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A REVIEW OF THE MECHANISMS OF POLLUTANT REMOVAL IN WATER HYACINTH SYSTEMS

by

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ABSTRACT

Presence of aquatic plants in natural or constructed wetlands not only reduces the concentration of problematic nutrients from the wastewater, but also alters the physico-chemical environment of the water, rhizosphere and underlying sediment (Reddy & Patrick, 1984). In addition to plant assimilation of nutrients, changes in the environment of the water also help in reducing the pollutant level of the wastewater through biochemical processes brought about by micro-organisms. This paper gives a review of the biochemical and physico-chemical processes occurring in a floating aquatic plant system.

Keywords : Water hyacinth, pollutant removal, biochemical/ physico-chemical processes.

INTRODUCTION

The degree of purification of wastewater within a hyacinth lagoon depends not only on the capacity of the plants to assimilate nutrients, but also on their potential to alter the wastewater environment to enhance removal of organic matter through biochemical processes. Water hyacinth lagoons function as horizontal trickling filters in which submersed plant roots provide physical support for a thick bacterial biofilm, which actively degrades organic matter (Stowell *et al*. 1981). They are considered to combine the physical process of filtration with fixed–film and suspended growth biological conversion processes. The micro-organisms degrade organic matter, producing metabolites, which they and the plants utilise along with nitrogen, phosphorus and other minerals as a food source.The system differs from other more conventional fixed-film systems in that the attachment medium is biologically active.

Organic Matter Removal

Suspended solids passing through the roots get entrapped, accumulate and finally settle by means of gravity or get metabolised by micro-organisms, while particulate matter settles at the bottom of the pond. The predominant dissolved organic matter (DOM) removal mechanism is the bio-oxidation by bacteria present in the biofilm attached to the root and in the water column (Stowell *et al*. 1981; Wolverton, 1987; DeBusk and Reddy, 1987). Additional DOM removal mechanisms include plant uptake and accumulation/degradation in the sediment after sorption onto particles. Bacteria utilise organic matter for the production of energy and synthesis of new cells. The biochemical reactions involved in energy production require the presence of electron-acceptors for organic matter oxidation. The reactions, which utilise free-oxygen as an electron-acceptor are predominant since they are the most energy efficient. A summary reaction of the multiple biochemical steps involved has the form:

$$C_5H_7O_2N \ + \ 5O_2 \longrightarrow 5CO_2 \ + NH_3 \ + 2H_2O \ + \text{energy}$$

where, $C_5H_7O_2N$ is a generalised formula of bacterial biomass obtained from experimental studies (Metcalf & Eddy, 1991).

In the absence of free oxygen, bacteria utilise other inorganic molecules such as nitrate and sulphate as alternative electron-acceptors. (Stowell *et al*. 1981, Reddy & Sutton, 1984).

Depending on the oxygen status of the water under the floating plants, the water column can be divided into three zones as shown in Fig 1., where Zone I is the rhizosphere area, where aerobic respiration takes place (Reddy, 1985).

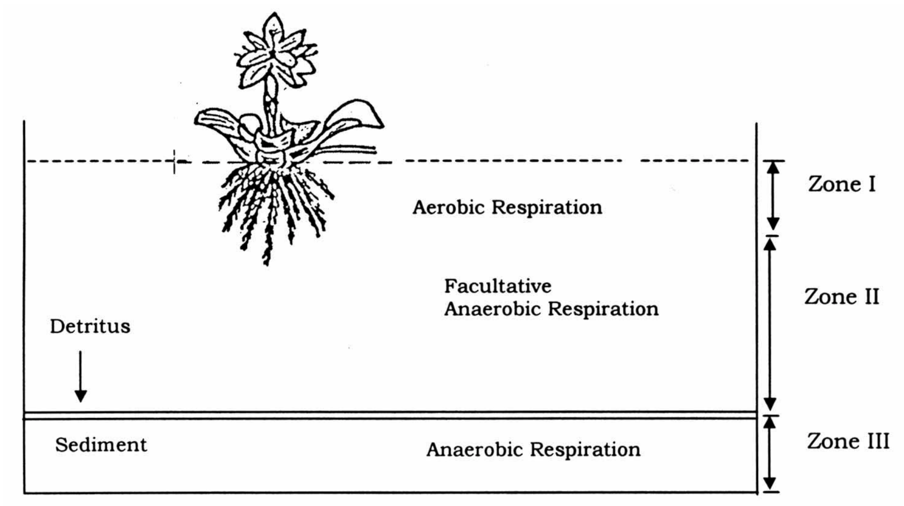

Fig. 1. Schematic presentation of a water hyacinth treatment system showing the zones with different microbial metabolism. (Reddy, 1985).

Oxygen required for bacterial oxidation in the lagoons is provided by atmospheric diffusion, production by algal photosynthesis, and release from water hyacinth roots. The first two processes transfer oxygen directly into the water column, while oxygen released by the plant roots is captured by the attached bacterial biofilm.

Atmospheric diffusion is a relatively inefficient transfer process. Oxygen transfer through the surface of open shallow ponds has been estimated at 0.5 - 1.5g m^{-3} d^{-1} (Imhoff *et al.* 1971). In water hyacinth lagoons the transfer is likely to be smaller since the dense plant cover reduces both surface gas-exchange and wind-induced turbulence.

It has been suggested that algae do not significantly contribute to lagoon oxygenation since shading by water hyacinth severely restricts algal growth (Gee & Jensen, 1980). This assumption might not be correct for all treatment conditions as algal concentrations of 3g dry wt m^{-3} have been measured in water hyacinth pond effluent (Dinges, 1976).

Release from plant roots appears to be a major source of oxygen in the lagoons. Oxygen release from the roots of water hyacinth, was tested by Moorhead and Reddy (1988). Short-term transfer capability of the plant was estimated at 0.12 to 1.3 mg O_2 (g root dry wt$)^{-1}$ h^{-1}. Extrapolation of laboratory results to treatment lagoons gave an estimate of 2.4 to 10g m^{-3} d^{-1} for the oxygen release rate from water hyacinth roots (Moorhead & Reddy, 1988). Depending on the oxygen demanding species present in the wastewater, oxygen diffused through the roots can be rapidly consumed, creating anaerobic conditions.

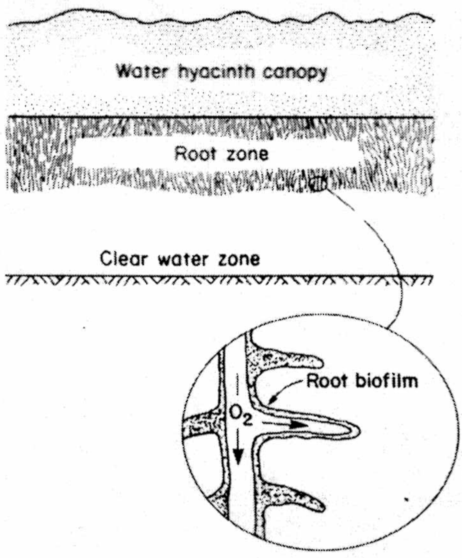

Fig. 2. Idealized cross-section of the root structure of water hyacinth showing flow of O_2

With regard to the biofilm on the active surface of the roots (Fig. 2.), an analogy can be drawn with the biofilm structure of the Permeable-Support Biofilm (PSB) system. This is an innovative wastewater treatment system in which pure oxygen is supplied to the biofilm support surface through a synthetic permeable membrane in order to enhance organic oxidation and nitrification.

A hypothetical biofilm structure was suggested by Timberlake (Timberlake *et al.*,1988) during a study on combined aerobic heterotrophic oxidation, nitrification and denitrification in a PSB. According to the author, a deep biofilm on the permeable membrane would hypothetically have four zones of microbial activity: a nitrification layer near the support, an anaerobic fermentation layer near the liquid surface, and 2 intermediate layers of denitrification and heterotrophic oxidation (refer to Fig. 3). Oxygen concentration in the water column decreases with depth, approaching near zero in Zone II (refer to Fig.1) (Reddy, 1985).

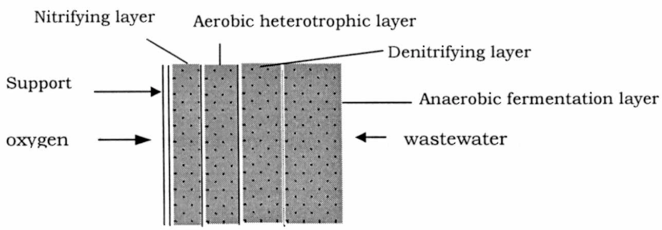

Fig. 3. Structure of support-aerated biofilm of a PSB wastewater treatment system.

In Zone II the microbial metabolism of the suspended biomass is mainly facultative anaerobic respiration, where microbes use nitrate as a source of electron acceptor. Most of the nitrate is probably consumed in the water column before it reaches the sediment surface. Most nitrate-reducing bacteria are facultative anaerobic heterotrophs, which proliferate in anoxic conditions (Metcalf & Eddy, 1991) The activity of facultative anaerobes in this zone will, however, be dependent on the availability of the electron acceptors such as nitrate, ferric iron, and manganese.

In the absence of oxygen, nitrate, manganic, and ferric compounds, true anaerobes utilise sulphate and carbon dioxide as electron-acceptors during oxidation of organic matter. These conditions exist in the detritus layer and in the underlying sediment in Zone III. This process can be significant since most of the wastewaters contain significant concentrations of sulphate and dissolved carbon dioxide (Fenchel & Jorgensen, 1977).

Removal of trace organic compounds in water hyacinth test tanks has been reported for phenolic compounds (Wolverton & McKown, 1976; O’Keeffe *et al.*, 1987) and the pesticides Diphenamid, Mirex, Toxophene and Mevinphos (Smith & Shore, 1978). In the case of phenols the removal was attributed to direct plant uptake and subsequent metabolism in the root tissues (O'Keeffe *et al*., 1987).

Nitrogen Removal Processes

Plant uptake of nitrogen is one of the processes involved in the removal of N from water hyacinth lagoons. Removal of N through plant uptake will depend on the growth rate of the plant, culture density and environmental parameters such as solar radiation and temperature. Hyacinth plants are capable of assimilating both ammonium and nitrate, however as with many aquatic plants there is a preferential uptake of ammonium over nitrate, even though both ions are present in the wastewater at the same time (Reddy & Tucker, 1983).

Table 1 gives the various nitrogen transformations which take place within an aquatic-macrophyte based treatment system. Nitrogen transformations include: mineralisation (organic N to ammonium), immobilisation (ammonium and nitrate to organic N), nitrification (ammonium to nitrate), volatilisation and denitrification (nitrate to nitrous oxide and nitrogen gas).

Table 1. : Nitrogen transformation influenced by microbial respiration in an aquatic macrophyte wastewater treatment system (Reddy, 1985)

Respiration		**Nitrogen Transformation**
Aerobic	Ammonification	Org-N $\longrightarrow$ NH_4^+
	Immobilisation	NH_4^+ $\longrightarrow$ Org.-N
	Nitrification	NH_4^+ $\longrightarrow$ NO_3^-
Facultative anaerobic	Denitrification	NO_3^- $\longrightarrow$ N_2O $\longrightarrow$ N_2
	Ammonification	Org.-N $\longrightarrow$ NH_4^+
	Immobilisation	NH_4^+ $\longrightarrow$ Org.-N
Anaerobic	Dissimilatory NO_3- reduction	NO_3^- $\longrightarrow$ NH_4

Relative rates of these reactions will however depend on the optimal environment conditions present in the water and sediment. Organic N is present in the influent wastewater and in the detritus plant tissue. Depending on the metabolic activity of the bacteria, organic bound N is mineralised to ammonium N. The rate of conversion, however, will depend on the nature of the organic N and C/N ratio of the organic matter and electron acceptor availability.

Nitrification involves the biological oxidation of ammonium to nitrate. The bacteria involved are chemo-autotrophic and utilise oxygen as their electron acceptor, while ammonium is used as their substrate. In a floating aquatic macrophyte system, nitrification potentially occurs in the water column and in the rhizosphere under low organic carbon concentration. Since oxygen concentration of the water under floating plants is usually low, nitrification rates in these systems can be limited by oxygen supply.

Denitrification occurs in the absence of oxygen, when facultative anaerobic microorganisms utilise nitrate as a terminal electron acceptor during their respiration. During this process, nitrate is reduced to gaseous end products such as nitrous oxide and nitrogen gas. This process is very active in zone II of the aquatic floating macrophyte system. Denitrification can potentially occur in the sediment, water column devoid of oxygen, and in the anoxic sites of the rhizosphere. (Firestone, 1982, Metcalf & Eddy, 1991)

Phosphorus removal

Phosphorus removal from water hyacinth lagoons is due to plant uptake, retention by the underlying sediments, and precipitation in the water column. Since phosphorus is retained by the system, the ultimate removal from the system is achieved by harvesting the plants and removal of sediment.

CONCLUSION

Pollutant removal by such a treatment system depends on the nutrient assimilative capacity of the plant and the biochemical/physico-chemical processes taking place within the system.

Removal of dissolved organic matter (DOM) is due to aerobic, facultative anaerobic and anaerobic activities. Rate of substrate degradation depends on its biodegradability and on the availability of electron acceptors, which ultimately dictates the mode of respiration. Nitrogen removal occurs via plant uptake and nitrification/ denitrification, while phosphorus removal is due to plant uptake, precipitation and microbial immobilisation.

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