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Desalination using algae ponds under nature Egyptian conditions

El Nadi M. H. A.[1], El Sergany F. A. G. H.[2], El Hosseiny O. M.[3]

[1]Public Works Dept., Faculty of Eng., ASU, Cairo, Egypt
[2]Civil Eng. Dept., HIT, 10th of Ramadan City, Egypt
[3]Civil Eng. Dept., Future Univ., Cairo, Egypt

Email address:

mhnweg@yahoo.com (E. Nadi M. H. A.), fatenelsergany@gmail.com (E. Sergany F. A. G. H.), Cloudvii@gmail.com (E. Hosseiny O. M.)

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Abstract: This study aims to study the suitability of using algae for water desalination as a new conceptual technique using algae ponds under the nature circumstances. A pilot unit consisted of three serial basins each divided to three parallel basins was erected outdoor in open area to be under natural climatic conditions. The algae were prepared in the lab using BG11 media to encourage its growth under saline water then put in the basins with 0.4 lit/path/run for algae rate and 0.1 lit/path/run for BG11 rate. The basins fed by several concentrations from saline water from 2000 ppm till 40000 ppm with several runs to get the TDS removal efficiency. The experimental work shows that the removal efficiency for TDS in the first basin varied between 61& 80.5% and became after second basin between 71& 93% which increased by third basin to 83 to 97.7%. These variations were due to inlet TDS concentration and the climatic conditions (Temperature & sunlight period). The results achieved *high removal efficiency for TDS* and the results in the highest inlet concentration were inside the permissible limits for drinking water after the third basin.

Keywords: Water Desalination, Innovative Techniques for Desalination, Biological Desalination, Desalination by Algae

1. Introduction

Several microorganisms are applied to remove salts from water. Some artificial bacteria, which are still under research, were applied for water desalination 3 years ago. Also, some algae spices from 5 years ago started to be applied under research manner to desalinate sea water with successful promising results.

Algae are simple plants without roots, stems, and leaves contain chlorophyll. They are a heterogeneous group of organisms and vary in size from microscopic unicellular forms to sea weeds of many feet in length with many different shapes. Algae kinds grow wherever in water either salinity water in seas or fresh water in rivers and lakes and under different weathers from snow weather to hot climatic, wherever they could synthesize their components and food by photo-synthesis [1].

Scendesmus species growth was successfully obtained in saline water as it absorbs salts and makes use of them in its metabolism, while *Chlorella* and *Scenedesmus* are described as the most active Algae in stabilization ponds, because they are extremely, and commonly exhibit extremely wide range of salt tolerance in their habitat. [2]

Micro-algae have a high capacity for inorganic nutrient uptake and can be used in mass culture in outdoor solar bioreactors. Unicellular green algae such as *Chlorella* and *Scendesmus* have been widely used in wastewater treatment because the often colonize the ponds naturally, and they have fast growth rates and high nutrient uptake capabilities. However, one of the major drawbacks of using micro-algae in wastewater treatment is the harvesting of biomass. [3]

Green algae was used for treatment of industrial wastewater from natural gas production fields of 1500 m^3 daily flow, which contains salinity up to 25000 ppm and oil content up to 100 ppm. The effluent could be re-used in irrigation of crops with a flow enough for about 60 fed./day. While the produced algae 1.5 ton/day that could be used in medical industry, pigments for industry, functional food, bio-fertilizers, and animal or fish fodders [4].

Another algae application in stabilization ponds for industrial wastewater treatment of high salinity and oil content was made through a pilot plant which was built in the site of N/D field in Abu-Mady north of Egypt. Several runs were made to ensure the results. The influent loads were varied between 35000 & 10900 ppm for TDS, 250 & 65 ppm for Oil, 212 & 59ppm for BOD & 344 & 88ppm for COD. The effluent concentrations after 7 days retention time in the pond were ranged between 2750 & 2120 ppm for TDS, 2 & 0.5ppm for Oil, 7,4 ppm for BOD & 16 & 12 ppm for COD. These removal efficiencies proved the suitability of algae application for saline industrial wastewater treatment [5].

Desalination based on the use of algae in the removal of salts from saline water, and water production for use in different purposes is a new concept and it has been used and tested in previous researches in industrial waste water treatment, where using the algae reduced the cost to the minimum while maintained the efficiency with no reduction. The achieved results were promising and good in the desalination of sea water and is successful, continuing to reach the removal efficiency up to 95% till the rates are relatively affordable for possible use in different purposes, opening the door to a new direction may succeed in solving the problem of water desalination with cost reduction to the minimum possible [6].

A study was made to assess the removal efficiencies of different nutrients in saline water by the means of the green algae *Scendesmus species*. Total dissolved solids, Sodium, Chloride, and Phosphate removal efficiencies measured in the output of the reactor after 14 days reached around 97%. While the removal efficiencies of both Nitrate and Sulfate reached around 93% and all the parameters in the effluent were inside the permissible limits for potable water except the presence of some enzymes due to algae decay. This shows the success of this system to produce suitable potable water from sea water. [7]

In March 2011, another study was made. The objective of this study was to assess the removal efficiencies of different nutrients in saline water by the means of the green algae *Scendesmus species* through a continuous flow treatment system. The saline water from Red Sea, Ismailia Governorate (about 40000 ppm) was used. Algae were added to two consecutive reactors in which a 7 days retention time was applied in each to prevent the enzymes formations in the basins. The experiment in the continuous flow was repeated for 4 runs and the average values were taken into consideration. Analysis of growth media was daily determined. Total dissolved solids, Sodium, Chloride, and Phosphate removal efficiencies measured in the output of the second reactor reached around 97%. While the removal efficiencies of both Nitrate and Sulfate reached around 93% [8, 9].

El Hosseiny, O.M., et al,[10] in their study proved the suitability of applying algae for biological desalination under nature Egyptian conditions with high removal ratios for TDS depending on the inlet water salinity and both of the sunlight period and the temperature.

2. Materials & Methods

A new system for water desalination was applied by using Algae for a natural, environment friendly and economic desalination. The *Scendesmus* algae species was the choice for operation process, thanks to its natural feature of growing very well in almost any mineral medium. The application was successfully worked under suitable conditions inside the lab as illustrated by El Nadi [5][6][9], El Sergany [5][6], Saad [7] & Badawy [8]. In this study the system is built outside the lab to meet the normal nature conditions.

The pilot plant located on the roof of the Material Lab of the Ain Shams university engineering faculty specified for open air pilots. The pilot plant consists of three storage tanks, three basins each divided to three equal paths and equipped with manual algae separators units. Figure (1) illustrates the pilot photo

Fig (1). *Photo of the applied Pilot for algae Ponds*

The pilot plant was operated from February 2013 till June 2013 to obtain the system suitability. It consisted of three runs, each with three different TDS concentrations for the three parts of each basin. Several concentrations of saline water 2000, 4000, 10000, 15000, 20000, 25000, 30000, 35000 & 40000 ppm were applied three in each run. The feeding media for algae BG-11 solution was added to give algae enough nutrition with rate 0.1 lit/path/run. *Scendesmus* algae were added by rate 0.4 lit/path/run to treat the saline water for a retention time of 7 days in first basin. Water after separating algae in the first basin was then transferred to the second basin. *Scendesmus* algae in second basin did the second stage of treatment for another 7 days. Then the work repeated in the third basin. Desalinated water was collected in the effluent after the third basin. Table (1) shows the chemical composition of BG-11 nutrient solutions.

Table (1). *Chemical composition of BG-11 nutrient solutions [6]*

Chemical	**BG-11(g/l)**
$NaNO_3$	1.5
$K_2HPO_4.3H_2O$	0.04
Na_2CO_3	0.02
$MgSO_4.7H_2O$	0.075
$CaCl_2.2H_2O$	0.036
EDTA-Na_2	0.001
$Fe(NH_3)_2$Citrate	0.006
Citric acid	0.006

Samples were taken each day from each part of each basin, as well as the effluent tank. The sample volume was 50 ml. Water samples were routinely collected at 9:00 am each morning and analyzed to investigate water quality during the examination period. The measured parameters were as Total dissolved solids (TDS), Air Temperature, Humidity, Sunlight period & Algae growth rate.

3. Results & Discussions

The first run started with small salts concentrations. The feeding tanks had concentrations of 2000, 4000 and 10000 mg/l. The run was applied for 21 days through the three basins for the three parallel lines.

The study measured the TDS concentrations at each basin effluent in addition to the climatic conditions during the run operation days. The results of the measured data during First, second & third runs are shown in tables (2), (3) & (4)

The pilot was found successful in removing TDS concentrations from the medium using Algae with BG11 media and under Natural variable conditions. However, the Removal efficiencies average differed according to inlet TDS concentration. Table (5) and figure (2) illustrated the variations in removal ratios due to the inlet TDS concentration.

Table (2). *Measured Parameters during First Run*

Basin	Date	Air Climatic Conditions				TDS mg/l		
		Temperature °C		Humidity %	Sun Light Period (hr)	Left Basin	Middle Basin	Right Basin
		Day	Night					
Basin 1	1/3/13	21	11	54	12.00	2000	4000	10000
	2/3/13	28	12	42	12.02	1020	3200	7920
	3/3/13	29	17	22	12.05	920	2920	6130
	4/3/13	21	15	57	12.07	890	2610	5080
	5/3/13	19	12	60	12.10	860	2370	4000
	6/3/13	20	11	53	12.12	820	2020	3333
	7/3/13	23	9	44	12.15	780	1730	2990
Basin 2	8/3/13	27	12	34	12.18	780	1730	2990
	9/3/13	23	14	63	12.20	730	1460	2420
	10/3/13	27	13	46	12.22	690	1190	2000
	11/3/13	30	17	30	12.25	650	980	1709
	12/3/13	34	22	18	12.28	620	910	1410
	13/3/13	28	17	51	12.30	600	840	1209
	14/3/13	36	16	36	12.32	580	790	1170
Basin 3	15/3/13	22	17	27	12.35	580	790	1170
	16/3/13	20	15	53	12.37	510	750	950
	17/3/13	14	14	48	12.40	450	710	850
	18/3/13	22	12	52	12.43	400	680	770
	19/3/13	24	11	57	12.46	380	650	730
	20/3/13	31	12	57	12.50	360	630	700
	21/3/13	25	12	47	12.54	340	610	680

Table (3). *Measured Parameters during Second Run*

Basin	Date	Air Climatic Conditions				TDS mg/l		
		Temperature °C		Humidity %	Sun Light Period (hr)	Left Basin	Middle Basin	Right Basin
		Day	Night					
Basin 1	1/4/13	28	21	29	12.57	20000	30000	40000
	2/4/13	28	16	34	13.00	13840	27030	34060
	3/4/13	32	19	28	13.04	9260	20200	29050
	4/4/13	23	16	53	13.07	7370	13270	22980
	5/4/13	24	15	52	13.10	6130	8960	14460
	6/4/13	29	13	40	13.14	5280	7340	9320
	7/4/13	35	19	22	13.17	4050	6220	7830
Basin 2	8/4/13	26	18	2	13.20	4050	6220	7830
	9/4/13	24	16	8	13.23	3240	5130	6120
	10/4/13	23	14	10	13.27	2890	4240	4980
	11/4/13	23	14	8	13.30	1940	3480	4020
	12/4/13	24	13	9	13.33	1330	3170	3250
	13/4/13	24	13	10	13.36	950	2760	3080
	14/4/13	28	14	11	13.39	890	2590	2840
Basin 3	15/4/13	29	14	48	13.42	890	2590	2840
	16/4/13	23	15	54	13.45	850	2260	2320
	17/4/13	22	15	53	13.47	810	1920	1980
	18/4/13	23	14	52	13.49	770	1580	1609
	19/4/13	23	14	49	13.51	730	1290	1330
	20/4/13	22	14	44	13.53	690	1090	1150
	21/4/13	21	14	51	13.55	640	900	920

Table (4). *Measured Parameters during Third Run*

Basin	Date	Air Climatic Conditions				TDS mg/l		
		Temperature °C		Humidity %	Sun Light Period (hr)	Left Basin	Middle Basin	Right Basin
		Day	Night					
	1/5/13	35	18	35	14.10	25000	35000	40000
	2/5/13	32	19	43	14.12	15160	30090	33480
	3/5/13	32	19	51	14.14	10470	24540	28270
Basin 1	4/5/13	36	19	46	14.16	7920	15480	22120
	5/5/13	34	19	39	14.18	6300	10760	13540
	6/5/13	33	19	42	14.20	4880	8130	8720
	7/5/13	33	20	51	14.22	3940	7250	7630
	8/5/13	31	20	56	14.24	3940	7250	7630
	9/5/13	31	20	52	14.26	3330	5820	6010
	10/5/13	33	21	48	14.28	2690	4210	4580
Basin 2	11/5/13	30	20	41	14.3	2480	3370	3730
	12/5/13	27	19	53	14.32	2130	2740	3070
	13/5/13	34	21	34	14.34	1840	2560	2750
	14/5/13	27	18	42	14.36	1620	2280	2520
	15/5/13	27	19	42	14.38	1620	2280	2520
	16/5/13	28	18	52	14.4	1370	1950	2240
	17/5/13	32	20	55	14.42	1010	1670	1960
Basin 3	18/5/13	34	20	41	14.43	860	1410	1600
	19/5/13	38	22	36	14.45	810	1130	1310
	20/5/13	33	21	28	14.46	750	860	1170
	21/5/13	33	21	50	14.48	690	830	880

Table (5). *TDS Removal Ratio*

Time (days)	Average Removal Efficiency %		
	Inlet TDS Above 20000 ppm	Inlet TDS Between 20000 and 1000 ppm	Inlet TDS Below 1000 ppm
1	0.0	0.0	0.0
2	20.9	17.6	7.0
3	38.5	31.9	13.3
4	55.0	43.4	18.8
5	68.9	52.1	22.7
6	76.9	58.1	25.9
7	80.6	62.3	29.5

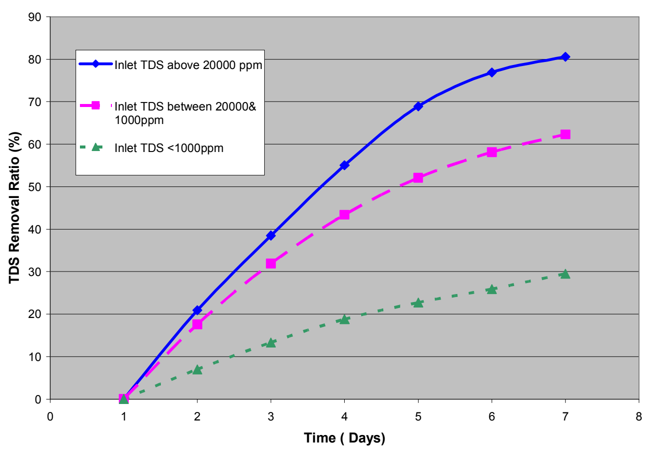

Figure (2). *TDS Removal Ratio with time for different inlet TDS concentrations*

From previous Table & figure, it is obvious that the removal efficiency increases with the increase of TDS. In other words, the removal efficiency average is directly proportional to the starting TDS concentration.

The results are showing the same trend from previous work made inside lab [6, 7, 8 & 9]. There is some deviation though which is occurring because of the effect of the nature condition of the day and night periods which was not applied in laboratory work.

In El Nadi et al [9] work, TDS average removal efficiency by 81.3% was achieved in 7 days in laboratory condition for any inlet TDS concentration. But in this study, three categories had been seen due to the inlet TDS concentration, the first for TDS more than 20000 ppm that achieved maximum removal ratio 77% in 7 days. The second for inlet TDS between 20000 and 1000 ppm and obtained maximum removal ratio of 64.7% and the third for inlet TDS less than 1000ppm that reached maximum removal efficiency 28.1%.

These variations could be explained for the effect of Temperature variations and the effect of sun light period differences in the nature circumstances.

This was also noticed on the continuous flow ponds system that the removal efficiency was very high in the first basin then decreased in the second one and be very slow changed in the third basin as shown in figure (3).

In figure (3), the shown TDS values resemble the average TDS values present in the three basins in series when starting with TDS of 40000 ppm. The behavior of Algae appears to be very effective in the first basin, and it decreases after in the second before turning to nearly constant in the third basin.

For the continuous flow pond system it was noticed that with inlet TDS 40000ppm, the overall efficiency of the 3 basins reached 97.7%, while the efficiency of the first two basins alone reached 93% while first basin alone achieved 80.6%.

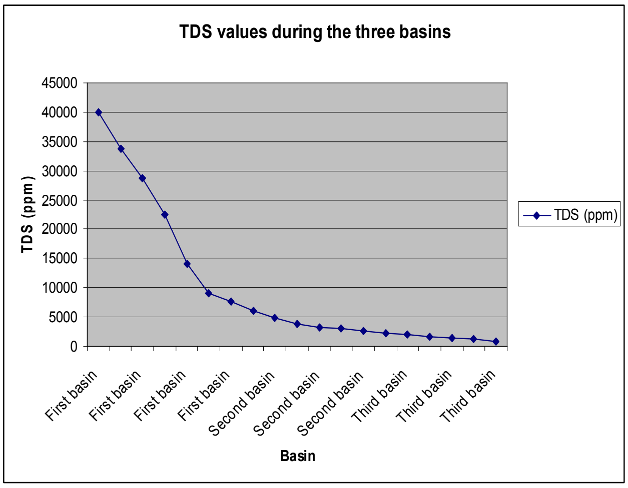

Figure (3). *TDS values all through the three basins*

4. Conclusions

Generally, results encourage the use of green algae for desalination and put an easy equation for the system design. The study had shown the following specific conclusions:-

1 The continuous flow algae ponds in the field under nature variable conditions achieved high removal for TDS from sea water.
2 *Scendesmus species* growth was successfully obtained in saline water as it uptakes salts and make use of them in its metabolism.
3 The effectiveness of the system increase as the starting total dissolved solids content increases. It was with high removal efficiency when TDS was above 20000 ppm. It was with moderate removal efficiency when TDS was between 20000 and 1000 ppm. And it was with low removal efficiency when TDS was below 1000 ppm.
4 The system efficiency affected mainly with the inlet TDS concentration.
5 For more removal for salinity second or third reactor could be applied with successful results.
6 The effect of the nature conditions of temperature, sunlight period was noticeable by about 5-15% lower in removal efficiency compared with the previous work made inside the laboratory
7 The advantages of the proposed continuous flow system are low cost, easy construction with low operation & maintenance cost, and low energy requirements.
8 The system gives low pollution to surrounding environment, with maximum benefit of by-products, besides it solves the problem of getting rid of the waste products.

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