

METHODS FOR CHARACTERIZING SORBENTS FOR DIRECT AIR CAPTURE AND POST-COMBUSTION CARBON CAPTURE

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INTRODUCTION

There is currently great interest in the development of carbon capture technology, with adsorption by porous materials being one of the main methods under serious consideration. Carbon capture involves the removal of CO₂ from a gas mixture, with the details defined by the specific carbon capture method. Direct air capture (DAC) is the removal of CO₂ from atmospheric air and therefore requires CO₂ adsorption at low concentrations, around 400 ppm, from a complex gas mixture (air) at ambient pressure. Post-combustion carbon capture, meanwhile, is the removal of CO₂ from point sources, typically fossil fuel power plants. In this case, CO₂ must be adsorbed from a flue gas, consisting mainly of N₂, with varying levels of other minor contaminants, and CO₂ at an approximate concentration of 15%. CO₂ adsorption from an 85%/15% mixture of N₂/CO₂ at ambient pressure has therefore become the standard under which sorbents for post-combustion carbon capture are typically studied.

Recent work has identified significant gaps in the data on adsorbent properties required for process modelling and design in the case of DAC¹, but there are also more general challenges associated with characterizing adsorbents for gas separations, which apply to both DAC and post-combustion carbon capture². Characterizing adsorbents for DAC is complicated by the presence of water in atmospheric air and the resultant competitive adsorption between H₂O and CO₂.

EXPERIMENTAL DETAILS

Water sorption isotherms were measured on Lewatit® VP OC 1065 Ion Exchange Resin (Sigma Aldrich) at five temperatures between 25 and 80°C using a Hidden Isochema ECOsorp. This instrument is equipped with four mass flow controllers (MFCs), two for CO₂ in different flow ranges and a wet and dry N₂ stream. A pure CO₂ adsorption isotherm was measured, under DAC conditions, using the same instrument, followed by H₂O/CO₂ co-adsorption isotherms, as a function of CO₂ partial pressure, with different pre-loaded relative humidities. Prior to each measurement, the sample was dried at 120°C under N₂ flow for 2 hours. Barometric pressure was measured throughout, to provide accurate partial pressure values for both H₂O and CO₂.



MULTICOMPONENT METHODS

Multicomponent or competitive adsorption can be measured using various techniques, including closed volumetric, open volumetric (dynamic column breakthrough), closed gravimetric, and the new Integral Mass Balance (IMB) method.^{2,3} Each approach has drawbacks, associated with the method used to determine the amount of each component adsorbed from a mixture.

As a result, for H₂O/CO₂, it is common to use gravimetric measurements in a flowing system to determine total co-adsorption under the assumption that any pre-adsorbed water remains in place following the introduction of CO₂. While there are limitations to this approach, it can provide valuable information and it is demonstrated here.

RESULTS AND DISCUSSION

Figure 1 shows the water sorption isotherms measured on the Lewatit® resin at multiple temperatures. As expected from thermodynamics, it can be seen that the quantity of water adsorbed at any partial pressure decreases significantly as a function of temperature.

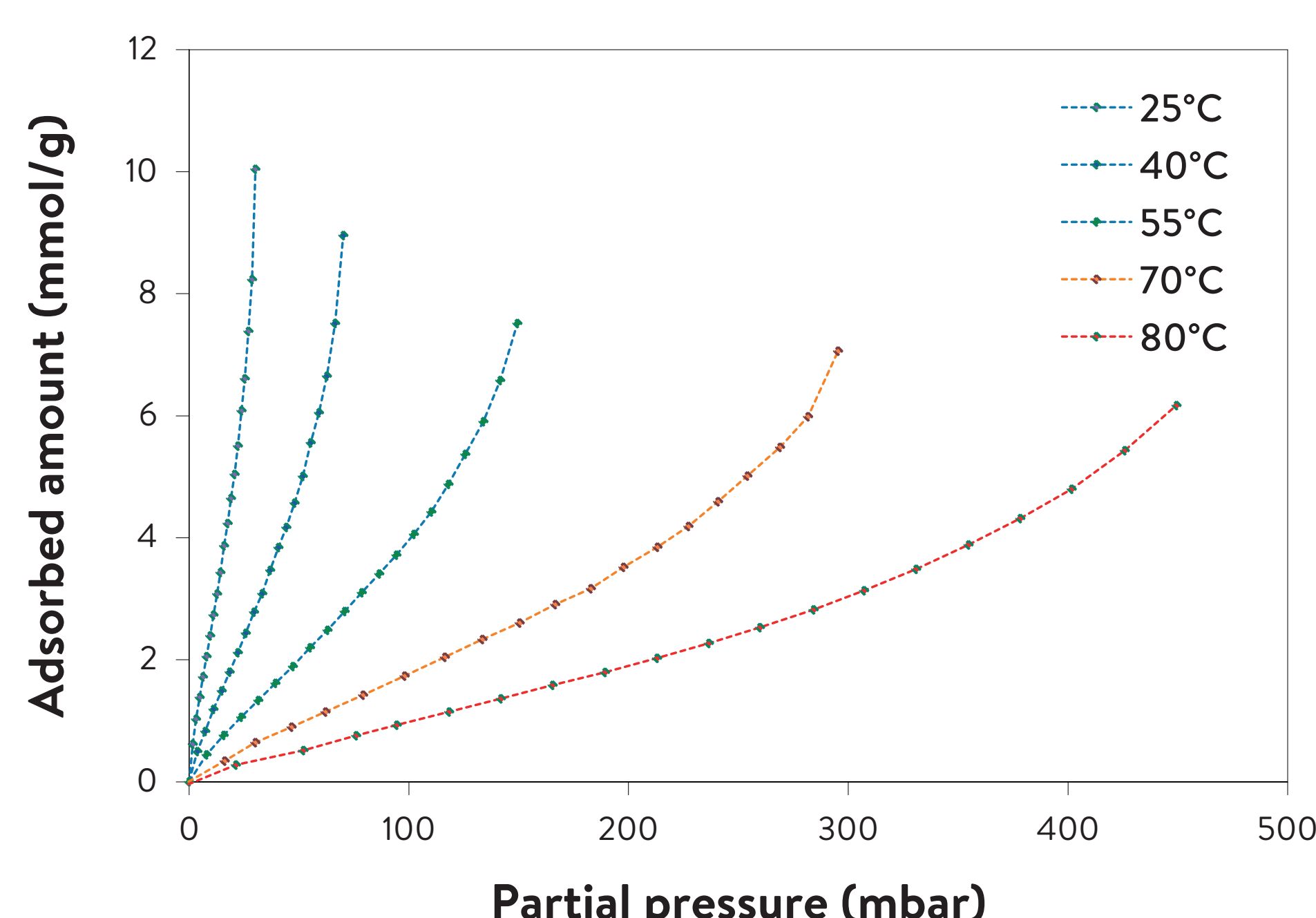


Figure 1: Water sorption isotherms for Lewatit® VP OC 1065 Ion Exchange Resin measured at five temperatures, between 25°C and 80°C, using a sample mass of 27 mg.

Figure 2 shows the pure CO₂ adsorption isotherm measured at 25°C, together with three co-adsorption isotherms for the relative humidities 5%, 10% and 15%. Total amounts adsorbed were calculated from the combined number of moles of CO₂ and H₂O, assuming the H₂O adsorbed in the pre-loading step remained in place.

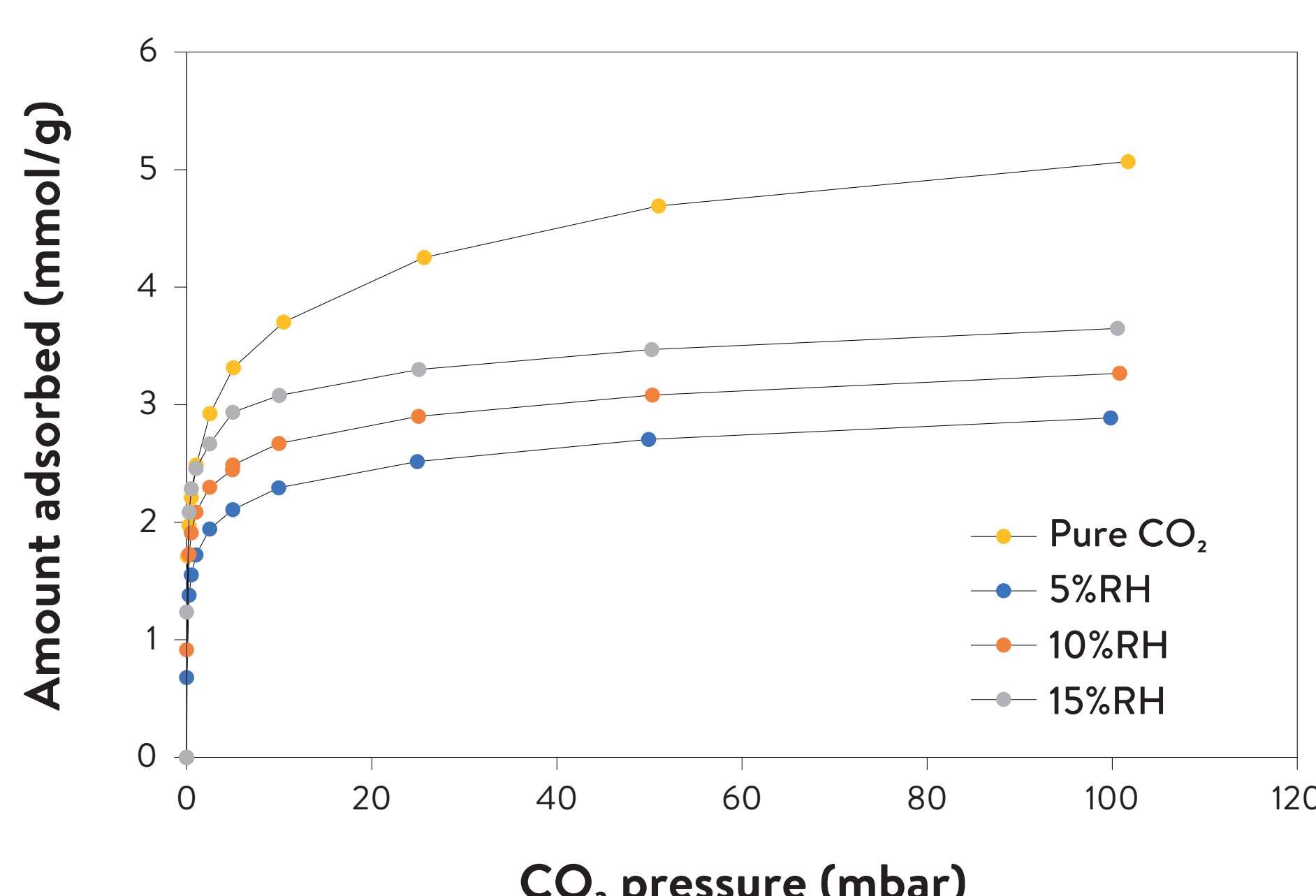


Figure 2: Low pressure CO₂ sorption and H₂O/CO₂ co-adsorption isotherms for Lewatit® VP OC 1065 Ion Exchange Resin measured at 25°C, using a sample mass of 27 mg.

Figure 3 shows an example kinetic plot, demonstrating how both H₂O and CO₂ can be introduced to the sample in an ECOsorp, and the resultant weight response, which contains important information about the adsorption properties of the material. In Figure 3, three CO₂ concentration steps are represented by the red lines, followed by three H₂O steps, represented by the blue lines. The black data points show the microbalance signal responding to each change in gas/vapor phase concentration.

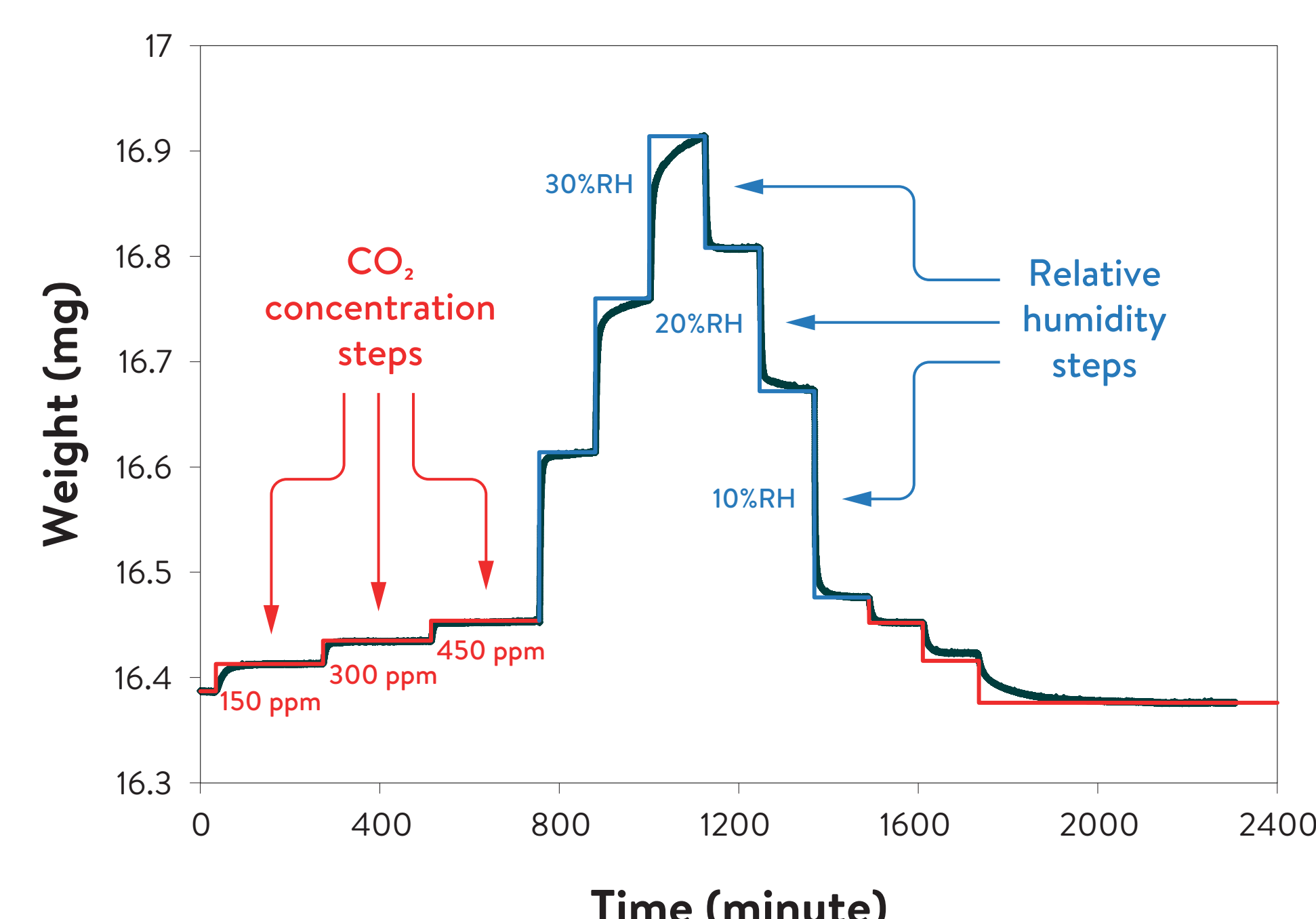


Figure 3: Kinetics of CO₂ and H₂O/CO₂ co-adsorption for Lewatit® VP OC 1065 Ion Exchange Resin measured at 60°C, using a sample mass of 16.4 mg.

SUMMARY

► H₂O/CO₂ sorption is important for assessing sorbents for carbon capture applications

► Multicomponent sorption measurements are challenging, particularly for H₂O and CO₂

► Co-adsorption of H₂O/CO₂ can be measured gravimetrically in a flowing system

► This was demonstrated using measurements on an ion exchange resin, performed in a Hidden Isochema ECOsorp

REFERENCES

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- 3 D. P. Broom, O. Talu & M. J. Benham, 2020, Industrial and Engineering Chemistry Research, 59(46), 20478-20491