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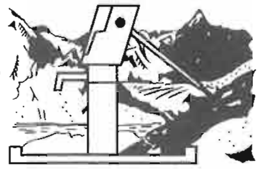
WATER, ENVIRONMENT AND MANAGEMENT



Lemnaceae based wastewater treatment and resource recovery

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The modern secondary biological wastewater treatment options for removal of Biochemical Oxygen Demand (BOD) or tertiary treatment systems for removal of nutrients like Nitrogen (N) and Phosphorous (P) are capital intensive and require large recurring operation and maintenance (O&M) costs. On the other hand, the traditional low cost options like stabilization ponds, lagoons etc., are inadequate to meet the existing secondary effluent disposal standards. Further more, in the absence of any direct economic returns or benefits, investments in expensive wastewater treatment systems receive the least priority in many developing countries. Therefore, development of a low cost *Lemnaceae*-based wastewater treatment system becomes significant, since they not only produce a tertiary effluent quality but also provide direct economic benefit in the form of protein-rich *Lemnaceae*.

LEMNACEAE

Lemnaceae, otherwise commonly known as duckweed, are small floating flowering plants found in all climatic regions except in entirely waterless deserts. *Lemna Sp.*, *Spirodella sp.*, and *Wolffia sp* are three genera commonly used in wastewater treatment systems. The bright green *Lemnaceae* plants range in size from less than 1 mm for the rootless *Wolffia* species - the world's smallest flowering plants to 1 cm or more, for *Spirodella* species. Both *Spirodella* and *Lemna* species have small, 1 - 2 cm root systems. These are green plants with fronds of a few mm wide and a short root usually less than 1 cm long. They commonly grow in polluted water bodies, including saline irrigation ditches and eutrophied ponds.

Advantages

The characteristics of Duckweed, which are useful for wastewater treatment and resource recovery are:

- vegetative growth - duckweed fronds can double their mass in two days under ideal conditions of nutrient availability, sunlight and temperature;

- tolerance to high concentration of nutrients up to 1 gm of N and 1.5 gm of P per litre;

- ability to absorb/accumulate nutrients, heavy metals and toxic substances - e.g., up to 100% uptake of Poly-Chlorinated Biphenyl (PCB) and produce a tertiary treated effluent quality;

- easy to harvest - they can easily be skimmed off by some kind of a net;

- control of odor;

- high protein - 35 to 45 % on dry basis; low fibre and lignin contents make it suitable as a food plant. Its application for human nutrition and as an animal feed has been known for a long time - in Mexico as poultry feed; in Thailand, Burma and Laos sold as "eggs of the water"; and in Bangladesh and Taiwan as fish feed; and

- very high protein harvest of about 15 tons per ha. year - about 20 times higher than the yield from the protein rich Soybean crop.

Disadvantages

Other characteristics, which goes against wastewater treatment and productive use of harvested duckweed are:

- reduction or stop in growth at low temperatures (less than 7ºC);

- like in stablisation ponds, large areas are needed to remove sufficient wastes from wastewater; and

- accumulation of heavy metals/toxicants can make harvested duckweed unfit for fish/animal feed.

LEMNACEAE BASED WASTEWATER TREATMENT SYSTEM

Treatment Mechanism

Duckweed systems are effective in removing BOD and Suspended Solids (SS) from wastewater. they support the right environment for their removal by microbial metabolism and physical sedimentation. Duckweed roots provide a good support medium for the growth of bacteria and for filtration, adsorption of SS. Pathogenic bacteria and viruses are removed by the same mechanisms as in conventional stabilization ponds - natural die-off - depending on detention time and wastewater temperature, predation, sedimentation and adsorption. (WPCF, 1990)

Design and Plant Performance

Lemnaceae systems have been developed by following the conventional design procedures for facultative lagoons, except for the need to control the wind effects - by introducing floating baffles or cells to prevent duckweed from being blown across the pond (Water Pollution Control Federation 1990). The important design parameters of a *Lemnaceae* system are hydraulic retention time, hydraulic loading and organic loading rates. Shallow (1.5 - 2.5 m depth) rectangular basins with a high length:width ratio are usually designed to reduce the potential for short circuiting and simplify harvesting operations.

Duckweed have significant ability to remove materials from the water in which they grow and produce a tertiary treated effluent quality. Also when harvested more frequently, duckweed become an excellent sink for nutrients, organic and inorganic materials, by absorbing as much as 99% of contents in the wastewater. Whereas in conventional stabilization ponds, algae account for most SS and BOD and also transport the most of nutrients from the treatment system to receiving water body. (William S. Hillman and Dudley D. Culley, Jr.)

The fast growing duckweed plants form a mat upto 1 cm thick covering the entire water surface thereby restricting the light penetration and growth of algae. Other positive effects of the duckweed mat are prevention of mosquito breeding and reduction in evaporation loss compared to a free surface water body. (Gideon Oron and Dan Porath; Hans Jansen).

BANGLADESH EXPERIENCE

An international NGO, the PRISM Group and the Kumudini Welfare Trust are jointly administering a *Lemnaceae* farming project called Shobuj Shona - literally "Green Gold" in Bengali language. The Kumudini Mirzapur complex project site is about 60 KM north-west of Dhaka. The project's primary objective is to develop and demonstrate convincing fresh water *Lemnaceae* farming techniques and its profitable use as fish feed. **Additionally,** the project seeks to demonstrate use of *Lemnaceae* for wastewater treatment.

Freshwater *Lemnaceae* Farming

Since April 89, extensive research on optimization of process conditions for sustained production of *Lemnaceae*, fertilizer requirements, seasonal effects, optimum plant density, wind buffering, raising of inter crops, water management and profitable use of *Lemnaceae* as poultry and fish feed is being done. Locally found common species - *Spirodella, Lemna minor, Wolffia*, are grown, through out the year in fifty fresh water ponds of various sizes in a total area of about 2 ha. of converted rice fields. *Lemnaceae* production from two ponds of equal size, from June 1991 to March 1992, are shown graphically in figure 1.

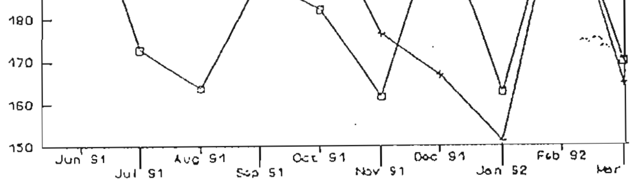

Fig.1: Freshwater Duckweed Production (June 1991 - March 1992)

Depending on the frequency of harvesting, the *Lemnaceae* production varied from 140 to 162 tons (wet weight)/ha/year. When harvested every day, except on Fridays, the *Lemnaceae* production was about 30 to 50% higher than harvesting every alternate day.

Fish Farming

Freshly harvested *Lemnaceae* is fed directly in three fish ponds with different species - ponds 1 and 3 - Carp polyculture - Grass carp, Common carp, Silver carp, Catla Rui (Indian gill feeders) and Mrigal (Indian mixed/bottom feeder) and pond 2 - Tilapia monoculture. The main conclusions, based on the actual measured figures of duckweed fed and fish harvested for a period of twelve months from April 1991 to March 1992, are:

a. Every ton of fresh *Lemnaceae* fed has given a yield of 80 to 120 Kgs of fish -an average of 100 Kgs.;

b. Increased quantities of *Lemnaceae* fed per ha.year did not necessarily result in increased fish yield per ha. year.; and

c. Fish catch per ha.year is about 10 tons, which is higher than typical fish catch levels of 3 to 5 tons per ha.year, from local fish ponds where only some fertilizers are applied to promote growth of phytoplankton for fish feed. About 0.5 to 0.75 ha of *Lemnaceae* farm is required to sustain the fish yield level of 10 tons/ha/yr.

USE OF *LEMNACEAE* FOR SEWAGE TREATMENT

Brief description of the treatment plant

The Kumudini Welfare Trust, Mirzapur complex generates about 350 m^3/day of wastewater from its 800 bed charity hospital, a girl's high school and residential areas with about 3000 residents. Till June 90, the wastewater was discharged without treatment to a nearby river, through a series of existing natural ponds. In July 90, the project installed a *Lemnaceae* based wastewater treatment plant consisting of: (a) a sewage collection and pumping station; (b) pretreatment pond - using one of the existing ponds as an anaerobic pretreatment pond and to retain most of the suspended solids in the raw sewage; (c) a fresh water pumping station to make up for the evapo-transpiration and seepage losses, particularly during the dry season i.e., November to April and (d) a plug flow *Lemnaceae* pond - one of the existing ponds of about 0.75 ha. of surface area was modified into a long serpentine channel of 8 m width, 40 cm water column. This channel is divided into several grids of 5 to 6 m long and 2 to 3 m wide with wind buffers for containing *Lemnaceae* within the grids.

Operation and Performance Results

a. Wastewater from the primary pond is pumped intermittently for about 3 hours in a day into duckweed pond. The estimated hydraulic retention time in the duckweed pond is about 20 -25 days.

b. While all three species of *Lemnaceae* are observed, *Spirodela* is more prevalent.

c. *Lemnaceae* is harvested manually with a hand net, by two laborers travelling in a small boat. Since the growth rate is higher than in the fresh water ponds, daily harvesting is carried out from August 91 and a plant density of about 650 gm/sq.meter is maintained.

d. Due to progressive decrease in nutrient levels, the effective *Lemnaceae* production area is only about 60 -70 % of the total area - the yield gradually decreases from about 1000 Kgs/ha/day in the initial reaches to an insignificant level in the last reach. The actual *Lemnaceae* production varied from 118 to 230 tons (wet weight) per ha. year, equivalent to an average production level of 183 tons/ha/year, which is 24% more than the average freshwater pond production. *Lemnaceae* production for 10 months, from June 91 to March 92, is graphically shown in figure 2.

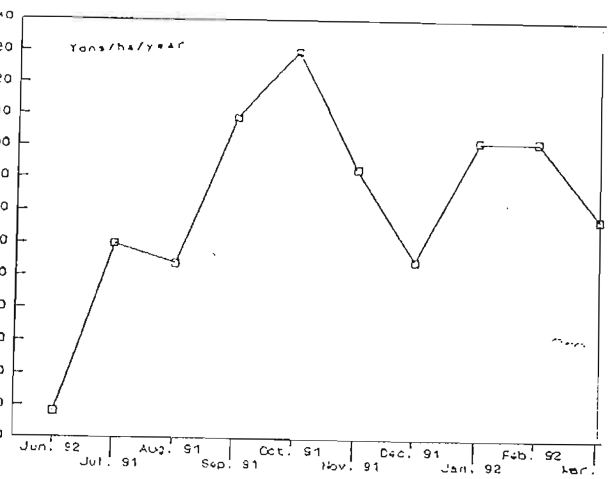

Fig.2: Wastewater Duckweed Production (June 1991 - March 1992)

e. Seasonal effects on plant growth, incidence of plant die off and fungus growth are insignificant. Negligible odor, suppression of algae growth - resulting in less suspended solids in the treated effluent, and absence of mosquito breeding are some of the other features.

f. The average measured wastewater characteristics are given below:

Sampling Points	BOD_5 mg/l	'P' mg/l	Amm.N mg/l	Turbidity NTU
Raw Sewage	229	2.1	36	153
Primary Effluent	124	1.9	30	80
Treated Effluent	5	0.1	0.6	11

As shown above, the plant performance in terms of its treated wastewater quality is comparable to that of a tertiary treatment system.

g. Overall cost benefit analysis: The approximate total O&M costs, including pumping, duckweed harvesting, finger-lings and pond maintenance costs, is TK. 100,000 per year (U.S.$ 1 = TK 38.5 as on 1.5.92). At the established duckweed to fish conversion rate of about 10:1 and at a cost of TK 50 per Kg fish, the gross economic returns are estimated as TK. 900,000 per year. While the above computation did not consider the land value, capital costs, interest rates etc., it does indicate the potential cost recovery prospect.

Conclusion

The *Lemnaceae* based wastewater treatment system successfully meets the challenge posed in developing countries for environmental protection, resource recovery and water conservation. However before replicating Bangladesh's experience it is necessary to first evaluate the experience through extensive performance monitoring. Such an evaluation will not only generate reliable design parameters (given below) but also provide answers to the following health & hygiene related issues:

a. Optimal BOD and hydraulic loading rates; Pretreatment requirements; Optimum hydraulic profile; Sludge accumulation rates; Evapo-transpiration losses; and

b. Transfer of pathogens with harvested duckweed; Health effects on laborers harvesting/handling *Lemnaceae*; Contamination of fish by pathogens; Entry of persistent pollutants like heavy metals in the food chain through the fish fed by *Lemnaceae*;

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