



Reducing the precipitation fouling of seawater feed to desalination processes using seeding and softening methods

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Received 13 April 2023; Accepted 17 June 2023

ABSTRACT

This research emphasizes the use of seeded softening methods in a batch crystallizer as a pre-treatment process for the reduction of the scaling tendency of seawater inlet to desalination process. The investigations showed that seawater supersaturation with respect to calcium carbonate can be decreased radically after a batch residence time of 60 min. The parameters of growth kinetics are estimated from the experimentally measured desupersaturation data. It is found that the calcite growth mechanism is controlled by the surface integration step and the rate of growth of calcite is enhanced with raising temperature and at higher mixing rates. The kinetic parameters affecting the growth rate of calcite-seeded crystals in supersaturated seawater are estimated at variable temperatures and mixing rates. The measured data are analyzed according to the two-step growth model. An increase in the mixing intensity has a slight variation in the growth rate order (n) at a seawater salinity of 45 g/kg. Nevertheless, the overall growth rate constant (K_c) value rises considerably at higher mixing rates over the 300–600 rpm range. An increase in temperature from 40°C to 70°C resulted in augmentation of the coefficients of mass transfer and surface reaction. The estimated activation energy for mass transfer and surface reaction steps are 46.5 and 81.5 kJ/mol, respectively.

Keywords: Calcite; Fouling precipitation; Growth; Scaling tendency; Seawater; Desalination

1. Introduction

As the world population increases, the global need for fresh water is steadily increasing. In many dry areas of the world, natural freshwater resources such as groundwater, spring water, rivers, and lakes can't cover the water supply demand [1]. More than 1.2 billion people live in physical water scarcity areas, the region having water availability of less than 1,000 m³/cap·y [2]. Water scarcity can be a major obstacle to health and economic development. Thus, increasing scarcity of freshwater resources has driven a motivation toward alternatives such as seawater desalination, wastewater treatment, and wastewater reuse. However, producing drinking water according to the standards of WHO needs the development of energy-efficient methods to fulfil

future sustainable water supply demand. The cost of production for 1 m³ of seawater desalination is 2.6–8.5 kWh [2]. Commercial desalination technologies can be divided into two main categories: thermally-driven [multi-stage flash (MSF), multi-effect distillation (MED), and adsorption desalination (AD)] and membrane separation reverse osmosis (RO) processes. Recently, hybridization trends of desalination technologies such as MED-AD, MSF-MED, and RO-MSF are developing to increase process performance by overcoming conventional methods margins [2].

Scale deposition of sparingly soluble compounds on heat transfer surfaces or membranes is one of the major challenges of the economy, operation, and maintenance in the thermal and membrane desalination process [3]. The solid scale layer development at the exterior side of MED

tubes was investigated by several authors [4]. Scale layer formation leads to additional resistance to heat transfer, therefore, a reduction in the overall efficiency of the desalination process, which contributes to increasing the energy that required per 1 m³ of freshwater produced.

The precipitation of calcium carbonate on the tube surface in thermal seawater desalination processes or on the surface of membranes used in the RO seawater desalination process is considered an economical and operational disadvantage [5]. Precipitation fouling of the membranes is a well-known phenomenon that occurs owing to the supersaturation and the concentration polarization process of seawater about calcium carbonate [6]. Precipitation fouling results in a blockage of the membrane because of the rapid generation of nucleation points covering the membrane surface [7]. Subsequent growth of these nuclei to form precipitated crystals attributable to supersaturation will cause the formation of a heat resistance layer on the surface of the tubes and thus increasing the energy cost and creating many operational problems in thermal desalination equipment. However, in membrane desalination, a block of the membrane pores will cause an inhibition in the flow of water through the membrane and thus a flux drop and a decline in the performance of RO membranes will result. Consequently, to compensate for this drawback and to maintain the same recovery rates, an increase in the applied pressure is required and also the membranes are needed to be cleaned regularly to prevent the accumulation of scaling materials [8]. These pose a major constraint on the efforts to induce sustainability in desalination processes [9].

The key parameter influencing the fouling precipitation process is supersaturation which is the driving force for the growth and nucleation processes of fouling materials, mainly CaCO₃. Crystallization fouling processes take place at the surfaces of the membranes as a result of the existence of concentration polarization of the scaling materials in seawater [10].

To reduce precipitation fouling desalination processes, an enormous number of scale control chemical inhibitors are used such as copolymers of poly(maleic acid) [11], polycarboxylic acid [12], and homopolymers of poly(maleic acid) and polyacrylic type of polymers [13]. The effectiveness of these scale inhibitors depends on the type and mechanism they act to reduce precipitation fouling. However, these chemical inhibitors, which are disposed of continuously with the reject streams cause considerable economic and environmental drawbacks [14].

Controlling precipitation fouling in the desalination industry without applying such inhibitors which are environmentally risky chemicals could be attained by an environmentally friendly physical softening of seawater based on the seeded crystal growth method. The method is based on adding seeds to supersaturated seawater that will force the scaling materials to be separated from seawater and thus precipitate on the seeds. Consequently, this method can be effectively used to control the supersaturation of seawater with respect to some major scaling compounds. This ensures keeping the seawater inlet to desalination plants at very low supersaturation levels and therefore the induction time of nucleation will be extended. A large volume of investigations about experimental studies

implementing seeding softening technologies for fouling inhibition is available. A recent review summarizes all these studies efficiently [15]. The outcome of these investigations supports the use of seeded fouling methods as pre-treatment processes to control the scaling and precipitate fouling. Pfefferkorn et al. [16,17] exhibited an effective implementation of seeded softening in terms of calcium sulfate scale prevention by conducting experiments using a pilot scale evaporator of 3,800 m³/d capacity with forced circulation. An effective parameter is the residence time of seeds to attain a certain level of desupersaturation with respect to calcium sulfate. This key operating parameter was controlled by applying a settling method. Complete prevention of gypsum scaling was achieved by operating the evaporator with a flow rate of 1.8 m/s in the tubes and keeping a solid content of the slurry at about 5 wt.%. Another study published by Stickney and Fosberg [18] presented the principle of using a seeded softening process on the industrial scale of a 50 m³/h capacity wastewater treatment plant which is implanted in the plant evaporation process. The evaporator used in this study is of vertical falling film type used to raise the concentration of the wastewater. The outcome of this study is the effectiveness of seeded fouling to prevent the scaling of calcium sulfate and silica. The use of a combined process of reverse osmosis and seeded fluidized bed crystallizer was reported by Bond et al. [19]. An important finding is that seeded softening is an effective method to achieve a reduction in the energy usage of the RO desalination process in addition to a decrease in treatment expenses. A seeded fluidized bed crystallizer was successfully applied to reduce the calcium ions concentration in the brackish water from 200 to 50 ppm through seeding with calcium carbonate particles. The application of seeding softening to evaporators of the horizontal tube film type as a scale inhibition technique was studied by Rautenbach and Widua [20]. An effective scale inhibition by seeding was attained when the seeds' growth rate is high enough to reduce the supersaturation generated due to the water evaporation, and therefore maintaining a very small residual supersaturation with a larger induction time for nucleation onset.

The objective of this study is to elucidate the parameters affecting the rate and kinetics of the growth process of calcite seeds in seawater solution. The influence of both temperature and mixing speed was assessed. The industrial implementation as well as the design of the seeding crystallization process as a pre-treatment step for scaling inhibition and control in the seawater desalination process necessitates the availability of data about the kinetics of growth of the seeds in the seawater.

2. Theoretical aspects

The crystallization process is determined by the degree of supersaturation which is considered as the main parameter which controls both growth and nucleation steps. In the case of a seeded softening in a batch crystallizer, carbonate (CO₃²⁻) and calcium (Ca²⁺) ions leave the diffuse from the supersaturated seawater and then in the second step integrate into the crystal matrix of calcite seeds. On the other hand, the supersaturation with regard to carbonate (CO₃²⁻) and calcium (Ca²⁺) ions in seawater is not simply dependent

on one factor such as concentration or temperature as usual happens in most crystallization practices. It is somewhat more complex and numerous equilibrium mechanisms occur simultaneously which control the level of supersaturation for the calcium carbonate growth with added seed crystals in the supersaturated seawater. The calcium carbonate supersaturation (σ) in seawater can be defined as:

$$\sigma = \left[\frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}} \right] \quad (1)$$

where $[CO_3^{2-}]_{eq}$ and $[Ca^{2+}]_{eq}$ are the equilibrium concentrations in mol/kg seawater of carbonate and calcium ions in seawater, respectively and K_{sp} is the equilibrium solubility product of calcium carbonate in seawater which is defined as:

$$K_{sp} = [Ca^{2+}]_{eq} [CO_3^{2-}]_{eq} \quad (2)$$

The seawater is considered to be supersaturated with regard to calcium carbonate simply in the case when $\sigma > 1$.

The CO_3^{2-} and Ca^{2+} ions supersaturation in seawater in the progression of seeded growth of diverse polymorphic modifications of calcium carbonate is controlled mostly by numerous reactions that happen throughout the crystal growth. These reactions are well known as the seawater carbonate system which is displayed in Fig. 1.

The supersaturation of carbonate ions $[CO_3^{2-}]$ in seawater depends on the equilibrium reactions presented in Fig. 1, which take place instantaneously in seawater throughout the seeded crystal growth of calcium carbonate. The equilibrium constants for each reaction can be estimated from available empirical correlations [21]. The pH value has a critical part in determining all the parameters of the seawater carbonate system. It influences considerably the

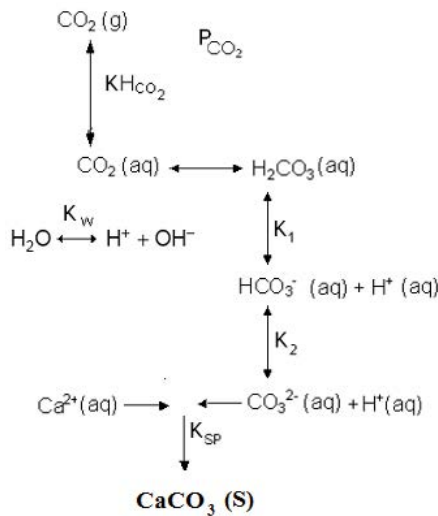


Fig. 1. Seawater carbonate system equilibrium mechanisms that happen consecutively throughout the seeded calcium carbonate crystal growth.

concentrations of CO_3^{2-} , HCO_3^- , and CO_2 . Fig. 2 displays the mole ratio of CO_3^{2-} , HCO_3^- , and CO_2 of the entire carbon compositions in seawater about the pH in artificially prepared seawater having a salinity of 45 g/kg seawater at a fixed temperature of 24°C. The effect of temperature and pH in determining the mole fractions of CO_3^{2-} , HCO_3^- and CO_2 in seawater at a fixed salinity was studied by Millero [22]. The mathematical estimations exhibited that at a fixed pH, the mole fraction of CO_3^{2-} rises significantly.

Eq. (1) can be rearranged to relate all the above-revealed parameters via the liquid-liquid equilibrium coefficients shown in Fig. 1. The following equation can be derived:

$$\sigma = \frac{[Ca^{2+}]A_t / K_{sp}}{2 + [H^+] / K_2} \quad (3)$$

where A_t refers to the seawater total-alkalinity and is defined as the neutralization capability of seawater to an acidic solution. This can be determined by hydroxide, bicarbonate, and carbonate ions concentrations in seawater. The total alkalinity in seawater is considered to be only due to these three ions. The total alkalinity can be estimated quantitatively by applying the well-known end-point potentiometric titration technique at a pH equal to 4.3. K_2 the equilibrium constant for the dissociation of bicarbonate ions to carbonate ions in seawater mol/kg (Fig. 1).

The single parameter that can be related to the solid/liquid equilibrium in Eq. (1) is the solubility product (K_{sp}) value, which determines the solubility of the calcite seeds in seawater. The K_{sp} value can be determined by the salinity as well as the temperature of seawater and also the type of crystal morphology of calcium carbonate.

The crystal growth factors $[H^+]$, K_2 , and total alkalinity (TA) are the key operational parameters that affect the degree of supersaturation. These parameters control the content of CO_3^{2-} ions in seawater, which is a significant parameter that can be employed to raise the supersaturation degree with respect to calcium carbonate seeds. The quantities of these parameters are intensely dependent on the temperature and pH of the seawater.

In a batch-seeded crystallizer, the concentration of carbonate ions declines because of the growth of calcium

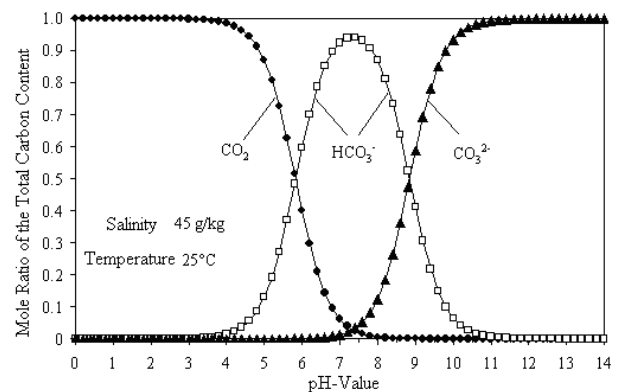


Fig. 2. Mole ratio of CO_3^{2-} , HCO_3^- , and CO_2 in relation to the pH value of seawater [22].

carbonate seeds in the supersaturated seawater. This resulted in a pH decline, that is, rise in $[H^+]$ as can be concluded from Eq. (2). Therefore, the decline in pH throughout the calcium carbonate seeds growth in seawater during the period (dt) can be employed to estimate the decline in carbonate ions concentration as a result of the crystal growth as given in Eq. (2). The amount of rate of mass growth of calcium carbonate (W) can be estimated from the mole balance:

$$\frac{dW}{dt} = MV \frac{-d[Ca^{2+}]}{dt} \quad (4)$$

Throughout a seeded growth experiment in a batch crystallizer, the variation of linear growth rate (G) of the crystal can be assessed using the equation:

$$G = \frac{LMV}{3W} \left(-\frac{d[Ca^{2+}]}{dt} \right) \quad (5)$$

where L (crystal size, m); M (molecular weight, g/mol); V (volume of seawater, m³). The mechanism of crystal growth can be considered using the two-step growth model [23]. This model splits the growth process into two steps: diffusion and surface reactions. The diffusion and surface reactions steps are related to the supersaturation according to Eqs. (6) and (7), respectively:

$$G = K_d(\sigma - \sigma_i) \quad (6)$$

$$G = K_r \sigma_i^r \quad (7)$$

where K_d is the diffusion coefficient, K_r is the surface reaction coefficient and r is the order of the face reaction step. The order of surface reaction of calcite growth is roughly 2 [24,25]. Thus, a combination of Eqs. (6) and (7) gives:

$$\frac{\sigma}{\sqrt{G}} = \frac{1}{K_d} \sqrt{G} + \frac{1}{\sqrt{K_r}} \quad (8)$$

The two-step model offers valuable kinetic data and will be employed in this investigation to examine the kinetics of crystal growth of calcite seeds in supersaturated seawater by employing a well-mixed batch crystallizer.

The growth rate comprising diffusion and surface reaction steps is recognized as the overall linear growth rate (G). It can be correlated to supersaturation (σ) by the power law correlation [23]:

$$G = K_G \sigma^n \quad (9)$$

where n and K_G are the growth rate order and the overall growth rate constant, respectively.

3. Experimental methods

The entire batch crystallization runs were conducted using artificially prepared standard seawaters of different salinities. Stock seawater of certain salinity was made

from chemicals of analytical grade (p.a., Merck, Germany) mixed with deionized water. The salt amounts and the ions concentration for a precise salinity are prepared according to the information available in the literature [26]. The experiments were performed in a 0.5 L well-mixed batch crystallizer (Fig. 3). The crystallizer is firmly closed, double walled coupled to a programmable thermostat to regulate the temperature. A magnetic stirrer was equipped to control the mixing intensity.

The experimental investigations were performed by the addition of calcite seeds to seawater which is supersaturated concerning carbonate. In all experiments, a fixed seed weight (4 g) was added to a constant amount of seawater (400 g) with a ratio of 1%. The size of the seeds was kept also constant (100 μ m). The initial pH and temperature were fixed as constant, which means a constant initial supersaturation.

Solution samples were withdrawn from the crystallizer for measurements at several time intervals to analyze their calcium contents, total alkalinity, salinity, conductivity, and pH. The pH of seawater was analyzed using the pH meter (WTW pH 315i, Germany). Inductively coupled plasma optical emission spectroscopy (Agilent 5900, USA) was used to analyze calcium ions concentration. The total alkalinity was measured by applying the potentiometric titration methods of analysis.

4. Results and discussion

4.1. Desupersaturation rate of calcium carbonate in seawater

The growth kinetics of calcite in the supersaturated seawater was evaluated by adding calcite seeds to supersaturated seawater at adjusted initial pH, temperature, and salinity. The desupersaturation rate was used to evaluate the kinetic parameters. The decay in supersaturation due to the crystal growth is calculated using Eq. (3) from the measured change in pH, calcium concentration, and total alkalinity. Typical measurements for the change of alkalinity, Ca^{2+} amount, and pH of seawater with time throughout 60 min of the seeded batch run are presented in Figs. 4–6. The calculated desupersaturation curve is displayed in Fig. 7.

Figs. 4 and 5 show decay in the total alkalinity and Ca^{2+} amount. This reduction is attributed to the calcite seeds' growth in the supersaturated seawater. Also, a measured

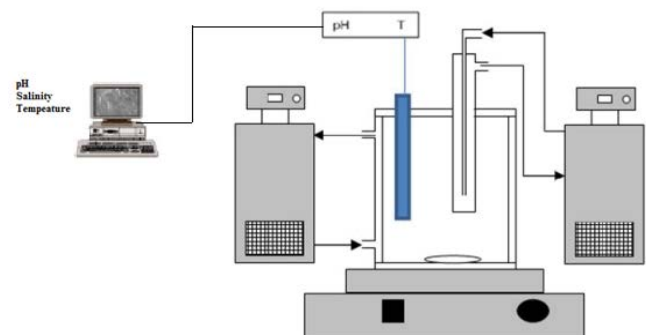


Fig. 3. Experimental set-up for measurement of seeded crystal growth in the batch crystallizer.

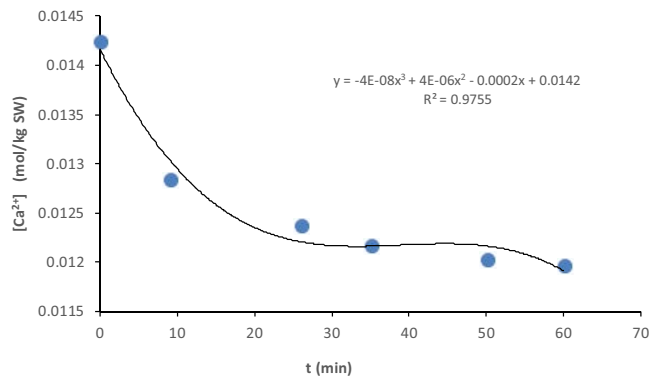


Fig. 4. Measured decay of calcium concentration for a seeded batch experiment ($S = 45$ g/kg, $T = 50^\circ\text{C}$, and initial pH of 8.3).

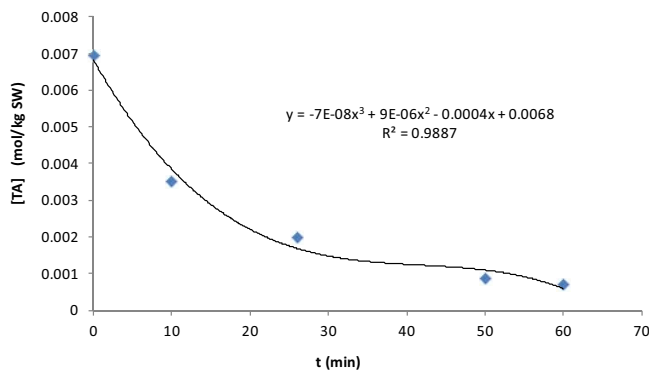


Fig. 5. Measured decay of total alkalinity for a seeded batch experiment ($S = 45$ g/kg, $T = 50^\circ\text{C}$, and initial pH of 8.3).

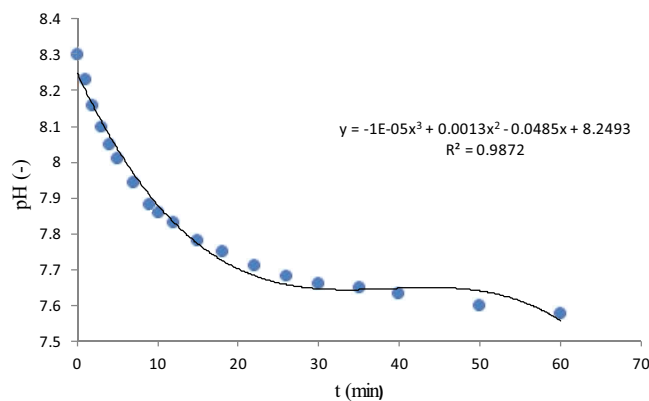


Fig. 6. Measured decline of pH for a seeded batch experiment ($S = 45$ g/kg, $T = 50^\circ\text{C}$ and initial pH of 8.3).

reduction in the pH of seawater throughout a period is shown in Fig. 6. In the course of the calcite seeds' crystal growth in supersaturated seawater, the concentration of CO_3^{2-} ions in seawater will decline. Therefore, further $[\text{H}^+]$ ions will be produced and hence a pH reduction will be accompanied by the growth of calcite crystals in seawater. Consequently, the growth of calcite in seawater will result in desupersaturation of seawater related to calcite

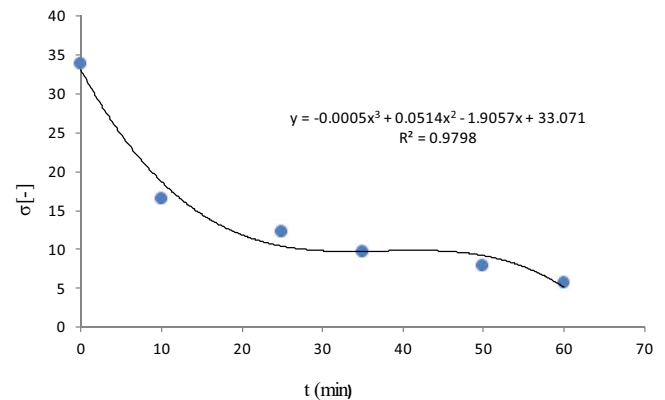


Fig. 7. Calculated desupersaturation curve [Eq. (3)] for a seeded batch experiment ($S = 45$ g/kg, $T = 50^\circ\text{C}$ and initial pH of 8.3).

is a key parameter in the design of the crystallization pretreatment step for the decrease in the tendency of calcium carbonate scaling of seawater feed to desalination plants. However, growth kinetics should be known for the successful design of the crystallizer.

The achieved reduction in calcium ion concentration from 0.01425 to 0.01197 mol/kg seawater using the seeded batch crystallization method will be very effective to control the scaling. However, Aghdam et al. [27] investigated the use of fluidized bed crystallization for rescale-forming species from treated municipal wastewater before water reclamation. Fluidized bed crystallization was very efficient and able to remove more than 97% of Ca^{2+} . Electrokinetic cells were applied with raw seawater collected from the gulf to decrease the Ca^{2+} , Mg^{2+} , SO_4^{2-} and bacteria contents [28]. The removal efficiency of the Ca^{2+} ions was 44%. On the other hand, Wang et al. [29] applied selective removal of calcium ions from seawater or desalination brine using a modified sodium carbonate method. The calcium removal efficiency of up to 85.4%. Selective precipitation of calcium ions from seawater desalination reverse osmosis was investigated [30]. Ca precipitation using NaHCO_3 was more efficient and Ca^{2+} removal efficiency higher than 90% coupled with an Mg^{2+} loss below 7% was obtained at 60°C and controlled pH, by using NaHCO_3 .

4.2. Calcite growth kinetics – influence of agitation

Fig. 8 shows the measurements of the variation of calcite growth rate [Eq. (5)] in supersaturated seawater at different supersaturation levels when carbonate (calcite) seeds are allowed to grow in supersaturated seawater at the stirring rates of 300 and 600 rpm. The seeded growth experiments are performed in a mixed batch vessel at a constant temperature. The growth rate and supersaturation are evaluated using Eqs. (3) and (5), respectively from the measurements of calcium ion concentration (Fig. 4), total alkalinity (Fig. 5), and pH (Fig. 6).

The results shown in Fig. 8 point out that the rate of growth of calcite rises as agitation speeds increase. The growth kinetic parameters are estimated by fitting the data in Fig. 8 as a power law relation according to Eq. (9). The kinetic parameters of growth at the different agitation speeds are listed in Table 1.

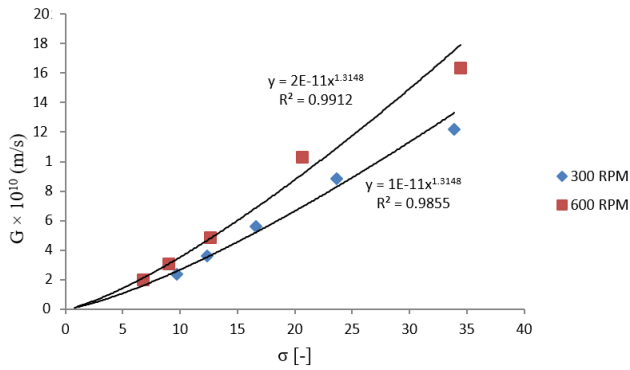


Fig. 8. Variation of the measured rate of growth of calcite seeds in supersaturated seawater with supersaturation at different agitation speeds. (Salinity = 45 g/kg, suspension density = 1 g/kg seawater, temperature = 50°C).

Table 1

Kinetic parameters of calcite growth on seawater solution at the different agitation speeds (salinity = 45 g/kg, suspension density = 1 g/kg seawater, temperature = 50°C)

Agitation speed	K_G (m/s)	n	R^2 [Eq. (9)]
300 rpm	1×10^{-11}	1.3148	0.9855
600 rpm	2×10^{-11}	1.3148	0.9912

The results listed in Table 1 illustrate that the rise in the mixing intensity will result in a slight alteration in the order of calcite growth rate (n). Nevertheless, the constant of the overall growth rate (K_G) rises significantly with increasing mixing intensity from 300 to 600 rpm.

According to Eq. (8), the mass transfer (K_d) and the surface reaction (K_r) coefficients can be estimated from the linear plot of σ/\sqrt{G} against \sqrt{G} at the different mixing intensities (Fig. 9). The obtained mass transfer (K_d) and the surface reaction (K_r) coefficients are summarized in Table 2.

The two-step growth model parameters presented in Table 2 illustrate that the value of the mass transfer coefficient is larger than that of the surface reaction coefficient at constant agitation speed. This reveals that the step of surface reaction could be the rate-controlling process. On the other hand, increasing the agitation speed leads to an increase in both mass transfer (K_d) and the surface reaction (K_r) coefficients.

4.3. Kinetics of growth of calcite in seawater – effect of temperature

The growth kinetics are estimated by experimental measurement of the supersaturation decline and growth rate in a batch-seeded crystallizer at different temperatures. Fig. 10 shows the change in the rate of growth of calcite seeds in seawater with supersaturation at temperatures 40°C, 60°C, and 70°C. The rate of growth is higher with rising the temperature. Elevated temperatures will result in a reduction in the calcium carbonate solubility and hence the value of K_{sp} will be reduced. Accordingly, the supersaturation

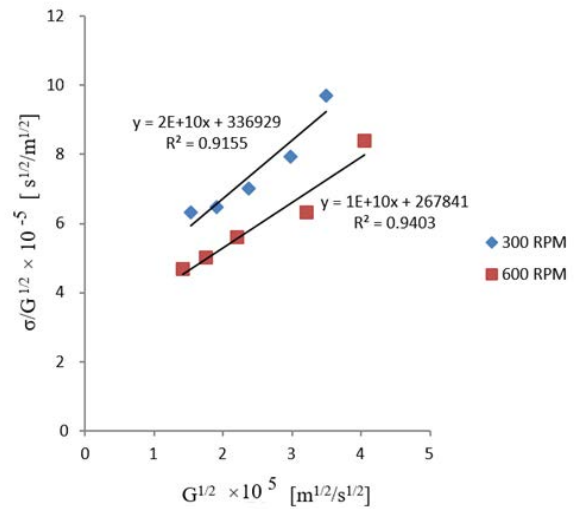


Fig. 9. Linear fitting of the growth rate data is presented in Fig. 8 according to the two-step model [Eq. (8)].

Table 2

Mass transfer (K_d) and the surface reaction (K_r) coefficients of crystal growth of calcite in supersaturated seawater at different agitation speeds

Agitation speed	K_d	K_r	R^2 [Eq. (8)]
300 rpm	5×10^{-11}	8.80×10^{-12}	0.91
600 rpm	1×10^{-10}	1.393×10^{-11}	0.94

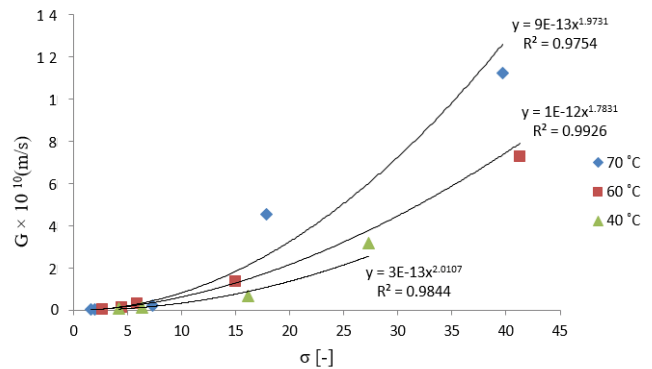


Fig. 10. Variation of the calcite linear growth rate in seawater with supersaturation at different temperatures. (Salinity = 45 g/kg, suspension density = 1 g/kg seawater, agitation speed = 500 rpm).

amount will be increased at higher temperatures as stated by Eq. (1). Furthermore, the temperature is a crucial parameter influencing the carbonate system and its related equilibrium constants such as K_{sp} , K_2 , and K_1 . These carbonate system parameters affect dramatically the concentration of CO_3^{2-} and hence the supersaturation level (Fig. 1).

The growth kinetic parameters are estimated by the power-law fitting [Eq. (9)] of the data shown in Fig. 10. The estimated growth rate parameters are listed in Table 3.

Table 3
Kinetic parameters of calcite linear growth rate [Eq. (9)] at variable temperatures

Temperature (°C)	K_G (m/s)	n	R^2 [Eq. (9)]
70	1.00×10^{-12}	1.7831	0.9926
60	9.00×10^{-13}	1.9732	0.9754
40	3×10^{-13}	2.0107	0.9844

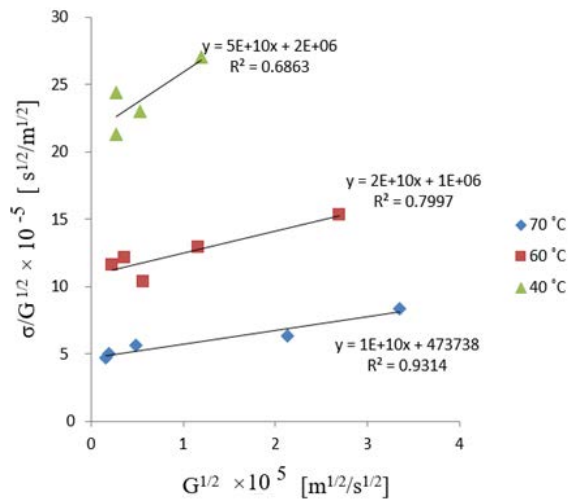


Fig. 11. Plot of the growth rate data is presented in Fig. 9 according to the two-step model [Eq. (8)].

Table 4
Calculated values of surface reaction (K_r) and the diffusion mass transfer (K_d) coefficients for the crystal growth of calcite in seawater at different temperatures

Temperature (°C)	K_d	K_r	R^2 [Eq. (8)]
70	1×10^{-10}	4.45×10^{-12}	0.9314
60	5×10^{-11}	1×10^{-12}	0.7997
40	2×10^{-11}	2.5×10^{-13}	0.6863

The data listed in Table 3 show that the rise in the temperature resulted in a slight change in the order (n) of the linear growth rate. The little temperature effect on the order of linear growth rate and the rise in the constant (K_G) of the linear growth rate of calcite where the temperatures ranging from 70°C to 40°C indicated that the surface integration is a more prevailing step.

The surface reaction (K_r) coefficient and diffusion mass transfer coefficient (K_d) can be estimated from the linearized plot of the growth rate against desupersaturation experimental data at different temperatures (Fig. 9) according to [Eq. (8) and (Fig. 11)]. The calculated values of surface reaction (K_r) and the diffusion mass transfer (K_d) coefficients are listed in Table 4.

The results of Table 4 indicate that both the surface reaction (K_r) and diffusion mass transfer (K_d) coefficients for linear crystal growth of calcite in seawater rise at elevated

temperatures. The surface reaction and diffusion mass transfer activation energies can be estimated from the Arrhenius plot of K_d and K_r values. The calculated surface reaction and diffusion mass transfer activation energies are 46.5 and 81.5 kJ/mol, respectively. This could be clear evidence that the step surface integration is the rate-determining for calcite seeded-growth in supersaturated seawater.

5. Conclusions

The results indicated that calcium ion content in seawater reduction was efficiently using seeded crystallization. The achieved reduction in calcium ion concentration from 0.01425 to 0.01197 mol/kg seawater. Hybridization of this process with thermal or membrane desalination can be promising in the contest of scale reduction and thus improve the economy and operation in the desalination industry. The crystallization process with added seeds can be applied as a softening process for the decline of precipitation fouling potential of seawater influent to desalination process. The seeded softening pretreatment process depends on the principle of the growth of added calcite seeds in supersaturated saline water to decrease its content as a fouling element in seawater. The attained results in this investigation point out that the process of growth of calcite in supersaturated seawater can be reached in definite circumstances of pH, temperature, and agitation speed. The crucial feature is generating the essential level of supersaturation to onset the growth of seeds added intentionally for this purpose. The calcium carbonate desupersaturation in seawater is attained in this study. The reduction of supersaturation due to the seeded crystallization is an important issue in terms of the reduction of fouling tendency and increase. Implementing this technology on the industrial level will be a smart way for developing and increasing the efficiency of membrane seawater desalination industrial applications. Nevertheless, engineering practices and kinetic investigations are required to be advanced to improve the useful implementation of this technology. In this study, the growth kinetics of calcite in supersaturated seawater and the effect of operating parameters such as agitation speed and temperature were determined.

Symbols

$[Ca^{2+}]$	—	Calcium ion concentration, mol/kg
$[H^+]$	—	Hydrogen ion concentration, mol/kg
G	—	Linear growth rate, m/s
K_2	—	Equilibrium constant for the dissociation of bicarbonate ions to carbonate ions in seawater, mol/kg
K_d	—	Diffusion mass transfer coefficient, m/s
K_G	—	Overall growth rate coefficient
K_r	—	Surface reaction coefficient, m/s
K_{sp}	—	Solubility product constant of calcium carbonate in seawater, mol ² /kg ²
L	—	Crystal size, m
M	—	Molecular weight, g/mol
n	—	Overall growth rate order
A_t	—	Total alkalinity as calcium carbonate, mol/kg
V	—	Volume of seawater, m ³

- W — Weight of seeds, kg
 σ — Supersaturation of calcium carbonate in seawater, –

Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

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