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# State-of-the-art review on post-treatment technologies

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## HIGHLIGHTS

- Alternative post-treatment processes are reviewed.
- Addition of calcium, carbonate alkalinity and magnesium is discussed.
- Re-mineralization kinetic design models are discussed extensively.
- Economic evaluations of widely applied re-mineralization processes are presented.

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## ABSTRACT

Desalinated waters are poor in minerals thus, a certain degree of re-mineralization is essential so as to make the water palatable and non-corrosive as well as to meet health requirement. Selection of re-mineralization process is determined by regulatory water quality standards. This review summarizes alternative post-treatment practices aimed to introduce calcium, carbonate alkalinity and magnesium to desalinated water with emphasis on kinetic design models. Among the methods discussed are: blending with source water, direct dosage of chemicals, limestone, dolomite and magnesium oxide dissolution, ion exchange and a novel micronized limestone dissolution process. Finally, cost evaluations of various re-mineralization alternatives are presented.



**Contents**



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## 1. Introduction

Desalination processes involve three major steps: pre-treatment, pure water production via membrane or thermal separations and post-treatment stabilization, as schematically outlined in Fig. 1. Since desalinated water is devoid of minerals, re-mineralization is necessary in order to provide essential ingredients to the water, to meet health requirement and to make the water palatable and non-corrosive. Water quality goals for post-treatment processes are most often site-specific based on the water source, the membrane process and the existing water system. Additionally, the end-use of the desalinated water determines the required quality of the product water.

Most of the desalinated water is produced for human consumption. Minor end-usages include irrigation, groundwater recharge and industrial utilization. Potable water is required to conform with health standards while water intended for irrigation is monitored for dissolved salts such as chlorides and boron. In irrigation water, sodium, calcium and magnesium concentrations are significant since they affect the physical properties of soils, specifically their permeability. The Sodium Adsorption Ratio (SAR) is used to determine the suitability of water for irrigation purposes. Generally, the higher the SAR, the less suitable the water is for irrigation.

Duranceau et al. [1,2] recommended goals for post-treatment based on literature, survey and case study reviews (Table 1). These goals were proposed to serve as drinking water criteria. Table 1 includes also the Israeli water regulations for desalinated drinking water [3]. The proposed guidelines are seen to differ from the Israeli regulations since Duranceau et al. differentiate between sea and brackish water sources and include some requirements absent in the Israeli regulations. Standards such as those presented in Table 1 raise the question whether there is sufficient technical evidence justifying the efforts and costs involved for achieving narrow water quality limits.

**Table 1**
Proposed and regulatory drinking water quality standards for re-mineralized desalinated water.

| Parameter | Seawater [1] | Brackish water [1] | Israeli regulation [3][a] |
|---|---|---|---|
| pH | 6.5–9.5 | 7.5–8.4 | 7.5–8.3 |
| Alkalinity (mg/L as $CaCO_3$) | 50–125 | 75–150 | >80 |
| Calcium (mg/L as CaCO3) | 70–75 | 60–100 | 80–120 |
| Hardness (mg/L as CaCO3) | 50–85 | 75–110 | 160–240 |
| TDS (mg/L) | 100–500 | 85–350 | – |
| Turbidity (NTU) | 0.6–3.0 | 0.2–2.0 | <0.5 |
| Boron (mg/L) | 0.5–1 | Not applicable | – |
| Bromide (mg/L) | <0.3 | <0.3 | – |
| LSI | – | – | >0 |
| CCPP | – | – | 3–10 |

[a] Referenced for both the seawater and brackish water quality standards.

## 2. Alternative Ca based post-treatment methods

### 2.1. Blending with source water

Blending desalinated water with source water or partially treated water is a common post-treatment practice. The quality of the source water used for blending is of particular importance from both microbial and mineral aspects. The amount of water used for blending may vary from less than 1% to 10%. Due to corrosion and taste considerations, the amount of source seawater is typically limited to 1% or less when blended with desalinated water. In addition, with higher blending percentage bromide is likely to react with residual disinfectants during storage and distribution [4]. More commonly, low-salinity brackish water is blended with desalinated water [5]. Blending of desalinated water with groundwater or potable water from other sources is often applied to increase the reliability and flexibility of water supply.

Blending is acceptable only when the source water is of high quality, and is adequately pre-treated for both microbial and chemical concerns. Anthropogenic pollutants, from a range of sources, need to be considered on a local basis [4]. A minimal requirement is cartridge filtration of the blending water. If the source water is exposed to organic contamination it should be filtered through activated carbon [5].

### 2.2. Direct dosage of chemicals

Another re-mineralization approach is by direct dosage of some essential ions to the desalinated water in order to achieve a desired balanced mineral content. The chemicals used include: carbon dioxide ($CO_2$), lime ($Ca(OH)_2$), sodium bicarbonate ($NaHCO_3$), sodium carbonate ($Na_2CO_3$), and calcium chloride ($CaCl_2$). Sodium bicarbonate is not generally used since it exhibits low solubility and is very costly. Its storage under humid conditions is difficult as it tends to cake at moisture settings [6].

Calcium and bicarbonate alkalinity re-mineralization has been achieved by dosage of the following combinations: $CO_2/Ca(OH)_2$; $CaCl_2/NaHCO_3$; $CaCl_2/Na_2CO_3$ and $CaCl_2/NaHCO_3/Na_2CO_3$. A drawback of the last three combinations is the increase in sodium and chloride concentrations [7]. These ions are of major importance in waters used for irrigation and they also determine wastewater salinity. The United States Environmental Protection Agency (EPA) has a secondary maximum contaminant level (MCL) for chloride, set at 250 mg/L [8].

The most common direct dosage method worldwide is carbon dioxide and excess hydrated lime [9] which has the advantage of re-mineralizing desalinated water with calcium and bicarbonate at an equivalence ratio of 1:1:

$$2CO_2 + Ca(OH)_2 \rightarrow Ca^{2+} + 2HCO_3^- \quad (1)$$

Lime exhibits inverse solubility characteristics and does not dissolve easily, resulting in residual turbidity often exceeding 5 NTU in the finished water [7]. Hydrated lime is fed into lime saturators in the form of lime slurry.

An effective lime saturator is a key feature in the $CO_2/Ca(OH)_2$ process. It is basically a thickener clarifier tank designed to enhance lime particles dissolution. The design aspects of a hydrate lime saturator include: mixing energy, residence time, feedwell configuration, control of lime bed level and recycle flow. In the saturator, the lime slurry is fed continuously into a reaction zone, where it is mixed with recycled lime particles. The bed level is critical in achieving effective flocculation and distribution of the feed into the settling zone of the tank (i.e., optimize solids dispersion). Lime particles are recycled from the settled lime bed into the feedwell to enhance particle flocculation and settling. Polyelectrolyte flocculant is often added to further increase flocculation and to prevent carryover of smaller slow-settling particles. The low solids concentration limewater, produced by the saturator, is injected into the untreated desalinated water. A solution of carbon

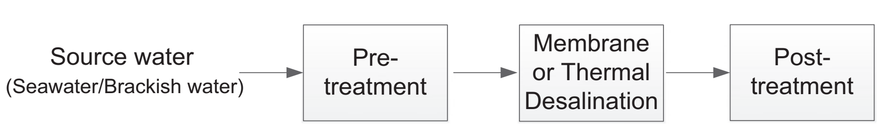


**Fig. 1.** General desalination process scheme.