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Post Treatment of UASB Reactor Effluent in an Integrated Duckweed and Stabilization Pond System for Treating of Domestic Wastewater

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Abstract: Post-treatment of effluent from an Up-flow Anaerobic Blanket (UASB) reactor, which was fed with domestic sewage, has been conducted in an integrated pond system. The UASB reactor was operated at a hydraulic retention time of 8 hrs, the effluent of which was directed to three series of ponds operated in parallel. The system consisted of a series of Duckweed pond (DWP) and stabilization ponds (SP). The main objective of post-treatment is removal of bacterial pathogens and further polishing of effluent quality. The results obtained indicated the superiority of the treatment scheme consisted of 2DWP, 2AP, 2DWP) are efficient with regard to organic pollutants removal as reflected residual COD and BOD values (COD: 75mg0_2/l, and BOD: 23.7mg0_2/l). Also, 83.1 % of TSS were removed. Percentage removal of fecal coliform was around 99.99%. Residual FC counts in the final effluent concentration were extremely variable, ranging from 3E+01 to 7E+03 per 100ml with an average value 8E+02per 100ml. However duckweed ponds with long retention time can be competitive in reducing pathogens. It was demonstrated that duckweed bio-mass production and wastewater treatment for reuse in irrigation can be achieved in one simple system. The highest duckweed production (23g dry weight/m^2 .d) has been recorded in the first (2DWP) and (23.46g dry weight/m^2 .d) of the second (2DWP). From the available data it can concluded that a treatment system consisting of UASB reactor followed by a series of duckweed and algal ponds is highly recommended for small communities such as rural areas and small cities.

Key words: Wastewater treatment, effluent reuse, UASB, duckweed, algal pond

INTRODUCTION

Several studies carried out in both pilot-scale and full-scale systems have demonstrated that the UASB reactor is a reliable and simple technology for treatment of domestic sewage (Peter van der steen, *et al,* 1999). Therefore, this technology could be applied in wastewater treatment and reuse schemes in arid and semi-arid regions in developing countries. However, the UASB effluent still contains high counts of fecal micro - organisms. In order to achieve the effluent quality required by the (WHO, 1989) for unlimited irrigation, the UASB effluent should undergo post- treatment. It has shown that post-treatment of UASB effluent in a series of (SP) can reduce the concentration of both helminth eggs and fecal coliforms below the guideline-concentrations of the WHO for unlimited irrigation. Waste stabilization ponds are low-cost and efficient systems for wastewater treatment, producing high quality effluent that enables water re-use in irrigation (Zimmo *et al,* 2003 and Zimmo *et al,* 2004). It was shown that bacterial pathogen decay results from complex interactions of several factors such as light radiation, depletion of nutrients, microbial antagonism, presence of anti-bacterial substances produced by algae and high oxygen concentrations (Saqqar and Pescod, 1992). Another important factor is the high pH that occurs during daytime, especially in SP with intensive algae-growth (Curtis *et al,* 1992) partly elucidated the mechanism by which light, in combination with high pH values and high oxygen concentration, accelerates the decay of bacterial pathogens. A drawback of SP is the low efficiency of TSS and BOD removal, due to the presence of algae in the effluent. This could result in difficulties to satisfy discharge criteria for BOD or in reuse applications for drip-irrigation. This work intends to show that algae can be removed from SP effluent by passing the SP effluent through a stage with reduced illumination. This shading is expected to cause the algae to die and to settle or disintegrate. The shading can be realized in a series of duckweed pond (DP). Duckweed ponds are covered by a floating mat of macrophytes, thus preventing light penetration into the pond. DP has been applied as a polishing treatment stage to remove

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nutrients from wastewater. Duckweed has the capability to purify wastewater in collaboration with both aerobic and anaerobic bacteria. The duckweed mat fully covers the water surface, resulting in three zones in the ponds. These are the aerobic zone (10cm below the duckweed mat) the anoxic zone and the anaerobic zone (Skillicorn *et al.,* 1993). The high growth rates of the macrophyte permits regular harvesting of bio-mass and hence nutrients are removed from the system. The produce bio-mass has an economic value because it can be applied as fodder for poultry and fish. (Van Der Steen *et al.,* 1999). An important sanitary disadvantage of DP is their poor performance with respect to bacterial pathogen removal due to the reduced light penetration into the water. This problem can be simply solved by combining DP with SP in an integrated pond system, to benefit from their respective advantages. The use of a low-cost pretreatment process, namely UASB followed by a series of duckweed and algae ponds to produce effluent which can be used for irrigation was the subject of this study.

MATERIALS AND METHODS

A continuous pilot - scale study of biological treatment units were designed. It consists of three schemes, they involved anaerobic treatment UASB (1.3m^3) was operated at a hydraulic retention time of 8 hrs, as a first stage of treatment. The second stage was either: -At the first scheme, the pond system comprises tow ponds in series, AP, especially for removal of bacterial pathogens followed by DP for the removal of algae. In the second scheme, the pond system comprises three ponds in series, DP, this stage is included to benefit from the nutrient concentration in the UASB effluent for duckweed production as well as for settling of solids, AP especially for the removal of bacterial pathogens, followed by DP for the removal of algae and for further nutrient conversion and effluent polishing. In the third scheme, the system consisted of six ponds in series, arranged in three stages, 2 DP as the first stage followed by 2 AP. the third stage consists of 2 DP. The algal ponds were seeded with natural phytoplankton collected from the Nile River. The duckweed species used was *Lemna gibba*. The stocking density of the duckweed is kept around 800 g/m^2 to ensure complete covering and avoid algal blooming. The operating conditions are summarized in Table (1). All physico-chemical and micro - biological examination were carried out in accordance with the APHA (1995).

Table 1: Operating conditions of the Duckweed/Algal pond Systems

Items	Scheme (1)	Scheme (2)	Up-scaling of scheme N02-(scheme N03)					
Surface organic loading rate (OLR) kg BOD/ha.day	33.936			29.8			31.1	
Hydraulic loading rate (HLR) m^3/ha.day	336			346.4			369.2	
Pond system	AP	DP	DP	AP	DP	2 DP	2 AP	2 DP
Volume/L	400	400	480	480	445	879.6	899.9	871.7
Hydraulic detention time(HRT)/day	5	5	3.16	3.36	3.36	3.3	3.3	3.3

RESULTS AND DISCUSSIONS

Physico -chemical Characteristics of Raw Sewage:

It has been found that the raw wastewater COD and BOD values were593.6mg O_2/l and 285mg O_2/l, respectively. Around 55.6% of the COD and 41.3% of the BOD were in a particulate form. TSS were relatively high, ranging from 68 to 505mg/l. Mean phosphorous, ammonia and TKN concentrations were 5.4mg/l, 28mg/l and 56.7mg/l, respectively. Geometric mean of total fecal coliform, and colloidal fecal coliform were 1.64E+09 and 2.9E+08, respectively. In general, sewage strength can be considered above normal.

Primary Treatment:

Physico-chemical analysis of anaerobic (UASB) effluent:

Available data indicated that average removal values of BOD_{tot}., COD_{tot}. and TSS were 66.8%, 61% and 64.4%, respectively. Mean residual phosphorous, ammonia and TKN concentration were 3.7mg/l, 31.5mg/l and 51.4mg/l, respectively Microbiological examination revealed a reduction of only one log. From these results it can be seen that the effluent quality from the anaerobic digester UASB was far too variable for it to be safely discharged directly without any further treatment into the environment and that a post-treatment step is required.

Post Treatment:

Treatment scheme N0.1:

The results of the performance of the integrated treatment scheme N0.1, are presented in Figures (1-2).

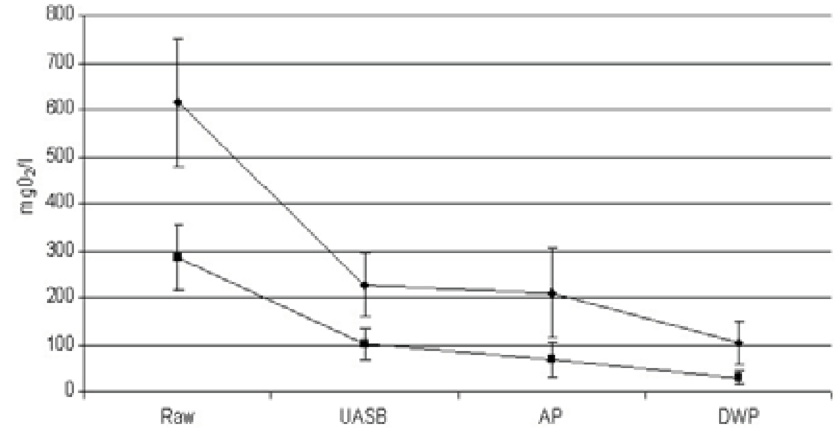

Fig. 1: Variation of COD&BOD along the treatment units of Scheme NO.1 (Average for 40 samples)

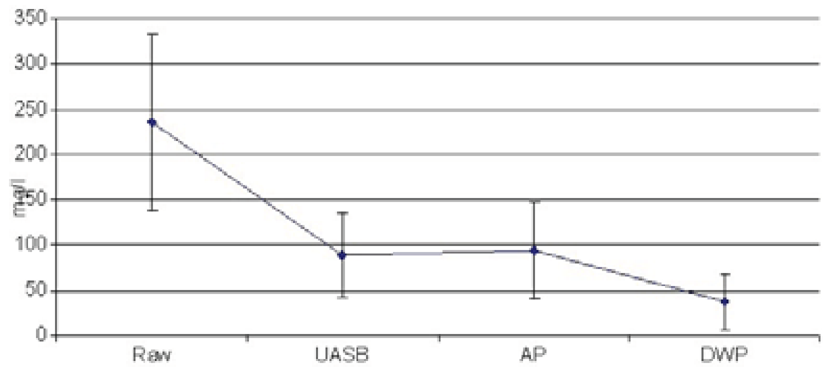

Fig. 2: Variation of TSS along the treatment units of scheme No.1

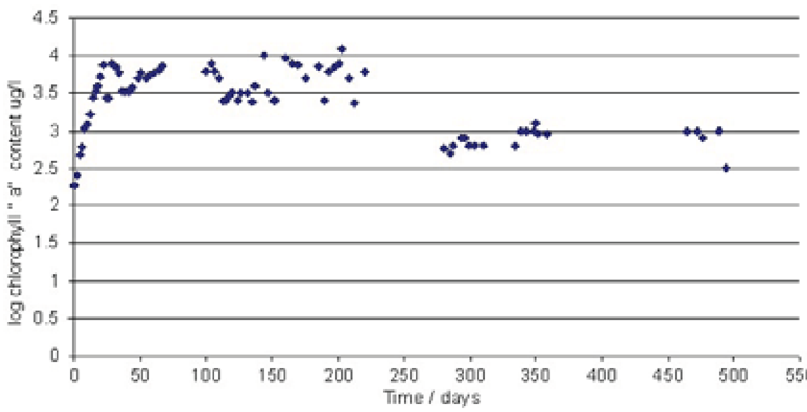

Fig. 3: Changes in chlorophyll" a" content for algal pond of scheme N01 (Samples N0.77)

***Algal pond*:**

$COD_{tot.}$ removal in the algal pond was very limited (1.4%). This is attributed to the presence of high concentrations of algae in the pond effluent. Similar results have been reported by (Fukunaga, 1992 and Jalali *et al* 2002). Corresponding $BOD_{tot.}$ removal values were 18.8%. TSS in the algal pond effluent ranged from 19.4 to 200mg/l, with an average residual value of 94.2mg/l. Total nitrogen and phosphorus uptake in the algal pond were 853mg/ m^2/d and 13.3mg/m^2/d., respectively. The geometric mean of fecal coliform counts indicated a reduction of two log in the pond effluent as compared to the UASB effluent.

Variation in algal growth calculated by determining chlorophyll" a" content is shown in Figure (5). Maximum algal growth was 11.4mg/l, which is equivalent to 763.8mg/l dry weight.

Microscopic examination of algal populations was carried out. The results obtained showed that initial flora was characterized by four algal groups, namely Chlorophyta (green algae), Euglenophyta (motile green algae), Cyanophyta (blue green algae) and Bacillariophyta (diatoms). The recorded four algal groups included 45 species (17 species of Chlorophyta, 3 species of Euglenophyta, 5 spicies of Cyanophyta and 20 species of Bacillariophyta). Diatoms represented the most dominant group, present in high numbers exceeding the other groups. The most dominant species *were Cyclotella comta, Melosira granulata, Diatoma elongatum,Nitzschia linearis* and *Synedra ulna*. A good diversity of green algae was present, the most dominant of which were *Scenedesmus quadrcauda* and *Pediastrum simplex*. Low diversity of blue-green algae has been recorded. During the experimental *run,* changes in diversity and redundancy of algal population took place. The more sensitive algal species disappeared completely, while the tolerant forms resisted the condition and increased in numbers. Euglenophyta represent the most abundant group present in good number during the investigated period. The most dominant species were *Euglena pissiformis* and *Chlamydomonus variabills*. Blooms of the tolerant algae, *Chamydomonus* and *Euglena* indicate the presence of high organic load. Mitchell & Buzzell (1971) recorded that, high organic load causes a great reduction in the number and kinds of algae. Also, Silva (1982), Shehata & Badr (1996) and Zimo et al (2004) found that the increase of the organic load led to the disappearance of the some algal species while some species are not affected such as *Euglena, Scenedesmus* and *Chlamydomonus*. The most dominant species of the green algae was *Oocystis solitaria*. Blue green algae were represented by only one species, *Merismopedia sp*. *Bacillarophyta* were fairly common at the beginning of the experiment and disappeared during the experiment and the species numbers were reduced by 80%. *Nitzschia linearis* was present in good numbers. However, gross pollution causes a great reduction in number and kinds of algae species.

Duckweed pond:

COD_{tot}. and $BOD_{tot.}$ removal values in the duckweed pond were 43.5 %. and 48.2%, respectively. TSS concentration in the duckweed pond effluent averaged 37mg/l. Total nitrogen uptake in the duckweed pond (880mg/m^2/d) was higher than that in the algal pond (853mg/ m^2/d) this indicates higher biomass production in the duckweed pond. The same trend has been observed for phosphorus. Total phosphorus uptake in the duckweed pond was 73.3mg/m^2/d. Corresponding value was 13.3mg/m^2/d for the algal pond. After reaching the steady state condition*, Lemna gibba* yielded good results in terms of relative growth rate and competitive condition for algae. The results of biomass production, relative growth and the dry matter content are presented in Table (2). Gideon *et al.,* (1984) found that the specific growth rate was in the range from 0.13 to 0.23 g/g per day, and the dry matter content was between 4.7 and 5.2%. Also, the maximum yield was around 15g/m^2/d (dry matter). The geometric mean of fecal coliform counts indicated a reduction of one log in the duckweed pond effluent, as compared to the AP effluent. Microbiological examination of the different suspended solids forms showed that most of the fecal coliform is associated with the colloidal fraction.

Table 2: Duckweed growth parameters for the scheme N0.1

	Wet weight g.m^{2-} d	Dry weight g.m^{2-}d	Relative growth rate g.g.d	Dry matter content %
Min	79.5	8.5	0.016	1.5
Max	3110	55.7	1.3	4.4
Average	686.7	20.7	0.3	3.2

Treatment Scheme N0.2:

Physico-chemical characteristics of raw sewage and the effluents of the treatment units are presented in Figures (4-5).

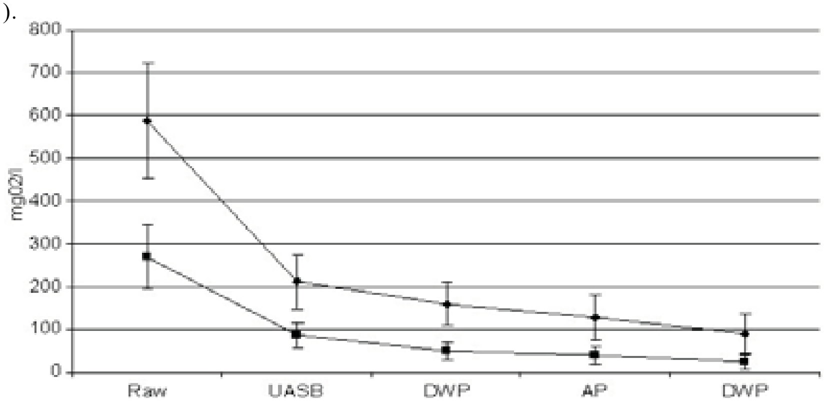

Fig. 4: Variation of CODtot. along the treatment units of scheme NO.2(Average for 62 samples)

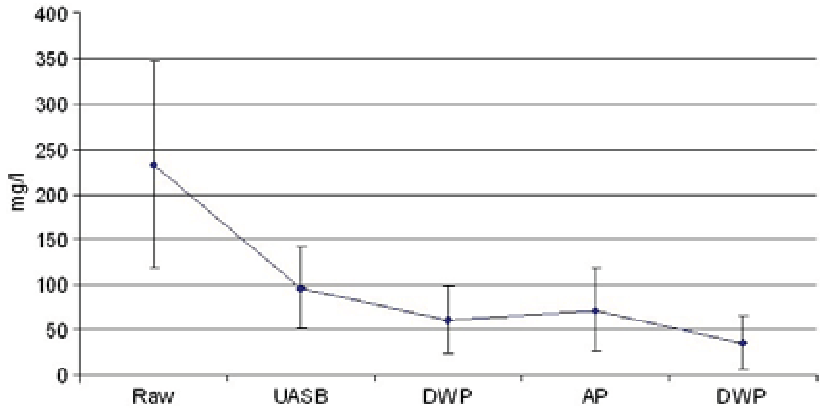

Fig. 5: Variation of the TSS along the treament units of scheme N0 2

First duckweed Pond:

COD reduction from 212mg0_2/l (in UASB effluent) to 159.8mg0_2/l in the pond effluent has been recorded. Corresponding, BOD values were 86.1mg0_2/l (in UASB effluent) to 51.2mg0_2/l. Average COD and BOD percentage removal values in the pond effluent were 15.8% and 35.9%, respectively. Mean value of TSS concentrations in the pond effluent was 61.2mg/l. Total nitrogen and phosphorus uptakes were 970 mg/m^2/d and 90mg/ m^2/d, respectively in the first duckweed pond. After reaching the steady state condition, *Lemna gibba* yielded good results in terms of relative growth rate and competitive condition for algae (Figure 6 and Table 3).

Table 3: Mean values of the Duckweed growth parameters in scheme N0.2

	Duckweed production of the 1st. Pond				Duckweed production of the 2nd Pond			
	Wet weight g.m2. d	Dry weight g.m2.d	Relative growth rate g.g.d	Dry matter content %	Wet weight g.m2. d	Dry weight g.m2.d	Relative growth rate g.g.d	Dry matter content %
Min	112.5	5.1	0.01	1.1	95	9.5	0.01	1.1
Max	2137.7	56.0	1.1	5.4	2175.0	56.0	0.9	6.2
Aver.	617.8	20.9	0.3	3.6	595	20.4	0.3	3.7

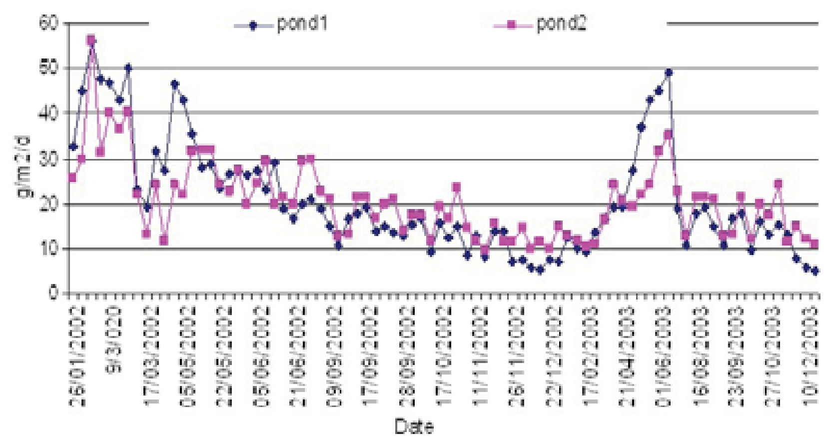

Fig. 6: Variation in the dry weight of duckweed ponds in scheme N0.2

Algal Pond:

COD concentrations decreased from 195.8mgO_2/l (in the first duckweed pond effluent) to 127.5mgO_2/l in the AP effluent. Corresponding, BOD values were 51.2.1mgO_2/l and 39.6 mg0_2/l. Average value of TSS concentrations in the algal pond effluent was 72.2mg/l. Nitrogen uptake in the algal pond was 880mg/m^2/d. Corresponding value was 853mg/m^2/d. for the algal pond in the first scheme. Phosphorus uptake in the algal pond was 50mg/m^2/d. Variation in algal growth calculated by determining chlorophyll" a" content is shown in Figure (7). Maximum algal growth was 11.5mg/l, which is equivalent to 770.5mg/l dry weight. Algal growth

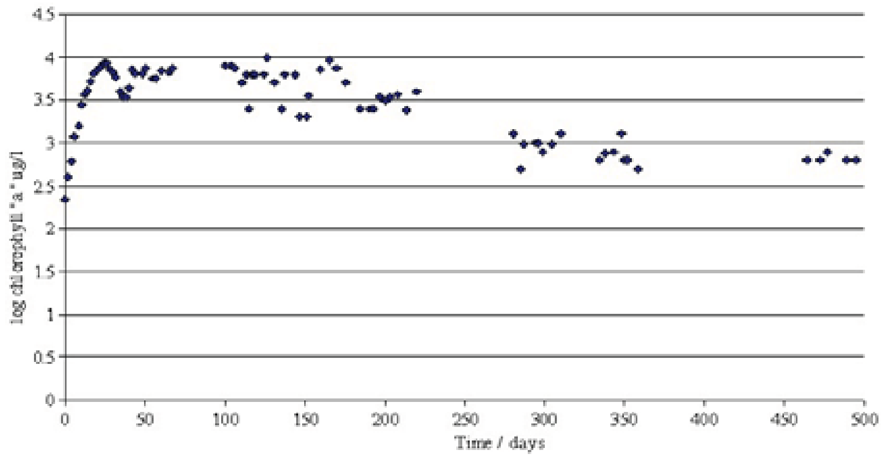

Fig. 7: Changes in chlorophyll" a" content for algal pond of scheme N02 (Samples N0.77)

in the AP of scheme N0.1 and scheme N0.2 was almost the same. The most dominant species of the green algae was *Haematococcus pluvialls*. Blue green algae were represented only by one species *Merismopedia sp. Bacillarophyta* were fairly common at the beginning of the experiment and disappeared gradually during the experimental period. Also, species numbers were reduced by 70%. *Nitzschia linearis* was present in good numbers. *Euglenophyta* represent the most abundant group present in good numbers during the investigated period. The most dominant species were *Euglena pissiforms* and *Euglena sangulnea*. Wrigley and Toerien (1990) found that, the flagellated algal genera Euglena and chlamydomonas were dominant during different seasons in sewage ponds.

Second duckweed Pond:

Average COD and BOD percentage removal values in the pond effluent were 27.9%and 36.7%, respectively. Corresponding, residual values were 91.8 and 24 mg/l, respectively. TSS concentration in pond effluent averaged 35.7mg/l. Iqbal, (1999) reported that removal of TSS in duckweed pond should be more effective than in uncovered ponds as algae. Algae growth in duckweed ponds is minimum due to lack of light penetration. Total nitrogen and phosphorus uptakes were 940 mg/m^2/d and 60mg/ m^2/d, respectively in the second duckweed pond. Corresponding values for the first duckweed pond. were 970 mg/m^2/d and 90mg/ m^2/d, respectively. Biomass production rate ranged from 9.5 to56 g/m^2 /d with an average value of 20.4g/m^2 /d. The dry matter content varied between 1.1 to 6.2% with an average value of 3.7% (Table 3).

Performance of scheme N0.2:

The integrated treatment scheme N0.2 was very efficient in reducing BOD, COD and TSS. BOD and COD concentrations were reduced from 267.8mg02/l (raw sewage) to 24mg02/l and from 586.2mg02/l (raw sewage) to 91.8mg/l. Corresponding average removal values were 90.2%, and 83.4%, respectively. The biomass production rate produced from the two duckweed ponds for the second scheme were 20.69 g/m^2 /d in average. Corresponding average value was 20.7 g/m^2 /d for the DP in the first scheme. Residual TSS concentration in the final effluent was around 35.7 mg/l. TSS is mainly reduced by sedimentation, biodegradation of organic matter, adsorption of a minor fraction by duckweed roots and inhibition of algal growth. Also, the removal of TSS in duckweed pond is expected to be more effective compared to the uncovered ponds (algae pond). Algae will not grow in DP due to reduced of light penetration. The greatest reduction in fecal coliform count has been observed in the last duckweed pond effluent. Microbiological examination revealed a reduction in the fecal coliform count from 1.57E+11 per 100ml in raw sewage down to 4.7E+03 in the final effluent. Fecal streptococci concentration in the final effluent reached 9.3E+02 per 100 ml. Pathogenic microorganisms removal is likely to be less effective in duckweed pond than in AP. This is caused by less sun light penetration, absence of antibacterial substances produced by algae, less oxygen concentration and lower alkalinity. However duckweed ponds with long retention time could be competitive in reducing pathogens (Iqbal, 1999).

Up-scaling of scheme N02-(scheme N03):

Based on the good performance of scheme N0.2, it was decided to up-scale this system by using 2DWP followed by 2 AP, then 2DWP (*Up-scaling of scheme N02)* Scheme N0.3. Available data indicated that Up-scaling of scheme N02 produced a better quality effluent with regard to COD& BOD, TSS. Figures (8-9) as compared to schemes N0.1 and scheme N0.2.

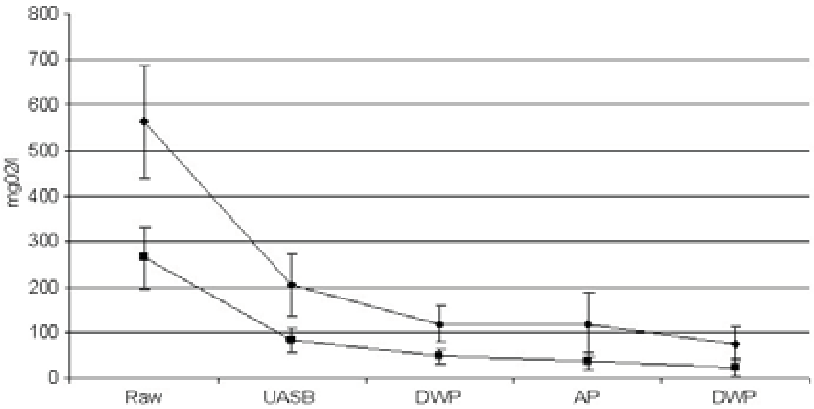

Fig. 8: Variation of COD along the treatment units of scheme N0.3 (Average for 38 samples)

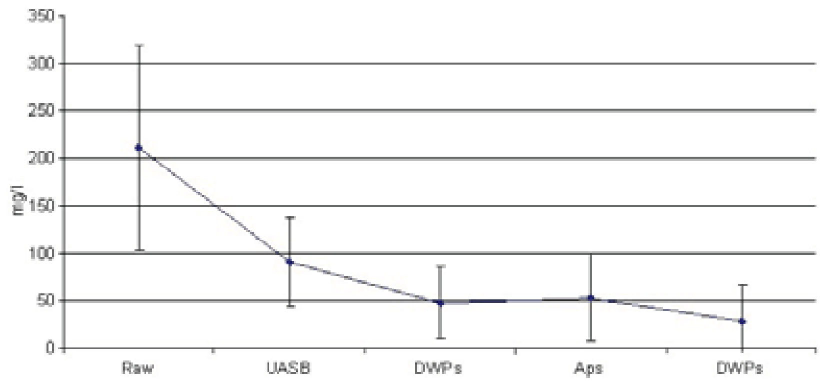

Fig. 9: Variation of TSS along the treatment units of scheme N03

Fist duckweed ponds:

Average COD and BOD percentage removal values were 32.1% and 40.6 % respectively. Corresponding residual values were 119.8mg0_2/l and 47.9mg0_2/l, respectively. TSS concentration in the DWPs effluent averaged 48.3mg/l. The uptake of total nitrogen and phosphorous in the first DWPs were 1123.6mg/m^2/d and 109mg/ m^2/d, respectively. After reaching the steady state condition, *Lemna gibba* yielded good results in terms of relative growth rate and competitive condition for algae. The biomass production rates in the two DWP units is illustrated in (Table 4 and Figure 10).

Algal ponds:

Inflow and the outflow characteristics of the two algal ponds are presented in Figures (12-15). Analysis of the pond effluent indicated that BOD, COD and TSS average removal values were 22 %, 1.7 % and –78.2%, respectively, with residual values of 37.2mg0_2/l, 117.4mg0_2/l and 53.6mg/l, respectively. Residual ammonia was 13.5mg/l. Nitrogen and phosphrous uptake in the algal ponds were 785.5 mg/m^2/d. and 76.36 mg/m^2/d, respectively Figure (11) illustrates the variation in algal growth for the algal ponds in SchemeN0.3. No clear variations in chlorophyll "a" content for two ponds. However, the maximum algal growth was 18.9 mg/l which was equivalent to 1266mg/l dry weight. Similar results were obtained by (Hala *et al.,* 1999), who found that the maximum algal growth was 21mg/l which equivalent 1047mg/l dry weight.

During the experimental run, changes in diversity and redundancy of algal population took place. The most dominant species of the green algae was *Scenedesmus sp.* Blue green algae were represented only by one species *Oscillatoria sp.* Bacillarophyta were present in good numbers. *Nitzschia sp*. and *Gomohonema olivaceum* were present in good numbers. *Euglenophyta* represent the most abundant groups during the investigated period. The most dominant species were *Euglena pissiforms* and *Euglena sangulnea.* In general the diversity of phytoplankton in the algal pond indicates that it is relatively eutrophic water. Dietmar Schwarz *et al.,* (2004) found that, the density and diversity of the algal community was typical to moderate eutrophic ponds. The absence of Cyanophyta blooms was also, indicative for moderate eutrophic conditions.

Table 4: Mean values of the Duckweed growth parameters in scheme N0.3

	Duckweed production of the 1st.pond of the first unit				Duckweed production of the 2nd pond of the first unit			
	Wet weight g.m2. d	Dry weight g.m2.d	Relative growth rate g.g.d	Dry matter content %	Wet weight g.m2. d	Dry weight g.m2.d	Relative growth rate g.g.d	Dry matter content %
Min	89	3.6	0.06	1.5	124	7.5	0.015	1.1
Max	601	20.5	0.7	4.7	760	27	1	7
Average	297.8	10	0.23	3.4	380	13	0.28	3.7

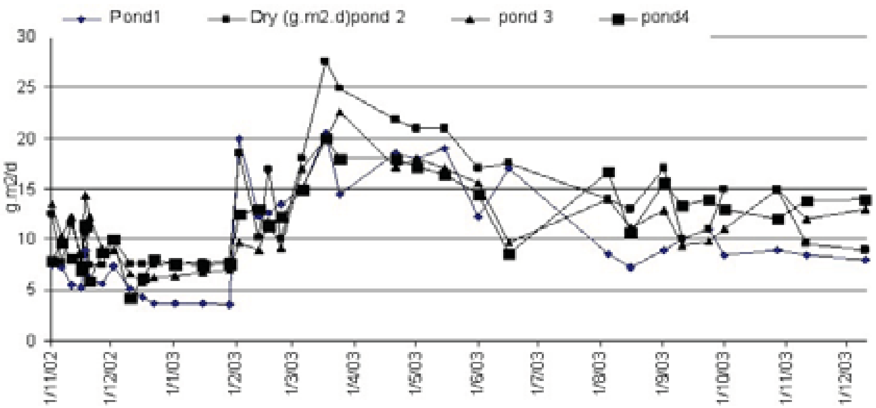

Fig. 10: Variation in Dry weight of duckweed in the up-scaled system

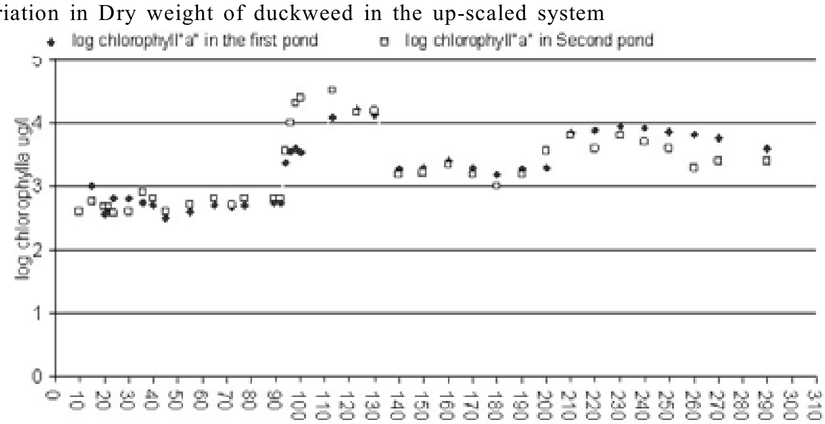

Fig. 11: Change on chlorophyll "a" content for algal pond of the up-scaling system

Second Duckweed Ponds:

Average COD percentage removal values in the first two DWPs and the last two DWPs were 32.1% and 31.6%, respectively. Corresponding values were 119.8mg0$_2$/l and 75mg0$_2$/l, respectively. BOD removal values were 40.6 % in the first DWPs and 38.8% in the last DWPs. Average residual values were 47.9mg0$_2$/l and 23.7mg0$_2$/l, respectively. TSS concentration in the final effluent averaged 28.6mg/l. The uptake of total nitrogen and phosphorous in the first two DWPs were 1123.6mg/m^2/d and 109mg/ m^2/d, respectively. Corresponding values for the last two DWPs were.992.7mg/m^2/d and 65.5mg/ m^2/d, respectively. Microbiological examination revealed a reduction in the geometric mean of fecal counts from 3.8E+10 in UASB effluent to 8E+02 in the last pond effluent. After reaching steady state condition*,* *Lemna gibba* yielded good results in terms of relative growth rate and competitive condition for algae. Biomass production rates in the two units are presented in (Table 5 and Figure 10). Oron and co-workers (1994) reported that the highest production of duckweed ranged from 8.2 to 16.4g/m^2.d for *lemna gibba* using settled sewage. Similar results were reported previously by Peter *et al.,* (1999) who found that the production of duckweed ranged from 7.4 to 16.4g/m^2.d (dry weight) in the first pond and from 2.7 to 8.2g/m^2.d in the last pond.

Performance of Up-scaling of scheme N02:

Pond systems of *Up-scaling of scheme N02* are efficient with regard to organic pollutants removal as reflected residual COD and BOD values (COD: 75mg0$_2$/l, and BOD: 23.7mg0$_2$/l). Also, 83.1 % of TSS were

Table 5: Mean values of the Duckweed growth parameters in scheme N0.3

	Duckweed production of the 1st pond. of the 2nd unit				Duckweed production of the 2nd pond of the 2nd unit			
	Wet weight g.m2. d	Dry weight g.m2.d	Relative growth rate g.g.d	Dry matter content %	Wet weight g.m2. d	Dry weight g.m2.d	Relative growth rate g.g.d	Dry matter content %
Min	149	5.8	0.01	0.87	105.7	4.2	0.05	1.5
Max	620	22.5	0.5	5.2	530	19.9	0.7	6.57
Average	393	11.77	0.2	3.3	323	11.69	0.25	3.63

removed. Percentage removal of fecal coliform was around 99.99%. Residual FC counts in the final effluent concentration of fecal coliform were extremely variable, ranging from 3E+01 to 7E+03 per 100ml with an average value 8E+02per 100ml. The high removal efficiency is in good agreement with published data where coliform removal is usually >97%, and many time exceed 99.9% (Soto et al., 1998). However duckweed ponds with long retention time can be competitive in reducing pathogens (Iqbal, 1999). The geometric mean of fecal streptococci counts indicated a reduction of 7 log as compared to the UASB effluent. Average residual value in the final effluent was 2.6E+02per 100ml. This is due to the ability of these amoebae to grow and multiply in the aquatic environment in the presence of bacteria and at the moderate temperature which dominate in Egypt.

Comparison Between the Efficiency of the Three Post-treatment Systems:

A comparison between the efficiency of the three post-treatment schemes is shown in Figures (12-13). The results indicated the superiority of the scheme N0.3 consisting of a series of 2DWP, 2AP and 2DWP with regard to organic matter, suspended solids, and pathogenic organism removal. This system produced treated effluent, which can be used for unrestricted irrigation.

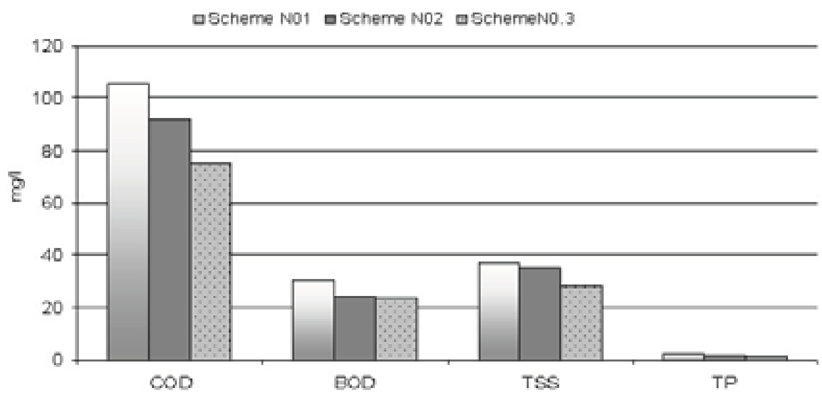

Fig. 12: Total removal efficiency of different treatment schemes:

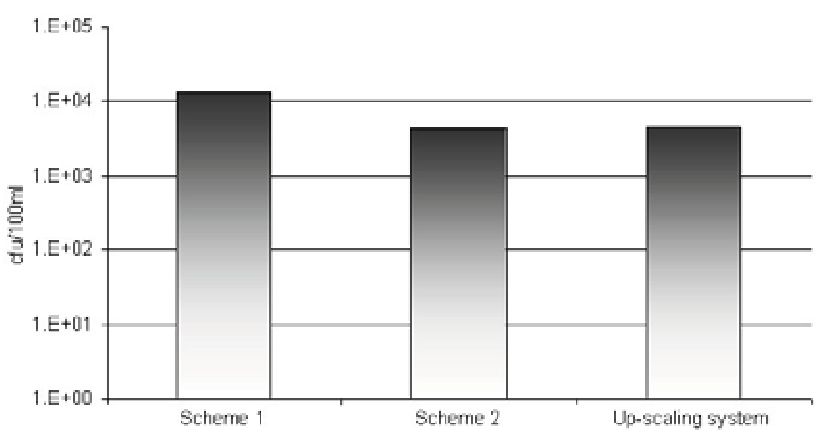

Fig. 13: Residual counts in the final effluents of the different treatment schemes

Conclusions:

From the results obtained, it may be concluded that:

- In general, raw municipal wastewater can be classified as above–medium strength for physico-chemical characteristics, but as strong in terms of bacteriological parameters.
- Before the reuse of wastewater, treatment of sewage is necessary.
- Rapid and efficient pathogen removal can be achieved in stabilization ponds but their effluent BOD and TSS is relatively high, due to presence of algae. Passing stabilization pond effluent through duckweed ponds was expected to remove algae due to reduced light penetration. Duckweed ponds have revenue generating potential since the produced biomass can be used as animal fodder
- Comparison between the three post-treatment systems indicates the superiority of the scheme consisting of series of 2DWP, 2AP and 2DWP. This system produced an effluent, which can be used for safely unrestricted irrigation.
- The integration of duckweed ponds with algae ponds (in series) for the treatment of UASB reactor effluent is a very efficient treatment system for the treatment of wastewater of small communities, such as rural areas and tourist resorts.

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