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Phytoremediation of Industrial Wastewater

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This paper aimed to determine the qualitative and quantitative effects of the phytoremediation process, for the treatment of wasterwater. It was noticed that a locally growing aquatic Lemnaceae plant (*Lemna minor* L.) is very effective in improving the properties of the pond stagnant water by its decolorization effect in addition to the removal of unpleasant odour and the viscous form. The rate of decolorization of textile industrial wastewater was studied in the presence of this plant. It was noticed that sunlight was very effective for the phytoremediation process. The percentage of degradation exceeds 70% in the presence of sunlight in 20 days. The rate of degradation was found almost the same for the samples put in the dark, shadow and sunlight for the first five days and the percentages of degradation were 3.13, 3.33 and 3.5% per day, respectively. The rate of decolorization was followed spectrophotometrically by measuring the maximum absorption at 230 and 615 nm.

Key Words: Phytoremediation, Industrial wastewater, *Lemna minor* L.

INTRODUCTION

The revolutionary growth in industry has led to the production of a huge amount of toxic and/or carcinogenic compounds, which may create a threat to the environment and human health[1]. Annually, more than one million ton of different synthetic dyes and pigments are produced. More than 25% of these dyes and pigments are discharged into the environment[2]. Due to the seriously harmful nature of the coloured pollutants, numerous researchers investigated the decolorization of industrial wastewater discharged to the environment from different industries. Among these industries is textile industry, in which the major problem is the consumption of large amounts of water besides the toxicity of the coloured discharged wastewater.

Because of the complexity of textile wastewater, its treatment is considered to be a difficult task[3]. Lately, several chemical and physical techniques have been

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operated for decolorization of textile wastewater. They include photocatalysis, photosensitization, ozonation, Fenton's oxidation and electrochemical destruction, which proved to be efficient for the removal of dye colour from wastewater[4-6]. However, these processes are economically impracticable or facing complicated procedures. An alternative process is required for complete dye decolorization in an economical route, namely, phytoremediation technique, which could be defined as a process in which aquatic plants are used to treat contaminated soil or water and this process could be considered as an alternative low cost natural treatment. It has been successfully utilized to treat wastewater by two alternative methods. The first one involves the use of what is called constructed wetlands and emergent aquatic plants, which are essentially employed in areas with temperate climates[7]. Toxic elements could also be removed by using aquatic plants[8].

The second approach applies to ponds with aquatic floating plants such as some genera of the Lemnaceae family (duckweed) and water hyacinths (*Eichhornia crassipes*) in the tropical and subtropical districts, where this sort of plants is undesirable[9].

Haberl *et al.*[10] used *Phragmites australis* for the treatment of domestic wastewater in the hilly region of Upper Austria. The study showed high performance in the reduction of biological oxygen demand (BOD), chemical oxygen demand (COD), NH_4N-N and PO_4-P. The reduction percentage exceeded 50%.

By using *Phragmites* Novais and Dias[11] eliminated the organic pollutants such as nitrobenzene, aniline and sulphanilinic acid, which were produced by Quimigal's industrial complex site at Estareeija, Portugal. The results showed high efficiency of the utilized system. The average reduction of the pollutants was 99%.

Schwitzguebel[12] reported that phytoremediation is an emerging technology, which requires for development fundamental and applied research. Recently[13], more than hundred plant species were tested for the process of phytoremediation.

Wastewater treatments by green plants could occur *via* four main different pathways[14], namely, degradation of organic contaminants, accumulation for the elimination of organic and/or metal pollutants, dissipation and immobilization. The degradation process takes place *via* two routes: rhizodegradation, which utilizes microorganisms to enhance the biodegradation and phytodegradation, which compromises the contaminant removal, followed by metabolism processes. The accumulation pathway occurs throughout two processes: phytoextraction, which includes the contaminants uptake followed by accumulation and elimination, while the second process, rhizofiltration, represents the adsorption of pollutants on roots for containment and exclusion. The dissipation process involves the exclusion of inorganic and/or organic contaminants to the atmosphere *via* a phytovolatilization process, *i.e.*, uptaking the contaminants followed by volatization. The last pathway, immobilization, includes the phytostabilization route, which supports the pollutant to the soil, followed by a hydraulic control, which monitors the ground-water flow *via* the uptake of water by the plant.

In the present work, Lemnaceae plants (*Lemna minor* L.), which grow naturally in the pond's water as a floating plant in Yemen, were used for the treatment of the textile industrial wastewater. According to our best knowledge from the literature survey, this species of aquatic plant is used for the first time in this research for the treatment of industrial wastewater.

EXPERIMENTAL

Qualitative analysis was done in Jabal Homaid village in Maktab region, Ibb Governorate, Yemen. The collected plant grows naturally in the ponds situated in Ibb area. It consists of three small leaves (with *ca.* 0.75 mm^2 area), each of them is attached to a relatively long root, compared with the leaf size (its length = 10.24 ± 2.46 cm). It proliferates continuously by seeds in the aquatic medium. Before transferring the plant to the shallow pond under investigation, the water looked muddy turbid, dark green, bad smelled and viscous. 1 kg of the plant was transferred to this pond (circle-shaped with 4 m radius and 1.7 m depth).

Quantitative analysis A sample of 20 L was withdrawn from the industrial wastewater collected from the spinning and textile factory in Sanaa, at the end of March 2004. The sample was subdivided into three groups, each having two containers (14.8 × 7.4 × 7.2 cm), A and B, which were filled with 500 mL of wastewater diluted to 1000 mL with distilled water. The three groups were:

1. The first group, which was put near one of the laboratory windows in the chemistry department, Ibb University, where it was exposd to direct sunlight (sunlight group).
2. The second group, which was put far away from the window (shadow group).
3. The third group which was hidden in a dark place (dark group).

20 g of Lemnaceae plants (*Lemna minor* L.) were laid only in the container A. Throughout the analyzing periods, 2 mL sample was withdrawn, using a syringe with a long pliable needle, every 24 h for 20 d, from each container. The samples were centrifuged. In each case, 1 mL of the supernatant was drawn, diluted to 50 mL and analyzed spectrophotometrically at λ_{max}'s 230 and 615 nm, using UV-Vis spectrophotometer, type UV 2100, supplied by Unico Company. The results were compared with a calibration curve, which was accomplished for different concentrations of the industrial wastewater.

RESULTS AND DISCUSSIONS

Qualitative results revealed remarkable water quality improvement within 20 d. The colour, the unpleasant smell and the turbidity were completely removed and the normal viscosity was recovered. Moreover, the microorganisms in the pond survived with high activity. These results can be attributed to four mechanisms, namely:

(i) Phytoextraction, where the pollutant is stored in the plant stem or leaves[15];
(ii) Phytovolatization, where the pollutant is volatized by the plant[15–17];
(iii) Phytodegradation[18], where the pollutant is metabolized by the plant[17];
(iv) Rhizodegradation, where the pollutant is broken down by microbial

activity, and this process is enhanced in the presence of the rizophore. All the four mechanisms took place under natural weathering conditions.

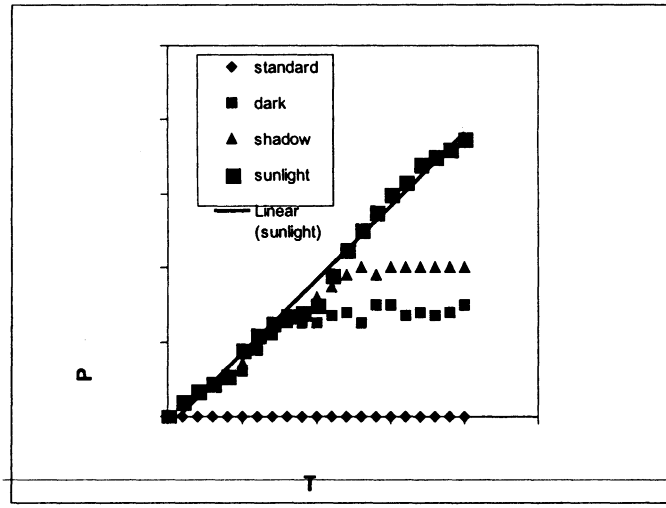

Fig. 1. Phytodegradation of coloured industrial wastewater.

Quantitative findings, shown in Fig. 1, demonstrated that the percentage of decolorization exceeds 70%, for the container put in sunlight, for 20 d period. However, for the container put in the shadow far away from the window and that in the dark, the percentage of decolorization was measured for 11 and 7 d, the final life days, respectively, when the plants died and the uptake stopped. These percentages were found to be 35 and 22%, respectively. Moreover, very similar results were obtained for the three samples, during the first 8 d. This indicated that the main process that occurred was phytoextraction. After the eighth and eleventh days, the dark and shadow plants started perishing, respectively. Hence, the photosynthesis process ceased. However, the sunlight plant survived and the perishing rate was normal and the percentage of degradation remained linear and exceeded 70%.

With the plant samples and throughout the first eight days, adsorption of the dye took place, whereas with the standard three samples, *i.e.*, dark, shadow and sunlight with the absence of the plant, no change was observed. This proved that the sole action was that of the plants. In addition, there was a close similarity, approaching 95%, for the results obtained at λ_{230} and λ_{615} . This similarity was found, in a previous study[19], to be close to 85%. This can be referred to that the photodegradation process of some compounds, in the presence of a catalyst, may lead to the formation of other compounds which absorb at λ_{615}. In present study, there was absorption of the pollutants, which were metabolized during the photosynthesis process inside the plant.

Concerning the comparison between the pond and the laboratory mean efficiencies, the pond was more efficient due to the rhizodegradation mechanism, where the microbial activity broke down the pollutant, a mechanism which is absent in the case of the laboratory tool.

Table-1 summarizes the four different mechanisms, which could take place within the plant in the groups, namely, sunlight, shadow and dark.

TABLE-1
COMPARISON BETWEEN THE ACTIVITIES OF PHYTO-REMEDIATION PROCESSES FOR THE THREE GROUPS

Process \ Experimental group	Sunlight	Shadow	Dark
Phytoextraction	Active	Active	Active
Phytovolatilization	Active	Less active	Inactive
Phytodegradation	Active	Less active	Inactive
Rhizodegradation	Inactive	Inactive	Inactive

The inactivity, which was marked for three experimental groups, indicated the absence of bacteria in the industrial water used.

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