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The Aquasanitation Treatment Process

Wastewater Treatment Lagoons

Aquatic plants of the botanical family *Lemnaceae*, the common duckweeds, bioaccumulate virtually all of the nutrients dissolved in wastewater and produce protein-rich duckweed biomass as a byproduct. Fresh duckweed is a complete nutritional package for carp and tilapia, while dried duckweed meal can comprise up to 40 percent of poultry feed by weight.

Conventional waste stabilization lagoon systems "treat" wastewater in three ways: (a) **pathogen reduction** by natural biological process that occur during a detention time of at least 20 days; (b) **nutrient transfer** from the wastewater to algae and (c) **biological oxygen demand reduction**. Secondary treatment standards can be met for some effluent criteria: (a) $BOD_5 < 40$ mg/l; (b) $N_T < 50$ mg/l and $P < 10$ mg/l. Suspended solids (the algae in this instance), however, will typically increase to over 200 mg/l, whereas minimal secondary standards specify less than 50 mg/l. By "trapping" nutrients in algae, lagoon systems achieve little real treatment. When discharged, these algae eventually die and release trapped nutrients into the receiving stream. Chemical and physical processes of removing nutrients from wastewater effluents are extremely energy intensive and costly.

Introduction

"Aquasanitation" is a sanitary treatment process for wastewater that uses duckweed growth as a biological filter in a lagoon system. It differs from conventional lagoon systems in that it (a) actively **removes nutrients** from the wastewater stream with energy supplied by the sun, and (b) **suppresses algae growth**. In terms of pathogen removal aquasanitation is equally effective.

The treated effluent from the system typically contains less nitrogen, phosphorus and algae than receiving bodies of water into which it is discharged. Treated effluent from the system contains few organic compounds and may therefore be chlorinated without risking significant trihalomethane production. Finally, because an aquasanitation system removes nutrients efficiently, additional treatment steps are not needed for the treated effluent to meet standards for reuse.

An aquasanitation system is managed as a farm to cultivate various duckweed species that use the wastewater as their growth medium. The rapidly growing duckweed colonies act as a **nutrient sink**, absorbing primarily N, P, Ca, Na, K, C and Cl from the wastewater. These are then permanently removed from the system as the plants are harvested.

Depletion of nutrients eventually slows duckweed growth. As the starved plants process increasing amounts of water in the search for growth nutrients, they absorb virtually everything dissolved in the wastewater stream. Depending on the quality of the influent, the small volume of plants harvested during this **polishing process** may contain significant levels of toxins and heavy metals. If so, they should be disposed of according to procedures for mildly hazardous materials.

Efficient duckweed growth is supported by an even distribution of a thick layer of plants across the entire lagoon surface. This has the additional effect of shading the water below from sunlight and preventing photosynthesis and growth of algae.

Duckweed tissue is contains from 92 to 94 percent water. However, the solid fraction of well nourished, rapidly growing fronds consists of up to 50 percent protein and may be used without processing (i.e., drying) as a complete feed for a carp polyculture or a monoculture of tilapia. Dried duckweed meal can supply the high protein component of various blended animal feeds. The vitamin A and pigment content of duckweed has proven particularly valuable in poultry diets.[1] A typical aquasanitation facility in Bangladesh with a treatment surface of one hectare will yield an average of about one ton/day of fresh plants. The daily harvest can be converted into about 100 kg of fish or about 80 kg of dried duckweed meal.

The aquasanitation treatment process is described in greater detail below:

Primary Phase

The primary phase of the wastewater treatment system receives raw wastewater. Like any primary treatment process the main objectives are to separate floating material and sediment significant amounts of solids. In the primary phase anaerobic digestion of primary sludge will release nutrients and methane in the process. Methane can be collected for subsequent use or simply vented. Primary treatment can take place either in a deep pond or enclosed tank. In a rural setting ponds would be preferred, while in a densely populated urban area, odors would be minimized by enclosed tanks.

Efficient sedimentation prevents degradation of initial treatment channels. Septage and influent wastewater will be introduced with minimal aeration to maintain an essentially anaerobic system. This can be achieved by maintaining methane storage under slight pressure in a circular tank with a vertical, centrally located low-pressure, large diameter inflow pipe to sediment efficiently and maintain anaerobic conditions within the tank. A pond may be covered with a floating rubber cap with periodic vent pipes.

Twin primary ponds or tanks are essential. Tanks should be located side-by-side with the elevation of the first tank about 30 centimeters above the second tank for gravity flow-through. Initially, both tanks should be operated in series, with the second tank receiving the effluent from the first tank. As sedimentation builds up in the first tank and the effective volume decreases, efficiency will also drop and increasing amounts of solids will be passed through and trapped by the second tank. When sludge reduces volume of the first tank by 50 percent it will be bypassed, and all influent will flow only through the second primary tank. The roof of the first tank should be removed, and it should then be drained and allowed to dry. Sludge may then be removed by the means preferred locally. The cleaned tank should be brought back into service as soon as possible. Eventually, the second tank will also need desludging. The process will then be repeated with second tank bypassed. Sludge should be analyzed for heavy metal concentrations. If found to meet established criteria, it should then be composted and sold as garden manure. Otherwise it should be disposed of according to procedures developed for mildly hazardous materials.

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1 This has been shown through four years of research conducted by The Prism Group in collaboration with the Agricultural University of Peru and the Ralston Purina affiliate in Peru.

Floating solid material will interfere with duckweed growth. It should be prevented from progressing to subsequent treatment stages by venting effluent 50 centimeters below the surface. The resulting crust of floating material will also minimize surface aeration.

Both primary settling tanks should be covered to keep odors to a minimum and enhance acceptance of the facility by persons who live or work nearby. To operate efficiently, the primary treatment stage needs to b maintained in an anaerobic condition. Fermentation will generate significant amounts of methane and hydrogen sulfide. These gasses should be trapped under an airtight cover and used as biogas, vented or flared off. Bad smells are the cause of most complaints by people living in the vicinity of wastewater treatment facilities. If designed and operated correctly, this type of primary treatment will not be objectionable.

System cost is an important consideration in the design of a primary process for a aquasanitation treatment system. Should cost prove to be a significant constraint, effective primary treatment is possible with two simple open-cut facultative lagoons. Unlike the closed system described above, open systems may be objectionable to people living near them.

Post Primary Treatment: Plug Flow System

An aquasanitation plug flow system consists of two elements: the **farm** and the wastewater **polishing facility**. Where raw wastewater is of domestic origin, these two elements may be indistinguishable. The farm consists of a shallow channel system designed to allow cultivation of duckweed colonies and incremental treatment of wastewater. It is designed to maximize duckweed production and to facilitate efficient harvesting and crop management while preventing short circuiting of the wastewater flow.

Duckweed Farm

The duckweed farm has two objectives: The first is to produce as much high quality biomass as possible while maximizing net returns from the process. Maximum biomass production achieves the second objective of maximum removal of nutrients from the wastewater stream.

Maintaining a Hospitable Growth Medium

Like all plants, duckweed species prefer certain combinations of growth conditions over others. Maintenance of these conditions is important to efficient plant growth and effective wastewater treatment because the two are different aspects of the same phenomenon. While duckweed colonies are known to survive under widely varying conditions of water temperature and water chemistry, their growth rate is sensitive to variations of both.

Removing all nutrients from wastewater inevitably leads to starvation of the duckweed colonies in the latter stage of the treatment process and cessation of plant growth. At the other extreme, high concentrations of ammonia and other nutrients can have a similar effect. This may be prevented by recirculating a portion of the final treated effluent to dilute raw wastewater. Aquasanitation systems should be designed with the influent side near the discharge to simplify recirculation to a matter of lifting it a few centimeters and pumping it a short distance.

Increasing the depth of the system and stimulating mixing are two means to moderate surface temperatures during hot and cold seasons. Designing for a detention time of twenty days to assure acceptable pathogen destruction involves a combination of surface area and system depth. A system with a maximum depth of 1.5 meters will provide acceptable temperature buffering and detention time at reasonable cost in moderate climates. Slightly perturbing the bottom flow with a small barrier placed on the bottom results in good mixing.

Distributing and Containing Duckweed Colonies

Unconstrained access to the pond surface is the most important factor affecting duckweed growth. Plants should be distributed across the entire surface to exploit the productive potential of the colony and distributed so that their growth is not constrained. Increasing the base population of plants in a given area increases the potential of that population to multiply. There is, however, a point of diminishing returns, when the inhibiting effect of crowding on plant reproduction outweighs the increased productive potential of a higher base population.

An interlocking containment grid floating on the pond contains and distributes duckweed plants across the available growing surface while suppressing the disruptive effects of wind and wave action. Mean wind conditions and maximum projected system flow velocity are the two main determinants of optimal grid size. The barriers should be resistant to degradation by ultraviolet light and corrosion and should be robust enough to survive several years of harvesting activity. Cell sizes on existing aquasanitation systems range between 30 to 50 m².

Harvesting

A strategy for efficient crop management is to maintain a steady state system at the **optimum standing crop density** which realizes the highest marginal duckweed production. Theoretically, this means constant harvesting, but for all practical purposes daily harvesting is close enough. Each cell should be harvested daily to bring the current standing crop density back to the target density, which will range seasonally from 600 to 800 g/m² of duckweed (in Bangladesh). Seasonal optima for crop density will need to be developed empirically for each location and with indigenous species, which are adapted to the local "environmental particulars".

System configuration and the local cost of labor and capital will determine the best choice of harvesting technique. The least complicated harvesting technique is to scoop plants from the pond surface with a dip net. A channel design about seven meters wide facilitates harvesting from the perimeter. Larger, wider systems require harvesting from a self-propelled craft and a correspondingly greater requirement for robustness of the floating containment grid. These harvesting vehicles may be motor or pedal driven. In most developing countries systems should be designed for labor intensive harvesting from the banks of the channels.

Regular harvesting is important not only to generate the biomass byproduct, but also to maintain healthy, vigorously growing duckweed colonies. Younger plants have more protein and less fiber and minerals; they also reproduce and grow faster than older plants. *Bioaccumulation* is the key to the aquasanitation process of wastewater treatment: harvesting permanently removes accumulated nutrients, minerals and toxic materials from the system.

Algae Suppression

Aquasanitation systems remove suspended solids more efficiently than other non-mechanical treatment systems by shading the water column. A dense layer of floating duckweed covering the water surface prevents sunlight from reaching any algae present in the water column. Also the floating duckweed mat creates a quiescent condition in the water column that is ideal for sedimentation. Unable to photosynthesize carbon, algae die and precipitate to the pond bottom. Systems with enclosed primary tanks inhibit algae growth from the outset and will be marginally better at removal of total suspended solids (TSS) than systems with open primary lagoons. However, any properly managed aquasanitation system can consistently meet a final effluent target with TSS below five mg/liter.

Nutrient Uptake Efficiency

Duckweed colonies are remarkably efficient at removing elements which are their growth nutrients. These include most organic compounds, as well as ions of N, P, K, Mg, Ca, Na, Cl, B, and Fe. Duckweed species have the ability to directly absorb and metabolize relatively complex organic compounds, such as the carbohydrates, sucrose and glucose, as well as organic nitrogenous compounds such as urea and most amino acids. This means that fermentation products in the water column need not be reduced to elemental form to be assimilated. Duckweed fronds will absorb growth nutrients from the water column preferentially over other elements. Well-nourished, fast growing duckweed plants do not concentrate trace minerals particularly well. While removal of toxins and heavy metals is an important objective of any wastewater treatment process, these materials are dealt with most economically by removing them from the wastewater stream at their source.

The propensity of duckweeds to assimilate growth nutrients selectively is an important issue affecting utilization of plants harvested from urban wastewater. Testing over several years of duckweed samples harvested from nutrient-rich urban wastewater has consistently failed to find heavy metals or known toxins in concentrations that would render the material unacceptable for direct consumption by humans, according to U.S. Food and Drug Agency food standards.

Polishing

Management of duckweed growth provides a complete wastewater treatment process. When duckweed plants are unable to find sufficient nutrients to maintain rapid growth, they undergo a remarkable metamorphosis: protein concentration drops below 20 percent; fiber content increases; rootlets (if the species has them) become long and stringy; fronds enlarge and become discolored; and, most importantly, as the plants process large amounts of water in search of sustenance, they absorb virtually everything still present in the effluent. The absorbed material shows up in a proximate analysis of a sample as *ash*. The mineralization phenomenon may be exploited as a pre-treatment process for raw surface- or groundwater prior to potable treatment to remove toxic ions such as arsenic, fluorides, etc, or for reuse for crop irrigation.

Polishing is the final stage of an aquasanitation system, and the latter reaches of the system are the polishing zone. In instances where analysis of raw wastewater indicates high concentrations of toxins and heavy metals, the beginning of the polishing zone should be marked. Plants harvested from the polishing zone should then be disposed of responsibly. However, most domestic wastewater streams do not contain significant concentrations of either toxins or heavy metals. The frequency of harvesting and biomass volume and quality will be lower than that of the bulk of the farming zone, but these inferior quality plants need not be excluded from the main harvest.

Pathogen Removal

Human enteric pathogens are removed in lagoon systems by three mechanisms: dilution, sedimentation and die-off. Parasite ova precipitate with other suspended solids and are trapped in the bottom sediment. Other pathogens suspended in the water die by natural processes as a function of time. Aquasanitation systems in moderate climates should be designed for a minimum detention time of approximately twenty days, which will achieve a pathogen removal of 99.999 percent.

Duckweed species do not concentrate pathogens in their tissue. Nevertheless, some bacterial or viral pathogens may adhere to the surface of the fronds. When the fresh plants are used as fish feed, the concentration of these bacteria or viruses in the water will be diluted by several orders of magnitude, which will cause a faster die-off rate in the fish pond. If any pathogen survives and is consumed by a fish it will be digested in the fish gut. Exposure to air, sunlight and desiccation of the plants accelerate the rate of die-off. No viable human pathogens could be cultured from dried sewage-grown duckweed meal in four years of testing in Peru.

Final Treated Effluent

Removal of refractory organic compounds in duckweed systems is so efficient that trihalomethane production as a byproduct of chlorination is negligible. Therefore, while chlorination of wastewater effluent is generally not recommended, it may be used as a precaution to remove any risk of residual bacteria in the treated effluent discharged from an aquasanitation system. The final treated effluent will usually be qualitatively superior to the receiving stream or water body across all major parameters and may therefore be used for almost any water-intensive operation. If filtered and disinfected by chlorination, ozone or ultraviolet light treatment, the aquasanitation treated effluent may be reused as raw water in a treatment process resulting in potable water.

Fish Farm Inputs

The most economical way to convert fresh duckweed into a marketable product is to feed it without processing either to tilapia or a carp polyculture containing grass carp, common carp, filter-feeders and detritus feeders. The conversion rate documented in Bangladesh is approximately 7-10 kg of fresh duckweed to one kg of fish. The associated fish farm should be located close to the aquasanitation facility to minimize duckweed handling costs and so that the final treated effluent can supply water inputs to the fishery. See <u>Duckweed Aquaculture: A New Aquatic Farming System for Developing Countries</u> for an analysis of costs and financial benefits of duckweed production and duckweed-fed carp production in Bangladesh.