ADVANCED LAGOON TREATMENT TECHNOLOGIES FOR WASTEWATER TREATMENT

by

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ABSTRACT

Lagoon-based wastewater treatment systems are popular around the world for their simplicity and cost-effectiveness. However, these systems are unable to reliably remove biochemical oxygen demand (BOD) and total suspended solids (TSS) to less than 30 mg/L or achieve nitrification during winter months in cold climates. Several innovative modifications have been developed, which have the potential to overcome these limitations by increasing the active biomass in the lagoons and managing the growth pressures associated with the microorganisms in the system. These technologies have been designed to support direct upgrades of existing lagoon-based systems without interrupting regular treatment.

KEYWORDS

Lagoon upgrade, advanced treatment, year-round nitrification, algae control, on-line retrofit

INTRODUCTION

Lagoon-based wastewater treatment systems have been used around the world for both municipal and industrial applications. These systems are attractive due to their low operating cost, in-situ solids storage capabilities, and low operator attention requirements. Where land availability and proper topography permit, lagoon-based systems are the preferred process solution for secondary treatment, which reduces both biochemical oxygen demand (BOD) and total suspended solids (TSS) of the wastewater to 30-50 mg/L.

Conventional lagoon-based systems utilize multi-cell or multiple earthen basins, which typically provide relatively long (several days) hydraulic retention times (HRTs). These systems are once through systems with no recycle of biological solids. Conventional lagoon-based systems have the following limitations:

- Large land area requirements
- Limited operator process control
- Reduced cold weather performance
- Poor ability to control algae and suspended solids in warm weather
- Limited BOD and suspended solids reduction below 30-50 mg/L
- Limited nitrification and nutrient (N and P) removal capabilities
The process limitations of lagoon-based systems stem mainly from two causes: (a) inability to retain sufficient biomass for higher levels of treatment and (b) operating temperature, especially in cold climates. This paper presents several advanced technologies which overcome these limitations while still maintaining the inherent advantages of lagoon-based systems. Following the review of available technologies, representative case studies are presented.

ADVANCED TREATMENT LAGOON TECHNOLOGIES

To overcome the limitations of conventional lagoon-based systems and to deliver improved treatment, several advanced lagoon treatment technologies have been developed. These achieve process performance comparable to activated sludge processes, with several unique process and operational benefits, such as:

- Advanced treatment levels for BOD and TSS with ammonia and nutrient control
- Year-round performance in warm or cold climates
- Low operator attention, monitoring, and maintenance requirements
- Simple and reliable long-term sludge management through in-situ sludge stabilization and storage
- Reduced land requirements
- Online upgrade of existing lagoons or use with new lagoon construction
- Low operating cost
- Long term system sustainability with additive technologies

Increasing Biomass

Multiple process configuration choices are available for increasing biomass in lagoons. These configurations utilize innovative solids-liquid separation techniques to increase and maintain the desired mixed liquor concentration in the biological reactor, or provide a fixed film media for biomass growth and retention.

Solids-Liquid Separation Technologies

**External Clarifier** - This configuration uses an earthen biological reactor and conventional clarifier components along with return activated sludge (RAS) and waste activated sludge (WAS) pumping to maintain biomass in the aerated zone of the lagoon (Figure 1).

The system is an economical option to conventional activated sludge when existing lagoon basins are available or when adequate land is available for new construction. The system has been applied in large facilities with stringent direct discharge requirements. The system also requires dedicated solids management facilities as regular solids wasting is required to maintain the desired biomass inventory in the system.

A floating lateral diffused air system is used for aeration and mixing. This type of aeration system floats on the reactor water surface. The diffusion elements are typically suspended from the floating air piping. Fine pore membrane diffusers are typically used for maximum operating ef-
ficiency. The aeration system may be installed in new or existing basins as the components are simply floated into position and restrained in place with cables.

**Figure 1 – Typical external clarifier (EC) configuration**

**Internal Clarifier** - This configuration uses an earthen biological reactor and an internal clarifier system that is constructed within the lagoon biological reactor basin. The clarifier is configured with sloped sidewalls and a trough sludge collection system. This eliminates the requirement for a conventional mechanical sludge collection system.

The internal clarifier system offers improved economics over systems employing conventional clarifier components. Savings in construction costs, RAS and WAS pumping equipment and sludge collection equipment are available with this option. The clarification components need to be conservatively sized to prevent solids washout during peak flow conditions due to the reduced volume available for settled solids with the sloped sidewall construction.

This system is ideal for small to medium-sized, new construction applications with independent solids management facilities.

**Figure 2 – Typical internal clarifier (IC) configuration**

**Internal Separator** - The patented Advanced Technology Lagoon Activated Sludge – Internal Separator (ATLAS-IS™) system consists of a series of lagoons or hydraulically separated zones and internal separation modules (Figure 3).
The first zone/ lagoon is a completely mixed (CM) zone, typically operated at 1-4 d hydraulic retention time (HRT), 30-80 d solids retention time (SRT), elevated mixed liquor suspended solids (MLSS) concentrations, and low food to microorganisms (F:M) ratio. Internal separator (IS) modules are placed in this zone/lagoon to retain biomass. Effluent from the IS modules containing low total suspended solids (TSS) is released to the downstream process. Downstream zones/lagoons are partially mixed (PM) to collect and digest solids that are discharged from the CM zone/lagoon. The PM zones/lagoons are followed by a quiescent zone/lagoon for final polishing before effluent discharge. The solids separation mechanism is self-regulating, which results in “equilibrium” biological solids management. Waste solids from the primary biological reactor are handled in downstream partial mix and quiescent lagoon reactors. ATLAS-IS is particularly suited for upgrades to existing lagoon applications in order to deliver full carbonaceous oxidation plus nitrification, even in cold climates.

The ATLAS-IS system is an economical solution to upgrade an existing lagoon system as minimal physical and operational modifications beyond a conventional lagoon-based system are required.

Lagoon - Sequencing Batch Reactor (SBR) - The lagoon-SBR system takes advantage of the lagoon biological reactor to establish a sequencing activated sludge process (Figure 4). Biological treatment, solids separation, effluent decanting and process cycling maintain biomass inventory. The process requires limited operator attention with no return or waste solids pumping.

Properly designed the process allows full carbonaceous oxidation plus total nitrogen control. It is best suited for large flows where multiple basins are available. The system is typically used in series with partial mix lagoons for simplified and economical solids management.
Fixed Film Technologies

Flexible Fixed - Film System – The provision of a fixed-film medium in the biological reactor can increase the biological solids that are retained in the system. By maintaining an appropriate biomass inventory, BOD and ammonia removal is improved.

The fixed-film medium is mounted on floating cables that span the aerated portion of the reactor and is submerged in the lagoon. This provides 3-dimensional flow-through and high surface-area:volume ratio. Biomass attaches to the fixed film and achieves enhanced BOD, TSS, and nitrogen removal. The medium is non-confined and is self-cleansing, resists fouling, and requires no maintenance for long-term performance. This system is ideally suited to improve the performance of conventional aerated lagoons and for effluent polishing when used in combination with systems described earlier. Figure 5 shows fixed-film system configuration and Figure 6 shows a photograph of flexible fixed film attached to a floating cable.

Figure 5 – Typical fixed-film system configuration
Temperature Control

A floating cover system improves the performance of all biological processes in extreme cold environments. By covering a portion of the lagoon with an insulating air blanket, there is a substantial reduction in heat loss to the atmosphere, thereby maintaining a higher wastewater temperature through the process (Figure 7).

Figure 6 – Flexible fixed film media attached to a floating cable

Figure 7 – Schematics of floating cover systems for temperature and algae control
With higher operating temperature, increased biological reaction rates are sustained. The system can extend the suitability of lagoon technologies into locations with severe winter environments.

A floating cover system also provides control of effluent suspended solids. It may be used with conventional aerated stabilization lagoons and all lagoon systems that use polishing lagoons for solids management. It is effective in reducing the presence of both algae and biological solids in the effluent stream by limiting sunlight penetration that triggers algae growth. Application of the system can assist in reducing effluent suspended solids concentration to well below 30 mg/L. The cover systems are designed to be self-deployed with no need for external cabling or anchoring. Installation is simple and no adjustment is required with varying water levels. The systems allow full access to equipment in the lagoon without removal of the cover.

CASE STUDIES

ATLAS - IC Demonstration Project at Washburn, Wisconsin

An ATLAS – IC system with an internal clarifier was commissioned in Washburn, WI in the summer of 1997, and was monitored for BOD and nitrification performance. The design flow of the system was 1440 m³/d (0.38 MGD). Influent BOD ranged between 100 and 250 mg/L. While effluent BOD concentrations over 40 mg/L were observed before the installation of the system, BOD levels remained below 15 mg/L after system was brought online (Figure 8). Ammonia levels were consistently low (Figure 9), except for a couple of observations (spring 2000) of over 8 mg/L effluent ammonia-N, which could be attributed to operational issues with extreme high flow events.

Figure 8 – BOD over time at Washburn, Wisconsin
To demonstrate the capabilities of the ATLAS - IS system, a full-scale demonstration project was conducted at Ashland, Missouri. The lagoon facility at Ashland was designed to treat 1098 m$^3$/d (0.29 MGD) containing 200 mg/L BOD, and consisted of a CM zone ahead of two PM zones and one quiescent zone, as shown in Figure 3. In December 2002, the ATLAS-IS system was installed online. The total design volume of the lagoon, 3.96 m (13 ft) deep with sloping side walls, was 13970 m$^3$ (3.7 MG). The volumes and HRTs of the various zones of the system were as given in Table 1.

**Table 1 - Volumes and HRTs of various zones of ATLAS-IS system at Ashland, Missouri**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Volume m$^3$</th>
<th>Volume MG</th>
<th>HRT (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM</td>
<td>2800</td>
<td>0.74</td>
<td>2.55</td>
</tr>
<tr>
<td>PM1</td>
<td>6620</td>
<td>1.75</td>
<td>6.03</td>
</tr>
<tr>
<td>PM2</td>
<td>2350</td>
<td>0.62</td>
<td>2.14</td>
</tr>
<tr>
<td>Quiescent</td>
<td>2200</td>
<td>0.58</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The IS modules were installed at Ashland in December 2002. After a few weeks of initial process stabilization, the MLSS concentration in the CM zone increased steadily, and stabilized in the 2000-3000 mg/L range (Figure 10). The increase in MLSS in CM zone resulted in excellent BOD removal (Figure 11). The average total BOD in the influent was about 91 mg/L, and the soluble BOD in CM zone was just under 9 mg/L. Thus over 90% BOD removal was achieved in the CM zone. Nitrification was also accomplished throughout the year, as shown in Figure 12. The system maintained nitrification through three winters.
Figure 10 – SS in CM zone and effluent at Ashland, Missouri

Figure 11 – BOD over time at Ashland, Missouri
Though the operation of the system was not specifically optimized for nitrogen removal through denitrification, substantial nitrogen reduction was observed (Figure 13).

Figure 13 – Nitrates over time at Ashland, Missouri
Considering a small amount of nitrogen assimilated into the biomass, most of the remaining nitrogen could be expected to be nitrified. The soluble nitrate-N concentration in the zone, however, was significantly lower than the influent TKN concentrations. Approximately 50% nitrogen removal was observed in this zone, suggesting simultaneous nitrification-denitrification.

**Fixed Film Application at Kingdom City, Missouri**

A fixed-film application was commissioned at Kingdom City, Missouri in late 2005. This was originally a typical partial mix lagoon system designed to treat 910 m$^3$/d (0.24 MGD), currently treating about 379 m$^3$/d (0.1 MGD). It was modified online with the addition of a floating fixed film media suspended from floating cables (Figure 6). The system was in start-up mode during the winter of 2005-2006, as biomass started building up on the fixed media. The system nitrified during summer months (Figure 14). Under normal operation, at low temperatures (below 10 C), nitrification would be expected to cease completely. This was not the case, as approximately 50% nitrification was accomplished by the system during the initial winter operating season. The demonstration project will be continued through the 2006 and 2007 winter period to confirm the performance capabilities of the system after full accumulation.

**Figure 14 – Ammonia over time at Kingdom City, Missouri**

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**Cover Application at Wardsville, Missouri**

A floating panel cover system was installed on the quiescent zone of a partial mix aerated lagoon system in summer of 2003. The design residence time provided in the covered quiescent zone is 4.4 days. The approximate residence time provided in this zone under current conditions is in
excess of 20 days. Reported effluent TSS values ranged from 8 mg/L in March 2006 to 12 mg/L in May 2006. Effluent BOD values were less than 6 mg/L throughout the period.

**CONCLUDING REMARKS**

While lagoon systems are simple to operate and provide cost-effective treatment, they are limited in their capability to nitrify during cold winter conditions in cold climates. To overcome this and improve treatment, several innovative processes have been developed, which provide process performance comparable to an activated sludge process, with the following process and operational benefits:

- Advanced treatment levels for BOD and TSS with ammonia and nutrient control
- Year-round performance in warm or cold climates
- Low operator attention, monitoring, and maintenance requirements
- Simple and reliable long-term sludge management through sludge stabilization and storage
- Reduced space requirements
- Online upgrade of existing lagoons or use with new lagoon construction
- Low operating cost

Some of these technologies have been successfully demonstrated and represent economical options to support the wastewater treatment needs of small communities. Others are under observation and continued performance testing and monitoring is warranted. Results from ongoing demonstration projects will be presented as they become available.

**ACKNOWLEDGEMENTS**

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