

Article

Production of Sodium Bicarbonate with Saline Brine and CO₂ Co-Utilization: Comparing Modified Solvay Approaches

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Abstract: The present work investigates the production of sodium bicarbonate in combination with the co-utilization of saline brine and carbon capture, utilization, and sequestration (CCUS). The use of ammonia in the traditional Solvay process could be eliminated by using a modified Solvay process. This study compared the modification with the addition of three buffering additives: Ca(OH)₂, KOH, and NH₄HCO₃. The effectiveness of these processes, using two qualities of saline brine (desalination and aquifer), is compared based on the purity of the produced NaHCO₃. It was found that the use of Ca(OH)₂ did not produce high-purity NaHCO₃, while NH₄HCO₃ and KOH performed better. Desalination brine utilization with NH₄HCO₃ resulted in the production of high-purity NaHCO₃, while the second most suitable method involved the use of KOH, and the main co-product formed was Na₂CO₃. Geochemical modeling is performed in order to have insights into the carbonation (in the reactor) and precipitation (in the oven) behavior of the reactions. It predicted the precipitation of mineral phases well, though kinetics might hinder some saturated solids to dissolve first. The present study shows that accurate characterization is critical to accurately assess the success of modified Solvay processes. The use of QXRD and SEM analyses, complemented with geochemical modeling, helped to better understand the processes and the formation of NaHCO₃. Further investigations on diverse brines could provide for their better utilization by the geological carbon sequestration and water desalination industries that produce them.

Keywords: carbon capture, utilization, and sequestration; carbon dioxide; brine; nahcolite; sustainability; waste utilization; climate change



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1. Introduction

Climate change is fueled by global warming and an imbalance in the natural cycles caused by greenhouse gas emissions, such as carbon dioxide (CO₂) emissions resulting from human activities [1–3]. CO₂ is usually emitted by burning fossil fuels and is associated with several other industrial processes. Double covalent bonds present between carbon and oxygen atoms, which feature the stability and inertness of CO₂ gas, therefore make them thermodynamically stable. This makes its activation difficult for conversion to value-added products [4]. On the other hand, CO₂ is also used as a source material for producing several industrial fuels and products [5–8]. The concentration of CO₂ in the atmosphere has surpassed 400 ppm, and the current global momentum shows its tendency to reach far more dangerous levels [9]. Due to anthropogenic activities, CO₂ emissions are causing ocean acidification and global warming [10]. The release of CO₂ is disturbing the ocean ecology and causing immense destruction of corals. A faster response to the climate crises, such as decarbonization, is required in the current state of affairs [11]. Decarbonization reinforces the importance of a transition to low-carbon activities including clean energy conversion and sustainability in every industrial activity. Over the last few years, there has been a growing interest in carbon capture, utilization, and storage (CCUS) technologies for

not only limiting the release of CO₂ in the atmosphere but also reducing its concentration by utilizing and storing carbonate products [12]. The production of value-added materials by capturing and utilizing the atmospheric CO₂, thus paves a pathway for a sustainable goal towards green energy and the environment.

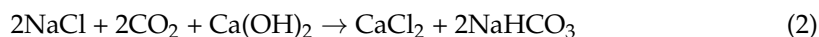
The combustion-released CO₂ from industries can be dumped into geological formations such as deep and large saline aquifers that store it permanently [13–15]. The estimated capacity of CO₂ sequestration is considered humungous for deep saline aquifers [16]. During the CO₂ injection phase, the CO₂ gas mixes with brine and, due to the density difference, CO₂ dissolved brine moves towards the bottom of the aquifer [17]. For deep aquifers, this phase is stable; however, the problem occurs with locations that have smaller, shallow aquifers. A stream of saline brine needs to be removed from shallow aquifers for CO₂ injection, thereby requiring subsequent utilization.

There are various methods [18–21] for CCUS available today, among which the use of chemical solvents for carbon capture is a promising technology [22]. Liquid ammonia (NH₃) [23] and amines (either immobilized on a solid support or in an aqueous solution) [24] are the most commonly used solvents. Aqueous ammonia has been considered a viable solution for CO₂ capture due to its economical chemical cost, relatively low regeneration temperature, and corrosiveness [25]. The use of liquid ammonia not only helps in utilizing saline water for CO₂ capture but also aids in producing reusable carbonates, such as baking soda (as indicated in reaction (1)) and soda ash (by heating the baking soda), through an ammonia-based Solvay process [26].



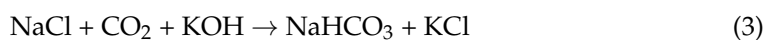
Along with the benefits, there comes some drawbacks to the Solvay process, among which the presence of ammonia is the major shortcoming, since it is considered a health and environmental hazard [21]. Severe injuries to the nose, skin, and throat can be caused by exposure to high concentrations of ammonia. It can also cause respiratory tract burning, which may lead to the failure of the respiratory system [27]. Therefore, several investigations have been conducted to modify the Solvay process to replace the use of ammonia [21,28–31].

El-Naas et al. conducted a study on modifying the Solvay process by using calcium hydroxide Ca(OH)₂ [12] instead of ammonia, as shown in reaction (2). They investigated the effects of operating parameters such as water pH, reaction temperature, and reaction stoichiometry on the efficiency of CO₂ capture and sodium removal. They claimed the CO₂ removal efficiency of their modified Solvay process to be 99% at 20 °C and at a pH greater than 10, while the traditional Solvay process showed CO₂ capture of 86% under similar conditions. They also indicated a sodium removal of 35% for their modified process, as compared to 29% for the traditional one [12].



In another study, Mourad et al. studied the role of potassium hydroxide KOH in modifying the Solvay process for CO₂ capture and brine treatment in a single process [31]. The reaction mechanism is illustrated as a reaction (3). They studied the role of KOH on the pH level, ion reduction, CO₂ capture efficiency, and the type of products obtained at 20 °C and 1 L/min gas flow rate. For the KOH/brine mixture under stoichiometric conditions and below the solubility limit, a CO₂ uptake of 0.31g CO₂/g KOH was recorded, while yielding baking soda and potassium chloride crystals [31–33]. The two reference studies modified the Solvay process for CO₂ utilization; however, the data analysis is doubtful since it lacks or poorly represents the XRD or SEM data. The present study was conducted to ensure that the approaches made in the reference studies actually worked, owing to doubtful data, while also studying the role of (NH₄)₂HCO₃ as a buffering additive in the modified Solvay process [12,31]. The research would help understand the potential use of

$(\text{NH}_4)_2\text{HCO}_3$ for eliminating NH_3 from the Solvay process and indicate the quality of the formation of prospective products at the end of the reaction.



The present investigation aims at producing the precipitated sodium bicarbonate NaHCO_3 by utilizing CO_2 and saline brine in an accelerated carbonation process while using a modified Solvay process. The synthesis of NaHCO_3 has recently been proposed using $\text{Ca}(\text{OH})_2$ [12] and KOH [31] as buffering additives. These two methods have been investigated for assessing the quality of NaHCO_3 formed. The novelty of the present work lies in using another buffering additive $(\text{NH}_4)_2\text{HCO}_3$ to modify the Solvay process, and then compare the products obtained with other $\text{Ca}(\text{OH})_2$ and KOH methods. The present study also used geochemical modeling, an important and powerful technique for $(\text{NH}_4)_2\text{HCO}_3$ and the reactions studied in the recent reference studies [12,31], to confirm the possibility of using different approaches for the formation of the same desired products. Two types of brines, i.e., the desalination brine and the aquifer brine, have been prepared and used in the investigation. The outcomes of the present study would yield novel ideas about CO_2 capture using saline brine while avoiding the use of ammonia.

2. Materials and Methods

2.1. Materials

The preparation of the brine was the first step for the experiments. Two types of brines were prepared: the desalination unit brine and the aquifer brine. Desalination brines are usually disposed of in the ocean, while aquifer brines are usually removed to create space for value-adding activities. The rationale behind using these two types of brines in this study is their better utilization for the carbon capture, utilization, and sequestration industry. The chemicals used for brine preparation and conducting experiments were sodium chloride NaCl (Fisher Scientific with purity $\geq 90\%$), magnesium hydroxide $\text{Mg}(\text{OH})_2$ (Fisher Scientific with purity $\geq 95\text{--}100\%$), calcium oxide CaO (Acros Organics with purity $\geq 98\%$), calcium hydroxide $\text{Ca}(\text{OH})_2$ (Acros Organics with purity $\geq 97\%$), potassium hydroxide KOH (Fisher Scientific with purity $\geq 85\text{--}100\%$), sulfuric acid, and ammonium bicarbonate $(\text{NH}_4)_2\text{HCO}_3$ (Acros Organics with purity $\geq 98\%$). Both types of brines were prepared with ultrapure water ($18.2 \text{ M}\Omega\cdot\text{cm}$). The desalination brine was prepared using only NaCl , while the aquifer brine was produced with a mixture of components (Na^+ , Mg^{2+} , Ca^{2+} , K^+ , Cl^- , SO_4^{2-} , according to Mourad et al. [31]), both having a total salinity of $73,517 \text{ mg/L}$ (equivalent to 1.258 molal NaCl).

Experiments 1 and 2 investigate the synthesis of NaHCO_3 using $\text{Ca}(\text{OH})_2$. The molal concentration of brine (NaCl -equivalent) and $\text{Ca}(\text{OH})_2$ is 2:1 in experiment 1, while this proportion is 1:1 for experiment 2. These two experiments tend to reproduce the results indicated in El-Naas et al. [12]. Experiments 3 and 4 use KOH as an ingredient with brine (NaCl -equivalent) and KOH molal concentration proportions of 2:1 and 1:1, respectively. These two experiments incorporate the idea of NaHCO_3 production represented in Mourad et al. [31]. The results from these four experiments and geochemical modeling would identify the quality of precipitated NaHCO_3 . Another modification of the Solvay process can be made using $(\text{NH}_4)_2\text{HCO}_3$ as a buffering additive. Experiments 5 and 6 use brine with $(\text{NH}_4)_2\text{HCO}_3$ with a molal concentration ratio of 2:1 and 1:1, respectively. Since all these buffering additives are being studied to eliminate the use of NH_3 , a comparison of the results of these six experiments would indicate which buffering additive is producing better quality NaHCO_3 , which would help design the feasibility of this integrative approach.

The reactant mixture is fed with CO_2 gas in the pressurized slurry reactor and, after achieving the reaction conditions and residence time, the slurry is filtered to obtain solid precipitates. For experiments that lacked carbonated precipitates, the filtrate was placed in an oven to provide the conditions for precipitate formation and to investigate if evaporating conditions could lead to the over-saturation and precipitation of target minerals.

2.2. Experimental and Modeling Setup

The experiments were conducted under a pressurized slurry carbonation reactor, which is a stirred batch reactor capable of handling high temperatures and pressures. 500 mL of ultrapure water (18.2 MΩ·cm) was poured in a 1 L bolted closure pressure vessel made up of Inconel (Parker Autoclave Engineers (Erie, PA, USA)). The solid ingredients were added to the reactor for the respective experiments. A CO₂ gas cylinder (99% vol.) was used to pressurize the reactor to 45 bars, while a chiller was used to cool the reactants to 5 °C. The mixture in the pressurized vessel was stirred by an Inconel-made straight-blade-turbine-impeller at 200 rpm, and the reaction was operated under the stated conditions for 4 h. With the completion of reaction time, the vessel was depressurized, and solids were recovered from the slurry using a filter paper (Whatman (Maidstone, UK) 2 V 150 mm (1202–150)). If in any case the precipitated products were not retained in the filter, then the filtrate was dried in an oven at 105 °C for 24 h, which through the evaporation of water led to the over-saturation of salts and their precipitation. An XRD analysis after every experiment revealed the subsequent mineral composition, thereby gauging the success of the experiment in terms of NaHCO₃ synthesis.

Geochemical modeling is an analytical technique, which makes use of computer simulations and mathematical models to predict the behavior of chemical elements and compounds in the earth's crust, ocean, and atmosphere. The dissolution and precipitation of minerals, the movement of gases and fluids, and the reactions between different chemical species are important features of geochemical modeling. A software package of Geochemist's Workbench (GWB) was used to model the experiments, as shown in Figure 1. The modeling conditions were set to indicate the experimental conditions going through the pressurized slurry reactor, followed by drying in the oven and retrieving the solid particles at the end. That is, the model predicted the formation of carbonated precipitates within the reactor (which would be recoverable by filtration), and those formed only after placing the filtrate in the oven for water evaporation, thus leading to the precipitation of all salts. Each modeling scenario is compared with the experimental outcomes to gain a mechanistic understanding of the approaches to synthesis that are more or less effective or completely ineffective.

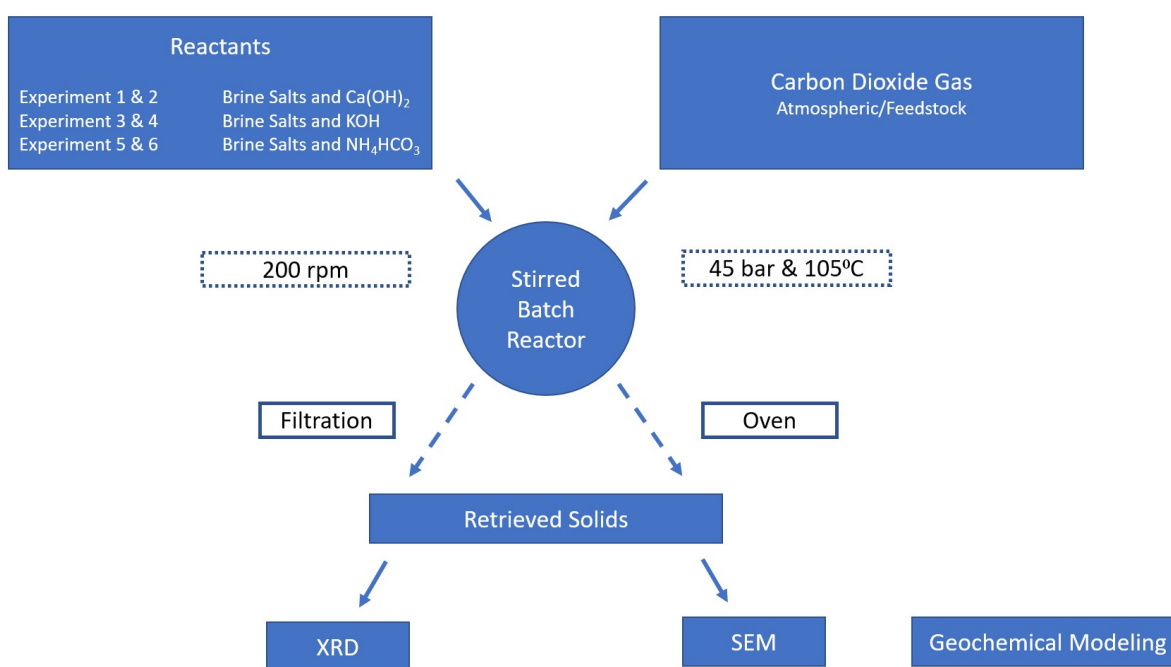


Figure 1. Schematic representation of NaHCO₃ production utilizing brine and CO₂.

2.3. Analytical Tests

For phase identification of all the recovered solids from the respective experiments, X-ray Diffraction (XRD) analysis was conducted. Prior to analysis, all solids were ground to deagglomerate any clustered particles using a pestle and mortar and then pressed in a cavity. Each sample was then loaded into a reflection-transmission spinner of the equipment (Malvern Panalytical (Almelo, The Netherlands) Empyrean XRD Diffractometer). For analysis, each sample was irradiated for 20–60 min and software packages Data Viewer and HighScore Plus (Malvern Panalytical (Almelo, The Netherlands)) were used for data analysis, peak identification, and Rietveld refinement. Scanning Electron Microscopy (SEM) was also then used in order to have some insight into the morphology of the precipitated solids. Figure 1 illustrates the schematic of NaHCO_3 production utilizing brine and CO_2 using various buffering additives.

3. Results and Discussion

The aim of the present investigation includes studying the integrative approach to utilize CO_2 emitting from various industries while stabilizing solid and aqueous wastes to produce valuable products. Few recent studies have indicated methods to modify the Solvay process for the production of nahcolite (NaHCO_3) using $\text{Ca}(\text{OH})_2$ and KOH as buffering additives, respectively [12,31]. However, these investigations are lacking credible tools for analyzing the success of experiments such as XRD and SEM analyses. The present study investigated the role of these buffering additives, as well as NH_4HCO_3 in modifying the Solvay process. The use of XRD and SEM techniques would allow better characterization of the processes, while geochemical modeling would help in understanding the precipitating behavior of solids retrieved at the end of the experiments. The three major peaks of nahcolite, in decreasing order of relative intensity (100, 90, 25), are at 30.06° , 34.47° , and 28.97° , and the three major peaks of natrite (Na_2CO_3), in decreasing order of relative intensity (100, 70, 60), are at 30.15° , 38.00° , and 35.24° [34].

Figure 2 presents the XRD diffractograms of the solid products obtained from the six carbonation experiments (as shown in Figure 1) with the utilization of both desalination and aquifer brines, respectively. When the XRD patterns of experiment 1 are analyzed, it is found that $\text{Ca}(\text{OH})_2$ does not promote the synthesis of NaHCO_3 at all. The use of desalination brine in the pressurized slurry carbonation reaction of $\text{Ca}(\text{OH})_2$ produces calcite (CaCO_3) as a major product, alongside some halite (NaCl) reactant that did not take part in the reaction. For the case of aquifer brine, major portions of the unreacted reactants $\text{Ca}(\text{OH})_2$ and NaCl were found, indicating the failure of the ability of $\text{Ca}(\text{OH})_2$ for synthesizing NaHCO_3 . Experiment 2 increases the molal concentration of the buffering additive ($\text{Ca}(\text{OH})_2$) to a 1:1 ratio of the brine concentration. The results were not majorly affected by this change, with the major product being, in all cases, the byproduct CaCO_3 rather than the desired product NaHCO_3 .

Experiment 3 studied the possible utilization of caustic potash (KOH) for the synthesis of NaHCO_3 . XRD results (Figure 2) of the desalination brine indicated the formation of NaHCO_3 and Na_2CO_3 as major products, while some traces of KCl were found. With the use of aquifer brine, NaHCO_3 and Na_2CO_3 were produced in smaller fractions, while CaCO_3 and thermonatrite ($\text{Na}_2\text{CO}_3 \cdot 1.5\text{H}_2\text{O}$) were found as byproducts of the reaction. In experiment 4, the molar concentration of KOH was increased to a 1:1 ratio of the brine. This change did not produce any NaHCO_3 , but rather, the potassium chloride (sylvite) and sodium carbonate (natrite) were predominant in the precipitates from desalination and aquifer brines, respectively. As such, the modified Solvay process, with KOH as a buffering additive, has potential for the synthesis of NaHCO_3 , but only under an optimized KOH to brine ratio. When the use of brine type is compared, desalination brine outperformed aquifer brine in terms of NaHCO_3 formation.

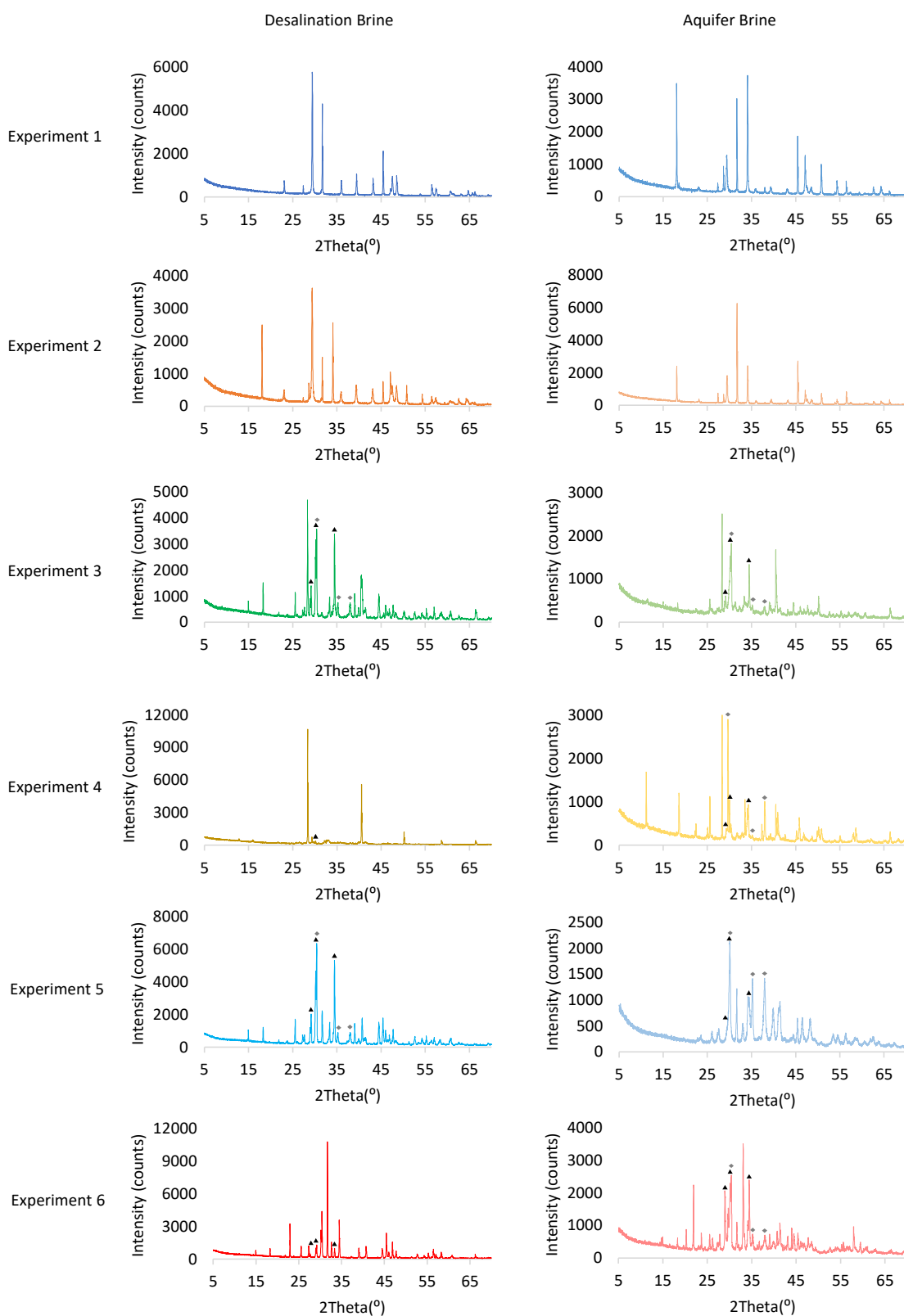


Figure 2. XRD diagrams of the solid products obtained from the six carbonation experiments performed using both the desalination unit and the aquifer brine, respectively. The three main peaks of the target minerals, nahcolite (black triangles), and natrite (grey diamonds) are indicated.

Experiment 5 studied the synthesis process of NaHCO_3 by a modified Solvay process, having NH_4HCO_3 as buffering additive of the reaction. Experiment 6 increases the molal concentration of buffering additive to the brine, with a ratio of 1:1. These two experiments are the novelty of the present study to investigate the synthesis of NaHCO_3 using NH_4HCO_3 as buffering additive. XRD analysis of the resultant products (Figure 2) indicated the formation of NaHCO_3 as the major product of the reaction and natrite as a byproduct. As such, the use of desalination brine with experiments 5 and 6 have indicated the most feasible reaction pathway for NaHCO_3 synthesis, followed by the desalination brine reaction of experiment 3 and then by the aquifer brine reaction of experiment 6. The aquifer brine reaction in experiment 5 showed that the reaction pathway of Na_2CO_3 was prevalent over that of NaHCO_3 synthesis, while increasing the molal concentration of NH_4HCO_3 in experiment 6 shifted the reaction pathway to produce more NaHCO_3 than Na_2CO_3 . Such XRD analysis is missing in the prior reference studies [12,31], so the present results illustrate the value of the mineralogical characterization of retrieved solids.

Table 1 presents the quantitative XRD analysis (QXRD) of the formation of various solid precipitates through the investigated experiments and brines, found by the Rietveld analysis of diffractograms. Only those minerals identified in the desalination brine samples were quantified for both sets of samples i.e., aquifer brine precipitates contain additional salts in oven-precipitated samples that were not quantified, and whose extra peaks can be seen in Figure 2 (e.g., for the experiment 4 aquifer brine sample). Experiments 5 and 6 dominated the synthesis of NaHCO_3 , followed by experiment 3. The precipitation of Na_2CO_3 was prominent after NaHCO_3 for these three experiments. The rest of the experiments were unable to synthesize NaHCO_3 . XRD data uncovers the reason, showing that either the reactant did not take an active part in the reaction (as shown by the presence of the formation of alkaline earth metal hydroxides and alkali chlorides) or other solids precipitated prior to the formation of NaHCO_3 (as evidenced by the precipitation of other alkali and alkaline earth metal carbonates).

Table 1. Mineral composition (wt%) of obtained precipitates, determined by the Rietveld refinement in HighScore Plus. For each sample, values sum to 100 wt% based on the combination of identified/quantified minerals.

Phase	Desalination Brine						Aquifer Brine					
Experiment	1	2	3	4	5	6	1	2	3	4	5	6
NaHCO_3			58.4%	9.3%	71.0%	82.0%			28.7%	11.4%	2.9%	34.7%
Na_2CO_3			33.2%		24.4%				11.2%	78.2%	77.2%	30.8%
$\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$									11.2%			
CaCO_3	81.9%	70.6%					32.4%	38.1%	44.6%			
Ca(OH)_2		22.5%					47.0%	28.8%				
Mg(OH)_2							2.9%	1.4%		8.0%		
NaCl	18.1%	6.8%		3.9%	4.6%	15.7%	17.7%	31.6%			2.5%	2.1%
KCl			8.4%	86.8%					4.3%	2.4%		
NaNO_3						2.4%					17.4%	34.7%

SEM analysis was conducted on the products obtained from experiments 1, 3, and 5 and prepared with both the desalination and the aquifer brines. Experiments 2, 4, and 6 had a double molal concentration of buffering additives as compared to experiments 1, 3, and 5, and therefore, SEM was used to analyze the additive-lean samples that only contained predominantly nahcolite (Table 1) to gain some insights on the morphology of synthesized powders, as shown in Figure 3.

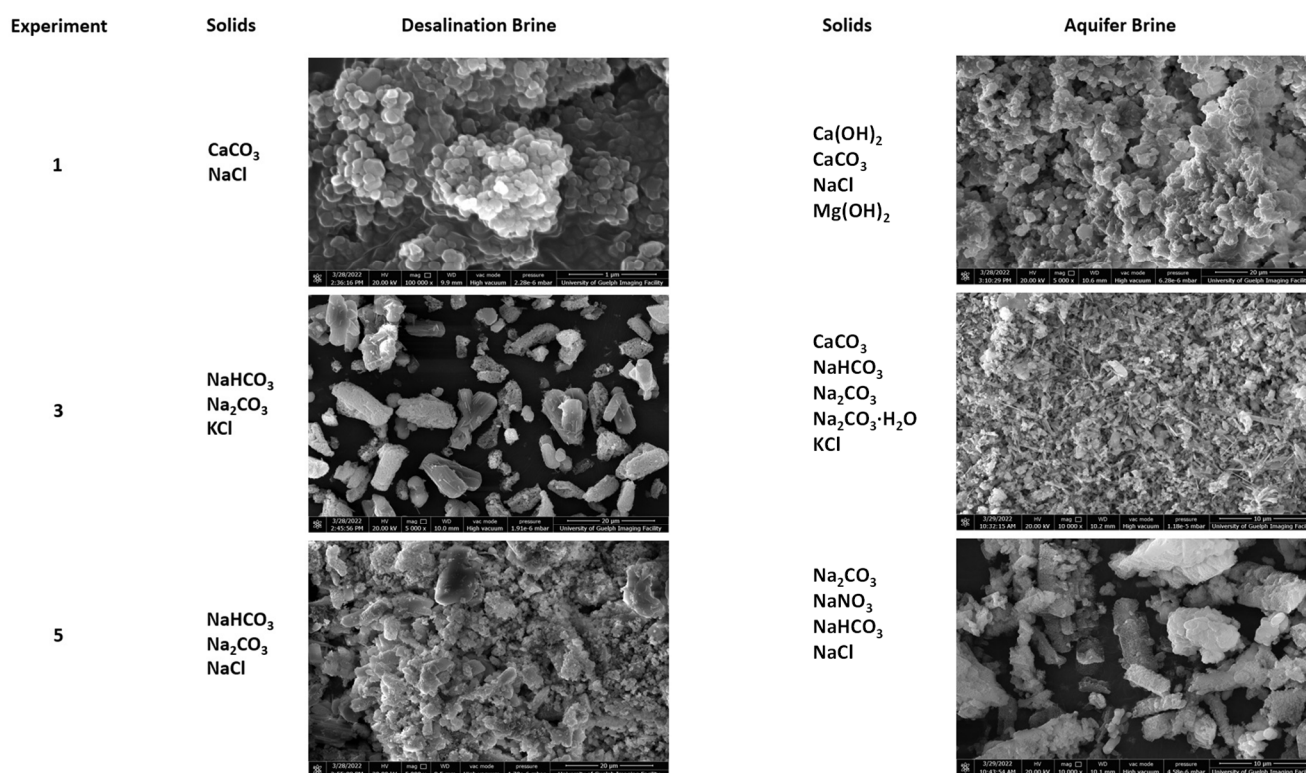


Figure 3. SEM images of the powders obtained from experiments 1 (top), experiment 3 (middle), and experiment 5 (bottom) with the desalination brine (left) and the aquifer brine (right); the mineral phases are listed in decreasing order according to amounts quantified from XRD analysis (Table 1).

The desalination brine case of experiment 1 (top left of Figure 3) produces CaCO₃, as might be indicated by small round particles. The square-shaped crystals represent unreacted NaCl. The aquifer brine case of experiment 1 has unreacted Ca(OH)₂ and NaCl particles, which would populate its image (shown in the top right of Figure 3). There is a mixture of cubic, hexagonal, and round particles. The hexagonal structures represent the presence of Ca(OH)₂, while cubic crystals are indicating the presence of unreacted NaCl. Few of the small round particles could denote the existence of CaCO₃. These results compliment the XRD analyses. NaHCO₃ and Na₂CO₃ have a monoclinic crystal structure. The presence of long cylindrical particles in the middle two images of Figure 3 could represent the existence of NaHCO₃ and Na₂CO₃ particles in experiment 3. Since the compositions of desalination and aquifer brine cases' products are not very different, the image in the middle right of Figure 3 seems like a closer view of the image on the middle left. The cubic shape structures in these two images represent the presence of a few KCl crystals. The aquifer brine version of experiment 3 also represents a few small spherical structures, indicating CaCO₃ particles. Similarly, the bottom two images of Figure 3 characterize the presence of NaHCO₃ and Na₂CO₃ particles in experiment 5, with long irregular shape particles. NaNO₃ has a trigonal and rhombohedral crystal structure, and a few of the rectangular-shaped structures would indicate its presence in these images. The previous reference studies did not include the characterization of the retrieved solids through SEM analysis [12,31]. Incorporating this SEM analysis can help in gauging the success of modifying the Solvay process for the production of NaHCO₃. The results showed that the use of Ca(OH)₂, as a buffering additive, did not produce high-quality nahcolite, while KOH and NH₄HCO₃ precipitated NaHCO₃.

The geochemical modeling of the investigated experiments (listed in Figure 1) was performed in order to have some insight into the precipitation state of NaHCO_3 (Figure 4). The saturation index (SI) of minerals gives information about whether it would be in a precipitating or a dissolving state. A negative SI indicates a dissolving state, while a positive represents precipitation. Experiments 1 and 2 have a negative SI, whether in the reactor or the drier, indicating that NaHCO_3 would be dissolved. This information was validated by experimental XRD analyses, as NaHCO_3 was absent from the obtained products. The drying stage of the rest of the experiments (i.e., 3, 4, 5, and 6) indicates that NaHCO_3 would be precipitating, as indicated by dotted green contours. For experiments 3, 5, and 6, this information is correct, as NaHCO_3 was found after drying in the oven. However, experiment 4 did not show any synthesized NaHCO_3 experimentally even after drying, while geochemical modeling predicts so. It can be due to the fact that reaction kinetics may hinder some saturated salts from precipitating before others, while the geochemical model forecast its precipitation alongside other salts. Because of the complex composition of the aquifer brine solution, geochemical modeling predicted that several additional salts would form. Some of them were predicted to precipitate during carbonation in the reactor (namely, $\text{CaMg}(\text{CO}_3)_2$, $\text{CaSO}_4 \cdot \text{H}_2\text{O}$, and MgCO_3), while others were predicted to precipitate after oven drying (namely Na_2SO_4 , K_2SO_4 , and CaSO_4). Some of these additional salts appear as minor components of the Figure 2 diffractograms for aquifer brine samples, but were not quantified in Table 1 as aforementioned. One reason for this is to avoid the confusion at times seen in literature, where unintended precipitates are considered products, when, in fact, they are undesired by-products. Conclusively, geochemical modeling is an adequate predictor of carbonation and drying precipitation reactions and can be used both for screening reaction conditions for thermodynamic feasibility, as well as to help confirm characterization results such as mineralogy from XRD and morphology from SEM.

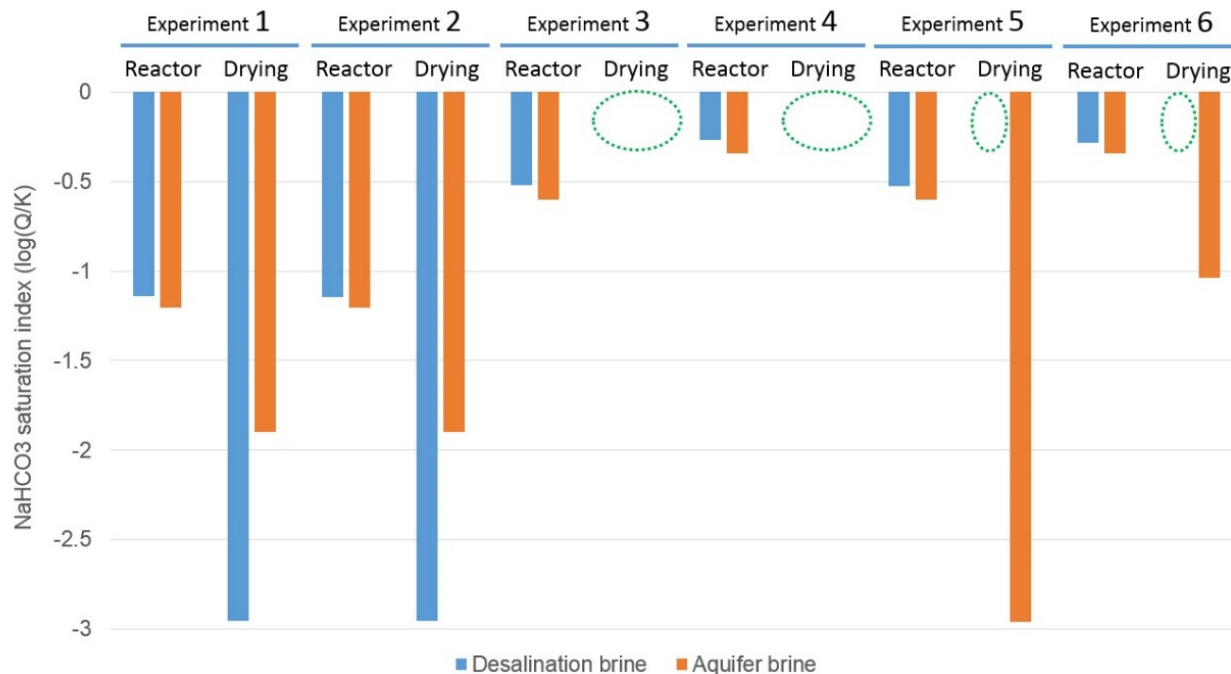


Figure 4. Geochemical modeling of the experiments indicating the saturation index of NaHCO_3 .

4. Conclusions

The present work investigated the use of various buffering additives to modify the Solvay process for synthesizing NaHCO_3 using brine water and CO_2 gas. It studied the composition of the precipitates obtained using $\text{Ca}(\text{OH})_2$ and KOH buffering additives, as reported in the literature, and using NH_4HCO_3 , as proposed in the present work. The effectiveness of the processes and saline brines is gauged quantitatively via Rietveld analysis of XRD data, qualitatively using SEM analysis, where SEM indicates the qualitative effects of the processes and the brines by visualizing the size, shape, and morphology of the obtained solid products, and theoretically through the use of geochemical modeling of the experimental conditions, which provides thermodynamic basis for the observed effectiveness by indicating the SI of NaHCO_3 under the various conditions. The previously reported approaches did not present any mineralogical nor morphological nor thermodynamic analysis, which makes those research outcomes doubtful. In the present work, XRD and SEM analyses clearly showed that NaHCO_3 was not produced with $\text{Ca}(\text{OH})_2$ and KOH as buffering additives, as the processes suffered from severe co-precipitation of other carbonates, chlorides, and hydroxides. These analysis results are in agreement with the geochemical modeling results, which do not predict precipitation of NaHCO_3 unless the solution is dried in an oven to induce saturation of this and other salts. The highest quality NaHCO_3 , with Na_2CO_3 as the main co-product, was produced at a low temperature and high pressure, using NH_4HCO_3 as the buffering additive, which is in line with the traditional Solvay process that uses NH_3 . Higher NaHCO_3 purity was obtained from the simulated desalination brine than from the aquifer brine, which is in agreement with the SI of NaHCO_3 being lower in the latter, meaning that other precipitates are favored. The proposed waste co-utilization approach has the potential to reduce CO_2 emissions by using brine and, in parallel, generating valuable products.

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