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THE USE OF ARTIFICIAL BIOFILMS TO STRIP NUTRIENTS FROM AN INDUSTRIAL SMELTER'S WASTE WATER UNDER CONDITIONS OF LOW TEMPERATURE AND HIGH PH

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The Victorian Environment Protection Authority (EPA) has identified Alcoa's Point Henry aluminium smelter as being a major source of recognized pollutant input due to its disposal of effluent into Corio Bay. Historically, the water quality parameters that have most often exceeded Point Henry's EPA limits have been pH and suspended solids from the smelter's discharge points. These waste water discharges also experience high nitrogen and phosphorus concentrations which result in algal blooms that occur at the onset of warm weather. The main hypothesis of this study was that "prevention of algal blooming with the onset of warm weather by removal of nutrients during the cooler months, and continued removal thereafter, is better than curing the problems chemically". Biofilms have been used to remove nutrients from waste waters, but not under the conditions experienced at Point Henry. The aim of this study, therefore, was to determine if significant biofilm growth would be observed on floating structures suspended in the Point Henry waste water stream during the cooler, winter months of the year. Statistically significant biofilm growth occurred on all suspended structures in all discharge ponds during the winter and early spring of 2000. The use of suspended structures, such as AquaMat^{TM}, as an artificial substrate to attract and support periphyton and bacterial communities (biofilms), which are then able to out-compete phytoplankton communities for available nutrients, is therefore a viable option for the Point Henry smelter. However, further research on the competitive performance of biofilms in the Point Henry ponds during the summer months is required before adequate biofilm management strategies can be developed.

INTRODUCTION

Port Phillip Bay has many qualities that make it important to Australians. The bay supports major commercial fisheries, is one of Australia's busiest ports and is a major center for recreation. But, the bay's environmental values are under threat from a number of directions, including inputs from stormwater and industrial effluent (SEPP, 1995). The Victorian Government's Environment Protection Authority (EPA) has identified Alcoa's Point Henry aluminium smelter as being a major source of recognized pollutant input due to its disposal of effluent into Corio Bay (Figure 1). The combined volume of effluent released from the smelter's discharge points (Figure 2) during this study was approximately 200 ML yr^{-1}. Historically, the Point Henry smelter has attributed discharge license violations to algal blooms in the discharge ponds at the onset of warm weather.

Planktonic algal blooms are limited by deficiencies of light, temperature or nutrients (Entwisle et al. 1997). It is not feasible to control temperature or light conditions in the Point Henry discharge ponds, and consequently there is a need to remove nutrients from the effluent. Of the

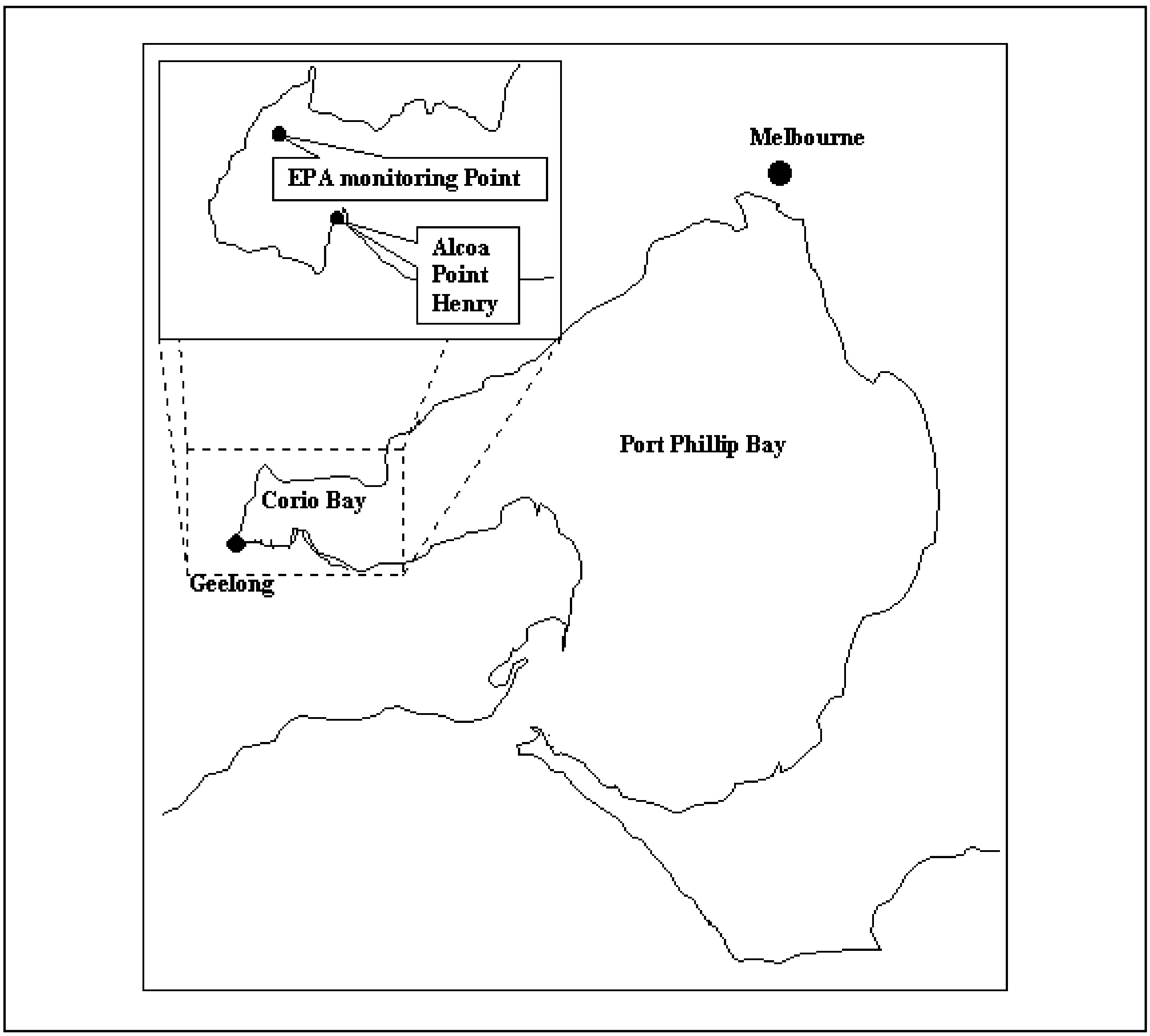

Figure 1. Location of Point Henry smelter, Geelong, Victoria, Australia.

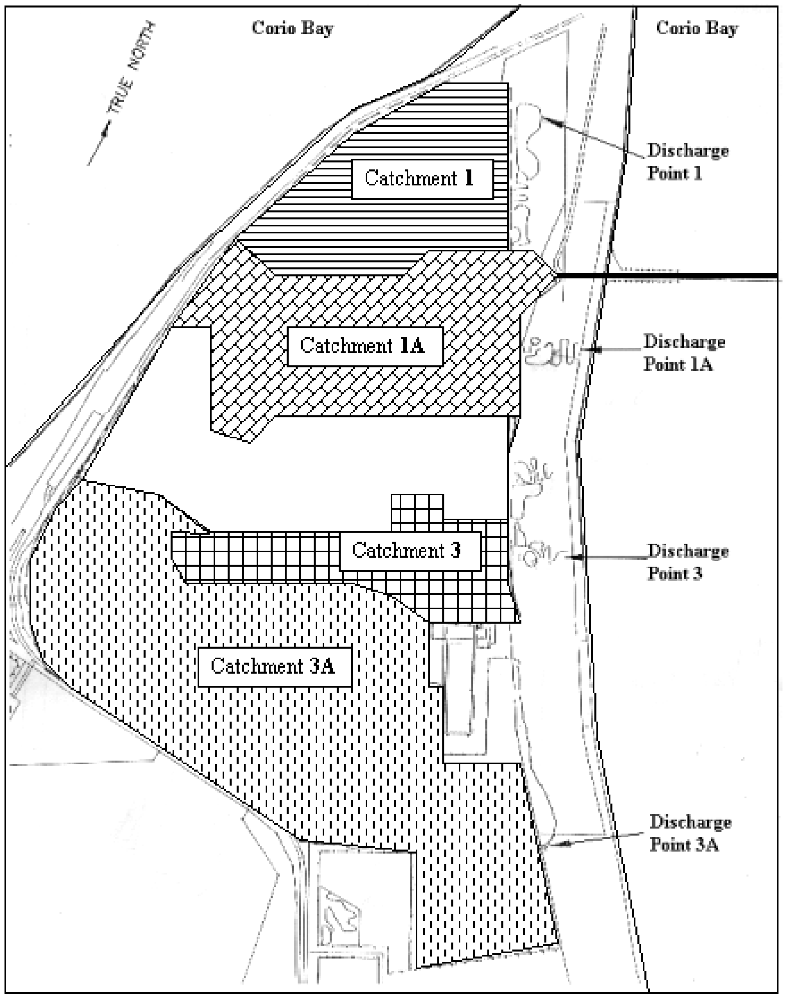

Figure 2. Location of sampling points at Point Henry smelter.

techniques available to removing nutrients from waste water, some involve the use of biofilm (attached periphyton and bacterial communities). Moving bed biofilms are commonly used in reactors for ammonium removal (Hwang et al. 2000; Rusten et al. 2000; Urrutia et al. 1999), and many different substrates are used to accommodate biofilm for nitrification of wastewater, which include polymer resins (Vanotti et al. 2000), floating beads (Golz et al. 1999) and biodegradable polymer pellets (Boley et al. 2000).

The present study investigated the use of AquaMat^{TM} to entice colonization of biofilm. The most attractive feature of AquaMat^{TM}, in terms of the current study, is the relatively high surface area of the product. AquaMats^{TM} can be likened to artificial seagrass in that the mats are anchored to the bottom of a tank or pond, and strips of mat float upward into the water column. The core comprises buoyant, closed cell foam, which is coated on each side by a fibrous food grade polymer.

The three factors most likely to inhibit biofilm growth in the effluent at Point Henry are the low temperatures, high pH and elevated fluoride concentration. There have been no previous investigations into the use of AquaMat^{TM} bound biofilms to remove nutrients from industrial effluent at low temperatures. The aim of this study, therefore, was to determine if significant biofilm growth would be observed on floating structures suspended in the Point Henry waste water stream during the cooler, winter months of the year. The aim is based on the assumption that prevention of algal blooming with the onset of warm weather by removal of nutrients during the cooler months, and continued, improved removal thereafter in the summer by more rapidly growing biofilms, is better than curing the problems chemically. These questions were addressed by placing AquaMat^{TM} into four sedimentation ponds, each receiving different types of effluent, and monitoring biofilm growth during winter and spring of 2000.

MATERIAL AND METHODS

Site selection was based on the aqueous inputs to each of four sedimentation ponds. These inputs comprise storm water or smelter process water, either alone or as a mixed stream. Discharge Point 1 (Figure 2) was chosen because there is little known toxicant present in the effluent at this location (inputs : storm water from electrode buildings, carpark and roadway, and process water from air compressor cooling system), and biofilm assessment was therefore likely to provide a good description of smelter process water induced variability. At the other extreme, discharge Point 1A (inputs: storm water from two-thirds of pot room buildings, courtyards and roadways) is generally very high in fluoride, and discharge Points 3 (inputs: storm water from rolling mill buildings and roadways, neutralized wash water and filter backwash water from demineralization water plant) and 3A (inputs: storm water from rolling mill buildings, courtyards and roadways, contractor yard, south car park, and car wash waste water) experience elevated pH and suspended solids levels.

AquaMat^{TM} was prepared for the field study in the following manner:

a) Two AquaMats^{TM} were cut in half, this provided four sections of mat with 39 – 40 mat strips on each section.

b) All fingers of mat were cut from the base to provide 39 – 40 mat strips, 750mm in length.

c) Strips were washed in tap water and then dried at 65ºC for 10 days to obtain constant weight (within 0.01% of final dry weight).

d) The dry weight of each strip was recorded.

e) Strips were tagged, for identification purposes, by fixing plastic tags to each strip with cable ties.

f) Strips were reattached to the mat ballast sleeve with cable ties.

g) The mat ballast sleeve was filled with pebbles and sealed with cable ties.

For the purpose of this study, the surface area of the AquaMat^{TM} is described as an “apparent surface area”, which is easily measurable with a rule having millimeter graduations. Actual surface area that provides substrate for biofilm colonization is at least an order of magnitude larger and is known as the “specific surface area”. One prepared section of mat was placed in each of four sedimentation ponds. Mat sections were sited as close as possible to pond outlets in an attempt to minimize interference from sediment, and also to locate the mats as close as possible to the water monitoring points. Ten strips of AquaMat^{TM} were collected monthly from each treatment. Dry weight determination was carried out on nine of the ten strips, with mass increase assumed to be indicative of biofilm growth. The remaining strip was analyzed for chlorophyll ‘a’.

STATISTICAL ANALYSIS

Since all samples were individually identified and weighed prior to installation on site, paired sample T-tests were undertaken to verify if samples underwent significant mass increases whilst in the field. Independent samples T-tests were performed to compare the month to month average mass and chlorophyll 'a' increases.

RESULTS AND DISCUSSION

As biofilm colonized the AquaMat^{TM}, increased mass was observed in samples taken from all discharge ponds (Figure 3). And, even though samples from discharge pond 1 supported little biofilm growth (~1 mg/cm^2) compared with Discharge Points 3 & 3A to (~7 mg/cm^2), paired samples T-tests comparing pre- and posttreatment mean mass values revealed statistically significant mass increases for samples in all discharge ponds ($p < 0.05$). Month on month increases in mass were observed for all samples but those in discharge pond 3, which experienced a statistically very significant decrease between July and August ($p < 0.01$). This decline is attributed to die off caused by a rapid increase in salinity in the pond (to 22.5 $^0/_{00}$ - more than double the normal value) attributed to a tidal inundation event.

In general, chlorophyll 'a' analysis supports the findings of mass examination, particularly between May and July (Figure 4). However, a statistically significant decrease in chlorophyll 'a' in samples extracted from discharge pond 1A was observed in July and August, attributed to a visible sediment deposit smothering biofilm on the mat. Towards the end of the study, clumps of algae up to 150mm long attached to the mats were also observed. If Aquamat^{TM} becomes smothered with algae, the effective surface area is reduced and consequently the biofilm will be less efficient at nutrient removal.

Scholz et al. (1993) investigated biofilm accumulation on submerged river red gum tiles in north Victorian billabongs (small ponds), using the same technique of biofilm chlorophyll 'a' determination, and obtained values that range between ~1.3 and 4.2 µg/cm^2. Chlorophyll 'a' values

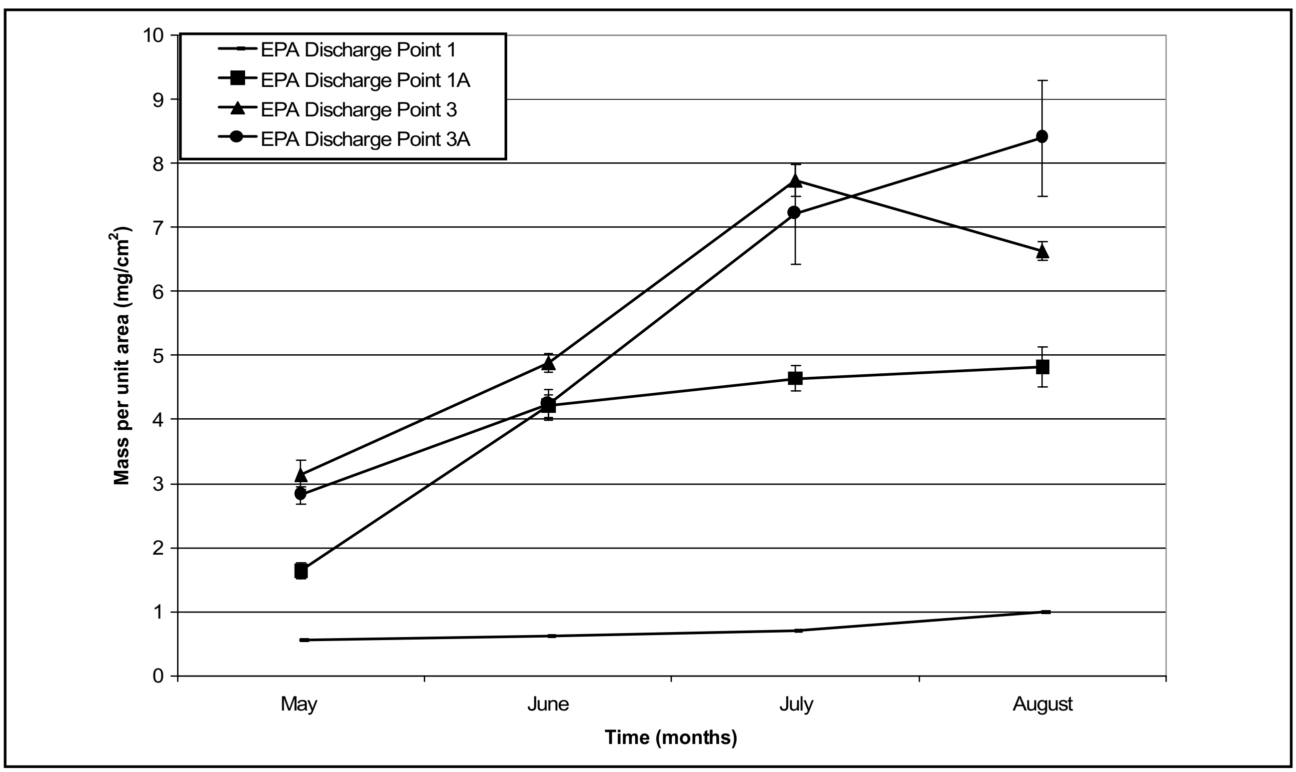

Figure 3. Biofilm growth, as determined by mass, in discharge ponds (April to August, 2000); Error bars denote 1 standard error, n = 9.

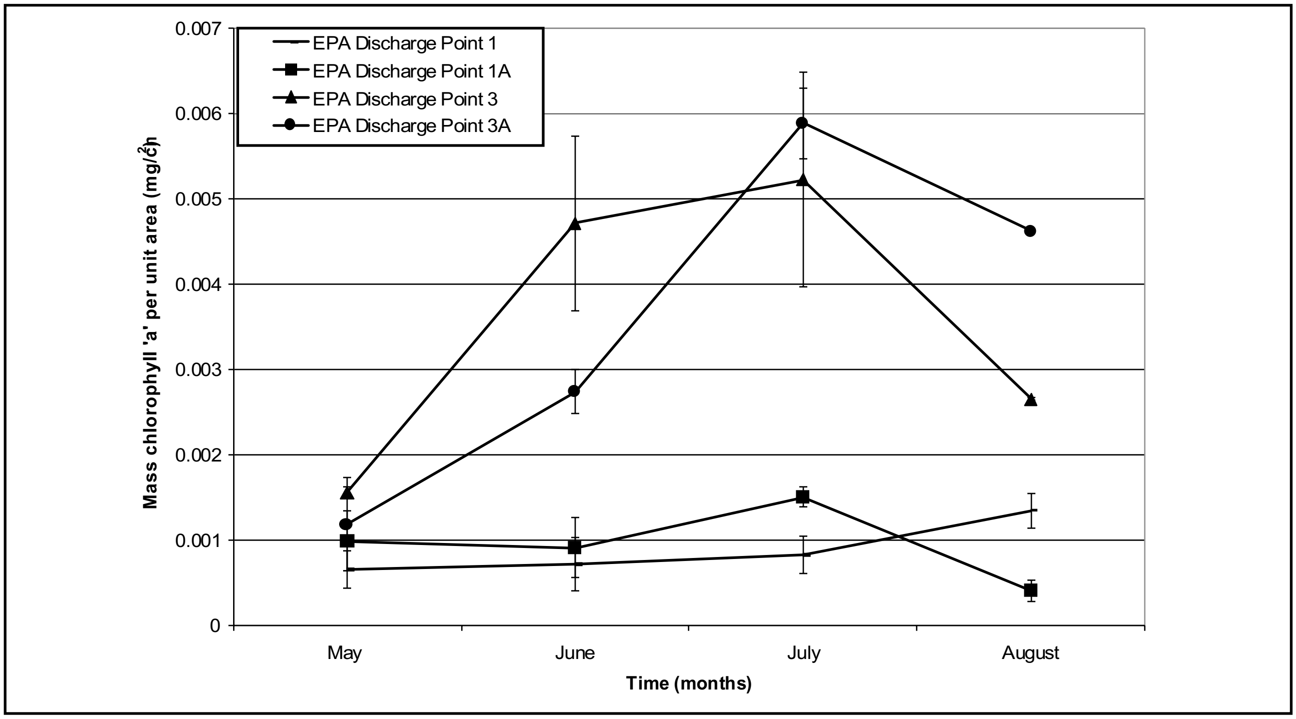

Figure 4. Biofilm growth, as determined by chlorophyll ‘a’, in discharge ponds (April-August, 2000); error bars denote range, (n = 2).

obtained in the current study were slightly greater (ranging between ~0.5 and 6 $\mu g/cm^2$), and were obtained in 4 months compared with the 6 months of the Scholz study. This indicated that AquaMat™ is, at the very least, a more effective substrate than red gum tiles for rapid biofilm colonization. However, in order to maintain the high surface area of AquaMat™ it will be necessary to periodically remove the mats from the waste water streams and wetlands, remove excess biofilm and attached algal clumps, then reinstate the mats into the effluent.

CONCLUSION

The use of artificial substrates, specifically AquaMat™ was shown to be an effective means of reducing nutrients from industrial waste water under conditions of low temperatures, high pH and high concentrations of fluoride. By reducing the volume of nutrients in this manner, the AquaMat™ is effective in reducing the risk of toxic algal blooms in the summer months. The Aquamats, however, require regular maintenance to remove excess biofilm and attached algal clumps.

REFERENCES

Boley, A., W.R. Muller, G.Haider; Biodegradable polymers as solid substrate and biofilm carrier for denitrification in recirculated aquaculture systems. *Aquacultural Engineering,* Vol. 22, pp. 75-85, 2000.

Entwisle, T.J., J.A. Sonneman, S.H. Lewis; Freshwater Algal Management. In “*Freshwater Algae in Australia*”, pp. 16 - 17. Sainty and Associates NSW, Australia, 1997.

Golz, W.J., K.A. Rusch, R.F. Malone; Modeling the major limitations on nitrification in floating-bead filters. *Aquacultural Engineering*, Vol. 20, pp. 43-61, 1999.

Hwang, B.H., K.Y. Hwang, E.S. Choi, D.K. Choi, J.Y. Jung; Enhanced nitrite build-up in proportion to increasing alkalinity/NH_4+ ratio of influent in biofilm reactor. *Biotechnology Letters*, Vol. 22, pp. 1287-1290, 2000.

Rusten, B., B.G. Hellstrom, F. Hellstrom, O. Sehested, E. Skjelfoss, B. Svendsen; Pilot testing and preliminary design of moving bed biofilm reactors for nitrogen removal at the FREVAR wastewater treatment plant. *Water Science and Technology*, Vol. 41, pp. 13-20, 2000.

Scholz, O., P. Boon; Biofilm development and extracellular enzyme activities on wood in billabongs of south-eastern Australia. *Freshwater Biology,* Vol. 30, pp. 359 – 368, 1993.

SEPP, (State environment protection policy). Waters of Victoria Draft Schedule F6 - (Waters of Port Phillip Bay), *Environment Protection Authority*, Melbourne, Australia, 1995.

Urrutia, H., R. Vidal, M. Baeza, E. Aspe; Effect of fishing industries effluents pH and organic load on the methanogenic bacteria biofilm developed over support in fixed biomass reactor. *Anaerobe*, Vol. 5, pp. 325-327, 1999.

Vanotti M.B., P.G. Hunt; Nitrification treatment of swine wastewater with acclimated nitrifying sludge immobilized in polymer pellets. *Transactions of the American Society for Agricultural Engineers,* Vol. 43, pp. 405-413, 2000.

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