Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.26455

208 (2020) 110–116
December

Integrated system of post-treatment for desalinated water using low cost Egyptian natural materials – a case study

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Received 22 March 2020; Accepted 18 August 2020

ABSTRACT

A specific degree of re-mineralization and carbonation is required for desalinated water as it is deficient with indispensable constituents like calcium, magnesium and alkalinity. This study illustrates how we can solve these problems by using low-cost Egyptian natural materials (about 1,000 Egyptian pounds per ton) such as calcite, dolomite and hydrated lime, rather than high cost imported calcite (about 36,000 Egyptian pounds per ton). Microtox analyzer 500 and other methods were used to characterize local materials to verify that they are free of toxic substances and accommodate the use of households, respectively. Results indicated that for an integrated system, concentrations of Ca^{2+}, Mg^{2+}, SO_4^{2-} and desalinated water alkalinity were recorded at 98, 12, 45 and 50 ppm, respectively. However, those parameters recorded 16, 00.00, 19 and 00.00 ppm, respectively, in the case of imported calcite. Accordingly, the integrated system was used instead of imported calcite in desalinated water re-mineralization due to low-cost, excellent efficiency and furthermore fits the Minister of Health Decree No 458/2007 as a safeguard for foreign currency and native substitute technology, valorization of local natural resources and green environmental protection.

Keywords: Reverse osmosis; Post-treatment; Carbonation; Calcite; Dolomite; Lime

1. Introduction

In the past 30 years, desalination has grown into a viable alternative source of non-conventional water supplies due to the rising water scarcity and water demands. In the following five years, 5.7 million m^3/d of the new production capacity will be added. This ability is expected to double before 2030 [1–3].

Several scientists have been using natural agro-residues and solid waste for water and wastewater treatment and met local and national guidelines [4–10]. In Egypt, the annual quantity of water touches 550 m^3/person/y (absolute scarcity), and the threshold of scarcity has been one thousand m^3/person/y, with drinking water in Egypt exceeding 25 million m^3/d. The desalinated water quantity is about 300,000 m^3/d which needs post-treatment.

The desalinated water permeate content no longer serves to drink or for irrigation purposes [11]. Desalinated water is known to be acidic and corrosive with low to no content of calcium and magnesium hardness which was considered unhealthy for drinking and is generally found to be violent towards metallic component parts of the distribution system. In addition, it can also be dangerous to drink water without dissolved oxygen and taste dry. Post-treatment of desalinated reverse osmosis water is therefore required prior to storage or forwarding to system distribution and must include disinfection [12–16].

The divalent constituents' calcium, magnesium, and sulfate will be rejected entirely via the membrane in an incredibly reverse osmosis process, leading to the permeation of binary compounds in a large amount regulated by diffusion or mass cutoff through the membrane [17].

Langelier saturation index and Larson indices are widely used as warning signs of the aggressiveness and corrosiveness of potable water [18–22].

Remineralization and recarbonation are achieved via any of the following materials: limestone dissolution through, the addition of sodium hydrogen carbonate, adding of slaked lime and soda ash, the addition of online lime, the addition of carbonic acid gas and excess lime [23].

The current method for carbonation and remineralization in the Remila plant at Matrouh Governorate with a capacity of 48,000 m^3/d is carbonic acid gas (CO_2) via a calcite bed ($CaCO_3$) as a source of alkalinity and imported calcite as a source of calcium. This process will produce water with a pH adequate to the permissible pH in compliance with the Minister of Health Decree no 458/2007 for the use of water for drinking and household use. Throughout the phase, the reaction was carried out within the process as shown in the following equation:

$$CO_2 + CaCO_3 + H_2O \rightarrow Ca(HCO_3)_2 \quad (1)$$

With the exception of Remila station (Matrouh Governorate) and El Yousser (Red Sea Governorate), most of Egypt's desalination plants were run without post-treatment, overpriced calcite imported from abroad was used. Post-treatment or remineralization processes are required to convert unsafe desalinated water that is produced for drinking and domestic use from the reverse osmosis desalination unit.

The contemporary method of recarbonation and remineralization at the Remila plant at Matrouh Governorate with a capacity of 48,000 m^3/d is carbon dioxide (CO_2) via calcite bed ($CaCO_3$) with a thickness of approximately 3 m and retention time about 15 min. The imported calcite costs are extraordinarily high (about 36,000 Egyptian pounds per ton). The operating cost of the drinkable metric capacity unit was 2 pounds/m^3.

The study is based on the use of alternative natural materials to imported excessive price calcite (2 pounds/m^3) used in the Remila plant via the post-treatment of desalinated water using an integrated system. The integrated system consisted of Egyptian materials (5 piasters/m^3) of low-cost nature. Calcite, dolomite and lime are included in the integrated system to include calcium, magnesium, sulfate and bicarbonates that were lost during desalination.

The integrated system was carried out laboratory-scale experiments as shown in this study followed by the scale-up of the system by replacing imported calcite with local natural materials as fabricated in the Remila plant for desalination by reverse osmosis.

2. Materials and methods

2.1. Materials

Natural materials, calcium carbonate (calcite), hydrated lime and dolomite were collected from the quarry of Samlot, which is located in Minia Governorate, Upper Egypt, Egypt, and the materials were characterized by Microtox analyzer 500 for toxicity. The purity of these materials has also been analyzed with APHA [24]. H_2SO_4 and NaOH were supplied from Alfa Aesar (Thermo Fisher Scientific, USA) with 97% purity (for initial pH adjustment).

2.2. Methods

The desalinated water collected from the Remila plant is shown in Fig. 1, distilled water was used for solution preparation. Physicochemical parameters of water before and after post-treatment were analyzed according to APHA [24].

2.3. Integrated system

The prototype (1 m^3/d) was fabricated in series as shown in Fig. 2 and the process of post-treatment is outlined in Table 1.

Factor affecting such as retention time and pH were performed to assess the optimum post-treatment system conditions.

3. Results and discussion

3.1. Identification of local raw materials

Raw materials used in an integrated system such as calcite, dolomite, and hydrated lime were characterized for their toxicity and purity as shown in Table 2.

There are no harmful properties of these materials from the previous tests, and these materials were very clean and safe for use in drinking water.

3.2. Analysis of desalinated water of Remila plant

The annual average water quality of Remila permeate water was reported in Table 3 compared with the Egyptian guidelines.

The results shown in Table 2 for the permeate water indicated that there no any cations such as calcium and magnesium or anions such as carbonate and bicarbonate alkalinity except NaCl (130 mg/L) as well as pH is out of the permissible limit, but only minor increases calcite concentration after interaction with calcite, no magnesium and even alkalinity and calcium ions.

3.3. Application of an integrated system with distilled water

The implementation of the integrated system that incorporates acid, hydrated, and lime addition, contact with calcite and dolomite and finally post-disinfection; all these processes have been explored as shown in Fig. 2.

The efficiency of post-treatment has been established through an integrated system; it can be verified by the utilization of distilled water which is used for post-treatment. Table 4 summarizes the variability of physicochemical properties of water before and after post-treatment via an integrated system.

From the previous results, there are no cations or anions found in distilled water and after the water passed through

Fig. 1. (a) Goggle earth of Remila station and (b) current view.

Table 1
The processing of the integrated system of post-treatment

Serial no.	Type of material	Quantity	Contact time(min)	Thickness	pH
1	Sulfuric acid (1 M)	1 mL	1	Liquid	3.5–4
2	Hydrate lime (5%)	0.5 mL	1	Liquid	5–6
3	Dolomite	1.5 kg	5	10 cm	6.5
4	Calcite	1 kg	5	10 cm	7–8

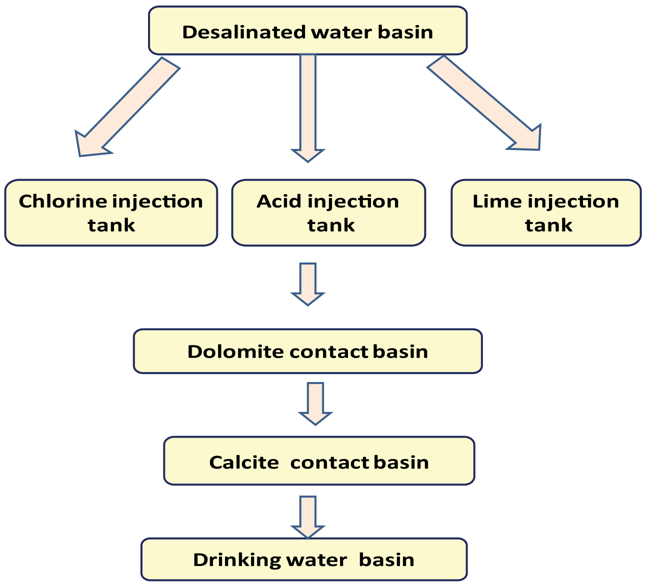

Fig. 2. Systematic graph of an integrated system of post-treatment of desalinated water.

the integrated system, the physicochemical parameters after post-treatment are within acceptable values.

3.4. First trial with an integrated system

The first trial of an integrated system was conducted under the following conditions; pH = 2 mL of acid dose (1 M), the contact time of dolomite and calcite stages is 4 and 3 min, respectively. The variations of physicochemical properties of desalinated water via an integrated system were summarized as shown in Table 5.

From the previous results, the total dissolved solids present in the permeate water reported 214 ppm after integration of the physicochemical parameters such as calcium, magnesium, alkalinity and sulfate in appropriate values after application.

3.5. Second trial with an integrated system

The second trial of an integrated system fabricated at the following conditions; pH (3.5), acid dose (2 mL, 1 M), contact time with dolomite and calcite is 6 and 3 min, respectively.

Table 2
Physicochemical properties of local natural materials

Parameters	Calcite	Dolomite	Hydrated lime	Methods
Toxicity	Not toxic	Not toxic	Not toxic	Microtox analyzer 500
Purity %	99.1	98.5	98.1	APHA [24]
Impurity %	0.1	0.3	0.15	APHA [24]

Table 3
Annual average water quality of the Remila plant

Parameter	Permeate	With imported calcite	Egyptian guidelines
pH	6.2	7.5	6.5–8.5
Turbidity, µs/cm	0.05	0.2	1
Total suspended solids, ppm	130	150	1,000
Calcium, ppm	00.00	16	up to 250
Magnesium, ppm	00.00	00.00	up to 150
Alkalinity, ppm	00.00	19	–
Boron, ppm	0.6	0.6	1

Table 4
Variation of physicochemical properties of distilled water via integrated system

Parameter	Distilled water	After lime addition	After dolomite contact	After calcite contact	Permissible limit
pH	8.0	5.0	6.0	7.5	6.5–8.5
Total suspended solids, ppm	6.3	110	130	150	<1,000
Cond., µs/cm	13	210	255	290	<2,000
Hardness, ppm	0	50	60	75	<500
Alkalinity, ppm	0	20	30	50	–
Sulphate, ppm	0	100	100	100	250

The variations of physicochemical properties such as calcium, magnesium, alkalinity and sulfate of desalinated water via an integrated system at the second trial were summarized in Table 6. From these results, the total dissolved solids in the permeate water were recorded as 214 ppm after applying an integrated at a particular condition. All the results after post-treatment comply with Egyptian guidelines.

3.6. Third trial with an integrated system

The third trial of an integrated system which fabricated using the following conditions; pH 4, a dose of acid (1 mL; 1 M), 0.5 mL, lime 5%, the contact time of dolomite and calcite 4 and 2 min, respectively. The variations of physicochemical properties of desalinated water through an integrated system in the third trial were summarized in Table 7. The water quality was improved with the lowest chemical usage; this means that the optimum conditions were reached. From these results as shown in Table 7, the total dissolved solids present in permeate water recorded 214 ppm after applying an integrated at a certain condition at optimum conditions. Physicochemical parameters such as calcium, magnesium, alkalinity and sulfate are recorded as 98, 12, 45 and 50 ppm, respectively; all these parameters are in permissible limits according to the ministry of health decree no 458/2007. It was also noticed that the dissolution of dolomite is much slower than that of calcite [25–29].

3.7. Comparative study between integrated and running systems of post desalination

From the results shown in Fig. 3 and previous results of the utilization of the imported calcite we can find that the integrated system of local natural materials which composed

Table 5
Variation of physicochemical properties of desalinated water via an integrated system in the first trial

Parameter	Desalinated water	After lime addition	After dolomite addition	After calcite addition	Permissible limit
pH	6.9	4	6.0	8.1	6.5–8.5
Total suspended solids, ppm	214	445	403	592	<1,000
Hardness, ppm	6	28	56	160	<500
Ca^{++}, ppm	6	28	44	148	<250
Mg^{++}, ppm	0	0	12	12	<150
Alkalinity, ppm	0	0	40	56	–
Sulphate, ppm	0	107	107	107	<250

Table 6
Variation of physicochemical properties of desalinated water via an integrated system in the second trial

Parameter	Desalinated water	After lime addition	After dolomite addition	After calcite addition	Permissible limit
pH	6.8	4	6.0	8.1	6.5–8.5
Total suspended solids, ppm	214	368	365	520	<1,000
Hardness, ppm	6	28	88	170	<500
Ca^{++}, ppm	6	28	80	162	<250
Mg^{++}, ppm	0	0	8	8	<150
Alkalinity, ppm	0	0	40	56	–
Sulphate, ppm	0	114	114	114	<250

Table 7
Variation of physicochemical properties of desalinated water via an integrated system in the second trial

Parameters	Desalinated water	After lime addition	After dolomite addition	After calcite addition	Permissible limit
pH	6.8	5	7	8.1	6.5–8.5
Total suspended solids, ppm	214	300	320	320	<1,000
Hardness, ppm	6	14	70	110	<500
Ca^{++}, ppm	6	14	58	98	<250
Mg^{++}, ppm	0	0	12	12	<150
Alkalinity, ppm	0	0	30	45	–
Sulfate, ppm	0	50	50	50	<250

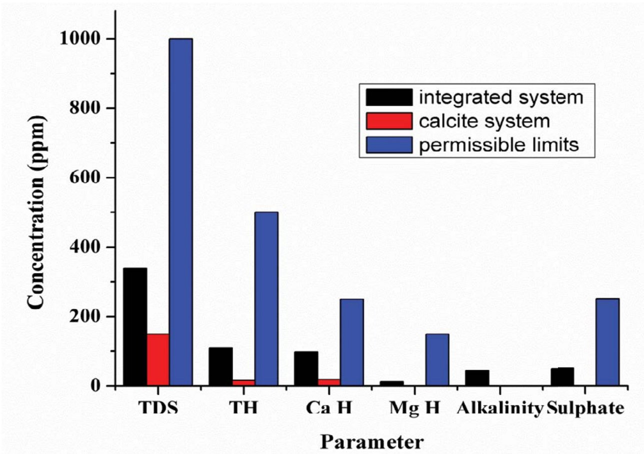

Fig. 3. Comparison between the average physicochemical properties of the remineralized reverse osmosis water through an integrated system, calcite system and the permissible limits according to the 458/2007 decree.

of hydrated lime, calcite and dolomite recorded chemical parameters such as calcium, magnesium, alkalinity and sulfate as 98, 12, 45 and 50 ppm, respectively. Alternatively, the same chemical parameters had been recorded 16, 00.00, 19 and 00.00, respectively. The running cost of an integrated system can be used as an alternative system instead of the imported calcite system due to a low cost (four Egyptian piasters) in contrast to (200 Egyptian piasters) in the case imported calcite system. The water quality after post-treatment after utilization of the integrated system sharply improved and comply with the Minister of Health decree no 458/2007 after the utilization of an integrated system.

4. Conclusion

From the study results of an integrated system, we concluded that concentrations of Ca^{2+}, Mg^{2+}, SO_4^{2-} and alkalinity were recorded at 98, 12, 45 and 50 ppm, respectively. However, those parameters recorded 16, 00.00, 19 and 00.00 ppm, respectively, in the case of imported calcite. The integrated system of low cost Egyptian natural materials consisting of hydrated lime, calcite and dolomite can be used as an alternative system for the improvement of desalinated water quality for several reasons: pH adjustment with Egyptian regulation, the addition of certain essential ingredients to desalinated water (calcium, magnesium, sulfate and alkalinity), save of foreign currency, local replacement technology, valorization of local natural resources, preservation of the water resources, compatibility with international and local guidelines, and finally increase the lifetime of electromechanical parts of the water system.

Acknowledgments

This project was supported financially by the Science and Technology Development Fund (STDF), Egypt, under grant no. 31324).

Dr. Fathy gratefully acknowledges the science and technology development Fund (STDF), who funded the project and faculty of Earth Sciences Staffs, Beni-Suef University additionally thankful to the holding company for water and wastewater as well as Matrouh company for water and wastewater, mainly chemists Amira El Ngar and Waleed Salheen. And finally, the authors also are grateful to Dr. R.E. Khalifa for careful checking of the details and for helpful comments that improved this paper.

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