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WATER HYACINTHS FOR THE CLARIFICATION OF WASTEWATERS AND THE PRODUCTION OF ENERGY

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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. Withits 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 bio-filter in a new prototype of tertiary treatment plant which could be energy self-sufficient.

The system has been designed for the domestic and industrial reuse of wastewater and it incorporates energy-conservative features such a 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 gone from a floral curiosity to a nuisance and pest in waterways. Much effort and money have been spent to eradicate this aquatic vascular plant, but because of its capacity to reproduce vegetatively, the results have not been satisfactory.

Penfound and Earle (1948) stated that several investigators were of the opinion that the hyacinth problem could be solved if a commercial use were available. However, they took the position of Bucknam (1920), 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 been used today or until some economic use can be made of the plants, water hyacinths, will continue to increase its wide distribution". Thus it is not surprising that most of the literature on the water hyacinths has dealt with control measures.

Today, the role of the water hyacinth has changed from a nuisance plant into a promise for the future. Several authors have proposed the use of hyacinths for a wide variety of applications. Some have proposed the use of the hyacinth as a nutrient and contaminant scavenger for the clarification of sewage and industrial effluents (Steward, 1970, Haller, 1970, Boyd, 1970, Calvin, 1976, Denton

1970, Dinges, 1976, Dunningam, 1974 and Wlverton, 1975, 1976, 1978). Others, have proposed and tested the water hyacinth's high productivity as a source of biomass for its conversion to methane by anaerobic digestion. Hyacinths have been also proposed as cattle feed (Chatterjee, 1938 Baldwin, 1975, Combs, 1970).

The increase of the Puerto Rican population has created many strains on services provided by the Commonwealth government. Population concentration in the cities creates an ever-increasing volume of sewage making necessary the augmentation of capacity of existing primary and secondary wastewater treatment plants and requiring the construction of new ones.

The complex worldwide energy outlook coupled with Puerto Rico's complete dependence upon imported oil for her electrical energy generation are factors which tend to discourage 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 and municipal treatment corporations and from the industrial sector.

This report presents the results of the first research phase, toward the total utilization of the water hyacinth. Cultivation is directed toward 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

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 in order 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. Carraízo, Trujillo Alto (Figure 1).

The system consisted of fifteen plastic lined pools provided with an inflow and outflow system (Fig. 2 and 3). The hyacinth growth media was secondary treated effluent, pumped from the plant chlorination chamber on a 24 hrs. basis.

The objectives of the initial studies were to measure the plant growth rate, the hyacinth biomass doubling time, the plant tissue water precent compositon and the relationship between effluent retention time and the plant growth rate.

Three hundred juvenile plants (100 g to 450 g) were harvested from Lake Carraízo 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 exposure of a known number of plants to five different retention times, which were one day, two four, eight, and sixteen days, respectively.

Table 1. Research Needs (From Robinson's et. al., 1976).

Parameters	Mechanisms(s)	Rationale/Comments
1. Ecology of the hyacinth	(a) growth rate/nutrient/location/season	The hyacinth/lagoon interaction is based on nutrient removal efficiency. Unless temporal and spatial efficiency curves can be established, design criteria cannot be evaluated.
	(b) growth/rate/percent cover/harvest rate/location/season	This information must be acquired before alterative disposition schemes (disposal/use schemes) can be costed.
2. Public Health Conderations	(a) Potential for the transmission of Pest to the General Public	The creation of shallow lagoons may result in breeding places for human pests (e.g. mosquitoes).
3. Legal Investigation of Water hyacinth status	Legal opinion of Law Federal and State noxious weed laws will affect municipalities use of hyacinth	Since the hyacinth has been declared a noxious weed, users may be libel for removal or control if hyacinths are introduce into noninfested areas.
3. Treatment efficiency mechanisms.	SS: loading rate; Filtration/Sedimentation/Feedback; Productivity/Harvest Scheme - percent cover/Location/Season.	These relationships must be established before cost-effective design criteria can be calculated. At present, we can only give estimates.
	BOD: (same as above)	
	N: (same as above) NITRIFICATION-DENITRIFICATION	
	P: (same as above)	
4. Phosphorus	Additional treatment mechanisms(s)	Phosphorus removal does not appear to be cost-effective. Additional treatment may be required.
5. Dissolved Oxygen	Additional treatment mechanisms (s)	DO levels in the effluent stream may be below allowable standards. Some additional treatment may be necessary.
6. Lagoon Design	Loading rate; detention time; aerobic/anaerobic depth relationships; rooting depth (microbial substrate) harvesting regime (summarized from 4 above).	System effectiveness is a function of the mechanisms listed for 4 above. Treatment costs can be optimed by lagoon design.
7. Post-harvest use of hyacinth	Materials, oils, chemicals, energy, etc.	Could reduce operating cost.
8. Quality Control for Ongoing Research		The existing design does not seem adequate for SS, BOD, N, P, and DO mechanism clarification.

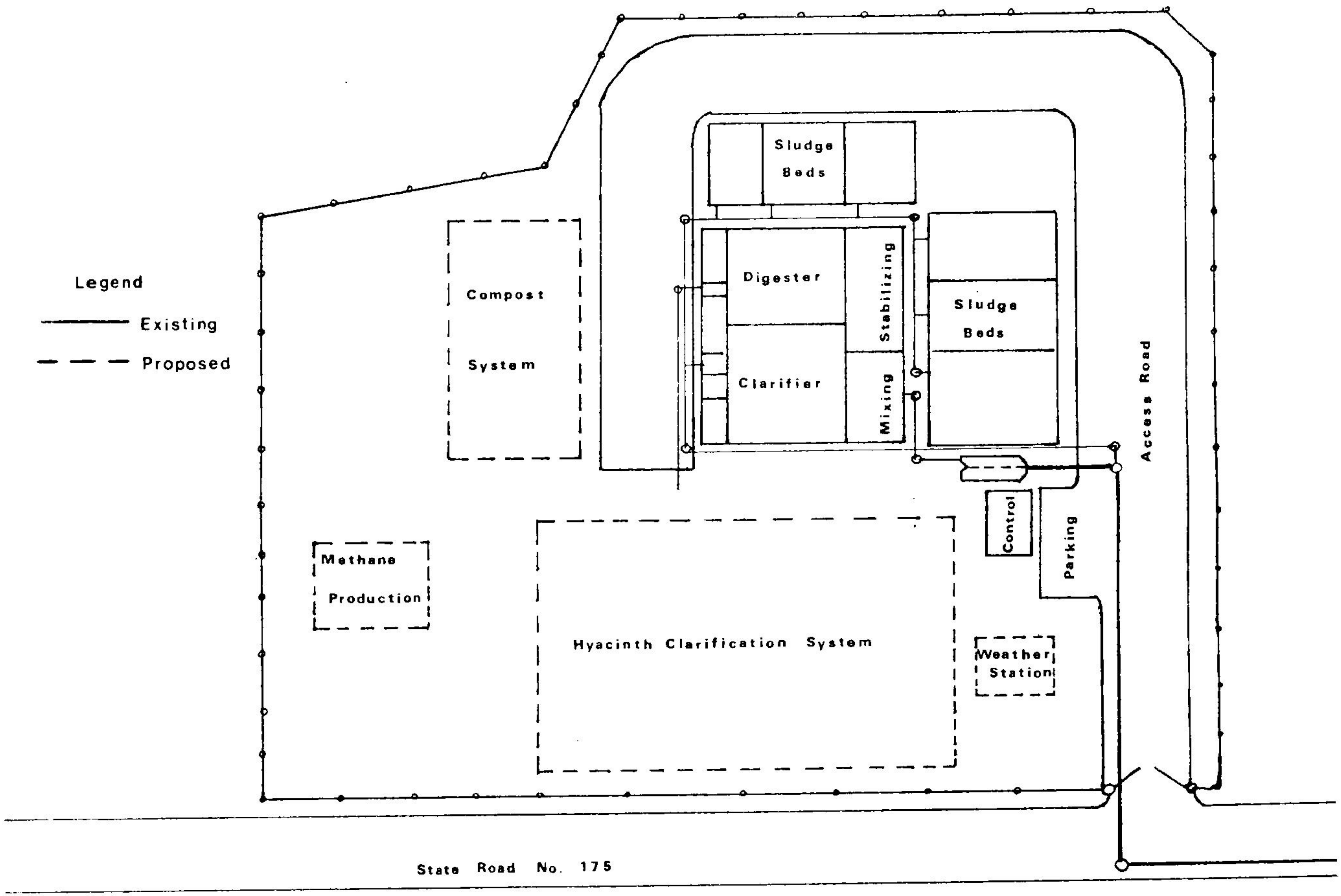


Figure 1 Research Facilities Layout in El Coquistador Tretment Plant.

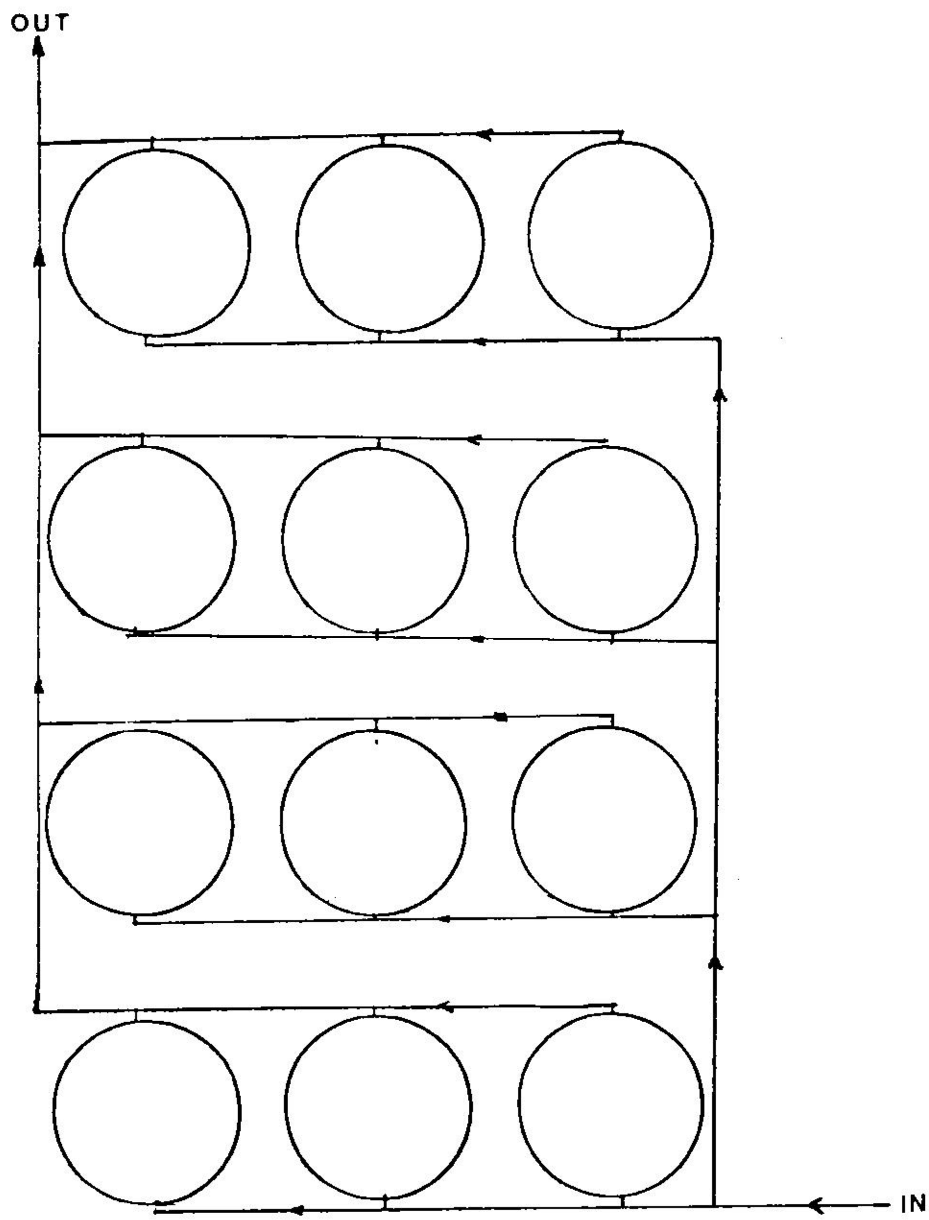


FIGURE 2 RETENTION POOLS SYSTEM LAYOUT

The plants were assigned at random to their pool location, retention time, harvest schedule and grid location in the pool. The 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 intersection lines of the grid using nylon cord.

The calculation of the daily incremental constant was made using the following equation.

$$X = \left(\frac{w_2}{w_1}\right)^{1/t}$$

in which:

W_1 = first weight

W_2 = 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, on the average, the hyacinth biomass doubles every seven days. The biomass doubling time is a very important parameter for the

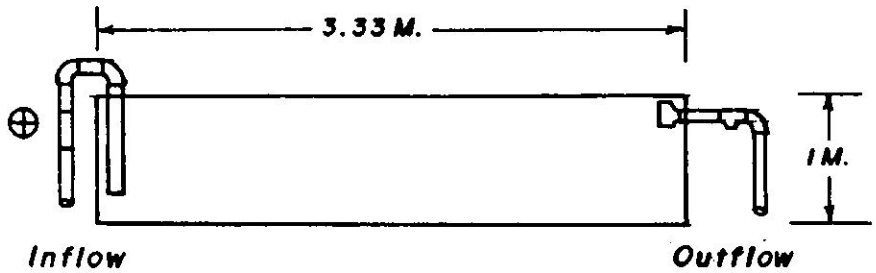


Figure 3. Retention Pool Detail

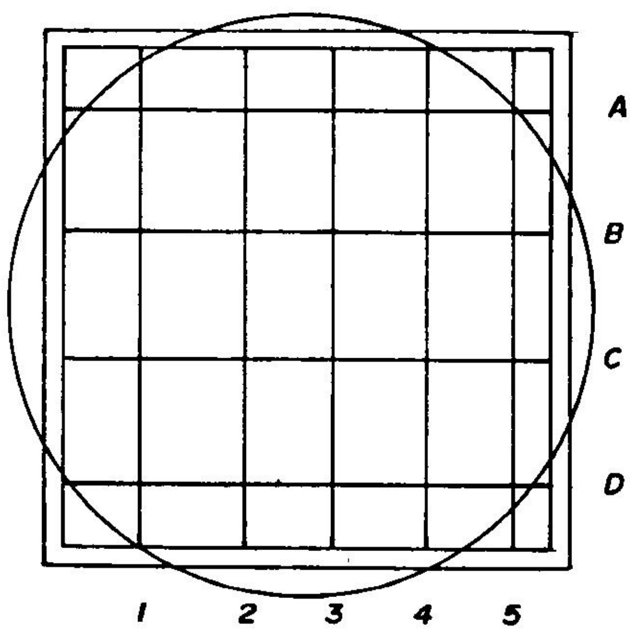


Figure 4. Grid Used Over The Retention Pools During The Growth Rate Studies

operation of a hyacinth wastewater treatment plant. To maintain a high (logarithmic type) growth rate, juvenile plants with a corresponding high metabolic rate are preferred and a harvesting program has to take into consideration 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 (Fig. 5).

The regression equation of this relationship could be used for the determination of the dry weight of any particular wetweighed 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. Probably, 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 Jan. and Feb., 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 a 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. The hyacinth's

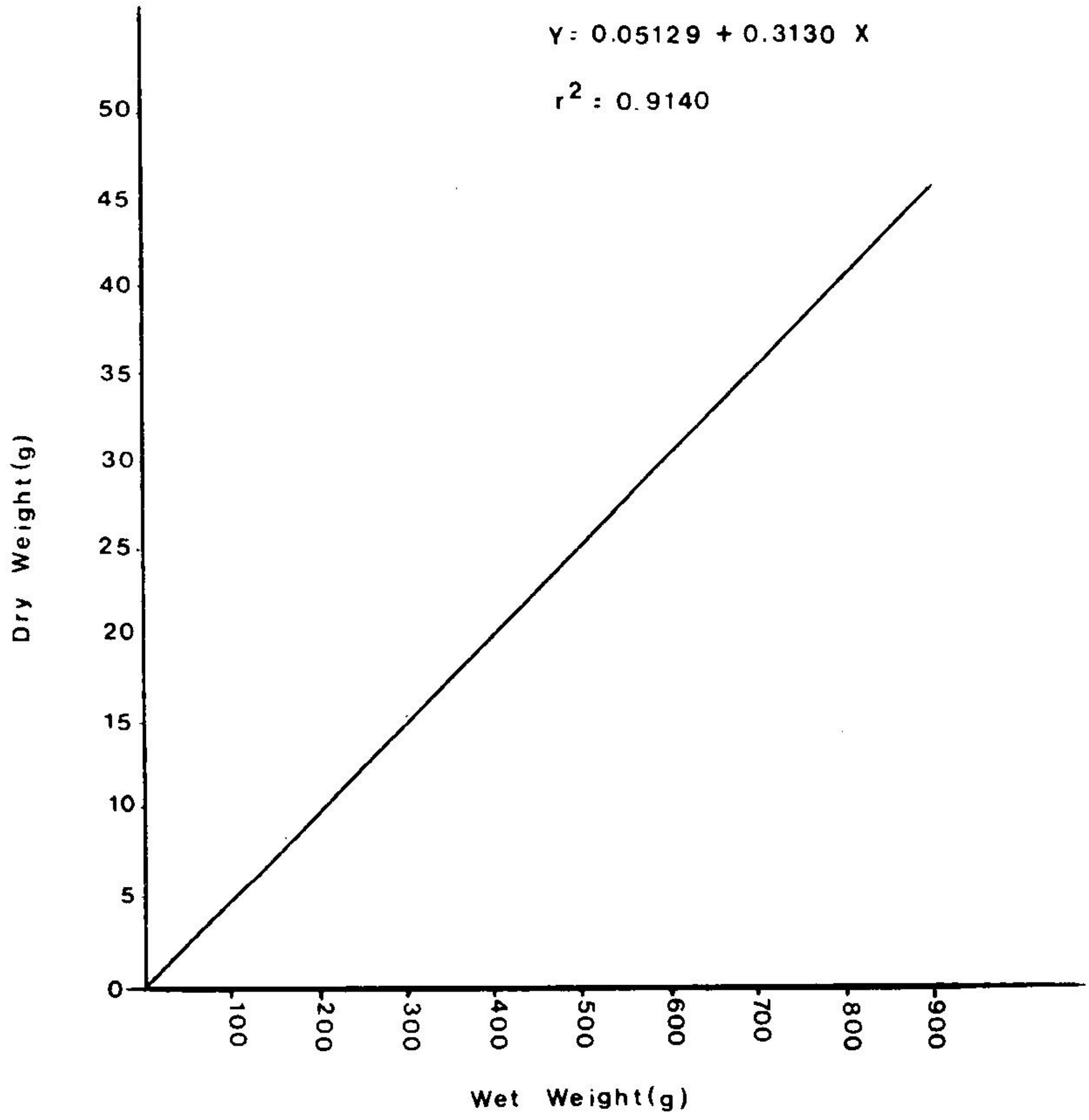


FIGURE 5: Linear regression between wet weight and dry weight of Eichhornia crassipes. Plants were dried at 70°C for three days.

high productivity provides an exceptional amount of biomass for use in various conversion options e.g. compost, biomass conversion to methane, fiber and cattle feed production.

WATER CLARIFICATION PERFORMANCE

The wastewater clarification performance of the hyacinth lagoon association it is not only due solely 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. Recycle of nutrients in the suspended and settled solids by bacteria and other detritovores.
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

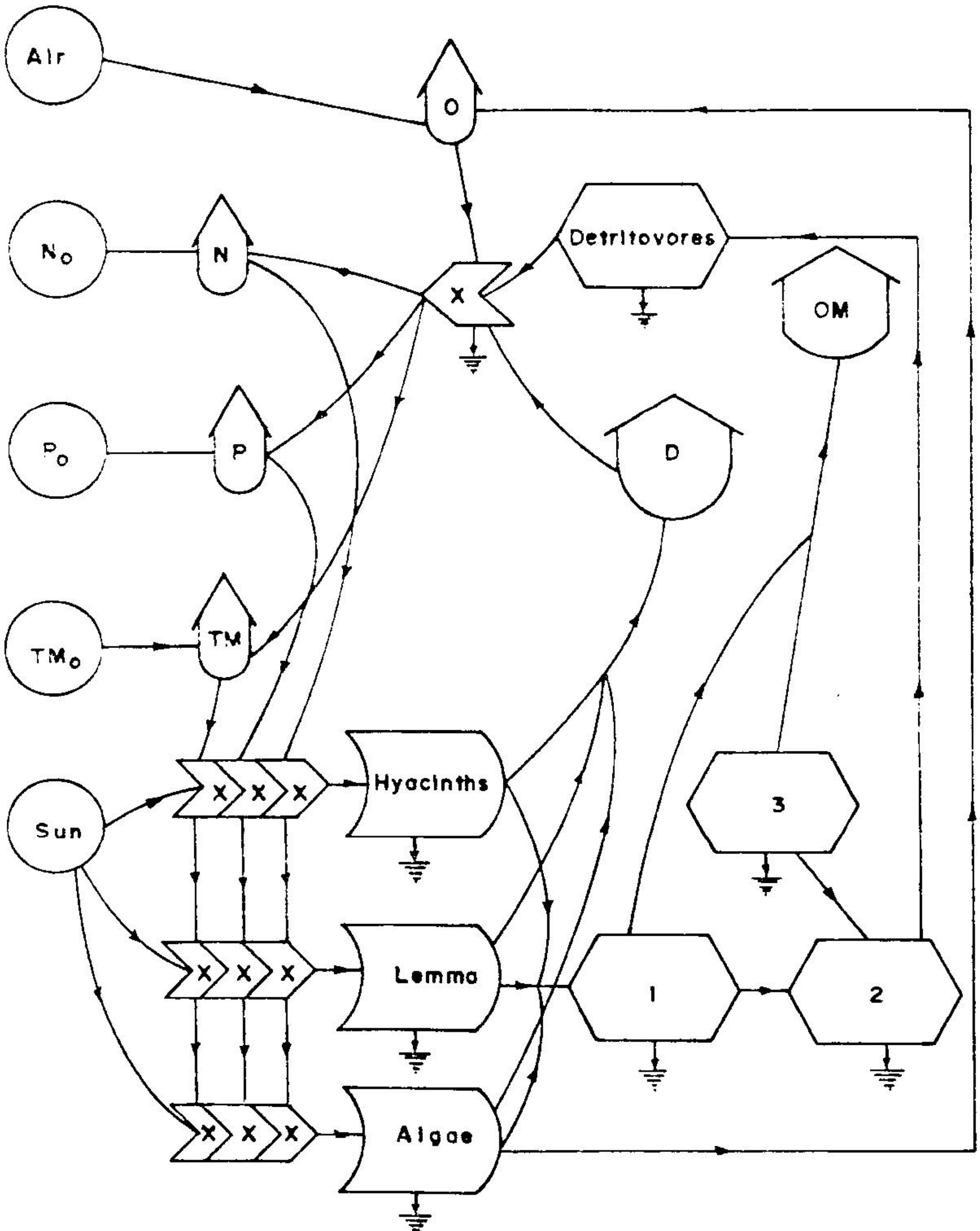


Figure 6: Biological Interactions in the Hyacinth lagunal Association

N_O - Nitrogen from the influent

N - Nitrogen in the system water

P_O - Phosphorus from the influent

P - Phosphorus in the system water

TM_O - Trace metals from the influent

TM - Trace metals in the system water

D - Detritus or settled solids

OM - Organic matter exported from the lagoon system

1 - Primary consumers, insects, amphibian larvae, protozoans, anelids, moluscs 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 primary productivity. Further removal and fixing of nutrients takes place at various other trophic levels and with their interactions with consumers from outside of the lagoon system. Photosynthesis of the algae in the water column would provide surplus dissolved oxygen, which in turn would be available for aerobic bacteria and to the lagoon zooplankton. This in turn will promote a greater removal and oxidation of the suspended and settled solids in the lagoon.

The nutrient and contaminant removal processes in the lagunal association could be accelerated and maximized by:

1. pH, adjustment of the nutrient media (wastewater).
2. Thus, the primary productivity (hyacinths) will be higher by buffering at pH 7.0 (Chadwick and Obeid, 1966).

3. Keeping a high growth and metabolic rate by means of a harvesting program.
4. Increasing the dissolved oxygen levels of the water.
5. Physical extraction and collection of the precipitated solids.
6. Post-lagoon chemical precipitation and collection of contaminants.
7. More contact of the wastewater with the ambient ultraviolet light and ozone, by means of water agitation.
8. Filtration of the final effluent.

The water clarification performance of the hyacinth association treatment is very promising. A mean 95% reduction of total N has been obtained, from a concentration of 30.4 mg/1 to 0.05 mg/1. The removal of total phosphorus accomplished was 25% from 1.12 mg/1 to 0.84 mg/1. Additional treatment will be needed for a maximum removal of phosphate. A 90% removal of total suspended solids was accomplished, from a concentration of 43.28 mg/1 to 0.48 mg/1.

The average dissolved oxygen concentration in the effluent of the pools was 5.61 ppm, the average dissolved oxygen in the effluent of the secondary treatment plant was 3.0 ppm. On the 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.

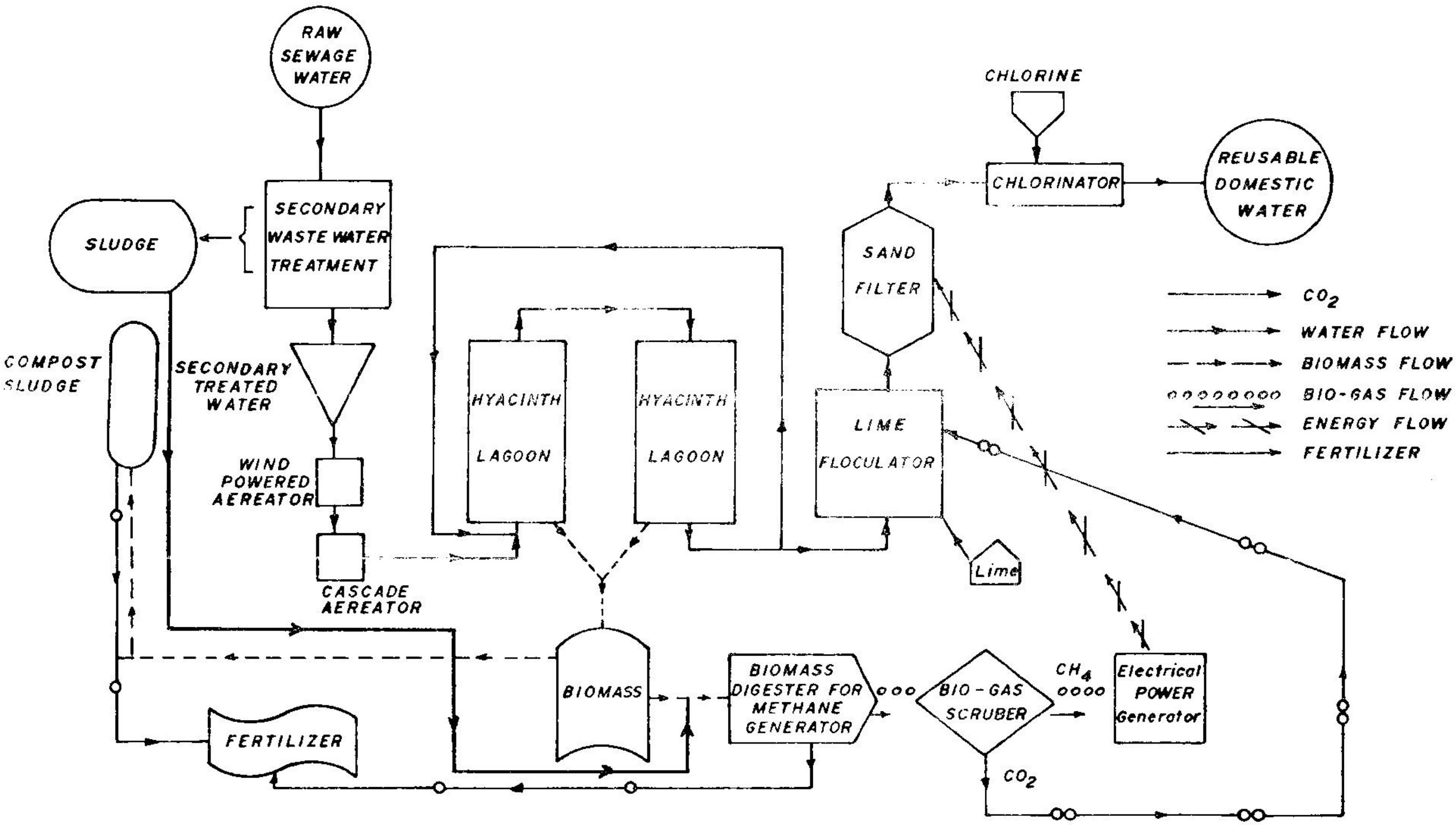
The BOD_5 levels in the hyacinth system proved to be within the U.S. EPA standards. The average BOD_5 in the hyacinth system was 4.2 mg/1. The BOD_5 in the secondary effluent was slightly lower than those of the hyacinth lagoons. One possible reason for this was the high algae population in the pools.

WATER HYACINTH-BASED TREATMENT SYSTEM

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 on 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 (Figure 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 (Figure 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 provided 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 (Figure 7). After the water has passed 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 virus and bacteria. (Grabow, 1978). After

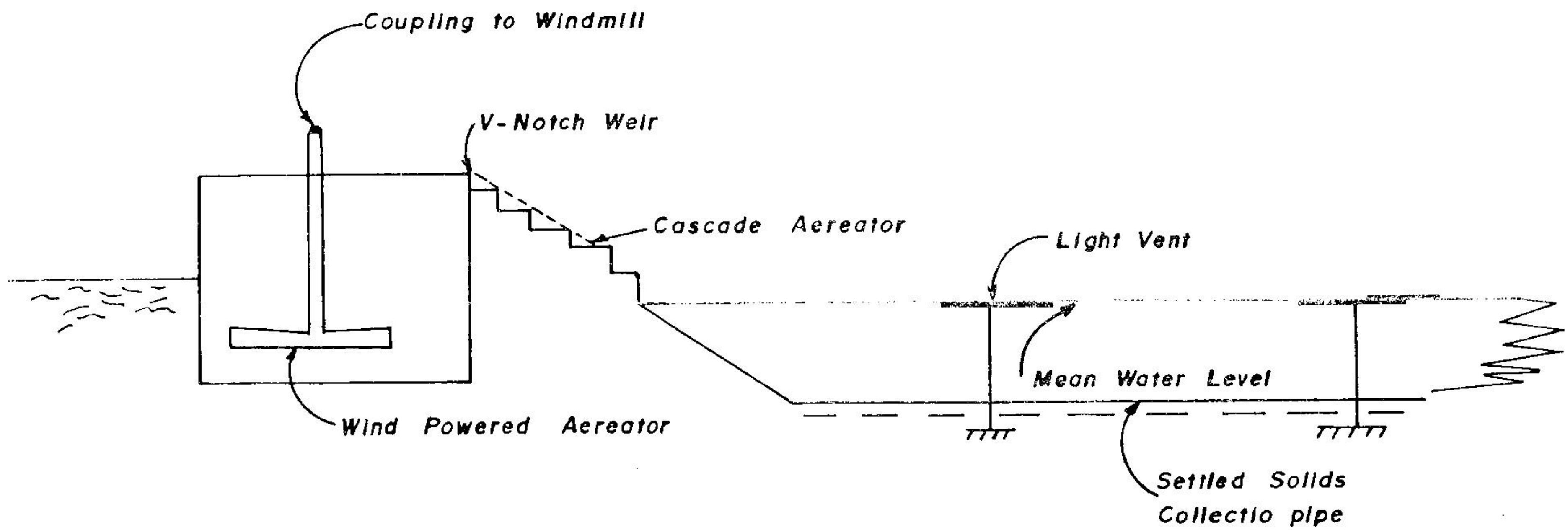


Water Recycle System Based on Water Hyacinths

FIGURE 7

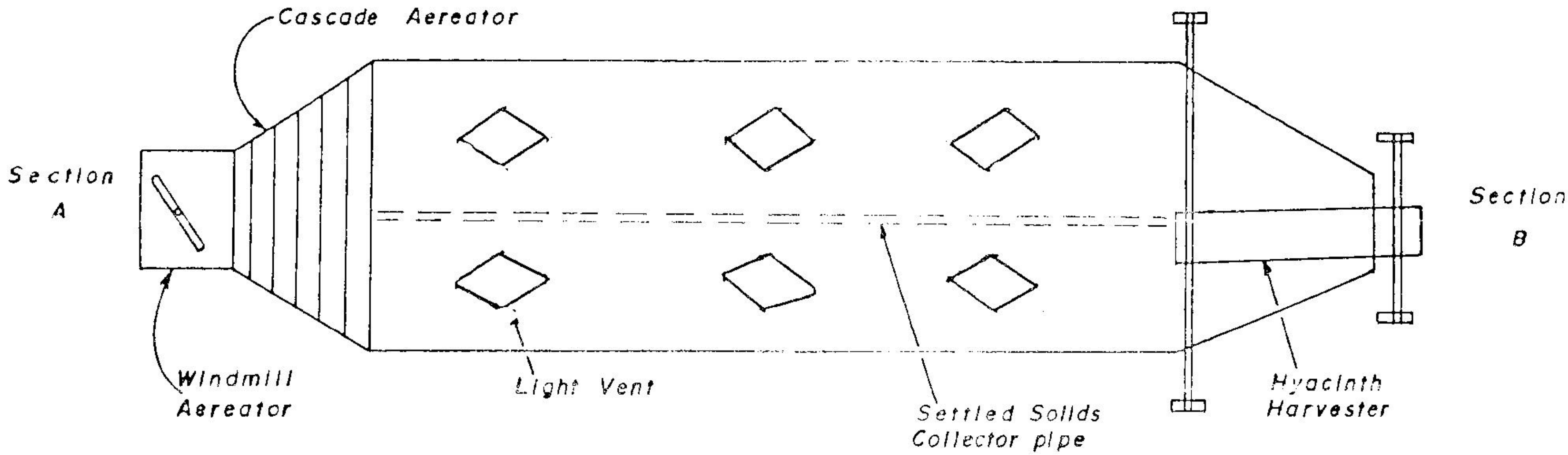
SIDE VIEW, ANTERIOR SECTION, PROPOSED HYACINTH LAGOON

FIGURE 8

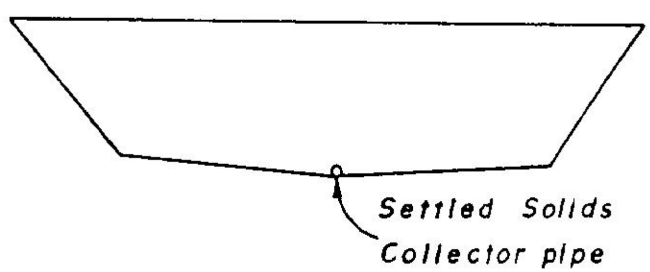


HYACINTH LAGOON TOP VIEW

FIGURE 9



Front View (Mid Section)



flocculation the supernatant will pass through a sand filter and then to a chlorination chamber (Fig. 10).

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 investigation 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° 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.

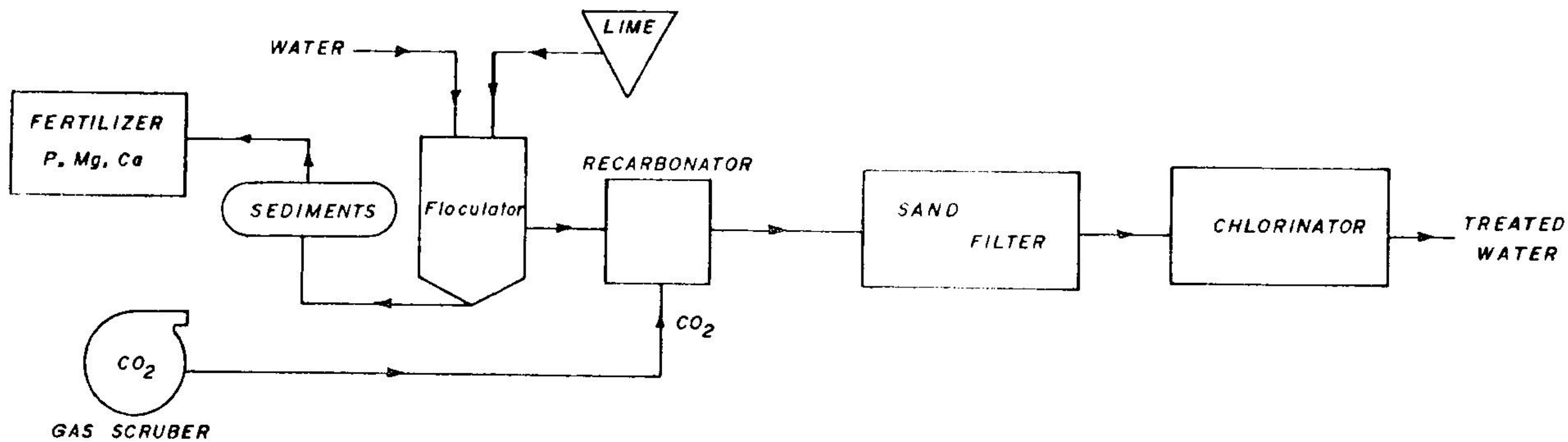
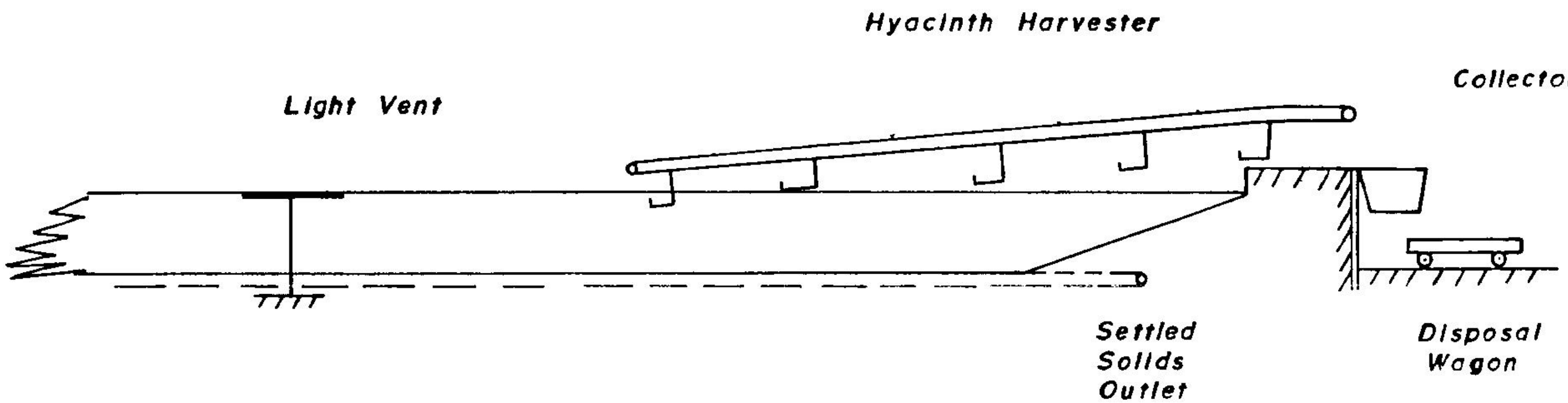


FIGURE 10
Final Water Treatment System

SIDE VIEW, POSTERIOR SECTION, PROPOSED HYACINTH LAGOON

FIGURE 11



Lecuyer, 1976, working on a commercial basis reported a bio-gas production rate of 6 ft^3./lb of dry hyacinth based upon a productivity of 373.2 Kg dry/Ha/day. The 600 Btu/Scf bio-gas, containing 60% CH_4 and 40% CO_2 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 bio-gas. No details were given on temperature, seeding or retention time of the fermentation process.

Based upon 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 weitht productivity of 2,365.64 lbs/acre/day. Two lagoons of 1.5 acre each, are proposed to be used to process 1.0 MGD, 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. Thus, 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 Kw hr/year the production will be 155,887.85 Kw hr/year. A typical 1.0 MGD tricklin filter treatment plant consumes 426,960 Kw hr/year, an activated sludge plant uses 505,270 Kw hr/year for its operation. Hyacinths solely anaerobically digested could provide 30.9% of the energetic needs of an 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 EPA, produces 2,096 lbs/day of dry solids from which 723 lbs/day are volatile solids which in turn could be converted into methane. The expected methane yield from the sludge produced from the treatment process will be 10,845.00 Scf this in turn will provide 6.5 million BTU/day. The methane expected to be produced from the sludge will provide 208,115.7 Kw hr/year. Thus, the methane expected to be produced from hyacinths and sludge combined will provide the proposed plant with 364,000.25 Kw hr/year. The combined mixture of hyacinth and sludge batches could provide 85.25% of the total energetic needs of a typical 1 MGD trickling filter plant and 72% of the needs of an activated sludge plant. The combined batch could make the proposed treatment plant almost energy self sufficient.

In the proposed system, the digestor is heated by solar radiation, the proposed digestion tanks are expected to be constructed utilizing the most cost effective material. The mixture to be digested will be periodically mixed by bubbling compresed CH_4 along a pipe on the bottom of the tank. The heating and mixing of the digestor batch should allow a 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 CH_4 of high purity, 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 in

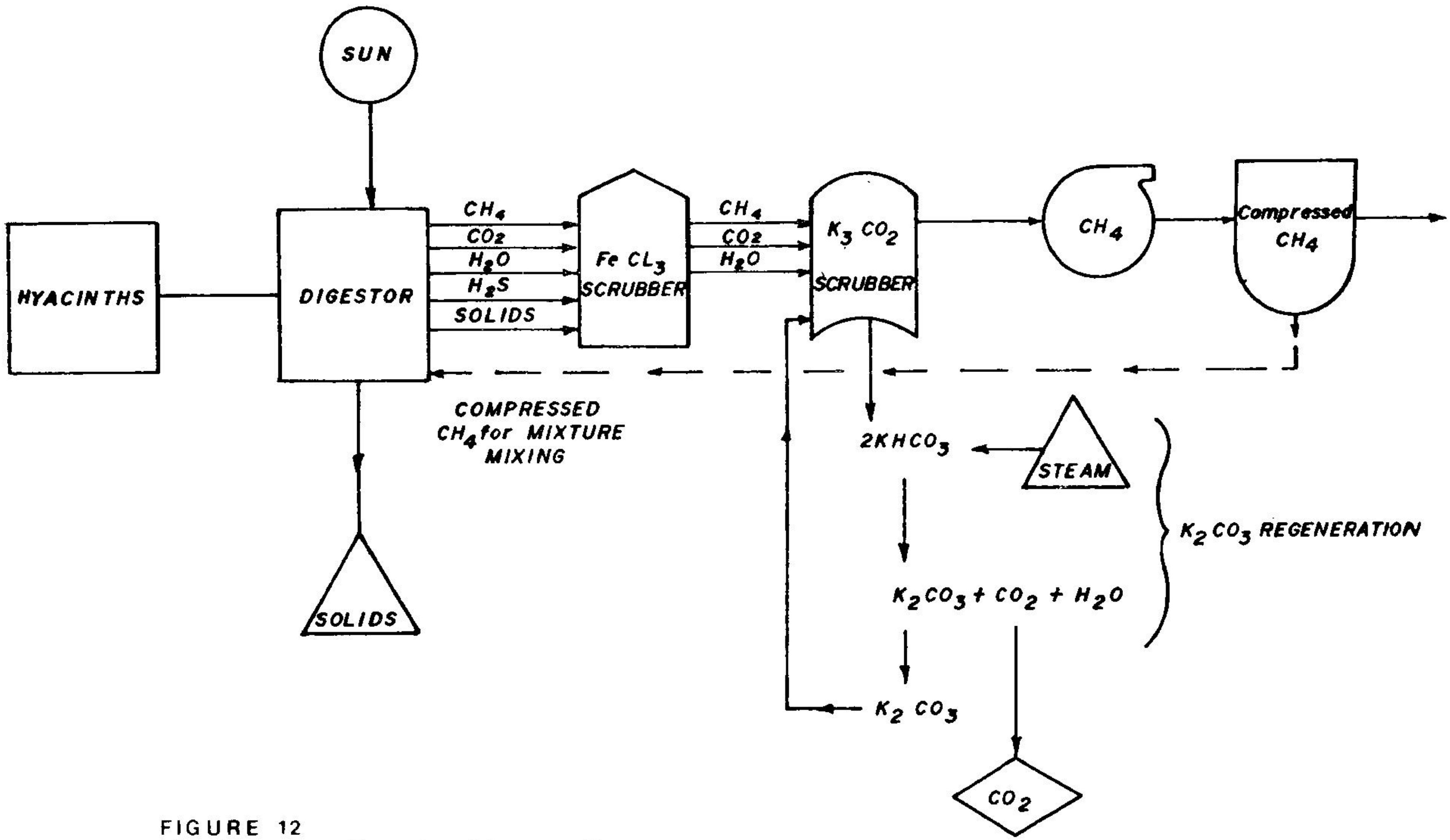


FIGURE 12
Methane Production Process

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 still could be used in motors with some carburation adjustments. The iron filings cartridges will be regenerated by roasting them using solar radiation (u.v.).

Figure 14 represents the system energy generation diagram. The wind mill aerator could be provided with a 2 kw generator to provide electrical power for some of the equipment. The methane produced from the digestion of hyacinths and sludge will be useful for electrical power generation in the proposed system.

CONCLUSION

(1) While this system is totally viable in tropical or sub-tropical climates only, it is hoped that innovations with respect to wind and solar utilization will help stimulate applications of aerobic and facultative lagooning world-wide.

(2) Most of the existing wastewater treatment plants in P. R. could be upgraded, polishing their effluents with water hyacinth lagoons to comply with EPA and EQB regulations with regard to TSS, BOD, Total N and Total P.

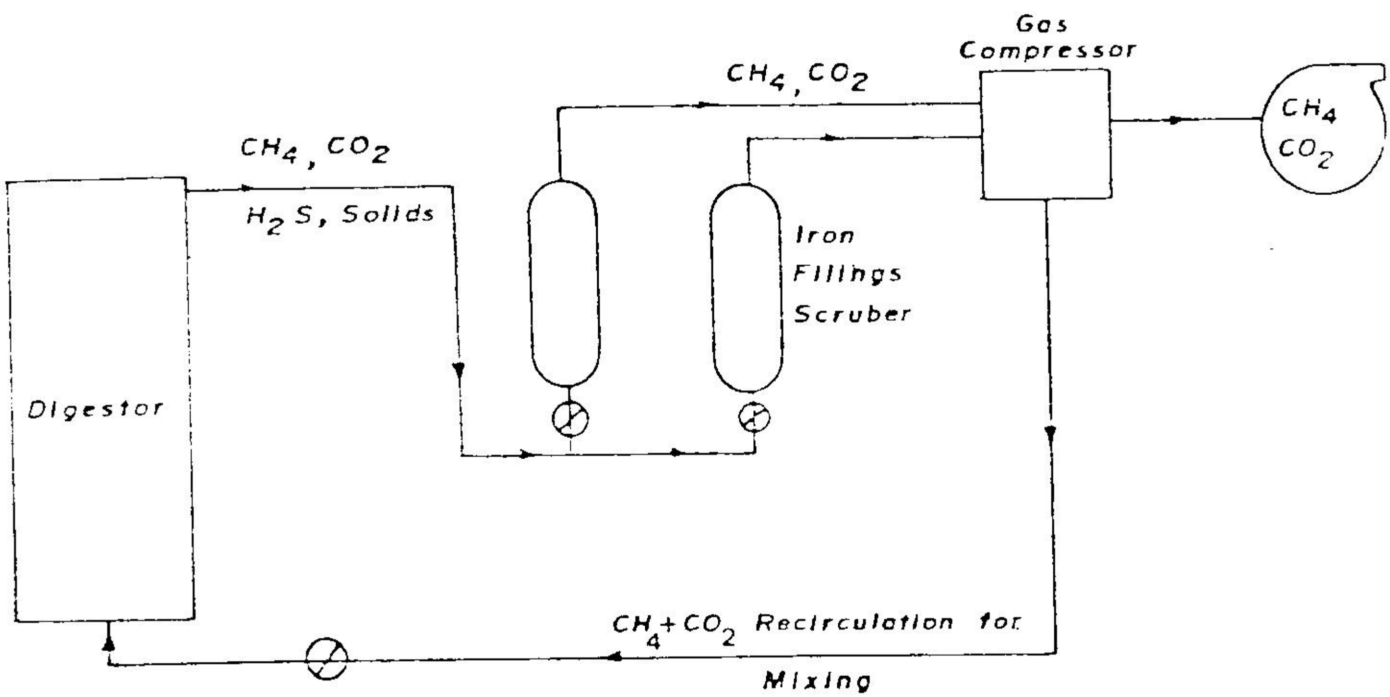


FIGURE 13. IRON FILINGS SCRUBBER

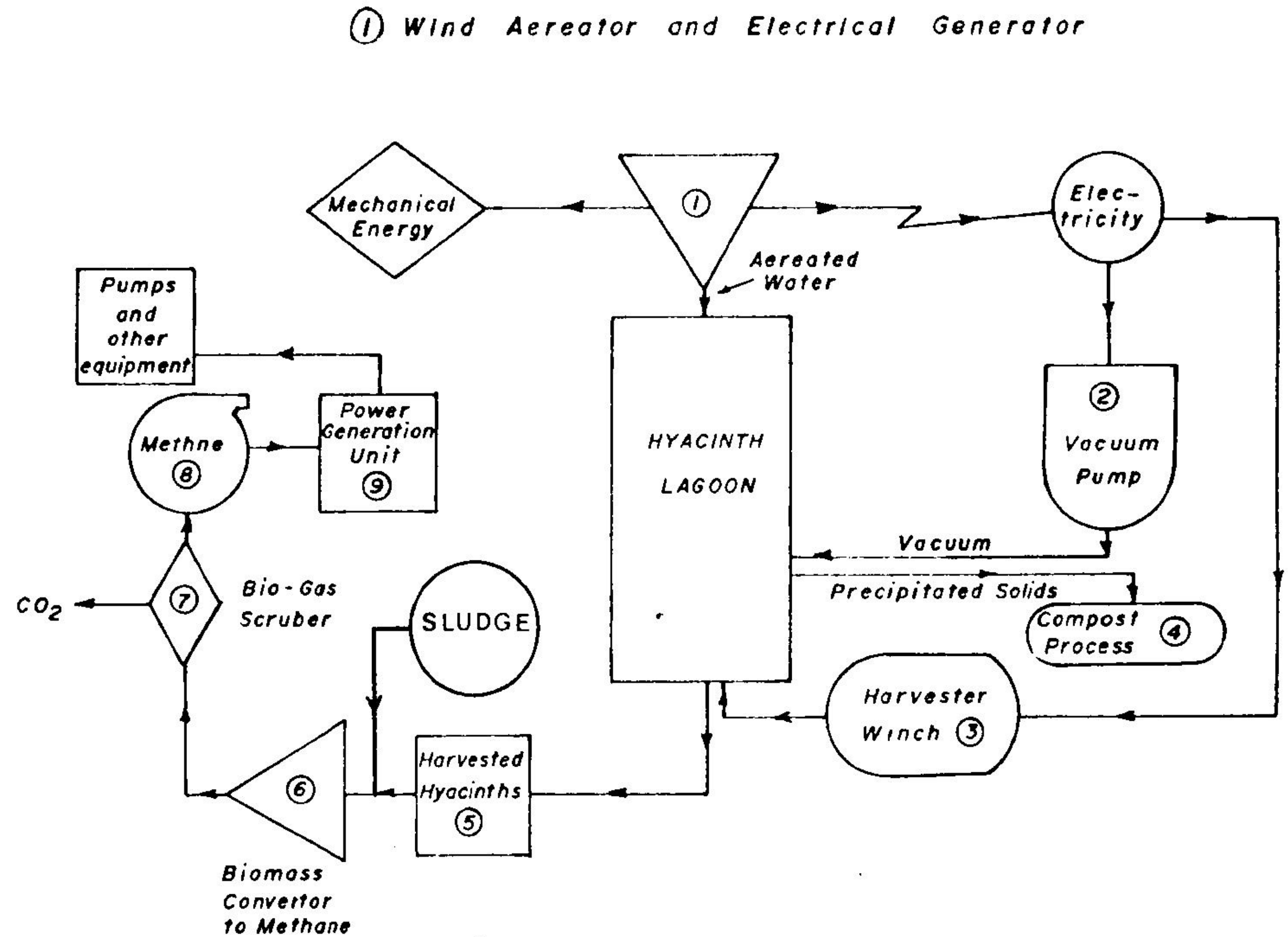


FIGURE 14.
System Energy Generation Diagram

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