Journal of Environmental Biology
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April 2007, 28(2) 307-314 (2007)

Performance of Duckweed (*Lemna minor* L.) on different types of wastewater treatment

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(Received: July 07, 2005 ; Revised received:April 06, 2006 ; Accepted: July 10, 2006)

Abstract: *Duckweed (Lemna minor L.) has a wide application in Turkey having suitable climatic conditions. In this study, the growth of duckweed was assessed in laboratory scale experiments. They were fed with municipal and industrial wastewater at constant temprature. COD, total nitrogen (TN), total phosphorus (TP) and ortho-phosphate (OP) removal efficiencies of the reactors were monitored by sampling influent and effluent of the system. Removal efficiency in this study reflects optimal results: 73-84% COD removal, 83-87% TN removal, 70-85% TP removal and 83-95% OP removal. The results show that the duckweed-based wastewater treatment is capable of treating the laboratory wastewater.*

Key words: *Duckweed, Aquatic systems, Nutrient removal*

Introduction

Ecological engineering, including the employment of constructed wetlands and the culture of aquatic macrophytes, for the purpose of pollution abatement has received growing acceptance (Reddind *et al.,* 1997). Wetland treatment process is a combination of all the unit operations in a conventional treatment process plus other physico-chemical processes, sedimentation, biological oxidation, nutrient incorporation, adsorption and inprecipitation (Gearheart, 1992). The use of duckweed in low-cost and easy-to-operate wastewater treatment systems has been studied in literature (Korner and Vermaat, 1998) because of rapid growth rates achieving high levels of nutrient removal. Whilst low fiber and high protein content make it a valuable fodder (Korner *et al.,* 1998).

Duckweed is a small, free floating aquatic plant belonging to *Lemnaceae* family (Cheng *et al.*, 2002). Duckweed is well known for its high productivity and high protein content in temperate climates. They are green and have a small size (1-3 mm). They also have short but dense roots (1-3cm) (Altay *et al.*, 1996). Duckweed fronds grow in colonies that, in particular growing conditions, form a dense and uniform surface mat (Hasar *et al.*, 2000).

Duckweed species have shown characteristics that make duckweed based wastewater treatment (DWWT) very attractive. They are used not only for wastewater treatment but also for nutrient recovery. The reason for this is the rapid multiplication of duckweeds and high protein content of its biomass (Caicedo *et al.*, 2000). Duckweed wastewater treatment systems have been studied for a wide range of wastewater types (Korner *et al.*, 1998). Most of the studies have focused on nutrient removal efficiencies and removal rates between 50-95% have been reported for duckweed covered systems (Korner *et al.*, 1998). Indirect effects like provision of surface and substrate by bacterial growth, change of the physicochemical environment in the water and the possibility of the direct removal of small organic compounds by heterotrophic growth are discussed in the literature.

The present research was carried out to analyze the performance of *Lemna minor* L. in municipal and industrial wastewater treatment in Bursa,Turkey. It aimed to establish the ability of the aquatic plant to remove TP (total phosphorus), PO_4^{-3} (artho-phosphate, OP), TN (total nitrogen) and COD (chemical oxygen demand) from wastewater.

Materials and Methods

Principle of duckweed based wastewater treatment: Duckweed has the capability to purify wastewater in collabration with both aerobic and anaerobic bacteria. The duckweed mat, which fully covers the water surface, results in three zones. These are the aerobic zone, the anoxic zone and the aerobic zone (Skillicorn *et al.*, 1993). In the aerobic zone, organic materials are oxidised by aerobic bacteria using atmospheric oxygen transferred by duckweed roots (Tchobanoglous and Burton, 1991). Nitrification and denitrification takes place in anoxic zones, where organic nitrogen is decomposed by anoxic bacteria into ammonium and ortho-phosphate, which are intermediate products used as nutrients by the duckweed (Smith and Moelyowati, 1998).

The system consists of two tanks in which *Lemna minor* L. has been grown. Tanks are formed in dimension with 40x20x15 cm. The surface area of each tank is 800 cm^2. The water depth of the reactors is 8 cm. The effective volume of the tank is 6.4 litres. Tanks are put into pond with a dimension of 80x50x16 cm to regulate environment temperature. Water temperature in the pond was around 21±0.5^oC which was measured using special thermometer (JAGER). Light has been supplied by a special lamp (OSRAM day light 18 W) during day times. During night, the lamp was switched off by a timer. The wastewater was supplied from the effluent water of Bursa west side municipal wastewater treatment system and Bursa organized industrial estate wastewater treatment system.

Duckweed cultures: Duckweed (*Lemna minor* L.) was collected from Susurluk stream in the area of Karacabey, Turkey and adapted to laboratory scale system in Department of Environmental Engineering, Uludag University.

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Analytical methods : At the influent and effluent of both reactors total nitrogen (TN), total phosphorus (TP), Ortho phosphate (PO_4-P) and chemical oxygen demand (COD) parameters have been measured for all retention times. COD analysis have been performed according to standart methods (APHA, 1998), other analyses have been performed with measurement kits and analysed using Dr. Lange Lasa 2 plus model photometer.

Natural environment of *Lemna minor* L. was 19°C and pH was 7.1. Therefore, in the experimental study natural environment conditions for *Lemna minor* L. were constituted. Waste water samples were taken every three day from wastewater treatment points. Experimental mechanism was maintained every day. pH was measured in every analyse at the influent and effluent of the system. COD analysis was observed throughout three weeks. TN, TP, OP were observed analysis throughout ten days. In addition to these analyses, monitoring for municipal and industrial wastewater was performed interval samples were taken throughout 48 hr (at 0, 15, 30, 45, 60, 120, 240, 360, 480, 960, 1440, 2880 min.) to determine the best removal time.

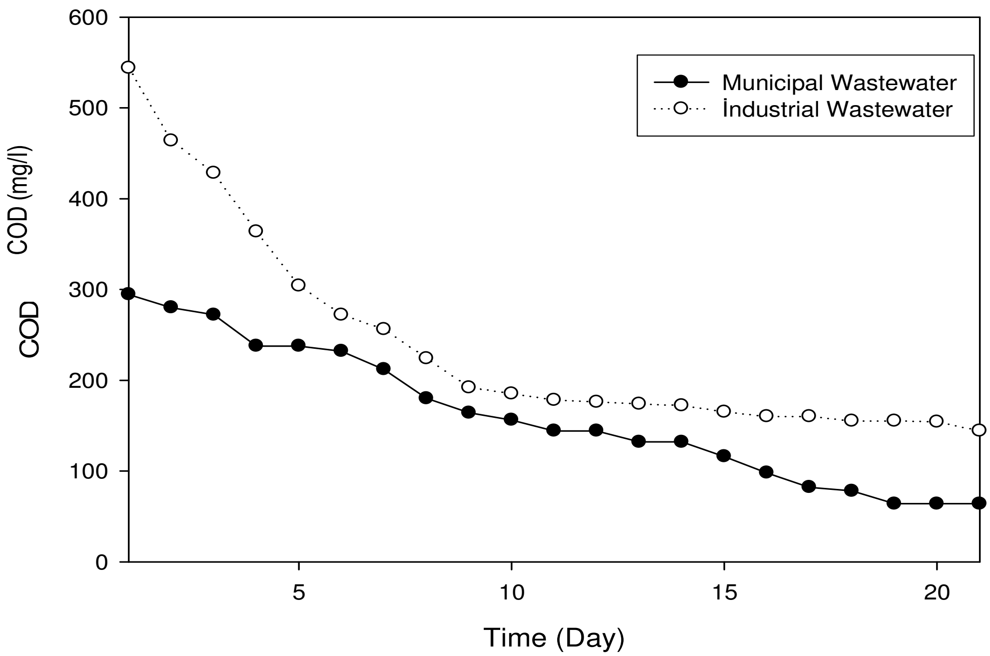

Fig. 1: Influent and effluent COD concentration of municipal and industrial wastewater

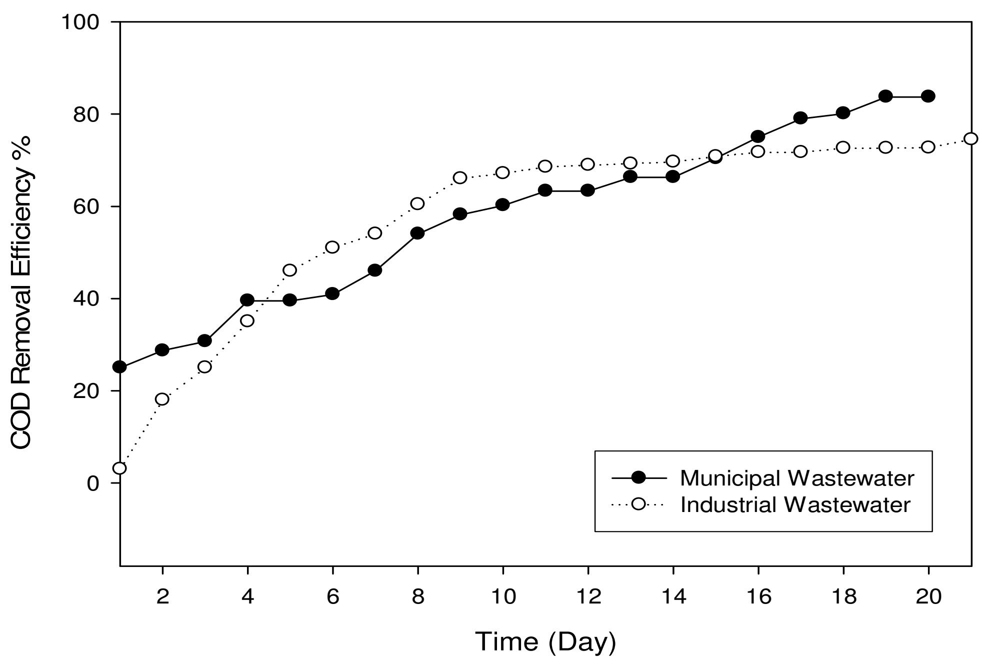

Fig. 2: COD removal efficiencies of municipal and industrial wastewater

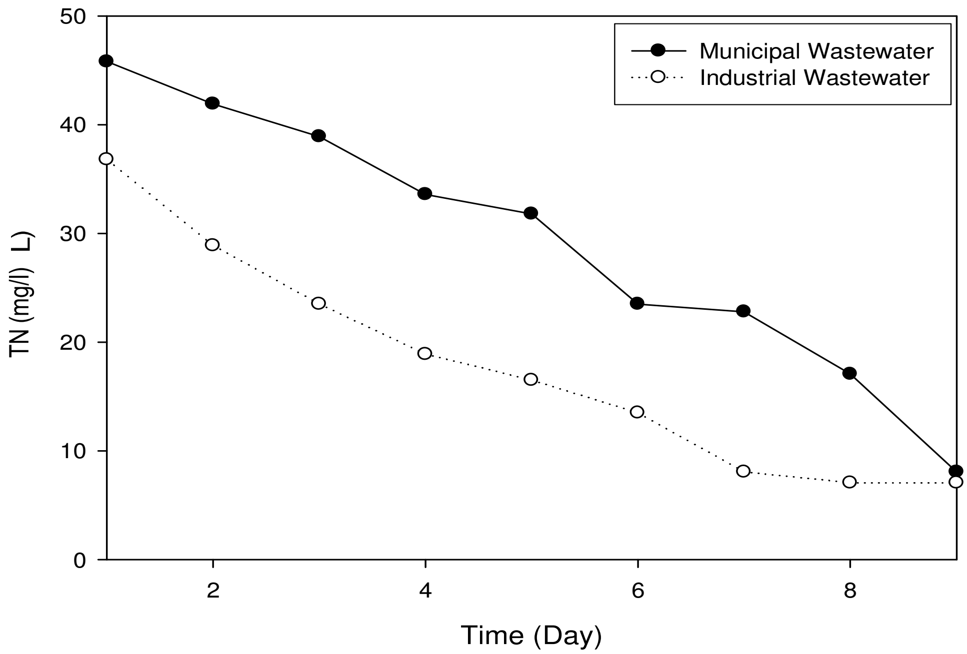

Fig. 3: Influent and effluent TN concentration of municipal and industrial wastewater

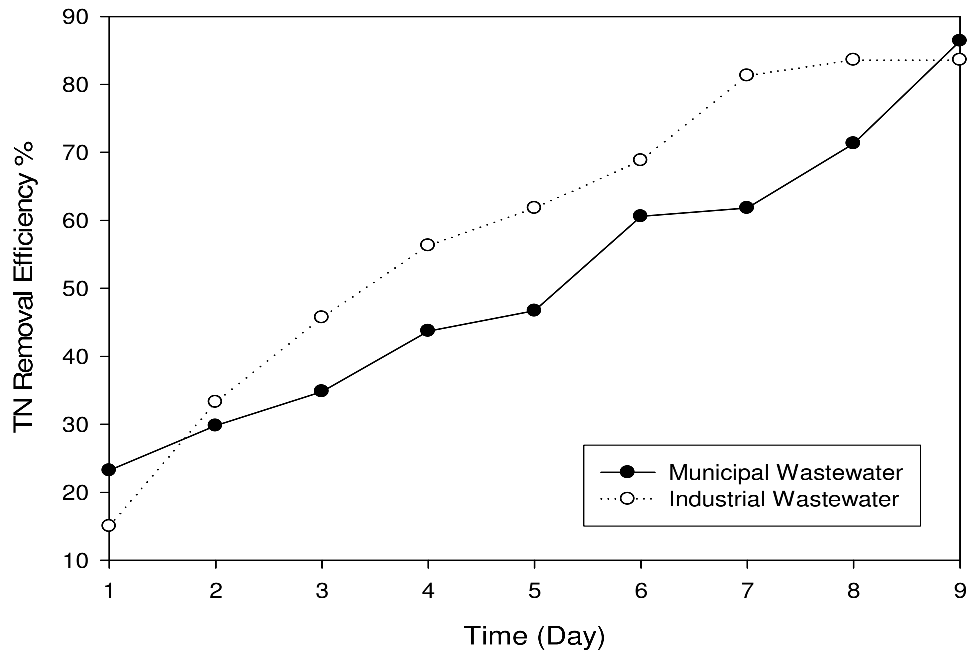

Fig. 4: TN removal efficiencies of municipal and industrial wastewater

Results and Discussion

The system has been operated as advanced treatment system. The results relate only to two sampling; at the influent and effluent. The system treatment efficiency was high. The removal efficiency of wastewater between the two reactors was similar.

Both municipal and industrial wastewater showed pH in the influent 7.2±0.2 and at the final effluent around 8.0±0.2. Water depth was 8 cm which is optimal level for the systems.

Although there are still different ideas about the temprature requirements for duckweed growth, the production of duckweed will decrease when the temprature is below 17^{o}C or above 35^{o}C (Smith and Maolyawati, 1998). Both for municipal and industrial wastewater temprature was 21±0.5^{o}C.

COD removal: DWWT is designed on the basis of volumetric COD loading due to possible anaerobic process underneath the duckweed mat. Mandy's experiment proved that DWWT ponds tolerate maximum influent COD concentrations from 300 to 500 mg/l (Smith and Moelyowati, 1998). Fig. 1 shows the COD concentration of municipal and industrial wastewater influent concentrations which were 294 mg/l and 544 mg/l respectively. The final effluent COD was 64 mg/l for municipal and 144 mg/l for industrial wastewater. Overall, the results show that DWWT are capable of removing COD pollutant.

Duckweed covered systems can attain COD removal rates between 50 and 95% (Korner *et al.*, 2003). A significantly faster removal of COD was found in reactors covered with *Lemna minor* L. in all experiments. Fig. 2 shows the COD removal efficiencies of municipal and industrial wastewater. COD removal efficiencies were 83.67% and 74.55% respectively for municipal and industrial wastewater. COD removal efficiencies were higher than those reported by Oron *et al*. (1987) for *L. gibba* on raw wastewater (500-750 mg/l COD) in 20 cm deep of ponds (66.5%). Mandi (1994) also found lower values at area studied on domestic wastewater (444 mg/l COD) in 14 cm deep of ponds (72.1%). Temprature significantly affected COD removal. Effects of temprature on COD removal depend on plant treatment and varied through time (Allen *et al.*, 2002).

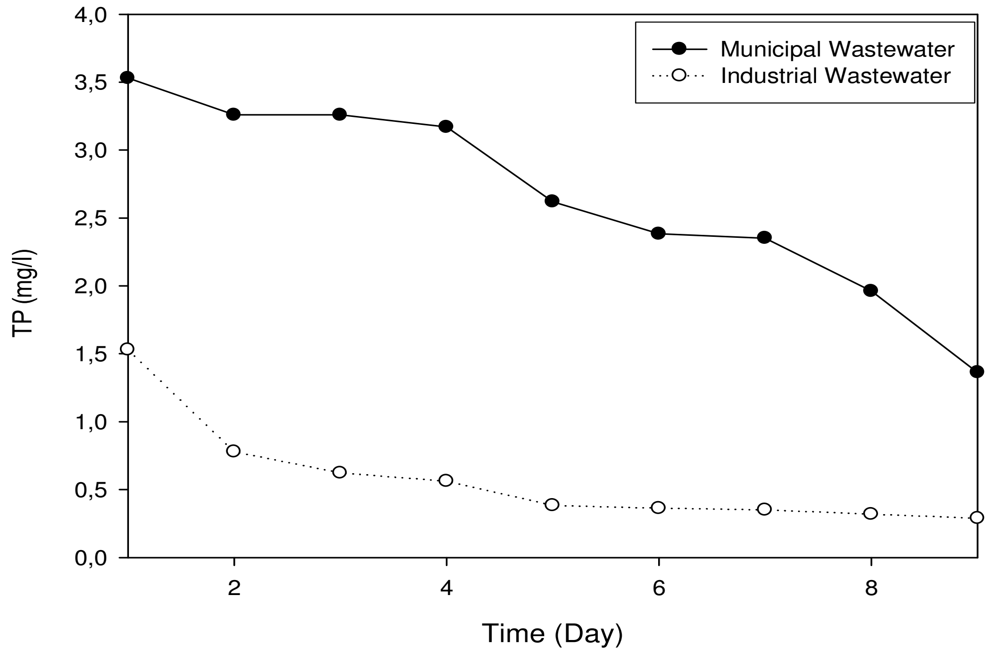

Fig. 5: Influent and effluent TP concentration of municipal and industrial wastewater

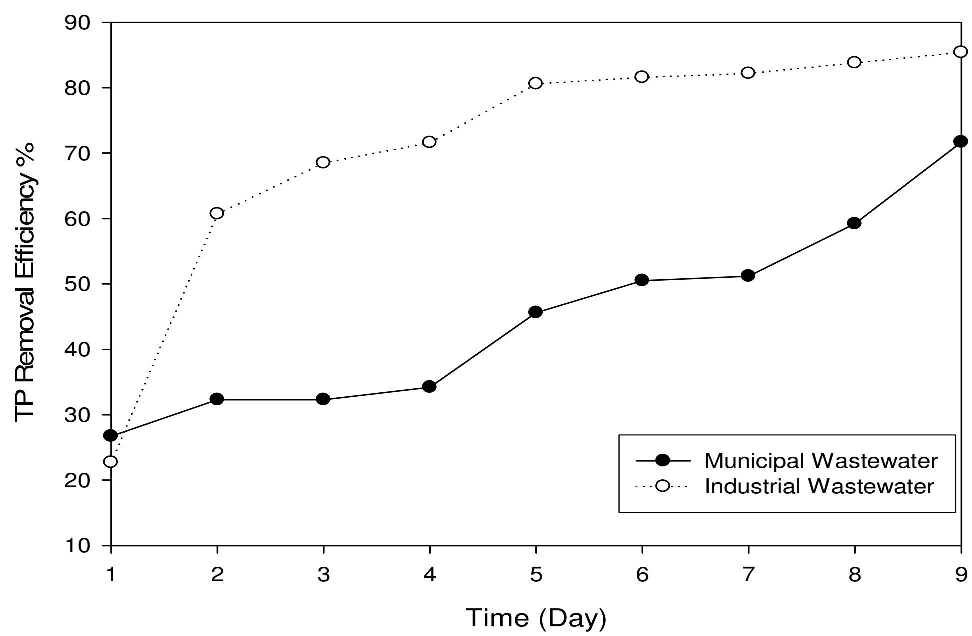

Fig. 6: TP removal efficiency of municipal and industrial wastewater

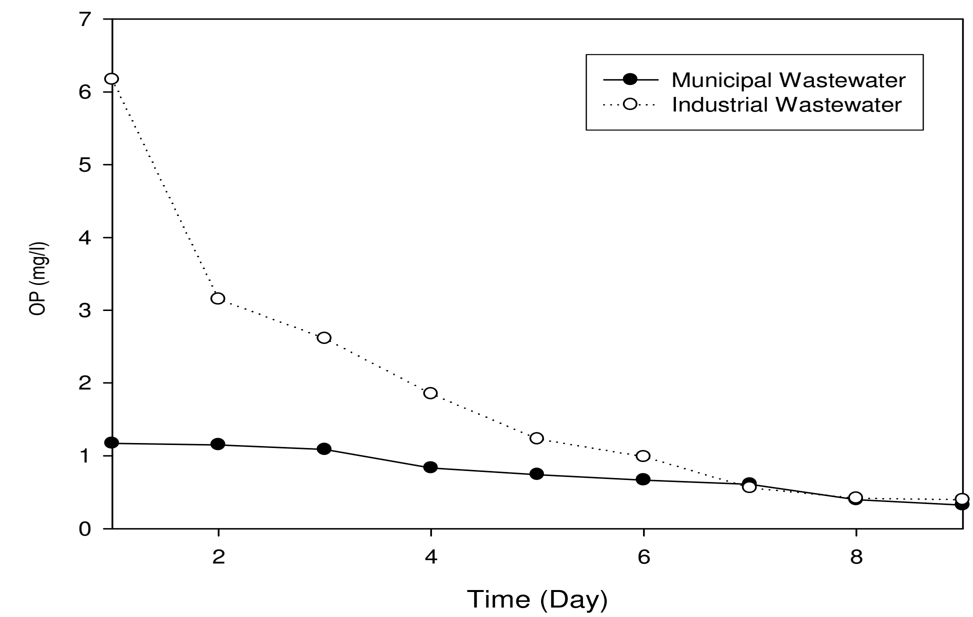

Fig. 7: Influent and effluent OP concentration of municipal and industrial wastewater

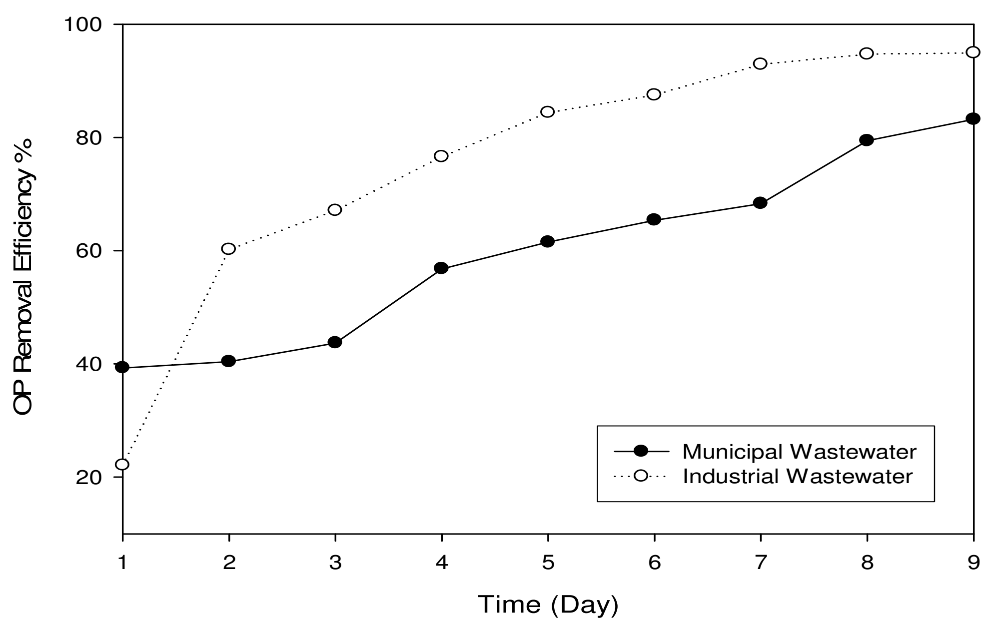

Fig. 8: OP removal efficiency of municipal and industrial wastewater

Nutrient removal: High levels of N and P are known to cause the enrichment of our natural water bodies and cause eutrophication. Nutrients (N, P) are generally accumulated in the plant biomass and are removed through harvesting (Gregory, 1999). N and P losses can be attributed to uptake by duckweed, its attached biofilm, the biofilm attached to the walls of the systems and sedimantation of particular N and P (Korner *et al.*, 2003).

The treatment efficiency of pollutants in a constructed wetland system is usually improved by decreasing the hydraulic loading; the longer the hydraulic retention time (HRT), the greater the nutrient removal (Jing *et al.*, 2002).

Nitrogen removal: Nitrogen (N) is a major component of municipal wastewater, stormwater runoff from urban and agricultural lands and wastewater from various types of industrial processes (DeBusk, 1999). The nitrogen is composed of various forms that can exist in water, such as particulate and dissolved organic N, ammonium, nitrite, and nitrate. These various forms can transform and serve as sources or end products for each other within the nitrogen cycle (Dotch and Gerald, 1995). For this reason, only TN is considered. Although the nitrogen components can be affected by various proceses, denitrification is the only major net, high term removal process for TN.

The influent TN concentrations of municipal and industrial wastewater were 45.8 mg/l and 36.8 mg/l respectively. Fig. 3 shows the influent and effluent TN concentration of municipal and industrial wastewater. The final effluent TN was 8.06 mg/l and 7.06 mg/l respectively. Duckweed has a productive removal capacity both for municipal and industrial wastewater. Nitrogen removal of municipal and industrial wastewater was similar.

Substantial removal of N may take place through settling of N containing particulate matter in the wetland inflow. In addition, since N is an essential plant nutrient, it can be removed through plant uptake of ammonium or nitrate, and stored in organic form in wetland vegetation (DeBusk, 1999).

Weber concluded that nitrification followed by denitrification was the principal nitrogen removal mechanism (Anonymus, 1998). The optimum pH for nitrification is in the range 7.5-9.0. Below pH 7.0 and above 9.8 nitrification rate is less than 50% of the optimum (Surampalli *et al.*, 1997). Both municipal and industrial wastewater showed pH in the influent 7.2±0.2 and at the final effluent around 8.0±0.2.

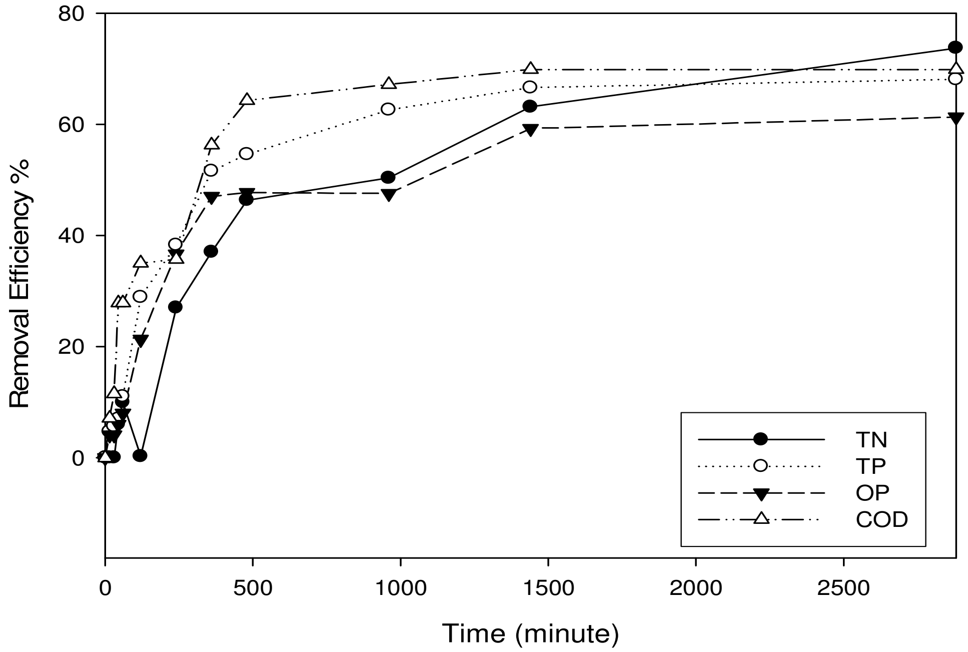

Fig. 10: Changes in removal of COD, TN, TP, OP throughout 48 hr monitoring of municipal wastewater

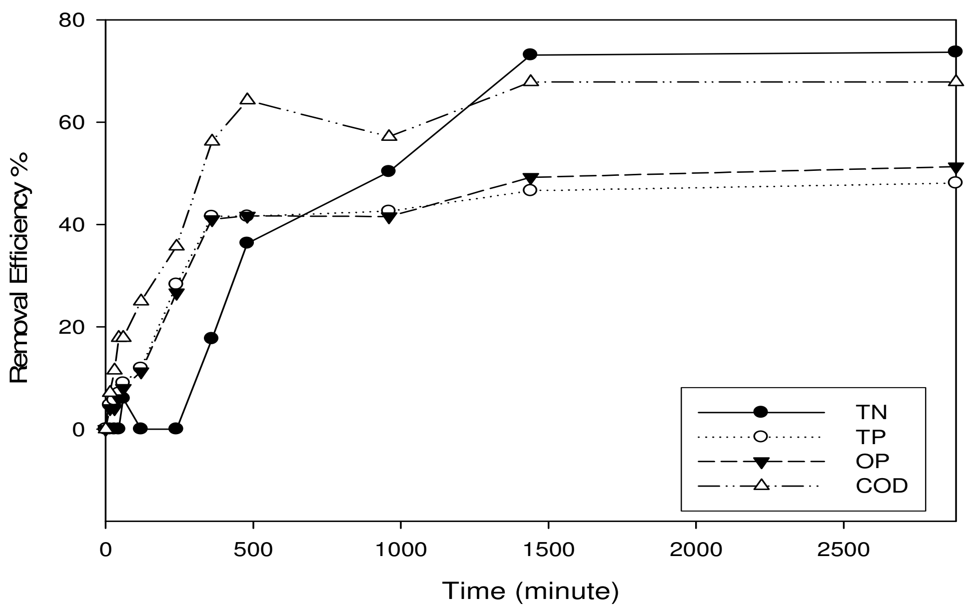

Fig. 9: Changes in removal of COD, TN, TP, OP throughout 48 hr monitoring of industrial wastewater

Fig. 4 shows the TN removal efficiencies of municipal and industrial wastewater. TN removal efficiencies were 86.49% and 83.69% respectively in municipal and industrial waste water. Removal efficiencies of 34-99% for N in system using *L.gibba* were reported by Korner and Vermaat (1998). Nutrient removal in the examined systems, in general, was found to be comparable to other experimental and land applied duckweed covered systems. Reported nitrogen removal efficiencies using *Typha* sp. were 73-97% by Korner and Vermaat (1998); 89% by Meutia (2001); 98% by Gonzalez *et al.* (2001) and using *Lemna minor* L. were 56-67% by Erol Nalbur *et al.* (2003).

Phosphorus removal: Phosphorus (P), like N, is a major plant nutrient, hence, addition of P to the environment often contributes to eutrophication of lakes. Phosphorus removal from aquatic macrophyte systems is due to plant uptake, microbial immobilization into detritus plant tissue, retention by underlying sediments and precipitation in the water coulumn (Anonymus, 1998). Phosphorus in wastewater may be present as ortho-phosphate, polyphosphate or organic phosphorus (Surampalli *et al*., 1997) which are affected by biotransformation, sorption, settling, sedimentation, mineralization and hydrolisis (Dotch and Gerald, 1995).

Like nitrogen only, TP was considered for analysis. Influent TP concentration of municipal and industrial wastewater was 3.53 mg/l and 1.53 mg/l respectively. Fig. 5 shows the TP concentration of municipal and industrial wastewater and the final TP of effluent was 1.363 mg/l and 0.289 mg/l respectively. Where as TN retention is practically constant with time, TP retention decrease with time for a relatively new wetland as the sediments become saturated with P. After the sediments reach a saturated equibilrium, the removal rate becomes relatively constant with time and is proportional to the sediment burial rate (Dotch and Gerald, 1995).

Fig. 6 shows the TP removal efficiencies in municipal and industrial wastewater. TP removal efficiencies were 71.72% and 85.4% respectively. Removal efficiencies of 14-92.2% for P in system using *L.gibba* were reported by Korner and Vermaat (1998). Removal efficiency of industrial wastewater is higher than that of municipal wastewater. Vermaat and Hanif (1998) reported that experimental study of domestic wastewater with Lemnaceae resulted in 77% removal of TP.

Ortho-phosphate is more easily removed of the three types of phosphorus. Orthophosphate is the predominant inorganic form of P in surface waters. This form of P readily accumulates in wetland vegetation and soils, as a result of biological uptake and chemical bonding (DeBusk, 1999). The main OP removal mechanism in DWWT is plant uptake.

Fig. 7 shows effluent concentration of municipal and industrial wastewater. OP influent concentrations were 1.17 mg/l and 6.17 mg/l respectively. The final effluent OP was 0.323 mg/l for municipal wastewater and 0.397 mg/l for industrial wastewater.

Table - 1: Dimension of DWWT

Application	For factory from organized industrial region	For a small town
Water depth (M)	0,9	0,9
Hydraulic retention time (Day)	15	15
Harvest program	1.5-2.0	1.5-2.0
Influent flow rate, (m^3/gun)	500	90
Initial investment cost (\$/m^3)	275	800
Operating cost, (\$/d)	0,13	0,75

Fig. 8 shows the OP removal efficiency in municipal and industrial wastewater. OP removal efficiencies were 83.26% and 94.99% respectively. Reported wetland removal results indicate a variable performance with net phosphorus removal rates ranging from 0 percent to 79 percent for a long term surface flow system in Netherlands (Gearheart, 1992). OP removal efficiecy of the experimental study compares well with other experimental sudies [Altay *et al.* 1996 (60%) ; Vermaat and Hanif, 1998 (97%); Jing *et al*., 2002 (73.2-88.8%)].

Fourty eight hr monitoring was performed both for municipal and industrial wastewater. Interval sample were taken throughout 48 hr (at 0, 15, 30, 45, 60, 120, 240, 360, 480, 960, 1440, 2880 min.) to determine the best removal time. Fig. 9 shows changes in removal of COD, TN, TP, OP throughout 48 hr monitoring of industrial wastewater and Fig. 10 shows changes in removal of COD, TN, TP, OP throughout 48 hr monitoring of municipal wastewater. The results indicate for TP, OP, COD maximum level of removal at 360 min. and for TN maximum level of removal at 1440 min. was observed. In industrial wastewater. After these times removal rate became constatnt. The maximum level of removal for TP, OP, COD was reached at 480 min. and for TN at 1440 min.

Constructed and natural wetlands have been used extensively to treat several types of wastewater. It has been observed that :-

- *Lemna minor* L. has a high capacity of adaptation.
- COD removal efficiencies in municipal industrial and wastewater were 83.67% and 74.55% respectively.
- TN removal efficiencies in municipal industrial and wastewater were 86.49% and 83.69% respectively.
- TP removal efficiencies in municipal industrial and wastewater were 71.72% and 85.4% respectively.
- OP removal efficiencies in municipal industrial and wastewater was 83.26% and 94.99% respectively.
- Duckweeds can play a substantial role in nutrient removal.
- Degradation of organic material in terms of COD is fast in duckweed covered wastewater treatment systems.

Table 1 shows results which are designed for a small town and factory. Overall, results demonstrated that wetland treatment is the best choice for treatment of wastewater because of the low maintenance costs and simplicity of operation.

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