Geothermal silica waste as raw material for preparing CO_2 sorbents

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Introduction

CO_2 management has been promoted and proposed in recent years due to the negative effects of increasing CO_2 emissions. That is why developing and deploying carbon capture, utilization and storage (CCUS) technologies has been widely recognized as a strong alternative for decarbonizing industry and promoting net CO_2 removal from the atmosphere (Zhang et al. 2022). One critical point to implementing CCUS technologies is the CO_2 sorbent material, which must have high CO_2 sorption capacity and stability under different gas stream conditions, good kinetics, and be able to regenerate at a low cost. It is thus that under the circular economy approach, the use of industrial waste as raw material for preparing CO_2 sorbent materials is an attractive topic due to the advantages it offers, such as availability, abundance, low cost, high reactivity, and a complex matrix where the presence of different elements can favor capture or regeneration processes.

Geothermal silica waste is a by-product of geothermal power plants where the water and steam extracted from the underground are used to generate electricity. It has been reported that approximately 50,000 tons of this type of waste are disposed of annually with no planned application (Gomez-Zamorano et al. 2016). Geothermal silica waste mainly comprises amorphous silica (>80%) with low sodium and potassium chloride. This waste could be used in construction as a silica source for alkaline silicate solutions, alkali-activated binders, geopolymers, and Portland cement replacement (Estévez-Jácome et al. 2022). Considering this wide range of potential uses, in this work, geothermal silica waste was used to prepare CO_2 sorbents, lithium silicate, and SiO_2-amine materials, and the CO_2 capture capacity, kinetic behavior and regeneration properties were evaluated.

Experimental

Silica waste was obtained from two Mexican geothermal power plants and characterized by X-ray fluorescence (XRF), X-ray diffraction (XRD), N_2 adsorption-desorption, and scanning electron microscopy (SEM). Two sorbents, alkaline silicate and SiO_2-amine materials, were prepared from geothermal silica waste. Alkaline silicate was prepared using the solid-state reaction method from silica waste and Li_2CO_3. At the same time, SiO_2-amine adsorbents were obtained by functionalizing silica waste with PEI (polyethyleneimine) and TEPA (tetraethylenepentamine) using the wet impregnation method. The CO_2 capture behavior of the two types of materials was evaluated by thermogravimetric analysis (TG) using CO_2 concentrations between 20 and 5vol% at different temperatures. Finally, the regeneration capacity was evaluated through consecutive adsorption-desorption cycles.

Results and discussion

According to the XRF results (Table 1), the main component of the geothermal silica waste is silicon (92 wt% as SiO_2), and DRX analysis confirms the silica's amorphous nature.

Table 1. Chemical composition of geothermal silica waste by X-ray fluorescence (wt%)

SiO_2	Na_2O	K_2O	CaO	Fe_2O_3	MgO	MnO	TiO_2	LOI[a]
92.088	0.98	0.208	0.529	0.069	0.055	0.024	0.047	6.00

[a] LOI: loss on ignition

The Li_4SiO_4 formation was corroborated by XRD analysis (Figure 1), and the specific surface area was less than 1 m^2/g. The CO_2 capture tests were performed at temperatures between 550 and 6500 ºC and CO_2 concentrations between 5 and 20 vol%. The CO_2 capture over time shows an exponential behavior at all temperatures and CO_2 concentrations. As the CO_2 concentration decreases, the reaction slows down, and the capture capacity also decreases. Li_4SiO_4 reached the maximum CO_2 capture of 143 $mg_{CO2}/g_{material}$ at 600 ºC and 20 vol% CO_2. Lithium silicate presents good stability over 20 cycles of adsorption-desorption.

For SiO_2-amine materials, the impregnation of PEI and TEPA molecules on the silica waste surface was corroborated by FTIR and TG analysis. The CO_2 adsorption in the SiO_2–PEI and SiO_2-TEPA materials was studied by isothermal thermogravimetric experiments. For SiO_2-amine materials, the impregnation of PEI and TEPA molecules on the silica waste surface was corroborated by FTIR and TG analysis. The CO_2 adsorption in the SiO_2–PEI and SiO_2-TEPA materials was studied by isothermal thermogravimetric experiments.

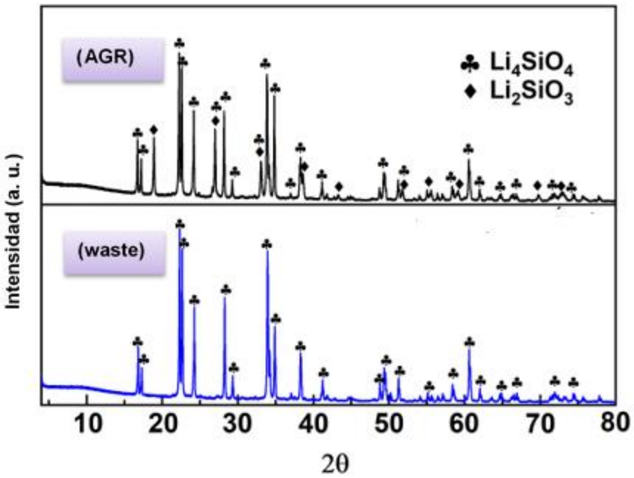

Figure 1. DRX patterns of the lithium silicates prepared with geothermal silica waste and analytical grade reagents (AGR).

The isotherms show an exponential behavior; at the beginning, the adsorption occurs very fast, and as time passes, this rate decreases. The rate of CO_2 adsorption diminishes because the active sites are occupied as the adsorption occurs. The effect of temperature on the CO_2 adsorption rate was assessed with 5 vol% of CO_2 (Figure 2). CO_2 adsorption increases as the temperature increases (30– 70 °C). Thus, the best CO_2 capture was achieved at 70 °C (28 mg_{CO2}/g_{mat}), and higher temperatures did not cause an increase in adsorption.

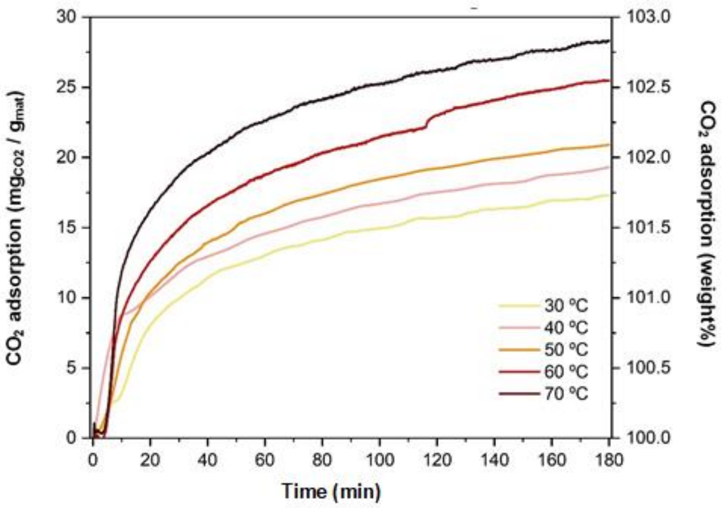

Figure 2. Temperature effect on the CO_2 adsorption capacity of the SiO_2–PEI adsorbent with 5 vol% CO_2 for 180 min.

Conclusions

Geothermal silica waste was successfully used as a precursor of two types of CO_2 adsorbents, alkaline silicates and SiO_2-amine materials, for high and low temperatures, respectively. According to the results, lithium silicate achieved a CO_2 capture capacity of 143 mgCO2/gmaterial and showed good stability over 30 cycles of sorption-desorption. The SiO_2-amine materials demonstrate good CO_2 adsorption with low CO_2 concentrations and temperatures up to 70 ºC, and regeneration was possible by increasing the temperature to 100ºC.

References

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