

Treatment of Domestic Wastewater Using Duckweed Plant

Mohammed Ali Al- Hashimi and Rasha Azeez Joda

Department of Building and Construction, College of Engineering,
University of Technology, Iraq.

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Abstract. Pollutants removal from domestic wastewater by growing Lemna gibba, a promising duckweed identified in previous studies, was investigated under laboratory conditions. The duckweed wastewater treatment system used in this study consists of sedimentation and Duckweed tanks. Samples from the wastewater media in both sedimentation and duckweed tanks were analyzed for Temp., pH, BOD, COD, TSS, TDS, EC, NH₃-N, NO₂-N, NO₃-N, Fecal coliform, and Total bacteria count. The average removal efficiencies of TSS, BOD, COD, NH₃-N, NO₂-N, NO₃-N, TN, TP, TDS, EC, Fecal coliform bacteria, and Total bacteria count for sedimentation tank were 55%, 27%, 24%, 26%, 30%, 27%, 19%, 32%, 6%, 4%, 50%, 39%, respectively. While the average removal efficiencies of BOD, COD, TSS, TDS, EC, NH₃-N, NO₂-N, NO₃-N, TN, TP, fecal coliform, and total bacteria count for duckweed tank were 60%, 54%, 63%, 9%, 5%, 63%, 64%, 63%, 63%, 65%, 96%, 98% at 66th day running time. The analysis of plant tissue was done. The rates of nitrogen and phosphorus uptake by duckweed growing in the system were 0.173 g/m².d and 0.032 g/m².d, respectively. The observed duckweed growth rate was close to 1.2 g/m².d. Wastewater concentration and climate conditions had direct impact on the duckweed growth and nutrient removal in the tank.

Introduction

Sewage is clearly a complex mixture of materials from varied sources. It is predominantly water, often approximately 99.9% water with less than 0.1% dry solid matter (Barnes & Wilson, 1976).

High levels of nitrogen and phosphorus in rivers and streams could cause "Eutrophication". This occurs when algae and phytoplankton experience a large "bloom" in growth due to the abundance of nutrients. This new Organic matter, along with any of that may have been discharged to the surface water with the nitrogen and phosphorus, creates a much higher chemical oxygen demand (COD) in the water. As the algae die, the bacteria consuming them have the potential to remove most of the available oxygen in the environment. This results in fish killing and overall degradation of the quality of a body of water (Lyerly, 2004).

Duckweed is a small, free-floating aquatic plant belonging to the Lemnaceae family. Several full scale applications of duckweed based wastewater treatment systems exist in USA, Bangladesh, and China (Leng *et al.* 1999).

Duckweed systems have been studied for secondary effluent (Harvey & Fox, 1973; Sutton & Ornes, 1977); waste stabilization pond effluents (Wolverton, 1979); dairy waste lagoons (Culley *et al.* 1981); fish culture systems (Porath & Pollock, 1982; Rakocy & Allison, 1981); and domestic sewage (Skillicorn *et al.* 1993, Oron, 1994, Alaers *et al.* 1996). These studies were carried out in different countries including: Morocco, Egypt, Palestine, Ghana, Colombia, Taiwan, China, Vietnam, Thailand, India (Gijzen & Ikramullah, 1999).

As a plant for wastewater treatment, duckweed has several advantages over other aquatic macrophytes. First, duckweed has a high rate of nutrients uptake, and can tolerate high wastewater nutrients levels (Landolt, 1986). Duckweed multiplies vegetatively and accumulates biomass rapidly. Furthermore, duckweed biomass has high protein content, ranging from 35-43% of dry weight (Leng *et al.* 1995).

Gijzen & Ikramullah (1999) reported that the average total nitrogen and phosphorus removal were 74% & 77%, respectively. While Sutton & Ornes (1975); Oron *et al.* (1986); Hammouda *et al.* (1995);

Vatta *et al.* (1995) Alaerts *et al.* (1996); Korner & Vermaat (1998); Vermaat & Hanif (1998) report the removal efficiency is 34 to 99% for N and 14 to 99% for P for systems using Lemna gibba. While Lyerly (2004) reports the average nitrogen and phosphorus removal of 62% & 49% respectively using Lemna gibba.

Zimmo *et al.* (2000) reports that the typical daily nitrogen and phosphorus uptake rates are (0.4 g N/m².day) and (0.03 g P/m².day) depending on growth rate, harvesting scheme and species. Culley *et al.* (1981); Zirschy & Reed (1988) report the nitrogen uptake rates of Lemna gibba vary between 0.045 and 1.67 gm/m².day While Culley *et al.* (1981); Reddy & Smith (1987); Zirschy & Reed (1988) ; Korner & Vermaat (1998); Vermaat & Hanif (1998) report the phosphorus uptake rates of Lemna gibba also vary between 0.008 and 0.022 gm/m².day. Duckweed species have been fed to cattle, poultry, fish, and ducks as a protein rich food Leng *et al.* (1995).

Cheng *et al.* (2002) report the nitrogen and phosphorus removal from swine lagoon liquid by growing lemna minor was investigated under laboratory and field conditions in North Carolina.

Landsman *et al.* (2005) conducted their research in the southern high plains of Texas and showed that lemna obscura grew well in cattle feedlot runoff water and produced leaf tissue with high protein content.

Research Objective

The main objectives of this research are to:

1. Present a group of tiny aquatic plants commonly are known as "Duckweed" and test the ability of duckweed in the wastewater treatment.
2. Test the ability of duckweed in acclimation with laboratory conditions.

Experimental Methods

A Pilot plant for the sedimentation tank and duckweed tank as sequential system was built and installed in the sanitary engineering laboratory-University of Technology . The experimental procedures for laboratory analysis were carried out according to standard methods for examination of water and wastewater manual 1985, These tests included Temp., pH, BOD, COD, TSS, TDS, EC, NH₃-N, NO₂-N, NO₃-N, TN, and TP. The bacteriological tests were done in the laboratory of the Food Research Centre (Ministry of Health). These tests included fecal coliform and total coliform

bacteria count, The experimental procedures for laboratory analysis were carried out according to Abawe, S.A. & Mohammed S.H. (1990). The details of building the pilot plant and setting up are explained as follows.

Sedimentation Tank

The source of wastewater was from the collective tank of Al- Talbiya community. The continuous flow rate 33 l/d was fed into a storage tank to mix the wastewater and remove the floating matter, after that the wastewater was fed to the cylindrical sedimentation tank as shown in Figure1 which was made from Galvanized iron. It consists of a cylindrical basin with diameter and depth 90 & 40 cm respectively.

A small cylindrical perforated plate was placed in the centre of tank with diameter and depth 25 & 40 cm respectively. This plate is connected to the hopper which lies down of the sedimentation tank and used for sludge processing. The hydraulic residence time for the sedimentation tank is 2hr.

Duckweed Tank.

The wastewater from sedimentation tank was then fed to the duckweed tank which was covered with Lemna gibba. This tank was made from Galvanized iron, its length and width were 1.95 and 0.67 m respectively. The hydraulic retention time was 3 days, so the wastewater was fed to the tank in three periods during three days. During the operation of the system the duckweed was harvested at a rate that would remove enough biomass to allow healthy growth, while not leaving any surface area exposed. Harvesting took place at the end of each run manually that plants were approximately 20% of the surface area of the tank removed. The harvest was air dried for about 10 minutes in order to remove excess water.

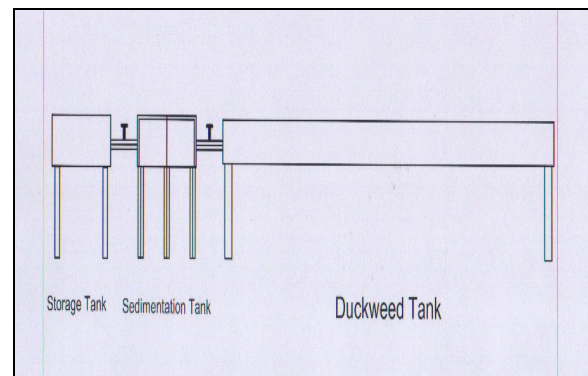


Fig. 1. Model of Duckweed wastewater treatment system.

The weight of duckweed harvested was recorded to measure the growth of the plant, and then the wet duckweed samples were dried in an oven at 105 °C for about 12 hrs to determine the dry weight. Light intensity was provided by fluorescent tubes at 72 W/m² with 12hrs photoperiod per day

Plant tissue was also sampled weekly for measuring of (TN, TP, and MC%), these tests were done in the biology laboratory (Baghdad University) to determine the nitrogen and phosphorus content in duckweed according to Ryan et al. (1996)

Results and Discussion

The efficiency of sedimentation tank on pollutants removal

The removal of TSS is lower than the removal efficiency reported by Barnes & Wilson (1976) which was (60-70)% although providing long retention time of (2) hrs to achieve more removal of settleable solids. Figure 2 shows that the removal of TSS increases with running time.

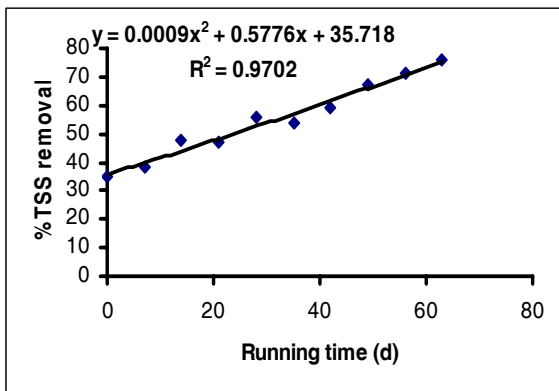


Fig. 2: %TSS removal with running time.

Also the removal of BOD is lower than the value reported also by Barnes & Wilson (1976) which was (30-40)%. The reason may be that the tank requires more hydraulic retention time. Figure 3 shows the BOD removal increases with running time.

As shown in Table 1, the laboratory results show that the sedimentation tank has a good performance in removing the parameters in comparison with other selected treatment plants in California FAO (1992) which were (31%, 54%,10%, 9%, 0, 53%, 1%) for (BOD, TSS, TN, NH3-N, TP, EC, TDS).

The efficiency of sedimentation tank increased with running time for other pollutants parameters as shown in Figs. 4, 5, 6, 7, 8, 9, 10 and 11.

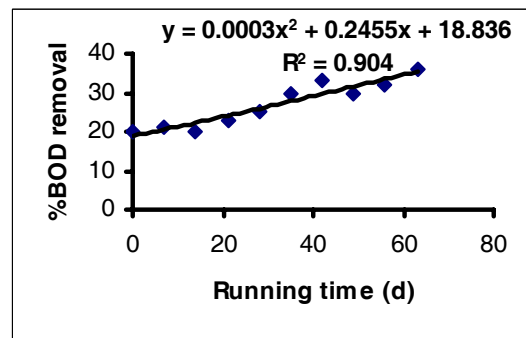


Fig. 3. %BOD removal with running time.

Table 1. The efficiency of sedimentation tank on removing the pollutant parameters

Pollutants parameters	% Reduction
TSS	55
BOD	27
COD	24
NH3-N	27
NO2-N	19
NO3-N	32
TN	26
TP	26
TDS	6
EC	4
Fecal coliform bacteria	50
Total bacteria count	39

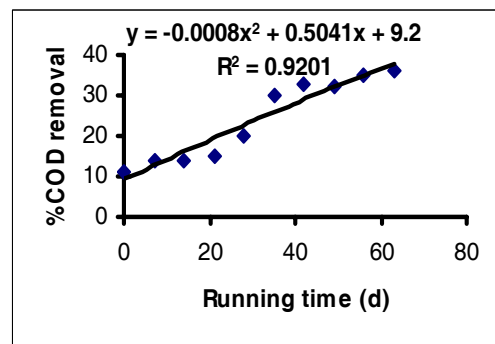


Fig. 4. %COD removal with running time.

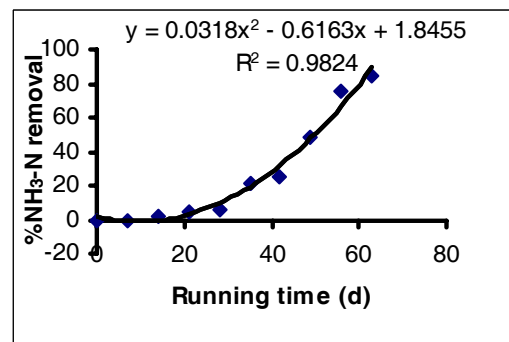


Fig. 5. % NH3-N removal with running time.

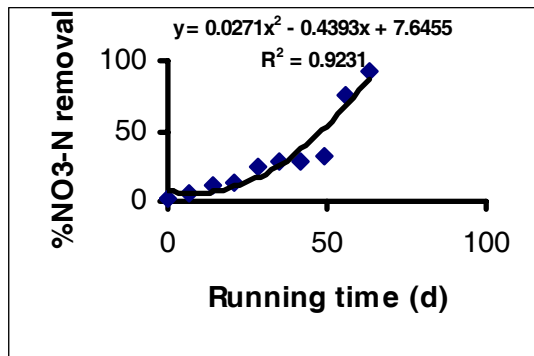
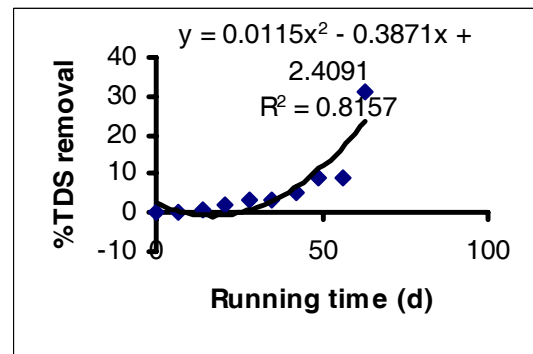
Fig. 6. %NO₃-N removal with running time.

Fig. 10. %TDS removal with running time.

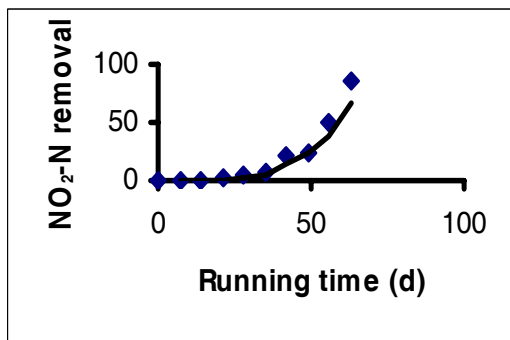
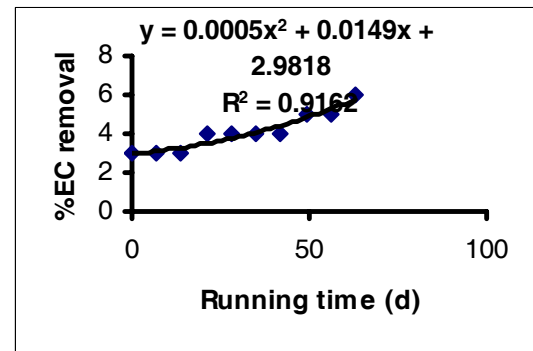
Fig. 7. % NO₂-N removal with running time.

Fig. 11. %EC removal with running time.

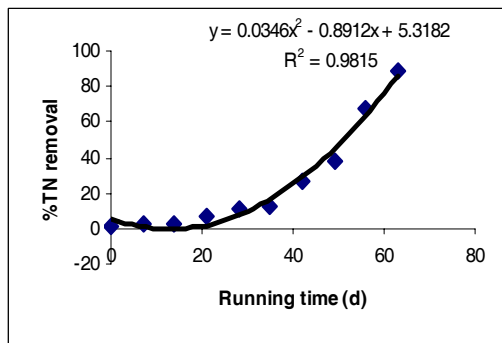


Fig. 8. %TN removal with running time.

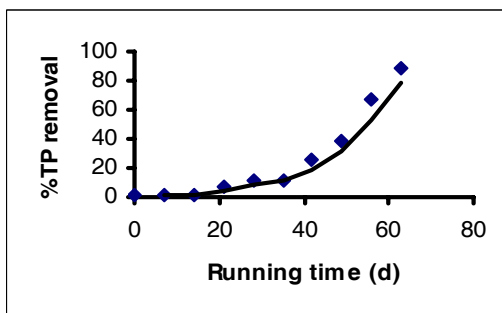


Fig. 9. %TP removal with running time.

Table 2. Efficiency of Duckweed tank

Pollutant parameters	% Reduction
BOD	59
COD	54
TSS	63
TDS	9
EC	5
NH ₃ -N	63
NO ₂ -N	64
NO ₃ -N	63
TN	63
TP	65
Fecal coliform bacteria	96
Total bacteria count	98

The efficiency of Duckweed tank on pollutants removal

The efficiency of Duckweed tank on pollutants removal is shown in Table 2.

Figure 12 shows that the removal efficiency increased with time but decreased at 56 days running time. This is likely due to duckweed die off in the tank which would increase organic loading.

The value of COD reduction is higher than the value reported by Dalu & Ndamba (2002) which was 50% but lower than the reduction reported by Lyerly (2004) which was 62%. Figure 13 shows the COD

removal efficiency increases with time. The COD levels could be high because the duckweed die off in the tank that in turn increases organic load. The chemical oxygen demand, that is the amount of oxygen available for chemical reactions.

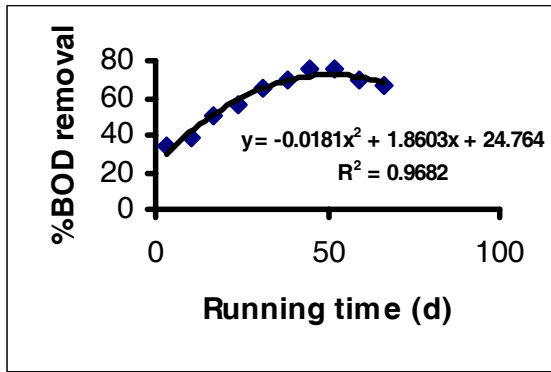


Fig. 12. %BOD removal with running time.

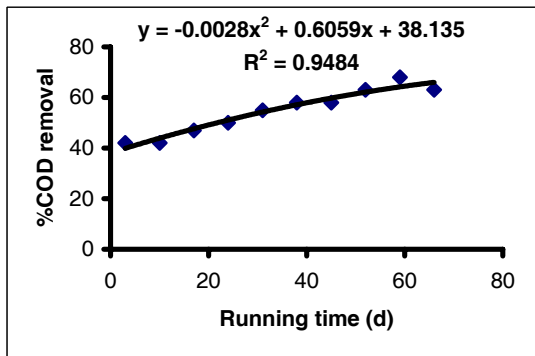


Fig. 13. %COD removal with running time.

The average duckweed influent wastewater temperature was 30.7°C. While the average effluent temperature was 29.5°C. This indicates that the effluent temperature of sedimentation tank dropped after the immersion of duckweed in the tank. The wastewater temperature results approximately coincide with that of the temperature that the duckweed can grow in Skillicorn *et al.*(1993).

The removal value of BOD is higher than the reported by Dalu & Ndamba (2002) which was (30-50)% but lower than the value reported by Gijzen & Ikramullah (1999) which was (96-99)%.

Average influent and effluent pH and alkalinity ranged between (7.6-8.9) and (318-466) mg/l respectively. The pH value is suitable for survival of the plants but the plant grows well at pH (6.5-7.5) range Skillicorn *et al.*(1993) .

The average reduction of TSS was 63%. This value is lower than the value reported by Dalu &

Ndamba (2002) which was 90%. The total duckweed cover in the tank suppresses the growth of algae that normally results in a build up of TSS Dalu & Ndamba (2002). Figure14 shows the TSS removal increases with running time but decreases at the 49 days running time because the duckweed dies off and settles at the tank bottom increase the suspended matter of the effluent Dalu & Ndamba (2002).

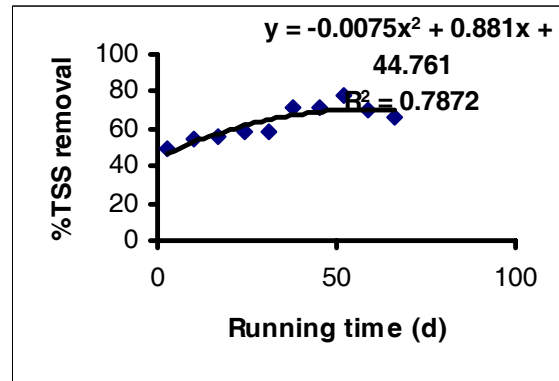


Fig.14: %TSS removal with running time.

The average reduction of TDS and EC were 9% and 5%. This indicates that the duckweed has a slight effect on removing dissolved solids and EC in wastewater. Figures 15 and 16 show the TDS and EC removal increase with running time.

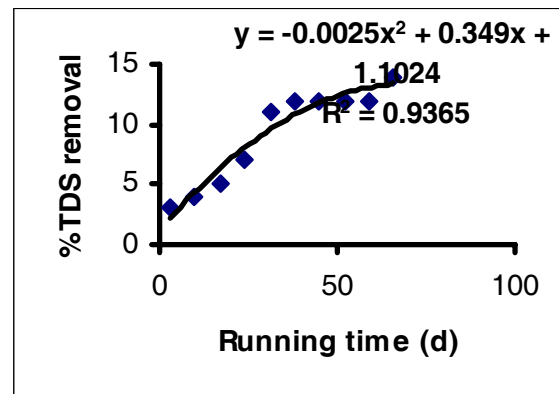


Fig. 15. %TDS removal with running time.

Duckweed uses NH₃-N, NO₂-N, NO₃-N as its growth nutrients and therefore remove these nutrients from the media as the same pattern as TN removal as shown in Figs. 17, 18, 19 and 20. Average reduction of TN was 63%, this value is lower than the value reported by Gijzen & Ikramullah (1999) which was 74% but higher than that reported by Lyerly (2004) which was 62%. The TN removal increases with the running time as illustrated in Fig. 20 but decreases

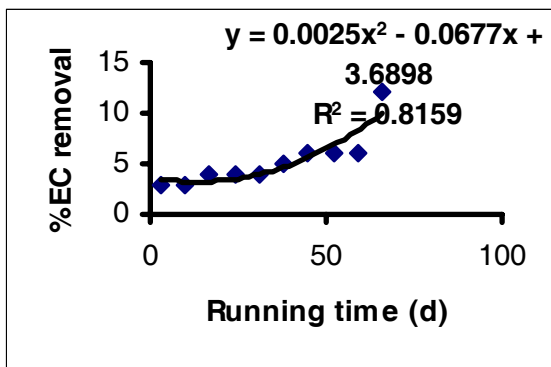


Fig. 16. %EC removal with running time.

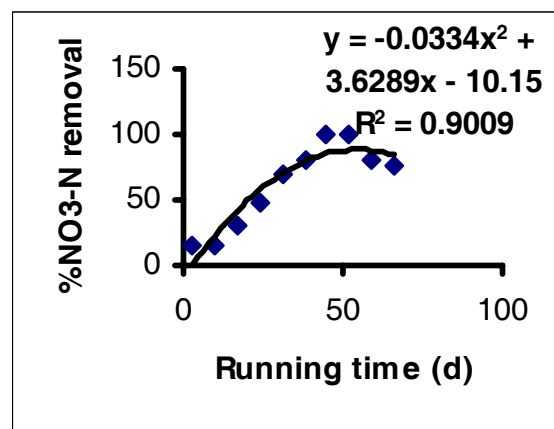


Fig. 19. %NO3-N removal with running time.

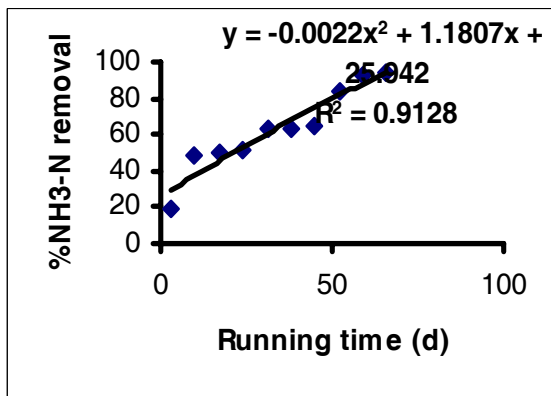


Fig. 17. %NH3-N removal with running time.

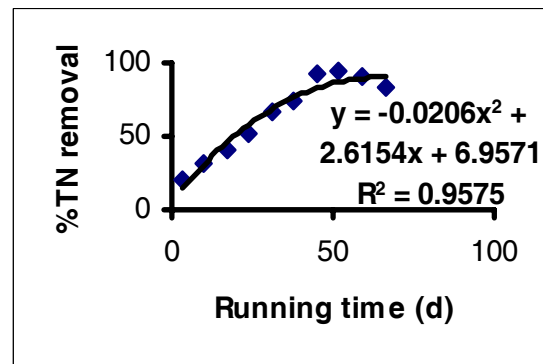


Fig. 20. %TN removal with running time.

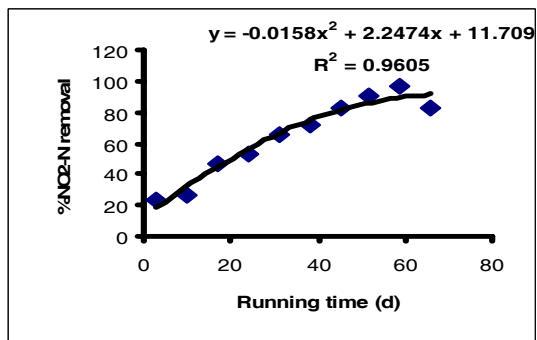


Fig. 18. %NO2-N removal with running time.

after 52 days of running time because the loading rate of nitrogen becomes too great for the mechanisms of removal to keep up and therefore results in an accumulation of nutrients in the tank.

The average influent and effluent phosphorus was 4.6 and 1.6 mg/l respectively, average reduction of phosphorus was 65%, this value was lower than the value reported by Alaerts *et al.* (1996) which was 77% but higher than that was reported by Lyerly (2004) which was 62%. The TP removal increases

with running time as shown in Fig. 21 but decreases also after 52 days of operation for the same above reason. The daily nitrogen and phosphorus uptake rates are 0.173 and 0.032 g/m².d respectively. These values are close to the values reported by Zimmo *et al.* (2000) for phosphorus uptake which was 0.03 g/m².d, but lower than the reported by the same researcher for nitrogen uptake which was 0.4 g/m².d and lower than the value reported by Lyerly (2004) which were (0.61 and 0.18) g/m².d for nitrogen and phosphorus uptake and Cheng *et al.* (2002) which was 0.95g/m².d for nitrogen uptake.

The initial seeding was 1.5 kg/m² to make complete duckweed cover; the plant grew at a rate of 1.2 g/m².d. This growth rate was lower than that stated by Oron *et al.* (1984) and Cheng *et al.* (2002) because of the non suitable growth conditions for duckweed growth.

The percentage of TN removal achieved by duckweed was 21%, while the percentage of TP removal achieved by duckweed was 30%. These values are higher than those reported by Lyerly (2004). And lie in the range reported by Reddy & De

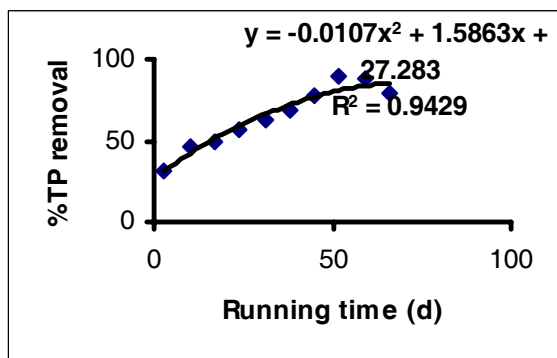


Fig. 21. %TP removal with running time.

Busk (1985); Alaerts *et al.*(1996); Korner & Vermaat, (1998); Vermaat & Hanif, (1998), Reddy & Smith (1987).

The average percent reduction of 96% is achieved for fecal coliform bacteria. This value is higher than the value reported by Al-Khateeb (2004) and equals to value reported by Islam *et al.* (1996) but lower than the value reported by Gijzen & Ikramullah (1999) due to low solar radiation, photosynthesis, and light intensity because the pilot plant is installed in the laboratory and when it is installed outside, the intensity of sun light is high and thus would degrade the duckweed pigments. Therefore, the duckweed requires medium light intensity to grow well.

The average reduction was 98% is achieved for total bacteria count. This is a good percentage reduction achieved by duckweed, due to suitable retention time provided to the system.

Conclusions

From the results demonstrated above, the following conclusions could be drawn :

1. The Sedimentation tank requires more hydraulic retention time to remove S.S.
2. The duckweed would limit the free diffusion of oxygen from the air into the water and may cause little BOD reduction in the tank.
3. The Duckweed die off in the tank that in turn increases organic load and may cause little COD reduction also.
4. The complete cover of Duckweed plants would attenuate sedimentation effluent temperature by preventing the effect of the air temperature on the wastewater below the duckweed mat may cause dropping in the sedimentation temperature after immersion of duckweed in the tank.
5. The duckweed requires more thickening to prevent algae growth which would cause high S.S removal.

6. The duckweed dies off and settling at the tank bottom increases the suspended matter of the effluent.
7. The loading rate of P&N become too great for the mechanisms of removal to keep up and therefore in an accumulation of nutrients in the tank.
8. The Duckweed requires medium light intensity to grow well.

Recommendations for Future Work

1. Duckweed wastewater treatment system must be installed near the natural habitat of duckweed; therefore, duckweed system is suitable for rural areas and communities near this natural duckweed lagoons.
2. Focus on possible transfer of pathogens to workers and the accumulations of toxic compounds (metals and pesticides), especially in industrial wastewater.
3. An important aspect is the possible health hazard associated with use of wastewater-grown duckweed as poultry and other animals feed.
4. The initial investigation for wastewater quality must be done to prevent inhabitation in duckweed growth by diluting the concentrated wastewater.
5. Studying the ability of duckweed in removing heavy metals from wastewater especially if industrial sources of waste enter the system.
6. Studying the possible use of wastewater effluent in fish ponds because the fish forms an important source of high quality animal protein for many people.
7. Studying how the duckweed ponds performs in comparison with algae ponds.
8. Adding sludge treatment unit to remove the sludge from sedimentation tank, depends on type and concentration of the sludge produced.

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معالجة مياه الصرف الصحي السكني باستخدام وحدة عدس الماء

محمد علي الهاشم، ورشا عزيز جودة

قسم البناء والانشاءات، كلية الهندسة، الجامعة التكنولوجية، العراق

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الكلمات المفتاحية: عدس الماء، مياه الصرف الصحي، المتطلب البايوكيميائي للأوكسجين، المتطلب الكيميائي للأوكسجين، النتروجين، الفسفور، المواد العالقة الكلية، العدد الكلي للبكتريا، البكتريا البرازية.

ملخص البحث. تمت دراسته إزالة النفايات من مياه الصرف الصحي السكني في ظروف مخبرية بواسطة زراعة لنا قيبا وهو نوع مبشر من نبات عدس الماء. يتكون نظام معالجة مياه الصرف الصحي بواسطة عدس الماء في هذا النظام من حوض ترسيب وحوض عدس الماء. أخذت عينات من حوض الترسيب وحوض عدس الماء وتم تحليلها لقياس درجة الحرارة، قياس الأس الهيدروجيني (pH)، المتطلب البايوكيميائي للأوكسجين (BOD)، المتطلب الكيميائي للإكسجين (COD)، المواد العالقة الكلية (TSS)، المواد الذائبة الكلية (TDS)، التوصيلة الكهربائية (EC)، الأمونيا (NH₃-N)، النتريتات (NO₂-N)، النترات (NO₃-N)، البكتيريا البرازية (Fecal coliform bacteria). والعدد الكلي للبكتيريا (Total bacteria count). وكان متوسط كفاءة إزالة المواد العالقة الكلية والمتطلب البايوكيميائي للإكسجين والمتطلب الكيميائي للإكسجين والامونيا والنتريتات والنترات والنتروجين الكلي (TN) والفسفور الكلي (TP) والمواد الذائبة الكلية والتوصيلية الكهربائية والبكتريا البرازية والعدد الكلي للبكتيريا لحوض الترسيب على النحو التالي :

55%, 27%, 24%, 26%, 30%, 27%, 19%, 32%, 6%, 4%, 50%, 39%

وكانت كفاءة إزالة المتطلب البايوكيميائي للأوكسجين والمتطلب الكيميائي والمواد العالقة الكلية والمواد الذائبة الكلية والتوصيلة الكهربائية والأمونيا والنتريتات والنترات والنتروجين الكلي والفسفور الكلي والبكتيريا البرازية والعدد الكلي للبكتيريا لحوض عدس الماء على النحو التالي :

60%, 54%, 63%, 9%, 5%, 63%, 64%, 63%, 63%, 65%, 96%, 98%

عند اليوم السادس والستين لوقت التشغيل. وقد وجد بتحليل أنسجة النبات ان معدل أستهلاك النتروجين والفسفور بواسطة زراعة عدس الماء في المنظومه 0.173 جرام / ٢م يوم و 0.032 جرام / ٢م على التوالي. وكان معدل نمو عدس الماء المقاس قريبا من 1.2 جرام / ٢م يوم ٠ كان لتركيز مياه الصرف الصحي والأحوال الجوية أثر مباشر على نمو عدس الماء وإزالة المواد الغذائية في الحوض.

