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POTENTIAL USE OF CHLORELLA VULGARIS ALGAE IN RAPID BIOLOGICAL DESALINATION

Louye B.[1,2]*, El Nadi M. H.[1], Nasr N. A. H.[1], E. l. Monayeri O. D.[2]

[1]Department of Civil Public Works, Faculty of Engineering, Ain Shams University (ASU), Cairo, Egypt.

[2]Environmental Engineering Unit, Department of Construction and Building, Faculty of Engineering, Arab Academy of Science, Technology and Maritime Transport (AASTMT), Cairo, Egypt.

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***Corresponding Author**
Louye B.
Department of Civil Public Works, Faculty of Engineering, Ain Shams University (ASU), Cairo, Egypt.

ABSTRACT

Currently, there is a limited availability of fresh water all over the globe. Conventional desalination methods are energy-consuming and air-polluting. Bio-desalination is an appealing, clean yet non-feasible solution compared to desalination using fossil fuel burning. This study, for the first time, attempted to use the fresh water algae *Chlorella vulgaris* in desalination.400 ml solutions of different salinities were prepared and added to each container to simulate different kinds of salt water starting from 38 ppt (parts per thousand) which represents sea water, going through 20 ppt as in brackish waters and ending with 5 ppt similar to that in low salt water. *Chlorella vulgaris* succeeded in removing salts from all specimens with a maximum of 3 ppt (in the first hour) from the highest salinity specimen. However, the salts in higher salinity specimens were found to rebound after 3-4 hours, which indicates that filtration time is critical when using *Chlorella vulgaris* in desalination. This study provides a new rapid approach in bio-desalination indicating that rapid small removal of salts can be achieved by using the algal species *Chlorella vulgaris.*This rapid desalination technique helps in plant area minimization and decrease cost compared to former studies using S*cenedesmus Obliqus.*

KEYWORDS: Desalination, Rapid, Algae, Chlorella vulgaris.

INTRODUCTION

Fresh water is among Earth's most precious resources, being required for drinking, agriculture, and daily life needs. Unfortunately, there is a limited availability of fresh water in many places across the world and it is predicted that its scarcity will increase in the upcoming years (McDonald et al., 2011). On the other hand, salty water in seas and oceans is readily available, representing 96.5% of all the Earth's water (Shatat and Riffat, 2014). The abundance of salty water, and the shortage of fresh water suggests that desalinationcan provide an unlimited source of fresh water.

Many countries already depend on desalination for their fresh water demand. Various conventional desalination methods were developed through time including multi-stage flash distillation, multi-effect distillation, vapor compression distillation, reverse osmosis, electro-dialysis and freezing methods (Shatat and Riffat, 2014). However, the aforementioned approaches for desalination have several drawbacks, including the high energy and maintenance costs (Al-Karaghouli and Kazmerski, 2013), the adverse consequences on the environment such as air, noise and thermal pollution as well as the detrimental effect of brine discharge on marine life (Einav et al., 2003). Desalination using renewable energy sources such as solar, geothermal and wind energy are much more environmentally-friendly but have the disadvantage of being even more costly than the conventional methods (Shatat and Riffat, 2014).

Recently, biological methods of desalination using cyanobacteria and green algae have been adopted (Amezaga et al., 2014). For instance, El Nadi et al. used S*cenedesmus* algae on brine water and reached a salt removal efficiency of 63% after 6 days (El Sergany et al., 2014). Another study reported 92.7% desalination after combining S*cenedesmus* with saline water for 21 days (Nagy et al., 2017). Furthermore, Minas et al. used different species of cyanobacteria for removal of sodium and chloride from seawater (Minas et al., 2015). The algae are thought to absorb and metabolize the surrounding salts(El Sergany F.A.R., et al., 2014) with no need for any source of energy. Moreover, algae are photosynthetic organisms that utilize sunlight and require no addition of substrate. Finally, they have no unfavorable effects on the environment, which makes them a promising clean and cost-effective approach for desalination.

A recent study by Church et al. described the ability of the fresh-water algae *Chlorella vulgaris* to survive and grow in salinities comparable to that of seawater or even higher

(Church et al., 2017). This result might provide a potential for the use of *C. vulgaris* in desalination, similar to cyanobacteria and S*cenedesmus.*The current study, for the first time, investigates the possibility of desalination using *Chlorella vulgaris* under different initial salinities.

METHODOLOGY

Algal culture

Chlorella vulgaris algae was brought from the National Research Center, Cairo, Egypt and cultured in fresh water. For each liter of algae solution, 5ml of UST (0.5 g/L urea, 0.25 g/L superphosphate and 0.05g/L trace elements) media were added. The algae were allowed to grow under continuous air mixing and a lighting of 4000 lux for two weeks prior to the experiment till they reached a cell count of 10 million cell/mL as counted by hemocytometer.

Desalination experiment

Figure 1: Containers of *chlorella* and salt water.

Ten containers were used in this experiment. In each container, 40 ml of *Chlorella vulgaris* solution and 2 ml of UST media were mixed. The nutrients (UST) were added to allow the algae to survive in the high salt mixtures. 400 ml solutions of different salinities were prepared and added to each container to simulate different kinds of salt water starting from 38 ppt (parts per thousand) which represents sea water, going through 20 ppt as in brackish waters and ending with 5 ppt similar to that in low salt water. All salinities used are given in ***table 1*** as total dissolved salts (TDS) in ppt.

Table 1: Initial salinities of the ten different specimens.

Specimen no.	1	2	3	4	5	6	7	8	9	10
Initial TDS (ppt)	38	35	32	29	26	21	17	13	10	5

Five replicates were done for each salinity. All samples were kept under continuous lighting and 30 °C throughout the experiment and mixing of the containers was done once at the start of the experiment. The experiment took a total time of 12 hours.

Measurement of total dissolved salts

The initial TDS was measured at the start of the experiment (***table 1***) and then remeasured every hour for 12 hours. Measurements were taken using seawater refractometer (HI96822 Digital Refractometer, HANNA instruments, Johannesburg, South Africa). The TDS value was taken after filtration of the solution using four layers of filter paper followed by a layer of fine steel mesh.

RESULTS

C. vulgaris was applied to ten water samples of varying salinities, and the TDS was measured on an hourly basis. Results of hourly measurements are shown in ***table 2***.

Table 2: Hourly TDS measurements for the ten specimens.

Specimen / TDS (p.p.t)	1	2	3	4	5	6	7	8	9	10
Initial	**38**	**35**	**32**	**29**	**26**	**21**	**17**	**13**	**10**	**5**
1 hr	35	33	30	27	25	20	16	13	10	5
2hr	35	33	30	27	25	20	16	13	10	5
3hr	35	33	30	27	25	20	16	12	10	5
4hr	37	34	31	28	25	20	16	12	10	5
5hr	38	34	31	28	25	20	16	12	9	5
6hr	38	35	32	29	25	20	16	12	9	4
7hr	38	35	32	29	25	20	16	12	9	4
8hr	38	35	32	29	25	20	16	12	9	4
9hr	38	35	32	29	25	20	16	12	9	4
10hr	38	35	32	29	25	20	16	12	9	4
11hr	38	35	32	29	25	20	16	12	9	4
12 hr	38	35	32	29	25	20	16	12	9	4

Amount and time of salt removal

Figure 1 shows that *Chlorella vulgaris* was capable of removing a maximum of 3 ppt from specimen 1 which has a salinity of 38 ppt. In specimens 2, 3 and 4 (TDS of 35, 32 and 29 ppt respectively), a total of 2 ppt was reduced. The rest of the specimens, ranging from a TDS of 26 to 5 ppm showed a 1 ppt salt removal.

Regarding the time taken for desalination, salt was removed immediately after one hour for the first seven specimens (higher salinity specimens). The 8^{th} specimen with 13 ppt was found to be reduced after two hours while the 9^{th} and 10^{th} specimens with the least salt concentrations took 4 and 5 hours respectively.

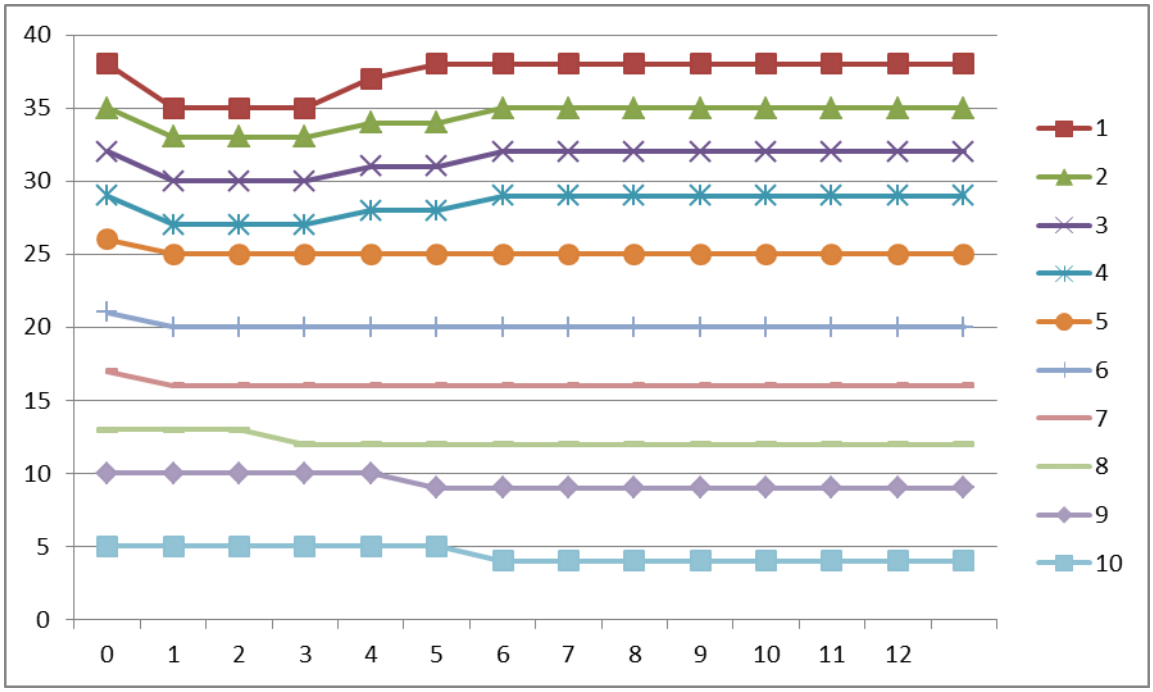

Figure 2: Specimens salt removal on 12 hour period.

Rebound time

Salinity of desalinated samples was found to return to its original values after some time. The rebound time was found to be inversely proportional with salinity (Figure 2). The salt levels in the first four specimens were found to rebound after three hours and then gradually increased till they reached their initial salinity after four hours for specimen 1 and after five hours for the rest. Specimens 5 to 10 after their 1 ppt salt removal maintained the same salinity for the entire experiment time.

Desalination model

Figure 2 was used to generate a model for the prediction of the amount of time and steps required for desalination of a 38 ppt sample (equivalent to seawater)to reach a salinity of 4 ppt using *Chlorella vulgaris.* Table 3 shows that this can be achieved through 29 steps in 47 hours where *R.T* is retention time and *Accum. R.T.* is accumulated retention time.

Table 3: Desalination achievement model based on current study experiment.

Step	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
TDS ppt	38	35	33	31	29	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
Removal ppt	3	2	2	2	2	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
R.T	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	3	3	3	4
Accum. R.T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	23	25	28	31	34	37	40	43	47

DISCUSSION

Desalination using algae is currently a promising arena for environmental engineers. However, research in this area is still in its beginning, and only a few algal species have been proved successful in desalination. This study is the first to examine the desalination potential of the green algae *Chlorella vulgaris*.

C. vulgaris in the current study was able to remove salts ranging from 1 ppt to 3 ppt depending on the starting salinity. Salt removal was greater at higher salinities, which agrees with the studies by Gan et al. and El Nadi et al., both of which have used S*cenedesmus obliqus* algae for desalination (Gan et al., 2016; Nadi M. H. A., 2014). The former study reported removing a maximum of 2.55 ppt from its highest salinity specimen of 8.8 ppt after 16 days while the latter study managed to reduce the salinity of water from 40 ppt to 0.8 ppt after passing the saline water through three desalination basins for 21 consecutive days.

Unexpectedly, *Chlorella vulgaris* in the current study displayed a considerably faster salt removal compared to the above studies making the use of *Chlorella vulgaris* a promising new technique for rapid desalination. That is, salt was removed after only one hour for most of the specimens, while the three lowest salinity specimens took from two to five hours. The salt removal was more rapid in higher salinities probably due to the higher salt concentration gradient between the intra and extracellular compartments.

The salinity of some specimens after desalination, especially the higher salinity specimens, was found to return to its initial values after three to four hours, a result that was not observed in studies utilizing other algal species. This can be due to an adaptive mechanism by *Chlorella* cells to pump the high salts out of their cytoplasm. Therefore, rapid filtration is necessary before rebound of salts.

Using a model based on the results, it was found that near-complete desalination, that is; reducing salts from 38 ppt to 4 ppt would require twenty nine successive filtration and *Chlorella* reapplication steps. This would take 2 days (47 hours) which is quicker than the time required for similar desalination using *S. obliquus* by previous studies (Nadi M. H. A., 2014).

The technique used in this study does not rely on growing the algae in saline water, but rather allows for a prompt desalination technique. It should be highlighted that the timing of

filtration is crucial; water should be filtered after two hours of when *C. vulgaris* was applied to water to prevent rebound of salts. Then, the filtered water at one stage can be resupplied with fresh algae to continue the desalination process. Furthermore, the filtered *Chlorella* can be used for lipid production, especially that lipid formation from algae is greater in higher salinities as per former studies (Church et al., 2017).

CONCLUSION

This study gives a new perspective of biological desalination, indicating that rapid small removal of salts can be achieved by using the algal species *Chlorella vulgaris*.

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