CO_2 capture using sodium silicates prepared from geothermal silica waste

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1 Introduction

Carbon dioxide (CO_2), mainly produced by fossil fuel combustion and other anthropogenic activities, has increased in atmospheric concentration and is a major contributor to global warming. Therefore, developing new CO_2 capture technologies is essential to mitigate emissions and meet environmental regulations.

Sodium orthosilicate (Na_4SiO_4) has emerged as a promising adsorbent for high-temperature CO_2 capture. Its synthesis requires SiO_2, which can be obtained from industrial wastes such as geothermal silica residues. Utilizing this waste not only addresses disposal issues but also enables the production of value-added adsorbents, supporting sustainable practices and circular-economy principles.

Silica waste was obtained from a geothermal power plant located in Mexico.

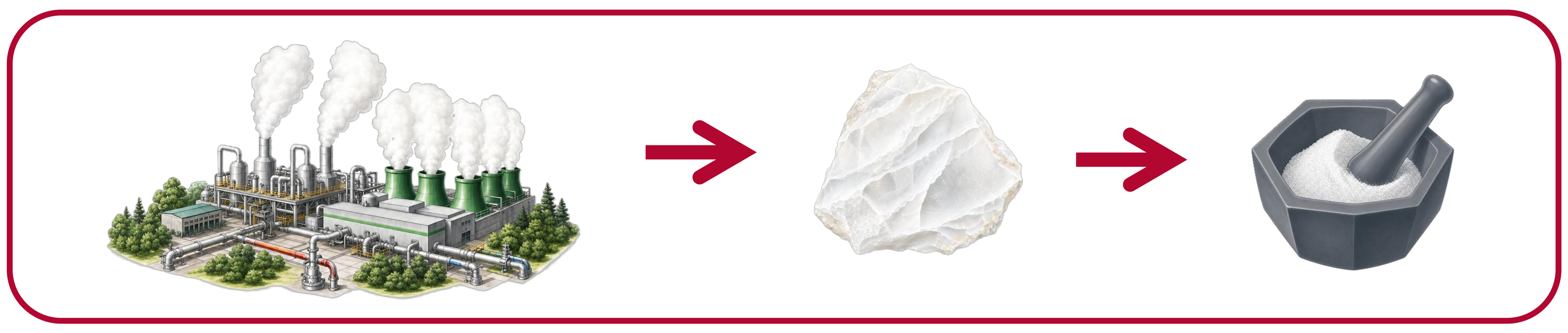

Figure 1. Obtention of geothermal silica waste

Analytical-grade reagents (Sigma Aldrich NaOH with a purity of >98% and IntensiLab Na_2SiO_3) were used for the synthesis of the silicates.

2 Materials and methods

The synthesis of sodium silicates was carried out using the wet mixing method and quenching.

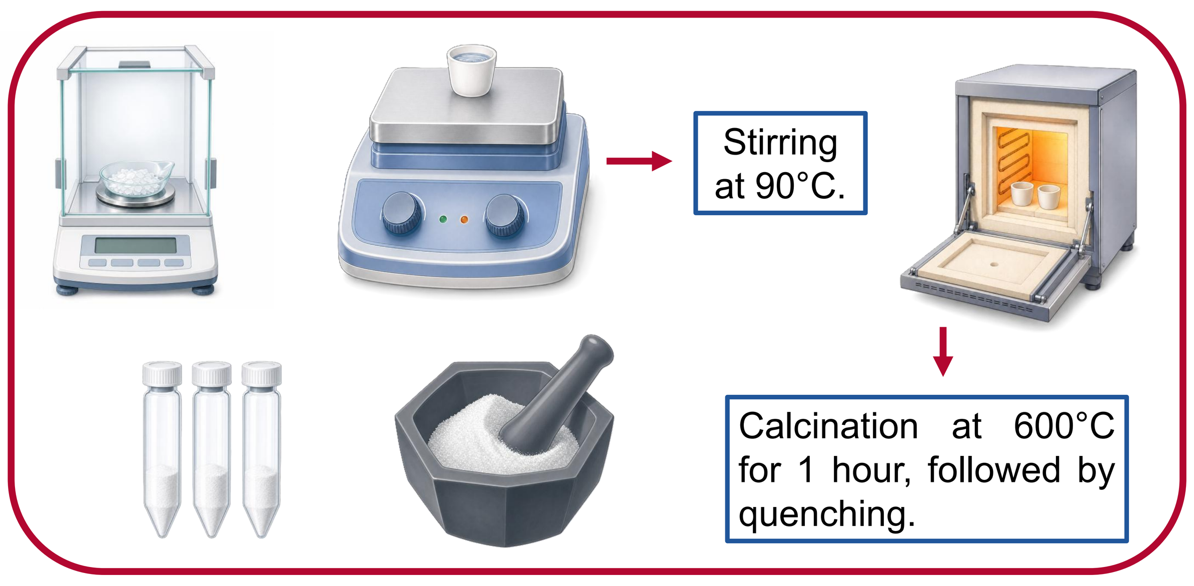

Figure 2. Wet mixing method and quenching

Based on the stoichiometry (Eq. 1 and Eq. 2), the amounts of analytical-grade reagents and geothermal silica waste required to obtain sodium orthosilicate were calculated (**NaSi-AG** and **NaSi-GW,** respectively).

$$2NaOH + Na_2SiO_3 \rightarrow Na_4SiO_4 + H_2O \quad \text{Eq. 1}$$

$$4NaOH + SiO_2 \rightarrow Na_4SiO_4 + 2H_2O \quad \text{Eq. 2}$$

- Geothermal silica waste was characterized by X-ray fluorescence (XRF) to determine its chemical composition.
- The synthesized materials were characterized by X-ray diffraction (XRD) and nitrogen physisorption.
- CO_2 capture performance was evaluated by thermogravimetric analysis (TGA), dynamic and isothermal experiments, using a CO_2 concentration of 15 vol.%.

3 Results & Discussion

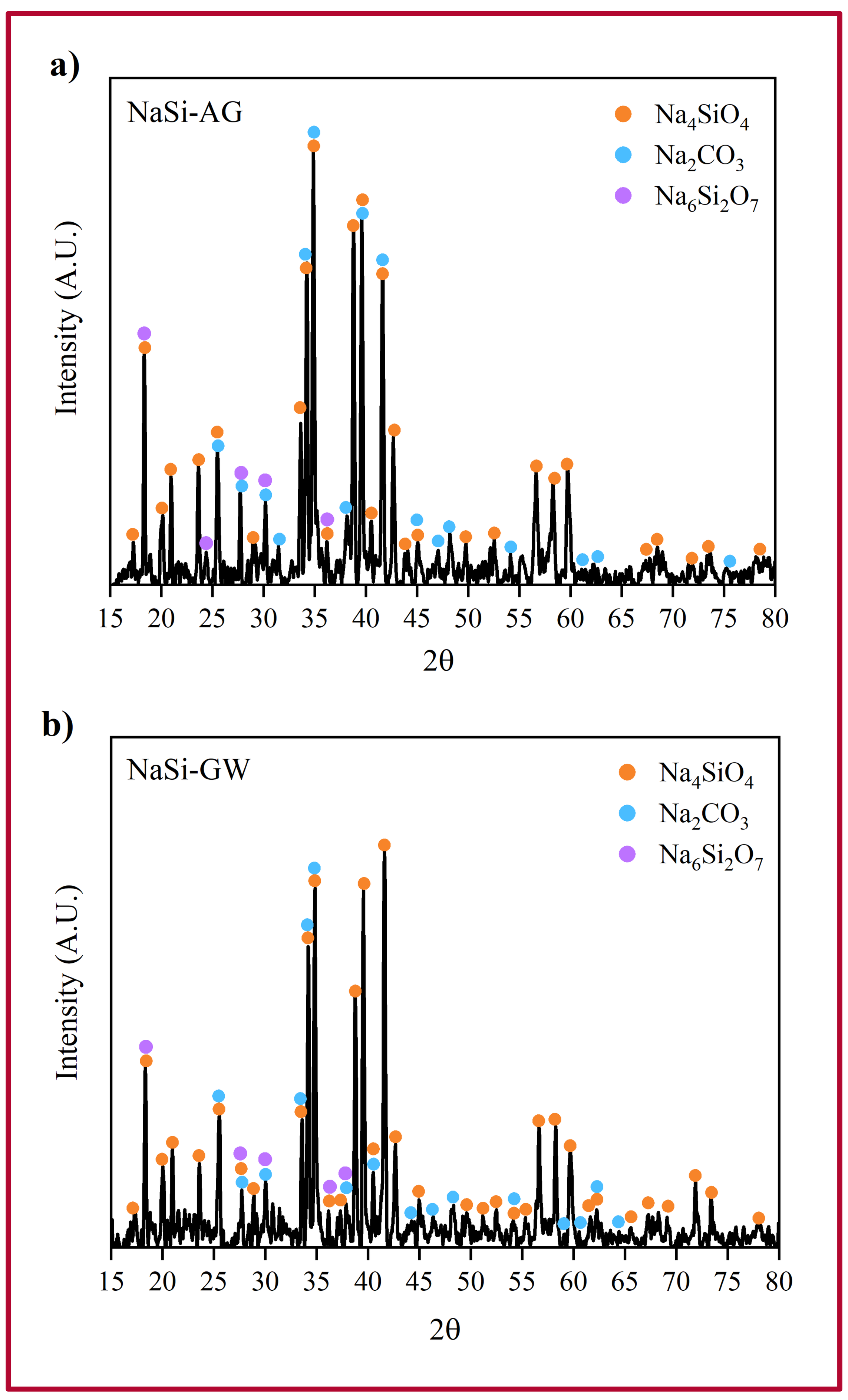

Figure 3. XRD patterns of: (a) NaSi-GA (b) NaSi-SH.

XRD patterns confirm the formation of the desired crystalline phase (Na_4SiO_4) in both synthesized materials.

The specific surface areas of **NaSi-AG** and **NaSi-GW** were calculated using the BET model, yielding values of 1.3 and less than 1 m²/g, respectively.

Table 1. Chemical composition of geothermal silica waste (wt%) by XRF.

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI*
95.163	0.059	0.329	0.078	0.003	0.083	0.174	0.273	0.152	0.017	3.67

*Lost on ignition

XRF analysis confirmed the high SiO_2 content present in the industrial waste.

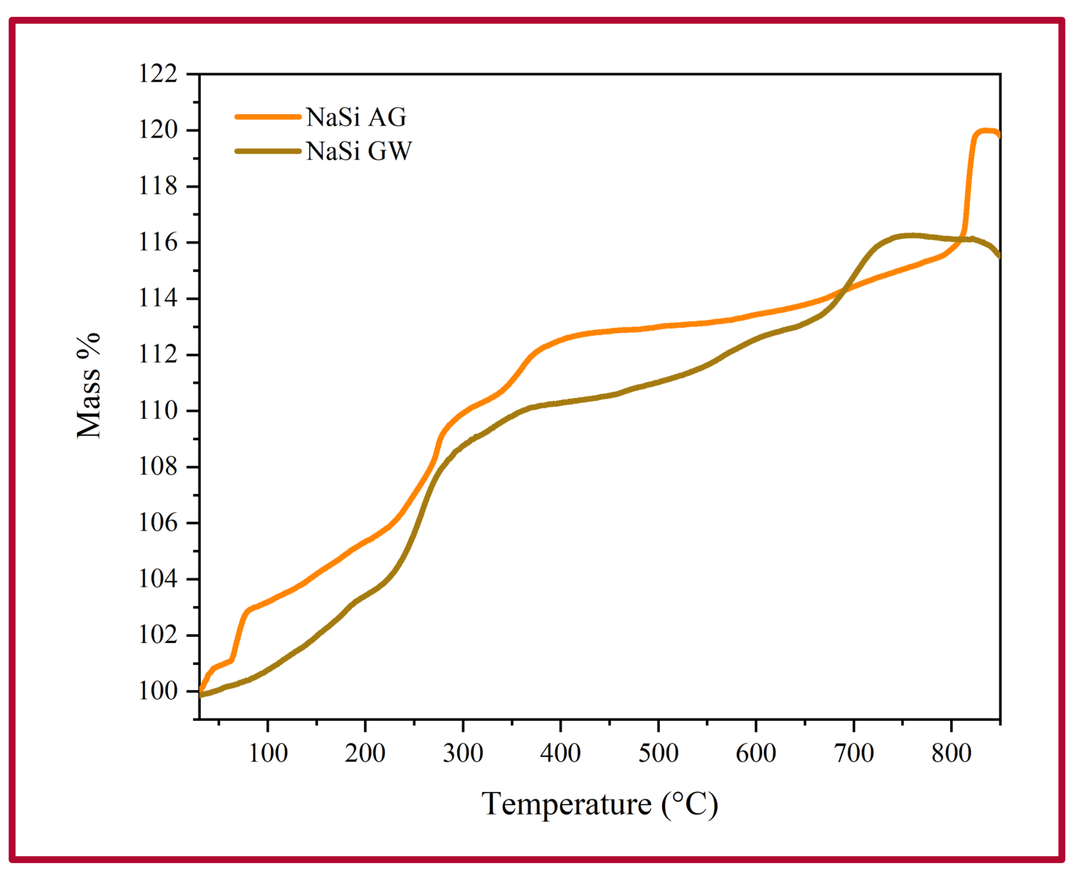

Figure 4. Dynamic thermograms of NaSi-AG and NaSi-GW sodium orthosilicates with 15 vol.% CO_2.

The theoretical CO_2 capture of Na_4SiO_4 is 23.91 wt%. **NaSi-AG** exhibited a CO_2 capture of 19.99 wt%, while **NaSi-GW** achieved 16.25 wt%.

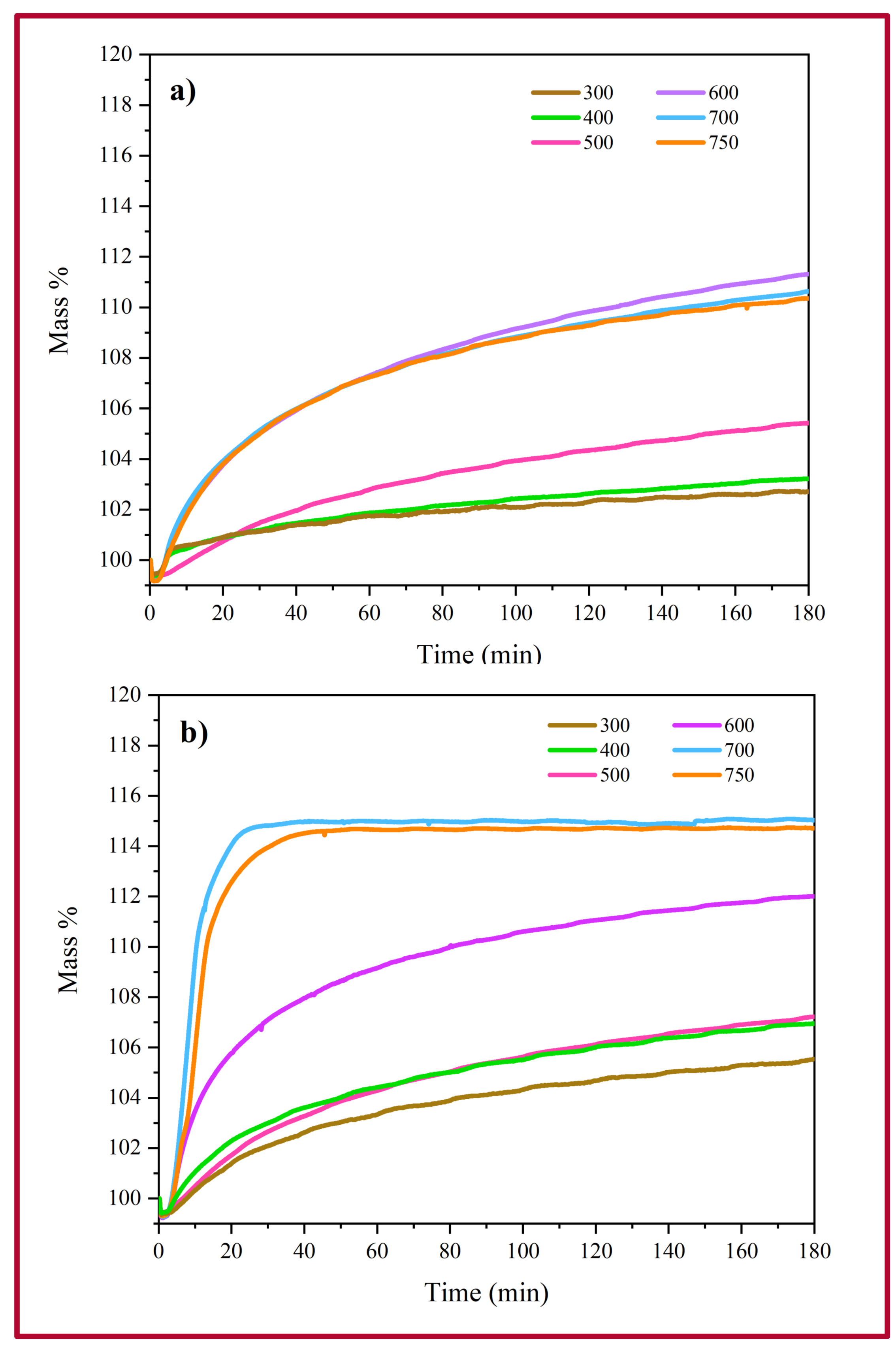

Figure 5. Isothermal thermograms of: (a) NaSi-AG and (b) NaSi-GW at different temperatures and 15 vol.% CO_2.

Kinetic evaluation

The results obtained during the isothermal experiments were analyzed using the **Avrami-Erofeev model** to explain the reaction mechanism between the solid materials and CO_2.

Table 2. Kinetic parameters of NaSi-AG

	Stage 2		
T (°C)	n	K (s^{-1})	R^2
300	0.8658	3.01E-02	0.9855
400	0.935	1.90E-02	0.9962
500	0.9567	1.51E-02	0.9958
600	0.9663	2.05E-02	0.9916
700	0.8984	3.19E-02	0.9895
750	0.9835	2.15E-02	0.9845

Table 3. Kinetic parameters of NaSi-GW

	Stage 1			Stage 2		
T (°C)	n	K (s^{-1})	R^2	n	K (s^{-1})	R^2
300				0.9923	1.61E-02	0.9972
400				0.9738	1.91E-02	0.9845
500				0.9996	1.52E-02	0.9995
600				0.8902	3.92E-02	0.9595
700	3.2797	5.66E-04	0.9897	0.9908	1.36E-01	0.9446
750	2.976	5.38E-04	0.9945	0.8727	1.52E-01	0.9235

5 Conclusions

Material characterization allowed for the identification of the Na_4SiO_4 phase and other phases involved in CO_2 capture. Thermogravimetric analysis determined the temperature range of interest (300–750°C) and the mass gain of both materials (NaSi-AG and NaSi-GW) during the CO_2 capture process.

The kinetic evaluation demonstrated that the first stage is controlled by crystal growth and formation, while the second stage corresponds to CO_2 diffusion.

Therefore, it is possible to synthesize sodium silicates from geothermal silica waste, which are used in CO_2 capture.

References

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