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"WATER HYACINTHS FOR THE CLARIFICATION OF WASTEWATER AND THE PRODUCTION OF ENERGY" by VILLAMIL, R.G, CLEMENTS, A.MCB. BLOCK, ENG, P. WEIL, ENG, A, GARCIA, ENG, W. LAO, L.T. ROSA, F. SANTOS at the CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, TERRESTRIAL ECOLOGY DIVISION, CAPARRA HEIGHTS STATION, SAN JUAN, P.R. 00935 and the PUERTO RICO AQUEDUCTS AND SEWERS AUTHORITY, LONG TERM PLANNING DEPARTMENT, SAN JUAN, PUERTO RICO 00916

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"WATER HYACINTHS FOR THE CLARIFICATION OF WASTEWATER AND THE PRODUCTION OF ENERGY" by J. Villamil, R.G, Clements, A.McB, Block, Eng. P. Weil, Eng. A. Garcia, Eng. W. Lao, L.I. Rosa, F. Santos at the Center for Energy and Environment Research, Terrestrial Ecology Division, Caparra Heights Station, San Juan, PR, 00935 and the Puerto Rico Aqueducts and Sewers Authority, LONG TERM PLANNING DEPARTMENT, San Juan, PR, 00916

ABSTRACT: Water hyacinth (Eichhornia crassipes) (Mart) Solms) has been proposed by several authors as a nutrient scavenger plant for the improvement of water quality in eutrophied water and wastewater. With its high productivity, the water hyacinths, if properly managed, could be used for a wastewater tertiary treatment and as a quickly renewable source of biomass for conversion to methane. This work presents the conceptual and engineering design of the total utilization of the hyacinth as a bio-filter in a new prototype of tertiary treatment plant which could be energy self-sufficient.

2: The system has been designed for the domestic and industrial reuse of wastewater and it...

The text incorporates energy-conservative features such as the conversion of waste sludge to compost, the utilization of solar and wind power for lagoon development, and some new concepts in sanitary engineering.

INTRODUCTION

Since its introduction in Puerto Rico, the water hyacinth, Eichhornia crassipes, has evolved from a floral curiosity to a nuisance and pest in waterways. Much effort and money have been invested in eradicating this aquatic vascular plant. However, due to its capacity to reproduce vegetatively, the results have not been satisfactory.

Penfound and Earle (1948) stated that several investigators believed the hyacinth problem could be solved if a commercial use were available. However, they agreed with Bucknam (1920), who asserted that "no commercial utilization of the hyacinth on any scale was likely to be a factor in the campaign for eradication or control".

Bock (1970) concluded "that until control methods are more effective than those being used today or until some economic use can be made of the plants, water hyacinths will continue to increase their wide distribution". Thus, most of the literature on water hyacinths has focused on control measures.

Today, the role of the water hyacinth has changed from being a nuisance plant into a promising solution for the future. Several authors have proposed using hyacinths for a wide variety of applications. Some have proposed using the hyacinth as a nutrient and contaminant scavenger for sewage and industrial effluents clarification (Steward, 1970; Haller, 1970; Boyd, 1970; Calvin, 1976; Denton, 1970; Dinges, 1976; Dunigham, 1974; and Wolverton, 1975, 1976, 1978).

Others have proposed and tested the water hyacinth's high productivity as a source of biomass for conversion to methane by anaerobic digestion. Hyacinths have also been proposed as cattle feed (Chatterjee, 1938; Baldwin, 1975; Combs, 1970). The increase in the Puerto Rican population has created many strains on services provided by the Commonwealth.

Government. The concentration of population in cities creates an ever-increasing volume of sewage. This necessitates the augmentation of the capacity of existing primary and secondary wastewater treatment plants and requires the construction of new ones. The complex worldwide energy outlook, combined with Puerto Rico's complete dependence on imported oil for its electrical energy generation, are factors that tend to discourage the planning and design of energy-intensive tertiary treatment systems. An energy-conservative system capable of meeting U.S.E.P.A. effluent quality standards projected for 1985 would save operation and maintenance costs and encounter less resistance to initial investment by public agencies, municipal treatment corporations, and the industrial sector. This report presents the results of the first research phase towards the total utilization of the water hyacinth. The cultivation is directed towards energy-conservative approaches to water treatment including wastewater clarification, production of sludge compost, methane production, and using relatively new conceptual and engineering designs. The project is presently supported by CEER's Research Institutional Program, working in close cooperation with Puerto Rico's Aqueducts and Sewers Authority Water Hyacinths Research Group, supported by PRASA Institutional Funds.

Methods

A realistic optimal design/operation for a hyacinth treatment system cannot be established before ecological, public health considerations, legal aspects, and treatment efficiency parameters are examined. A substantial research effort was required to resolve these questions. The research needs quoted in Table 1 are directly from Robinson et al., 1976. Our research effort has followed Robinson's research priorities. The ecological and clarification performance of the hyacinth association has been studied using a retention pools system, constructed at El Conquistador Secondary Treatment Plant located in Bo. Carrafzo, Trujillo Alto (Figure 1).

"The system consisted of fifteen plastic-lined pools equipped with an inflow and outflow system

(Fig. 2 and 3). The growth medium for the hyacinths was secondary treated effluent, pumped from the plant chlorination chamber on a 24-hour basis. The objectives of the initial studies were to measure the plant growth rate, the hyacinth biomass doubling time, the plant tissue water percent composition, and the relationship between effluent retention time and plant growth rate.

Three hundred juvenile plants (ranging from 100 g to 450 g) were harvested from Lake Carrefzo for use in these experiments. Five treatments, with three replicas of each, were applied to the plants for the growth rate study. The treatment consisted of exposing a known number of plants to five different retention times: one day, two days, four days, eight days, and sixteen days, respectively.

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FIGURE our 2 RETENTION POOLS SYSTEM LAYOUT

The plants were assigned randomly to their pool location, retention time, harvest schedule, and grid location in the pool. A nylon cord grid positioned over the pool provided a fixed position and the same effective surface area for growth to each of the plants (Fig. 4). Plants were physically attached to the intersection lines of the grid using nylon cord. The calculation of the daily incremental constant was made using the following equation. «(ee * in which Le Ws first weight ip second weight t = number of days between weighing x daily incremental constant

Kjeldahl nitrogen, total suspended solids, and total phosphorus measurements of the effluent from each pool were performed according to APHA Standard Methods 13th edition. Effluent dissolved oxygen measurements were performed using a YSI dissolved oxygen meter. The effluent pH was measured by means of a Corning pH meter.

RESULTS

The mean incremental constant was determined to be 0.290. Thus,"

growth rate makes it a great candidate for wastewater treatment.

On average, the hyacinth biomass doubles every seven days. The biomass doubling time is a crucial parameter for the operation of a hyacinth wastewater treatment plant.

Figure 3. Retention Pool Detail
Figure 4. Grid Used Over The Retention Pools During The Growth Rate Studies

To maintain a high (logarithmic type) growth rate, juvenile plants with a corresponding high metabolic rate are preferred. A harvesting program has to take into account the biomass doubling time.

The plant water content was determined by drying the harvested hyacinths at 70°C for 3 days, after weighing them drip dried for five minutes. The mean dry weight percent of the plant was found to be 5.2%.

A direct linear relationship was found between the wet weight and the dry weight of the hyacinths. The regression equation of this relationship could be used to determine the dry weight of any particular wet weighed plant:

$$Y = 0.05129 + 0.3130\,x$$

where:

Y= dry weight
X = wet weight

No significant relationship was found between the water retention time and the growth rate of the water hyacinth. Likely, the high nutrient content of the wastewater provided as the growth media was the reason for the non-observance of significant differences between the pools and the treatments.

The productivity study took place during the months of January and February, 1979, which are the months of low solar radiation in Puerto Rico. The mean productivity in terms of wet weight was 216.39 g/m^2/day. The productivity per hectare on a wet weight basis was determined to be 2163.9 Kg/ha/day or on dry weight 108.195 Kg/ Ha/day based on a 5.2% dry weight composition.

$$Y= 0.05129 + 0.3130\,x$$

Figure 6: Linear regression between wet weight and dry weight of Eichhornia crassipes. Plants were dried at 70°C for three days.

The hyacinth's high growth rate makes it a great candidate for wastewater treatment.

Productivity provides an exceptional amount of biomass for use in various conversion options, such as compost, biomass conversion to methane, fiber, and cattle feed production.

Water Clarification Performance: The wastewater clarification performance of the hyacinth lagoon association is not solely due to the hyacinth metabolism. The nutrient and contaminant removal from the wastewater is affected by various processes, which are as follows:

1. Hyacinth metabolism.
2. Other aquatic vascular plant metabolism, such as Lemma and Pistia.
3. Metabolism of algae and other phytoplankton in the water column.
4. Trophic relationships in the hyacinth lagoon.
5. Recycling of nutrients in the suspended and settled solids by bacteria and other detritivores.
6. Physical hold-up in the surface tissue of the organisms in the lagoon.

The biological interactions responsible for the nutrient contaminant removal are represented in Figure 6. This figure includes the energy and nutrient flows using the standard notation of Odum (1967) for the hyacinth association. Other symbols used have the following definitions:

O - Dissolved oxygen in the water.

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Figure 6: Biological Interactions in the Hyacinth Lagoon Association.

14 Ng - Nitrogen from the influent.
N - Nitrogen in the system water.
Po - Phosphorus from the influent.
P - Phosphorus in the system water.
My - Trace metals from the influent.
TH - Trace metals in the system water.
D - Detritus or settled solids.
OU - Organic matter exported from the lagoon system.
1 - Primary consumers: insects, amphibian larvae, protozoans, annelids, molluscs, and others.
2 - Secondary consumers: insects, amphibians, lizards, and others.
3 - Tertiary consumers: birds, amphibians, lizards, and others.

The removal of nutrients in the hyacinth-based system is mostly accomplished by the system's primary productivity. Further removal and fixing of nutrients take place at various other trophic levels and with their interactions with consumers from...

Outside of the lagoon system, algae photosynthesis in the water column could provide surplus dissolved oxygen. This, in turn, would be available for aerobic bacteria and lagoon zooplankton. Consequently, this would promote a greater removal and oxidation of the suspended and settled solids in the lagoon. The nutrient and contaminant removal processes in the lagoon association could be accelerated and maximized by:

1. Adjusting the pH of the nutrient media (wastewater).
2. Increasing primary productivity (hyacinths) by buffering at pH 7.0 (Chadwick and Obeid, 1966).
3. Maintaining a high growth and metabolic rate through a harvesting program.
4. Increasing the dissolved oxygen levels in the water.
5. Physically extracting and collecting the precipitated solids.
6. Implementing post-lagoon chemical precipitation and collection of contaminants.
7. Enhancing contact of the wastewater with ambient ultraviolet light and ozone through a water station.
8. Filtering the final effluent.

The water clarification performance of the hyacinth association treatment is promising. A mean 95% reduction of total N has been obtained from a concentration of 30.4 mg/l to 0.05 mg/l. Phosphorus removal was 25% from 1.12 mg/L to 0.84 mg/L. Additional treatment will be needed for maximum phosphate removal. A 90% removal of total suspended solids was accomplished, from a concentration of 43.28 mg/l to 0.48 mg/l.

The average dissolved oxygen concentration in the effluent of the pools was 5.61 ppm, compared to 3.0 ppm in the secondary treatment plant effluent. On average, the hyacinth system increased the dissolved oxygen concentration in the wastewater by 2.61 ppm.

The pH in the lagoon system was 6.60, compared to 6.52 for the secondary treated effluent. The BOD5 levels in the hyacinth system met the U.S. EPA standards, with an average of 4.2 mg/l. In contrast, the BOD5 in the secondary effluent was... (text ends abruptly)

The text is slightly lower than those of the hyacinth lagoons. One possible reason for this was the high algae population in the pools.

Chapter 16: WATER HYACINTH-BASED TREATMENT SYSTEM

The PRASA Research Group on Water Hyacinths has collaborated with CEER for the preliminary conceptual and engineering design of several alternatives of a water hyacinth based system. A water recycle or reuse system for domestic applications based on water hyacinths is presented in Figure 7. Before the secondary treated water enters the hyacinth lagoon system, it will be aerated by two means, 1) wind powered aerator, and 2) cascade aerator (See Figures 8 and 9). These two systems could provide a very high dissolved oxygen content to the lagoon, they will provide enough dissolved oxygen to support an extensive association of aquatic fauna which will further remove nutrients from the water.

Light vents or passages through the water column will be provided at the water level using floating frames to prevent hyacinths from fully covering the water surface (See Figures 8 and 9). This will permit increased algal growth and improved nutrient removal as well as a higher dissolved oxygen content, product of algal photosynthesis. The expected high dissolved oxygen content will provide a less suitable environment for mosquito larvae development than currently employed facultative lagoons.

Two hyacinth lagoons connected in series and with water recirculation from the second lagoon to the first are also proposed. This configuration will provide a dilution factor for a decreased nutrient load and contaminants (See Figure 7). After the water has passed through the lagoon system, it will be flocculated with lime. The lime flocculation serves as an additional treatment for phosphorus and for an anticipated 99% removal of viruses and bacteria (Grabow, 1978).

Chapter 17: [Title not provided in the original text]

Chapter 18: [Title not provided in the original text]

Note: The text after the third page break is unclear and seems to be fragmented. It might be helpful if you could provide a clearer version of this text.

The text appears to be a mixture of different parts of a document and contains some unreadable or irrelevant content. Here's an attempt to clean it up:

Section 19: In our system, supernatant from the flocculation process will pass through a sand filter and then to a chlorination chamber (Fig. 10).

Section 20: SYSTEM ENERGY GENERATION

It is proposed that hyacinths from the lagoon be harvested every seven days by means of a harvester machine (Figure 11) located at the end of each hyacinth lagoon. The harvested plants may be used in two ways: for sludge compost as enrichment and bulking agent and for biomass conversion to methane after combining with sludge.

Previous investigations into the production of methane from the bioconversion of the water hyacinth have been conducted by Wolverton, 1975 and Lecuyer, 1976. Wolverton, 1975, conducted hyacinth fermentation studies using 3 liter Erlenmeyer flasks at temperatures ranging from 25°C ± 5°C to 36°C using both chopped hyacinths. There were no significant differences between the methane yields of chopped and blended hyacinths. The chopped water hyacinths produced 11.0 and 6.4 ml. methane per gram wet weight as compared with production of 7.9 ml. methane per wet gram weight of the blended hyacinths. All fermentation units were seeded with already decomposed hyacinth plants.

Temperature played an important role in the rate of bio-gas and methane production. The time lag between the production of biogas and the production of methane gas was reduced from an average of eight days for those maintained at 25°C + 5°C to approximately one day for those incubated at 36°C. The methane content of the total bio-gas produced in the experiment at 36°C was 69.2%. This percent methane was higher than the average methane content of 59.9% for the experiments conducted at room temperature.

Section 22: Lecuyer, 1976, working on a commercial basis reported a bio-gas...

[The rest of the text is unreadable or irrelevant and has been omitted.]

The text is about the production rate of 6 ft3/lb of dry hyacinth, based on a productivity of 373.2 Kg dry/ha/day. A biogas containing 60% CH_4 and 40% CO_2, produced at a rate of 600 Btu/Scf, was upgraded by the Benfield scrubbing process to PQG (1,000 Btu/Scf) by removing the CO_2. The total production of the plant was set at 392 million Scf/day of biogas. No details were given on the temperature, seeding, or retention time of the fermentation process.

Based on Lecuyer’s (1976) methane production rates of 6 Scf/lb dry hyacinths, the estimated Scf production on the proposed system will be 4,868.78 Scf per day, assuming a dry weight productivity of 2,365.64 lbs/acre/day.

Two lagoons, each of 1.5 acres, are proposed to process 1.0 GD. The total productivity for this area will be 7,096.92 lbs/3 acres/day. The energetic content of one methane Scf is 1,000 BTU, according to Lecuyer (1976). Therefore, the estimated energetic value of the methane expected to be produced from hyacinths will be an average of 4,868,775 BTU/day. In terms of kWh/year, the production will be 155,887.85 kWh/year.

A typical 1.0 MGD trickling filter treatment plant consumes 426,960 kWh/year, while an activated sludge plant uses 505,270 kWh/year for operation. Hyacinths, when solely anaerobically digested, could provide 30.9% of the energy needs of a trickling filter plant and 36.5% of the needs of an activated sludge plant. In the proposed wastewater treatment plant, the sludge and hyacinths will be digested together.

A domestic 1.0 MGD wastewater treatment plant, according to the EPA, produces 2,096 lbs/day of dry solids, from which 723 lbs/day are volatile solids that could be converted into methane. The expected methane yield from the sludge produced from the treatment process will be 10,845.00 Scf, which will provide 6.5 million BTU/day. The methane expected to be produced from the sludge will provide 208,115.7 kWh/year.

Thus, the methane expected to be produced from hyacinths and sludge combined will provide the proposed plant with 364,000.25 kWh.

Per year, the combined mixture of hyacinth and sludge batches could provide 85.25% of the total energetic needs of a typical 1 NGD trickling filter plant and 72% of the needs of an activated sludge plant. This combined batch could make the proposed treatment plant almost self-sufficient in terms of energy. In the proposed system, the digestor is heated by solar radiation, and the digestion tanks are expected to be constructed utilizing the most cost-effective material. The mixture to be digested will be periodically mixed by bubbling compressed CH_4 along a pipe on the bottom of the tank. The heating and mixing of the digestor batch should allow methane production in even higher yields than those observed by Wolverton (1975) and Lecuyer (1976).

Two biogas scrubbing systems have been studied for use at the proposed plant. Methane purity and cost of the system will be the two criteria for the implementation of either of the proposed scrubbing systems. The Benfield process is illustrated in Figure 12. This scrubbing process yields high-purity CH_4, but the operation and maintenance of the plant are costly due to the relatively expensive regeneration of Benfield reagent. The steam necessary for the reagent regeneration could be provided by a solar steam generator, which is presently under development at CEER.

A considerably simpler biogas scrubbing process is illustrated on page 25 in Figure 13. This system will be provided with cartridges of iron filings to scrub the hydrogen sulfide (H_2S) and aerosols. The product is expected to be a mix of 60% CH_4 and 30-40% CO_2 (600 BTU/SCF, Lecuyer, 1976) which could still be used in motors with some carburation adjustments. The iron filings cartridges will be regenerated by roasting them using solar radiation (UV). Figure 14 represents the system energy generation diagram. The windmill aerator could be provided with a 2 kW generator.

The generator provides electrical power for some of the equipment. The methane produced from the digestion of hyacinths and sludge will be used for electrical power generation in the proposed system.

Conclusion: While this system is only viable in tropical or sub-tropical climates, it is hoped that innovations in wind and solar utilization will stimulate applications of aerobic and facultative lagooning worldwide. Most of the existing wastewater treatment plants in P.R. could be upgraded to comply with EPA and EQS regulations regarding TSS, BOD, Total N, and Total P by polishing their effluents with water hyacinth lagoons.

Figure 13 depicts iron gas compressors, digestor, and various other components of the system.

The following information is not clearly understandable due to possible errors in text transcription.

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