Algal Turf Scrubber: A Promising Eco-Technology For Polishing Waste Water Treatment Plant Effluent.

by

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ABSTRACT

The Algal Turf Scrubber (ATS) is a novel biological waste water treatment method relying on a periphytic community of filamentous algae for the removal of BOD_5, inorganic nutrients and heavy metals. The method has been shown to reduce ammonia, total phosphorus (TP) and total Kjeldahl nitrogen (TKN) by 100%, 93% and 83% respectively. Other biological benefits of the ATS include oxygenation, disinfection and detoxification. Significant economic returns can be derived through a variety of algal biomass uses including production of fish feed, algal filters for heavy metal extraction from idustrial water, balanced organic fertilizers, natural gas, and paper and plastics. These benefits, combined with low initial and operational costs, uncomplicated maintenance and a broad spectrum of biomass uses, make the ATS ideally suited for final polishing of waste water treatment plant effluent.

INTRODUCTION

Thorough waste water treatment may include up to five distinct stages (OSWALD 1989). Treatment cost, however, rises disproportionately with treatment stage, often limiting the operation of waste water treatment plants to the primary and secondary stages *i.e.* sedimentation and BOD removal. The breakdown of organic matter during BOD removal releases large amounts of inorganic nutrients in the water which, if discharged without further processing, can cause eutrophication with adverse effects on the receiving ecosystems (Table 1). Such effects are especially pronounced in cases where the dilution

TABLE 1

The effects of eutrophication on the receiving ecostystem and the problems to man associated with these effects (MASON, 1991).

EFFECTS
1. Species diversity decreases and the dominant biota change
2. Plant and animal biomass increases
3. Turbidity increases
4. Rate of sedimentation increases, shortening of the life-span of the lake
5. Anoxic conditions may develop

PROBLEMS
1. Treatment of potable water may be difficult and the supply may have an unacceptable taste or odour
2. The water may be injurious to health
3. The amenity value of the water may decrease
4. Increased vegetation may impede water flow and navigation
5. Commercially important species (such as salmonids and coregonids (whitefish)) may disappear

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provided is inadequate to prevent a deterioration of water quality. Therefore, the removal of phosphates and nitrates from waste water treatment plant effluent, known as polishing or tertiary treatment, is often necessary to return natural waters to their original state.

The following is a list of some other issues of current waste water treatment that need improvement:

- Bacteriological processes have a limited capacity to remove phosphorus.
- Chemical phosphorus removal is costly and results in difficult sludge handling and disposal.
- After BOD removal, denitrification (if applied) requires the addition of organic substrates.
- Organic matter breakdown requires constant pH regulation.
- Disinfection and detoxification methods are largely chemical and expensive.

The above problems call for the development of alternative solutions in waste water treatment. Desirable features of environmentally acceptable solutions include a) substitution of chemical treatment by biological processes, b) production of a useful or recyclable by-product, and c) cost and energy reductions in the aeration, pH control, and disinfection processes.

A variety of natural methods for waste water treatment are reviewed by REED *et al.* Such methods employ natural of artificial ecosystems *e.g.* wetlands, floating aquatic plants, stabilization ponds, etc., with reduced management and operations requirements. There is a common tendency in the above methods towards extensive use of plant organisms.

The algal turf scrubber (ATS) is a novel technology relying on the capacity of natural periphytic communities of filamentous algae to effectively remove nutrients, oxygenate, disinfect and detoxify the aquatic environment.

TECHNOLOGY DESCRIPTION

The ATS is a bioreactor specifically designed for the culture of a benthic algal community commonly known as algal turf. A basic ATS unit consists of a tray, a wave generator, and an artificial substrate lining the tray's bottom (Figure 1). Surge motion generated by a tipping bucket at the upstream end of the ATS greatly enhances algal turf productivity (ADEY and HACKNEY, 1988; LEIGH *et al.*, 1987). Natural or artificial illumination drives photosynthesis by algal turf, a multi-specific assemblage of algae dominated by attached filamentous forms (Figure 2). Such filamentous algae range in size from a few millimeters to a maximum of 10-15 cm, and are characterized by rapid growth and reproduction cycles (ADEY and HACKNEY, 1988). Despite their lack of protective mechanisms (thallus strength, toxicity, unpalatability, etc.) algal turfs growing in the wild are able to withstand constant grazing through basal cell persistence.

Figure 3 shows an ATS flow-way - a modified ATS design intended to simulate natural stream conditions suitable for large scale applications. Water leaving the secondary treatment stage of a biological waste water treatment plant enters the ATS system at the "INTAKE" point. Weirs are placed along the flow-way every few meters to ensure sheet flow over the entire surface of the course. As water flows over the developing community the algae remove pollutants, release oxygen into the water, and provide habitat for a diversified microfauna and bacteria community. Water treatment is comleted along the multiple food chains and complex biological interactions of this community. Depending on algal growth rate, every 3-10 days the plastic screens are removed from the trays, and the algae with the stored pollutants are harvested by scraping. The screens are then returned to the trays, and vegetative regeneration of algal turf begins immediately from basal cells left onto the substrate, much in the same fashion lawn comes back after mowing. Frequent harvesting is crucial for maintaining the community in its young, vigorous growth stage when water purification capacity is optimal, and pollutant release by senescent thalli minimal to non-existent.

SYSTEM PERFORMANCE

The results of an initial test on ATS waste water treatment performance are summarized below (SANTAS, 1992). Seven gallons of sewage, obtained after primary settlement from the Blue Plains waste water treatment plant, Washington, DC, were treated with a $0.5m^2$ ATS, subjected to a 12:12 photoperiod. Twelve hours after the addition of sewage, average effluent water quality parameters were DO 7.5ppm, NH_3-N 0ppm (100% removal; starting concentration 5ppm), NO_3^- 0.1ppm, NO_2^- 0.01ppm, PO_4^{-3} 0.05ppm (95% removal), TP 0.08ppm (93% removal), TKN 1.2ppm (83% removal). The pH ranged from 7.2 at the end of the dark period to 9.2 at the end of the light period. No chemicals, aerators or other biological filters were used.

TABLE 2

Benefits of the ATS process

EFFECTS OF PHOTOSYNTHESIS

- **Oxygenation** (direct photosynthetic release of dissolved oxygen into water)
- **CO_2 stripping** (direct CO_2 removal from the water)
- pH increase results in
  - **PO_4^{-3} removal** through precipitation
  - **NH_3 removal** through volatilization
  - **Disinfection** (pathogen elimination through prolonged exposure to elevated pH)

EFFECTS OF NUTRIENT UPTAKE

Removal of

- **NH_3, NO_3^-, NO_2^-**
- **PO_4^{-3}**

MICROHABITAT EFFECTS

- Community development allows for **complete treatment** (along food chain interactions)
- **Detoxification** (heavy metal adsorption onto metalloproteins of algae cell walls)

EFFECT OF SOLAR ULTRAVIOLET RADIATION

- **Disinfection** (pathogen elimination through prolonged exposure of shallow water to UV-A and UV-B)

DISCUSSION

The advantages of using microalgae in waste water treatment are outlined by OSWALD (1990). Integrated bacterial-microalgal treatment in "high-rate ponds" achieves 80% nitrogen and phosphorus removal, although the residence times required are days not hours. Other benefits include disinfection (the elimination of pathogens) due to prolonged exposure to solar ultraviolet radiation, as well as the removal of heavy metals through adsorption onto the cell wall of microalgae. Algal scrubbing bears all the benefits of high-rate ponding, but is a superior method in terms of manageability, and in that it provides improved oxygenation and throrough pathogen elimination in a shorter detention time. The benefits of the ATS method are summarized in Table 2.

The ability of the ATS to eliminate pathogens and remove inorganic nutrients and heavy metals from the water (SACK *et.al.,* 1992; SANTAS *et.al.,* 1993) makes it ideally suited as a method for tertiary treatment of sewage, septage, storm or agricultural runoff, industrial waste water or other waste water types (dairy farm, parer mill, etc.). In addition to the direct amelioration of water quality, the by-product of the ATS method can have multiple uses.

Fish Feed
Algae constitute an excellent source of protein, vitamins, carbonates, lipids and trace minerals for aquatic organisms. Algal turf periodically harvested from the ATS can be used directly as food in aquaculture operations.

Organic Fertilizer
Microalgae are readily biodegradable. Upon decomposition, the nitrogen, phosphorous and trace elements in the algal biomass are released as low molecular weight organics, which are subsequently transformed to inorganic plant nutrients. Because of their biodegradability and high content of nitrogen, phosphorous and micronutrients at ratios best utilized by higher plants, algal turf is a valuable organic fertilizer.

Cellulose
Most algae, just like higher plants possess a cellulose cell wall. Cellulose is the raw material for plastics, explosives and paper production. Paper has been made from algae as early as 1809. Large amounts of algal turf produced as a by-product of any application may be utilized as a raw material in the paper or plastics industries.

Methane
Finally, algae are one of the best substrates for biogas production. They are used to boost methane production from anaerobic digestion of other substrates. The amount of methane produced per unit weight of algae is double than that yielded when other organic substrates are used.

REFERENCES

ADEY, W.H., 1989. "Harvest Production of Coral Reef Algal Turfs", *in "The Biology, Ecology and Mariculture of Mithrax spinosissimus Utilizing Cultured Algal Turfs"*. W.H. Adey, ed.: Washington, D.C., Mariculture Institute.

LEIGH, E.G., R.T. PAINE, J.F. QUINN, and T.H. SUCHANEK, 1987. "Wave Energy and Intertidal Productivity". *Proc. Nat. Acad. Sci. USA*, 84:1314-1318.

MASON, C.F. 1991. *"Biology Of Freshwater Pollution"*. 2nd ed., p. 105. Longman Scientific & Technical; Essex CM20 2JE, England.

OSWALD, J.W., 1989. "The Role of Microalgae in Liquid Waste Treatment and Reclamation", *in "Algae and Human Affairs"*, C.A. Lembi and J.R. Waaland, eds. Cambridge; Cambridge University Press, pp. 255-281.

REED, S.C., E.J. MIDDLEBROOKS, and R.W. CRITES, 1988. *"Natural Systems for Waste Management and Treatment"* New York, NY: McGraw-Hill Book Company.

SACK, W.A., R. SANTAS, J. A. McCUNE, and R. M. TOMICEK, 1992: Removal of Nutrients, Trace Elements, and Organics Using an Algal Turf Scrubber System. *Proc. 65th Annual Conference of Wat. Envir. Feder.*; New Orleans, LA.

SANTAS, R., 1992: "The Algal Turf Scrubber: A New Biological Waste Water Treatment Method." *Proc. 24th Mid-Atlantic Industr. & Hazardous Waste Conf.*; Morgantown, WV, pp. 323-330.

SANTAS, Ph., D. DANIELIDES and R. SANTAS, 1993: "Removal of Heavy Metals from Industrial and Municipal Waste Waters Using an Algal Turf Scrubber." *HELECO Conf.*; Athens, Greece.

ALGAL TURF SCRUBBER™

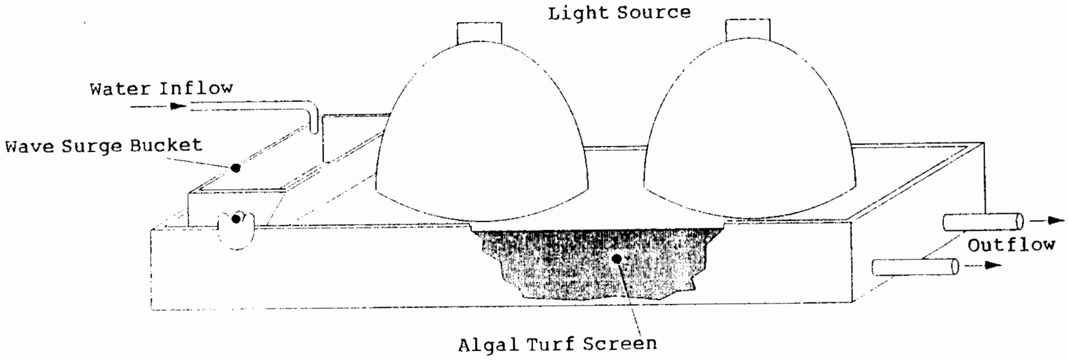

Figure 1

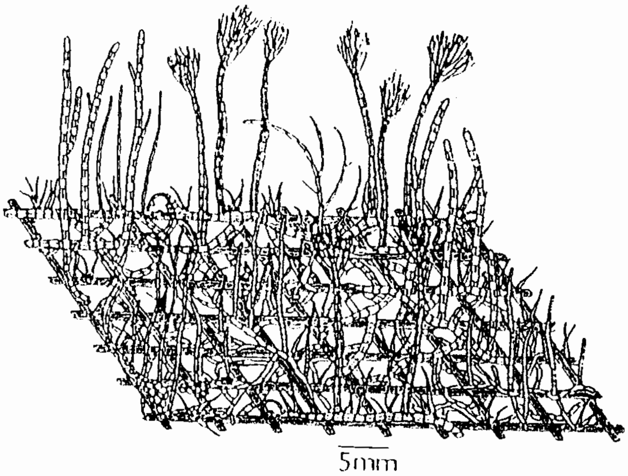

Figure 2

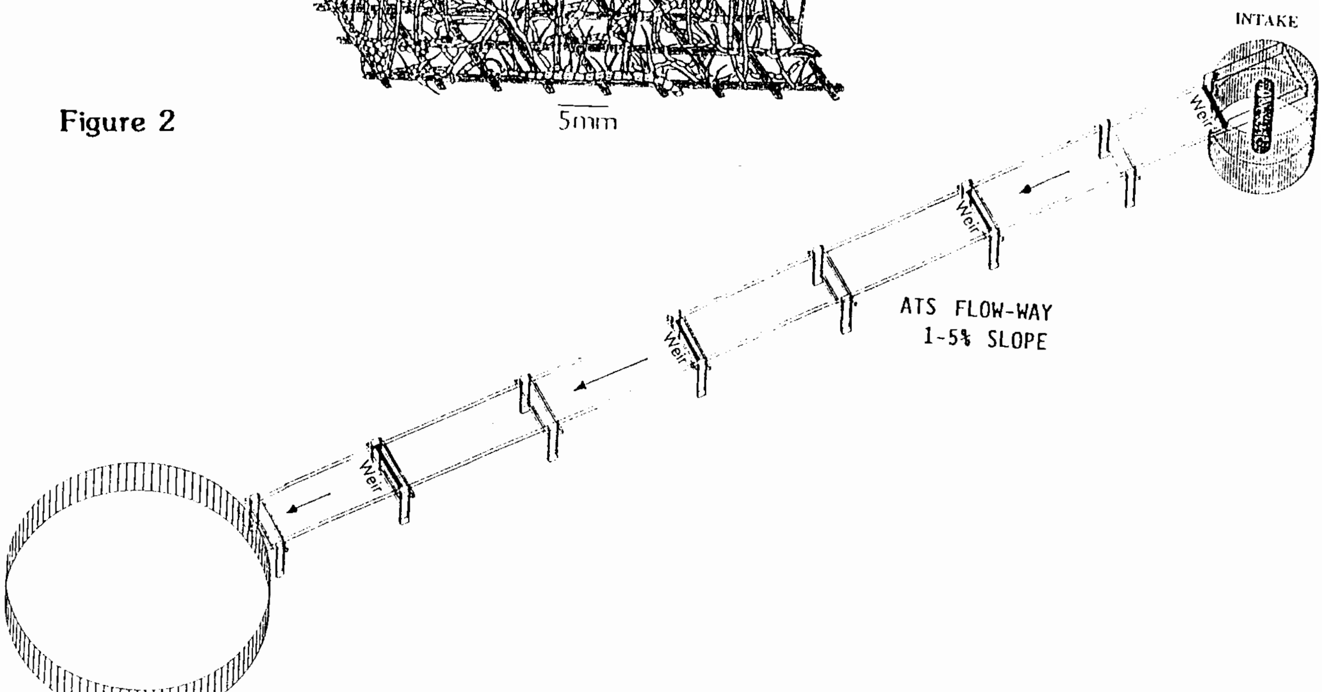

Figure 3

Figure 1: Algal Turf Scrubber - basic unit design
Figure 2: Diagrammatic view of algal turf growing on artificial substrate
Figure 3: Conceptual design of an ATS flow-way for polishing of waste water treatment plant effluent