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Scientific Chemical Process Engineering Consultancy

Carbon-Negative Soda Ash (CODA)-

Entwicklung eines umweltfreundlichen Verfahrens zur Herstellung von Soda

Abschlusskonferenz KlimPro Industrie

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Berlin

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the European Union

Federal Ministry
of Research, Technology
and Space

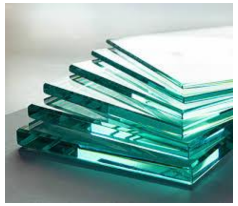
FONA
Research for sustainability

Soda ash (Na_2CO_3) facts

- Globally **69 million metric tons/a** produced in 2022 (+3.2% from 2021):
- **40 %** by Ammonia-Soda (Solvay) process
- Global soda ash market size **$4.9 billion** in 2022 (CAGR of 3.1% 2023-2030)

Applications



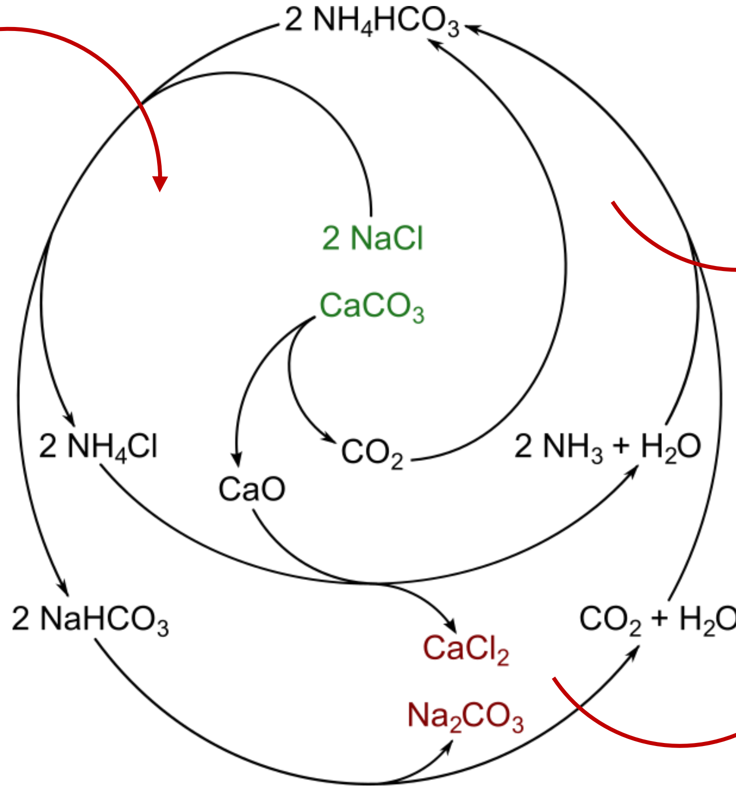



https://zipdo.co/soda-ash-industry-statistics/

Ammonia-Soda Process

- 1864 by Ernest Solvay, one of first highly integrated process but based on fossil carbon/ energy sources

Fossil energy from coal and natural gas

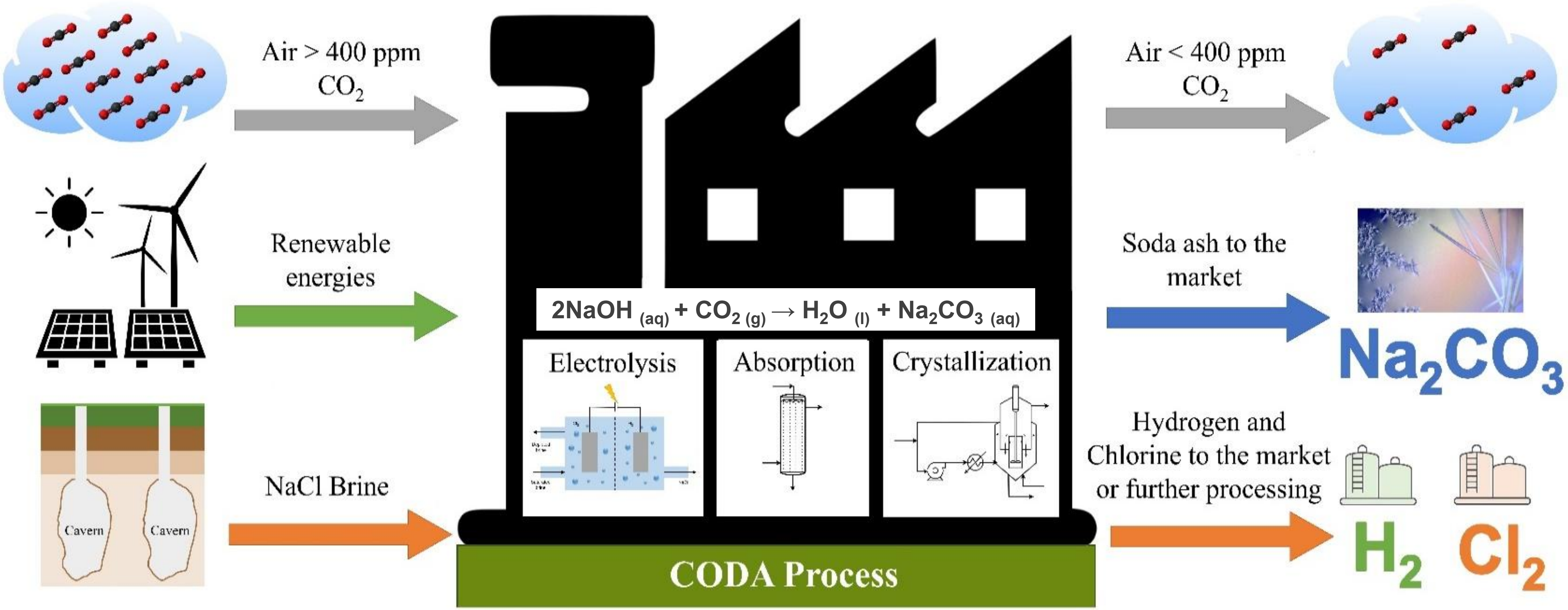


~790 kg/t soda ash fossil CO_2 emissons (EU)

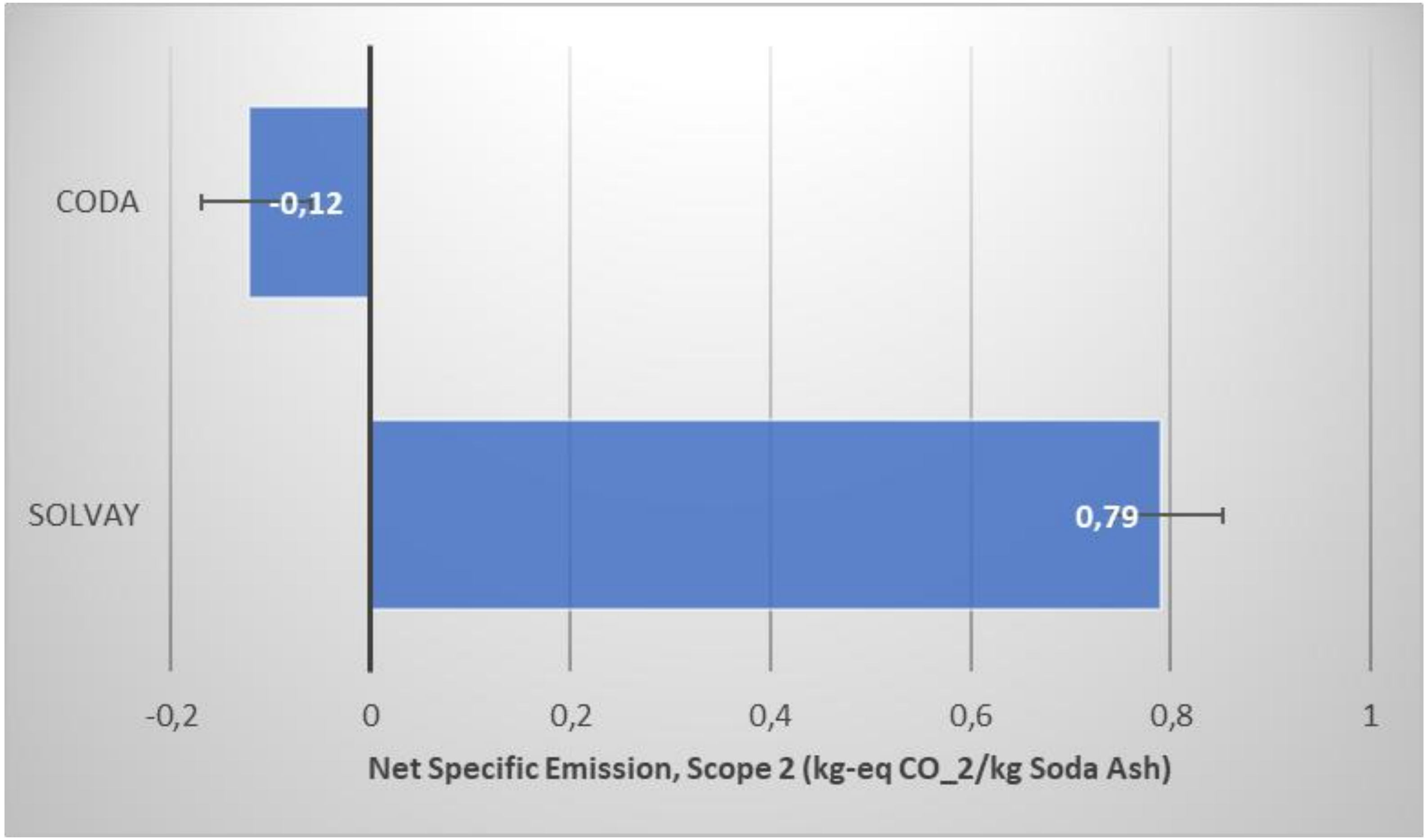
~1t $CaCl_2$ /t soda + ammonia emission

Czaplicka N, Konopacka-Łyskawa D. SN Applied Sciences. 2019 May;1(5):1-8
https://en.wikipedia.org/wiki/Solvay_process#/media/File:Solvay_process_reaction_scheme.svg

CODA Concept

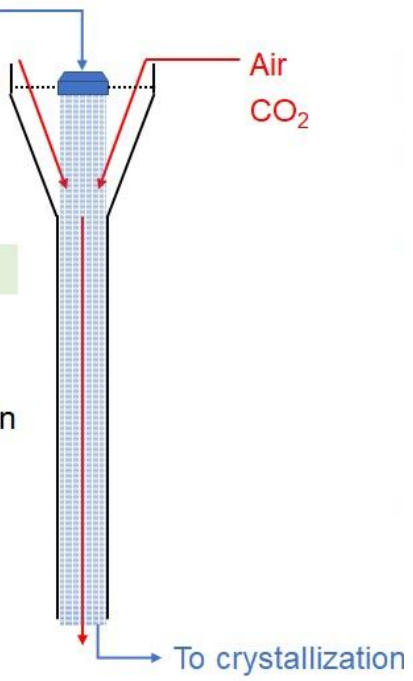


Emissions: Carbon-negative*



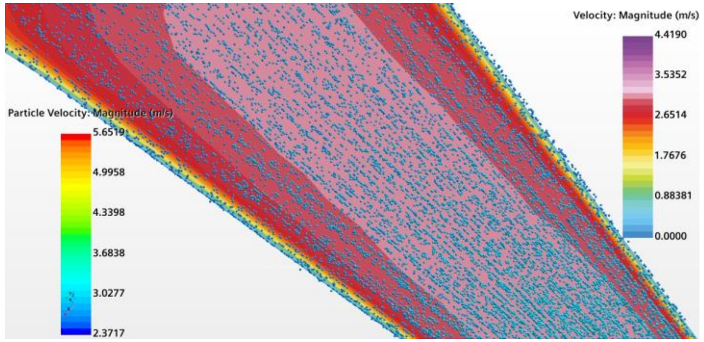
* Emissions for plant construction not yet considered in this study

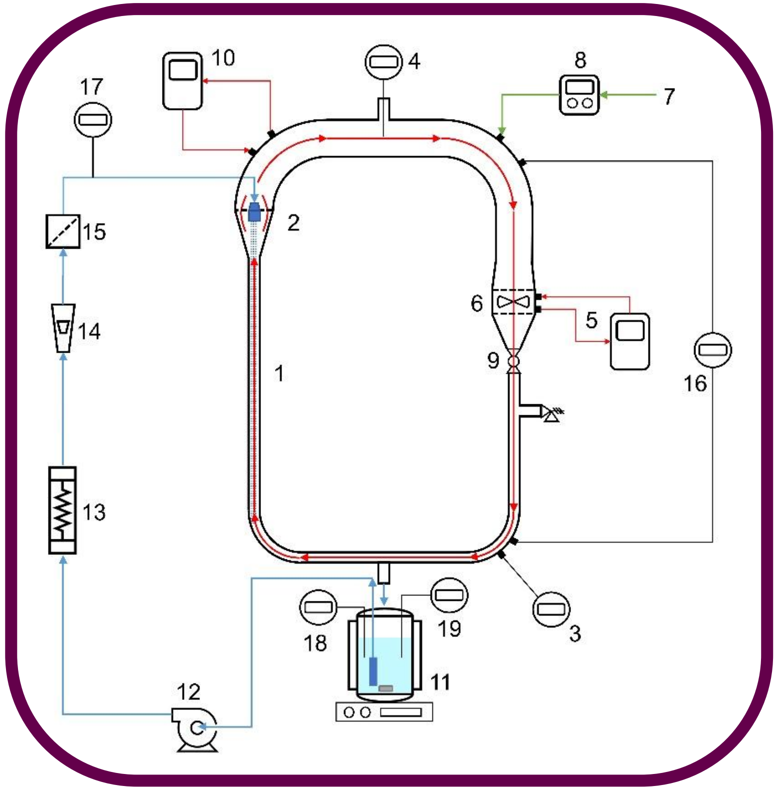
Absorber Development

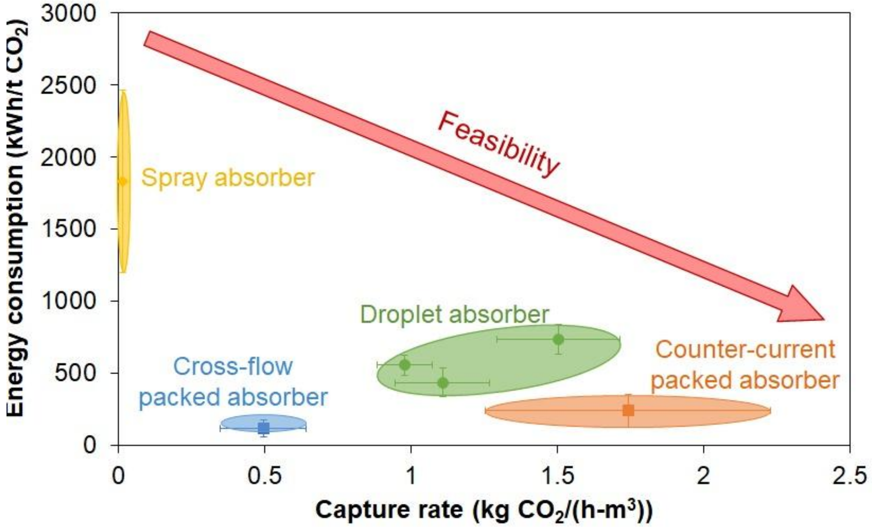


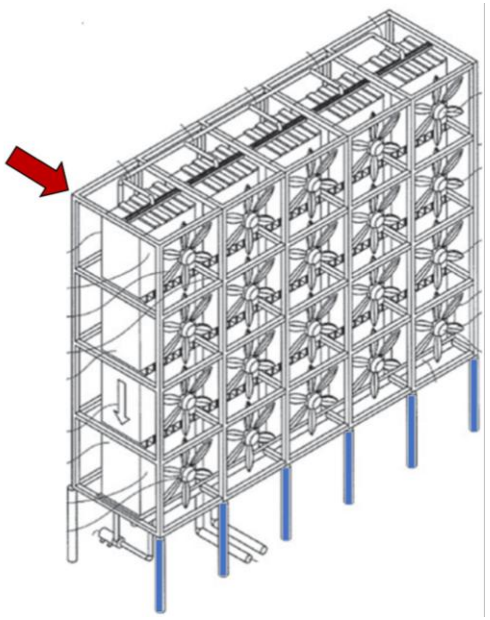
Droplet absorber

- Co-current
- No fan
- Vertical injection









L. Jiang, et al., Sorption direct air capture with CO2 utilization, Prog. Energy Combust. Sci., Vol.95, 2023.

Absorber Publications

I&EC research
Industrial & Engineering Chemistry Research
pubs.acs.org/IECR
Article

Sodium Hydroxide-Based CO_2 Direct Air Capture for Soda Ash Production—Fundamentals for Process Engineering

Somayyeh Ghaffari,* Maria F. Gutierrez, Andreas Seidel-Morgenstern, Heike Lorenz, and Peter Schulze

Cite This: Ind. Eng. Chem. Res. 2023, 62, 7566−7579
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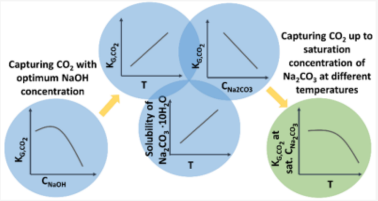

ABSTRACT: This work introduces the principles and supplies the first key parameters for replacing the conventional ammonia-soda (Solvay) process with a new environmentally friendly and sustainable process. For this, the absorption of diluted CO_2 (0.0153−1.2 vol %) in carbonated NaOH solutions was experimentally studied in a temperature range relevant for direct air capture (DAC) in the middle Europe (5−20 °C). A dynamic process model was formulated and solved based on the literature parameters. It was found that by refitting the parameters, the average error was reduced from 9.49 to 7.8%. The absorption performance was evaluated using the mass transfer coefficient (K_{G,CO_2}), which is considered as a useful parameter for the future process design. The mass transfer coefficient reaches a maximum amount of about 3 mm/s at around 6 wt % NaOH, 0 wt % Na_2CO_3, 20 °C, and 500 ppm CO_2. The effects of NaOH and Na_2CO_3 concentrations and temperature on the mass transfer coefficient were experimentally and theoretically studied. Considering all effects simultaneously, the design aspects for an efficient NaOH-based CO_2 DAC process for Na_2CO_3 production are concluded, in which K_{G,CO_2} decreases with rising temperature while operating at saturated ion concentrations of Na_2CO_3.

applied sciences
MDPI

Article

Comparative Study of Droplet Diameter Distribution: Insights from Experimental Imaging and Computational Fluid Dynamics Simulations

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Experimental study and modeling of a droplet CO_2 absorber for the carbon-negative soda ash production

Maria F. Gutierrez [a,*], Kasimhussen Vhora [a,b], Somayyeh Ghaffari [a], Gábor Janiga [b], Andreas Seidel-Morgenstern [a], Heike Lorenz [a], Peter Schulze [a]

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ARTICLE INFO

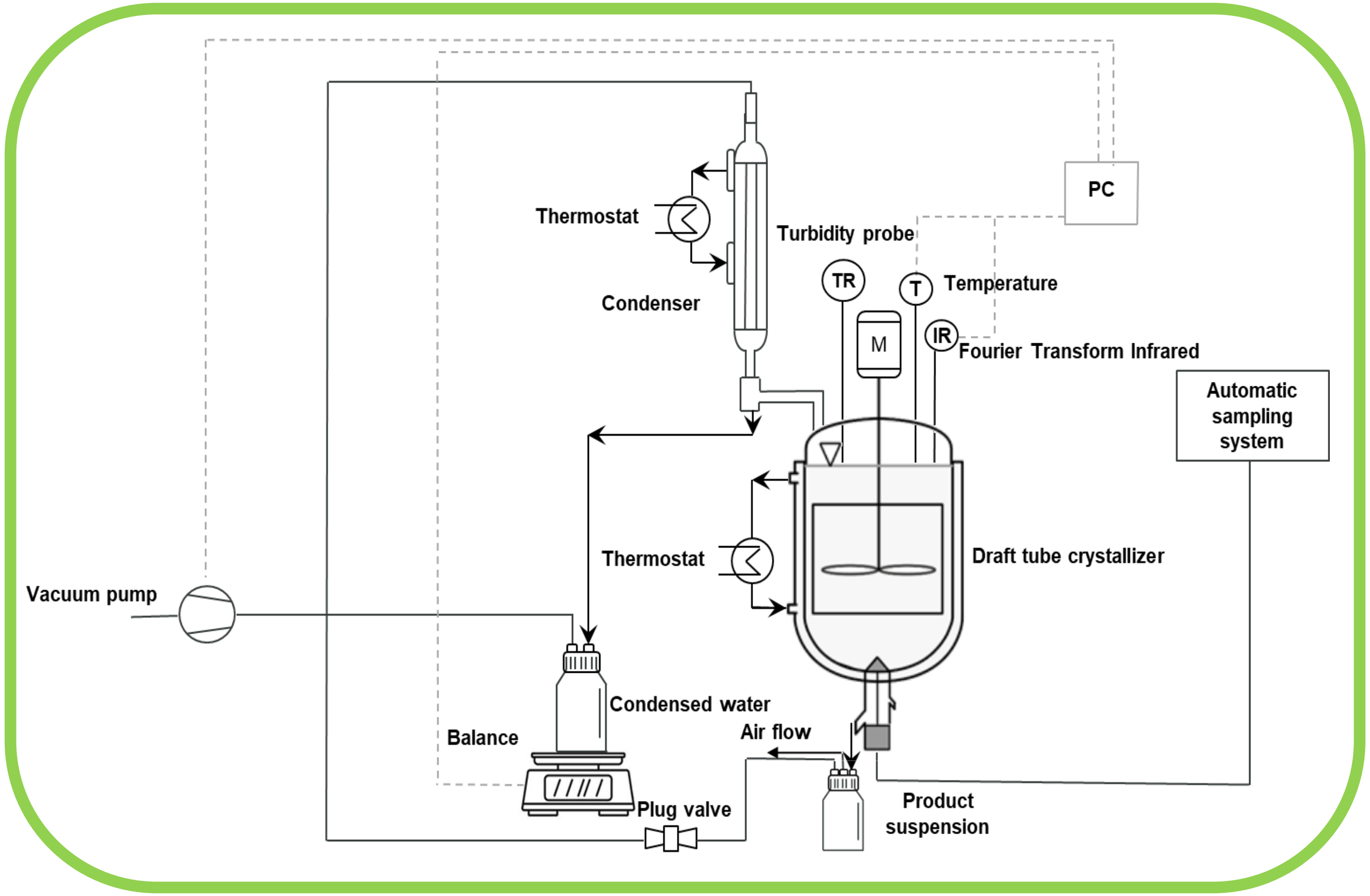
Keywords:
Carbon dioxide
Absorption
Capture rate
Energy consumption

ABSTRACT

As part of a new environmental-friendly and carbon-negative process for soda ash production, the use of a novel droplet absorber for the Direct Air Capture (DAC) of CO_2 with NaOH solutions is studied experimentally and by concomitant process modeling. Two different nozzle plates with different number of holes are tested, and the counter-current and co-current arrangements are evaluated in terms of change of CO_2 concentration, capture rate and energy consumption. In the co-current operation, the fall of small droplets drives the flow of air inside the absorber and no fan is required. The effect of the liquid flow rate, the CO_2 inlet concentration, the gas velocity, the temperature and the liquid concentration is quantified. Two models are compared: one neglecting and the other considering droplet coalescence using CFD simulations. The inclusion of the force balances in the model allowed proper description of the fluid velocities and specific surface area inside the droplet absorber. Due to the high specific surface areas obtained (100–400 m^2/m^3), the studied droplet absorber outperforms reported spray absorbers for CO_2 capture. The capture rate is in the range between 0.7 and 2.4 kg CO_2/(h·m^3 absorber) and the energy consumption between 248 and 1008 kWh/(t CO_2), depending on the operational conditions. The performance and practical implementation of the droplet absorber in comparison with standard absorbers for DAC applications are discussed.

Crystallization Development

Experimental setup, 3 Liter Draft-Tube-Baffle (DTB) crystallizer with vacuum evaporation facilities



I&EC research
Industrial & Engineering Chemistry Research

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Solubility and Metastable Zone Width Measurement of Na_2CO_3 Hydrate Phases in the Na_2CO_3–NaOH–H_2O System as a Basis for a Novel Carbon-Negative Soda Ash Production Strategy

Somayyeh Ghaffari,* Maria F Gutierrez, Peter Schulze, Andreas Seidel-Morgenstern, and Heike Lorenz

Cite This: *Ind. Eng. Chem. Res.* 2025, 64, 10564–10577 Read Online

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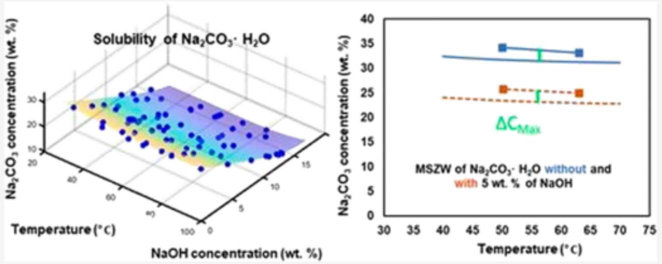

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Crystal Growth Kinetics of Na_2CO_3 Hydrate Phases in the Na_2CO_3–NaOH–H_2O System for Sustainable Soda Ash Production

Somayyeh Ghaffari,* Jonathan Gänsch, Peter Schulze, and Heike Lorenz

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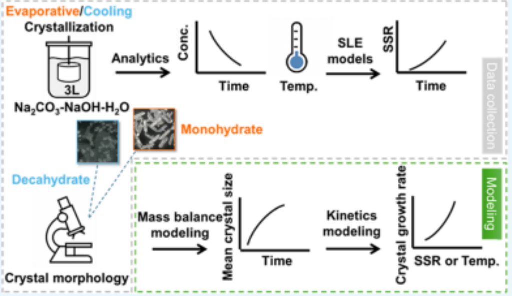
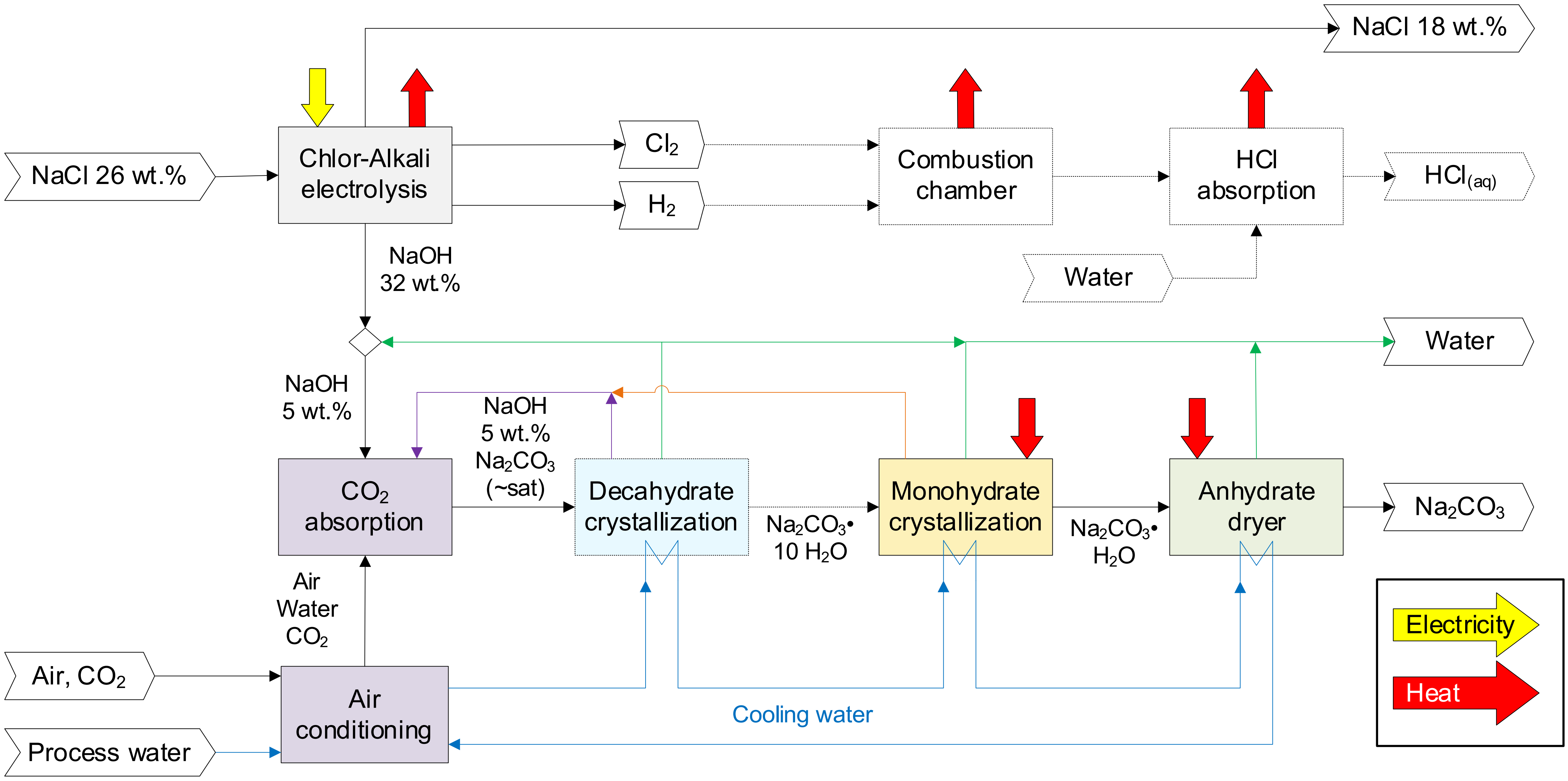
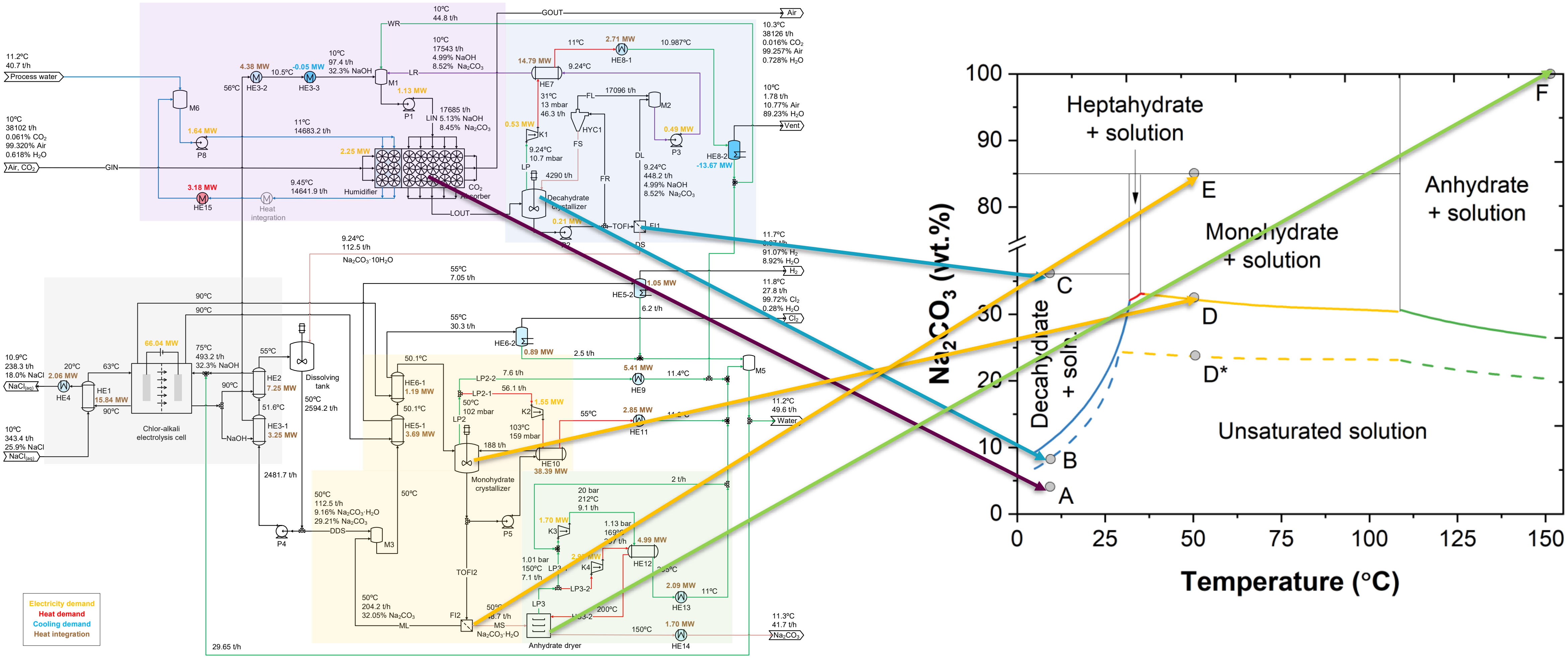


ABSTRACT: As part of the CODA project, which is laying the foundation for a novel sustainable soda ash (Na_2CO_3) production strategy, this study provides essential parameters and insights for the design, optimization, and scale-up of the required crystallization processes. It investigates the crystal growth kinetics of $Na_2CO_3 \cdot 10H_2O$ and $Na_2CO_3 \cdot 1H_2O$ within the Na_2CO_3–NaOH–H_2O system using cooling and vacuum evaporative crystallization, respectively. Experimental studies were conducted utilizing a shortcut method based on seeded batch experiments in a 3 L-scale. The growth rate of $Na_2CO_3 \cdot 10H_2O$ was studied over a temperature range of 17–6 °C, while $Na_2CO_3 \cdot 1H_2O$ was examined at a constant temperature of 50 °C under a fixed evaporation rate. Minimal secondary nucleation was confirmed through offline crystal size distribution measurements. $Na_2CO_3 \cdot 10H_2O$ growth peaked at a critical supersaturation (~1.03) and afterward slowed despite further increases in supersaturation, alluding to a potential crystal surface roughening mechanism. The presence of NaOH did not alter the crystal habit of $Na_2CO_3 \cdot 10H_2O$ but did alter that of $Na_2CO_3 \cdot 1H_2O$. Despite the relatively low supersaturation, the monohydrate exhibited a higher growth rate than the decahydrate. Furthermore, the monohydrate produced yielded dense (heavy) soda ash, addressing a significant challenge within the soda ash industry.

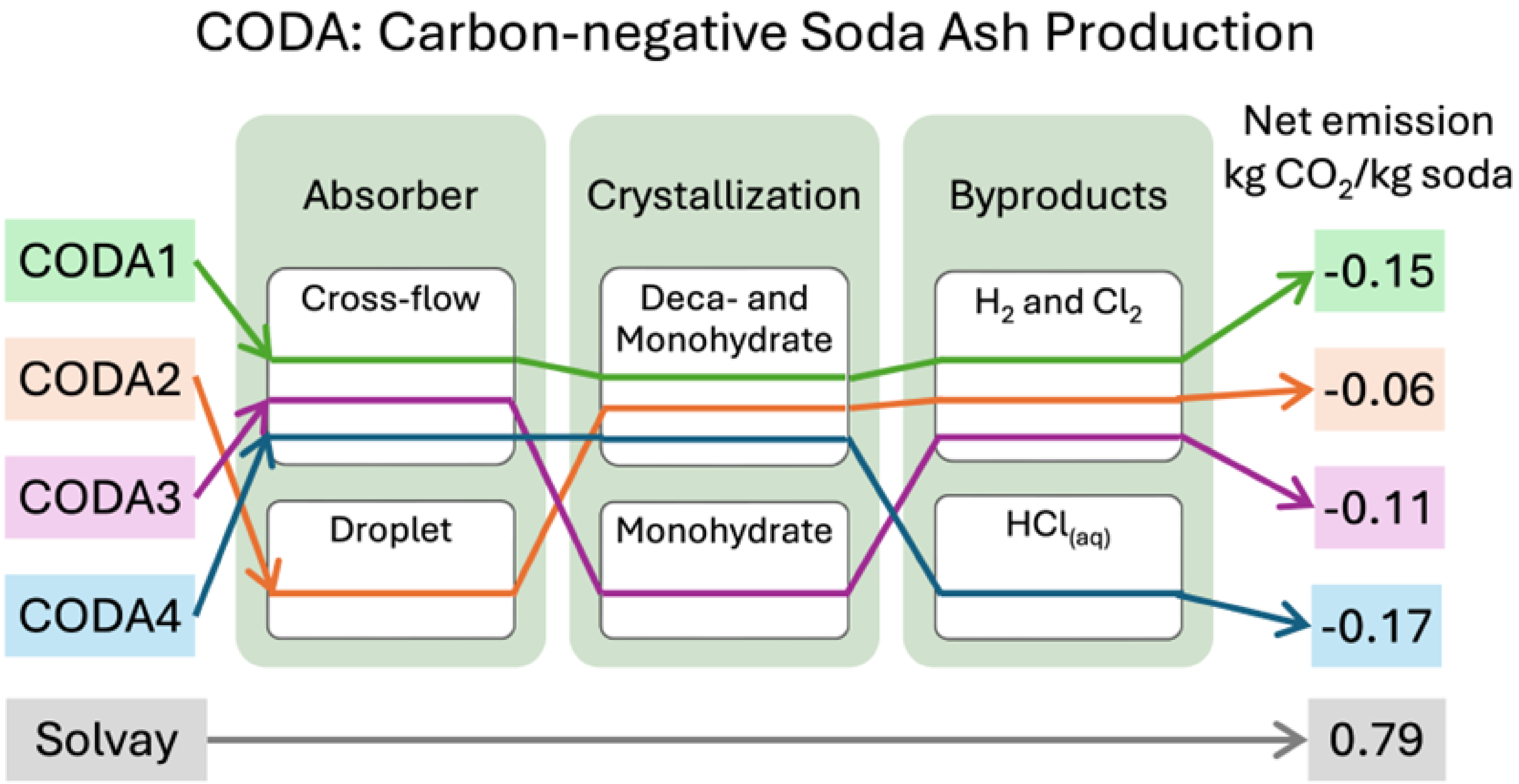
Process Simulation & Development



ASPEN Simulation Process Variant 1

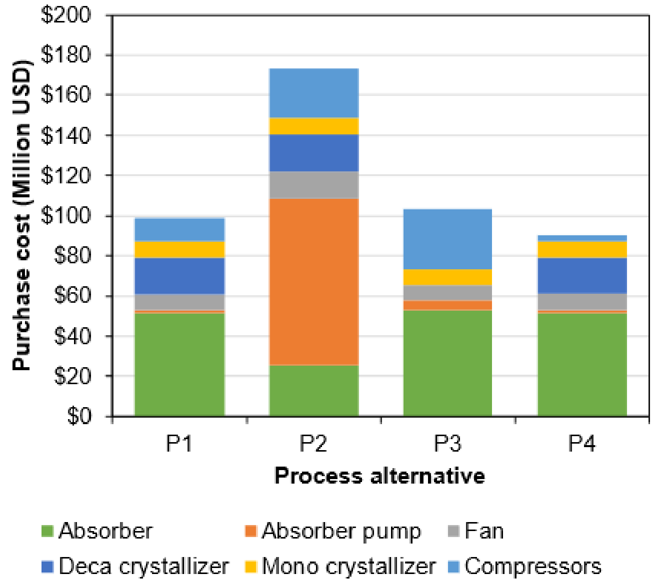


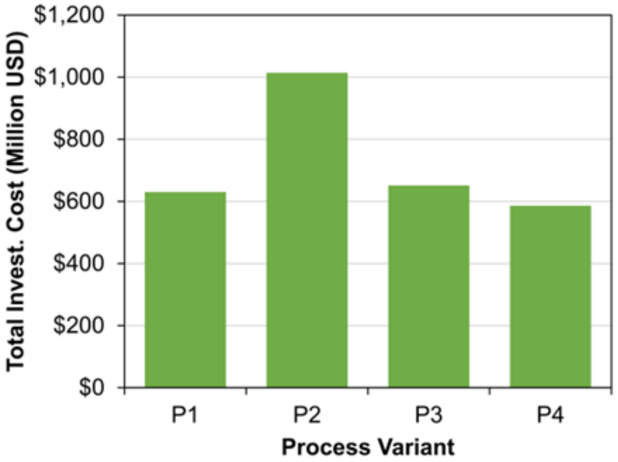
CO_2 Emissions

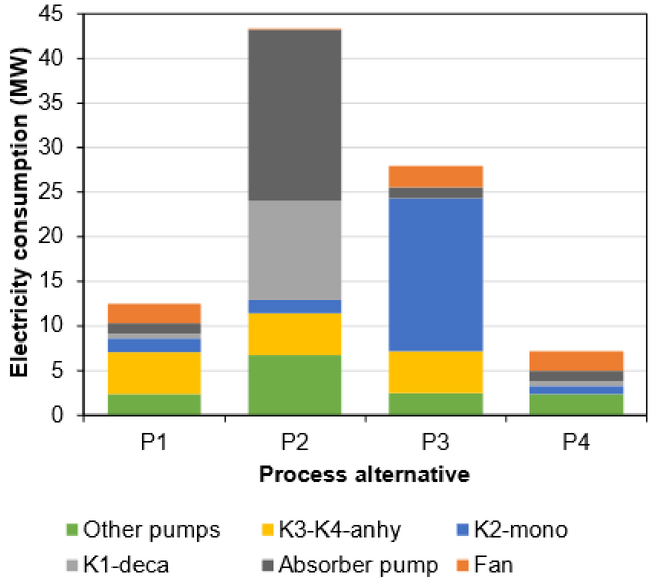


Simulation results

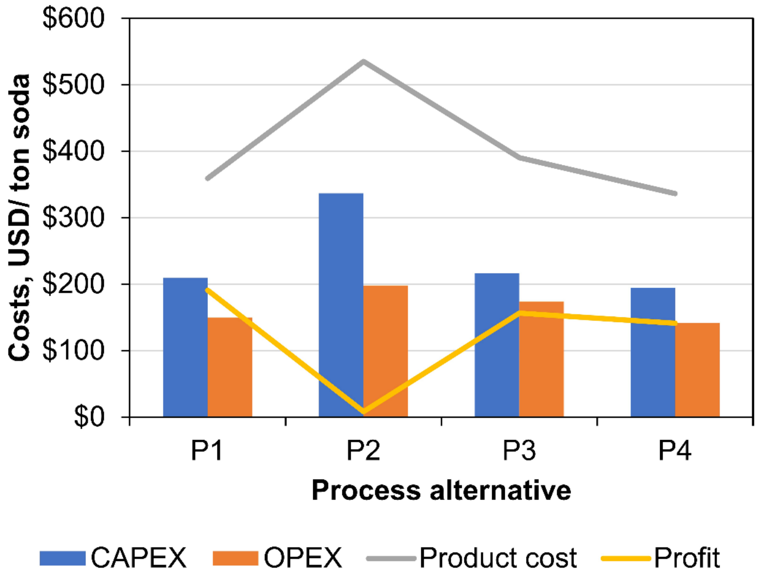
1000 t/d commercial plants seam techno-economic feasible







+73 MW Elektrolysis in P1-4



Simulation Publication

I&EC research
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Article

Carbon-Negative Production of Soda Ash: Process Development and Feasibility Evaluation

Maria F. Gutierrez,* Heike Lorenz, and Peter Schulze

Cite This: *Ind. Eng. Chem. Res.* 2025, 64, 11474–11496

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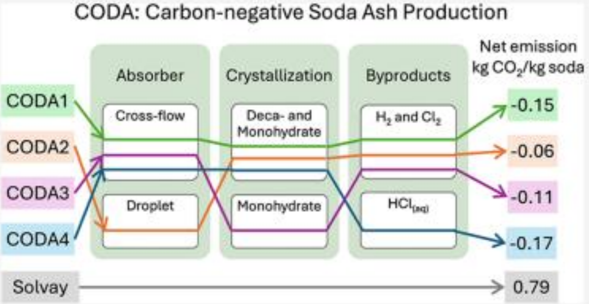
ABSTRACT: Aiming to produce carbon-negative soda ash, chlor-alkali electrolysis, CO_2 direct air capture, and sodium carbonate crystallization are combined in a so-called CODA process. In this study, four variants of the CODA process are developed and evaluated by means of modeling and simulation. Variations of the process design are related with the CO_2 absorption technology, the crystallization strategy, and the possible byproducts of the process. The processes using a cross-flow packed absorber had a smaller CAPEX (between 195 and 209 USD/ton soda) than the process using a droplet absorber (337 USD/ton soda). When coupled with the cross-flow packed absorber, the two-step crystallization strategy had a smaller OPEX (150 USD/ton soda) than the one-step crystallization (175 USD/ton soda). The revenue of selling the process byproducts such as hydrogen, chlorine, and CO_2 certificates was key to the profitability of the CODA process. The most promising CODA variant (cross-flow packed absorber and two-step crystallization) consumes about 0.15 tons of CO_2 from the air and earned nearly 200 USD/ton soda ash, making CODA an attractive alternative that deserves to be scaled-up.



Economic Exploitation Efforts

No-patent strategy: A conscious decision against patents to support commercialization (no license fees favor the profitability of a future investment).

Economic Exploitation Activities:

Soda Ash Industry (former partner Ciech/ Qemetica):

- ✓ pilot plant on-site in Staßfurt,
- ❖ cancelled due to unfavorable financial conditions (energy crisis and Covid)

Lithium Carbonate Start-up Company:

- ✓ on-site soda ash production in Chile,
- ❖ cancelled due to unfavorable political conditions in Chile

Large Engineering Company:

- ✓ Joint development of a turn-key plant,
- ❖ On-hold until customer found

Waste-to-Energy Industry:

- ✓ CCU + on-site soda ash and bicarbonate production in Germany (BiCoda),
- ❖ Active project in earliest stage (pre-feasibility), currently convincing key partners

Acknowledgements

CODA project 2021 - 2025 funded by:

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With funding from the:

Federal Ministry of Research, Technology and Space

FONA Research for sustainability

MPI Team:

(former) Industrial partner:

Ciech

QEMETICA

SChPrEngCo
Scientific Chemical Process Engineering Consultancy

Please contact peter.schulze@schprengco.de for (pilot/demo/commercial) scale-up of CODA process!

Crystals of soda ash on a sodium hydroxide droplet in contact with air

Abschlussbericht - TIB

Schlussbericht zum BMFTR-Verbundprojekt KlimPro-Industrie

Entwicklung eines umweltfreundlichen Verfahrens zur Herstellung von Soda (CODA)

SACHBERICHT

Finanziert von der Europäischen Union

With funding from the:

Federal Ministry of Research, Technology and Space

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Forschung für Nachhaltigkeit

Akronym: CODA (Carbon-negative sODA ash plant)

Förderkennzeichen: 01LJ2003A, B, C