



Synthesis and CO₂ adsorption properties of hydrotalcite-like compounds prepared from aluminum saline slag wastes



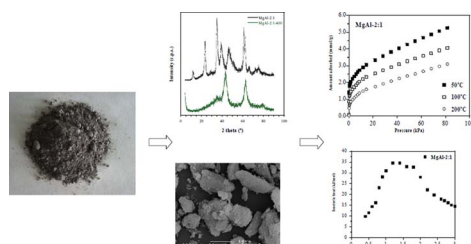
A. Gil^{a,b,*}, E. Arrieta^a, M.A. Vicente^c, S.A. Korili^{a,b}

^a Departamento de Química Aplicada, Edificio de Los Acebos, Universidad Pública de Navarra, Campus de Arrosadía E-31006 Pamplona, Spain

^b Instituto de Materiales Avanzados-INAMAT, Universidad Pública de Navarra, Campus de Arrosadía, 31006 Pamplona, Spain

^c GIR-QUESCAT, Departamento de Química Inorgánica, Universidad de Salamanca, E-37008 Salamanca, Spain

GRAPHICAL ABSTRACT



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ABSTRACT

This study describes the synthesis of hydrotalcite-like materials by the co-precipitation method using aluminum extracted from saline slags wastes. Saline slags were chemically treated with 2 mol/dm³ aqueous solutions of NaOH for 2 h using a reflux system. The aluminum aqueous solutions were used as precursors with cobalt, magnesium and nickel nitrates, and Na₂CO₃, to obtain hydrotalcite-like materials with two mole M²⁺/Al³⁺ ratios, 2:1 and 4:1. The resulting solids were characterized by X-ray diffraction, thermogravimetric analyses, nitrogen adsorption at –196 °C and scanning electron microscopy. After thermal treatment at 200 °C, the CO₂ adsorption at 50, 100 and 200 °C was evaluated under dry conditions. The results showed a remarkable sorption capacity of 5.26 mmol/g at a pressure of 80 kPa and at a temperature of 50 °C for the MgAl-2:1 sample, with sorption capacities considerably higher than those reported in the literature for hydrotalcites under similar conditions. The Henry's law constants were obtained directly from the adsorption isotherms at low pressures and the values found are between 0.01 and 4.20 mmol/kPa·g. The isosteric heats of CO₂ adsorption found, using the Clausius-Clapeyron equation, were in the range of 5.2 to 16.8 kJ/mol.

1. Introduction

Aluminum saline slags are hazardous materials generated during secondary aluminum melting processes. In these processes, NaCl and KCl are used to cover the aluminum melt scrap or dross to reduce the melting temperature; protect the aluminum against oxidation; dissolve, absorb, and allow the metal oxides and other impurities to easily be

separated from the metallic aluminum [1]. Considering the composition of the saline slags generated, the fraction known as *non-metallic products*, NMP, is the most important, with a content of various oxides between 20 and 50 wt% [2]. Metallic aluminum, flux brines and other components in smaller proportions are also present.

Saline slags are managed by separation of their components for possible recovery or by storage in controlled landfills [3]. In a first step,

* Corresponding author at: Departamento de Química Aplicada, Edificio de Los Acebos, Universidad Pública de Navarra, Campus de Arrosadía E-31006 Pamplona, Spain.
E-mail address: andoni@unavarra.es (A. Gil).

the aluminum metal is separated from the material by crushing and screening. The waste is treated with water to separate the soluble and insoluble fractions, generating a new solid waste containing less salt and a saline solution containing the salts to be recovered. The composition of this new solid waste varies and depends on the nature of the materials used for the recycling treatment. The applications are limited due to the heterogeneous composition, reason by which the waste is sent for landfill. As such, controlled landfill storage has been reported as the best alternative to saline slag management once the aluminum metal fraction has been separated. The fact that aluminum saline slags are a mixture of oxides means that these materials can be used for direct applications such as inert filling for construction, road paving, mortar components, aluminum salts, inert filler in polymer composites, adsorbents, mineral wool, etc [3]. Aluminum can also be recovered as a high-value-added product and used to synthesize materials such as pure alumina, salts and hydroxides [3]. The synthesis of MgAl-, CaAl-, and ZnAl-type layered double hydroxides was carried out using aluminum dross leachates dissolved with HCl and NaOH solutions followed by co-precipitation [4]. These materials were used as anion exchangers for inorganic ions such as Cr, B, As and Se, and organic compounds such as terephthalates and dodecyl sulfates. In two recent works [5,6], MgAl hydrotalcites were also prepared from an aluminum hazardous waste by co-precipitation at a pH of 10 and the assistance of basic modifiers as ammonia and triethanolamine. The authors suggested the application of these materials as anticorrosive coatings.

Hydrotalcite-like compounds have attracted much attention as catalysts, catalyst supports, or catalyst precursors [7,8]. These solids consist of layered double hydroxides of lamellar structure with a general formula $[M_{1-x}^{2+}M_x^{3+}(\text{OH})_2][A^{m-}]_{x/m}n\text{H}_2\text{O}$, that can be visualized as brucite-type octahedral layers, where M^{3+} partially substitute for M^{2+} cations. The resulting positive charge is balanced by anions, often carbonate, playing an important role when ion exchange is considered as the main process. Thermal treatment of these materials at temperatures above 500 °C yields mixed oxides with interesting properties as high specific surface areas, high dispersion of the elements, and the possible reconstruction of the original hydrotalcite structure when the thermal treated material contact with aqueous solutions or gaseous streams containing anions (memory effect) [9,10]. The last characteristics of the materials increase the number of possible applications as adsorbents, flame retardants and anticorrosives [11–13]. In this regard, hydrotalcite-related materials have been reported in the literature for CO₂ adsorption, mainly for the temperature range between 200 and 500 °C [14–16].

In the present study, aluminum extracted using NaOH aqueous solutions from saline slags generated during aluminum recycling processes was used as alternative aluminum source for the synthesis of hydrotalcites by a modified co-precipitation method. The aluminum solutions were employed as precursors combined with cobalt, magnesium and nickel nitrates, and Na₂CO₃, in order to obtain CoAl-, MgAl- and NiAl-hydrotalcite-like compounds with a variable mole ratio. The mole ratios have been selected considering that x from the general formula of the hydrotalcite-like compounds is generally between 0.2 and 0.4. An important novelty in this work is that the precipitating agent is already included in the dissolution of Al³⁺. The remaining reagents needed to synthesize the hydrotalcites are added to this aqueous solution. The objectives of the study also included assessing the capacity adsorption of CO₂ in the interval temperature range from 50 to 200 °C and pressures up to 80 kPa, and the estimation of the isosteric heat of adsorption applying the Clausius-Clapeyron equation in the low-pressure region.

2. Experimental procedure

2.1. Materials

Reagents used for the synthesis of the hydrotalcites were: Co

(NO₃)₂·6H₂O (Panreac, PA), Mg(NO₃)₂·6H₂O (Sigma-Aldrich), Ni (NO₃)₂·6H₂O (Panreac, PA) and Na₂CO₃ (99%, Sigma-Aldrich). Sodium hydroxide (Panreac) was used in the aluminum extraction process from the aluminum saline slags. Carbon dioxide (Praxair, 99.990%), nitrogen (Praxair, 99.999%) and helium (Air Liquide, 99.998%) were also used.

2.2. Hydrotalcite-like materials synthesis

The material used in the present study was a saline slag previously treated with hot water in order to separate the soluble salts. This material was used for aluminum chemical extraction, which was carried out using aqueous solutions 2 mol/dm³ of NaOH for 2 h using a reflux system. The conditions and reagents have been studied in a previous work of our research group [17]. In this treatment, 10 g of saline slag was added to 100 cm³ of aqueous reagent solution and the resulting suspension stirred at a speed of 500 r.p.m. The slurries were separated by filtration and the extracted aluminum, determined by ICP-OES, was about 7 g_{Al}/dm³.

The CoAl, MgAl and NiAl hydrotalcites synthesized were based on Me²⁺/Al mole ratios of 2:1 and 4:1. The materials were prepared via the co-precipitation method. For this purpose, 200 cm³ of 0.2 mol/dm³ of Na₂CO₃ and Me²⁺, with the amount of this cation for reaching the Me²⁺/Al required mole ratio, was added drop-wise to a stirred solution composed of 200 cm³ of Al³⁺, 0.04 mol. The final mixture was continuously stirred for 1 h at 60 °C. The resulting solid material was separated by filtration and washed with hot water to remove unreacted substances. The cake obtained was dried at 60 °C for 48 h and manually grounded with a mortar. The nomenclature used for these samples is MeAl-x:1-T, where Me is the divalent metal used in the synthesis of the hydrotalcite and T the temperature of treatment. Thus, for example, MgAl-2:1-300 is a hydrotalcite synthesized using Mg considering a mole ratio of 2:1 and a temperature of treatment of 300 °C.

2.3. Characterization techniques

Powder X-ray diffraction (PXRD) patterns of the materials were obtained using a Siemens D-5000 diffractometer equipped with a Cu Kα filtered radiation source (λ = 1.5418 nm). The working conditions employed were 30 mA, 40 kV and a scan rate of 2° (2θ)/min from 5 to 90°.

Thermal analyses were performed in a Hi-Res TGA2950 apparatus from TA-Instruments; the measurements were carried out at a heating rate of 10 °C/min from room temperature to 900 °C under air dynamic atmosphere (60 cm³/min).

Nitrogen adsorption-desorption was carried out at –196 °C using a static volumetric apparatus (Micromeritics ASAP 2010 adsorption analyzer). Prior to the adsorption measurements, the samples were outgassed at 200 °C for 24 h under a vacuum better than 0.1 Pa.

Scanning electron microscopy (SEM) analysis of the materials was performed using a JEOL microscope (model JSM-6400), operating at 20 kV. A drop of powder suspension was deposited on a copper grid and the selected area recorded.

2.4. CO₂ adsorption experiments

The adsorption of CO₂ was evaluated using a static volumetric method and a Micromeritics ASAP 2010 instrument with 0.2 g of solid. The samples were pre-treated at a heating rate of 10 °C/min, under a flow of He, at 200 °C for 1 h and then cooled to the adsorption temperature in the same stream. The samples were degassed under vacuum at the adsorption temperature to a pressure of less than 0.6 Pa. CO₂ adsorption data were collected in the pressure range between 6 and 80 kPa.

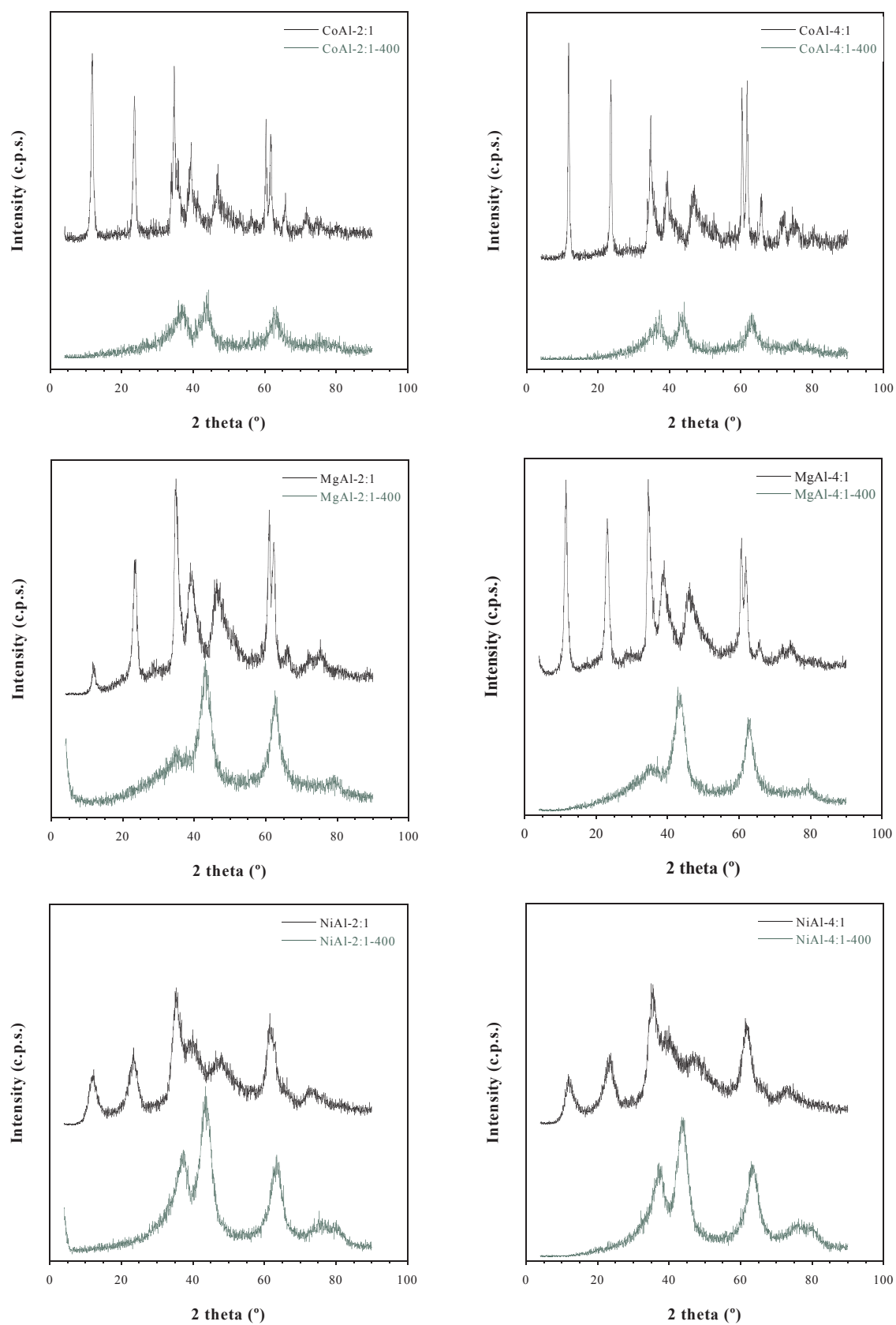


Fig. 1. PXRD patterns for the samples.

Table 1

Crystallite size (D) measured by Scherrer equation for the (003) basal reflection and cell parameters (a and c).

Sample	D (Å)	a (Å)	c (Å)
CoAl-2:1	116	3.071	22.68
CoAl-4:1	200	3.071	22.68
MgAl-2:1	82	3.045	22.68
MgAl-4:1	87	3.045	23.23
NiAl-2:1	37	3.020	22.54
NiAl-4:1	37	3.020	22.42

3. Results and discussion

3.1. Characterization of the hydrotalcites

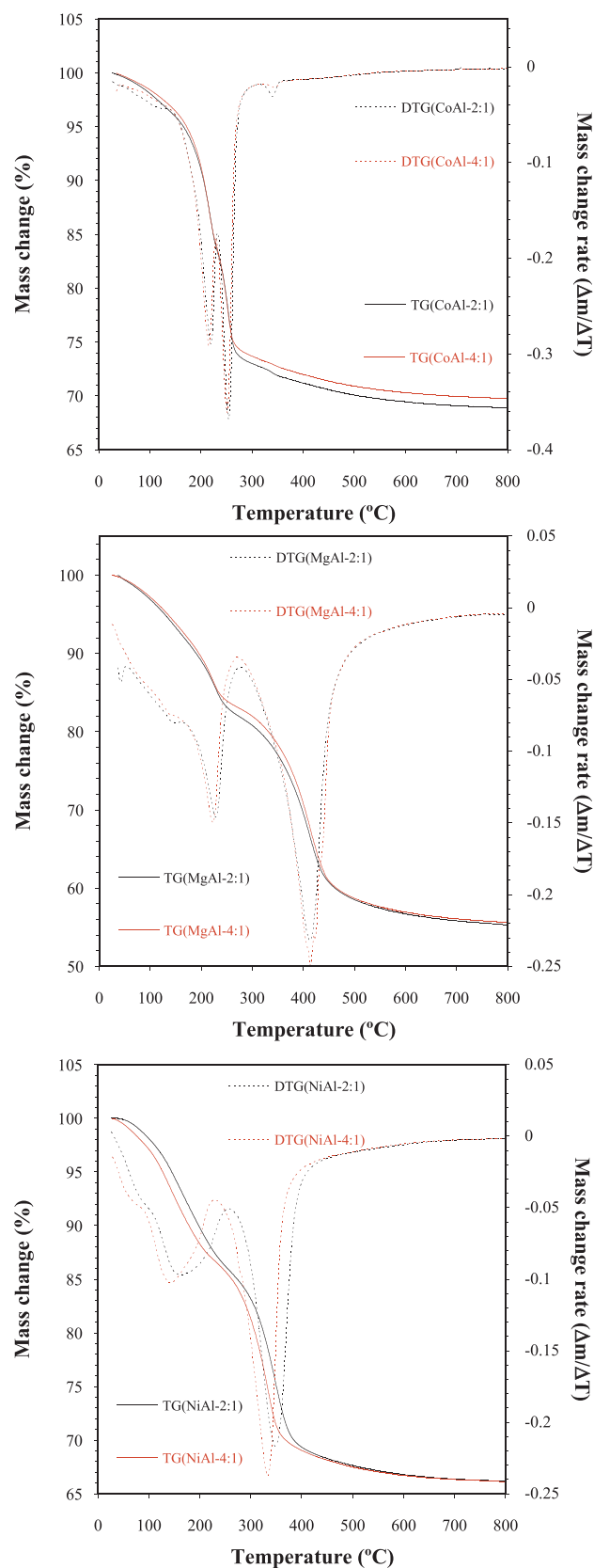
The powder X-ray diffraction patterns of samples dried at 60 °C and treated at 400 °C are shown in Fig. 1. The uncalcined samples evidenced the presence of the typical hydrotalcite structure with a high crystallinity (JCPDS file 14-0191). In all the series, more crystalline solids were obtained when the ratio Me^{2+}/Al was 4.0 instead of 2.0. The crystalline size (D) determined by the Debye-Scherrer equation considering the (003) basal reflection of the solids, and the parameters a and c of the layered structure, assuming a hexagonal cell [7], are summarized in Table 1. The a parameter is related to the average cation-cation distance within the layers and c is associated to the thickness of the brucite-like layer and the interlayer distance. The lattice parameter a was affected by the type of metal cation in the brucite layers: 3.071 Å for Co^{2+} , 3.045 Å for Mg^{2+} and 3.020 Å for Ni^{2+} , respectively. This behavior was coherent in all cases and it was explained by the ionic radii of the metals in these layers. In this sense, the ionic radii of the metal cations are 0.745 Å for Co^{2+} , 0.72 Å for Mg^{2+} and 0.69 Å for Ni^{2+} , that is in accord to the behavior of the a parameters. Concerning the lattice parameter c , it is affected by two factors: the aluminum content in the layer and the presence of anions in the interlayer. In this sense, no differences should be considered because the same anion was present for all the samples. The slight differences between samples can be related to a lower content of water in the interlayer. The crystallite size (D) showed a higher value for CoAl hydrotalcites than for NiAl, 200 and 37 Å, with MgAl between these two values. The PXRD patterns of the samples calcined at 400 °C corresponded mostly to amorphous materials, and only weak and broad signals were observed. The maxima related to the layered hydroxide structure completely disappeared for all samples. This behavior was due to the fact that calcination at 400 °C is severe enough to destroy the layered structure (see TGA results). The main diffraction maxima recorded at values of 2 theta close to 35.3, 42.9 and 61.9° corresponded to the rock-salt structure of metals. No differentiated diffraction maxima due to the presence of Al, Co or Ni species were recorded, indicating that these cations were probably as amorphous phases.

Results from the thermogravimetric analyses of the samples dried at 60 °C for 16 h are summarized in Table 2, while the corresponding curves are included in Fig. 2. Two well defined mass-loss steps were recorded in all cases. A first mass-loss step from room temperature to 230 °C, up to 275 °C in the case of MgAl samples, was due to the water

Table 2

Mass losses (%) in the temperature ranges indicated for hydrotalcites.

Sample	First peak	Second peak	Total
CoAl-2:1	16.1 (30–232 °C)	14.6 (232–800 °C)	30.7
CoAl-4:1	16.3 (30–232 °C)	14.0 (232–800 °C)	30.3
MgAl-2:1	18.2 (30–278 °C)	26.5 (278–800 °C)	44.7
MgAl-4:1	17.0 (30–274 °C)	27.4 (274–800 °C)	44.4
NiAl-2:1	14.3 (30–260 °C)	19.5 (260–800 °C)	33.8
NiAl-4:1	13.4 (30–232 °C)	20.5 (232–800 °C)	33.9

**Fig. 2.** TG and DTG curves of selected samples.

lost, adsorbed and interlayer, and dehydroxylation by removal of structural OH^- which represented around 18% of the total mass. A second mass-loss step in the temperature range 230–800 °C, its maxima

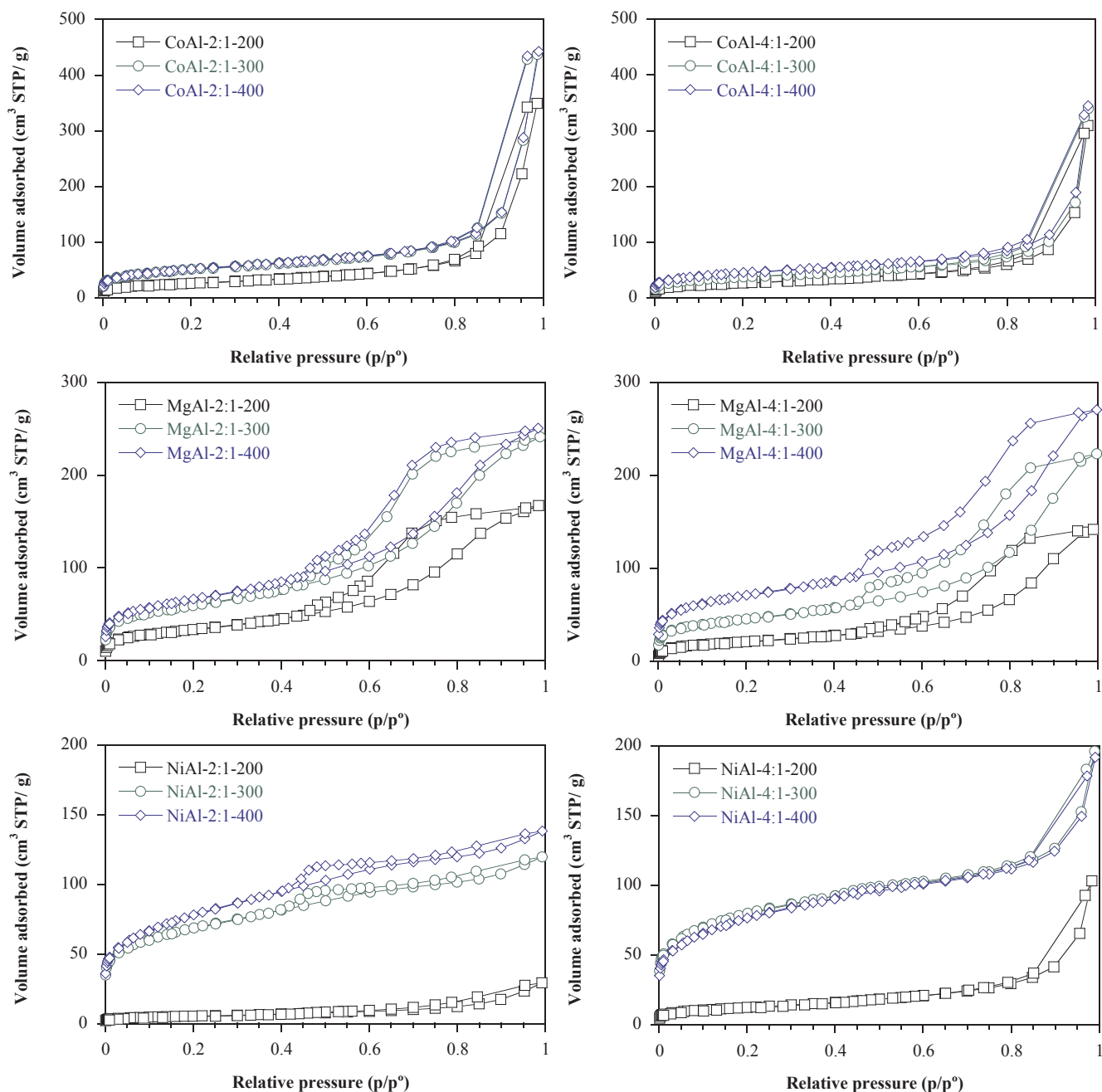


Fig. 3. Experimental isotherms for the adsorption of nitrogen at $-196\text{ }^{\circ}\text{C}$.

were located at $414\text{ }^{\circ}\text{C}$, was ascribed to dehydroxylation by removal of structural OH units of Me^{2+} , interlayer carbonates and the complete collapse of the structure and formation of mixed oxides [18]. While MgAl and NiAl samples showed very similar behavior, CoAl samples were less stable, that is, their decomposition took place at lower temperature, which has been reported for hydrotalcites containing oxidizable cations [19]. In this case, a slight mass loss effect took place close to $360\text{ }^{\circ}\text{C}$ (easily visible in the DTG curve), probably associated to the formation of the spinel. This suggested that Co(II) may be oxidized to Co(III) in the previous decomposition steps, finally giving rise to the spinel at this temperature, but not shown in this work. The mass loss in the different steps is similar for all the solids, except higher values for the second decomposition step in MgAl solids (Table 2). This may be due to the fixation in this series of higher amounts of CO_2 from the atmosphere during the synthesis procedure and during the handling of the solids, due to the more basic character of Mg(II).

The nitrogen adsorption-desorption data for samples at $-196\text{ }^{\circ}\text{C}$ are shown in Fig. 3. The adsorption isotherms are mainly of type II and IV in the Brunauer, Deming, Deming and Teller (BDDT) classification [20]. The adsorption isotherms for CoAl-2:1, CoAl-4:1 and NiAl-4:1 exhibited the type II. The rest of samples exhibited a less asymptotic behavior at high relative pressures with the presence of an incipient plateau that can be related to type IV. H3 and H4-type hysteresis loops were found in the case of CoAl and MgAl samples, which can be related to materials comprising non-rigid aggregates of plate-like particles. This is the case of some clay materials. In the case of NiAl samples, a H5-type was observed that could be related to pore structures containing both open and partially blocked mesopores. The results relating to the textural properties obtained for the samples are listed in greater detail in Table 3. The BET surface area (S_{BET}) was calculated from adsorption data obtained over the relative pressure range 0.05–0.20, taking the cross-sectional area of the nitrogen molecule to be 0.160 nm^2 [20]. The

Table 3
Specific surface areas and pore volumes from nitrogen adsorption at $-196\text{ }^{\circ}\text{C}$.

Samples	S_{BET} (m^2/g)	S_{ext} (m^2/g)	V_{Pr} (cm^3/g)	V_{MUP} (cm^3/g)
CoAl-2:1-200	97	91	0.541	0.002
CoAl-2:1-300	186	135	0.677	0.20
CoAl-2:1-400	189	142	0.685	0.18
CoAl-4:1-200	96	82	0.478	0.006
CoAl-4:1-300	134	100	0.525	0.014
CoAl-4:1-400	163	119	0.533	0.017
MgAl-2:1-200	122	117	0.258	0.001
MgAl-2:1-300	212	181	0.373	0.013
MgAl-2:1-400	238	206	0.387	0.013
MgAl-4:1-200	75	73	0.219	–
MgAl-4:1-300	161	133	0.345	0.012
MgAl-4:1-400	253	211	0.418	0.017
NiAl-2:1-200	19	17	0.045	–
NiAl-2:1-300	243	33	0.185	0.124
NiAl-2:1-400	281	36	0.214	0.149
NiAl-4:1-200	44	42	0.160	–
NiAl-4:1-300	286	57	0.304	0.116
NiAl-4:1-400	276	56	0.297	0.114

total pore volume (V_{Pr}) was calculated from the amount of nitrogen adsorbed at a relative pressure of 0.99, assuming that the density of the nitrogen condensed in the pores was equal to that of liquid nitrogen at $-196\text{ }^{\circ}\text{C}$ (0.81 g/cm^3) [20]. The external surface area (S_{ext}) and micropore volume (V_{MUP}) were estimated using the t-plot method [20]. In the case of the samples dried and degassed at $200\text{ }^{\circ}\text{C}$, the specific surface areas ranged from 19 to $281\text{ m}^2/\text{g}$, being MgAl-2:1 the sample that showed the higher value. After thermal treatment, the specific surface areas increased up to $281\text{ m}^2/\text{g}$ in the case of NiAl-2:1, which can be related to the presence of amorphous mixed oxides. Comparing both series, the solids from 2:1 series showed higher values, mainly of V_{Pr} , independently of the nature of the divalent cation. It has been reported that under calcination, the hydrotalcite phase progressively evolved to spinel [19], segregating the divalent hydroxide-oxide, due to the difference in stoichiometry between the hydrotalcites and the spinels. The amount of divalent hydroxide-oxide was higher in the 4:1 series, as the excess of Me(II) was higher, which resulted in the better textural properties of the solids in this series.

The SEM micrographs for CoAl, MgAl and NiAl solids are shown in Fig. 4. No significant differences can be observed between the samples indicating that the morphology was very similar for the three samples and the typical hexagonal shapes of hydrotalcites were present. The average size of the crystals was significantly higher in the case of the MgAl samples, about $44\text{ }\mu\text{m}$, than for CoAl and NiAl, about $24\text{ }\mu\text{m}$. The surface of the crystals of MgAl appears clean, while in the case of CoAl and NiAl flakes are observed. EDX analysis was also performed to determine the composition of the samples. The chemical composition, included in Fig. 4, found mole ratios between 2.2 and 2.9. In addition, considering that the aluminum source is an industrial waste, no impurities as metals or metal oxides were detected.

3.2. CO_2 adsorption experiments

The CO_2 adsorption capacity of the synthesized hydrotalcites at 50, 100 and $200\text{ }^{\circ}\text{C}$ and pressures up to 80 kPa is shown in Fig. 5. As shown in this Figure, the amount of CO_2 adsorbed decreased with increasing adsorption temperature, which could be related to a physical interaction between the surface of the adsorbents and CO_2 . In the same way, MgAl-2:1 sample presented higher adsorption capacity than the rest of samples. It has been reported that the CO_2 capture capacities of hydrotalcites are somewhat lower than those of other adsorbents, lower than 1.0 mmol/g . Ding and Alpay [21] reported adsorption capacities under wet feed conditions about 0.49 and 0.59 mmol/g as a function of the temperature. Similar values have been reported by Rodrigues

[22,23] and Reijers [24] considering several commercial hydrotalcites containing various cations and anions, and also several adsorption temperatures. Several factors as the type of cations or anions used in the synthesis, the synthesis method, or the incorporation of alkali metals by impregnation have been reported to improve the adsorption capacity [25–33]. In the present work, MgAl-2:1 showed a maximum adsorption capacity under dry conditions of 5.26 mmol/g at the temperature of $50\text{ }^{\circ}\text{C}$. This value decreased with increasing the adsorption temperature to 3.09 mmol/g at $200\text{ }^{\circ}\text{C}$. The other synthesized solids had a lower adsorption capacity, but higher than the results reported by other authors in which hydrotalcites were used as adsorbents. A comparison of the results obtained in this work with others reported in the literature under dry conditions is summarized in Table 4. The experimental results obtained show that hydrotalcites synthesized from the aluminum extracted from saline slag wastes are promising adsorbents to retain CO_2 from gaseous effluents.

The Henry's constant is an important characteristic of adsorption because it provides an indication of the strength of adsorption and the isosteric heat of adsorption at low pressure. In the current work, the Henry's constant (H) is obtained directly from the isotherm. This method has been suggested as more accurate than others if sufficient data in the low-pressure region are available [41]. The results are summarized in Table 5. A comparison of the Henry's law constants for the hydrotalcites showed that those for CoAl samples at $50\text{ }^{\circ}\text{C}$ were higher than for NiAl and MgAl solids at the same temperature. The difference between the values decreased as the temperature increased indicating that the interaction at the surface of the hydrotalcites was more important at low temperatures.

The heat effects produced by the adsorption processes can be described by the isosteric heat of adsorption and can be determined from the amount of gas adsorbed. The isosteric heat defines the energy change resulting from the phase change of an infinitesimal number of molecules at constant pressure and temperature and a specific adsorbate loading. A method to calculate the isosteric heat of adsorption involves the application of the Clausius-Clapeyron equation [42], which relates the isosteric heat to the pressure change of the bulk gas phase as a consequence of a temperature change for a constant amount adsorbed:

$$q_{st} = -R \left[\frac{\partial \ln p}{\partial (1/T)} \right]_n \quad (1)$$

where p (kPa) is the equilibrium pressure, n is the amount of gas adsorbed at temperature T (K) and R ($\text{kJ/mol}\cdot\text{K}$) is the universal gas constant. The isosteric heat can be obtained from the experimental isotherms at various temperatures by plotting $\ln(p)$ versus $1/T$ for a constant loading n . The isosteric heat corresponds to the slope of the straight line. The dependence of the isosteric heats of adsorption on the amount adsorbed for the hydrotalcite materials is shown in Fig. 6, which clearly indicates that the isosteric heats of adsorption varied with the surface loading. Our findings show a maximum of isosteric heat of adsorption with loading for hydrotalcites. This maximum is observed in all the samples except in the case of NiAl-2:1, which may be due to the low adsorption capacity shown by this solid. The values of the maximum isosteric heats are also included in Fig. 6. The maximum value corresponds to an adsorbed amount of $0.5\text{--}0.8\text{ mmol/g}$, which may be related to the coating of the hydrotalcites surface with CO_2 [43]. From this value, the adsorption on lower energy sites of the surface and the formation of multilayers of CO_2 adsorbed can be the reasons for the continued decreasing of the isosteric heat of adsorption with increasing loading.

The limiting heat, q_{st}^0 , can be obtained directly from the temperature dependence of Henry's constant by applying the Clausius-Clapeyron equation in the low-pressure region, where the isotherm obeys Henry's law [44].

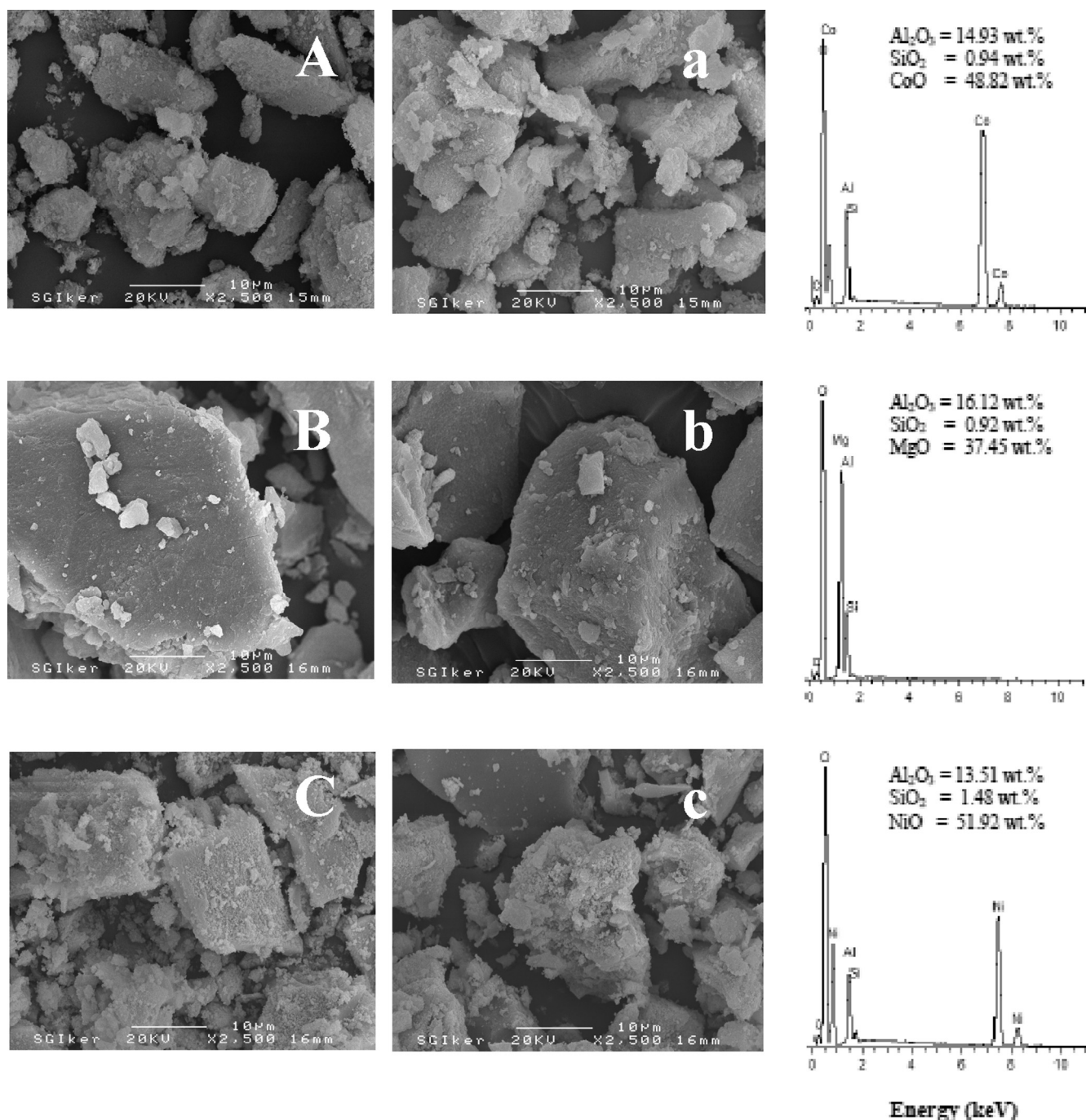


Fig. 4. SEM micrographs and EDX analysis, including chemical analysis, for the samples dried (capitals) and calcined at 400 °C (lower case). (A, a) CoAl-4:1, (B, b) MgAl-4:1, (C, c) NiAl-4:1.

$$q_{st}^0 = R \left[\frac{d \ln H_i}{d(1/T)} \right]_{n=0} \quad (2)$$

The isosteric heats obtained from Eq. (2) and the first experimental values included in Fig. 6 are compared in Table 5. The values found using the two methods were in general similar among them, the isosteric at zero coverage heats being higher when they were determined from the results included in Fig. 6.

4. Summary and conclusions

Herein a procedure for the valorization of the aluminum present on the saline slags generated during secondary aluminum recycling

processes as adsorbent of CO₂ has been presented. For this purpose, aluminum extracted with 2 mol/dm³ aqueous solutions of NaOH using a reflux system was used as alternative aluminum source for the synthesis of hydrotalcites by a modified co-precipitation method. CoAl-, MgAl- and NiAl-hydrotalcite-like compounds with 2:1 and 4:1 mol ratios were obtained. The uncalcined samples evidenced the presence of the typical hydrotalcite structure with a high crystallinity from XRD analyses. After calcination at 400 °C amorphous materials were obtained, leading to formation of metals in a rock-salt structure. The textural properties, namely specific surface area and pore volume, increased with the temperature of calcination, related to the presence of amorphous mixed oxides.

The CO₂ adsorption capacity found for the synthesized hydrotalcites

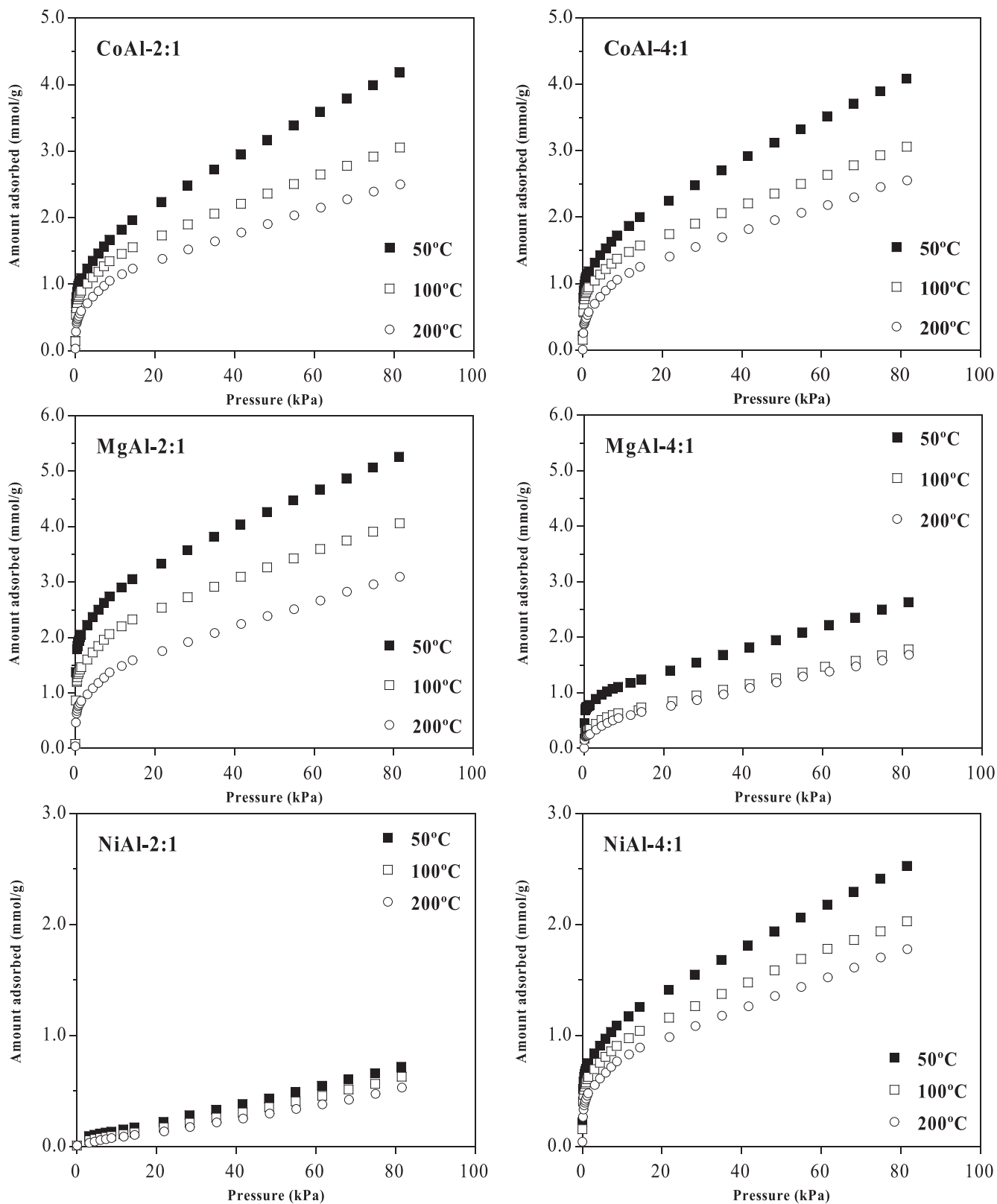


Fig. 5. CO₂ adsorption on the hydrotalcites-like materials at 50, 100 and 200 °C.

was higher than the results reported by other authors in the literature. A maximum adsorption capacity of 5.26 mmol/g at 50 °C was measured for the sample MgAl-2:1. This result indicated that the hydrotalcites synthesized by the procedure presented in this work are interesting adsorbents to retain CO₂ from gaseous effluents.

The Henry's law constants were obtained directly from the adsorption isotherms and the values found were between 0.01 and 4.20 mmol/kPa·g. The isosteric heats of CO₂ adsorption were calculated using the Clausius-Clapeyron equation, finding values in the range of 5.2–16.8 kJ/mol.

Table 4
Comparison of the CO₂ adsorption capacities for various hydrotalcites-derived compounds and conditions reported in the literature.

Samples	$T_{\text{calcination}}$ (°C)	$T_{\text{adsorption}}$ (°C)	p_{CO_2} (kPa)	q_{CO_2} (mmol/g)	References
HTlc	400	330	100	3.55	[34]
K-HTlc	400	250	130	2.25	[35]
cK-HTCGa MW	400	300	105	1.70	[15]
K-Mg/Al	550	240	100	1.2	[33]
K-HTC	400	400	85	0.97	[36]
K-MG30	600	400	100	0.94	[29]
cHTC	400	300	105	0.90	[15]
HTlcs	400	200	110	0.9	[25]
K-HT	400	300	100	0.85	[37]
K-HTC	450	450	100	0.77	[38]
Na-MG70	550	400	100	0.75	[32]
N-100	80	100	100	0.70	[39]
Ni-MO-5	500	300	100	0.57	[16]
HT	400	100	100	0.53	[37]
MG50	300	300	100	0.5	[22]
HTlc	400	200	100	0.49	[40]
Mg ₃ Al ₁	400	200	100	0.41	[28]
HTC	500	300	100	0.22	[16]
CoAl-2:1	200	200	80	2.50	This work
CoAl-4:1	200	200	80	2.55	This work
MgAl-2:1	200	200	80	3.10	This work
MgAl-4:1	200	200	80	1.68	This work
NiAl-2:1	200	200	80	0.53	This work
NiAl-4:1	200	200	80	1.78	This work

Table 5
Henry's constants for CO₂ adsorption on hydrotalcites-derived compounds at several temperatures and isosteric heats of adsorption at zero coverage.

Samples/Temperature (°C)	H (mmol/kPa·g)	q_{st}^0 (kJ/mol) ¹	q_{st}^0 (kJ/mol) ²
CoAl-2:1			
50	3.53		
100	2.76	7.9	10.7
200	1.42		
CoAl-4:1			
50	4.00		
100	2.95	9.6	16.8
200	1.32		
MgAl-2:1			
50	4.20		
100	3.14	5.9	9.8
200	2.09		
MgAl-4:1			
50	1.89		
100	0.81	7.7	7.6
200	0.72		
NiAl-2:1			
50	0.023		
100	0.014	7.1	12.1
200	0.010		
NiAl-4:1			
50	2.41		
100	1.90	5.2	13.7
200	1.31		

¹ From the Henry constant.

² From the Clausius-Clapeyron equation.

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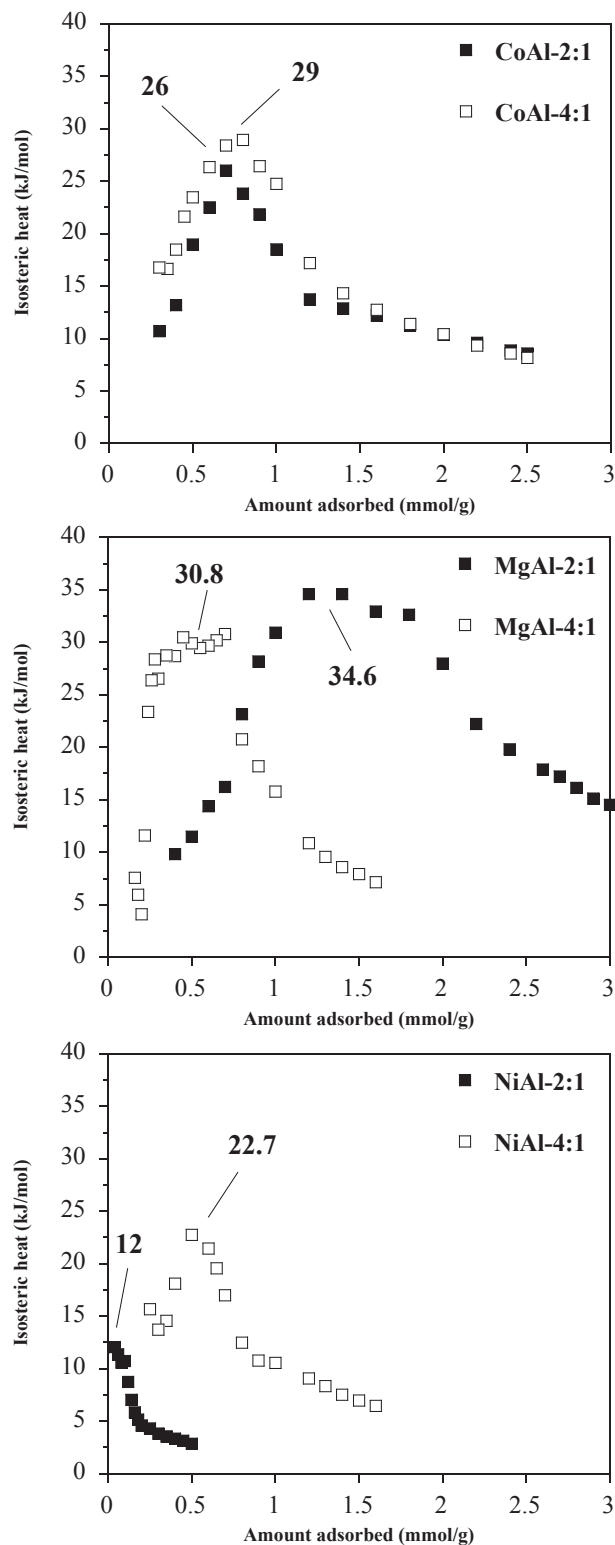


Fig. 6. Isosteric heat of CO₂ adsorption as a function of the amount of CO₂ adsorbed on the hydrotalcites compounds.

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