Eco-Friendly Innovation for Electrical Conductivity Reduction of Persian Gulf Seawater Using Highly Efficient Recyclable Sorbent

Rahman, Fatemeh; Nabi Bidhendi, Golamreza*+; Sharifi, Forood; Mehrdadi, Naser; Rahman, Farangis

Department of Environmental Engineering, University of Tehran, I.R. IRAN

ABSTRACT: *The use of seawater containing Reverse Osmosis effluent is very serious for the daily living of the coastal residents, especially for farmers. In this study, a one-year field test was carried out for electrical conductivity reduction of Persian Gulf seawater in Iran, during 2017 and 2018. The test was conducted in two filters each with a diameter 2.5 cm (or 0.025 m) and 18.5 cm (or 0.185 m). In the filters, crumb mineral mussel was used as one of the main components of filter materials. The minor components of filter materials were comprised of coarse-grained gravel, fine-grained activated carbon, and fine-grained sand. The well water as low-saline water for the background of seawater treatment and seawater as super-saline water were treated. The test was performed as the pilot, batch, and column design with three replicates. The volume of daily treated seawater and the efficiency of reduction of electrical conductivity and salinity were determined. The volume of treated seawater by each of the filters was at least 10 times the diameter of each of those. The maximum reduction efficiency of electrical conductivity and salinity in a filter with 2.5 cm (or 0.025 m) diameter was 97.09% (from 85.2 to 2.48 mS/cm or from 8.52 to 0.248 S/m) and it was 98.2% (from 61 to 1.1), respectively. Maximum reduction efficiency of the parameters in filter with 18.5 cm (or 0.185 m) diameter was 97.5% (from 84.8 to 2.12 mS/cm or from 8.48 to 0.212 S/m) and it was 97.69% (from 60.7 to 1.4), respectively. Electrical conductivity in outlet water from filters was less than 3 mS/cm (or 0.3 S/m), below the permissible limit recommended by World Health Organization and also the Iranian Department of Environment for agriculture and irrigation usage. Based on these results a non-continuous method seems promising in the biological growing phase in filters.*

KEYWORDS: *Bio-filtration; Desalination; Electrical conductivity reduction; Seawater treatment.*

INTRODUCTION

The increasing scarcity of water in the world along with the rapid population increase in urban areas gives reason for concern and the need for appropriate water management practices. Because water is a limited resource, especially in countries with arid environments, water conservation has become of increased importance. Reverse Osmosis (RO) has been widely utilized in water reclamation plants. RO is the pressure-driven separation

---

** To whom correspondence should be addressed.*

+ E-mail: ghhendi@ut.ac.ir

1021-9986/2022/4/1322-1334 14/$/6.04

of contaminants through a semi-permeable membrane that allows water to pass through while retaining contaminants. The dissolved ions are retained in a brine solution that requires management or disposal. Therefore, RO produces a brine (or reject) stream as a by-product. RO brine contains vast quantities of salts and dissolved organic matter, such as biomass and humic-like substances [19].

The brine, the produce is typically 20% to 30% of the influent flow in a single system, depending on influent water quality.

Management and disposal of the brine solution that is generated and can require higher operating costs. For locations where atmospheric evaporation is not feasible, thermal treatment may be needed. The brine waste stream is typically disposed of through evaporation, deep well injection, or ocean discharge. Brine disposal can locally impact benthic communities if the poorly diluted discharge is allowed to flow across the marine bottom. Impacts on benthic communities from brine discharges can be minimized by using properly-designed diffuser systems designed and located based on current and flow modeling [24]. In the case of seawater, desalination emerges as an alternative to extract salt and other pollutant elements from it, turning it into water suitable for human consumption, or for productive uses such as agriculture and mining, among others. Desalination is identified as a safe source of water that guarantees a stable supply as compared with the variability of natural sources and the scarcity of this resource in the basins [4]. For example, bench tests of Salton Seawater using Reverse Osmosis achieved initial contaminant rejections of 99% salinity (Sal), 97.7% conductivity, 98.6% total dissolved solids, 98.7% chloride, 65% sulfate, and 99.3% turbidity [27]. The most important filter materials in this study were mineral mussel and GAC. Characterization of the materials is as follows:

The purest type of calcium in nature is known as a mineral mussel. Mineral mussel generally contains large amounts of calcium carbonate, $CaCO_3$, which accounts for approximately 2% of the Earth's crust. They consist of two main phases: aragonite and calcite with irregular shapes. Other minerals in mussel are sodium oxide with the formula Na_2O, silicon dioxide (SiO_2), magnesium oxide (MgO), potassium oxide (k_2O), chlorine (Cl), and iron oxide with the famous formula Fe_2O3 and alumina with the formula Al_2O_3 up to varying degrees [15]. In addition, mineral mussel also contains organic matter. These organic matters are formed as dense protein layers or sheets. Proteins bind minerals to each other and the amount depends on several factors. These include salinity, concentration, and temperature [21]. Iron ore; travertine, marble, and aragonite are the most important minerals that form mineral mussel. There is also mineral mussel in the eggshell. What determines the use of mineral mussels is its purity. Areas that have been left behind by seawater fossils and corals for many years constitute fossilized mineral mussel. Production of mineral mussel can be done in both natural and artificial ways.In a natural way, the mineral mussel is extracted directly from its mines. In another way, it is synthetic and is present in the membranes of animals such as crabs and snails [22]. Granular activated carbon adsorbs organic compounds that were not filtered in previous treatment stages where land use needs to be optimized. GAC can be used in conjunction with other methods (e.g. slow filtration) to face pollution that results from potentially outdated water networks (especially in less developed areas). GAC performance has been proven better than other media such as sand and anthracite [26]. Generally, Biological Activated Carbon (BAC) systems are constructed with activated carbon granules arranged in packed bed columns. Contaminants are removed through adsorption onto the surface of the carbon material during transport through the reactor as well as biological degradation. Once the available adsorption sites are filled the removal efficiency is significantly diminished [14]. Bio-carbons are generally considered low-cost alternatives for commercial activated carbons. The cost is reduced by utilizing locally available biomass in the preparation of bio-carbon adsorbent [1]. Fig. 1 shows the mineral mussel used in this study.

The present study, for the first time, presents a simple and inexpensive treatment method for the polluted Persian Gulf seawater to Reverse Osmosis effluent which is one of the important seas in the south of Iran. The objective of this study is the reduction of electrical conductivity and salinity in seawater for the usage of agriculture and irrigation. It is worth noting that other researchers mainly focused on the expensive treatment of seawater salinity reduction (reverse osmosis, electro-dialysis, ions exchange and etc.) or inexpensive treatment of water salinity other than seawater (the well-water, mine water, drinking water, etc.); however, this research focuses on electrical conductivity and salinity reduction during the biological

Fig. 1: Mineral mussel.

filtration in relation to important seawater parameters such as pH, salinity, electric conductivity, and temperature. Therefore, super salty seawater is treated in a method simple and inexpensive using native materials without the use of chemicals.

EXPERIMENTAL SECTION

Materials and methods

The field experiment was conducted in Tehran in 2017 and 2018. The climate of the experimental region was a state of stationary and without wind flow. The temperature and lighting were in moderate conditions. The temperature was the amount of 10 to 35-degree centigrade. The lighting was sunlight or bulb light (any type of lamp) or moonlight. The setup consisted of a biological slow filtration method with filter materials consisting of, gravel, sand, activated carbon, and mineral mussel crumb. Slow filtration was a simple and easy-to-operate process for the retention of solids, microorganisms, and heavy metals; land use was a limiting factor [12]. Sand filters can be used for a broad range of applications, including single-family residences, large commercial establishments, and small communities [29]. The interest in using filter materials was growing since the technique was promising for other types of wastewater streams, for instance, domestic wastewater, landfill leakage, and stormwater. The filter technique was regarded as an adequate alternative to more technical solutions or other small-scale solutions [31].

Study details

The most common use of microbial biotechnology was biological filtration in water treatment. This involved the filtration of oxic or oxygenated water through granular media such as sand, Granular Activated Carbon (GAC), or anthracite and might include slow sand filtration. The bioreactors used microorganisms to remove contaminants with a solid reactive mixture acting as a source of carbon for the bacteria and as a substrate for microbial attachment [8]. The efficiency of bioreactors depended on the activity of bacteria, which was mainly controlled by the composition of the reactive mixture. The organic substrate was generally a mixture of locally available organic materials, and often contains materials to provide additional neutralizing capacity and gravel to increase substrate penetrance.

Therefore, an eco-friendly and very cost-effective alternative technique based on EC was introduced for successful control of the process. Material saturation in the filter bed occurred very late because microbial growth in the upper layer of materials in the filter bed reduced EC in water.

Recover filter materials

Once the material was saturated, it can be regenerated for cyclic use. These uses ensured both economic and environmental benefits by avoiding contamination of the groundwater by salinity [10]. The inefficiency of the filter materials was due to the reduction of the biological mass grown on the filter materials. EC reduction was performed in water by microbial regrowth in the filter bed materials. Table 3 and Table 4 mentioned in the column the number of times used to filter, and microbial growth was performed in the filter by adding low-saline water and water retention in the filter. In this study, this was called materials recycling. In that case, the filter was ready to reduce the EC of water. No chemical process was performed to recycle the filter materials.

Instrumentations, Materials, Analysis, and Procedure

Instruments and equipment were comprised of:

a) 2 Cylinders of glass or plastic, the diameter of 2.5 cm (or 0.025 m) and 18.5 cm (or 0.185 m) with a height of 46 cm (or 0.46 m) and 48 cm (or 0.48 m), respectively, which were connected to the rubber hose for the out the filtered water. They were considered filters.

b) 2 beakers, volume of 250 cm^3 (or 0.00025 m^3), for measuring parameters.

c) Instrument of measuring EC, salinity, pH, and temperature of the water as named pH/Cond 340i/SET.

In the filters, the mineral mussel crumb was used as the main component of filter materials (in the third layer from the bottom). The minor components of materials comprised: coarse-grained gravel (in bed holder layer), fine-grained

Fig. 2: Bio-filter.

activated carbon (in the second layer from the bottom), and fine-grained sand (in the upper layer and in the fourth layer from the bottom). In the present study, each material was used weighing 200 to 300 grams (or 0.2 to 0.3 kilograms) in 2.5 cm (or 0.025 m) filter. Each material was used weighing 2000 to 3000 grams (or 2 to 3 kilograms) in 18.5 cm (or 0.185 m) filter. Experiments were arranged as the pilot, batch, and column designs with three replicates. Treatments were two water types comprising:

1) Low-saline water.

2) Persian Gulf seawater

They were treated gravitationally during filtration. Fig. 2 shows the used filter with a diameter of 2.5 cm (or 0.025 m) and filter materials.

In this study, all materials required for water filtration were of natural ore type in Iran's mines and eco-friendly materials. Water (low-saline) was added to the filter. The amount of EC in the samples served as the control to be compared with the filtered water outlet from the filters. Filters were held for 48 hours (or 172800 seconds) in the room, workshop, or laboratory environment. After two-day of the addition of low-saline water, the Persian Gulf seawater was added. Experiments were done daily. Water samples were taken for analysis from the Tehran purification station. The treated water and raw water samples were analyzed for pH, EC, and salinity contents based on standard methods of the American Public Health Association (APHA) [3]. The reduction efficiency of EC and salinity were calculated by using Equation (1). Water quality standards were shown for EC and pH parameters in agricultural usage according to the World Health Organization (WHO) and the Iranian Department of Environment (IRNDOE) in Table 1. The water salinity guideline (EC) was used for irrigation application in Table 2. The average values of the water parameters analysis were mentioned in Tables 3 and 4.

$$\% \Delta X = \frac{X_i - X_f}{X_i} \times 100 \qquad (1)$$

X_i = Electrical conductivity or salinity of water (Initial).

X_f = Electrical conductivity or salinity of water (Secondary).

%ΔX= Reduction efficiency EC or salinity of water (%).

RESULTS AND DISCUSSION

Physical and chemical properties of the process

As was discussed in the previous section, the well water was used as a sample of low-saline water and Persian Gulf seawater was used as a sample of saline water. Following the inlet of low-saline water and then seawater to the filters, as mentioned in the previous section, the Physico-chemical parameters of outlet water were measured and recorded as shown in Table 3 and Table 4. After 4 days (or 345600 seconds) of filters operation, EC and Sal reduction was significant in outlet seawater from the filters thus, the ultimate goal of this study, reducing the electrical conductivity of seawater , was achieved according to Figs. 3 and 4. A comparison of results showed that EC and Sal reduction efficiency in the filters was high. The increase rate was because of the chemical formula of the mineral mussel crumb. Due to the enrichment of the nutrition in the chemical formula of mineral mussel crumb, mentioned in the section on the characterization of the experiment, biological growth was increased on filled materials in filters. Results of the present study showed that the main factor reduction of EC and Sal in seawater was the biological layer growth that was the result of water staying for 48 hours (or 172800 seconds) on filter materials. The optimal time, 48 hours (or 172800 seconds) staying of water on filter materials, was determined experimentally and by performing tests to obtain the minimum throws time. Similar results were reported by [16]. Who reported that biological filtration was used for the removal of inorganic and organic compounds. Microorganisms grew on the surface of the materials and they were involved in removing a range of substances

Table 1: Water quality standard for agricultural usage [7].

Parameters	IRNDOE	WHO
Electrical conductivity (EC)	3,000 µS/cm (or 300 S/m)	< 3000 µS/cm (or < 300 S/m)
pH	6.5 to 8.4	6 to 8.5

Table 2: Saline water classification for irrigation [1].

Irrigation water salinity		Impacts on crops
Low salinity	EC < 4000 µS/cm (or EC < 400 S/m)	Most plants will have a suitable product. Some plants sensitive to salinity such as corn lose 30% and highly sensitive plants such as beans lose about 50% of the crop.
Brackish	µS/cm 4000 < EC < 8000 µS/cm (or S/m 400 < EC < 800 S/m)	Salinity-resistant plants such as beetroot, cotton, and barley provide suitable crops. Semi-resistant plants such as wheat lose about 30% and alfalfa 50% of the crop.
Salinity of average	µS/cm 8000 < EC < 12000 µS/cm (or S/m 800 < EC < 1200 S/m)	Resistant plants to salinity lose about 30% and plants semi-resistant to salinity lose more than %50 of the crop.
High salinity	EC < 12000 µS/cm (or EC < 1200 S/m)	Suitable for the cultivation of halophyte plants. Resistant plants to salinity lose more than %50 of the crop.

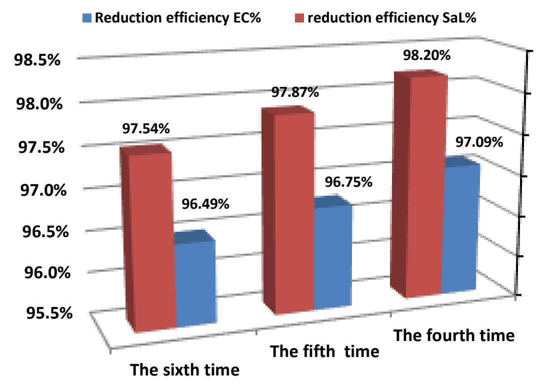

Fig. 3: Diagram of reduction efficiency EC% and Sal% in filter (diameter = 2.5 cm or 0.025 m).

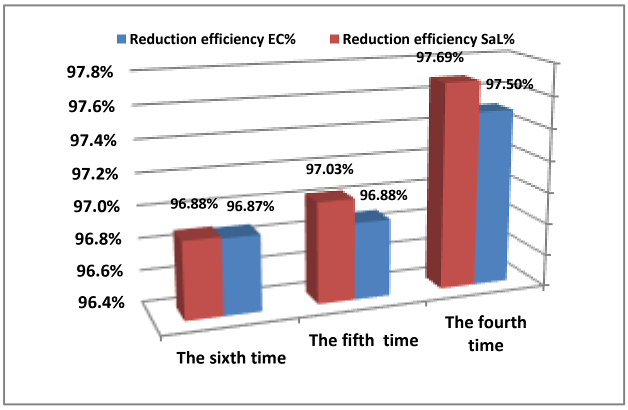

Fig. 4: Diagram of reduction efficiency EC% and Sal% in filter (diameter = 18.5 cm or 0.185 m).

depending on the source of water. Biological filtration was used for the removal of inorganic compounds (e.g. ammonium, nitrite, sulphide, methane, iron, arsenic, and manganese), and organic compounds including natural organic matter. Some of which were components of EC and Sal. EC consisted of [2]:

- Cations: Magnesium, Calcium, Potassium, Sodium.
- Anions: Carbonate, Bicarbonate, Sulfate, Chloride.
- Phosphate, Nitrate.

Sal consisted of [5]:

- Magnesium, Calcium, Potassium, Sodium, Sulfate.
- Chloride.

Effect of low-saline water

After passing low-saline water through filters, the ability for seawater treatment (EC=85 mS/cm or 8.5S/m) was achieved. Bacteria in untreated water could utilize organic and inorganic matter as growth substrates and they enhanced biological stability [30]. The presence of NOM (natural organic matter) acted as a substrate for biological re- growth [28]. The used low-saline water was stored and it was reused as a background seawater treatment in the reuse of filters, Table 3 and Table 4.

Effect of pH

After the start of the operation of the filter, pH increased in the outlet water of the filters. The increase of pH in treated water was due to the formation of metallic and non-metallic hydroxides of elements in the structure of the mineral mussel (such as NaOH, KOH, $Mg(OH)_2$, ...) due to the passage of seawater through the filters bed, The suitable pH was close to neutral for the growth of most microorganisms. Because of this, water was entered into the filter with an almost neutral pH. Microorganisms can increase the pH of their environment by releasing alkaline products or by removing certain ions from the environment. Bacterial species change due to changes in pH caused by metabolic productions. For those reasons, water was exited from the filter with alkaline pH [9].

The effect of temperature and light on microbial growth

Increasing or decreasing water temperature was affected by ambient air temperature, Table 3 and Table 4. In summer, when the weather was warm and the light was high, the working time of the filters was short due to the high growth of microorganisms. Most microbial species had the highest growth rate at a temperature between 20 and 45-degree centigrade (optimum temperature) [13]. The effect of temperature on the experiments of this research was done by increasing the growth of microorganisms in the filters. The effects of microorganism growth included: the shortness of start-up time of filters less than 4 days (or 345600 seconds), slow filtration speed compared to the beginning of filtration, septic of treated water, reduction of EC and salinity in treated outlet water from filters. Most microbial species in this study had suitable activity in the optimal light intensity in the range of night darkness and sunlight.

Effect of the sample volume

In a filter with a diameter of 2.5 cm (or 0.025 m), a daily volume of 25 cm^3 (or 0.000025 m^3) of seawater was treated. In a filter with a diameter of 18.5 cm (or 0.185 m), a daily volume of 2650 cm^3 (or 0.00265 m^3) of seawater was treated. As a result, the volume of seawater treated in filters was at least 10 times the diameter of each of the filters, Tables 3 and 4. The optimum volume was determined by the ratio of the diameter of the filter corresponding to the ratio of the daily volume of treated seawater by the filters.

Effect of microorganisms

In the 2.5 cm (or 0.025 m) filter, which was similar in size to a pilot filter and had a small surface area, the microbial growth on the filter materials was fast and complete. Therefore, the treated outlet water from the filter was useable from the first time used to filter, Table 5. In the 18.5 cm (or 0.185 m) filter, which was close to the actual operating filter for scale-up and had a large surface area, the microbial growth on the filter materials was long and the filter reached maturity with a time delay. Therefore, the treated outlet water from the filter was useable after the third time use of the filter, Table 6. In biological filters, a microbial ecosystem developed as a biofilm on the sand particles and contributed to the cleaning process. A highly diverse community dominated by bacteria was living in these biological filters. The bacteria in the sand consumed organic matter and multiply [6]. Flow behavior and microporosity (<1μm) in porous materials (e.g., activated carbon) were equally important since they regulated the transport of nutrients for biofilm growth on activated carbon [11]. The reduction in the particle size could lead to an increased area [25].

The evidence for microbial growth in filters

Slow sand filters have been used in water treatment since the early nineteenth century. A unique feature of slow sand filters is the presence of a thin layer of medium on the surface of the filter bed, known as the Schmutzdecke, loosely translated as "dirty mat". This special layer contains a layered variety of microorganisms and enables these filters to remove bacteria by a factor of 10^3 to 10^4 and E.coli by a factor of 10^2 to 10^3. The Schmutzdecke also removes organic matter and reduces the turbidity of the raw water. Schmutzdecke is composed of filamentous algae or non-filamentous organisms, such as diatoms. Slow sand filters are easily clogged by excessive amounts of algae. Intermittent operation of the filters may degrade the quality of the filter effluent by promoting anaerobic conditions within the filter bed [18]. In this study, sand was used in filters. Filters were considered a kind of sand filter. While the sand filter does not reduce the salinity and electrical conductivity of water. In this study, making changes in the structure of the sand filter, such as replacing mineral mussel and activated carbon instead of part of the structure of the sand filter, better conditions were provided for the growth of microorganisms. Therefore, the Schmutzdecke layer grew in the sandy section of these under-study filters. The Schmutzdecke layer included a variety of microorganisms. The evidence for the increase and track of biological growth were consisting of:

1) The water outlet from the filters was slow compared to the first 4 days (or 345600 seconds) of filtering due to the growth of large amounts of microorganisms and clogging of filters.

2) The water outlet from the filters was septic due to water retention and anaerobic conditions of microorganisms in the filter bed. Septic water was detected by olfactory inhalation.

The time passage of 4 days after the start of filtration was caused a negative efficiency of EC%, according to

Table *2* and

Table *2*. Therefore, the process of chemical adsorption and microbial adsorption was inactive for over 4 days. Within 4 days, there was no sign of chemical adsorption and as a result, EC of water increased instead of reducing it. However, the reduction of EC of water was repeated many times without the need for the replacement of new materials and without chemical regeneration after 4 days. It was done only using the growth of microorganisms in the filter materials. The reason for the delay in microbial adsorption after 4 days from the start of filtration was the need to adapt the microorganisms to the filter materials. Therefore, in this study, the factor reducing EC of water was only microbial absorption. It was repeated by using microbial recovery. In this paper, chemical adsorption was not performed; therefore effective adsorption parameters were not presented. According to the title of the manuscript, the presentation of various parameters involved in microbial adsorption was beyond the scope of this paper. The growth and function of microorganisms on filter materials reduced EC and salinity of outlet water of filters. It was according to "The evidence for microbial growth" in this section.

Comparison diagrams of outlet water of the filters

By using results in Table 3 and Table 4, diagrams of reduction efficiency EC% and Sal% in outlet seawater from filters were shown in Fig. 3 and Fig. 4. It was concluded that the reduction efficiency of these two parameters gradually decreased. Afterward, filters should be used again as before for the biological regrowth and return of the efficiency reduction of the parameters. Note the "reduction efficiency of EC%" column in Tables 3 and 4 for results interpretation. It showed that:

A) In the first time of filter use, the second time of filter use, and the third time of filter use, the reduction efficiency of EC% of water has been negative and was decreased.

B) In the fourth time of filter use, the reduction efficiency of EC% of water was increased and reached 97.5%.

C) In the fifth time of filter use, the reduction efficiency of EC% of water was decreased and reached 96.88%.

D) In the sixth time of filter use, the reduction efficiency of EC% of water was decreased again and reached 96.87%.

Decrease, increase and then gradual decrease for EC% in water indicated that the factor of change of EC% of water, i.e. the growth of microorganisms, did not exist at the beginning of water entering the filter and therefore EC% decreased. Over time and with the continued contact of water with filter materials, the growth of microorganisms was achieved in the filter. After repeated use of the filter, by removing the microbial mass with water from the filter, a decrease was achieved in the biofilm density of the filter. This resulted in a reduction of EC%. Biological re-growth was done again in filters. Also, the numeric value of Sal was less than EC in Tables 3 and 4 while, the reduction efficiency percentage of Sal was more than EC in filters in Fig. 3 and Fig. 4. It was because Sal was a subset of EC and it included fewer elements.

Investigating treated seawater parameters for agriculture and irrigation use

The results of this study were summarized for seawater agriculture usage in accordance with standards WHO and IRNDOE in Table 5 and Table 6. Also, the results were surveyed for seawater irrigation use in accordance to the guideline of the National Committee on Irrigation and Drainage of Iran in Table 5 and Table 6.

The increase of EC in output water from the filters compared to input water to them was due to the passage and contact of water with filter bed materials before biological growth on the filters. The decrease of EC and Sal in output water from the filters compared to input water to them was due to 48-h (or 172800 s) rest of filters and biological growth on them. The growth of microorganisms, in particular, microalgae (e.g., cyanobacteria) in filters provided the conditions for the reduction of EC and Sal. They had long-term adaptation to high salinity, were cultivated in brackish or salt water, and had high growth rates at low area consumption [20]. Cyanobacteria were oxygen-producing and photosynthetic bacteria. Moreover, they grew with minimal nutrient requirements and under natural sunlight [23]. The most important parameters in regulating algal growth by means of photosynthesis were the environmental conditions like light intensity, pH, temperature, salinity, and nutrients [17].

Table 3: Measurement parameters in filter (filter diameter = 2.5 cm or 0.025 m).

Name			Measurement parameters (Raw water - Inlet to the filter)					Measurement parameters (The filtered water - Outlet from the filter)					Reduction efficiency		How of changes	
The number of times used filter	Date of test	additive water type	Volume (m^3)	Electrical conductivity EC (S/m)	Salinity (Sal)	pH	Temperature: θ(°C)	Volume (m^3)	Electrical conductivity EC (S/m)	Salinity (Sal)	pH	Temperature: θ(°C)	Reduction efficiency Of EC%	Reduction efficiency of SaL%	pH	Temperature: θ(°C)
The first time	10/20/2019	low-saline water	5×10^{-4}	0.103	0.3	7.36	25.4	35×10^{-5}	0.262	1.2	8.95	26.2	Negative	Negative	Increasing= 1.6	Increasing= 0.8
The second time	10/22/2019	low-saline water	5×10^{-4}	0.09	0.2	7.98	27	45×10^{-5}	0.165	0.7	8.16	27.2	Negative	Negative	Increasing= 0.2	Increasing= 0.2
The third time	10/24/2019	low-saline water	5×10^{-5}	0.17	0.7	7.92	28.6	5×10^{-5}	0.265	1.3	8.48	28.9	Negative	Negative	Increasing=0.6	Increasing= 0.3
The fourth time	10/26/2019	seawater	25×10^{-6}	8.52	61	7.49	30.9	25×10^{-6}	0.248	1.1	8.51	29.4	97.09%	98.2%	Increasing= 1	Decreasing= 1.5
The fifth time	10/27/2019	low-saline water	5×10^{-5}	0.17	0.7	7.91	28.7	5×10^{-5}	0.244	1.1	8.73	28.6	Negative	Negative	Increasing= 0.8	Decreasing= 0.1
		seawater	25×10^{-6}	8.53	60.9	7.79	28.5	25×10^{-6}	0.277	1.3	8.3	26.2	96.75%	97.87%	Increasing= 0.5	Decreasing= 2.3
The sixth time	10/28/2019	low-saline water	5×10^{-5}	0.096	0.2	7.75	31.6	5×10^{-5}	0.247	1.1	8.65	28.8	Negative	Negative	Increasing= 0.9	Decreasing= 2.8
		seawater	25×10^{-6}	8.51	60.9	7.84	30.7	25×10^{-6}	0.299	1.5	8.42	29.2	96.49%	97.54%	Increasing= 0.6	Decreasing= 1.5

Table 4: Measurement parameters in filter (filter diameter = 18.5 cm or 0.185 m).

Name			Measurement parameters (Raw Water - Inlet to the filter)					Measurement parameters (The filtered water - Outlet from the filter)					Reduction efficiency		How of changes	
The number of times used filter	Date of test	additive water type	Volume(m^3)	Electrical conductivity EC (S/m)	Salinity (Sal)	pH	Temperature:θ(°C)	Volume (m^3)	Electrical conductivity EC (S/m)	Salinity (Sal)	pH	Temperature:θ(°C)	Reduction efficiency of EC%	Reduction efficiency of SaL%	pH	Temperature: θ(°C)
The first time	10/20/2019	low-saline water	0.004	0.1	0.3	7.16	29.6	0.002	2.13	12.9	7.91	29.9	Negative	Negative	Increasing= 0.8	Increasing= 0.3
The second time	10/22/2019	low-saline water	0.004	o.09	0.2	7.88	31.2	0.002	0.825	4.6	8.21	29	Negative	Negative	Increasing= 0.3	Decreasing= 2.2
The third time	10/24/2019	low-saline water	0.004	0.08	0.2	7.27	27.9	265×10^{-5}	0.414	2.1	8.72	29.7	Negative	Negative	Increasing= 1.5	Increasing= 1.8
The fourth time	10/26/2019	seawater	0.004	8.48	60.7	7.56	30.6	265×10^{-5}	0.212	1.4	8.01	31.4	97.5%	97.69%	Increasing= 0.5	Increasing= 0.8
The fifth time	10/27/2019	low-saline water	0.004	0.09	0.2	7.25	28.9	265×10^{-5}	0.273	1.3	8.71	28.4	Negative	Negative	Increasing= 1.5	Decreasing= 0.5
		seawater	0.004	8.46	60.6	7.56	32	265×10^{-5}	0.264	1.8	8.28	31.4	96.88%	97.03%	Increasing= 0.7	Decreasing= 0.6
The sixth time	10/28/2019	low-saline water	0.004	0.1	0.2	7.49	28.7	265×10^{-5}	0.276	1.3	8.72	28	Negative	Negative	Increasing= 1.2	Decreasing= 0.7
		seawater	0.004	8.51	60.8	7.31	29.6	265×10^{-5}	0.266	1.9	8.28	30	96.87%	96.88%	Increasing= 1	Increasing= 0.4

Table 5: The Results summary of treated water for agriculture and irrigation use (Filter diameter=2.5cm or 0.025 m).

Name			Measurement parameters (The filtered water - Outlet from the filter)		Possibility of using outlet water from the filter for agriculture (Based on standards) (According to Table 1)		Final usability for agriculture	Possibility of using outlet water from the filter for irrigation (Based on standards) (According to Table 2)		Final usability for irrigation
The number of times used filter	additive water type	Date of test	EC (S/m)	PH	EC (S/m)	PH	-----------	EC (S/m)	PH	------------
The first time	low-saline water	10/20/2019	0.262	8.95	According to WHO	Out of WHO, IRNDOE	Yes (with pH correction)	Most plants will have a suitable product.	Out of WHO, IRNDOE	Yes (with pH correction)
The second time	low-saline water	10/22/2019	0.165	8.16	According to WHO	According to WHO, IRNDOE	Yes	Most plants will have a suitable product.	According to WHO, IRNDOE	Yes
The third time	low-saline water	10/24/2019	0.265	8.48	According to WHO	According to WHO	Yes	Most plants will have a suitable product.	According to WHO	Yes
The fourth time	seawater	10/26/2019	0.248	8.51	According to WHO	Out of WHO, IRNDOE	Yes (with pH correction)	Most plants will have a suitable product.	Out of WHO, IRNDOE	Yes (with pH correction)
The fifth time	low-saline water	10/27/2019	0.244	8.73	According to WHO	Out of WHO, IRNDOE	Yes (with pH correction)	Most plants will have a suitable product.	Out of WHO, IRNDOE	Yes (with pH correction)
	seawater		0.277	8.3	According to WHO	According to WHO, IRNDOE	Yes	Most plants will have a suitable product.	According to WHO, IRNDOE	Yes
The sixth time	low-saline water	10/28/2019	0.247	8.65	According to WHO	Out of WHO, IRNDOE	Yes (with pH correction)	Most plants will have a suitable product.	Out of WHO, IRNDOE	Yes (with pH correction)
	seawater		0.299	8.42	According to WHO	According to WHO	Yes	Most plants will have a suitable product.	According to WHO	Yes

Table 6: The Results summary of treated water for agriculture and irrigation use (Filter diameter=18.5 cm or 0.185 m).

Name			Measurement parameters (The filtered water - Outlet from the filter)		Possibility of using outlet water from the filter for agriculture (Based on standards) (According to Table 1)		Final usability for agriculture	Possibility of using outlet water from the filter for irrigation (Based on standards) (According to Table 2)		Final usability for irrigation
The number of times used filter	additive water type	Date of test	EC (S/m)	pH	EC (S/m)	pH	----------	EC (S/m)	pH	------------
The first time	low-saline water	10/20/2019	2.13	7.91	Out of WHO, IRNDOE	According to WHO, IRNDOE	NO	Suitable for the cultivation of halophyte plants.	According to WHO, IRNDOE	Yes
The second time	low-saline water	10/22/2019	0.825	8.21	Out of WHO, IRNDOE	According to WHO, IRNDOE	NO	Resistant plants to salinity lose about 30% and plants semi-resistant to salinity lose more than 50% of the crop.	According to WHO, IRNDOE	Yes
The third time	low-saline water	10/24/2019	0.414	8.72	Out of WHO, IRNDOE	Out of WHO, IRNDOE	NO	Salinity-resistant plants such as beetroot, cotton, and barley provide suitable crops. Semi-resistant plants such as wheat lose about 30% and alfalfa 50% of the crop.	Out of WHO, IRNDOE	Yes (with pH correction)
The fourth time	seawater	10/26/2019	0.212	8.01	According to WHO, IRNDOE	According to WHO, IRNDOE	Yes	Most plants will have a suitable product.	According to WHO, IRNDOE	Yes
The fifth time	low-saline water	10/27/2019	0.273	8.71	According to WHO, IRNDOE	Out of WHO, IRNDOE	Yes (with pH correction)	Most plants will have a suitable product.	Out of WHO, IRNDOE	Yes (with pH correction)
	seawater		0.264	8.28	According to WHO, IRNDOE	According to WHO, IRNDOE	Yes	Most plants will have a suitable product	According to WHO, IRNDOE	Yes
The sixth time	low-saline water	10/28/2019	0.276	8.72	According to WHO, IRNDOE	Out of WHO, IRNDOE	Yes (with pH correction)	Most plants will have a suitable product	Out of WHO, IRNDOE	Yes (with pH correction)
	seawater		0.266	8.28	According to WHO, IRNDOE	According to WHO	Yes	Most plants will have a suitable product.	According to WHO	Yes

The richness of the constituents of mineral mussel was suitable for biological growth. The mentioned results in the final usability column in Table 5 and Table 6 indicated that low-saline water and treated seawater were capable of use for agriculture, irrigation, or both. In other words, the causative agent of EC and Sal reduction in the biological filter proposed in this study was the biological growth on filter materials that mostly consist of sand-activated carbon and mineral mussel. Biological organisms, microorganisms, fed from nutrients in the water (especially fed from components of EC and Sal), activated carbon, and mineral mussel for growth and reproduction. Therefore, they also induced a reduction of EC and Sal in water.

CONCLUSIONS

From the data presented in this experiment the following conclusions can be drawn:

The designed bioreactors can be used as an effective treatment alternative for EC and Sal treatment of seawater and also RO system effluent in similar cases. The efficiency of the pilot has been gradually increasing over course of time and then gradually decreasing. Due to the nature of seawater , containing nutrients needed for biological growth on filter materials, it is preferred to add non-nutrients. Reduction of outdoor temperature can lead to lower efficiency of bioreactors. The new method introduced in this study is considerable in terms of high reduction efficiency for EC and Sal in the outlet water from bioreactors as compared to the inlet water to those below the permissible limit recommended by WHO and IRNDOE. Seawater treatment can be suggested for agriculture and irrigation usage where the amount of fresh water is scarce.

Acknowledgments

The author would like to thank from professors for their thorough advice and guidance.

Received : Nov. 20, 2021 ; Accepted : Feb. 23, 2022

[1] Abedi M.J., Nairizi S., Ebrahimi Birang N., Maherani M., Khaledi H., Mehrdadi N., Cheraghi A.M. "Book of Use of Saline Water in Sustainable Agriculture." National Committee on Irrigation and Drainage. Tehran, Iran (1999).

[2] Amiri M. "Book of Principles of Water Treatment", Arkan, 11th ed., Esfahan, Iran (2019).

[3] APHA. "Book of Standard Methods for the Examination of Water and Waste Water", American Public Health Association. 21st ed., Washington (2005).

[4] Arias D., Cisternas A., Rivas M., Biomineralization Mediated by Ureolytic Bacteria Applied to Water Treatment, *Journal of Crystals*, **7(11)**: 45 (2017).

[5] CATDS. "Sea Surface Salinity Remote Sensing at Salinity Expert Center", CEC-OS Center (2017).

[6] Chan S., Pullerits K., Riechelmann J., Monitoring Biofilm Function in New and Matured Full-Scale Slow Sand Filters Using Flow Cytometric Histogram Image Comparison, *Journal of Water Research*, **138**: 27-36 (2018).

[7] Department of Environment, "Iran Water Quality Standards." (2016).

[8] EPA. "The United States Environmental Protection Agency" (2014).

[9] Gholami M., Mohammadi H., "Book of Water and Wastewater Microbiology", Hayan.Tehran, Iran (1999).

[10] Golie M., Yedira A., Upadhyayula, S., Recovery of Nitrate from Water Using Chitosan & Bentonite Biocomposite in a Continuous Stirred Tank Reactor, *Journal of Environment and Bio Research*, **2**: 1-3 (2018).

[11] Heshmat B., Andrews G., Montoya A., Terahertz Scattering and Water Absorption for Porosimetry, *Journal of Optics Express*, **25**: 27370-27385 (2017).

[12] Hoslett J., Massara T., Malamis S., Surface Water Filtration Using Granular Media and Membranes, *Journal of Science of the Total Environment*, **639**: 1268–1282 (2018).

[13] Hosseinian M., "Book of Water Treatment Plant Design", Shahrab.Tehran, Iran (2008).

[14] Huggins M., Haeger A., Biffinger C., Granular Biochar Compared with Activated Carbon for Wastewater Treatment and Resource Recovery, *Journal of Water Research*, **94**: 225-232 (2016).

[15] Ideal Trades Men Groops. "Ideal Trades Men." (2008).

[16] Jane F., Smets B., Microbial Biotechnologies for Potable Water Production, *Journal of Microbial Biotechnology*, **10(5)**: 1094-1097 (2017).

[17] Kamyab H., Fadhil M., Ponraj M., Isolation and Screening of Microalgae from Agroindustrial Wastewater for Biomass and Biodiesel Sources, *Journal of Desalination and Water Treatment*, 1-8 (2016).

[18] Kawamura S., "Book of Integrated Design and Operation of Water Treatment Facilities." 2nd ed., John Wiley & Sons, Inc. Canada (2000).

[19] Kim D., Park S., Yoon Y., Removal of Total Dissolved Solids from Reverse Osmosis Concentrates from a MunicipalWastewater Reclamation Plant by Aerobic Granular Sludge, *Journal of Water*, **10(7)**:882 (2018).

[20] Lorenzen J., Igl N., Extraction of Microalgae Derived Lipids with Supercritical Carbon Dioxide in an Industrial Relevant Pilot Plant, *Journal of Bioprocess and Biosystems Engineering*, **40(6)**:911–918 (2017).

[21] Massia Co. "Massia Product Company." (2019).

[22] Meshkat S. Arad Sadaf. Animal Feed Production Group (2020).

[23] Minas K., Karunakaran E., Bond T., Biodesalination: an Emerging Technology Fortargeted Removal of Na^+ and Cl^- from Seawater by Cyanobacteria, *Journal of Desalination and Water Treatment*, **55(10)**: 2647-2668 (2015).

[24] Missimer M., Maliva G., Environmental Issues in Seawater Reverse Osmosis Desalination, *Journal of Desalination*, **434**: 198–215 (2018).

[25] Mohajeri P., Smith C., Selamat M. "Enhancing the Adsorption of Lead (II) by Bentonite Enriched with pH-Adjusted Meranti Sawdust, *Journal of Water*, **10**:1-21 (2018).

[26] Nguyen T., Jeong S., Pham T., Effect of Granular Activated Carbon Filter on the Subsequent Flocculation in Seawater Treatment, *Journal of Desalination*, **354**:9-16 (2014).

[27] Pontius F. Treatability of a Highly-Impaired, Saline Surface Water for Potential Urban Water Use, *Journal of Water*, **10**:324 (2018).

[28] Rajapakse J., Millar J., Gunawardana C., Applicability of Pebble Matrix Filtration for the Pre-Treatment of Surface Waters Containing High Turbidity and NOM, *Journal of Desalination and Water Treatment*, **57**: 24820-24832 (2016).

[29] Shafy H., Khateeb M., Shehata E., Greywater Treatment Using Different Designs of Sand Filters, *Journal of Desalination and Water Treatment*, 1-6 (2013).

[30] Shuili L., Li L., Liu G. "Microbial Communities Shaped by…", *Journal of Frontiers in Microbiology*, **8**. PP:2465 (2017).

[31] Westholm L., Repo E., Sillanpaa M. "Filter materials for Metal Removal from Mine Drainage", *Journal of Environmental Science and Pollution Research International*, **21**:9109-9128 (2014).