to and out of lagoons”.

In continuous discharge lagoons, comparison of influent and effluent flows can be used to assess flow metering accuracy.

A number of methods can be used to measure or estimate flows, including:

- run time meters and pump capacities on raw sewage pump stations;
- magnetic flow meters on pump station discharges;
- velocity/area meters in channels;
- various open channel flow meters such as weirs or flumes;
- changes in water level in lagoons during periods of discharge or fill.

A variety of references are available such as Grant and Dawson (1995) on flow meter installation and calibration. Flow meters should be electronically calibrated (secondary flow element) annually and physically calibrated (primary element) at least once, or more often if physical changes are made to a meter that might affect its accuracy.

7.4.- Dissolved oxygen

Dissolved oxygen is an essential indicator of aerobic biological activity. The DO test is performed on a grab sample and must be performed immediately. The easiest method for analyzing for DO is with a portable meter. The test should be performed at sunrise and again around 2 - 3 p.m.

Large fluctuations in the primary cell may signal problems with the influent, such as shock loading or toxic waste problems. Some fluctuation in day-to-day DO in the pond system is expected. The operator should plot daily readings and identify trends in concentrations. A decreasing trend in DO in the early morning test may indicate an increasing organic load, a developing short-circuiting problem or an algal overgrowth problem. In aerated lagoons the minimum DO concentration is set at 2 ppm for optimum performance. And, all measures should be taken to avoid the DO concentration dropping to zero. This will cause incomplete treatment of the wastewater and will result in discharge permit violations. The operator may have to take corrective action, such as increasing aerator running time or aeration capacity or switching to parallel operation. An increasing trend in the DO concentration, on the other hand, may allow the operator to decrease aerator running time or switch from parallel to series operation.

7.5.- TSS to BOD_5 ratio

The suspended solids (TSS) test measures the dry weight of solids retained on a glass fiber filter and is expressed in mg/L. Suspended solids removal is as important as BOD5 removal in preventing stream pollution. The origin of the suspended solids in the influent is not the same as in the effluent, as the former comes from the sewage, while the latter from algae growing in the final pond. As a result, the TSS may be higher than the BOD_5 in the effluent from pond systems.

Effluent BOD_5 violations are often accompanied by high effluent TSS concentrations. The table presents TSS to BOD_5 ratios that may indicate the cause of violations.

Table.- TSS to BOD_5 ratios as problem indicators (Richard and Bowman, 1997, cited by U.S. EPA 2011).

TSS to BOD_5 ratio	Cause(s)
<1	Old sludge solubilization and release of soluble BOD_5. Nitrification in the BOD_5 test bottle.
	Poor treatment or short circuiting with untreated wastewater mixing with the effluent.
1.5	Normal for most pond systems.
2.0-3.0	Algal overgrowth. Loss of old sludge particles.

7.6.- pH value

Large fluxes in influent pH may signal an industrial waste problem. The pH is a good indicator of the health of the pond system. Pond cells that have a dark green color generally have a high number of green algae and a corresponding higher pH. At night, algae and aerobic bacteria utilize O_2 and produce CO_2. The CO_2 in solution forms carbonic acid and drives the pH down. These diurnal pH patterns are indicators of internal pond conditions. Pond cells that appear black or grey in color and have a decreasing pH value (< 6.8) may be septic or moving toward a septic condition.

8.- OPERATION AND MAINTENANCE

Most of this section is based on "Advanced Stabilization Ponds and Aerated Lagoons Study Guide" published by Wisconsin Department of Natural Resources (WDNR 1998).

Permanent, skilled staff is required to maintain and repair aeration machinery and the pond must be wasted every 2 to 5 years and the sludge needs to be either post-treated (e.g. anaerobically digested, composted, or correctly disposed) (Tilley et al. 2014). The influents need also to be screened or settled as any large object could damage the aeration system. The pond itself must also be fenced off so no coarse objects can be thrown in.

Care should be taken to ensure that the pond is not used as a garbage dump, especially considering the damage that could result to the aeration equipment.

Depending upon the rate of aeration and the environment, aerated lagoons may experience ice formation on the water surface during cold weather periods. Reduced rates of biological activity also occur during cold weather. If properly designed, a system will continue to function and produce acceptable effluents under these conditions.

The potential for ice formation on floating aerators may encourage the use of submerged diffused aeration in very cold climates. The use of submerged perforated tubing for diffused aeration requires maintenance and cleaning on a routine basis to maintain design aeration rates. There are numerous types of submerged aeration equipment that can be used in warm or cold climates, which should be considered in all designs. In submerged diffused aeration, the routine application of HCl gas in the system is used to dissolve accumulated material on the diffuser units.

Any earthen structures used as impoundments must be periodically inspected. If left unchecked, rodent damage can cause severe weakening of lagoon embankments.

In respect to operation
Isolation of a pond cell which is experiencing an algae bloom gives the cell a chance to "rest" and recover.

If chemicals are used for pond weed control, they must be approved for that specific use and label directions must be followed precisely. It may be necessary to provide additional monitoring for toxics. Many times, the use of a surfactant is recommended to improve the "wetting" ability of the mixture so it adheres better to the treated plants.

The deeper the pond, the longer the contact time before the bubbles reach the surface. The smaller the bubbles, the more contact surface between the air and water, which increases the transfer rate.

Balancing of aeration within and between ponds is accomplished by using the valves on the manifold to get an even agitation pattern.

Floating aerators are used for additional aeration capacity to handle larger than expected organic loads during the summer months.

In respect to maintenance
Monitor all equipment: blowers, check valves, air diffuser orifices, dikes, all pumps, control manholes, and shear gates. Maintain seepage cells. A planned maintenance program will prevent problems and will identify potential concerns before they actually become problems.

Maintenance at a pond system involves simple housekeeping items which are critical to good treatment. Good housekeeping items are:

a. Remove any scum which impedes oxygen transfer and causes odors.
b. Mow dikes to the water line to keep weeds down, discourage burrowing muskrats, and promote wind mixing.
c. Maintain dikes by restoring any erosion and/or fill muskrat dens.
d. Skim floating duckweed regularly.
e. Control cattails regularly.
f. Perform preventive maintenance on all mechanical equipment as instructed in the O&M manual and the equipment manufacturers' manuals.
g. Exercise valves in the system on a regular basis.

The list of the maintenance items on aeration equipment:
a. Piping: check all air piping, including valves and diffusers to ensure that there are no blockages.
b. Centrifugal blowers: check oil levels, air filters, relief valves, and drive motors.
c. Positive displacement blowers: maintain oil levels, air relief valves, v-belts, air filters, and drive motors.
d. Floating aerators: maintain floats, electric lines, check oil levels, anchors, drive motors. Make sure impellers are not clogged.

Cleaning of air diffusers in pond systems can be done in several ways. If the plugging is minor, the air flow can be increased by shutting down some sections to increase the air to the remaining sections or by increasing blower output (if possible). Another cleaning method would be to introduce hydrogen chloride or oxygen /ozone gas through the air lines.

In some instances, divers have been used to mechanically clean the diffusers (rolling tubing through a flex tool or other methods). If none of these procedures work, the last option would be to draw the pond down to repair/replace diffusers.

The inlet air filter removes particulates from the air before the compression stage so debris does not get into the air line and plug diffuser orifices. It is also essential to protect the compressor from any damage, especially from gritty materials. The main maintenance requirement is to keep the filter clean. Usually, this is done by removing the filter and blowing it out with compressed air. The frequency of cleaning is dependent on filter size and ambient air quality. Other maintenance activities should be specified by the manufacturer or as listed in the O&M manual. Failure to adequately clean filters can cause reduced blower air output, an overheated blower, possible diffuser clogging, and possible damage to blower and drive motor.

The main methods for preventing dike erosion are proper dike vegetation and the use of rip rap around the normal operating pond levels to prevent erosion from wave action.

Ice damage occurs most often to floating aerators when they tip over. The motors and power cables can be damaged or broken during tipping. The best method is to stabilize them with adequate guy cables. Since oxygen requirements are lower in the winter, it is possible to protect equipment by removing some of the aerators.

BIBLIOGRAPHY

ARCIEVALA S.J., and MOHANRAO G.J. (1969). Design Construction and Operation Waste Stabilization Ponds in India. CPHERI, Nagpur.

ARTHUR, J.P. (1983): Notes in the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries. (World Bank Technical Paper, 7). Washington: The World Bank.

CRITES, R.; TCHOBANOGLOUS, G. (1998): Small and decentralized wastewater management systems. New York: The McGraw-Hill Companies Inc.

CURTIS, T.P.; MARA, D.D.; SILVA, S.A. (1992): Influence of pH, oxygen and humic substances on ability of sunlight to damage Faecal Coliforms in waste stabilization pond water. Applied and Environmental Microbiology, 58: 1335-1343.

FCM & NRC (2004). Optimization of Lagoon Operation. Issue No. 1.0. Published by Federation of Canadian Municipalities and National Research Council: Canada.

GRANT, D.M.; DAWSON B.D. (1995). Isco Open Channel Flow Measurement. Fourth Edition. Isco Environmental Division: Lincoln, Nebraska.

MARA, D.D. (1975). Discussion, Water Res., 9: 595.

MIDDLEBROOKS, E.J. et al. (1982). Wastewater Stabilization Lagoon Design, Performance and Upgrading. McMillan Publishing Co.: New York, NY.

MPDES (2012). “Domestic sewage treatment lagoons general permit. Fact Sheet”. Published by Montana Pollutant Discharge Elimination System.

NATURGERECHTE TECHNOLOGIEN, BAU UND WIRTSCHAFTSBERATUNG (TBW). (2001): Decentralized Wastewater Treatment Methods for Developing Countries. GTZ and GATE.

OPITZ D.C. (1974). Lagoon treatment of combined textile and domestic wastes. A thesis in Civil Engineering submitted to the graduate faculty of Texas Tech University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

ROSE, G.D. (1999). Community based technologies for domestic wastewater treatment and reuse: options for urban agriculture IDRC: Research Programs, Cities Feeding People, Report 27.

REED, S.C., et al. (1995). Natural Systems for Waste Management and Treatment, 2nd ed. McGraw Hill Book Co., New York, NY.

SASSE, L. (1998): Decentralized Wastewater Treatment in Developing Countries. Bremen: Bremen Overseas Research and Development Association (BORDA).

SHAH, M., HASHMI H.N., WAHEED, H. (2012). Determination of kinetic coefficients for the biological treatment of textile wastewater. Int. J. of Physical Sciences, 7(10): 1726-1740.

SPERLING, M. von (2005): Part Three; Stabilization Ponds. In: Sperling, M. von; Lemos Chernicharo, C.A.: Biological Wastewater Treatment in Warm Climate Regions Volume 1. London, 495-646.

SSWM (2015). “Aerated Pond”, compiled by Eawag (Swiss Federal Institute of Aquatic Science and Technology), Dorothee Spuhler (seecon international gmbh), published on SSWM (http://www.sswm.info).

TCHOBANOGLOUS, G.; BURTON, F. L.; STENSEL, H. D.; (2003): Wastewater Engineering, Treatment and Reuse. (Fourth Edition). METCALF & EDDY Inc. (Editor). New York: McGraw-Hill Companies, Inc.

TILLEY, E.; ULRICH, L; LUETHI, C.; REYMOND, P.; ZURBRUEGG, C. (2014): Compendium of Sanitation Systems and Technologies. 2nd Revised Edition. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag).

U.S. EPA (1977). Operations Manual Stabilization Pond. EPA-430/9-77-012. United States Environmental Protection Agency.

U.S. EPA (1980). Onsite Wastewater Treatment Systems Manual. (EPA 625/1-80, 12). United States Environmental Protection Agency, Office of Water Office of Research and Development.

U.S. EPA (1983). Design Manual - Municipal Wastewater Stabilization Ponds, EPA-625/1-83-015, US IPA CERI, Cincinnati, OH.

U.S. EPA (2002). Aerated, partial mix lagoons. EPA Technology Fact Sheet 832-F-02-008. United States Environmental Protection Agency, Office of Water.

U.S. EPA (2011). Principles of design and operations of wastewater treatment pond systems for plant operators, engineers, and managers, EPA/600/R-11/088, published by United States Environmental Protection Agency (U.S. EPA).

WDNR (1998). Advanced stabilization ponds and aerated lagoons study guide. Wisconsin Department of Natural Resources, Bureau of Sciences Services, Madison, WI 53707. Downloaded from http://dnr.wi.gov

WEPA (2015) Wastewater Treatment Plant at Kongka Textile Mill Limited Company. Information source: Project report, Department of industrial work, Ministry of Industry. Accessed on July 16, 2015, http://www.wepa-db.net/technologies/individual/datasheet/tha/37_kongka_textile_mill.htm

WILLIAMS, S.W., HUTTO, G.A. (1961). Treatment of textile mill wastes in aerated lagoons. In: Proceedings of 16th. Industrial Wastes Conference, Indiana. 518-529.

WPCF, ASCE. (1988). Aeration. Manual of Practice FD-13.

WPCF (1990). Natural Systems for Wastewater Treatment, MOP FD-16, WPCF, Alexandria, VA.

ANNEX 1
AREA REQUIREMENTS ESTIMATION

1.- AREA REQUIRED FOR AERATED LAGOONS

Surface demand is presented for an aerated lagoon at different sizes of the textile industry expressed in terms of the average flow of treatment. It is considered to be a homogenization tank for flows and concentrations. The homogenized concentrations influent are:

- BOD_5 = 300 mg / L
- COD = 1000 mg / L

The design criteria are:

Parameter	Partial mix pond	Complete mix pond
HRT (days)	20	4
Depth (m)	3	2

Thus, the following results were obtained:

Table 1.- Estimation of surface needs to aerated lagoons according to the flow (Q) to be treated

	Partial mix pond				Completely mixed pond			
Q	**HRT**	**Volume**	**Depth**	**Area**	**HRT**	**Volume**	**Depth**	**Area**
(m^3/d)	**(days)**	**(m^3)**	**(m)**	**(ha)**	**(days)**	**(m^3)**	**(m)**	**(ha)**
200	20	4000	3	0,13	4	800	2	0,04
400	20	8000	3	0,27	4	1600	2	0,08
2000	20	40000	3	1,33	4	8000	2	0,40
4000	20	80000	3	2,67	4	16000	2	0,80

2.- AREA REQUIRED FOR SECONDARY CLARIFICATION

2.1.- Partial mix aerated pond

If the lagoons are arranged in a series of 3 cells, the third cell can serve as settler. Otherwise, a pond with two days of HRT and 4 m depth would be necessary.

2.2.- Completely mixed aerated pond

Completely mixed aerated lagoons should be followed by settling ponds. These may be either several short HRT ponds (i.e. 2 days), requiring frequent wasted; or a single 10-day facultative pond with sufficient depth to allow long-term sludge storage.

Table 2.- Estimation of surface needs to secondary clarification according to the flow (Q)

	Partial mix pond					Completely mixed pond				
Q	**HRT**	**Volume**	**Depth**	**Area**	**SHL**	**HRT**	**Volume**	**Depth**	**Area**	**SHL**
(m^3/d)	**(days)**	**(m^3)**	**(m)**	**(m^2)**	**(m/h)**	**(days)**	**(m^3)**	**(m)**	**(m^2)**	**(m/h)**
200	2	400	4	100	0,08	10	2000	4	500	0,02
400	2	800	4	200	0,08	10	4000	4	1000	0,02
2000	2	4000	4	1000	0,08	10	20000	4	5000	0,02
4000	2	8000	4	2000	0,08	10	40000	4	10000	0,02

SHL = Surface Hydraulic Load ($m^3/m^2/h$)

3.- TOTAL AREA REQUIRED

Table 3.- Total area required: lagoons + clarifiers

	PMAP	CMAP
Q	**Area**	**Area**
(m^3/d)	**(ha)**	**(ha)**
200	0,14	0,09
400	0,29	0,18
2000	1,43	0,90
4000	2,87	1,80

PMAP: Partial mix aerated pond
CMAP: Complete mix aerated pond

ANNEX 2
UNIT PROCESSES GRAPHIC DESCRIPTION

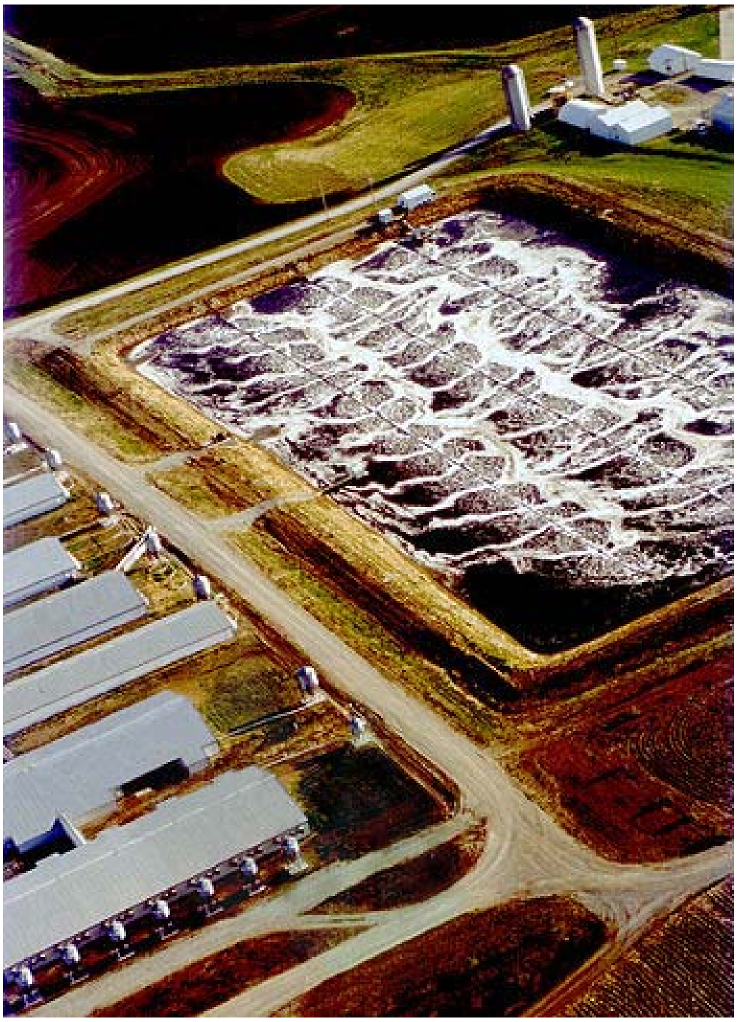

Figure 1
Aerated lagoon used to treat wastewater from a hog farm. Courtesy of Environmental Dynamics Inc. (https://en.wikipedia.org/wiki/Aerated_lagoon#/media/File:Aerated_Lagoon.jpg, accessed July 22, 2015).

Figure 2
Partial mix aerated pond (http://blog.thecivilengg.com/wp-content/uploads/2012/03/aerated-lagoon1.png, accessed July 23, 2015)

Figure 3
Completely mixed aerated lagoons system (http://www.lagoonsonline.com/, accessed July 23, 2015)

Figure 4
Typical mechanical surface aerator at work. It is often difficult for this type of machine to aerate the entire water column (https://en.wikipedia.org/wiki/Water_aeration, accessed July 23, 2015)

Figure 5
An aerated pond utilizing floating Surface Aerators.
(http://www.propondandlakes.com/aqua-mastervolcano2.aspx, accessed July 23, 2015)

Figure 6
An aerated lagoon utilizing roots blower (http://www.aquatec.vn/roots-blower-at-50-19/applications/?hl=en, accessed July 23, 2015).