Nutrient Limitations in Industrial Treatment Wetlands

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Abstract: Historically, constructed wetlands have been applied to municipal wastewater sources where nutrients are not a limiting factor, as loadings of nitrogen, phosphorus (macronutrients) and potassium, calcium, magnesium, sulfur, sodium, chloride, iron, zinc, manganese, copper, molybdenum, and cobalt (micronutrients) are more than adequate to support the development of a microbial biomass sufficient to remove organic compounds from the wastewater.

Mature wetland ecosystems often can be characterized as having accumulated large internal storages of nutrients associated with the growth, death, decay and re-growth of vegetation in the plant biomass cycle. In mature wetlands, this internal cycling of nutrients serves as an additional buffer against nutrient limitations in the context of wastewater treatment.

However, in industrial treatment applications, the organic compounds that have to be removed may be composed of a few specific chemicals, which may not provide the appropriate nutrient mix. For example, the primary chemicals used in aircraft deicing are propylene glycol ($C_3H_8O_2$) and ethylene glycol ($C_2H_6O_2$). Neither of these chemicals contain nitrogen, phosphorus or micronutrients, so the possibility exists to create a nutrient-limited wetland that is incapable of creating enough microbial biomass to meet treatment objectives.

There is another potential danger in operating wetlands under conditions of severe nutrient limitation. The metabolic response of heterotrophic bacteria growing under nutrient-limited conditions is to produce an excess of polysaccharide slime, which can result in reduced hydraulic performance, especially in subsurface flow wetland systems. This problem is exacerbated in wetlands which receive rapidly escalating chemical oxygen demand (COD) loadings without associated nutrients. A key index which appears to control wetland treatment effectiveness is the availability of sufficient nutrients to allow adequate growth of microbial communities in response to pollutant loadings.

Keywords: Aircraft deicing, constructed wetlands, nutrient limitation

INTRODUCTION

Within the wastewater engineering profession, it is well understood that bacteria will grow and multiply when exposed to an expanding food source. This response can be characterized by a *lag phase* (adaptation to a new food supply), a *log-growth phase* (exponential growth in response to the new food supply), a *stationary growth phase* (growth and death rates are approximately equal as the new food supply begins to dwindle) and a *death phase* (as the food source becomes exhausted) (Crites and Tchobanoglous 1998).

For heterotrophic bacteria degrading carbon-based food sources, the proportion of nutrients present in biomass cells is well understood (Grady, Lim et al. 1999), as summarized in Table 1:

Table 1: Approximate Nutrient Requirements for Bacterial Growth (Grady, Lim et al. 1999)

Nutrient	Approximate need, g/kg of biomass produced
Nitrogen	85
Phosphorus	17
Potassium	10
Calcium	10
Magnesium	7
Sulfur	6
Sodium	3
Chloride	3
Iron	2
Zinc	0.2
Manganese	0.1
Copper	0.02
Molybenum	0.004
Cobalt	<0.0004

APPLICATION TO TREATMENT WETLANDS

The concept summarized in Table 1 has historically been applied to mechanical treatment systems (such as activated sludge) that are environmentally simplified and only have to consider one set of nutrient demands – those associated with the growth of treatment bacteria. Wetlands are a different type of treatment system in which the nutrient demands, storages, and releases of the plant biomass cycle are often very significant (or at least nontrivial) compared to the external nutrient loadings associated with wastewater application (Kadlec and Wallace 2009). The relative size of the plant biomass cycle is a function of climate (Hill 1987; Hocking 1989), nutrient availability (Boyd 1971; Jordan, Whigham et al. 1999; Mueleman, Beekman et al. 2002), and time (Rybczyk, Day et al. 2002)

It has been observed that nutrient-limited treatment wetlands perform differently than systems without nutrient limitations. In North America, a distinction has been made between agronomic wetlands (lightly loaded systems where plant uptake largely governs treatment performance) and microbially dominated wetlands (those which contain sufficient nutrients such that microbial biofilms can determine treatment performance), with a nitrogen loading rate of approximately 120 gN/m^2-yr being required to shift away from an agronomic system (Kadlec 2005). This is not insignificant in many surface flow wetland systems; out of a sample set of 135 wetlands, 41% were below the agronomic loading threshold (Kadlec and Wallace 2009).

When treating nutrient-limited wastewaters, treatment wetlands can be nutrient-starved, especially during the first few years of startup as the system is accumulating nutrients.

Role of the Microbial Yield Ratio

One major unknown parameter in treatment wetlands is the yield ratio of microbial growth, which can be defined as the fraction of the influent biochemical oxygen demand (BOD) converted to microbial biomass. For suspended-growth activated sludge systems, this parameter can be easily measured and is often quite high; in the range of 1.0 to 0.7.

Treatment wetlands are attached growth systems with a very long solids retention time where microbial predation would presumably substantially reduce the yield ratio. In one study of a pilot-scale, fill-and-drain subsurface flow wetland, the yield ratio was estimated to be 0.068 (Austin, Maciolek et al. 2007). With such a low yield rate, this would imply that treatment wetlands would not require large amounts of nutrients to maintain a mature microbial community under steady-state conditions.

However, some types of wetlands treating industrial wastewaters are subject to severe start-up stresses or do not operate under steady-state conditions (seasonal loading). A notable example of this is wetland systems treating deicing runoff. The primary chemicals used in airplane deicing are propylene glycol ($C_3H_8O_2$) and ethylene glycol ($C_2H_6O_2$). Neither of these chemicals contains nitrogen, phosphorus or micronutrients, so the possibility exists to create a nutrient-limited wetland that is incapable of creating enough microbial biomass to meet treatment objectives. Furthermore, these systems receive little or no loading during the summer months and are then subjected to sudden and quite large COD loadings at the onset of winter weather.

Case Studies: Deicing Runoff Treatment Wetlands

A case in point was the wetland treatment system at Buffalo International Airport in Buffalo, New York, which was commissioned in the Fall of 2009. Although the design had anticipated the need for nutrient addition, establishment of effective treatment was slow, and the system began to experience foaming associated with the formation of polysaccharide slimes by the resident bacteria. Foaming and slime formation is known to occur at wastewater treatment plants subject to severe nutrient limitations (Stover 1980; Karnoup, Dielman et al. 2007).

Due to the observed slime formation at Buffalo, estimates on the yield ratio had to revised upwards, and was finally estimated by the authors to be at least 0.3. This had profound implications on the rate of nutrient addition, as the Buffalo wetland was designed to process 4,500 kg/d of BOD; a yield ratio of 0.3 implies 1,350 kg/d per day of microbial biomass production. Based on the information in Table 1, this amount of biomass production would require 115 kg/d of nitrogen and 23 kg/d of phosphorus, in addition to micronutrients. After feeding the appropriate amount of nutrients, slime formation ceased and treatment performance improved dramatically.

The same concept of nutrient addition was employed at the Mayfield Farm wetland treatment works serving Heathrow Airport in London. This facility, which also treats deicing runoff, experienced record COD loadings during the winter of 2009/2010. Three of the twelve horizontal flow treatment wetland cells were involved in an optimization study; nutrient addition to these cells was increased 10-fold on February 1, 2010. Immediate and dramatic improvements in treatment performance were noted, especially in the wetland cell intensified by mechanical aeration. While oxygen transfer has been noted as an important parameter for design of deicing runoff treatment wetlands (Wallace, Higgins et al. 2007), it now appears that nutrient availability plays an equally important role.

CONCLUSIONS

Many industrial wastewaters lack sufficient nutrient composition to allow adequate development of microbial biomass. This can have a crippling effect on treatment performance. While documented in mechanical treatment processes, nutrient limitation has the potential to inhibit the performance of wetland treatment systems as well. Two wetland systems treating a nutrient-deficient waste stream (aircraft deicing runoff) were supplemented with increased nutrients during the winter of 2009/2010. Treatment performance in both systems improved in response to nutrient availability, and operational problems such as foaming and slime formation were eliminated.

REFERENCES

Austin, D. C., D. J. Maciolek, et al. (2007). "Damköhler number design method to avoid clogging of subsurface flow constructed wetlands by heterotrophic biofilms." Water Science and Technology 56(3): 7-14.

Boyd, C. E. (1971). "Further studies on productivity, nutrient, and pigment relationships in *Typha latifolia* populations." Bulletin of the Torrey Botanical Club 98(3): 144-150.

Crites, R. and G. Tchobanoglous (1998). Small and Decentralized Wastewater Management Systems. New York, New York, McGraw-Hill.

Grady, C. P. L. J., H. C. Lim, et al. (1999). Biological Wastewater Treatment. New York, New York, Marcel Dekker, Inc.

Hill, R. B. (1987). "Typha productivity in a Texas pond: Implications for energy and nutrient dynamics in freshwater wetlands." Aquatic Botany 27: 387-394.

Hocking, P. J. (1989). "Seasonal dynamics of production, nutrient accumulation, and cycling by *Phragmites australis* (Cav.) Trin ex Stuedel in a nutrient enriched swamp in inland Australia. Part I: Whole Plants." Australian Journal of Marine and Freshwater Research 40: 421-444.

Jordan, T. E., D. F. Whigham, et al. (1999). Restored wetlands in crop fields control nutrient runoff. J. Vymazal. Leiden, The Netherlands, Backhuys Publishers: -.

Kadlec, R. H. (2005). Vegetation Effects on Ammonia Reduction in Treatment Wetlands. J. Vymazal. Leiden, The Netherlands, Backhuys Publishers: 233-260.

Kadlec, R. H. and S. D. Wallace (2009). Treatment Wetlands, Second Edition. Boca Raton, Florida, CRC Press.

Karnoup, A., D. Dielman, et al. (2007). "Exopolysaccharide isolated from a Dow wastewater treatment facility." Proceedings of the Water Environment Federation(Session 31 through Session 40).

Mueleman, A. F. M., J. P. Beekman, et al. (2002). "Nutrient retention and nutrient-use efficiency in *Phragmites australis* stands after wastewater application." Wetlands 22(4): 712-721.

Rybczyk, J. M., J. W. Day, et al. (2002). "The impact of wastewater effluent on accretion and decomposition in a subsiding forested wetland." Wetlands 22(1): 18-32.

Stover, E. L. (1980). "Start-up problems at a plant treating food processing wastewater." Journal (Water Pollution Control Federation) 52(2).

Wallace, S. D., J. Higgins, et al. (2007). Degradation of aircraft deicing runoff in aerated engineered wetlands, Padova, Italy, University of Padova and International Water Association.