Wat. Sci. Tech. Vol. 18, Split, pp. 49–56, 1986.

0273–1223/86 $0·00 + ·50

A LOW COST METHOD FOR NUTRIENT REMOVAL FROM DOMESTIC WASTEWATERS

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ABSTRACT

At the town of Sokobanja, experiments were conducted with selected aquatic macrophytes in order to remove nutrients from domestic wastewater and thus improve the effluent quality and help prevent the eutrophication of lake Bovan. The effective use of *Eichornia crassipes Martius* (water hyacinith), *Pistia stratiotes l.* (water lettuce) and *Salvinia auriculata* for the removal of BOD, NH_3 and PO_4 has been demonstrated. In the course of the experiments temperature proved to be the most significant limiting factor under local conditions. The plants are of tropical origin which makes them very suitable for use in Mediterranean countries. A special advantage of this technology also lies in the fact that the plants cannot survive in brackish water and there is no danger of their propagation into marine ecosystems. The technology can be implemented very efficiently by slightly adapting the existing stabilization ponds or by constructing new specialized systems. In any case, the economic effects can be extremely positive since there is no need for expensive equipment and skilled labour.

KEYWORDS

Water; wastewater treatment; aquaculture; aquatic plants; nutrient removal; stabilization ponds; eichornia crassipes; pistia stratiotes; salvinia auriculata.

INTRODUCTION

Due to the rise in the cost of energy the use of low cost technologies for wastewater treatment is now receiving increased attention. Hydrophytoculture or in other words the use of aquatic macrophytes in wastewater treatment is a technology that has in the last few years been given careful consideration and has as a result been studied throughout the world.

After initially using only herbivores and exotic fish in the treatment of wastewaters in the aquaculture systems in the town of Sokobanja the research work has now been extended to also include aquatic macrophytes - *eichornia crassipes*, *pistia stratiotes* and *salvinia auriculata*.

This paper gives the results of a short term pilot plant investigation of the effects of aquatic macrophytes upon the efficiency of the treatment plant with respect to the removal of BOD, NH_3 and PO_4 at the above location, evaluating at the same time the economic effectivnes of such measures.

Sokobanja is a town in the S.R. Serbia located about 200 km southeast of Belgrade. It is also a spa and a resort place with as many as 25000 tourists using it daily during the summer months. The town has had a primary wastewater treatment plant since 1975 and the effluent from the treatment plant (20 to 120 l/sec) is discharged into the river Moravica which flows into the Bovan reservoir. Due to the limiting dilution capacity of the river Moravica and the extremely seasonal character of the pollution load from Sokobanja, it was quite clear from the very begining that primary treatment would not be able to give the required efficiency and prevent the excessive nutrient loading of the Bovan reservoir during the summer months. Considering the fact that the Bovan reservoir is to be partially used for water supply purposes, it was important to determine how to control the nutrient loading of the Bovan reservoir. The limited funds available for this purpose as well as sound engineering judgement led to the use of tropical aquatic macrophytes which at other locations gave satisfactory results. A pilot plant was set up with a portion of the effluent from the existing treatment plant flowing in as the influent to the aquatic plant growing units. Thus it was possible to reduce the pollution load of the Bovan reservoir even during the experimental stages. As this short period pilot investigation has given satisfactory results, the unit process for the growth of aquatic plants is now being added to the treatment plant at the town of Sokobanja.

METHODS AND MATERIALS

Prior to the pilot plant investigation, preliminary laboratory tests were carried out in order to gain operational experience that could be used in the pilot plant design. These experiments established the need for a flow through system with a hydraulic loading with the effluent from the Sokobanja treatment plant equaling 10 to 40 $l/day/m^2$ of the surface area. At the beginning of the experimental work only a limited number of plants were available but a vegetative reproduction of the plants did occur so that the pilot plant was stocked with an adequate number of plants from the very beginning of the experiments.

The pilot plant facilities consisted of four aquatic plant growing ponds, each of an area of 32 m^2 (8*4 m) and a depth of 0.6 m. The ponds were insulated by PVC foil and by a layer of sand and clay 10 cm thick which was placed on the bottom of each pond in order to prevent the damage of the foil during the harvesting of the plants. The four ponds were connected in series and baffles were set in such a way as to induce a flow that would approximate plug flow as much as possible.

The ponds were initially filled with diluted primary effluent (1:3 dilution) and were left unattended for a period of time so that the system could stabilize. Each pond was stocked with the plants at the beginning of July and the system was operated until the end of November. The effluent from the treatment plant was pumped to the first pond on a continuous basis throughout the experimental period, (flow Q_{in} = 5.5 l/min), and the detention time of approx. 2 days was thus maintained in each pond.

Since mosquito development was observed during the laboratory experiments, the ponds were stocked with *Gambusia affinis* and *Guppy* in order to control this development. All four ponds were left undisturbed for approximatly one month (except for local harvesting) to develop full stands of aquatic plants and to fully mature ecologically.

Following this initial accomodation period, the system performance was monitored daily with respect to the efficiency of the BOD, NH_3 and PO_4 removal throughout the remaining experimental period. The growth and reproduction of the aquatic plants in the system was also monitored on a weekly basis.

The analytical methods that were used were standard methods (WPCF, 1981). The growth of the plants was observed on the basis of the wet biomass (plants were drained for 10 min prior to weighing).

Composite water samples were collected at the inlet and the outlet of each pond once a day (every 30 min for 6 hours, from 8.00 a.m to 2.00 p.m.). Besides the parameters mentioned so far the pH, D.O., turbidity and electrical conductivity were also measured daily. The air and water temperature were continuously measured throughout the experiment. The visual observation of the colour of the water and of the status of the fish population was also carried out on a regular basis.

RESULTS AND DISCUSSION

Even though the ponds were left to stabilize for a full month prior to the beginning of monitoring, the obtained results have shown that the system was not in fact stabilized until early September. Furthermore, after November 1, the water and air temperature fell below 10 ^{o}C and even though the plants did survive the effects dropped significantly so that the results that have been given really only refer to the two months , (September and October). This is a rather short period of time to make any definite conclusions, especially so in the case of Sokobanja since this period does not include the peak load at the middle of the tourist season. However, the results that were obtained do justify further work and the effects that were observed justify the general discussion and conclusions.

At the beginning of the experiments the basic stock in each of the ponds was an equal mixture of 1:1:1 of *eichornia crassipes* , *pistia stratiotes* and *salvinia auriculata*. None of the ponds was completely covered at the end of the experiments. Pond 1 was completely covered with ~90% eichornia and 5% of pistia and salvinia respectively, pond 2 and pond 3 were covered approximately 60% each and this time ~90% of the plants were pistia, while pond 4 was covered only approximately 30%, and mostly with salvinia.

In ponds 1 and 2, filamentous algae developed and interfered with the development of macrophytes. As a result, the data for the standing crop and the daily biomass gain on the basis of the wet biomass that was observed and shown in table 1 is several times smaller than the data reported by NAS (1976), J.R.Houser (1984), and Wolverton and Mc Donald (1978).

Table 1. Observed Standing Crop and Biomass Gain During the Period Between Sept. 1 - Oct. 30, 1984

PLANT	STANDING CROP kg/m2 (wet biomass)	BIOMASS GAIN kg/m2/day (wet biomass)	TOTAL GAIN kg/m2 (wet biomass)
Eichornia crassipes	4.2 - 10.0	0.23 - 0.55	26.23
Pistia stratiotes	0.9 - 3.3	0.04 - 0.12	6.30
Salvinia auriculata	1.5 - 2.5	0.07 - 0.12	7.55

The figures given above imply that the maximum growth of 5.5 tons of wet biomass could be harvested daily per hectare of water surface. This is 4 to 7 times less when compared with the data reported by NAS (1978), for plants of the similar type in Florida and Texas. Wolverton and Mc Donald (1978), reported that a production of 154 tons/ha of dry hyacinth biomass could be achieved from April to October in southern USA.

Considering the fact that the time scope of the pilot plant study did not cover the full growing season, it is not surprising that the biomass gain that was observed did not compare favourably with the results of other researchers. For example, the size of the *eichornia crassipes* that was grown at Sokobanja was only about 30% of the size reported by Wolverton and Mc Donald (1978). The exact reasons why our plants were of such a small size is not known but it could be that the reason lies in their genetic nature. The plants that we used were all obtained from the Botanical Gardens in Zagreb and they are all the offspring of one to five plants. This implies that the genetic pool in the initial stock was not satisfactory, i.e. the selection of plants with the maximum reproduction potential in mind has not been carried out.

On the basis of the obtained results and the assumption that the biomass would increase according to equation (1) (the validity of the assumption has been experimentally confirmed) it was possible to calculate the rate of growth k for each of the plants and for three different temperatures. These values of k are given in table 2.

$$B = B_0 * e^{kt} \quad (1)$$

where :
B = probable biomass on wet biomass basis
Bo = initial biomas on wet biomass basis
k = the rate constant of growth
t = time

e = Napierian constant

Table 2. Experimentally Determined Values for the Growth Constant k

Plant	k - 1/day 30 °C	20 °C	10 °C
Eichornia crassipes	0.082	0.035	0.015
Pistia stratiotes	0.061	0.026	0.011
Salvinia auriculata	0.070	0.030	0.013

As can be seen from the data in table 2, the growth of plants is highly dependent on the temperature and the higher the temperature is, the higher is the growth. However, if the temperature exceeds approximately 35 °C or falls below approximately 8 °C the growth of plants seems to stop or is so small that it cannot be observed by means of the usual methods.

Since these plants are used for treating wastewaters due to the fact that they assimilate the nutrients in water it is evident that the proposed technology is only suitable for the warmer regions of the world or for locations such as at Sokobanja where they are only to be used on a seasonal basis.

The efficiency of treatment as observed during the pilot plant study is given in table 3. The results that are presented refer to the period from September through October while the given figures refer to the minimum, average and maximum daily efficiencies that were observed for each pond and overall for the four ponds in series. The figures were computed on the basis of mass flow at the inlet and outlet for the retention time of two days in each pond. It should be mentioned that the actual retention time was somewhat longer due to the evapotranspiration which was slightly higher than the precipitation during the experimental period.

Table 3. The Observed Treatment Efficiency in the Macrophite Growing Ponds

Parameter	Treatment efficiency, %/ reduction/day												
	Across pond A			B			C			D			Overall
	min.	av.	max.	min.	av.	max.	min.	av.	max.	min.	av.	max.	av.
BOD_5	41	51	61	26	41	48	12	27	29	7	16	24	85.1
NH_4	36	38	39	41	51	54	43	49	51	38	41	53	88.6
PO_4	29	34	36	41	59	64	37	45	49	33	39	41	91.8

The high overall efficiencies for the BOD and NH_4 that were achieved during the pilot plant investigation are not surprising when one keeps in mind that the total retention time was over 8 days. For this long a retention time, similar treatment efficiencies are also achieved with the conventional stabilization pond technology.

The only surprising figures are the relatively high removal efficiencies observed for the phosphate removal since this could not be attributed entirely to plant assimilation. Table 4 shows the results of the analysis of the biomass collected at the end of the experiments and on the basis of the dry biomass phosphorous is only 0.42 % of the biomass by weight. This accounts for approximately 10% of the total phosphorous input into the system. It must be mentioned that the analyses were carried out only on the leafy parts of the plant and it could well be that the root parts have a higher P content. Furthermore, the submerged parts of the plant are an extremely favourable site for microbiological activity so that the adsorption of P at these locations is probably very high. This and the adsorption of P on clay particles as well as its precipitation in the ponds accounts for the very high efficiency of the P removal that was observed during the pilot plant experiments.

Table 4. The Composition of Biomass (Eichornia crassipes) at the End of Pilot Plant Experiments

Parameter	%, by weight (dry biomass)
% Dry matter	4.60
Protein	14.60
Nitrogen	2.80
Cellulose	26.00
Phosphorous	0.42
Calcium	1.40
Potassium	4.40
Sodium	1.80
Ash content	17.00
Energy content	~4.00 Kcal/gr dry

The data presented in table 4 is in good agreement with the data presented by C.E.Boyd (1969). This in turn confirms the suitability of the biomass production based on the use of wastewater and its use as a supplementary diet for livestock. The high protein content makes aquatic macrophyte biomass a very desired byproduct of the technology.

The results of the pilot plant experiments (even though they need further confirmation) prove that hydrophytoculture or the use of macrophytes for wastewater treatment is a viable alternative for warm climatic regions. The removal efficiencies with respect to the BOD, NH_4 and PO_4 removal from wastewater are comparable to other much more expensive technologies (chemical precipitation, activated sludge etc.). The technology can easily be adapted to the existing stabilization pond systems by simply cultivating the macrophyte population in the ponds. The effects will not be decreased. They will in fact be improved and the effluent will be of a higher quality. The economic considerations of the technology are very positive if one considers the potential for the recirculation of nutrients and the value of the produced biomass in terms of its protein and energy content. Labour requirements are not higher than for the operation of the stabilization ponds. The only extra expenses that will be incurred are for the supply of the initial population of macrophytes and for the harvesting of the biomass. The harvesting can be done manually and in areas with cheap labour the costs will not be significant. Mechanical harvesting is a possibility and the harvesting equipment could be easily manufactured locally (NAS, 1978).

The energy costs involved when using this technology are minimal. If the flow through the system is by gravity the only energy to be consumed is for the harvesting of the biomass. The value of the biomass will certainly cover the costs of the energy used.

According to W.F.Owen (1982) the specific energy consumption of the stabilization ponds is 1.5 to 2.0 kWh/kg BOD removed and the figure would be similar for the hydrophytoculture systems. The corresponding figures for the phosphorous removal by a variety of the chemical precipitation processes range from 6.40 to 22.0 kWh/ kg P removed. Since the P removal in the hydrophytoculture systems is achieved without the supplementary energy input, it is evident that when compared to the classical methods, the P removal by the proposed technology is a number of times more efficient with respect to the energy consumption for similar removal efficiencies.

However, the following disadvantages of the proposed technology were also observed on the basis of the pilot plant investigation. First of all, the area requirements necessary to achieve a high level of treatment are large. For the town of Sokobanja, the required area would be approximately 6-7 ha. Secondly, the process is not easy to control. The development of the filamentous algal species can reduce the production of macrophytes and even though the effects upon the quality of the effluent are not significant economically they can still be quite high since the valuable biomass production would be lost.

The technology itself hides certain dangers since aquatic macrophytes are the most pernicious weeds on earth and if introduced into natural waters, they could cause enormous economic problems (navigation, recreation etc.). At Sokobanja, this aspect is not a problem since the plants cannot survive temperatures below 0 ^{o}C which regularly occur at the location during the winter months. This however results in the need to construct the wintering ponds in which an adequate stock of plants could be saved for the next season. In countries where the temperature does not fall below 0 ^{o}C an adequate and complete control must be ensured in order to prevent the introduction of these plants into the natural environment. As for the Mediterranean region, even if effluents are discharged directly into the sea, there is no danger since the plants used in this experiment cannot survive in sea water (Goldman, 1980). We confirmed this by unsuccessfully trying to grow the plants in synthetic sea water in the laboratory.

The potential problems that could be encountered due to the mosquito development can be controlled either by the introduction of selected fish species or by other measures commonly used for these purposes. The problem is no more intensive than in the case of the use of conventional stabilization pond technology.

CONCLUSIONS

The pilot plant experiments carried out at Sokobanja have confirmed the suitability of the hydrophytoculture technology for the removal of nutrients from domestic wastewaters. The proposed technology offers an economically justified means for the control of nutrients discharged into the river Moravica and it is thus a measure that should be taken if the eutrophication of the Bovan lake is to be prevented.

Further research is necessary in order to determine the most suitable pond configuration and the stocking density of different macrophytes. Preliminary results indicate that monoculture ponds in series can give excellent results.

The technology is especially suitable for warm climatic regions provided adequate measures are taken to prevent the accidental introduction of macrophytes into the natural water systems.

The biomass that is produced during the treatment process is a valuable resource and can be used to feed livestock or for energy production after the pretreatment done to remove any excess water. Further research is necessary in order to establish the optimal ways to use the produced biomass.

ACKNOWLEDGEMENT

The research grant from the Republic of Serbia Science Research Council is gratefully appreciated. Special thanks go to the staff of the treatment plant at Sokobanja for their help in conducting the experiment.

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