CO_2 capture using sodium silicates prepared from geothermal silica waste

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Introduction

Carbon dioxide (CO_2) is a greenhouse gas mainly produced by the combustion of fossil fuels and other anthropogenic activities. Its atmospheric concentration has increased over recent decades and is considered one of the main causes of global warming. Therefore, it is necessary to investigate and develop new CO_2 capture technologies to mitigate emissions from large point sources and to comply with environmental regulations (Díez Martín, 2018).

In this context, sodium orthosilicate (Na_4SiO_4) has been identified as an innovative adsorbent material for high-temperature CO_2 capture (Ling et al., 2023). The synthesis of sodium silicates requires silicon oxide (SiO_2), which can be obtained from different industrial waste sources. One such source is geothermal power plants, which generate silica-rich residues that have become a significant operational problem. Consequently, the use of geothermal silica waste represents a waste valorization strategy that enables the production of CO_2 adsorbents while reducing the environmental impact of waste disposal. Furthermore, this approach promotes circular-economy principles by generating value-added materials and offering a sustainable solution.

Experimental

Silica waste was obtained from a geothermal power plant located in Mexico and characterized by X-ray fluorescence (XRF) to determine its chemical composition. Subsequently, this silica and analytical-grade reagents were used to synthesize sodium silicates via the wet-mixing method. The synthesized materials were characterized by X-ray diffraction (XRD), nitrogen physisorption, and scanning electron microscopy (SEM). CO_2 capture performance was evaluated by thermogravimetric analysis (TGA) using a CO_2 concentration of 15 vol%. for dynamic and isothermal experiments.

Results and discussion

XRF analysis confirmed the high SiO_2 content present in the industrial waste (Table 1). Minor components were also detected at very low concentrations, which are not expected to interfere with the formation of Na_4SiO_4.

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

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

[a] LOI: loss on ignition

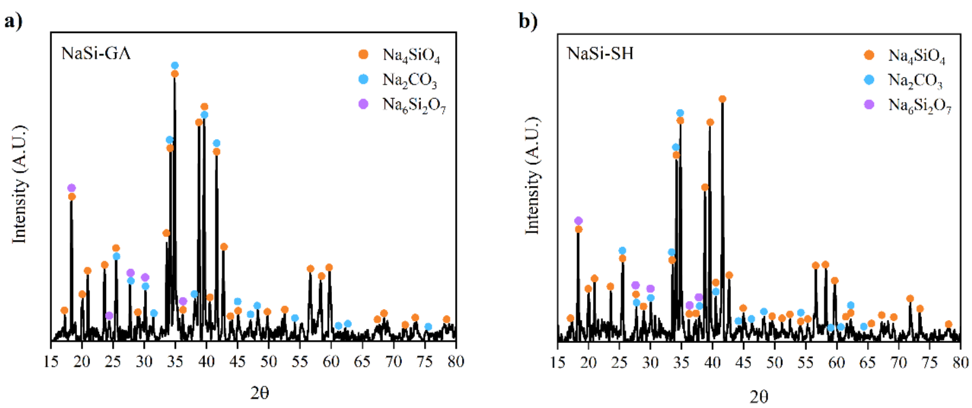

Figure 1. XRD patterns of: (a) sodium silicate from analytical-grade reagents (NaSi-GA) and (b) sodium silicate from silica waste (NaSi-SH).

XRD patterns shown in Figure 1 confirm the formation of the desired crystalline phase (Na_4SiO_4) in both synthesized materials. Characteristic peaks corresponding to Na_2CO_3 were also observed, indicating that the samples were exposed to atmospheric CO_2 and reflecting their high reactivity. Additionally, the presence of sodium pyrosilicate ($Na_6Si_2O_7$) was identified; this phase has been reported to be kinetically stable at temperatures above 620 °C (Plascencia-Hernández et al., 2022). No significant differences were observed in the diffraction patterns of the two samples, indicating that geothermal silica waste is an effective precursor for the synthesis of sodium silicates. Nitrogen physisorption analysis revealed that the materials exhibit a specific surface area lower than 1 m^2/g.

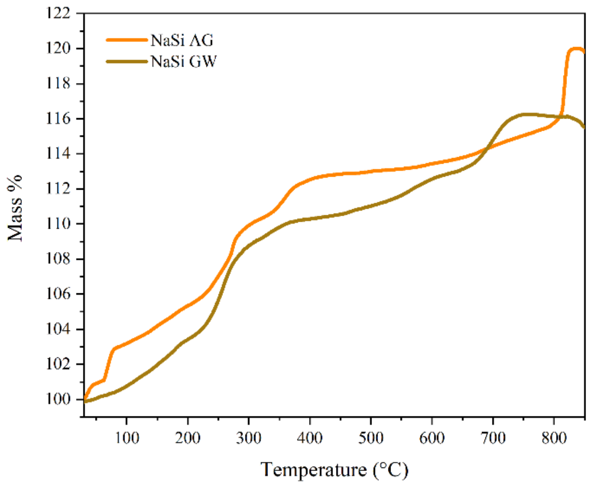

Figure 2. Dynamic thermograms of GA and SH sodium orthosilicates under 20 vol.% CO_2.

The dynamic thermogram shown in Figure 2 exhibits a mass gain starting at room temperature and stabilizing at approximately 300 °C, indicating CO_2 capture in both materials and the formation of sodium carbonate. However, the Na_4SiO_4 synthesized from geothermal silica waste exhibits a higher mass gain compared to the material synthesized from analytical-grade reagents.

The theoretical CO_2 capture efficiency of Na_4SiO_4 is 23.91 wt.%. The NaSi-GA sample achieved a CO_2 capture of 19.99 wt.%, while NaSi-SH reached a CO_2 capture of 16.25 wt.%. Based on the dynamic evaluation, the temperature range of interest for CO_2 capture was determined to be 300-800 °C.

Conclusions

The results demonstrate that sodium silicates can be successfully synthesized from geothermal silica waste and applied for CO_2 capture. The characterization techniques employed confirmed the presence of the Na_4SiO_4 phase as well as other phases involved in the capture process. Dynamic thermogravimetric analysis identified a relevant operating temperature range of 300-800 °C. Furthermore, the SH sodium silicate exhibited a higher CO_2 capture capacity than the GA sample. The impurities present in geothermal silica waste promote the formation of active sites and reactive phases toward CO_2, making this waste an effective silica source for the production of alkaline ceramic CO_2 sorbents.

References

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