

Direct CO₂ capture from air using adsorbents made from geothermal residues

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Direct CO₂ capture from air (DAC) has become a key strategy to address climate change as its implementation can contribute to a decrease in the concentration of this greenhouse gas in the atmosphere, which, until November 2024, had an upward trend of 423.85 ppm (Global Monitoring Laboratory, 2024). Direct capture, unlike other methods such as post-combustion, aims to extract CO₂ directly from ambient air, so it is necessary to work at low concentrations of the gas at atmospheric conditions.

The vast majority of DAC techniques are based on sorption processes where ambient air flows over a sorbent that selectively removes carbon dioxide. Among the main characteristics that these sorbents must possess are high gas adsorption capacity, good selectivity, easy regeneration, low energy penalty, adequate adsorption and desorption kinetics, excellent chemical stability and low cost (Jiang, et al., 2023). To improve some of these characteristics such as adsorption capacity and selectivity, numerous studies propose changes in the porous and chemical structure of these surfaces by amine impregnation, while to obtain economically viable adsorbents, the use of waste as a source of these materials has been investigated.

The general objective of this research is to develop a SiO₂-amine adsorbent material from geothermal waste, efficient for direct CO₂ capture from air. The following methodology is proposed to achieve this objective (figure 1).

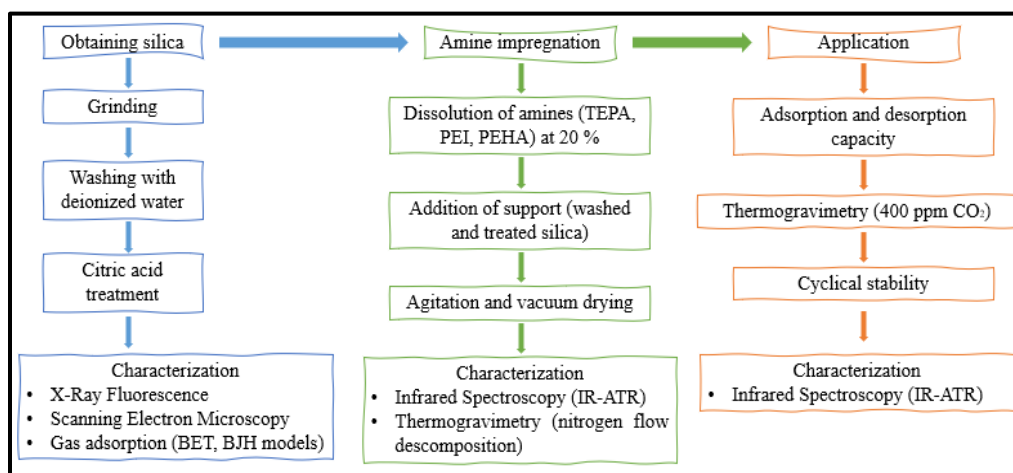


Figure 1: Flow diagram of the methodology used

The wastes used as a source of silica come from the geothermal power plants of Humeros in Puebla and Cerro Prieto in Baja California. The amines selected for impregnation are 20 wt% TEPA, PEHA and PEI according to the methodology used by (Miao, et al., 2021).

Once the silica samples have been characterised by X-ray fluorescence, scanning electron microscopy and nitrogen adsorption, as well as the impregnation of the amines with their corresponding characterisation by infrared spectroscopy and thermogravimetric analysis, the results obtained during the evaluation of the CO₂ capture capacity for each adsorbent prepared are presented. Three isothermal tests are performed at 25°C, 30°C and 35°C for a constant concentration of 0.04 %v/v CO₂.

Table 1 shows the amount of carbon dioxide captured by the adsorbents at 30 °C. It is decided to report only the results at this temperature as they present the best behaviour under the study conditions.

Table 1: Amount of CO₂ captured by the different adsorbents at 30 °C

Amines (20%)	Samples	Capture (%)	30 °C
			Capture (mmoles CO ₂ /g adsorbente)
TEPA	Lavada Cerro Prieto	1.84	0.42
	Tratada Cerro Prieto	2.87	0.65
	Lavada Humeros	1.42	0.32
	Tratada Humeros	1.12	0.26
PEI	Lavada Cerro Prieto	2.21	0.50
	Tratada Cerro Prieto	2.58	0.59
	Lavada Humeros	1.09	0.25
	Tratada Humeros	1.43	0.32
PEHA	Lavada Cerro Prieto	1.55	0.35
	Tratada Cerro Prieto	2.21	0.50
	Lavada Humeros	1.15	0.26
	Tratada Humeros	1.07	0.24

The highest adsorption is achieved on the surface of the adsorbents prepared from the Cerro Prieto plant waste as they have a higher specific area and pore volume. A larger specific area implies that there are more active sites available for the interaction between the gas and the adsorbent, while a larger pore volume allows for better gas retention. On the other hand, the highest amount of CO₂ captured is obtained in the TEPA-impregnated materials despite being the least reactive amine of the three studied, which indicates that the capture efficiency will depend mainly on other factors such as molecular size. In this case, impregnation with smaller amines (TEPA and PEHA) facilitates the diffusion of CO₂ across the surface of the material. On the contrary, for PEI amines, which have a more complex chemical structure, impregnation on the support hinders the diffusion of the gas, as they occupy a larger volume, blocking its access to the active sites.

The highest mass of CO₂ adsorbed was 2.87 % equivalent to 0.65 mmoles/g, a value obtained on the surface of Cerro Prieto silica treated with citric acid and impregnated with 20% TEPA (at 30 °C). This adsorbent is subjected to a thermogravimetric analysis to determine its stability during 10 consecutive adsorption-desorption cycles and thus to know what percentage of the material is degraded or lost with the passing of the cycles. In this case the loss was 2.24 %, which is mainly related to the decomposition of the amines with increasing temperature during desorption.

The following conclusions can be drawn from the results obtained. The geothermal wastes studied can be used as adsorbent materials due to their high silica content. The treatment with citric acid modifies the surface characteristics of the waste: it increases both the specific area and the pore volume. The materials are synthesised by the wet impregnation method, using 20 wt% TEPA, PEI and PEHA amines. Spectroscopic and thermogravimetric analyses show that the impregnation process is efficient. The maximum amount of CO₂ adsorbed was 2.87 mass % equivalent to 0.65 mmol/g, value obtained for SiO₂ (Cerro Prieto treated) + 20 % TEPA in an environment with a concentration of 0.04 %v/v and 30 °C temperature. The material with the best performance under the study conditions presents a good stability after 10 consecutive adsorption-desorption cycles with a loss of 2.24 % of the adsorbent.

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