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(54) Title: METHOD OF OBTAINING MULTIMETALLIC OXIDES DERIVED FROM HYDROTALCITE-TYPE COMPOUNDS

(57) **Abrégé/Abstract:**

The invention relates to a method of preparing multimetallic hydrotalcites, the physicochemical characteristics thereof and the use of same as sulphur oxide (SO_x) reducing materials, such as SO₂ or SO₃ which are contained in gaseous streams, particularly in flue gases emitted by the regeneration section of the fluid-bed catalytic cracking process. The inventive method improves the SO_x absorption capacity per unit of specific area of multimetallic hydrotalcite obtained and the absorption and regeneration speeds of the calcination products of the aforementioned hydrotalcites, with the incorporation of ternary and/or quaternary cations in the laminae of said precursor materials. In order to discover the effect of the composition of said hydrotalcites, a combination of physical and chemical methods were applied such as to characterise same by means of X-ray diffraction, textural analysis, CO₂ absorption microcalorimetry and, primarily, SO₂ oxidation reduction.

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(54) Title: METHOD OF OBTAINING MULTIMETALLIC OXIDES DERIVED FROM HYDROTALCITE-TYPE COMPOUNDS

(54) Título: OBTENCIÓN DE ÓXIDOS MULTIMETÁLICOS DERIVADOS DE COMPUESTOS DEL TIPO HIDROTALCITA.

(57) Abstract: The invention relates to a method of preparing multimetallic hydrotalcites, the physicochemical characteristics thereof and the use of same as sulphur oxide (SO_x) reducing materials, such as SO₂ or SO₃ which are contained in gaseous streams, particularly in flue gases emitted by the regeneration section of the fluid-bed catalytic cracking process. The inventive method improves the SO_x absorption capacity per unit of specific area of multimetallic hydrotalcite obtained and the absorption and regeneration speeds of the calcination products of the aforementioned hydrotalcites, with the incorporation of ternary and/or quaternary cations in the laminae of said precursor materials. In order to discover the effect of the composition of said hydrotalcites, a combination of physical and chemical methods were applied such as to characterise same by means of X-ray diffraction, textural analysis, CO₂ absorption microcalorimetry and, primarily, SO₂ oxidation reduction.(57) Resumen: La presente invención se relaciona con un procedimiento para la obtención de una serie de óxidos mixtos multi-
metálicos derivados de compuestos del tipohidrotalcita. En esta invención se describen las características físicas de las hidrotalcitas multimetálicas y su aplicación como materiales reductores de óxido de azufre (SO_x) tales como (SO₂ ó SO₃) contenidos en las co-
rrientes gaseosas, particularmente en los gases de combustión emitidos por la sección de regeneración del proceso de desintegración catalítica fluida (FCC). Estos materiales se pueden utilizar también para el propósito anterior en los gases de combustión del carbón o combustión de hidrocarburos en las plantas generadores de energía y/o plantas químicas. El procedimiento utilizado mejora la capacidad de absorción de SO_x por unidad de área específica de material obtenido, objeto de la presente invención, su velocidad de absorción y su velocidad de regeneración de los productos de calcinación de las hidrotalcitas mencionadas al incorporar cationes terciarios y/o cuaternarios a las láminas de estos materiales.

WO 2005/003034 A1

METHOD OF OBTAINING MULTIMETALLIC OXIDES DERIVED FROM HYDROTALCITE-TYPE COMPOUNDS

DESCRIPTION

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TECHNICAL FIELD OF THE INVENTION

This invention is related to a procedure for obtaining a series of mixed multimetallic oxides derived from hydrotalcite type compounds. This invention describes the physical features of the multimetallic hydrotalcites and their application as sulfur oxide reducing materials (SO_x), such as (SO_2 or SO_3) contained in gas currents, particularly in combustion gases emitted by the regeneration section of the fluid catalyst disintegration process (FCC). These materials may be used also for the foregoing purpose in carbon combustion or hydrocarbon combustion gases in energy generating plants and/or chemical plants. The procedure employed improves the absorption capability of SO_x per specific area unit of obtained material, subject matter of this invention, the absorption speed and the regeneration speed of the calcining products of the aforementioned hydrotalcites by incorporating tertiary and/or quaternary cations to the plates of these materials.

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BACKGROUND OF THE INVENTION

The FCC process effects the transformation of heavy fractions of oil, normally mixtures of atmospheric gas oils and vacuum, into valuable products such as gas, LP

Gas and light olefins, the latter, inputs of processes from the síntesis of fuels and petrochemicals, and it employs acid catalysts. The FCC industrial units are designed basically with two operation stages, the first one of reaction and the second one of regeneration, and between them the catalyst circulates permanently at a constant speed. Due to the nature of the chemical reactions involved, a carbonaceous subproduct is produced, better known as coke, and this is deposited on the surface on the catalyst surface and de-activates it. The catalyst regeneration takes place by means of the combustion of the coke deposited on the catalyst, and this occurs in the regeneration stage by means of controlled air injection. Coke combustion is an exothermic reaction increasing the catalyst temperature from about 773 to 803K in the reactor up to 923K in the regenerator. The coke combustion process produces, likewise, the oxidation of the sulfur associated to the latter, and this produces in turn the corresponding sulfur oxides in relative proportions very close to thermodynamic equilibrium. These, under the occurring operation conditions, are of approximately 10% SO₃ and 90% SO₂. In cases where a gas purifying system is not installed, they are emitted together with the combustion gases, into the atmosphere.

Sulfur oxides, named SO_x, are toxic gases referring to sulfur dioxide mixtures (SO₂) and those of sulfur trioxide (SO₃), and these due to the action of ultraviolet light and the humidity of the atmosphere can be transformed into sulfuric acid and generate the so-called acid rain, according to the following chemical reactions:

The extremely negative environmental of the SO_x emissions has been recognized by the international scientific and industrial communities, as well as by various government agencies of most countries in the world.

The number of SO_x emissions produced in the regenerator of an FCC unit is basically a function of the sulfur concentration on the load, the coke yield and the catalyst circulation rate. Approximately between 45 and 55% of the sulfur of the load is converted into H₂S inside the FCC reactor, between 35 and 45% remains on the liquid products (gasoline, light cyclic oil and heavy oil) and between 5 and 10% is deposited on the catalyst associated to coke.

It is well known to persons familiar with the FCC process that control of the SO_x emissions can be performed effectively and efficiently by using the catalyst itself, adequately modified with certain compounds or by means of the employment of materials known as Sox additives, added to the main catalyst inventory in relatively low (normally 10%) and controlled proportions.

Essentially, the materials that may be employed to reduce the SO_x emissions should in principle be active for forming the corresponding sulfate and possess high adsorption capability. This is the case of magnesium oxide or aluminum oxide. On the other hand, thermodynamic calculations indicate that the capture of sulfur trioxide in alkaline metals is much more favorable in comparison with sulfur dioxide (Kocaefer and Karman, *Cand. J. Chem. Eng.*, 63, 971-977 [1985]). This way, in order for a material to be employed efficiently in the FCC process, as an active agent in SO_x additives, it should also possess sufficient activity to catalyze the transformation of sulfur dioxide into sulfur trioxide. Certain metals like cerium or vanadium and their oxides may be employed, due to their recognized activity as oxidation catalysts, especially suitable for oxidation from SO₂ to SO₃. An essential attribute for an SO_x additive is that referring to its capability for detaching itself from the absorbed sulfate,

and this permits regenerating the active entity and thus avoiding the saturation many materials show during the course of their use in the FCC unit. The loosening of sulfates takes place in the reaction stage upon contact of the material with the hydrocarbons found in the environment, or any other reducing agent, such as hydrogen produced as a subproduct.

The SO_x additives that have been most extensively employed in the FCC units are based on magnesium aluminate spinels (MgAl_2O_4) containing cerium oxide and vanadium oxide. These additives are described in USA patent No. 4,790,982, granted to Yoo and col. and USA patent No. 4,728,635, granted to Bhattacharyya and col.

This type of additives, however, have shown in general a relatively limited absorption capability, a tendency to lose activity quickly due to the synthetization of the active phase and a slow regeneration speed regarding the residence time there is in the reaction stage in the FCC unit. The need to use materials permitting an increase in the activity of sulfur assimilation has been recognized, both due to a greater amount and due to a higher dispersión of the active metal. One of these materials is constituted by certain anionic clays known as hydrotalcites, comprised essentially of magnesium and aluminum in a sheet structure, and the general formula of the hydrotalcites is the following: $\text{Mg}_6\text{Al}_2(\text{OH})_{16}(\text{CO}_3)4\text{H}_2\text{O}$. The presence of aluminum atoms produces negative charges in the stucture, and these are compensated with interlaminar anions. What is more common, these anions are carbonates, but they may be sulfates, chlorides or others. On the other hand, the Mg/Al atomic relationship in these materials may vary betwen 1.7 and 5 and it is possible that bivalent or trivalent cations substitute Mg or Al.

The hydrotalcite synthesis is generally performed by means of a co-precipitation of metal salts. A classic preparation consists in mixing an aqueous solution of magnesium and aluminum salts, for example, nitrates or chlorides, and add it to a sodium carbonate solution under continuous stirring. The precipitate formed is submitted to heating for several hours at temperatures between 333 and 473K.

In USA patent 5,750,020 (1998), of Bhattacharyya and col., granted to AMOCO, Co., a collapsed hydrotalcite composition is described, and this may be obtained by calcining a mixed sheet hydroxide having monometallate anions on the interlaminar region. This collapsed composition is comprised substantially of microcrystals represented collectively by means of the formula: $M_{2m}^{2+}Al_{2-p}M_p^{3+}T_rO_{7+r.s}$, where M^{2+} is a divalent metal, M^{3+} is a trivalent metal and T is Vanadium, Tungsten or Molybdenum. The little crystals are so small they cannot be detected by means of conventional X-ray diffraction techniques; however, high resolution electronic microscopy reveals that a considerable portion of the little microcrystals is comprised of a solid solution of molecularly disperse aluminum oxide in the crystalline structure of the divalent metal monoxide. Another portion of the little microcrystals is constituted by the spinel phase. The collapsed composition functions to absorb sulfur oxide and has a comparatively high absorption capability and comparatively high absorption and desorption speeds, and also functions as a catalyst for nitrogen oxide reduction.

In USA patent 5,785,938 (1998) of Pinnavaia T. J. and col. a process to remove and later capture sulfur oxides from gas currents is described, particularly those effluents from the energy generating plants through coal burning, by using double

metal hydroxides containing Ni, as recyclable absorbents. The absorbing compositions contain metal components forming stable sulfites and sulfates at a temperature, but they are decomposed at a higher temperature to regenerate the absorbing material.

5 In USA patent 5,928,496 (1999), a process for the sorption of sulfur oxide by using hydrotalcite type materials, like contact solids, is described. Hydrotalcite type materials are stable when transformed to the crystalline structure of the oxide and are essentially reversible in an exchange of anions. These materials, made up of large
10 cristal sheets and with a high Sox sorption capacity, are benefited in their sorption properties when modifying them with certain species of organic acid anions, which modify the hydrotalcite/brucite structure.

In USA patent 6,028,023 (2000) of Vierheilig A. A. , assigned to Bulldog Technologies Inc., a process for the preparation of hydrotalcite type compounds is described, where a non-hydrotalcite type (or hydrotalcite type) compound is thermally
15 treated and afterwards hydrated to form hydrotalcite type compounds, thus obtaining properties (such as: greater hardness, and/or density) differing from those of hydrotalcite type compounds synthesized by methods reported in the prior state-of-the-art, where non-hydrotalcite type materials (or hydrotalcite type compounds) are not thermally treated in a similar manner or hydrated for forming such hydrotalcite
20 type compounds.

Hydrotalcite type compounds, also called: double or triple laminar metal hydroxides or anionic clays, are materials with laminar structure represented by the following formula:



where:

M(II), represents a divalent cation.

M(III), represents a trivalent cation.

5 A, represents any anion.

Metals form octahedrons joining their edges to form positively charged bidimensional sheets. The positive residual charge is originated in the metal or trivalent cation. To neutralize this residual charge, it is necessary for there to be anions located among the sheets, which may be exchanged by others of chemical composition different from the initial one. Due to the polar and hydrophilic nature of the sheets and depending on the space vacated by the anions, a certain amount of water may be accommodated among the anions and among the sheets.

Specialists in this field will notice that anionic clays are commonly called "mixed metal hydroxides." This expression is derived from the fact that, such as was indicated previously, the positively charged sheets of the metal hydroxides may contain two diverse metal cations in different oxidation states (for example, Mg^{2+} , Al^{3+} , and so forth). Additionally, and given that the X-ray diffraction patterns of so many anionic clays are similar to the mineral named hydrotalcite, $Mg_6Al_2(OH)_{16}(CO_3) \cdot 4H_2O$, it is common for them to be called "hydrotalcite type compounds." This term has been broadly used in the literature of scientific articles and patents during many years (See for example: Pausch "Synthesis of Disordered and Al-Rich Hydrotalcite-Like Compounds", *Clays and Clay Minerals*, Vol. 14, 507-510 (1986). Such compounds

are frequently referred to as "Anionic clays." In fact, the terms "Anionic clays", "Mixed metal hydroxides" and "Hydrotalcite type compounds" are very closely related, if not used indistinctly. On the other hand, USA patent 5,399,329 contains the following sentence: The term "hydrotalcite type" is recognized in its field, defined and used
5 consistently with the use comprised in the monograph type revision articles referred to by Cavani and col." Therefore and for the purposes of this patent, the autores will use (unless otherwise indicated) the compound term(s) "hydrotalcite type" in the understanding that this term should be considered inclusive of anionic clays; the hydrotalcite itself, as well as any member of the class of materials known as
10 "Hydrotalcite-type compounds." What is more, and due to its frequent use in this document, the authors will continue to abbreviate the term "hydrotalcite-type" as "HT."

It is also known that HT's are decomposed in a predictable manner when heated without exceeding certain temperatures. The resulting materials from decomposition may be re-hydrated (and optionally, re-supplied with certain anions, e.g. CO_3^{2-} ,
15 removed during heating); and likewise, the original HT or a similar one may be reproduced. Products from the decomposition of such heating are frequently referred to as "collapsed" or "meta-stable" hydrotalcite type compounds. If these collapsed or meta-stable materials, however, are heated at certain temperatures higher than 1023K, then the products of the decomposition of such HT's cannot be re-hydrated
20 and/or reconstituted anymore. Therefore, they cannot rebuild the original HT.

Such termal decomposition process of hydrotalcite type compounds has been studied in detail in academic and patent literature. For example, Miyata, "Physico-Chemical

Properties of Synthetic Hydrotalcites in Relation to Composition”, Clays and Clay Minerals, Vol. 28, 50-56 (1980).

One of the most difficult problems to solve when wishing to prepare ternary or
5 multimetallic hydrotalcites, in which the three or more cations have actually been
incorporated into the laminar structure, is the fact that depending on the chemical
nature of the cation, its precipitation speed may be different from that of the other
cations, assuming a constant pH. If the precipitation speeds are very different among
themselves, non-hydrotalcite separate crystallographic phases will be obtained, that
10 is, the three cations may not be incorporated uniformly into the hydrotalcite layers. If
the situation is complicated when we have a binary system (two cations) due to the
aforementioned reasons, the situation becomes even more complicated when we
have three or more. Therefore, it is difficult to obtain ternary hydrotalcites whose
crystallographic phases show that they are pure within an ample range of
15 compositions of the three cations. Even so, there are some reports demonstrating it is
possible to obtain them (J. Sánchez-Valente, Doctoral Thesis, “*Synthèse et
Characterisation des solides du type hydrotalcite et leurs applications en Catalyse*”
IRC, Francia 1999., M. Sánchez-Cantú, Bachelor’s Degree Thesis IMP, March 2002).

In scientific literature there are some examples of ternary hydrotalcites, that is,
20 those made up in their laminar composition of three different cations. However, these
examples are scarce, since a greater effort has been devoted to the study of binary
hydrotalcites. For example, Kooli and col. (1995) have reported the preparation of Ni-
Al-Cr and Ni-Al-Fe hydrotalcites containing carbonate anions in their interlaminar

region. These ternary hydrotalcites, where the traditional trivalent cation (Al^{3+}) is partially substituted by Fe^{3+} or Cr^{3+} cations, were obtained by means of a co-precipitation with sodium carbonate and sodium hydroxide at a $\text{pH}=10$, at 333K, followed by a hidrothermal treatment at 423K. The ternary hydrotalcites were obtained
 5 in pure crystallographic phases when the following atomic relationship ranks were maintained between the cations: $3.6 \leq \text{Ni}/(\text{Cr}+\text{Al}) \leq 6.8$ or $2.3 \leq \text{Ni}/(\text{Fe}+\text{Al}) \leq 9.9$; beyond these ranks other non-hydrotalcite phases were detected.

The foregoing group of authors (F. Kooli and col., 1995) have also described the preparation of ternary hydrotalcites where the divalent cation is partially substituted by
 10 others, for example Mg-Zn-Al and Zn-Cu-Al. In this procedure, the solids are obtained by means of co-precipitation with sodium carbonate and sodium hydroxide at 333K and $\text{pH}=10$. The atomic relationships between which it is possible to obtain crystallographically pure hydrotalcite phases were the following: $1.3 \leq (\text{Mg}+\text{Zn})/\text{Al} \leq 5.9$ and $2.7 \leq (\text{Zn}+\text{Cu})/\text{Al} \leq 3.1$; however, even within these ranks there were
 15 occasional non-hydrotalcite phases.

Cu-Ni-Al ternary hydrotalcites, where the divalent cation is partially substituted by another one and with carbonate and nitrate anions in the interlaminar region, have been obtained by means of co-precipitation with an aqueous solution of NaOH, at $\text{pH}=10$ and room temperature, as is reported by A. Alejandre and col. (2001). The
 20 precipitate obtained was aged at 343K during 2 h. However, in the case of these ternary hydrotalcites, where Cu is from 0.11 to 0.32, Ni is 0.15 to 0.36 and Al is constant and equal to 3, that is, in order to maintain a divalent / trivalent cation atomic

relationship ≈ 0.16 , their diffraction patterns always show different phases from those of hydrotalcite, or mixtures of such phases.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to show the performance as SO₂ absorbers of the multimetallic oxides obtained from hydrotalcite type compounds, reference is made to the figures herein included.

5

Figures 1 to 4 show the X-ray diffraction patterns of the solids synthesized in this invention, which are characteristic of pure hydrotalcite type compounds, where the formation of crystalline phases additional to the hydrotalcite type structure is not observed, thus indicating that with the procedure of this invention it is possible to incorporate three, four or more cations on the sheets of the hydrotalcite type materials.

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Figure 5 represents the plan of the gravimetric evaluation process of solids in the oxidation-reduction of SO₂. This method allows us to compare and discriminate the oxidizing-reducing properties of the solids subject matter of this invention and commercial ones.

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Figures 6 to 10 exemplify the gravimetric study of the absorption-reduction process of SO₂, described previously, in multimetallic oxides obtained as of the calcining, at 923 K, of the precursor multimetallic hydrotalcites.

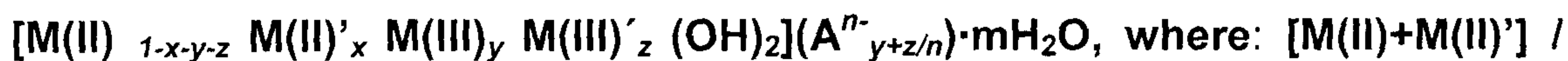
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DETAILED DESCRIPTION OF THE INVENTION

This invention is related to a procedure for obtaining a series of mixed multimetallic oxides derived from hydrotalcite type compounds and their use as absorbent materials, capable of being regenerated, to remove or reduce the sulfur oxides (SO_x) contained in gas currents, preferably in combustion gases emitted by

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the regeneration section of the fluid catalyst disintegration process (FCC). The syntheses of absorbent materials or multimetallic hydrotalcite type compounds of this invention are represented by the following formula.



5 $[(M(III)+M(III)')]$, is the molar relationship between the divalent cations and the trivalent cations and is found between 0.5 and 10 ; $M(II)$, represents an element of group 2, 6-12 of the periodic table with valence equal to two; $M(II)'$, represents an element of group 2, 6-12 of the periodic table with valence equal to two or three, and this may be equal to $M(II)$ but with a different valence, $M(III)$, represents an element of group 4-8,
10 13 with valence equal to 3 and different from $M(II)$ y $M(II)'$, $M(III)$, represents an element of group 4-8, 13 with valence equal to 3 and different from $M(II)$ and $M(III)$ or equal to $M(III)$ but with different valence.

A , represents any anion located between the sheets comprised of the aforementioned cations.

15 $n-$, represents the negative electronic charge of the interlaminar anion and may be from -1 to -8.

$x=0.01$ up to 0.99

$y=0.01$ up to 0.99

$z=0.01$ up to 0.99

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The procedure subject matter of this invention is characterized in that it is performed as follows: (1) Preparation of aqueous or organic solutions containing at least three or up to four cations, where the precursor compounds may be oxides, hydroxides, chlorides or any combination of them; (2) preparation of the alkaline
25 solutions from 0.5 to 10 molar, preferably from 1 to 5 molar of KOH, K_2CO_3 ,

(NH₄)OH, (NH₄)₂CO₃, Urea or any alkaline compound, different from sodium, or any combination of them; (3) a combination of solutions 1 and 2 until precipitation of the cations in the form of hydroxides is caused; (4) mechanic agitation at temperatures between 293 and 373K from 14 to 20 hours; (5) washing of the precipitate with
5 enough water to eliminate the non-precipitated ions; (6) drying with air, oxygen or nitrogen current or any combination of them; (7) Finally, calcining of the obtained material is effected, between 673K and 1073K, preferably from 850K to 950K in air atmosphere during 4 hours.

The solids obtained with different concentrations of metallic cations in their
10 laminar structure are classified in the series named: MgFeAl, MgZnAl, MgNiAl and MgZnAlFe; and in some cases binary hydrotalcites were prepared (MgAl, ZnAl, MgFe, and so forth) to compare them with the multimetallic ones subject matter of this invention. Material characterization techniques involve the determination of important parameters, such as surface area, pore diameter, pore volume, structural
15 arrangements, crystallinity, crystalline phase composition, sulfur absorption and thermal analysis.

The elementary analysis for calculating the developed formula of the multimetallic hydrotalcites was effected by atomic absorption, X-ray analysis in a diffractometer with CuK α radiation (1.5406 Å) to identify the crystallographic phases
20 of the solids and the textural properties in an equipment, ASAP, at 77 K by means of the adsorption-desorption of nitrogen.

The materials obtained presented the patterns of X-ray diffraction characteristic of the pure multimetallic hydrotalcites subject matter of this invention, as shown in Figures 1 to 4; where the formation of compounds additional to the hydrotalcite type structure is not observed, and by this we wish to indicate that with the procedure of this invention it is possible to incorporate three, four or more cations on the sheets of hydrotalcite type materials. It is also demonstrated that the hydrotalcites, constituted by three or more cations in their laminar structure, are converted after being calcined between 673 and 973K, into materials with improved basic properties in comparison with a hydrotalcite constituted of only two cations.

It is important to emphasize that the product of calcining a conventional binary hydrotalcite, for example, Mg/Al, may function as an absorbent material for SO_x in gas currents, the removal of the sulfites or sulfates formed, or in other words, the regeneration of the absorbent material, becomes difficult due to the fact that the sulfates are strongly interlocked to the material mentioned. Hence, we need a third or up to a fourth highly disperse cation, forming part of the layers of the initial hydrotalcite, to modulate the basic strength of the sites where SO_x acid molecules interact and/or which they capture.

This invention demonstrates that the reduction speed (that is, the removal of sulfates of absorbent material) increases considerably in calcined ternary or quaternary hydrotalcites. This parameter is crucial for the commercial utilization of these materials as SO_x reducing additives in the FCC process, since contact times are usually between close to 2 to 5 seconds with reducing gases. The latter are the hydrocarbons and/or oxygen involved in the FCC process.

Microcalorimetric procedure to measure the heat emitted or absorbed in the hydrotalcites in CO₂ adsorption.

To measure the heat emitted or absorbed in the materials subject matter of this invention, a flow isothermal calorimeter of the Tian-Calvet type was used: The procedure is performed as follows: (a) All hydrotalcites obtained according to examples 1 to 24 were thermally treated at 723K during 5 hours, under a flow of nitrogen of 7 L/h, with a temperature ramp of 10 K/min. (b) The materials were placed inside the microcalorimetric cell, by using a glove bag in an argon atmosphere, in order to avoid contact of the solid with the air and consequently its de-activation, (c) Afterwards, the cell was heated in the pretreatment oven, until the necessary vacuum was reached to initiate the experiment (10⁻⁵ Torr), (d) Later, this was carried on to room temperature by keeping the vacuum in the cell, which was transferred to the microcalorimeter (Tian-Calvet), e) Afterwards, successive dosages of CO₂ of a known volume were sent to the study sample, thus awaiting thermal equilibrium after every dosage. The pressure was determined with an absolute pressure meter (BARATRON), until there was a residual equilibrium pressure of the order of 0.14 Torr.

Results of CO₂ adsorption.

On Table 1 we present the results of CO₂ adsorption in the calcined hydrotalcites, and these were previously treated according to the protocol described in the preceding experimental part. CO₂ is an acid gas molecule and it is adsorbed

only on the basic sites. To examine the effect of the different metallic cations on the solid basic quality, and at the same time the effect of the precursor salts of the metallic cations on the basic properties of the same, the samples were studied starting with nitrates and chlorides with different cations. The samples synthesized as
5 of chlorides were exchanged by following the anionic exchange protocol described in this process. It is important to mention that the solids obtained from chlorated salts without being exchanged practically do not adsorb CO₂, and this indicates that the active basic sites are inhibited by the presence of chlorine.

An important result of this study, in the case of hydrotalcites containing only Mg
10 and Al, is that there is almost no difference whatsoever between the number and the strength of basic sites, obtained starting either with nitrated or chlorated salts. On the other hand, in the case of hydrotalcite type compounds (HT), containing either Mg and/or Fe and/or Ni and/or Cu and/or Zn and/or Cr, there is a considerable difference between the solids obtained as of nitrates or chlorides. Solids synthesized as of
15 chlorides present greater CO₂ adsorption enthalpies, and this indicates they are compounds of a greater strength and number of basic sites than those obtained starting with nitrates: When chlorated salts are used, the number of sites oscillates between $0.5\text{-}3.0\ \mu\text{mol CO}_2\text{ adsorbed/m}^2$ with adsorption enthalpies comprised within a range of $60\text{-}120\ \text{KJ/mol}$, the number and strength of sites of the calcined solids will
20 be determined by the nature and proportion of the cations present in the structure of the precursor HT type compound. Also varying the composition of the precursor HT, it is possible to obtain solids with a number of sites going from $0.4\text{-}1.5\ \mu\text{mol CO}_2$ within

a range of ΔH adsorption: 60-110 KJ/mol. These results show that the number and strength of the active basic sites may be modulated within an ample gamut of energy.

5 **Table 1. Microcalorimetric results of CO₂ adsorption on calcined hydrotalcite-like compounds (923K/4 h).**

Sample	$\mu\text{molCO}_2/\text{m}^2^*$	ΔH (KJ/mol)
$[\text{Mg}_{0.714}\text{Fe}_{0.107}\text{Al}_{0.179}(\text{OH})_2](\text{CO}_3)_{0.143} \cdot 0.83 \text{H}_2\text{O}$	1.5	60-110
$[\text{Mg}_{0.651}\text{Fe}_{0.063}\text{Al}_{0.286}(\text{OH})_2](\text{CO}_3)_{0.174} \cdot 0.82 \text{H}_2\text{O}$	1.1	60-100
$[\text{Mg}_{0.704}\text{Fe}_{0.192}\text{Al}_{0.104}(\text{OH})_2](\text{CO}_3)_{0.148} \cdot 0.92 \text{H}_2\text{O}$	1.3	60-105
$[\text{Mg}_{0.493}\text{Zn}_{0.165}\text{Al}_{0.342}(\text{OH})_2](\text{CO}_3)_{0.171} \cdot 0.98 \text{H}_2\text{O}$	0.8	60-100
$[\text{Mg}_{0.478}\text{Zn}_{0.232}\text{Al}_{0.290}(\text{OH})_2](\text{CO}_3)_{0.145} \cdot 0.86 \text{H}_2\text{O}$	0.6	60-95
$[\text{Mg}_{0.589}\text{Ni}_{0.111}\text{Al}_{0.300}(\text{OH})_2](\text{CO}_3)_{0.150} \cdot 0.88 \text{H}_2\text{O}$	1.3	60-110
$[\text{Mg}_{0.457}\text{Ni}_{0.292}\text{Al}_{0.251}(\text{OH})_2](\text{CO}_3)_{0.126} \cdot 0.85 \text{H}_2\text{O}$	1.0	60-90
$[\text{Mg}_{0.658}\text{Cu}_{0.098}\text{Al}_{0.244}(\text{OH})_2](\text{CO}_3)_{0.122} \cdot 0.69 \text{H}_2\text{O}$	0.9	60-80
$[\text{Mg}_{0.17}\text{Ni}_{0.51}\text{Al}_{0.32}(\text{OH})_2](\text{CO}_3)_{0.16} \cdot 0.91 \text{H}_2\text{O}$	1.3	60-110
$[\text{Mg}_{0.744}\text{Al}_{0.256}(\text{OH})_2](\text{CO}_3)_{0.128} \cdot 0.85 \text{H}_2\text{O}$	1.2	60-100
$[\text{Mg}_{0.730}\text{Al}_{0.270}(\text{OH})_2](\text{CO}_3)_{0.135} \cdot 0.71 \text{H}_2\text{O}^{**}$	1.4	60-100
$[\text{Mg}_{0.688}\text{Fe}_{0.311}(\text{OH})_2](\text{CO}_3)_{0.160} \cdot 0.80 \text{H}_2\text{O}$	0.5	60-100
$[\text{Mg}_{0.670}\text{Fe}_{0.330}(\text{OH})_2](\text{CO}_3)_{0.165} \cdot 0.80 \text{H}_2\text{O}^{**}$	2	60-100
$[\text{Mg}_{0.69}\text{Cr}_{0.31}(\text{OH})_2](\text{CO}_3)_{0.173} \cdot 0.84 \text{H}_2\text{O}$	0.4	60-105
$[\text{Mg}_{0.76}\text{Cr}_{0.24}(\text{OH})_2](\text{CO}_3)_{0.120} \cdot 0.79 \text{H}_2\text{O}^{**}$	3.5	60-120
$[\text{Co}_{0.63}\text{Al}_{0.37}(\text{OH})_2](\text{CO}_3)_{0.185} \cdot 1.1 \text{H}_2\text{O}$	0.48	60-80
$[\text{Cu}_{0.751}\text{Al}_{0.249}(\text{OH})_2](\text{CO}_3)_{0.418} \cdot 1.41 \text{H}_2\text{O}$	1.5	60-78
$[\text{Ni}_{0.833}\text{Al}_{0.167}(\text{OH})_2](\text{CO}_3)_{0.0835} \cdot 0.68 \text{H}_2\text{O}$	0.8	60-90
$[\text{Zn}_{0.75}\text{Al}_{0.25}(\text{OH})_2](\text{CO}_3)_{0.125} \cdot 0.84 \text{H}_2\text{O}^{**}$	0.5	60-96

*Only the CO₂ adsorbed amount >60 KJ/mol was considered as a real chemisorption.

**This solids were synthesized from chloride salts and exchanged post-synthesis with CO₃ anions.

Evaluation of multimetallic hydrotalcites in the oxidation-reduction of SO₂.

By means of this method, the absorption-reduction efficiency was determined in the multimetallic hydrotalcites of this invention, of sulfur oxides (SO_x), by means of thermo-gravimetric analysis. The temperature interval of every test was performed from the room temperature up to 923K. The temperature employed depended on the absorption-reduction properties of the materials studied.

The analysis equipment consists of the following:

- Perkin-Elmer thermo-gravimetric analyzer, TGA-7 model: This consists mainly of an ultrasensitive microscale, measuring weight changes from 0.1μg up to 1300 mg; and of a high temperature oven, whose operation range is from 298 to 1773K, and thus an excellent accuracy is obtained.
- TAC 7/DX thermal analysis controlling instrument.
- Manual set of valves for the processes of oxidation-reduction absorption and cleansing of the system.

To evaluate the hydrotalcites, 40-60 mg was taken from the samples presented on Table 2, and these were transferred to a temperature of 923 K in an air atmosphere in order for them to be activated and stabilized. The absorption of SO₂ in the material is effected by exposure to a mixture of SO₂ (1.0% Vol.)/air at the same temperature. Once total saturation has finished, the system is purged with N₂. Immediately following, the sample is reduced with a current of H₂ at 823 and 923K, thus obtaining again the initial calcined hydrotalcite, and this may be submitted to a new absorption-reduction cycle. With this test the total adsorption capacity is

determined, as well as the adsorption speed and reduction speed, besides the material stability in several absorption cycles (Figure 5).

Some results with this evaluation method are presented in Figures 6 to 10.

5 With this test, the following parameters are determined:

- Total Absorption: The maximum amount of SO₂ (% weight) absorbed until reaching equilibrium at a given time (the latter depends on the sample studied).
- 10 • Absorption speed: Amount of SO₂ (% weight) absorbed per time unit, calculated for all cases after 30 minutes.
- % Reduction: Amount of SO₂ reduced at a given temperature (823 or 923 K).
- Reduction speed: Amount of SO₂ (% weight) absorbed per time unit at 823 and/or 923 K.
- 15 • Catalytic Stability: Intrinsic capability of the solid to recover its initial absorption capacity.

The results of these tests are summarized on Tables 2 and 3.

From the above described parameters, one of the most important and crucial ones for optimal performance of the additives in actual operation conditions is the reduction speed, since it is limited by the temperature of the *riser* reaction zone (its acronym in English) of the FCC process, and this oscillates between 793 and 873 K. Consequently, solids that present a greater reduction speed at temperatures situated within this range are better than those that need greater activation temperatures. From the results of Table 2, it is demonstrated that said speed may be modulated
25 depending on the nature and content of the metallic cations constituting the solid,

thus obtaining results up to 9.7 times greater when compared with the better ones obtained in commercial additives, evaluated under the same conditions.

On Tables 2 and 3, it is demonstrated that the reduction speeds at 823 K of the ternary hydrotalcites with iron (series MgFeAl) are (between 9.7 and 14.7 times) faster than that of the binary MgAl hydrotalcite or that of commercial additives. The amount of SO₂ in % weight that the MgFeAl ternary series of hydrotalcites can absorb is from 1.1 to 2.7 times greater than that of the best of the commercial additives (Additive C). This means that in one application lesser amounts of multimetallic hydrotalcite will be required, subject matter of this invention, in order to offer the same SO₂ absorption levels, thus contributing to the economy of the process. Additionally in this same series, the SO₂ absorption speeds, although they are not so crucial as the SO_x reduction speeds, as was explained previously, improve 1.3 and 2.0 times in comparison with the best of the additives (Additive C).

From the results on Table 3, it may be observed that the MgFeAl multimetallic hydrotalcite series has between 83 to 94% reduction at 823 K, whereas the additives have only between 20 to 29% at 823 K. Commercial additives need greater temperatures (923 K) to reach elevated reduction levels.

The MgZnAl multimetallic hydrotalcite series presented reduction speeds between 1.2 and 3.4 times greater than the MgAl binary hydrotalcite or commercial additives, although lower than the MgFeAl series, as is shown on Table 2. The absorption speeds were between 0.9 and 1.8 times greater than the best of the commercial additives (Additive C) and their capturing capacities were from 0.67 to 2 times better than the best of the commercial additives (Additive C).

In general, from Tables 2 and 3, it is clear that the type and amount of ternary cation has a positive impact on most of the evaluation parameters in order to be able to determine whether or not an SO_x absorbent is good.

5

Table 2. Total absorption and absorption-reduction rates of SO₂ oxo-reduction test on calcined HT's (923K/4h).

Sample	Total Absorption* (%Wt SO ₂ /m ²)	¹ Absorption rate (1/min)	Reduction rate (1/min)	
			823K	923K
[Mg _{0.651} Fe _{0.063} Al _{0.286} (OH) ₂](CO ₃) _{0.174} ·0.82 H ₂ O	10	1.44	2.13	0.10
[Mg _{0.714} Fe _{0.107} Al _{0.179} (OH) ₂](CO ₃) _{0.143} ·0.83 H ₂ O	13	1.52	2.13	0.26
[Mg _{0.704} Fe _{0.192} Al _{0.104} (OH) ₂](CO ₃) _{0.148} ·0.92 H ₂ O	25	2.24	2.72	0.49
[Mg _{0.610} Zn _{0.090} Al _{0.290} (OH) ₂](CO ₃) _{0.15} ·0.73 H ₂ O	6	1.02	0.27	1.65
[Mg _{0.493} Zn _{0.165} Al _{0.342} (OH) ₂](CO ₃) _{0.171} ·0.98 H ₂ O	11	1.97	0.68	1.79
[Mg _{0.487} Zn _{0.201} Al _{0.312} (OH) ₂](CO ₃) _{0.156} ·0.90 H ₂ O	14	1.94	0.72	1.90
[Mg _{0.478} Zn _{0.232} Al _{0.290} (OH) ₂](CO ₃) _{0.145} ·0.86 H ₂ O	18	1.88	0.74	1.97
[Mg _{0.589} Ni _{0.111} Al _{0.300} (OH) ₂](CO ₃) _{0.150} ·0.89 H ₂ O	4	1.08	0.41	1.47
[Mg _{0.483} Ni _{0.222} Al _{0.295} (OH) ₂](CO ₃) _{0.147} ·0.88 H ₂ O	7	1.14	0.89	1.43
[Mg _{0.457} Ni _{0.292} Al _{0.251} (OH) ₂](CO ₃) _{0.126} ·0.85 H ₂ O	2	0.56	0.30	0.43
[Mg _{0.307} Cu _{0.118} Al _{0.578} (OH) ₂](CO ₃) _{0.289} ·0.80 H ₂ O	4	1.69	0.15	0.44
[Mg _{0.658} Cu _{0.098} Al _{0.244} (OH) ₂](CO ₃) _{0.122} ·0.69 H ₂ O	2	1.29	0.17	0.42
[Mg _{0.600} Cu _{0.148} Al _{0.252} (OH) ₂](CO ₃) _{0.126} ·0.71 H ₂ O	2	1.30	0.21	0.21
Binary hydrotalcites and Commercial Additives***				
[Mg _{0.744} Al _{0.256} (OH) ₂](CO ₃) _{0.128} ·0.85 H ₂ O	24	3.42	0.22	1.41
[Mg _{0.688} Fe _{0.311} (OH) ₂](CO ₃) _{0.160} ·0.80 H ₂ O	27	3.44	3.25	-**
[Zn _{0.75} Al _{0.25} (OH) ₂](CO ₃) _{0.125} ·0.84 H ₂ O	35	1.78	1.10	-**
[Ni _{0.833} Al _{0.167} (OH) ₂](CO ₃) _{0.0835} ·0.68 H ₂ O	3	0.25	1.15	-**
Commercial Additive A	7	0.98	0.22	1.60
Commercial Additive B	8	1.02	0.21	1.26
Commercial Additive C	9	1.09	0.21	1.73

- 5 *Evaluated at 923K **The samples were completely reduced at 873 K, ¹ In all cases, the rate was measured at 30 min. Commercial catalyst A is mainly constituted of MgAl₂O₄, commercial catalysts B and C are made with hydrotalcite doped with Ce and V. *** Binary hydrotalcites and commercial additives were only used as references and they are not object of this patent request.

Table 3. Total absorption, regeneration and reduction percentage of SO₂ oxo-reduction test on calcined HT's (923K/4h).

Sample	Total Absorption * (gSO ₂ /gcat)	Reduction (%)		Regeneration (%)
		823K	923K	
[Mg _{0.651} Fe _{0.063} Al _{0.286} (OH) ₂](CO ₃) _{0.174} ·0.821 H ₂ O	1.031	94	6	98
[Mg _{0.714} Fe _{0.107} Al _{0.179} (OH) ₂](CO ₃) _{0.143} ·0.828 H ₂ O	1.013	92	8	100
[Mg _{0.704} Fe _{0.192} Al _{0.104} (OH) ₂](CO ₃) _{0.148} ·0.920 H ₂ O	1.145	83	17	98
[Mg _{0.610} Zn _{0.090} Al _{0.290} (OH) ₂](CO ₃) _{0.15} ·0.73H ₂ O	0.774	14	86	55
[Mg _{0.493} Zn _{0.165} Al _{0.342} (OH) ₂](CO ₃) _{0.171} ·0.978H ₂ O	0.836	30	64	32
[Mg _{0.487} Zn _{0.201} Al _{0.312} (OH) ₂](CO ₃) _{0.156} ·0.902H ₂ O	0.881	30	65	41
[Mg _{0.478} Zn _{0.232} Al _{0.290} (OH) ₂](CO ₃) _{0.145} ·0.857H ₂ O	0.918	29	67	43
[Mg _{0.589} Ni _{0.111} Al _{0.300} (OH) ₂](CO ₃) _{0.150} ·0.885H ₂ O	0.656	30	66	104
[Mg _{0.483} Ni _{0.222} Al _{0.295} (OH) ₂](CO ₃) _{0.147} ·0.876H ₂ O	0.842	42	55	104
[Mg _{0.457} Ni _{0.292} Al _{0.251} (OH) ₂](CO ₃) _{0.126} ·0.849H ₂ O	0.293	54	44	134
[Mg _{0.307} Cu _{0.118} Al _{0.578} (OH) ₂](CO ₃) _{0.289} ·0.803H ₂ O	0.377	16	46	168
[Mg _{0.658} Cu _{0.098} Al _{0.244} (OH) ₂](CO ₃) _{0.122} ·0.687H ₂ O	0.309	21	49	154
[Mg _{0.600} Cu _{0.148} Al _{0.252} (OH) ₂](CO ₃) _{0.126} ·0.709H ₂ O	0.227	33	36	202
Binary Hydrotalcites and Commercial Additives**				
[Mg _{0.744} Al _{0.256} (OH) ₂](CO ₃) _{0.128} ·0.850H ₂ O	1.214	9	52	96
[Mg _{0.688} Fe _{0.311} (OH) ₂](CO ₃) _{0.160} ·0.800H ₂ O	1.050	96	4	102
[Zn _{0.75} Al _{0.25} (OH) ₂](CO ₃) _{0.125} ·0.840H ₂ O	0.666	82	5	-***
[Ni _{0.833} Al _{0.167} (OH) ₂](CO ₃) _{0.0835} ·0.683H ₂ O	0.294	100	0	-***
Aditivo Comercial A	0.644	26	73	100
Aditivo Comercial B	0.550	29	68	114
Aditivo comercial C	0.665	20	80	109

*Evaluated at 923K ** Binary hydrotalcites and commercial additives were only used as references and they are not object of this patent request ***The activity was not regenerated at all. The regeneration is calculated from a second absorption cycle. Commercial catalyst A is mainly constituted of MgAl₂O₄, commercial catalysts B and C are made with hydrotalcite doped with Ce and V.

To conclude, as if deriving from the results of Tables 2 and 3, it is possible to state that a third or up to a fourth cation on the sheets of the multimetallic hydrotalcites offers a modulating function between the basic strength necessary to retain the SO_x and its commitment to loosen this molecule at relatively low
5 temperatures and to regenerate the material.

It is important to emphasize that the product of calcining a conventional binary hydrotalcite, for example, constituted by magnesium and aluminum, may function as an absorbent material of SO_x in gas currents. Removal of the sulfites or sulfates
10 formed, or in other words the regeneration of the absorbing material, is rendered difficult due to the fact that the sulfites or sulfates are strongly interlinked to the material mentioned. Therefore, it is important for the hydrotalcites to contain a third or up to a fourth highly disperse cation, forming part of the layers of the initial hydrotalcite, to modulate the basic strength of the sites where SO_x acid molecules
15 interact and/or which they capture. In this invention, it is demonstrated that the reduction speed (that is, the removal of sulfates from the absorbent material) increases considerably in calcined ternary or quaternary hydrotalcites. The reduction speed is crucial for the commercial utilization of these materials as SO_x reducing additives in the FCC process, since contact times are usually between close to 2 to 5
20 seconds with reducing gases. The latter are the hydrocarbons and/or hydrogen involved in the FCC process.

The following examples will illustrate a few of the aspects described in this invention. These examples, however, should not be used to limit the sphere of this

invention, since there are many variations that can be derived without distancing ourselves from the topic of this invention.

Co-precipitation methods, at low and high supersaturation for obtaining the HT's compounds, were employed. The selection of one method or the other will be determined, in some cases, by the nature of the cations to be precipitated. The pH optimizations and the ageing time of the solids permit to obtain well crystallized solids.

a) Co-precipitation at low supersaturation.

In co-precipitation at low supersaturation, at a constant pH, the most commonly used conditions are the following: pH rank from 7 to 10, temperature from 333 to 353 K, low concentration of reagents and a slow addition speed for the cation solution and the alkaline solution. The precipitate obtained is given an ageing time under the conditions of co-precipitation, and this induces the dissolution of the small crystals and the growth of the large ones. Afterwards the solid is washed with hot water and finally dried at a temperature generally not exceeding 393K.

b) Co-precipitation at high supersaturation.

The main difference between this method and the foregoing one is that in this one the metal solution is added to the alkaline solution within a relatively short time (only the final precipitation pH is controlled). This method generally gives rise to less crystalline materials than those obtained by the low supersaturation method, due to the fact that in this case the nucleation speed is comparable to the speed of growth of the crystals.

EXAMPLES

Preparation of the MgFeAl series .

Hydrotalcite type solids with the developed formula $[\text{Mg}_{1-y-z} \text{Fe}_y \text{Al}_z (\text{OH})_2]^{X+} (\text{A}^{n-})_{y+z/n}^{X-} \cdot m\text{H}_2\text{O}$, were prepared by co-precipitation at high supersaturation.

Example 1

Obtaining the hydrotalcite with the developed formula $[\text{Mg}_{0.714} \text{Fe}_{0.107} \text{Al}_{0.179} (\text{OH})_2] (\text{CO}_3)_{0.143} \cdot 0.828 \text{H}_2\text{O}$, was carried out in the following manner: First an aqueous solution (A) was prepared with 49.06 g of $\text{Mg} (\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, 13.28 g of $\text{Al} (\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and 11.49 g of $\text{Fe} (\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ in 250 cm³ water. On the other hand, an alkaline solution was prepared (B), containing 23.27 g of K_2CO_3 and 22.00 g of KOH in 250 cm³ of water. The (A) solution was added to a glass reactor, the (B) solution began to drip slowly until it reached a final pH of 9. The solution obtained was kept under mechanical stirring at a temperature of 353K during 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (333-353K) during enough time to eliminate excess ions. Drying was performed at a temperature of 373 K during 24 h.

Example 2

Synthesis of $[\text{Mg}_{0.704} \text{Fe}_{0.192} \text{Al}_{0.104} (\text{OH})_2] (\text{CO}_3)_{0.148} \cdot 0.920\text{H}_2\text{O}$. An aqueous solution (A) was prepared with 49.06g of $\text{Mg} (\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, 7.50g of $\text{Al} (\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and 17.77g

of $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ in 250 cm^3 of water. On the other hand, an alkaline solution (B) was prepared, containing 23.27 g of K_2CO_3 and 22.00 g of KOH in 250 cm^3 of water. Solution (A) was added to a glass reagent, solution (B) began to drip slowly until it reached a final pH of 9. The solution maintained was kept under vigorous mechanical stirring, at a temperature of 353 K for 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (353 K) during enough time to eliminate excess ions. Drying took place at a temperature of 373K during 24 h.

Example 3

Synthesis of $[\text{Mg}_{0.651} \text{Fe}_{0.063} \text{Al}_{0.286} (\text{OH})_2] (\text{CO}_3)_{0.174} \cdot 0.821\text{H}_2\text{O}$. An aqueous solution (A) was prepared with 98.12g of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, 37.47g of $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and 11.20g of $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ in 500 cm^3 of water. On the other hand, an alkaline solution (B) was prepared, containing 46.48g of K_2CO_3 and 44.03g of KOH in 500 cm^3 of water. Solution (A) was added to a glass reagent; solution (B) began to drip slowly until it reached a final pH of 9. The solution obtained was kept under vigorous mechanical stirring, at a temperature of 353 K for 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (353 K) during enough time in order to eliminate excess ions. Drying took place at a temperature of 373K during 24 h.

Table 4 shows the texture properties of the synthesized compounds. Figure 1 exhibits the diffraction patterns of these solids, which correspond to a hydrotalcite type structure.

Table 4. Developed formula and textural properties of HT's .

Sample*	BET Area (m ² /g)	Dp (nm)	Vp (cm ³ /g)
[Mg _{0.651} Fe _{0.063} Al _{0.286} (OH) ₂] (CO ₃) _{0.174} · 0.82 H ₂ O	206	12.36	0.782
[Mg _{0.714} Fe _{0.107} Al _{0.179} (OH) ₂] (CO ₃) _{0.143} · 0.83 H ₂ O	169	9.13	0.558
[Mg _{0.704} Fe _{0.192} Al _{0.104} (OH) ₂] (CO ₃) _{0.148} · 0.92 H ₂ O	124	14.30	0.603

*Textural properties of calcined samples at 923K in air atmosphere for 4h.

Dp: Average pore diameter. Vp: Total pore volume.

5

Preparation of the MgZnAl series.

These solids, having a general developed formula: [Mg_{1-x-y} Zn_x Al_y (OH)₂]_X + (An-y/n)_X · mH₂O, were prepared by the co-precipitation method at low supersaturation.

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Example 4

Synthesis of [Mg_{0.614}Zn_{0.093} Al_{0.293} (OH)₂] (CO₃)_{0.146} · 0.731H₂O. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of Mg(NO₃)₂ · 6H₂O (19.51g), Zn (NO₃)₂ · 6H₂O (3.27g) and Al(NO₃)₃ · 9H₂O (10.88g) in 116 cm³. On the other hand, an alkaline solution (B, 2M) was prepared, containing K₂CO₃ (18.15g) and KOH (17.22g) in 200 cm³ of H₂O. Solutions (A) and (B) were added simultaneously to a glass reactor, containing previously 100 cm³ of de-ionized H₂O, at a controlled pH of 9. The precipitate obtained was kept under vigorous mechanical stirring, at a temperature of 353 K for 18 hours. Afterwards, the final product was washed and filtered with hot de-ionized water (353 K) , enough in order to eliminate excess ions. Drying was carried out at a temperature of 373K for 24 h.

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Example 5

Synthesis of $[\text{Mg}_{0.493} \text{Zn}_{0.165} \text{Al}_{0.342}(\text{OH})_2] (\text{CO}_3)_{0.171} \cdot 0.978\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (16.94g), $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (5.35g) and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (10.50g) in 112 cm^3 . On the other hand, an alkaline solution (B, 2M) was prepared, containing K_2CO_3 (18.15g) and KOH (17.22g) in 200 cm^3 of H_2O . Solutions (A) and (B) were added simultaneously to a glass reactor, containing previously 100 cm^3 of de-ionized H_2O , at a controlled pH of 9. The precipitate obtained was kept under vigorous mechanical stirring, at a temperature of 353 K for 18 hours. Afterwards, the final product was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K for 24 h.

Example 6

Synthesis of $[\text{Mg}_{0.478} \text{Zn}_{0.232} \text{Al}_{0.290}(\text{OH})_2] (\text{CO}_3)_{0.145} \cdot 0.857\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (14.12g), $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (7.73g) and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (10.13g) in 108 cm^3 . On the other hand, an alkaline solution (B, 2M) was prepared, containing K_2CO_3 (18.15g) and KOH (17.22g) in 200 cm^3 of H_2O . Solutions (A) and (B) were added simultaneously to a glass reactor, containing previously 100 cm^3 of de-ionized H_2O , at a controlled pH of 9. The precipitate obtained was kept under vigorous mechanical stirring, at a temperature of 353 K for 18 hours. Afterwards, the final product was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying was performed at a temperature of 373K for 24 h.

Example 7

Preparation of $[\text{Mg}_{0.487} \text{Zn}_{0.201} \text{Al}_{0.312} (\text{OH})_2] (\text{CO}_3)_{0.156} \cdot 0.902\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (15.14g), $\text{Zn} (\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (6.84g) and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (10.13g) in 109 cm^3 . On the other hand, an alkaline solution (B, 2M) was prepared, containing K_2CO_3 (18.15g) and KOH (17.22g) in 200 cm^3 of H_2O . Solutions (A) and (B) were added simultaneously to a glass reactor, containing previously 100 cm^3 of de-ionized H_2O , at a controlled pH of 9. The precipitate obtained was kept under vigorous mechanical stirring, at a temperature of 353K for 18 horas. Afterwards, the final product was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K for 24 h. Table 5 shows the results of the texture analyses of the solids obtained. Figure 2 shows the diffraction patterns of these solids, and they correspond to a hydrotalcite type structure.

Table 5. Developed formula and textural properties of HT's .

Sample*	BET Area (m^2/g)	Dp (nm)	Vp (cm^3/g)
$[\text{Mg}_{0.614}\text{Zn}_{0.093}\text{Al}_{0.293} (\text{OH})_2] (\text{CO}_3)_{0.146} \cdot 0.73\text{H}_2\text{O}$	175	14.2	0.480
$[\text{Mg}_{0.493}\text{Zn}_{0.165}\text{Al}_{0.342} (\text{OH})_2] (\text{CO}_3)_{0.171} \cdot 0.98\text{H}_2\text{O}$	193	16.22	0.870
$[\text{Mg}_{0.487}\text{Zn}_{0.201}\text{Al}_{0.312} (\text{OH})_2] (\text{CO}_3)_{0.156} \cdot 0.90\text{H}_2\text{O}$	175	16.53	0.842
$[\text{Mg}_{0.478}\text{Zn}_{0.232}\text{Al}_{0.290} (\text{OH})_2] (\text{CO}_3)_{0.145} \cdot 0.86\text{H}_2\text{O}$	139	24.35	0.925

*Textural properties of calcined samples at 923K in air atmosphere for 4h.
Dp: Average pore diameter. Vp: Total pore volume.

Preparation of the MgNiAl series .

These solids, with the general developed formula: $[\text{Mg}_{1-x-y} \text{Ni}_x \text{Al}_y (\text{OH})_2]^{X+} (\text{A}^{n-y/n})^{X-} \cdot m\text{H}_2\text{O}$, were prepared by the co-precipitation method at low supersaturation.

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Example 8

Synthesis of $[\text{Mg}_{0.589} \text{Ni}_{0.111} \text{Al}_{0.300} (\text{OH})_2] (\text{CO}_3)_{0.150} \cdot 0.885 \text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (45.69 g), $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (3.79 g) and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (23.92 g) in 250 cm^3 . On the other hand, an alkaline solution (B, 2M) was prepared, containing K_2CO_3 (23.26 g) and KOH (20.67 g) in 250 cm^3 of H_2O . The two solutions (A and B) were mixed by dripping in a glass reactor containing 200 cm^3 of de-ionized water; the addition was performed by maintaining a constant pH of 9. The addition time was ± 30 minutes. The precipitate obtained was kept at a temperature of 343 K during 18 h under vigorous stirring; afterwards it was washed/filtered 8 times with hot de-ionized water (333 K). Drying the paste obtained was performed at 373 K during 24 h.

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Example 9

Synthesis of $[\text{Mg}_{0.483} \text{Ni}_{0.222} \text{Al}_{0.295} (\text{OH})_2] (\text{CO}_3)_{0.147} \cdot 0.876 \text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (42.07 g), $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (7.84 g) and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (23.92 g) in 250 cm^3 . On the other hand, an alkaline solution (B, 2M) was prepared, containing K_2CO_3 (23.26 g) and KOH (20.67 g) in 250 cm^3 of H_2O . The two solutions (A and B) were mixed by dripping in a glass reactor containing 200 cm^3 of de-ionized water; the addition was

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carried out by maintaining a constant pH of 9. The addition time was ± 30 minutes. The precipitate obtained was kept at a temperature of 343 K for 18 h under vigorous stirring; afterwards it was washed/filtered 8 times with hot de-ionized water (333 K). Drying the paste obtained was carried out at 373 K for 24 h.

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Example 10

Synthesis of $[\text{Mg}_{0.457} \text{Ni}_{0.292} \text{Al}_{0.251}(\text{OH})_2] (\text{CO}_3)_{0.126} \cdot 0.849\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (38.25 g), $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (12.13 g) and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (23.92 g) in 250 cm^3 . On the other hand, an alkaline solution (B, 2M) was prepared, containing K_2CO_3 (23.26 g) and KOH (20.67 g) in 250 cm^3 of H_2O . The two solutions (A and B) were mixed by dripping in a glass reactor containing 200 cm^3 of de-ionized water; the addition was performed by maintaining a constant pH of 9. The addition time was approximately 30 minutes. The precipitate obtained was kept at a temperature of 343 K during 18 h under vigorous stirring; afterwards it was washed/filtered 8 times with hot de-ionized water (333 K). Drying the final product was performed at 373 K for 24 h.

Table 6. Developed formula and textural properties of HT's .

Sample*	BET Area (m ² /g)	Dp (nm)	Vp (cm ³ /g)
[Mg _{0.589} Ni _{0.111} Al _{0.300} (OH) ₂] (CO ₃) _{0.150} ·0.89H ₂ O	240	6.96	0.534
[Mg _{0.483} Ni _{0.222} Al _{0.295} (OH) ₂] (CO ₃) _{0.147} ·0.88H ₂ O	251	7.23	0.604
[Mg _{0.457} Ni _{0.292} Al _{0.251} (OH) ₂] (CO ₃) _{0.126} ·0.85H ₂ O	231	4.75	0.373

*Textural properties of calcined samples at 923K in air atmosphere for 4h.

Dp: Average pore diameter. Vp: Total pore volume.

- 5 Table 6 shows the results of the texture analyses of the calcined hydrotalcites. In Figure 3 we appreciate the diffraction patterns of X-rays corresponding to a hydrotalcite type structure.

Preparation of the M(II) Cu Al series, where M(II): Mg²⁺, Co²⁺ (Ternary)

- 10 These compounds, with the general developed formula: [M(II)_{1-x-y} Cu_x Al_y (OH)₂]^{X+} (Aⁿ⁻_{y/n})^{X-} ·mH₂O, were prepared by the co-precipitation method at low supersaturation. It is worth mentioning that to synthesize this type of solids, a very strict control should be exercised over the parameters, given that the cations presenting the well-known Jahn-Teller effect, in this case particularly Cu²⁺, tend not to
15 become incorporated or to exit the hydrotalcite structure easily.

Example 11

Synthesis of [Mg_{0.307} Cu_{0.118} Al_{0.578}(OH)₂] (CO₃)_{0.289}·0.803H₂O. A 2Molar solution was prepared, containing the metallic nitrates Mg(NO₃)₂·6H₂O (36.73g),

Al(NO₃)₃·9H₂O(19.14g), Cu(NO₃)₂·6H₂O (2.28 g), within a volume of 100 cm³, solution A. A second 2Molar solution was prepared, containing K₂CO₃ (111.68g) dissolved in 400 cm³ of de-ionized water, solution B. The two solutions were mixed by dripping in a glass reactor, containing previously 100 cm³ of de-ionized water at 333K. The addition was carried out by maintaining a constant pH of 10. The addition time was of approximately 25 minutes. The precipitate obtained was kept at a temperature of (333K) for 20 minutes under vigorous mechanical stirring; afterwards the greenish product was washed/filtered 5 times with hot de-ionized water (333K). Drying of the HT obtained was carried out at 373K during 24 h.

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Example 12

Synthesis of [Mg_{0.658} Cu_{0.098} Al_{0.244} (OH)₂] (CO₃)_{0.122}·0.687H₂O. A 2Molar solution was prepared, containing the metallic nitrates Mg (NO₃)₂·6H₂O (51.10g), Al(NO₃)₃·9H₂O(28.71g), Cu(NO₃)₂·6H₂O (7.05g), within a volume of 150 cm³, solution A. A second 2Molar solution was prepared, containing K₂CO₃ (181.49g) dissolved in 650 cm³ of de-ionized water, solution B. The two solutions were mixed by dripping in a glass reactor, containing previously 100 cm³ of de-ionized water at 333K. The addition was performed by maintaining a constant pH of 10. The addition time was approximately 26 minutes. The precipitate obtained was kept at a temperature of (333K) during 20 minutes under vigorous mechanical stirring; afterwards the greenish product was washed/filtered 5 times with hot de-ionized water (333K). Drying of the HT obtained was carried out at 373K during 24 h.

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Example 13

Synthesis of $[\text{Mg}_{0.600} \text{Cu}_{0.148} \text{Al}_{0.252}(\text{OH})_2] (\text{CO}_3)_{0.126} \cdot 0.709\text{H}_2\text{O}$. A 2Molar solution was prepared, containing the metallic nitrates $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (31.13g), $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (19.14g), $\text{Cu}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (7.35g), within a volume of 100 cm^3 , solution A. A second 2Molar solution was prepared, containing K_2CO_3 (139.61g) dissolved in 450 cm^3 of de-ionized water, solution B. The two solutions (A and B) were mixed by dripping in a glass reactor containing previously 100 cm^3 of de-ionized water at 333K. The addition was performed by keeping a constant pH of 10. The addition time was approximately 21 minutes. The precipitate obtained was kept at a temperature of (333K) for 20 minutes under vigorous mechanical stirring; afterwards the greenish product was washed/filtered 5 times with hot de-ionized water (333K). Drying of the HT obtained was carried out at 373K for 18 h.

Example 14

Synthesis of $[\text{Co}_{0.620} \text{Cu}_{0.206} \text{Al}_{0.173}(\text{OH})_2] (\text{CO}_3)_{0.108} \cdot 0.910 \text{H}_2\text{O}$. A 1M solution was prepared, containing the metallic nitrates $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (87g), $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (37g), $\text{Cu}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (23g), within a volume of 500 cm^3 , solution A. A second 2M solution was prepared, containing K_2CO_3 (117.97g) and KOH (9.89g) dissolved in 500 cm^3 of de-ionized water, solution B. The two solutions (A and B) were mixed by dripping in a glass reactor containing previously 300 cm^3 of de-ionized water at 353K. The addition was carried out by keeping a constant pH of 8. The precipitate obtained was kept at a temperature of 353K during 18 hours, under vigorous mechanical

stirring; afterwards, the product was washed/filtered 10 times with de-ionized water. Drying of the HT obtained was performed at 373K for 18 h.

Table 7 shows the results of the texture analysis of the calcinated hydrotalcites. Figure 4 presents the difraction patterns of X-rays coresponding to a hydrotalcite type structure.

Table 7. Developed formula and textural properties of HT's .

Sample*	BET Area (m ² /g)	Dp (nm)	Vp (cm ³ /g)
[Mg _{0.307} Cu _{0.118} Al _{0.578} (OH) ₂] (CO ₃) _{0.289} ·0.80H ₂ O	200	4.74	0.346
[Mg _{0.658} Cu _{0.098} Al _{0.244} (OH) ₂] (CO ₃) _{0.122} ·0.69H ₂ O	184	5.17	0.338
[Mg _{0.600} Cu _{0.148} Al _{0.252} (OH) ₂] (CO ₃) _{0.126} ·0.71H ₂ O	136	6.06	0.334

*Textural properties of calcined samples at 923K in air atmosphere for 4h.

Dp: Average pore diameter. Vp: Total pore volume.

Example 15

Synthesis of [Mg_{0.655}Al_{0.115}Mn_{0.230}(OH)₂] (CO₃)_{0.146}·0.729 H₂O. The preparation of this type of compounds required the employment of this special manner of synthesis, since due to the great size of the ionic radius of the metallic cation Mn (II) with respect to the other metallic cations employed, which renders its incorporation into the structural network difficult, the procedure was the following: An aqueous solution (A) 2M was prepared with 38.85g of Mg(NO₃)₂·6H₂O, 9.57g of Al(NO₃)₃·9H₂O and 14.64g MnCl₂·4H₂O in 500 cm³ of de-ionized water. On the other hand, an alkaline solution (B) 2M was prepared, containing 52.30g of K₂CO₃ and 37.75g of

KOH in 500 cm³ of water. Solution B was placed previously in a glass reactor; solution A began to drip slowly until it reached a final pH of 9.5. The solution obtained was kept under vigorous mechanical stirring, at room temperature, during 3 hours. Afterwards, the precipitate obtained was washed and filtered with de-ionized water 10 times in order to eliminate excess ions. Drying took place at a temperature of 353K during 12 h. The BET specific area determined in this sample, calcined at 923K in air atmosphere for 4 hours, was of 200 m²/g, with a pore volume of 0.587cm³/g and an average pore diameter comprised between 5-12 nm.

10 **Preparation of the MgZnAlFe (Quaternary) series**

Solids of the hydrotalcite type $[\text{Mg}_{1-x-y-z} \text{Zn}_x \text{Al}_y \text{Fe}_z (\text{OH})_2]^{X+} (\text{A}^{n-}_{y+z/n})^{X-} \cdot m\text{H}_2\text{O}$, were prepared by co-precipitation at high supersaturation.

Example 16

Obtaining the HT type solid with the developed formula: $[\text{Mg}_{0.68} \text{Zn}_{0.07} \text{Al}_{0.17} \text{Fe}_{0.08} (\text{OH})_2] (\text{CO}_3)_{0.125} \cdot 0.90 \text{H}_2\text{O}$, was performed as follows: First, an aqueous solution (A) was prepared with 10.03g of $\text{Mg} (\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, 1.19g of $\text{Zn} (\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, 3.75g of $\text{Al} (\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and 1.65g $\text{Fe} (\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ in 57 cm³ of water. On the other hand, an alkaline solution (B) was prepared, containing 28.12g of K_2CO_3 and 25.80 g of KOH in 305 cm³ of water. Solution A was added previously to a glass reactor; solution B began to drip slowly until it reached a final pH of 9. The solution obtained was kept under vigorous mechanical stirring at a temperature of 353 K for 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized

water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K during 24 h.

Example 17

5 Obtaining the HT type solid with the developed formula: $[\text{Mg}_{0.71} \text{Zn}_{0.04} \text{Al}_{0.14} \text{Fe}_{0.11} (\text{OH})_2] (\text{CO}_3)_{0.125} \cdot 0.87 \text{H}_2\text{O}$, was carried out as follows: First, an alkaline solution (A) was prepared with 10.51g of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, 0.56g of $\text{Zn} (\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, 3.00g of $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ y 2.43g $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ in 57 cm³ of water. On the other hand, an aqueous solution (B) was prepared, containing 28.12g of K_2CO_3 and 25.80 g of KOH
10 in 305 cm³ of water. Solution A was added previously to a glass reactor; solution B began to drip slowly until it reached a final pH of 9. The solution obtained was kept under vigorous mechanical stirring at a temperature of 353 K during 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a
15 temperature of 373K during 24 h.

Binary Hydrotalcites

The following examples refer to binary hydrotalcites used only with purposes comparative to multimetallic hydrotalcites. The characterization results of this group
20 are integrated on the respective Tables and Figures of multimetallic hydrotalcites.

Example 18

Synthesis of $[\text{Mg}_{0.643} \text{Fe}_{0.357} (\text{OH})_2] (\text{CO}_3)_{0.143} \cdot 0.807\text{H}_2\text{O}$. An aqueous (A) 1 molar solution was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (21.62g) and $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (11.55g) in 112 cm^3 of de-ionized water. On the other hand, an
 5 alkaline solution (B) 2M was prepared, containing K_2CO_3 (9.3g) and KOH (8.51g) with a molar relationship of $\text{KOH}/\text{K}_2\text{CO}_3=2$, in 100 cm^3 of de-ionized water. Solution A was placed previously in a glass reactor; then solution B began to drip slowly until it reached a final pH of 9 in the reactor. The solution obtained was kept under mechanical stirring at a temperature of 353K for 18 hours. Afterwards, the precipitate
 10 obtained was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K during 24 h.

Example 19

Synthesis of $[\text{Mg}_{0.744} \text{Al}_{0.256} (\text{OH})_2] (\text{CO}_3)_{0.128} \cdot 0.850\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (23.1g) and
 15 $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (11.25g) in 120 cm^3 of de-ionized water. On the other hand, an alkaline solution (B) 2M was prepared, with a molar relationship of $\text{KOH}/\text{K}_2\text{CO}_3=2$, and for this 11.17g of K_2CO_3 and 10.20g of KOH were dissolved in 120 cm^3 of de-ionized water. Solutions A and B were added simultaneously to a glass reactor
 20 containing previously 100 cm^3 of de-ionized water. The precipitation was performed at a constant pH of 10. The solution obtained was kept under vigorous mechanical stirring, at a temperature of 353 K, during 18 hours. Afterwards, the precipitate

obtained was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K for 24 h.

Example 20

5 Preparation of the compound $[\text{Zn}_{0.750} \text{Al}_{0.250} (\text{OH})_2] (\text{CO}_3)_{0.125} \cdot 0.840\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (19.63g) y $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (8.25g) in 88 cm^3 of de-ionized water. On the other hand, an alkaline solution (B) 2M was prepared, with a molar relationship of $\text{KOH}/\text{K}_2\text{CO}_3=2$, and for this 9.30g of K_2CO_3 and 8.51g of KOH were dissolved in 100
10 cm^3 of de-ionized water. Solutions A and B were added simultaneously to a glass reactor containing previously 100 cm^3 of de-ionized water. The precipitation was performed at a constant pH of 9. The solution obtained was kept under vigorous mechanical stirring, at a temperature of 353 K, for 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (353 K) 8
15 times in order to eliminate excess ions. Drying took place at a temperature of 373K for 24 h.

Example 21

Synthesis of $[\text{Ni}_{0.833} \text{Al}_{0.167} (\text{OH})_2] (\text{CO}_3)_{0.084} \cdot 0.683\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (20.56g) and
20 $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (7.50g) in 90 cm^3 of de-ionized water. On the other hand, an alkaline solution (B) 2M was prepared, with a molar relationship of $\text{KOH}/\text{K}_2\text{CO}_3=2$, and for this 9.3g of K_2CO_3 and 8.51g of KOH were dissolved in 100 cm^3 of de-ionized water. Solutions A and B were added simultaneously to a glass reactor containing

previously 100 cm³ of de-ionized water. The precipitation was performed at a constant pH of 9. The solution obtained was kept under vigorous mechanical stirring, at a temperature of 353 K, during 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K for 24 h.

Example 22

Synthesis of $(\text{Mg}_{0.670} \text{Fe}_{0.330} (\text{OH})_2 (\text{CO}_3)_{0.165} \cdot 0.80 \text{H}_2\text{O})$. An aqueous solution (A) 1 molar was prepared, containing the dissolved salts of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ (17.43g) and $\text{FeCl}_3 \cdot 9\text{H}_2\text{O}$ (7.72g) in 112 cm³ of de-ionized water. On the other hand, an alkaline solution (B) 2M was prepared, containing K_2CO_3 (9.3g) and KOH (8.51g) with a molar relationship of $\text{KOH}/\text{K}_2\text{CO}_3=2$, in 100 cm³ of de-ionized water. Solution A was placed previously in a glass reactor; later solution B began to drip slowly until it reaches a final pH of 9 in the reactor. The solution obtained was kept under mechanical stirring at a temperature of 353K during 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K for 24 h.

Example 23

Synthesis of $[\text{Mg}_{0.730} \text{Al}_{0.270} (\text{OH})_2 (\text{CO}_3)_{0.135} \cdot 0.71 \text{H}_2\text{O}]$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ (18.67g) and $\text{AlCl}_3 \cdot 9\text{H}_2\text{O}$ (7.32g) in 120 cm³ of de-ionized water. On the other hand, an alkaline

solution (B) 2M was prepared, with a molar relationship of $\text{KOH}/\text{K}_2\text{CO}_3=2$, and for this 11.17g of K_2CO_3 and 10.20g of KOH were dissolved in 120 cm^3 of de-ionized water. Solutions A and B were added simultaneously to a glass reactor containing previously 100 cm^3 of de-ionized water. The precipitation was carried out at a constant pH of 10.

5 The solution obtained was kept under vigorous mechanical stirring, at a temperature of 353 K for 18 hours. Afterwards, the precipitate obtained was washed and filtered with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K during 24 h.

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Example 24

Preparation of compound $[\text{Zn}_{0.750}\text{Al}_{0.250}(\text{OH})_2](\text{CO}_3)_{0.125} \cdot 0.84\text{H}_2\text{O}$. An aqueous solution (A, 1M) was prepared, containing the dissolved salts of $\text{ZnCl}_2 \cdot 6\text{H}_2\text{O}$ (9.18g) and $\text{AlCl}_3 \cdot 9\text{H}_2\text{O}$ (5.36g) in 88 cm^3 of de-ionized water. On the other hand, an alkaline solution (B) 2M was prepared, with a molar relationship of $\text{KOH}/\text{K}_2\text{CO}_3=2$, and for this

15 9.30g of K_2CO_3 and 8.51g of KOH were dissolved in 100 cm^3 of de-ionized water. Solutions A and B were added simultaneously to a glass reactor containing previously 100 cm^3 of de-ionized water. The precipitation was carried out at a constant pH of 9. The solution obtained was kept under vigorous mechanical stirring, at a temperature of 353 K for 18 hours. Afterwards, the precipitate obtained was washed and filtered

20 with hot de-ionized water (353 K) 8 times in order to eliminate excess ions. Drying took place at a temperature of 373K during 24 h.

Table 8 shows the results of the texture analyses of the calcined hydrotalcites. Figures 1 to 4 show the diffraction patterns of the X-rays of such compounds, where we may appreciate a hydrotalcite type structure.

5 **Table 8. Developed formula and textural properties of HT's .**

Sample*	Area BET (m ² /g)	Dp (nm)	Vp (cm ³ /g)
[Mg _{0.643} Fe _{0.357} (OH) ₂](CO ₃) _{0.143} ·0.81H ₂ O	177	2-12	0.391
[Mg _{0.744} Al _{0.256} (OH) ₂](CO ₃) _{0.128} ·0.85H ₂ O	276	7-16	0.674
[Zn _{0.75} Al _{0.25} (OH) ₂](CO ₃) _{0.125} ·0.84H ₂ O	48	2-7	0.085
[Ni _{0.833} Al _{0.167} (OH) ₂](CO ₃) _{0.084} ·0.68H ₂ O	260	2-5	0.511
[Mg _{0.670} Fe _{0.330} (OH) ₂](CO ₃) _{0.165} ·0.80 H ₂ O	159	5-10	0.362
[Mg _{0.730} Al _{0.270} (OH) ₂](CO ₃) _{0.135} ·0.71 H ₂ O	234	12	0.564
[Zn _{0.750} Al _{0.250} (OH) ₂](CO ₃) _{0.125} ·0.84 H ₂ O	51	2-12	0.112

*Textural properties of calcined samples at 923K in air atmosphere for 4h.

Dp: Average pore diameter. Vp: Total pore volume.

Anion Exchange:

Given that in certain of the aforementioned preparations, all or some of the precursor salts, where there were metallic chlorides ((Mg 0.670 Fe 0.330 (OH)₂) (CO₃) 0.165.0.80 H₂O, [Mg_{0.730} Al_{0.270} (OH)₂] (CO₃)_{0.135} 0.71 H₂O, [Zn_{0.750} Al_{0.250} (OH)₂] (CO₃)_{0.125} .0.84 H₂O, [Mg_{0.655} Al_{0.115} Mn_{0.230} (OH)₂](CO₃)_{0.146} 0.729 H₂O), an anionic exchange was effected after the synthesis in such compounds, to have carbonate anions in the interlaminar region, more easily removable than chlorides, since these latter anions remain in hydrotalcites up to 1073 K, thus inhibiting the basic sites. The exchange protocol was the following: An 0.2 M solution of K₂CO₃, was placed in contact with the sample to be exchanged, during 3 hours, under vigorous stirring, at a temperature of 343K. Afterwards, it was washed and filtered 8 times with de-ionized water. Drying of the product obtained veces was performed at 373K for 24 h. In order to obtain a high degree of carbonate anion exchange, the above operation is repeated once more.

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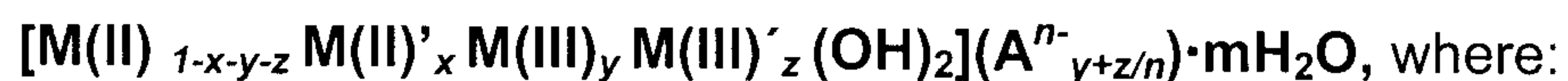
NOVELTY OF THE INVENTION

After this invention has been described, it is considered a novelty and therefore what is contained in the following clauses is claimed as property:

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1. A procedure for obtaining mixed multimetallic oxides derived from hydrotalcite type compounds, characterized in that the laminar metallic hydroxides obtained are constituted by three or four metallic cations, forming part of the sheets of the hydrotalcite type material represented by the following formula:

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$[\text{M(II)} + \text{M(II)'}] / [(\text{M(III)} + \text{M(III)'})]$, is the molar relationship between the divalent cations and the trivalent cations, and it is found between 0.5 and 10.

15

M(II) represents an element of group 2, 6-12 of the periodic table with valence equal to two.

M(II)' represents an element of group 2, 6-12 of the periodic table with valence equal to two or three, and this may be equal to **M(II)** but with different valence

M(III) represents an element of group 4-8, 13 with valence equal to 3 and different from **M(II)** and **M(II)'**.

20

M(III)' represents an element of group 4-8, 13 with valence equal to 3 and different from **M(II)** and **M(III)** or equal to **M(III)** but with different valence.

A , represents any anion located between the sheets comprised of the aforementioned cations.

n- , represents the negative electronic charge of the interlaminar anion, and it may be from -1 to -8 ; $x=0.01$ up to 0.99 ; $y=0.01$ up to 0.99 and $z=0.01$ up to

0.99. The preparation of the multimetallic hydrotalcites subject matter of this invention comprises the following stages: (1) Aqueous or organic solutions containing three or more cations are prepared, where their precursor compounds are oxides, hydroxides, chlorides, nitrates, and/or acetates or any combination among them; (2) An alkaline solution of 0.5 to 10 molarity, preferably from 1-5 molar, of KOH, K_2CO_3 , $(NH_4)_2CO_3$, $NH_4(OH)$, Urea or any different alkaline compound, different from sodium, or any combination among them; (3) Solutions (1) and (2) are combined slowly to cause the co-precipitation of the cations in the form of hydroxides at a pH between 7 and 12, preferably between 8 and 10, at temperatures between 293 and 373 K, preferably 333 and 353K; (4) Washing of the precipitate containing the hydrotalcites with water, until there is the removal of all the non-precipitated ions; (5) Drying between 333 and 473K, with air, nitrogen or at vacuum, or any combination among them; (6) Finally, the hydrotalcites are calcined between 573 and 1273K, preferably between 673 and 973K, with a current of air, oxygen, nitrogen or any combination among them.

2. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clause 1, characterized in that the interlaminar

A anions are of inorganic or organic origin and form volatile gases at temperatures between 573 and 1173K.

3. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 and 2, characterized in that the interlaminar **A** anions are of inorganic origin and are found in the interlaminar region as unique anionic species, or in combination with other different non-volatile or volatile anions between 573 and 1273K.
4. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 3, characterized in that M(II) is Mg^{2+} , M(II)' is Zn^{2+} , M(III) is Al^{3+} and M(III)' is zero.
5. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 4, characterized in that M(II) is Mg^{2+} , M(II)' is Ni^{2+} and M(III) is Al^{3+} and M(III)' is zero.
6. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 5, characterized in that M(II) is Mg^{2+} , M(II)' is Cu^{2+} and M(III) is Al^{3+} and M(III)' is zero.
7. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 6, characterized in that M(II) is Mg^{2+} , M(II)' is Co^{2+} and M(III) is Al^{3+} and M(III)' is zero.
8. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 7, characterized in that M(II) is Mg^{2+} , M(II)' is Fe^{2+} and M(III) is Al^{3+} and M(III)' is zero.

9. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 8, characterized in that M(II) is Mg^{2+} , M(II)' is zero, M(III) is Al^{3+} , and M(III)' is Fe^{3+} or Co^{3+} or Mn^{3+} or Ga^{3+} or Cr^{3+} .
- 5 10. A procedure for obtaining mixed metallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 9, characterized in that M(II) is Mg^{2+} , M(II)' is Fe^{2+} and M(III) is Al^{3+} , and M(III)' is Fe^{3+} or Co^{3+} or Mn^{3+} or Ga^{3+} or Cr^{3+} .
- 10 11. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 10, characterized in that M(II) is Mg^{2+} , M(II)' is Co^{2+} and M(III) is Al^{3+} , and M(III)' is Fe^{3+} or Co^{3+} or Mn^{3+} or Ga^{3+} or Cr^{3+} .
- 15 12. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 11, characterized in that M(II) is Mg^{2+} , M(II)' is Ni^{2+} and M(III) is Al^{3+} , and M(III)' is Fe^{3+} or Co^{3+} or Mn^{3+} or Ga^{3+} or Cr^{3+} .
- 20 13. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 12, characterized in that M(II) is Mg^{2+} , M(II)' is Zn^{2+} and M(III) is Al^{3+} , and M(III)' is Fe^{3+} or Co^{3+} or Mn^{3+} or Ga^{3+} or Cr^{3+} .
14. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 13, characterized in that M(II) is

Mg^{2+} , M(II) is Cu^{2+} and M(III) is Al^{3+} , and M(III) is Fe^{3+} or Co^{3+} or Mn^{3+} or Ga^{3+} or Cr^{3+} .

15. A procedure for obtaining mixed multimetallic oxides derived from multimetallic hydrotalcites, in accordance with clauses 1 to 14, characterized in that the metallic salts, precursors of multimetallic hydrotalcites, are oxides, hydroxides, chlorides, nitrates, and/or acetates or any combination among them.
16. The mixed multimetallic oxides obtained as of clauses 1 to 15, and these are characterized by having CO_2 (ΔH) adsorption heats, measured at room temperature, comprised between 50 and 150 KJ/mol, preferably between 60 and 120 KJ/mol with a number of basic sites between 0.2 and 5.0 $\mu\text{mol CO}_2$ adsorbed/ m^2 , preferably between 0.4 and 3.0 $\mu\text{mol CO}_2$ adsorbed/ m^2 .
17. The resulting multimetallic oxides, in accordance with clause 16, and these are characterized by being obtained using NaOH and Na_2CO_3 , and after the laminar structure is destroyed by calcining between 573 and 1073K, they are rebuilt with the alkaline compounds of clause 1, and solutions containing anions according to clauses 2 and 3, or any combination of them.
18. The resulting multimetallic oxides, in accordance with clause 17, and these are characterized in that they appear in any physical form; preferably as powders with a particle size between 20 and 120 microns, preferably between 60 and 80 microns, and densities between 0.7 and 1.0 cm^3/g , preferably between 0.8 and 0.9 cm^3/g .

19. The resulting multimetallic oxides, in accordance with clauses 1 to 15, characterized in that for obtaining them non-hydrotalcite compounds are combined, and after being mixed they are calcined between 673 and 1073K, preferably between 773 and 973K, and they are transformed into multimetallic hydrotalcites when placing them in contact with water or aqueous solutions containing anions according to clauses 2 and 3.
20. The mixed multimetallic oxides resulting from calcining in accordance with clause 19, which are characterized by removing the SO₂ and/or SO₃ of gas currents resulting from the combustion of coal, coke or hydrocarbons, preferably from the gases of fluid catalytic disintegration plants.
21. Mixed multimetallic oxides obtained in accordance with clause 20, characterized in that when placed in contact with a gas current containing SO₂ or SO₃, at a temperature between 673 and 1273K, they absorb said sulfur oxides.
22. The mixed multimetallic oxides obtained in accordance with the procedure described in clause 21, which are characterized in that they have capacities of total absorption of sulfur oxides comprised between 2.5 and 30 % weight of S/m² of absorbent material, at 923K, preferably between 5 to 20% weight of S/m² of absorbent material, at 923K.
23. The mixed oxides obtained in accordance with the procedure described in clause 22, and these are characterized in that they present SO₂ or SO₃ absorption speeds of 0.25 at 4.0 min⁻¹ at 923 K, preferably from 1.3 to 3.44 min⁻¹ at 923 K.

24. The resulting mixed oxides in accordance with clause 23, after having absorbed previously SO_2 and/or SO_3 at a temperature between 673 and 1273K, are characterized in that they place themselves in contact with a gas current containing hydrocarbons and/or hydrogen, to remove the sulfur oxides and regenerate the products of calcining of hydrotalcites.
25. The mixed multimetallic oxides obtained in accordance with clauses 1 to 24 are characterized in that they present a reduction speed between 0.2 and 5 min^{-1} , comprised between 793 and 873 K, preferably from 2 to 3.25 min^{-1} at 873K.
26. The mixed multimetallic oxides obtained in accordance with clause 25 are characterized in that they present a reduction percentage (of removal of absorbed SO_x) between 30 and 100% at 873K, preferably from 80 to 96% at 873K.
27. The mixed multimetallic oxides obtained in accordance with clause 26 are characterized in that they present BET areas from 150 to $260 \text{ m}^2/\text{g}$, a pore diameter from 9 to 25 nanometers and a pore volume from 0.112 to $0.870 \text{ cm}^3/\text{g}$.

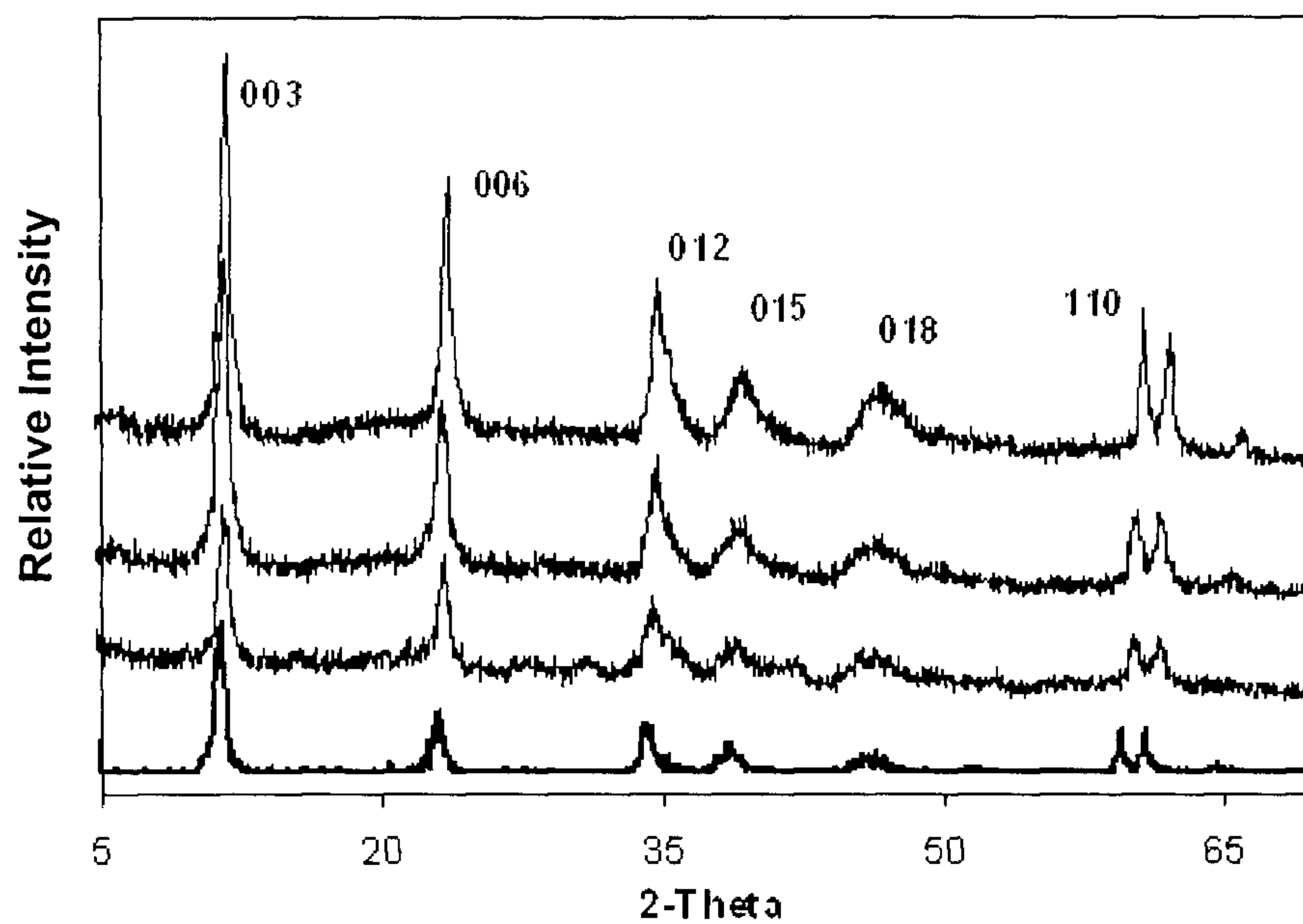


Figure 1. X-ray diffraction patterns of the hydrotalcite-like materials:

- a) $[\text{Mg}_{0.651}\text{Fe}_{0.063}\text{Al}_{0.286}(\text{OH})_2](\text{CO}_3)_{0.174} \cdot 0.821 \text{H}_2\text{O}$
- b) $[\text{Mg}_{0.714}\text{Fe}_{0.107}\text{Al}_{0.179}(\text{OH})_2](\text{CO}_3)_{0.143} \cdot 0.828 \text{H}_2\text{O}$
- c) $[\text{Mg}_{0.704}\text{Fe}_{0.192}\text{Al}_{0.104}(\text{OH})_2](\text{CO}_3)_{0.148} \cdot 0.920 \text{H}_2\text{O}$
- d) $[\text{Mg}_{0.688}\text{Fe}_{0.311}(\text{OH})_2](\text{CO}_3)_{0.160} \cdot 0.800 \text{H}_2\text{O}$

2/10

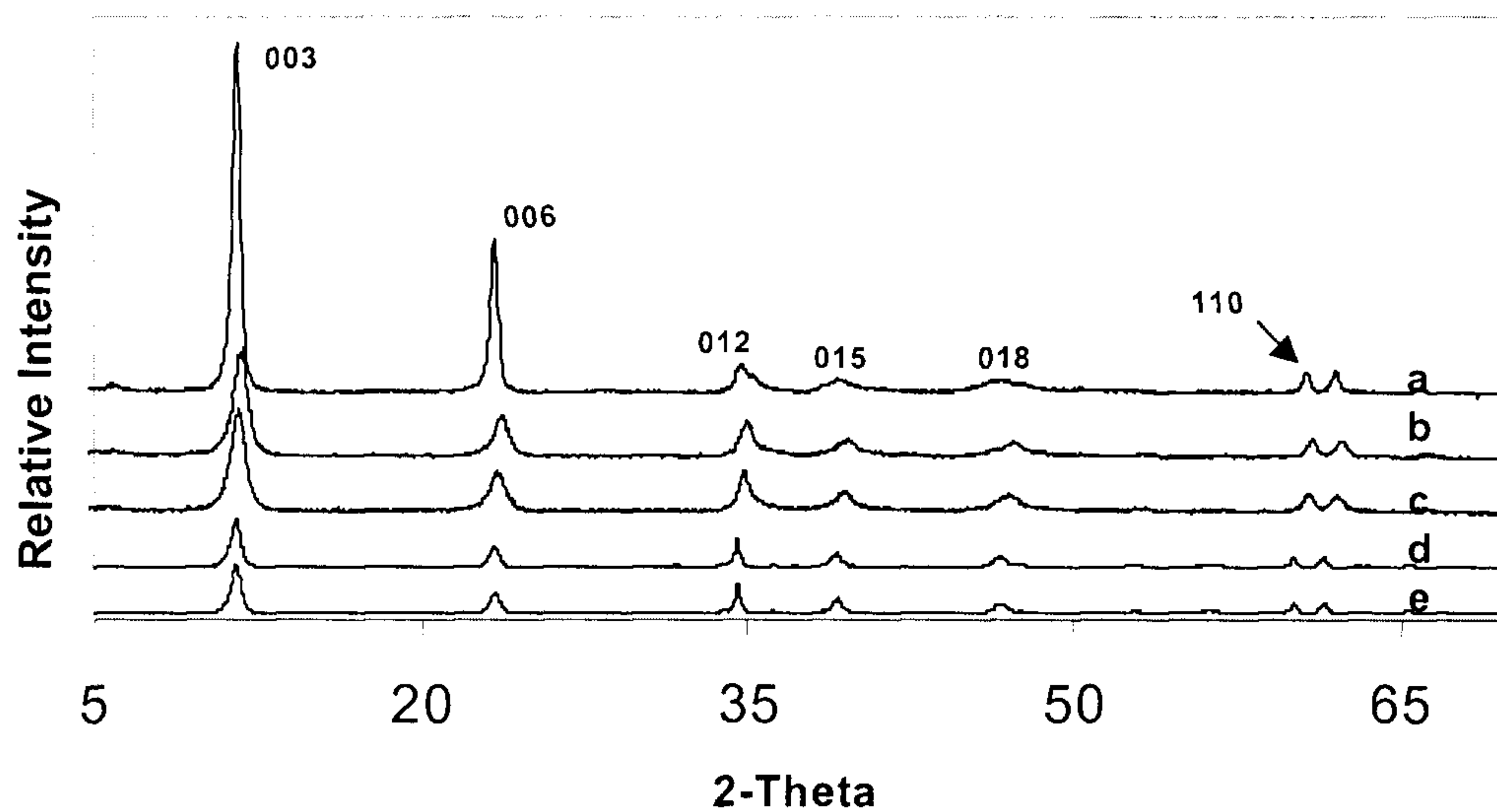


Figure 2. X-ray diffraction patterns of the hydrotalcite-like materials:

- a) $[\text{Mg}_{0.478}\text{Zn}_{0.232}\text{Al}_{0.290}(\text{OH})_2] (\text{CO}_3)_{0.145} \cdot 0.857 \text{H}_2\text{O}$
- b) $[\text{Mg}_{0.487}\text{Zn}_{0.201}\text{Al}_{0.312}(\text{OH})_2] (\text{CO}_3)_{0.156} \cdot 0.902 \text{H}_2\text{O}$
- c) $[\text{Mg}_{0.493}\text{Zn}_{0.165}\text{Al}_{0.342}(\text{OH})_2] (\text{CO}_3)_{0.171} \cdot 0.978 \text{H}_2\text{O}$
- d) $[\text{Zn}_{0.75}\text{Al}_{0.25}(\text{OH})_2] (\text{CO}_3)_{0.125} \cdot 0.840 \text{H}_2\text{O}$
- e) $[\text{Mg}_{0.744}\text{Al}_{0.256}(\text{OH})_2] (\text{CO}_3)_{0.128} \cdot 0.850 \text{H}_2\text{O}$.

3/10

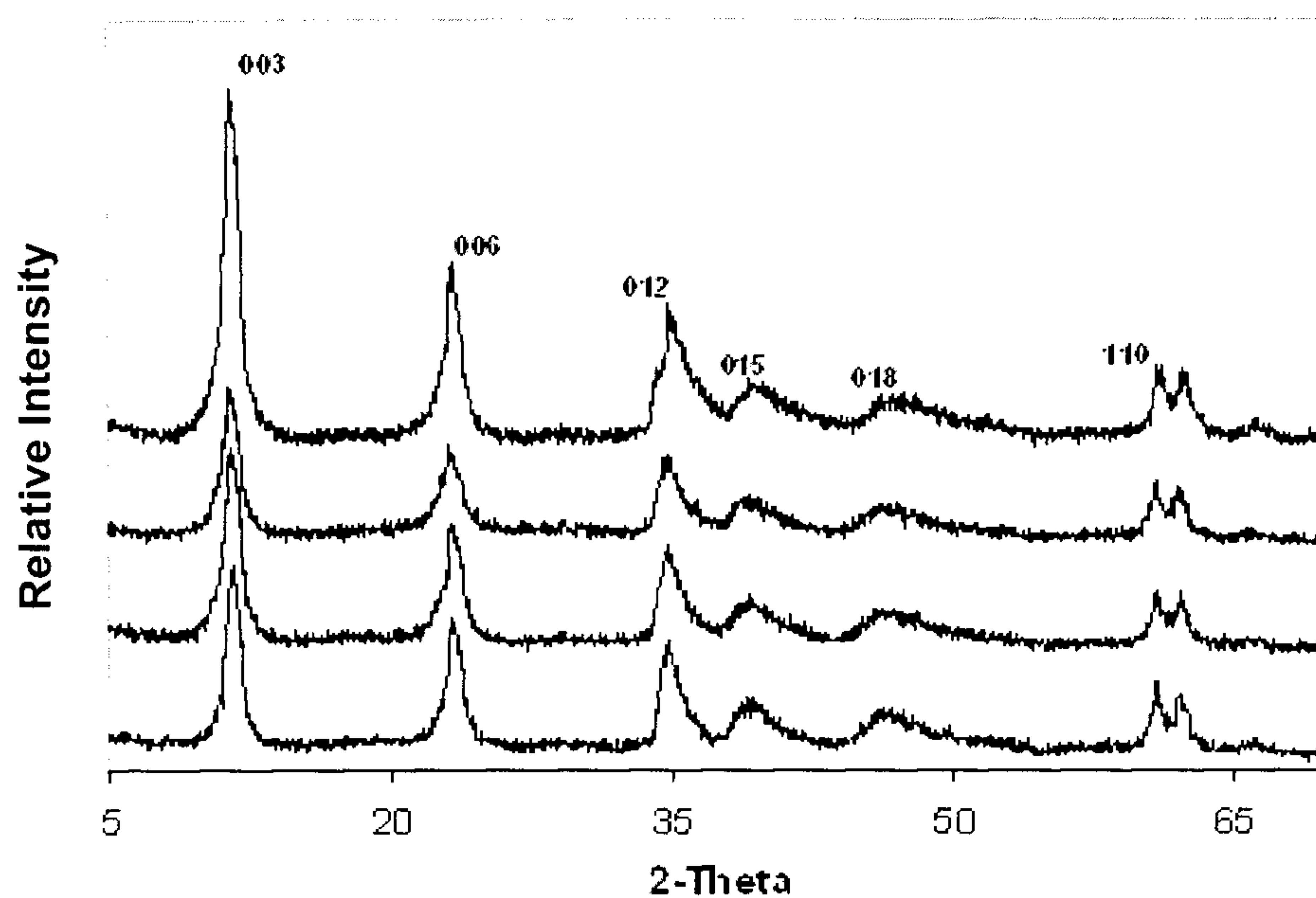


Figure 3. X-ray diffraction patterns of the hydrotalcite-like materials:

- a) $[\text{Ni}_{0.833}\text{Al}_{0.167}(\text{OH})_2](\text{CO}_3)_{0.084} \cdot 0.683 \text{H}_2\text{O}$.
- b) $[\text{Mg}_{0.457}\text{Ni}_{0.292}\text{Al}_{0.251}(\text{OH})_2](\text{CO}_3)_{0.126} \cdot 0.849 \text{H}_2\text{O}$
- c) $[\text{Mg}_{0.483}\text{Ni}_{0.222}\text{Al}_{0.295}(\text{OH})_2](\text{CO}_3)_{0.147} \cdot 0.876 \text{H}_2\text{O}$
- d) $[\text{Mg}_{0.589}\text{Ni}_{0.111}\text{Al}_{0.300}(\text{OH})_2](\text{CO}_3)_{0.150} \cdot 0.885 \text{H}_2\text{O}$

4/10

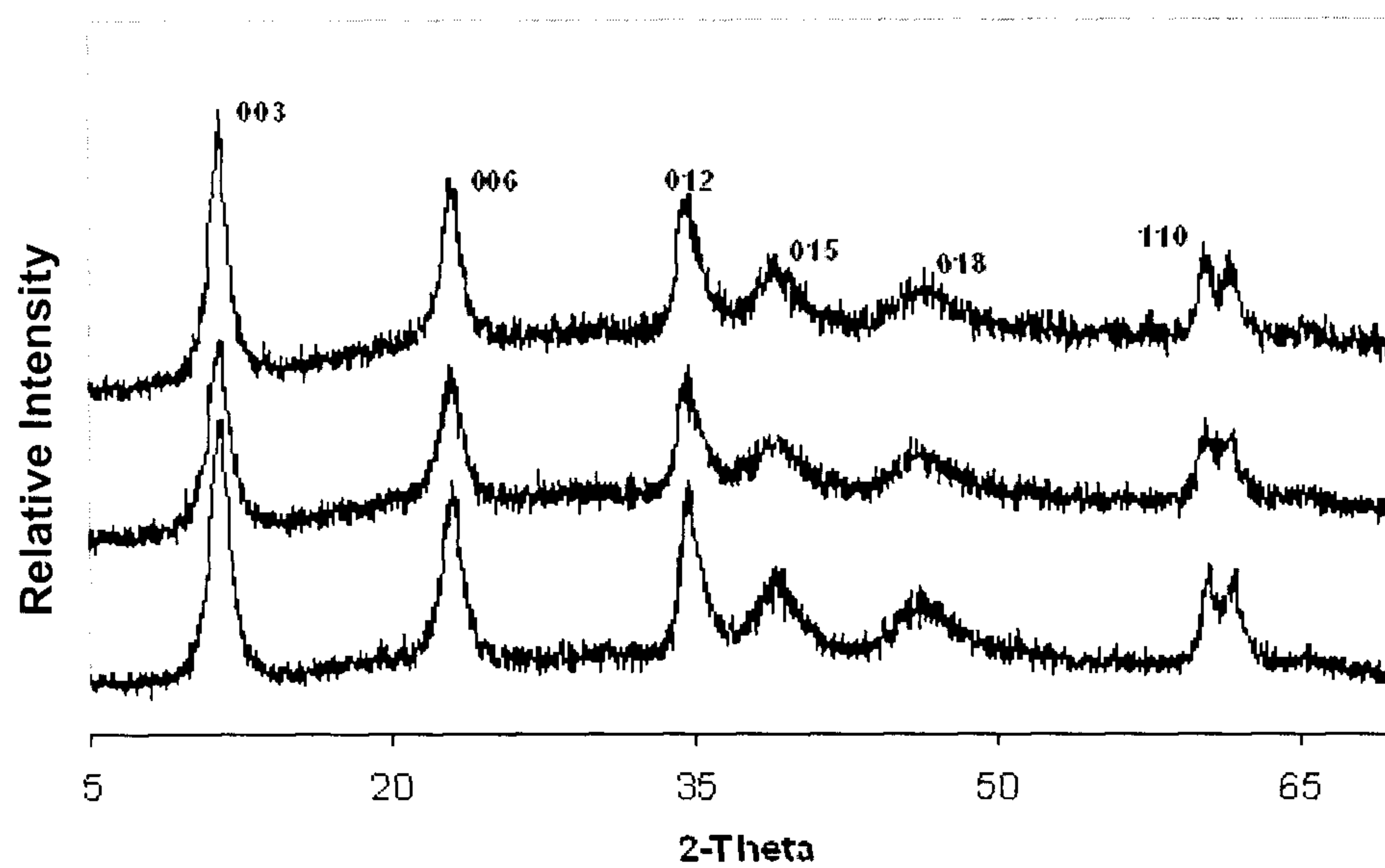


Figure 4. X-ray diffraction patterns of the hydrotalcite-like materials:

- a) $[\text{Mg}_{0.600}\text{Cu}_{0.148}\text{Al}_{0.252}(\text{OH})_2](\text{CO}_3)_{0.126} \cdot 0.709 \text{H}_2\text{O}$
- b) $[\text{Mg}_{0.658}\text{Cu}_{0.098}\text{Al}_{0.244}(\text{OH})_2](\text{CO}_3)_{0.122} \cdot 0.687 \text{H}_2\text{O}$
- c) $[\text{Mg}_{0.307}\text{Cu}_{0.118}\text{Al}_{0.578}(\text{OH})_2](\text{CO}_3)_{0.289} \cdot 0.803 \text{H}_2\text{O}$

5/10

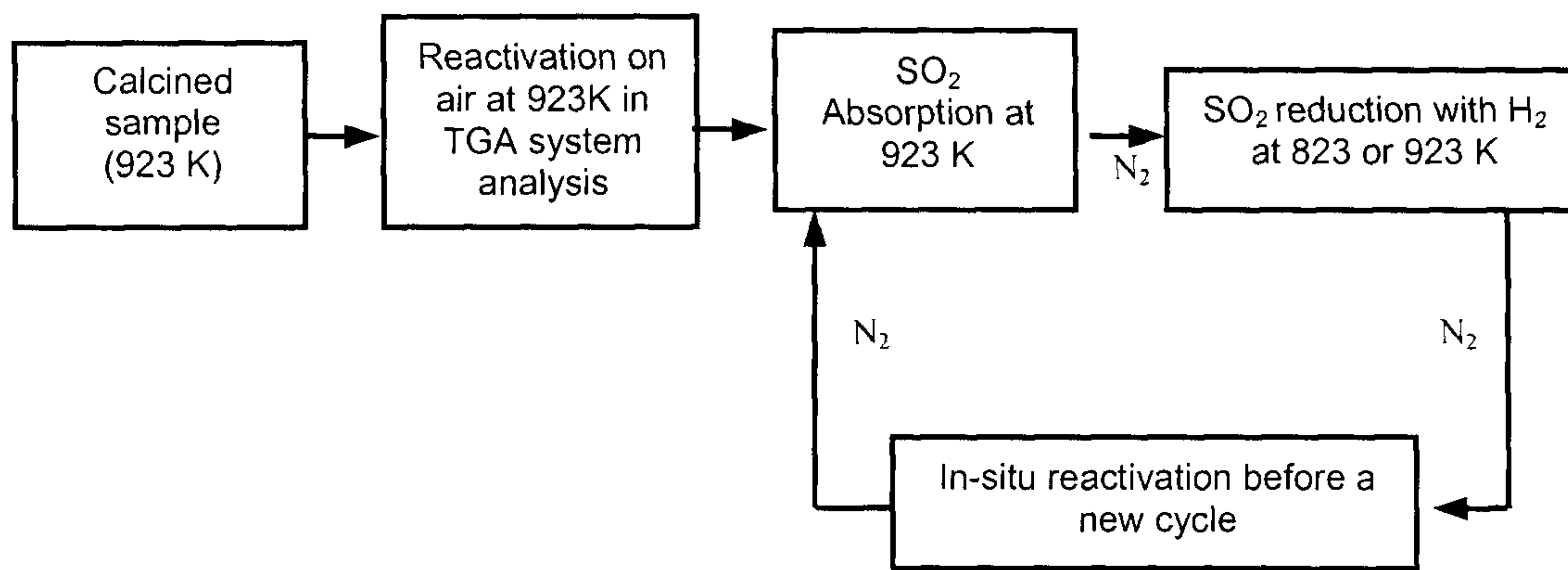


Figure 5. Evaluation scheme of SO₂ absorption-reduction test on multimetallic calcined hydrotalcite-like compounds.

6/10

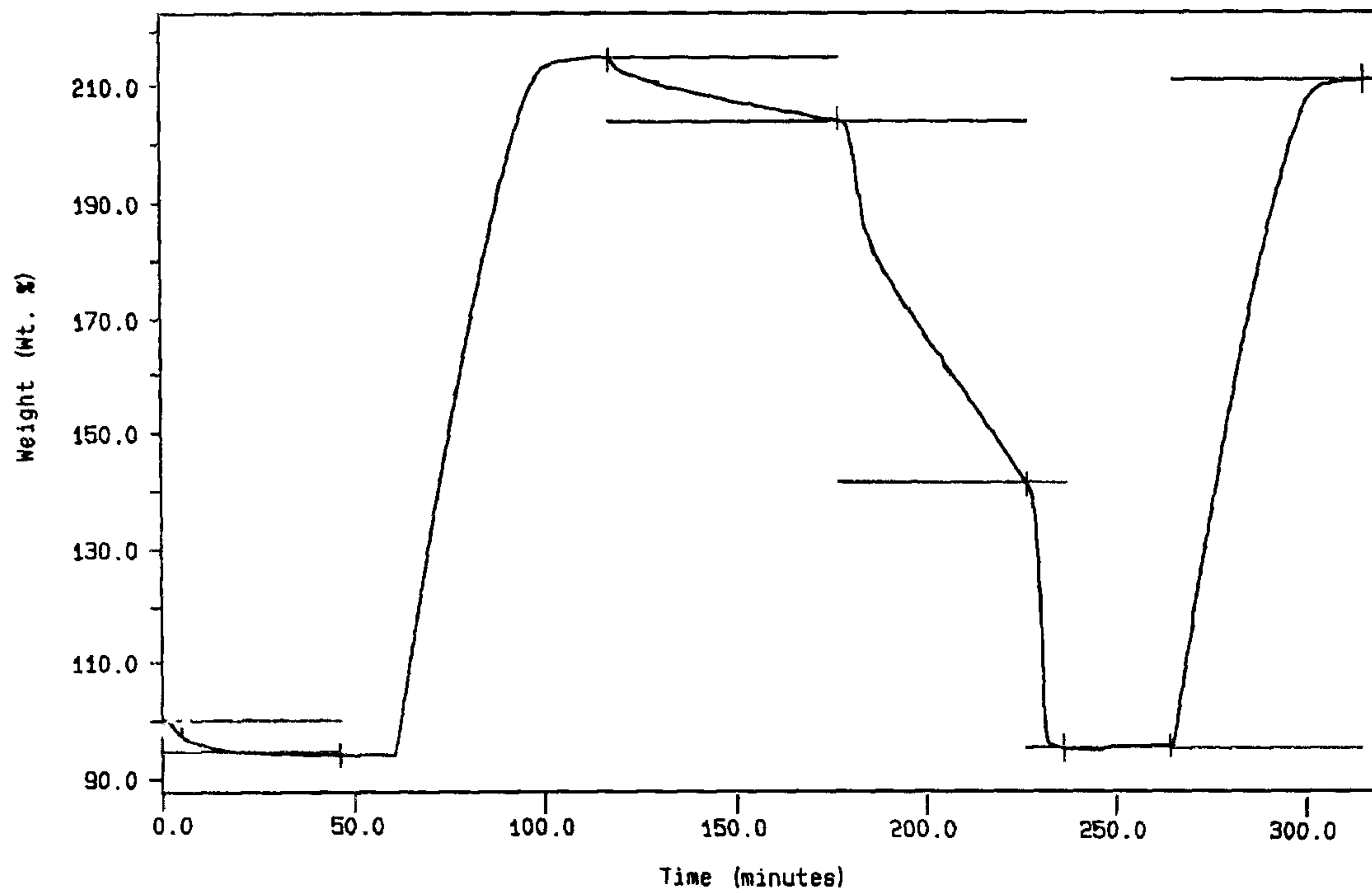
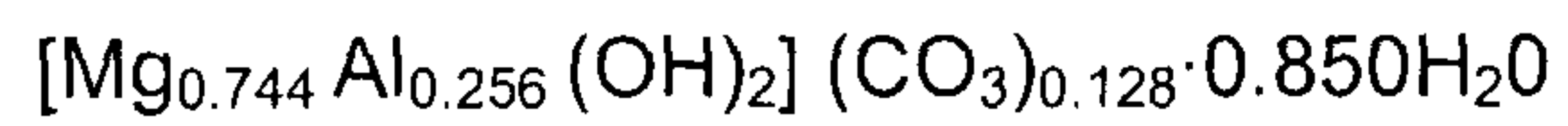


Figure 6. TGA-SO₂ Absorption on calcined:



7/10

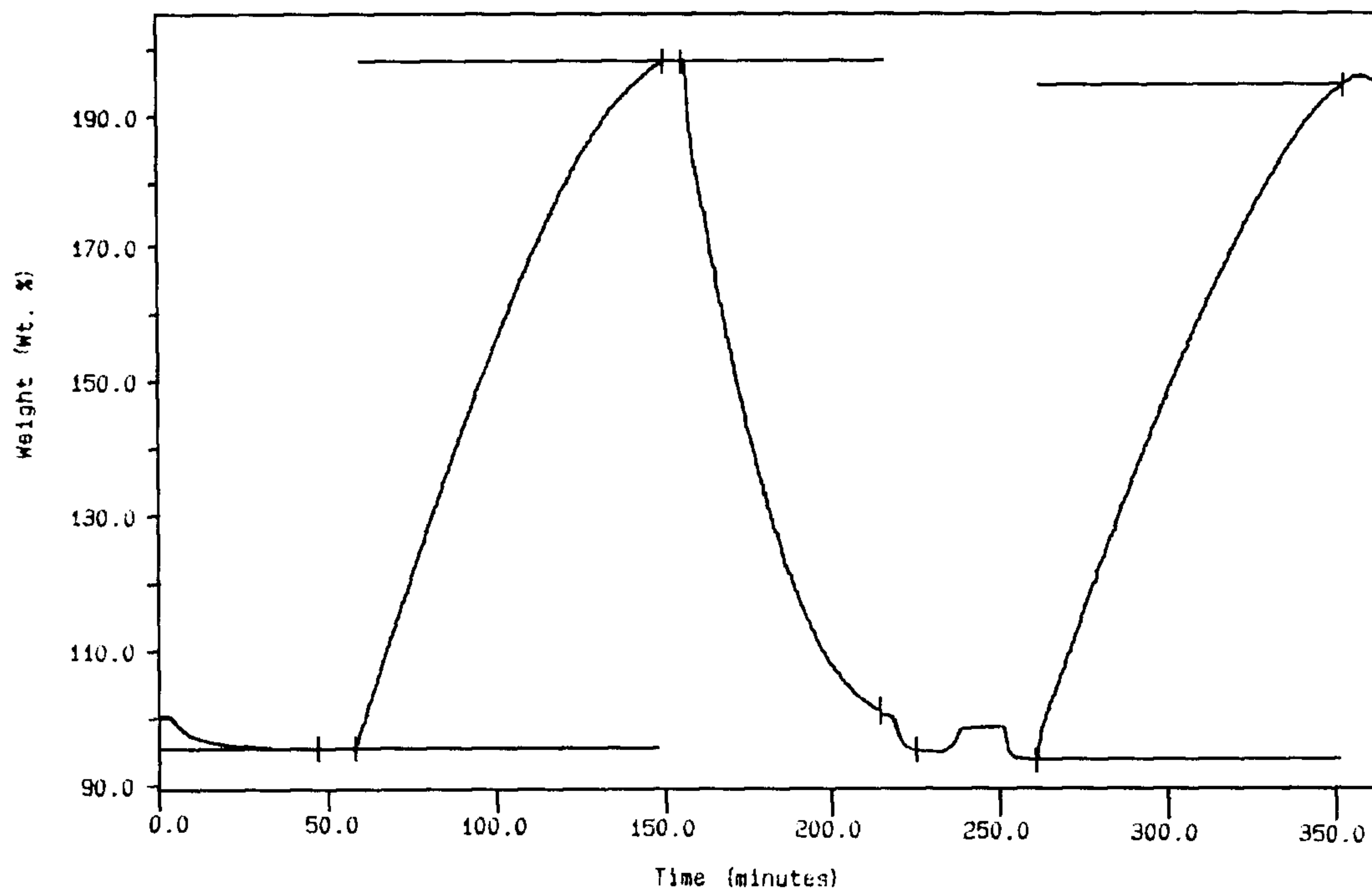


Figure 7. TGA-SO₂ Absorption on calcined:
[Mg_{0.651} Fe_{0.063} Al_{0.286}(OH)₂] (CO₃)_{0.174} · 0.821 H₂O

8/10

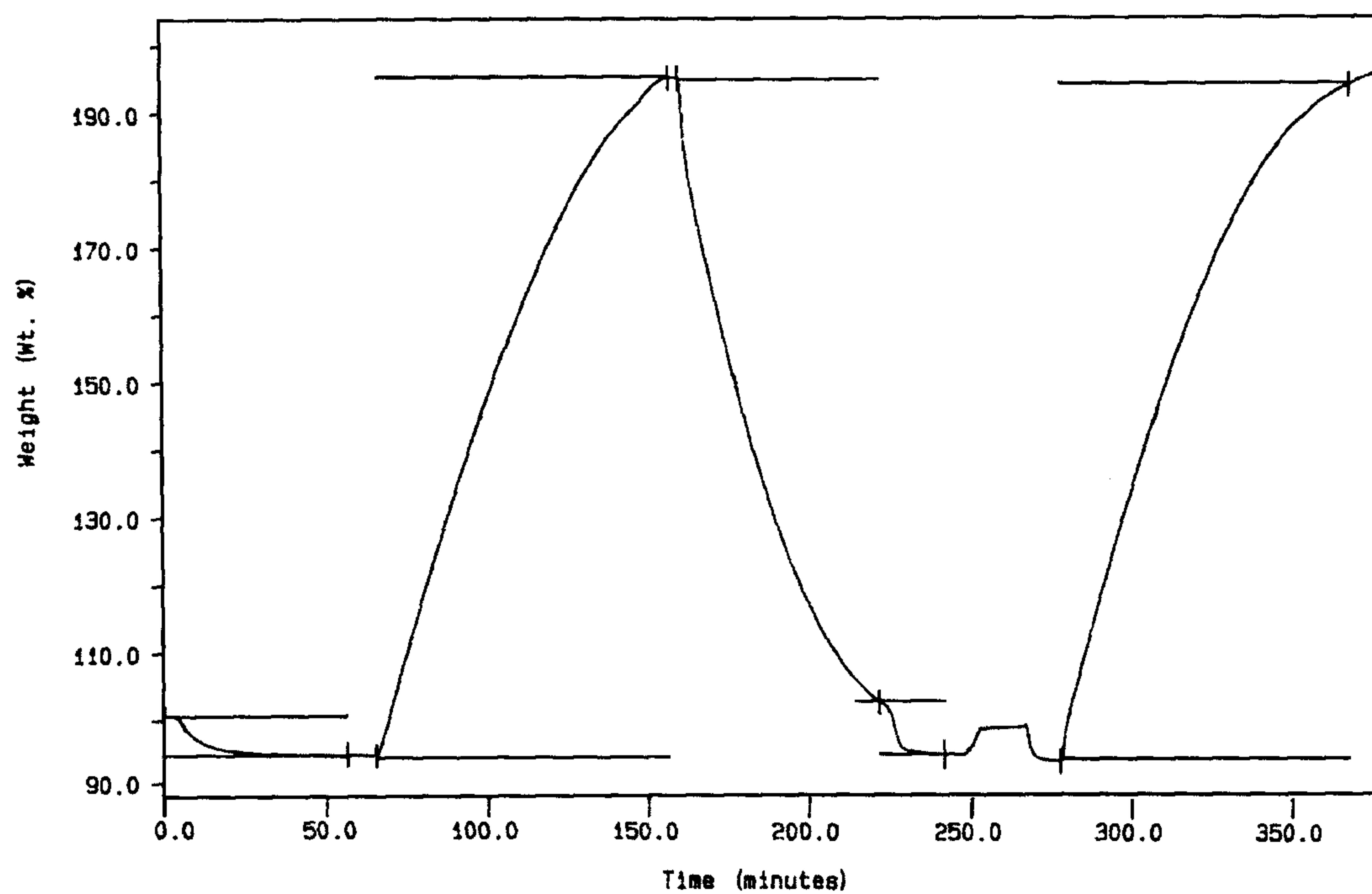


Figure 8. TGA-SO₂ Absorption on calcined:
[Mg_{0.714} Fe_{0.107} Al_{0.179}(OH)₂] (CO₃)_{0.143} · 0.828 H₂O

9/10

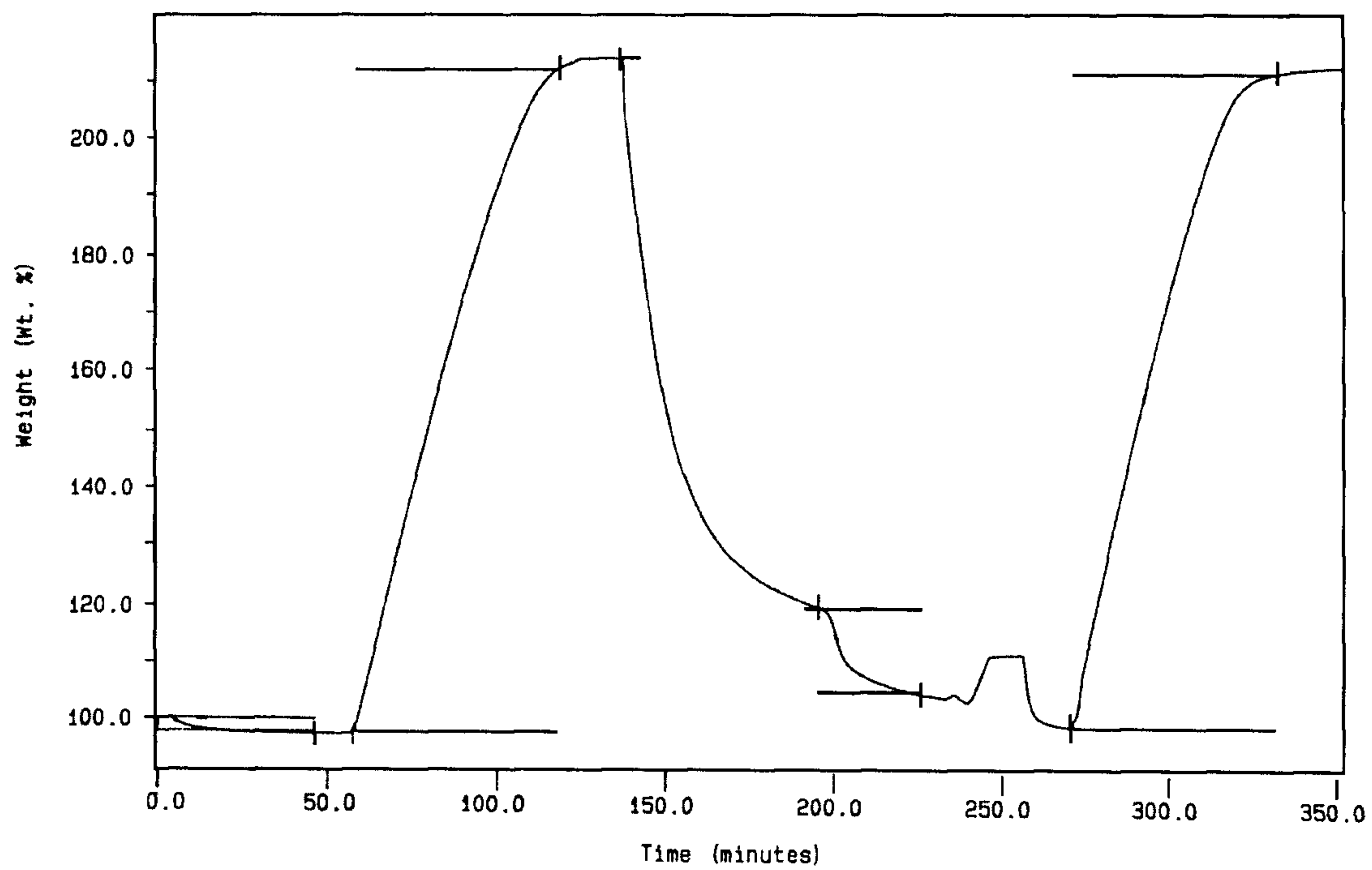


Figure 9. TGA-SO₂ Absorption on calcined:
[Mg_{0.704} Fe_{0.192} Al_{0.104} (OH)₂] (CO₃)_{0.148} · 0.920 H₂O

10/10

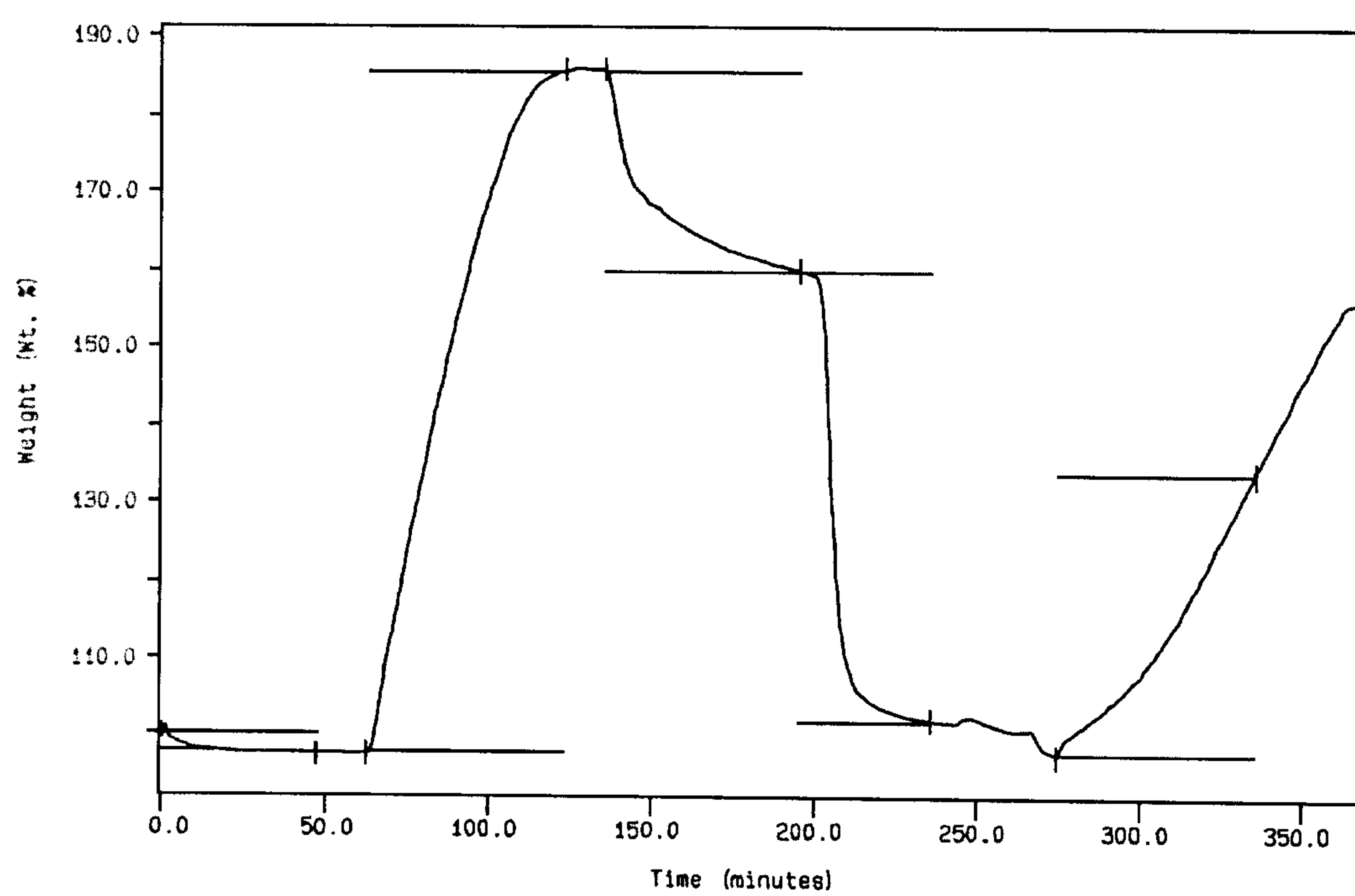


Figure 10. TGA-SO₂ Absorption on calcined:
[Mg_{0.487} Zn_{0.201} Al_{0.312} (OH)₂] (CO₃)_{0.156} · 0.902H₂O