Office of Water Programs
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Sacramento Regional County Sanitation District

The Fate of Ammonia in Facultative Lagoon Sludge Treatment Processes: An Investigation of Methods for Reducing Ammonia in Recycle Streams:

a Literature Review

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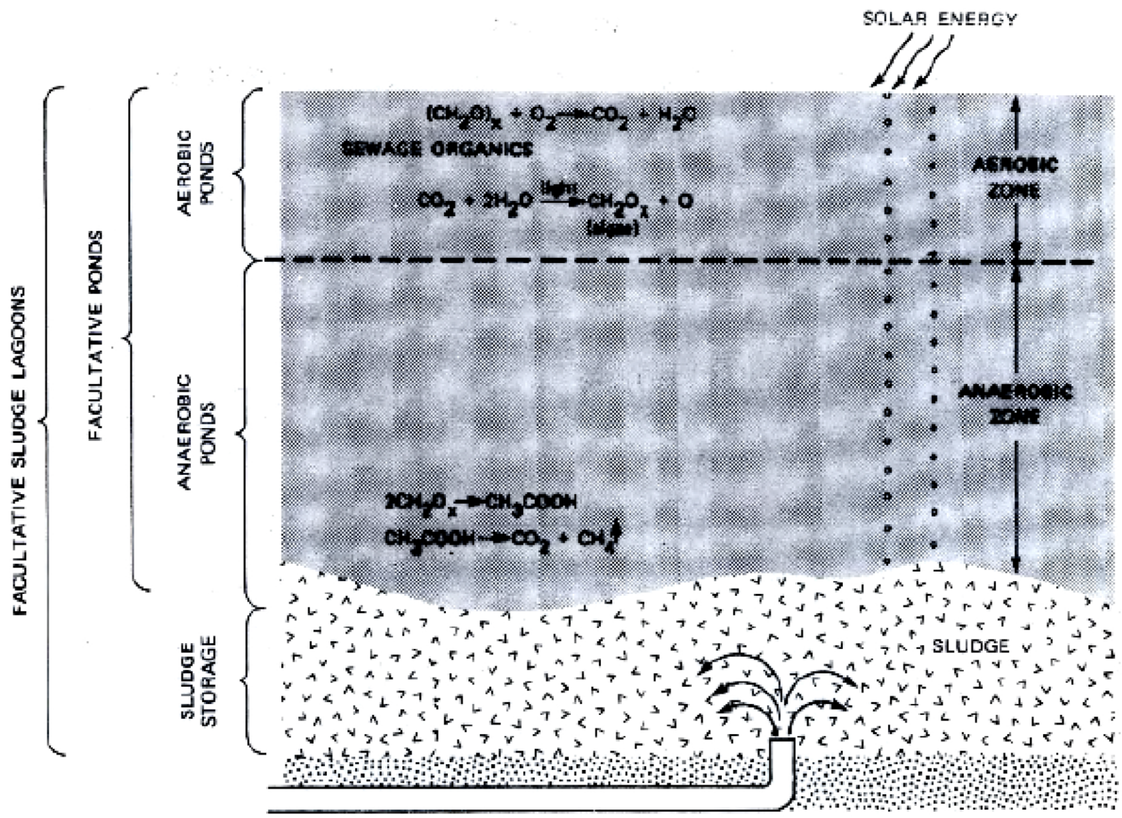
Introduction

Facultative sludge lagoons are sludge stabilization and storage facilities that are commonly operated in conjunction with anaerobic digesters to stabilize and store wastewater treatment residual solids (McFarland, 2001). Anaerobically digested sludge solids fed to facultative sludge lagoons are further stabilized through anaerobic, microbially mediated reduction processes occurring in the sludge layer at the bottom of the lagoon. Facultative sludge lagoons are also characterized by an aerobic supernatant layer that helps mitigate odor potential from gases released by the anaerobic processes in the sludge layer. Malodorous gases such as hydrogen sulfide are oxidized as they bubble up through the aerobic supernatant layer. An active algae population, present in the supernatant layer, generates dissolved oxygen as a byproduct of photosynthesis and replenishes dissolved oxygen consumed by aerobic bacteria and oxidation-reduction reactions in the supernatant layer (Boyce, 2008).



(McFarland, 2001)

Figure 1: Facultative Sludge Lagoon Schematic

Ammonia in Facultative Sludge Lagoons

Ammonia is produced by the biochemical reduction of proteinaceous or non-protein nitrogenous compounds in the anaerobic sludge stabilization process (Hobson and Wheatley, 1993). Ammonia produced in anaerobic digesters is transferred to facultative sludge lagoons used to store and further stabilize sludge solids. Additional ammonia is produced in the facultative sludge lagoon as sludge stabilization continues in the anaerobic zone at the bottom of the lagoon. Ammonia volatilization at the water surface produces some ammonia release, but not enough to significantly reduce the ammonia concentration in the lagoon. Little nitrification of ammonia occurs in the aerobic supernatant layer and ammonia fed to and produced in the facultative sludge lagoon is most commonly returned to plant headworks as a constituent of supernatant return flow to the plant. The ammonia load to a plant from this type of recycle stream can be significant.

Ammonia removal in facultative lagoons can occur by ammonia volatilization (gaseous ammonia release to the atmosphere), ammonia assimilation into algal biomass, and by biological nitrification (Pano and Middlebrooks 1982). Ammonia release into the atmosphere is a function of pH, temperature, and mixing conditions (Redacted Consultants 1979). Figure 2 illustrates ammonia speciation as a function of pH. Aqueous inorganic ammonia is present predominantly as ammonium ion (NH_4^+) below pH 9.25 and predominantly as aqueous ammonia (NH3) above pH 9.25. To volatilize aqueous ammonia, it must be in the NH_3 form and the process is therefore most effective at pH 10 and above. Ammonia volatilization is the major process for ammonia removal at low temperatures, when biological activity decreases in conjunction with well mixed surface layer conditions due to wind effects (Pano and Middlebrooks 1982).

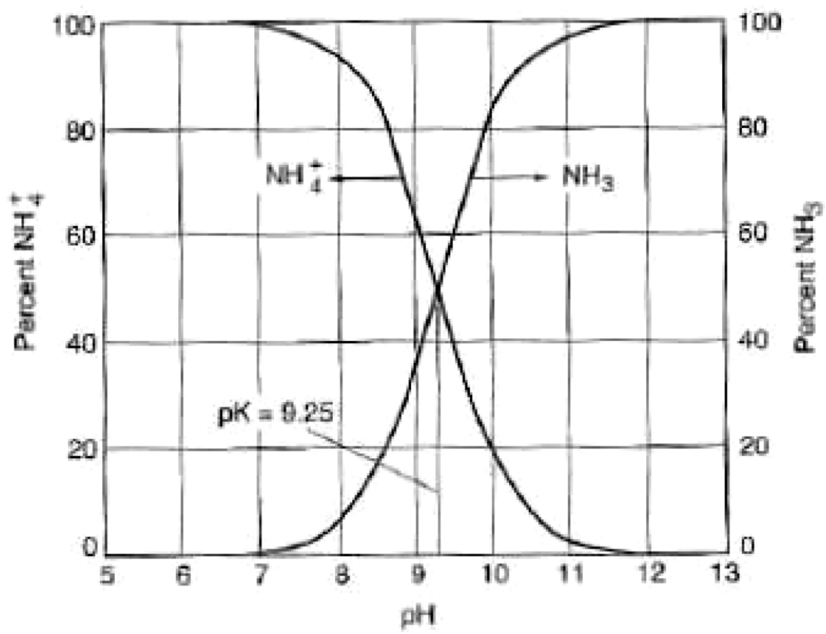


Figure 2. Distribution of ammonia (NH_3) and ammonium (NH_4^+) as a function of pH.
(Metcalf & Eddy 2003)

$$NH_4^+ (aq) + OH^- \leftrightarrow NH_3 (aq) + H_2O$$

Ammonia assimilation in algal biomass is limited by the capacity of the system to support algal growth. Ammonia assimilated into algal biomass is retained in the facultative lagoon unless algae are routinely harvested from the lagoon. Algae harvesting methods are generally costly due to their requirements for energy, chemicals, and other materials (Bich, 1999) and algae harvesting has not been carried out unless the algae have economic value. Recent interest has arisen in cultivating algae in wastewater for use as a biofuel (WEFTEC, 2008). Identifying economic value for algae can enhance its viability as a nitrogen sequestering and removal mechanism from facultative lagoons.

Biological nitrification is the microbially mediated oxidation of ammonia to nitrate. Nitrifying bacteria, operating in an aerobic environment, sequentially oxidize ammonia to nitrite then further oxidize the nitrite to nitrate. Nitrate returned to a wastewater treatment plant as a constituent of a recycle stream doesn't add to the plant ammonia load but does add to the inorganic nitrogen load.

Nitrifying bacteria are relatively slow growing relative to heterotrophic bacteria, making it difficult to establish high enough concentrations to effect nitrification in facultative lagoons. Investigators have had some success with integrating fixed film media into wastewater treatment lagoons and achieving nitrification (Magulauri, 2007; Ripple, 2002). The fixed media provides a location for colonization by nitrifying bacteria, enabling the concentrations to get high enough to achieve near complete nitrification of ammonia in the tested lagoons.

Ammonia Reduction Alternatives

Nitrification Facilitation Using Integrated Fixed Film Media

Maguluri (2007) conducted a study on the nitrification performance of a modified aerated lagoon (treating wastewater), using integrated fixed film media to assess the effectiveness of the media in enhancing ammonia treatment in Kingdom City, Missouri. Maguluri used polyethylene media, with a large surface to volume ratio, submerged in the partial mixed zone of an aerated wastewater treatment lagoon. The objective was to provide a solid medium for slow growing nitrifying bacteria to colonize and for the nitrifying bacteria to nitrify the ammonia in the lagoon. The results indicated that the average annual ammonia removal rate achieved was 87%, with up to 98% ammonia removal achieved during the summer. Integrated polyethylene fixed film media proved to be a cost effective and efficient method to reduce ammonia concentrations in the tested wastewater lagoon application.

Ripple (2002) investigated two different types of integrated fixed media in a New Hampshire facultative wastewater lagoon to effect nitrification. A looped cord media was used, side by side, with an abrasive fabric media. Nitrification was enhanced with both media types. Complete nitrification was achieved during the summer when warm water temperatures facilitated relatively rapid nitrifier growth and some nitrification was evident during winter months when water temperature approached freezing.

No reports of similar studies in facultative sludge lagoons were identified. Because the organic and solids loading of facultative sludge lagoons is much higher than for wastewater treatment lagoons, studies would be required to determine whether similar results could be achieved (Sharma and Ahlert, 1976).

Ammonia Reduction using an 84-acre Poplar Tree Plantation

The City of Woodburn, Oregon designed and installed an 84 acre poplar tree plantation, planted at a density of 515 trees per acre, to reuse a portion of the wastewater treatment plant's effluent, biosolids, and facultative sludge lagoon supernatant during the summer months. The method mitigated ammonia load exceedance of TMDL limitations in the effluent discharge to the Pudding River, and will help the City of Woodburn meet permit requirements, especially during the summer when the ammonia load restriction is most stringent (Madison and Emond 2003).

The facultative sludge lagoon supernatant at the Woodburn WWTP is high in ammonia and is difficult to treat when returned to the plant headworks. To reduce ammonia load to the plant, supernatant is diverted from the headworks, combined with biosolids and used as an irrigation source and nutrient supplement in the poplar tree plantation. No additional fertilizer is used (Madison and Emond 2003).

Plant A

Plant A currently has 20 facultative sludge lagoons, called sludge storage basins (SSBs), used to store and further stabilize digested sludge solids. The aerobic surface layer of the SSBs is maintained by limiting the amount of organic loading into the lagoon to promote algae growth and by mechanically mixing the aerobic layer using brush aerators (Boyce, 2008). At approximate five year intervals, stored solids are removed from the SSBs using floating dredges. The dredged solids are disposed in lined, dedicated land disposal fields located on-site (Redacted 2001).

Between 1994 and 2007, Plant A influent and effluent Ammonia-N concentrations increased from 18 mg/L and 15 mg/L, respectively, to 28 and 25 mg/L. During that period, an SSB supernatant dilution program using secondary effluent was implemented that increased the volume of SSB supernatant returned to the plant headworks. Return flow from the post anaerobic digestion Solids Storage Basins (SSB) and Biosolids Recycling Facility (BRF) currently contribute approximately 25% of the ammonia load to the plant influent. Reducing SSB return flow by eliminating the SSB flushing has the potential to reduce ammonia concentrations in the influent by up to 14%, assuming that the ammonia concentration remains constant (*Redacted* 2008). A field study is being conducted in conjunction with this review to investigate the impacts of SSB flushing on the ammonia load returned to the headworks via the SSB supernatant recycle stream.

Applicability of Identified Ammonia Reduction Approaches to Plant A

Nitrification Facilitation by use of Integrated Fixed Film Media

Nitrification of ammonia in the Plant A SSB supernatant has the potential to significantly reduce the ammonia load returned to the plant. The successful study of nitrification inducement in aerated lagoons in Kingdom City, Missouri using integrated fixed film media lends itself to consideration for application in the Plant A SSBs. Nitrification requires the presence of ammonia, readily degradable BOD, dissolved oxygen, and high concentrations of nitrifying bacteria. The SSBs have ammonia, BOD, and dissolved oxygen present in the supernatant layer. Using integrated fixed film media in the SSB would provide a location for the slow growing nitrifying bacteria to colonize and increase their concentration. A pilot test of the process is worth considering to evaluate its feasibility in the Plant A SSBs.

Urban Forest Support using SSB Supernatant

The City of Woodburn, Oregon successfully developed and implemented a system to reuse facultative sludge storage lagoon supernatant and sludge to irrigate and supply nutrients to a tree farm. The diversion of those process fluids to the tree farm successfully reduced ammonia loading to the plant from recycle streams.

A similar approach to the SSB supernatant diversion and reuse might be applicable to Plant A to divert an ammonia source from the plant influent. Plant A is surrounded by 2,650 acres of multiple use open space, including urban forest and grazing land, (*Redacted* 2006). The SSBs' supernatant and the BRF contribute approximately 25% of the influent ammonia load to the plant (*Redacted* 2008). Allocating the SSBs' supernatant to a plantation similar to the City of Woodburn WWTP has the potential to reduce the ammonia return concentration from the SSBs.

Conclusions

Facultative sludge lagoons contain high levels of ammonia resulting from biochemical reduction of protinaceous and non-protein nitrogenous compounds in the sludge lagoons and in the preceding anaerobic digestion process. Ammonia returned to the plant headworks by the facultative sludge lagoon supernatant recycle stream can be a significant component of the total ammonia load to the plant. Diverting that recycle stream for other uses or treating the recycle stream to remove the ammonia can benefit the plant by reducing the total ammonia load.

Madison and Emond (2003) reported successful reduction of ammonia from the plant headworks by diverting facultative sludge lagoon supernatant, biosolids, and recycled effluent to irrigate and fertilize a poplar plantation. Magulury (2007) reported successful reduction of ammonia in aerated wastewater treatment lagoons by adding integrated fixed film media to facilitate nitrification of the lagoon supernatant. Both reported approaches have potential applications at Plant A to reduce ammonia load to the plant influent.

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