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Wastewater Treatment Utilizing Water Hyacinths (*Eichhornia Crassipes*) (Mart) Solms

B. C. Wolverton
and
Rebecca C. McDonald
National Aeronautics and Space Administration
NSTL Station, Mississippi

INTRODUCTION

In the last two decades, the practice of dumping either untreated or partially treated waste into rivers and streams has become a major source of conflict between industry and groups of citizens concerned about protecting our environment. Consequently, the U.S. Environmental Protection Agency was chartered to impose and enforce regulations on the quality of the wastewater that industries can discharge into receiving water. This agency is slowly imposing stricter standards on industrial wastewater effluents with the aim of eventually achieving "zero discharge" of any industrial pollutants into receiving waters (Public Law 42 500).

Whether or not zero discharge is a realistic goal is a matter of debate. In any case, the discharge of industrial waste must be regulated, since its constituent components, both organic and inorganic, have been shown to have deleterious effects. Some organic compounds may act directly as toxins or carcinogens. Others may increase the biochemical oxygen demand (BOD) and consequently lower the dissolved oxygen in receiving waters, causing suffocation and death of many aquatic species. Still others may impart objectionable taste and odors to drinking waters, a less harmful but certainly undesirable effect.[8]

Inorganic compounds also have many adverse effects on man and the environment. Toxic heavy metals tend to concentrate in the fauna and flora of the aquatic environmental and produce a variety of effects in man once they are ingested. For example, cadmium, besides being a carcinogen, has been linked to kidney ailments, hypertension, and other cardiovascular conditions; hexavalent chromium is toxic and carcinogenic to both man and organisms found in the aquatic environment; mercury concentrates in the human fetus and causes permanent fetal brain damage; and silver produces a permanet blue-gray discoloration of the skin and becomes toxic if allowed to accumulate.[4,6,10]

The National Space Technology Laboratories (NSTL), Bay St. Louis, Mississippi, has the problem of treating chemical and photographic waste products that contain a variety of organic compounds as well as silver and trace amounts of such metals as cadmium and chromium. Public Health Service (PHS) recommendations for maximum discharge levels of some heavy metals are presented in Table I.

Present techniques for treating photographic wastewater include package activated sludge plants and aerobic lagoons.[6] Heavy metals can be removed with varying degrees of efficiency by chemical precipitation, electrodeposition, solvent extraction, ultrafiltration, ion exchange and activated carbon absorption.[3] Mixed wastes such as the wastes discharged at NSTL would require a combination of these treatment techniques. All of these methods are expensive to install and maintain and do not always meet EPA standards.

In an effort to develop a relatively inexpensive and effective means of treating the chemical and photographic waste at NSTL, the National Aeronautics and Space Administration (NASA) has installed a water hyacinth filtration system. The water hyacinth, (*Eichhornia crassipes*) (Mart.) Solms, is an excellent candidate for a biological filtration system for a number of reasons. Water hyacinths possess an extensive root system which allows them to feed directly from the aqueous medium, extracting chemicals and nutrients rapidly and efficiently. In experimental sewage and chemical treatment systems, water hyacinths have demonstrated the ability to substantially reduce the concentrations of organics, minerals, and heavy metals in the effluent waters.[7,9,17,18] Another feature is the plant's tremendously high growth rate. Capable of producing 17.5 metric tons of wet biomass per hectare per day under ideal growing conditions[18], the water hyacinth is believed by many botanists to be the most productive plant on earth.[1] These features, which make the water hyacinth such a successful pest species, can also be of great potential benefit to man when the plants are properly utilized.

Table I: Public Health Service Recommendations for Maximum Discharge Levels of Heavy Metals

Metal	Maximum Discharge Level, mg/l
Lead	0.05
Silver	0.05
Cadmium	0.01
Chromium	0.05

Description of the Water Hyacinth Treatment System

A specially designed lagoon was contructed at the National Space Technology Laboratories by NASA for the treatment of photogrpahic and chemical laboratory waste. The lagoon was constructed in a zig-zag configuration with the following specifications: length, 332 m; width, 6.4 m; depth, 0.78 m; total volume 1,675,010 liters, total surface area, 0.22 ha (See Figure 1). The zig-zag design promotes efficient filtration by maximizing the lagoon's length within a relatively small area. In addition, this design facilitates access of harvesting machines to the water hyacinths.

This lagoon receives approximately 95,000 liters per day. A minimum retention time of 20 days was built into the system, assuming that this would be the maximum time during the winter months in which the plants would be metabolically inactive.

In May 1975, this system was stocked with sufficient water hyacinths to cover approximately 20 percent of the surface area, and the waste from the chemical photographic laboratories was diverted into the lagoon. Although chemical waste was the sole source of nutrients available to the plants, they grew rapidly, multiplying to 75 percent coveragg within four weeks. During the summer months, the water hyacinths were sprayed with malathion to control spider mites, (*Bryobia praetiosa*). The plants thrived during all months of the experiment with the exception of January and February, when freezing temperature caused the tops of the plants to die back.

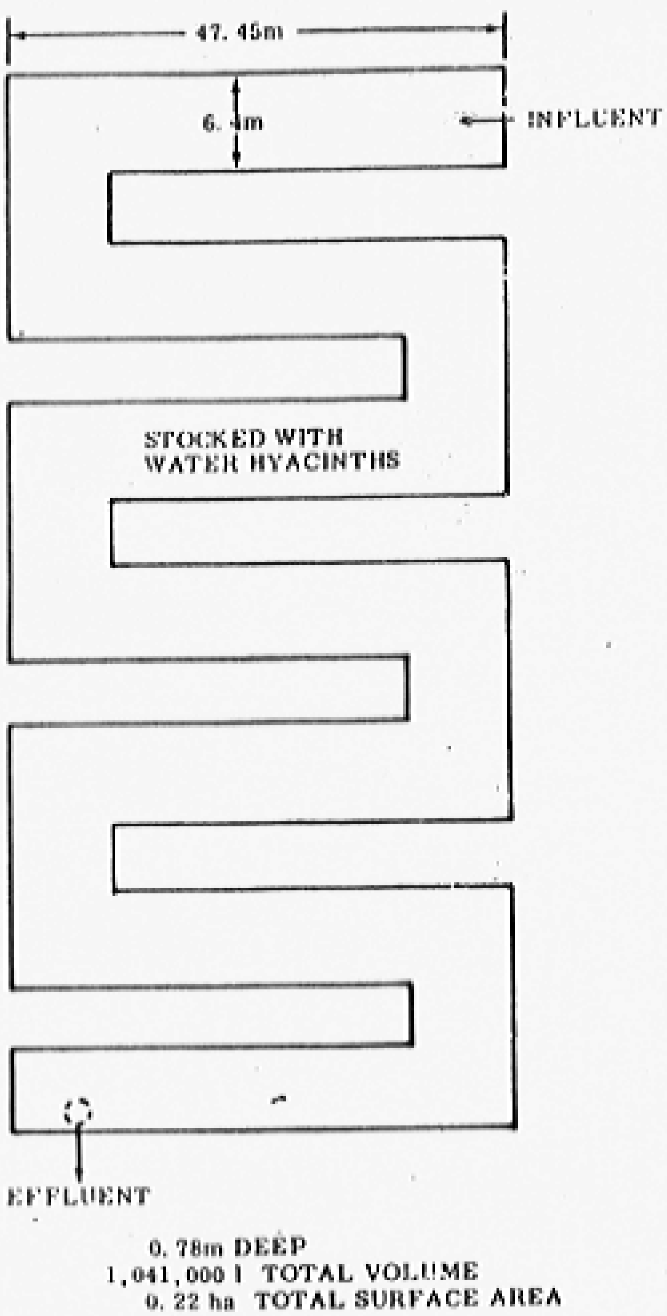

Figure 1: NASA/NSTL Water Hyacinth Chemical Waste Filtration System

Methods

Daily grab samples were taken from the wastewater before it entered the lagoon and from the effluent waters. Water samples were analyzed for pH, dissolved oxygen (DO), total suspended solids (TSS), total organic carbon (TOC), 5-day biochemical oxygen demand (BOD_5), total phoshporous, and chemical oxygen demand (COD), according to Standard Methods.[11] Heavy metal content of water samples was determined with the aid of an IL Model 253 Atomic Absorption/Flame Emission Spectrophotometer.

Over a six-week period, sample water hyacinths were taken from the lagoon weekly and analyzed for heavy metals. Roots, stems and leaves were analyzed separately to determine whether the metals migrated to upper parts of the plants. These plants were washed, dried in an oven at 110°C for 48 hours and ground to an even, fine consistency in a Waring commercial blender. All glassware was acid-washed prior to use. One gram samples were weighed out and transferred to 100 ml Kjeldahl flasks. To the flask was added 10 ml concentrated nitric acid, approximately 60 ml distilled water and boiling chips. The samples were digested until only a clear solution and a fine residue remained. The supernatant was filtered into 100 ml volumetric flasks and diluted to volume. The solution was analyzed by atomic absorption. A blank was digested with all samples and used as a correction factor for any contaminants in the reagents that might have been introduced.

Results

Table II shows a complete yearly analysis by month of the influent and effluent waters of this system. Silver was the only metal present in quantities sufficient to be noted. Traces of other metals were occasionally detected in the influent waters, but no other metals were found in the effluent. The water hyacinths maintained the effluent pH between 6.8 and 7.8. The dissolved oxygen remained above the generally accepted standard of 5 mg/l all but one month. No algal blooms were observed during these twelve months as indicated by the relatively low suspended solids. The reduction in dissolved solids varied from 29 percent to a high of 75 percent.

The concentrations of total Kjeldahl nitrogen and total phosphorous were also reduced by large percentages, as indicated in Table II. The most significant demonstration of water hyacinths biological filtration capabilities was the reduction of BOD_5. The chemical oxygen demand has also been reduced by 83 percent to 92 percent.

Table III shows the systemic uptake of the heavy metals that were routinely detected in the influent wastewaters. Over a 6-week period, water hyacinths accumulated these heavy metals to concentrations several hundred times the initial levels. The highest concentrations of heavy metals were found in the roots, the site of uptake of these substances, but there was also a significant accumulation in the plant stems and leaves.

Table III. Analyses of Water Hyacinths Before Introduction into the Chemical Waste System and After Six Weeks Exposure

Metal	Concentrations, ppm (Dry Weight)					
	Leaves		Stems		Roots	
	Initial	Six Weeks Exposure	Initial	Six Weeks Exposure	Initial	Six Weeks Exposure
Copper	13.5	32	10.9	48	24.0	594
Lead	8.4	35	3.1	45	<0.0	293
Silver	0.8	9	<0.1	4	36.0	113
Cadmium	<0.1	3	<0.1	30	<0.1	164
Chromium	<0.1	4	<0.1	12	<0.1	188

Table II: Monthly Average Data of the Water Hyacinth Chemical Waste Filtration System

Months	pH		Dissolved Oxygen mg/l		Total Suspended Solids mg/l		Total Dissolved Solids mg/l			Silver mg/l		Total Organic Carbon mg/l		
1975	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	% Red.	Inf.	Eff.	Inf.	Eff.	% Red.
May	5.79	6.88	-	-	7	33	368	216	37	-	-	61	23	43
June	7.06	7.20	7.17	5.67	8	16	480	166	67	0.74	<0.02	81	16	80
July	7.57	6.85	2.55	3.10	6	17	500	282	44	0.80	<0.001	7?	13	82
August	7.82	6.80	1.45	6.75	17	9	622	291	50	0.66	<0.001	61	7	89
September	7.64	7.36	4.19	6.88	9	6	434	299	30	2.40	<0.001	40	6	85
October	7.47	7.86	2.89	6.88	7	5	414	230	48	0.37	<0.001	27	11	59
November	7.74	7.35	6.50	6.31	6	3	495	201	61	0.49	<0.001	47	15	68
December	7.52	7.62	7.10	6.78	8	8	391	221	43	0.50	<0.001	48	14	70
1976														
January	7.60	7.76	2.30	6.88	8	10	366	273	28	1.19	0.04	45	12	71
February	7.42	7.58	1.16	6.67	9	5	656	297	65	1.00	0.02	64	16	75
March	7.70	7.51	0.15	10.50	6	20	1302	376	76	3.30	0.06	140	27	85
April	7.30	7.67	0.14	9.96	12	11	852	367	55	3.78	[illegible]	142	26	82
May	7.56	7.63	1.22	10.66	7	25	619	400	45	1.99	0.06	63	27	67
June	7.76	7.45	1.11	6.77	17	34	527	[illegible]	35	2.06	0.07	43	29	49

Months	Biochemical Oxygen Demand mg/l			Total Kjeldahl Nitrogen mg/l			Total Phosphorus mg/l			Chemical Oxygen Demand mg/l		
1975	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.
May	-	-	-	1.87	2.16	18	0.72	0.04	91			
June	-	-	-	6.41	0.55	92	1.29	0.10	47			
July	33	4	88	7.36	0.13	87	0.65	0.08	92			
August	73	0	99	3.67	0.18	94	1.00	0.04	96			
September	49	0	99	6.19	0.30	96	0.95	0.04	96			
October	133	0	99	9.30	0.44	95	0.34	0.02	96			
November	11	2	95	6.10	1.29	84	1.06	0.02	98			
December	89	0	99	11.70	1.27	89	0.87	0.03	91			
1976												
January	250	3	88	13.60	3.13	78	1.06	0.03	91	197	33	43
February	110	2	99	16.00	6.44	65	8.7	0.79	33	303	49	82
March	97	3	93	67.00	4.18	83	4.50	0.91	79	525	61	87
April	671	3	96	21.30	3.71	[illegible]	1.7	1.29	54	965	63	87
May	160	8	91	11.50	5.54	[illegible]	7.1	[illegible]	64	501	69	81
June	130	5	96	12.31	[illegible]	[illegible]	1.50	0.46	70	240	57	94

NOTE: Data partially presented for May and June 1975 due to insufficient data to average for [illegible] until January 1976.

Discussion

The water hyacinths proved to be a very effective filtration system for cleaning wastewater containing a complex chemical mixture. Organics, heavy metals and other elements were effectively removed from the wastewater by plant root sorption, concentration and/or metabolic breakdown (Table II). Trace elements entering the lagoon system were effectively removed to levels which comply with PHS recommendations.

Even the hardy water hyacinth is not immune to heavy metal pollutants. Approximately every eight weeks during the summer, the leaf tips began to turn brown and curl, indicating that the plants had sustained permanent metabolic injury from the environmental pollutants. The damaged sections of water hyacinths were harvested and piled nearby, since it is believed that plants in this condition are no longer maximally efficient at purifying wastewaters. When water hyacinths are used in permanent chemical waste treatment systems, periodic harvesting of damaged and/or saturated plants may be necessary if the discharge of toxic heavy metals is very high.

Since the plant stems and leaves, as well as roots, were found to contain heavy metals, no part of the harvested plants can be used as feed or fertilizer. However, the harvested plants can be used safely for the production of biogas. Whole harvested plants (or remaining sludge, if biogas is produced) should be put in a pit specially designed to eliminate ground water infiltration. Such a pit is planned to be utilized at the NSTL zig-zag lagoon. Over a period of years, the heavy metals in the pit may accumulate to levels high enough that their extraction becomes economically feasible. Such small "mining" operations—particularly of silver—may prove to be an efficient method of recycling valuable metals for industrial use.

Determining the optimal retention time for a system designed to remove heavy metals is complicated by the fact that these substances readily undergo chelation in the presence of the organic chemicals also discharged into the system.[3,5] Although plants will rapidly take up metals in the ionized form, chelated metals are not readily sorbed by the plant roots. Some chelates are very stable and can be broken down only by active microbial degradation. Once degradation has occurred, the plant roots will readily sorb the free metal ions. More research is needed to understand the time lag engendered by the process of chelation/microbial degradation and the effect of this process on determining the proper retention time for maximum removal of heavy metals from the system.

CONCLUSIONS

As a result of the water hyacinth's demonstrated ability to treat chemical waste effectively, the experimental lagoon system has been permanently installed at NSTL.

In combination with microorganisms, aquatic plants such as water hyacinths must be seriously considered in developing filtration systems for removing trace toxic chemicals such as heavy metals and carcinogenic organics. For large industrial systems, use of the water hyacinth may be limited to warm climates, but small volume operations should consider greenhouse techniques for maintaining these plants. Additional research and screening should be conducted with the numerous chemicals found in industrial waste to establish chemical concentration levels that the water hyacinth and other aquatic plants can tolerate and remove.

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