CO$_2$ chemisorption and cyclability analyses in α–Li$_5$AlO$_4$: effects of Na$_2$CO$_3$ and K$_2$CO$_3$ addition

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Abstract: Lithium aluminate (α–Li$_5$AlO$_4$) was synthesized and mixed with potassium carbonate or sodium carbonate. The addition of these alkaline carbonates was produced during or after the synthesis process. The CO$_2$ chemisorption was evaluated using dynamic, isothermal, and cyclic thermogravimetric analyses. The presence of the K or Na in α–Li$_5$AlO$_4$ changes the sorption properties in a wide temperature range. K- and Na-Li$_5$AlO$_4$ samples, when the alkaline carbonates were added 10 wt% presented better CO$_2$ capture properties, capturing 37–39 wt% at 660 °C and ~50 wt% at 710 °C, for doped samples prepared mechanically or synthetically, respectively. The results revealed that the weight gained on α–Li$_5$AlO$_4$ mixed with K- or Na-carbonates was attributed to the formation of the eutectic phases. These materials would be suitable for CO$_2$ capture over a wide temperature range depending on the application process. Nevertheless, the cyclic experiments showed important variations in their respective efficiencies, depending on the temperature. © 2015 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: chemisorption; CO$_2$ capture; thermal analysis

Introduction

It is well known that human activities contribute significantly to the increase in the atmospheric concentration of carbon dioxide (CO$_2$) and other greenhouse gases (GHGs), which contributes to further global warming.[1–4] In this way, there are different alternatives such as energy efficiency improvements, substitution of low or non-carbon fuels.[2] Most efforts are focused mainly on reducing the amount of CO$_2$ emitted to the atmosphere.[4–6] The success of these issues depends on the design and development of new materials with good CO$_2$ capture properties. In general, a large sorption capacity, adequate kinetics, cyclability, stability, and a wide thermal operation range could define the ideal perfect capture material.[7] Thus, it different kinds of materials as potential CO$_2$ captors had been proposed, such as membranes,[8,9] zeolites,[10,11] activated carbons,[9,11–13] hydrotalcites,[14,15] metal–organic frameworks (MOFs),[9] amine-based adsorbents,[9,13] alkaline oxides and earth alkaline oxides,[16,17] among others. However, CO$_2$ capture capacity in these materials is not good enough, and several of these materials cannot be regenerated.

Among alkaline ceramics, Nakagawa and Ohashi[18] showed that lithium metazirconate (Li$_2$ZrO$_3$) was able

to trap CO_2 at high temperatures (400 °C–600 °C), presenting a great advantage because the combustion gas flow does not have to be cooled, and that CO_2 can be removed thermally or chemically regenerating the lithium ceramic. Since then, other lithium and sodium ceramics have been tested as CO_2 captors.[16–50] However, the ceramics most extensively studied are the lithium zirconates,[18,21–29] the lithium silicates[20,28,30–40] and the sodium zirconate.[26,27] Other lithium ceramics tested as possible CO_2 captors are lithium cuprate,[41,42] lithium ferrite,[43,44] lithium titanate,[45,46] and lithium aluminates ($LiAlO_2$ and Li_5AlO_4).[47,48]

Li_5AlO_4 seems to be able to trap CO_2 chemically, in the temperature range from 200 to 700 °C.[47] Li_5AlO_4 has two polymorphs, at low and high temperatures, α–Li_5AlO_4 and β–Li_5AlO_4, and the $\alpha \rightarrow \beta$ structural transition occurs at around 780 °C. Although, Li_5AlO_4 has a CO_2 theoretical chemisorption of 15.9 mmol/g, experimentally it has been reported chemisorptions of 15.3 and 12.1 mmol/g for the β–Li_5AlO_4 and α–Li_5AlO_4 phases, respectively.[48] Furthermore, when Li_5AlO_4 reacts with CO_2, $LiAlO_2$ is produced. This secondary phase does not react with CO_2 due to thermodynamic factors. However, when $LiAlO_2$ is contained in the external shell, it promotes the lithium diffusion into the Li_2CO_3-$LiAlO_2$ external shell at temperatures higher than 600 °C.[51]

Some of the lithium ceramics, previously mentioned, have been doped adding different carbonates such as K_2CO_3, Na_2CO_3,[2,52] $MgCO_3$ and $CaCO_3$.[52] The addition of these carbonates favors the formation of eutectic phases on the carbonate external shell, improving the CO_2 chemisorption kinetics and efficiencies, compared with their respective alkali pure ceramics.[2,19,21,27,45–55] Thus, the aim of the present work was to produce K- or Na-doped Li_5AlO_4 samples, as these mixtures would improve the CO_2 chemisorption rates due to the Li_2CO_3-K_2CO_3 or Li_2CO_3-Na_2CO_3 eutectic phase formations, resulting in a partial molten shell that facilitates the CO_2 diffusion throughout the external shell.

Experimental

The α-Li_5AlO_4 phase was synthesized using a solid-state reaction that employs lithium oxide (Li_2O, Aldrich, St. Louis, MO, USA) and gamma alumina (γ-Al_2O_3). Powders were mechanically mixed, pressed into pellets (2.5 tons/cm^2) and heated under different thermal conditions. The α-Li_5AlO_4 pellets were heated

to 500 °C for 24 h and slowly cooled down to room temperature. After the thermal treatment the α–Li_5AlO_4 pellets were pulverized.[48] To obtain pure α–Li_5AlO_4, 30 mol% excess of lithium was used, as lithium tends to sublimate.[56] The formation of α–Li_5AlO_4 phase was confirmed by powder X-ray diffraction (XRD, data not shown). However, very small peaks corresponding to lithium carbonate were found in the α-Li_5AlO_4 sample. After the α–Li_5AlO_4 synthesis, powder was mechanically mixed with 10 wt% of potassium (K_2CO_3, Aldrich) or sodium (Na_2CO_3, Aldrich, St. Louis, MO, USA). These samples were labeled as m-K-α-Li_5AlO_4 and m-Na-α-Li_5AlO_4. Additionally, Na- and K-doped α–Li_5AlO_4 samples were synthesized by a solid-state reaction, adding 10 wt% of potassium or sodium carbonates during the synthesis process mentioned above. In these cases, the samples were labeled with an initial s- instead of m-. Again, the XRD patterns fitted to the α–Li_5AlO_4 phase (data not shown).

After the synthesis and structural characterization all the samples were analyzed by N_2 adsorption-desorption analysis and different thermal analyses. N_2 isotherms were performed using a Minisorp II instrument (BEL-Japan, Osaka, Japan) at 77 K. Samples were previously degassed at room temperature for 24 h in a vacuum. The BET model was used to determine the sample's surface area.[57–59]

Different thermal analyses were performed using TGA and DSC equipments. The thermobalance used was a Q500HR instrument, from TA Instruments. Initially, a set of samples was dynamically heated from room temperature to 900 °C at 5 °C/min, using a saturated CO_2 flow (60 mL/min, Praxair, grade 3.0). Subsequently, the samples were tested isothermically at different temperatures (from 400 to 700 °C) in presence of the same CO_2 flow. For the isothermal experiments, each sample was heated to the corresponding temperature into a N_2 flux (Praxair, grade 4.8). Then, once the temperature was reached, the gas was switched from N_2 to CO_2. Regenerability tests were conducted under the uptake conditions in a CO_2 atmosphere (700 °C for 20 min, 60 mL/min) and the desorption conditions in a N_2 atmosphere (750 °C for 20 min, 60 mL/min).

Differential scanning calorimetry (DSC) experiments were performed using a DSC equipment from Instruments Specialists Incorporated (Twin Lakes, WI, USA). Different Li-K and Li-Na carbonate mixtures were heated from room temperature to 600 °C at 20 °C/min, into a N_2 atmosphere. Then, the mixture

were cooled down to 200 °C and reheated from 200 °C to 600 °C at the same rate, in order to elucidate the fusion temperature of each eutectic mixture.

Results and discussion

CO_2 capture preliminary experiments were performed by adding different quantities of potassium or sodium carbonates (3, 10 or 20 wt%). The addition was produced during or after the α–Li$_5$AlO$_4$ synthesis processes. Then, theses samples were analyzed thermogravimetrically in the presence of a CO_2 flux (data not shown). The dynamic thermograms showed that the best conditions were presented when 10 wt% of the corresponding carbonate was added, in the temperature range of 400 to 700 °C. Based in these results, only the Na- and K-doped α–Li$_5$AlO$_4$ results are presented here.

The surface area of the pristine α–Li$_5$AlO$_4$ sample was determined using the BET model. The obtained value was 0.8 m²/g. Furthermore, in the K- and Na-doped lithium aluminates synthesized cases, the surface areas were 0.8 and 0.6 m²/g, respectively. As it can be seen, the surface area of the ceramic tended to decrease by the K and Na addition. It must be mentioned that, in any case, the surface area is considerably low (>1 m²/g), so it should not influence the CO_2 capture.

After the textural characterization, the CO_2 capture was evaluated in all these samples. It has been reported that Li$_5$AlO$_4$ chemisorbs CO_2 according to the following reaction, which is independent of the Li$_5$AlO$_4$ crystalline phase:

$$Li_5AlO_{4(s)} + 2CO_{2(g)} \rightarrow 2Li_2CO_{3(s)} + LiAlO_{2(s)} \qquad (1)$$

Initially the CO_2 chemisorption capacities of both Na- and K-doped α-Li$_5$AlO$_4$ samples (prepared mechanically or synthetically) were analyzed in the presence of a CO_2 flux. Figure 1 shows the dynamic thermograms of these samples and their comparison with the pristine α-Li$_5$AlO$_4$. In the pure α–Li$_5$AlO$_4$ case, the dynamic thermogram clearly shows two different processes. First, between 180 and 407 °C, there is an initial weight increment of 8.5 wt%, which corresponds to the superficial CO_2 chemisorption process. Then, at higher temperatures (510−798 °C) occurred the second processes, where the weight increment was equal to 39.8 wt% and it corresponds to CO_2 chemisorption process through the ceramic bulk, which is produced once different diffusion
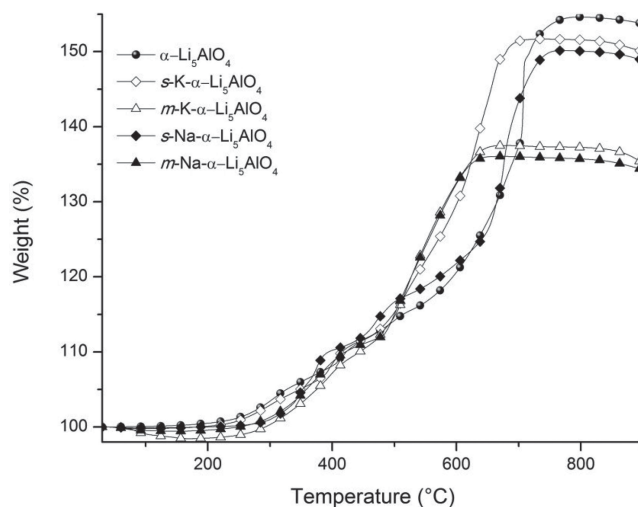

Figure 1. Comparative dynamic thermogravimetric analyses of Na- and K-containing α-Li$_5$AlO$_4$ samples with pure α-Li$_5$AlO$_4$ sample into a CO_2 flux.

processes are thermally activated. So, the total weight increase was 54.6 wt%. Similar thermal trends have already been observed for other lithium ceramics.[40,41,45,47,49,60,61]

Then, all the Na- and K-doped α–Li$_5$AlO$_4$ samples lost some weight between 30 and 200 °C, which can be associated to dehydration and dehydroxylation processes, induced by the sodium or potassium carbonates presence. However, in the s-K-α-Li$_5$AlO$_4$ and s-Na-α-Li$_5$AlO$_4$ samples, the weight loss is almost imperceptible, while it is more pronounced in the sample where the K and Na were added mechanically. It should be simply explained as a consequence of the K and Na surface availabilities, as in the synthesis cases these two elements may be located into the Li$_5$AlO$_4$ material.

After the dehydroxylation process, doped samples presented similar CO_2 chemisorption trends with slight temperature variations. Initially, there were superficial CO_2 chemisorption reactions, which were continued at higher temperatures once the diffusion processes were thermally induced. Nevertheless, most of the doped samples presented slight increases at moderate temperatures (380−425 °C, between the superficial and bulk CO_2 chemisorptions). All the temperature variations and the third weight increase at moderate temperatures must be associated to the K- or Na-doping processes. In addition, something else must be pointed out. While the s-Li$_5$AlO$_4$ samples presented similar final weight increments than Li$_5$AlO$_4$ (~50 wt%), the m-Li$_5$AlO$_4$ samples did not
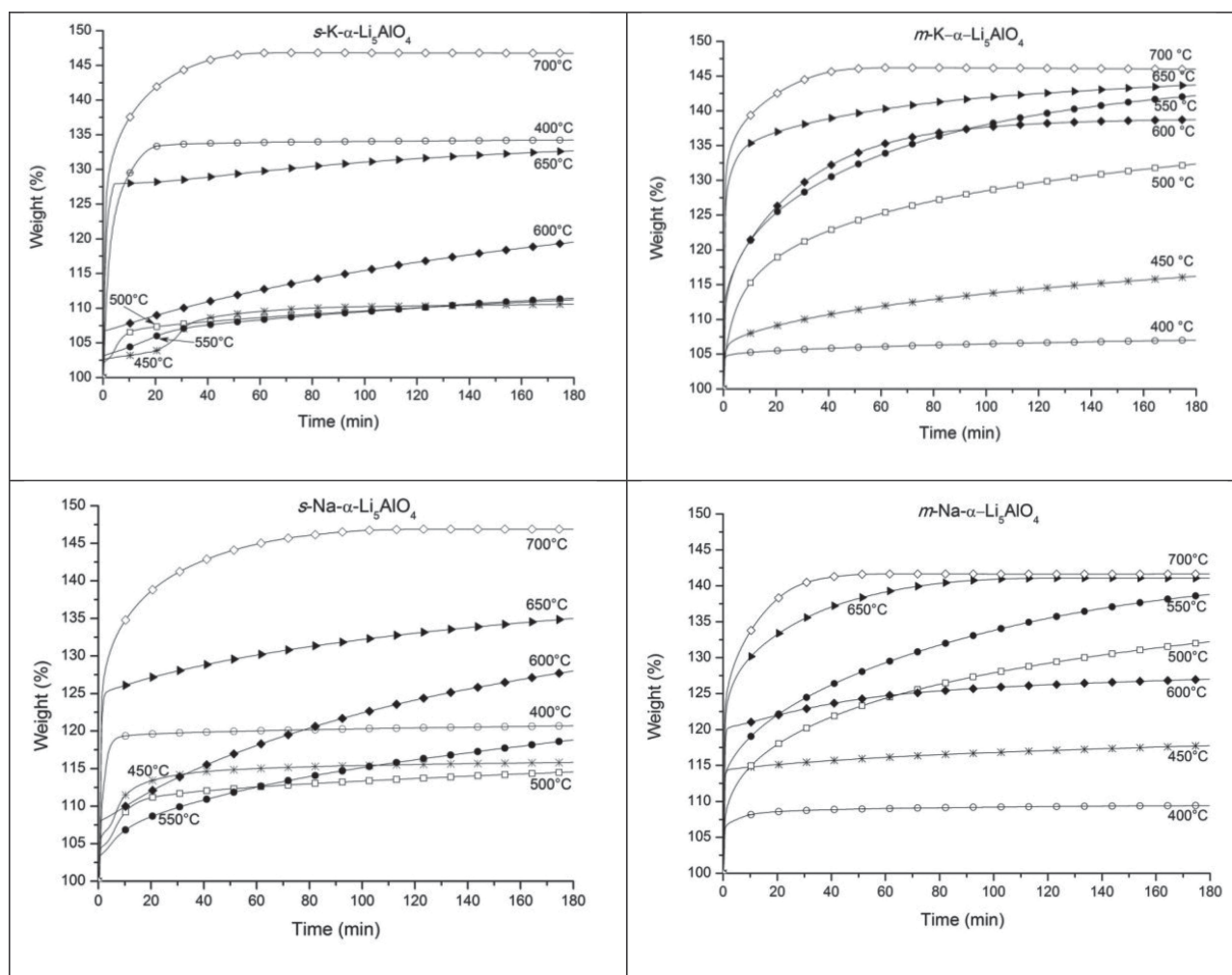
Figure 2. CO_2 isotherms of s-K-α-Li_5AlO_4, m-K-α-Li_5AlO_4, s-Na-α-Li_5AlO_4 and m-Na-α-Li_5AlO_4 samples at different temperatures.

reach those weight increments. In those samples, the final weight increased only around 37–39 wt%. It seems that K_2CO_3 and Na_2CO_3, at the Li_5AlO_4 surface, reduce the CO_2 chemisorption at high temperatures.

To further analyze and understand the K- and Na-doping effects, mechanically or synthesized, in α-Li_5AlO_4, different and independent kinetic experiments were performed. Figure 2 shows the CO_2 isotherms at different temperatures. s-K-α-Li_5AlO_4 thermally treated at 400 °C showed an exponential weight increase of 34.2 wt%. In this case, the isotherm reached equilibrium after 30 min. However, a totally different behavior was observed t higher temperatures. At 450 °C, s-K-α-Li_5AlO_4 seemed to stay non-reactive during the first 20 minutes, and only after that time, the isotherm showed a slight weight increment of 10.6

wt% after 180 min, without reaching equilibrium. Similar but shorter lag-periods were observed at 500 and 550 °C. At these temperatures, the final weight increases were 11.2 and 11.5 wt%, respectively. A similar isothermal behavior had been already reported on the K-doped Li_8SiO_6 in the same temperature range.[55] In that case, the explanation given to the isotherms was as follows. At low temperatures, the CO_2 chemisorption must be mainly limited to the lithium ceramic surface (Li_5AlO_4 in the present case), as the diffusion processes have not been activated. Then, between 400 and 550 °C, the Li_2CO_3 and K_2CO_3 surface (products of the CO_2 chemisorption) must produce eutectic phases which fusing partially. This liquid phase in addition to the possible presence of mesoporous in the external shell microstructure, as it has been seen for other lithium ceramics in a

similar temperature range,[62] may modify the CO_2 diffusion. At temperatures higher than 550 °C, these isotherms (600, 650, and 700 °C) presented a fast weight increment in the first minutes, which may be associated to the activation of diffusion processes enhanced by the eutectic phase formation.

Conversely, if the potassium was added mechanically, after the Li_5AlO_4 synthesis, the isotherms presented a different thermal trend. Between 400 and 550 °C all the isotherms presented exponential growths, which increased as a function of temperature from 7 to 42.2 wt%. Here, it was not evidenced the double increment weight observed on the previous samples. Latter, the isotherm preformed at 600 °C slightly decreased the final weight increment (38.7 wt%), although the kinetic behavior shows to be faster than that produced at 550 °C. The decrement observed at this temperature may be related to a sintering ceramic process.[47] Finally, the weight increases at higher temperatures increased to 43.7 and 46.0 wt%, at 650 and 700 °C, respectively.

Identical experiments were performed for the Na-doped Li_5AlO_4. The results produced were very similar to those previously described for the K-doped samples. On the contrary, samples, in which sodium or potassium were added mechanically as carbonates, seem to diminish the CO_2 as in the K systems. Figure 3 summarizes the maximum weight increase obtained in the isotherms.
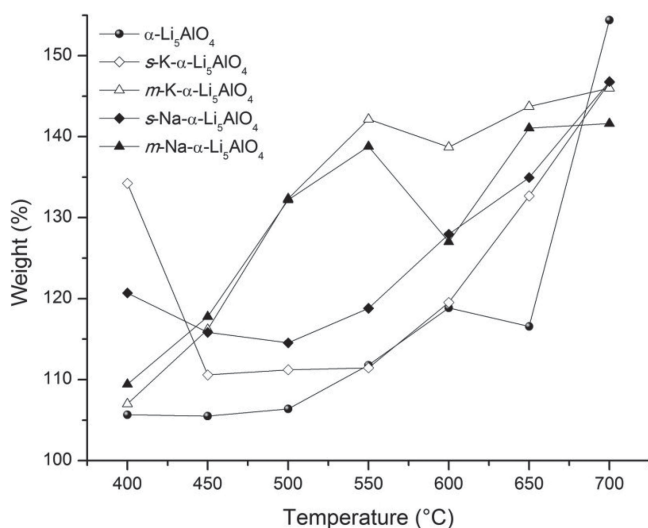
After the qualitative analysis, the resulted curves were fitted to different kinetic models, as previously reported for the other alkaline ceramics.[20,61,62] In general, for this kind alkaline ceramics, isotherms have been fitted to a double o triple exponential models. But, it was not the case for the Na- and K-doped α–Li_5AlO_4 samples. Thus, the kinetic data had to be analyzed by a different kind of approximation,[40,60,61] a first-order reaction model with respect to Li_5AlO_4 (Eqn (2)),

$$ln[\,Li_5AlO_4\,] = -kt \qquad (2)$$

Where k is the reaction rate constant, t is the time, and $[Li_5AlO_4]$ is the molar concentration of the ceramic. $ln[Li_5AlO_4]$ *versus* time were plotted in order to fit to the first-order reaction model and obtain k values (data not shown). The data only followed a straight line at short times, before the external shell was completed. The corresponding k values *versus* temperature are plotted in Fig. 4 for all Na- and K-containing α-Li_5AlO_4 samples.

Once the external shell was completed, diverse diffusion processes must be activated. Thus, it was necessary to employ a diffusion model.[60] If the reaction is controlled by the interface movement from the surface inwards it can be described as:
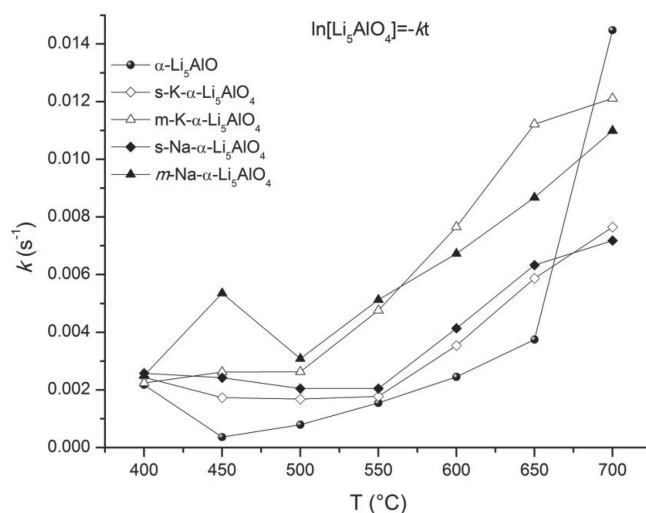
$$1-(1-\alpha)^{1/3} = k_D t \qquad (3)$$

Figure 3. Comparison of maximum weight increment obtained at isotherm analysis of Na- and K-containing α-Li_5AlO_4 samples with the α-Li_5AlO_4.pure sample.

Figure 4. Comparison of plots of k *versus* Temperature, for the data obtained at kinetic analysis of Na- and K-containing α-Li_5AlO_4 samples and the α-Li_5AlO_4 pure sample, assuming a first-order reaction of α-Li_5AlO_4 for short times.
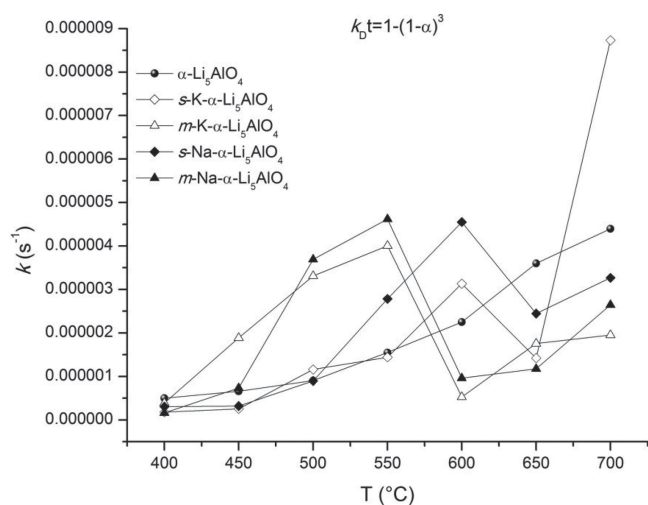
Figure 5. Comparison of plots of k *versus* Temperature, for the data obtained at kinetic analysis of Na- and K-containing α-Li₅AlO₄ samples and the α-Li₅AlO₄ pure sample, assuming a diffusion mechanism controlled by the interface movement from the surface inward for long times.

where α is the molar fraction of Li_2CO_3 produced (Eqn (1)), t is time and k_D is a constant which depends on the diffusion coefficient, particle size, and temperature. Assuming a diffusion mechanism controlled by the interface movement from the surface inwards $(1-(1-\alpha)^{1/3})$ *versus* time were plotted in order to obtain k_D values (data not shown). The data only followed a straight line at long times, when the diffusion behavior has started. The corresponding k_D values *versus* temperature are plotted in Fig. 5 for all Na- and K-containing α-Li₅AlO₄ samples. Eyring's model (Eqn (4)), is typically used on heterogeneous reactions and solid–gas system to describe this kind of temperature dependence diffusion processes, then k and k_D were to Eyring's model.

$$\ln(k_i/T) = -(\Delta H^{\ddagger}/R)(1/T) + \ln E + \Delta S^{\ddagger}/R \qquad (4)$$

where k_i is the rate constant value of the process i; E is the pre-exponential factor, which in Eyring's formulation is equal to the ratio between the Boltzmann and Planck constants; R ideal gas constant; and $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ are the activation is the enthalpy and entropy, respectively. Data demonstrate that $\ln(k_i/T)$ versus $1/T$ plots cannot be described by a linear trend when using Eyring's model (data not shown). Thus, by means of fit the data obtained to a linear model, the activation enthalpies $(\Delta H^{\ddagger})$ were calculated for both different processes (Tables 1 and 2), for at least two temperature ranges. $\Delta H^{\ddagger}$ values for CO_2 direct

Table 1. The activation enthalpies ($\Delta H^{\ddagger}$) for the CO₂ direct chemisorption in the temperature range from 500 to 700 °C.

Sample	$\Delta H^{\ddagger}$ (kJ/mol)
α–Li₅AlO₄	75.324
m-K-α–Li₅AlO₄	42.440
m-Na-α–Li₅AlO₄	31.451
s-K-α–Li₅AlO₄	45.323
s-Na-α–Li₅AlO₄	38.131

chemisorption are lower in K- and Na-containing samples compared to the α-Li₅AlO₄ pure sample. However, these values are higher for the kinetically controlled chemisorption processes. It means that the direct chemisorptions process is less dependent of temperature for doped samples than without doping. In the kinetically controlled chemisorption case it could be observed the opposite behavior. This implies that the direct chemisorption process is more temperature dependent than the chemisorption process kinetically controlled by diffusion processes.

It is also possible to observe that in CO_2 direct chemisorption processes, K_2CO_3-doped samples have less temperature dependence than the Na_2CO_3-containing samples. In contrast, the chemisorption controlled by diffusion processes, Na_2CO_3-doped samples present higher temperature dependence than that of K_2CO_3 -containing samples.

Based on the obtained results and previous papers,[51] it is proposed the following explanation: At temperatures lower than 500 °C the direct chemisorption is limited by the surface of the ceramic, due to the formation of external shell containing an $LiAlO_2$ secondary phase and Li_2CO_3, product of direct reaction between the CO_2 and Li_5AlO_4 (Eqn (1)).[51] At around 500 °C it should appear the molten points caused by the eutectic phases of potassium or sodium

Table 2. The activation enthalpies ($\Delta H^{\ddagger}$) for diffusion mechanism controlled by the interface movement from the surface inward in the temperature range from 400 to 550 °C.

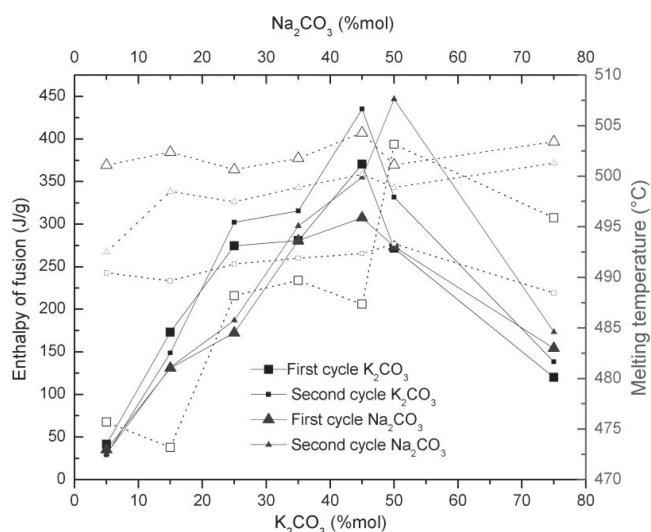| Sample	$\Delta H^{\ddagger}$ (kJ/mol)
α–Li₅AlO₄	27.676
m-K-α–Li₅AlO₄	65.193
m-Na-α–Li₅AlO₄	102.939
s-K-α–Li₅AlO₄	65.447
s-Na-α–Li₅AlO₄	62.965

Figure 6. Comparison of temperatures (dotted lines) and enthalpies of fusion (solid lines) of different Li-K (squares) and Li-Na (triangles) carbonate mixtures. They were heated from room temperature to 600 °C at the rate of 20 °C/min, into a N₂ atmosphere. Then, the mixtures were cooled down to 200°C and again heated from 200°C to 600 °C at the rate of 20 °C/min.

carbonate added before exposure to CO_2 with lithium carbonate produced. At this temperature range the partial molten generated by eutectic phases should promote diffusion processes. Then, at temperatures higher 500 °C CO_2 chemisorption is controlled by the interphase diffusion mechanism from the surface inwards. Finally, the chemisorption process kinetically controlled by diffusion processes is completely activated at 700 °C.

In order to understand the formation of the partial molten phases due to the presence of Li-Na or Li-K carbonate eutectic phases, different DSC experiments were performed. Initially, the samples were heated from room temperature to 600 °C, and then cooled down to 200 °C. After that, the samples were reheated to 600 °C. Figure 6 shows the different temperatures and enthalpies of fusion for different the mixtures of Li_2CO_3-K_2CO_3 and Li_2CO_3-Na_2CO_3. From these data, it is clear that both systems melt at around 500 °C, so it may be possible to find partial molten phases in the ceramics.

Finally, to test the regeneration properties and the thermal stability after several cycles of CO_2 chemisorption/desorption in Na- and K-containing α–Li₅AlO₄ samples, the samples were analyzed using a multicycle method (data not shown). The result for the s-K-α–Li₅AlO₄ sample indicates that the CO_2

chemisorption capacity reaches approximately 37.7 wt% for the first cycle, for the second cycle, the CO_2 chemisorption capacity decreases to 9.8 wt% and after 20 cycles, it is observed 17.1 wt%. For the m-K-α–Li₅AlO₄ sample, the CO_2 chemisorption in the first cycle was 45.9 wt%, but for the second cycle, its capacity decreased dramatically to only 12.5 wt% and after 20 cycles it was stabilized in 18.2 wt%. The result, for the s-Na-α–Li₅AlO₄ sample, shows that the CO_2 chemisorption capacity reaches around 43.6 wt% for the first cycle, but its capacity was stabilized in 19.9 wt% after 20 cycles. For the m-Na-α–Li₅AlO₄ sample, the CO_2 chemisorption in the first cycle was 39.4 wt%, but for the second cycle the CO_2 chemisorption capacity decreases to 11.6 wt%, and after 20 cycles, its capacity is 15.5 wt%.

Making a comparison of the regeneration behavior during each cycle of chemisorption/desorption of CO_2, it is observed that α–Li₅AlO₄ pure sample presented a CO_2 chemisorption capacity of 9.4 mmol/g, similar capacity Na- and K-containing α-Li₅AlO₄ samples, and 4.4 mmol/g for the second cycle, much higher than that obtained for the Na- and K-doped samples. However, from the second cycle the CO_2 chemisorption capacity begins to increase gradually for the Na- and K-containing samples, so when the last cycle is analyzed, the obtained values are similar than those observed by the pure sample (3.6–3.9 mmol/g). The different tendencies observed may be related to the different eutectic phases produced, which increase the diffusion processes enhancing the CO_2 chemisorption, but these eutectic phases must decrease the carbonate decomposition processes, enabling the cyclability.

Conclusions

Na- and K-doped α–Li₅AlO₄ samples were synthesized using a solid-state reaction and then characterized by XRD and N₂ adsorption. At the same time, pure α–Li₅AlO₄ was mixed mechanically with potassium or sodium carbonates. During the dynamic thermal analyses, the different α–Li₅AlO₄ samples showed similar trends, exhibiting higher CO_2 chemisorptions than that of α–Li₅AlO₄, at specific temperatures each. Thus, the possible application of each sample may depend on temperature. Isotherms were fitted to the first-order surface chemisorption and diffusional mechanism controlled by the movement of an interface moving from the surface inward. The kinetic constant values were fitted to Eyring's model.

$\Delta H^{\ddagger}$ values obtained showed that the CO_2 direct chemisorption process is more dependent of temperature for α–Li₅AlO₄ pure sample than for Na- and K-doped α-Li₅AlO₄ samples. On the contrary, in the kinetically controlled chemisorption processes the opposite behavior was observed.

Finally, the cyclic analysis showed that Na- and K-doped α–Li₅AlO₄ samples exhibit a dramatic decrease, after one cycle. Then, the CO_2 chemisorption tended to increase gradually, until stability was reached after ten cycles. It is evident that the CO_2 chemisorption capacities in the doped samples are more stable than α–Li₅AlO₄ after 20 cycles. Thus, these materials might be good considered as possible candidates for multicycle CO_2 chemisorption processes.

## Acknowledgments

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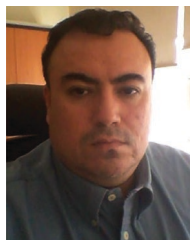
Heriberto Pfeiffer

Heriberto Pfeiffer works on different sorption processes and heterogeneous catalysis. His research is mainly focused on CO$_2$ capture and its catalytic conversion to added value products. At the same time, Heriberto works on the CO oxidation-chemisorption process, as a possible syngas (CO+H2) separation mechanism. Additionally, Heriberto works in the biodiesel production and have some experience with different thermal, volumetric and gravimetric, techniques.