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(54) **NOVEL PROCESS FOR MAKING
BISPHOSPHONIC ACIDS USING DILUENTS
OTHER THAN HALOGENATED
HYDROCARBONS**

(76) Inventors: **Rami Lidor-Hadas**, Kfar Saba
(IL); **Zvi Harel**, Kfar Saba (IL);
Revital Lifshitz-Liron, Herzlia
(IL); **Eti Kovalevski-Ishai**, Netanya
(IL)

Correspondence Address:
KENYON & KENYON LLP
ONE BROADWAY
NEW YORK, NY 10004 (US)

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(57) **ABSTRACT**

Provided is a novel method of making bisphosphonic acids, e.g. risedronic acid, including the step of combining a carboxylic acid, phosphorous acid, and a halophosphorous compound in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid. When the diluent is an aromatic hydrocarbon, an inert support or ortho-phosphoric acid codiluent is advantageously included.

**NOVEL PROCESS FOR MAKING
BISPHOSPHONIC ACIDS USING DILUENTS
OTHER THAN HALOGENATED
HYDROCARBONS**

**CROSS-REFERENCE TO RELATED
APPLICATION**

[0001] This application is a divisional of U.S. Ser. No. 11/350,462, filed Feb. 8, 2006, which is a divisional of U.S. Ser. No. 10/442,001, filed May 19, 2003, now U.S. Pat. No. 7,038,083 B2, which claims the benefit of U.S. Provisional Application Ser. No. 60/381,284, filed May 17, 2002, Ser. No. 60/401,313, filed Aug. 6, 2002, Ser. No. 60/423,337, filed Nov. 1, 2002, Ser. No. 60/431,838, filed Dec. 9, 2002, Ser. No. 60/450,193, filed Feb. 25, 2003 and Ser. No. 60/470,473, filed May 13, 2003.

FIELD OF THE INVENTION

[0002] The present invention relates to a method of making bisphosphonic acids, salts of which are useful in the treatment of bone disorders.

BACKGROUND OF THE INVENTION

[0003] The bisphosphonates, which are salts of bisphosphonic acids, are an important class of medicaments useful in the treatment of bone disorders such as Paget's disease and osteoporosis. See, e.g., Robert Marcus, *Agents Affecting Calcification and Bone Turnover*, in *Goodman and Gilman's The Pharmacological Basis of Therapeutics* 1519, 1537-39 (Joel G. Hardman & Lee E. Limbird, eds. in chief, 9th ed., 1996). The sodium salt of risedronic acid (i.e. [1-hydroxy-2-(3-pyridinyl)ethylidene]bis[phosphonic acid] monosodium salt), marketed under the trade name Actonel® and the sodium salt of [4-amino-1-hydroxybutylidene]bis[phosphonic acid] are examples of pharmaceutically useful bisphosphonates.

[0004] The bisphosphonates are derived from the corresponding bisphosphonic acids. Several methods have been reported for preparing 1-hydroxy-1,1-bisphosphonic acids. The syntheses are based on reacting a carboxylic acid with a mixture of phosphorous acid and one of the following phosphorous halides: phosphorous trichloride (PCl₃), phosphorous oxychloride (POCl₃), phosphorous pentachloride (PCl₅), phosphorous tribromide (PBr₃), phosphorous oxybromide (POBr₃) or phosphorous pentabromide (PBr₅), then quenching the reaction mixture with water or a nonoxidizing aqueous acid, followed by heating to hydrolyze the phosphorous intermediates to the final product.

[0005] U.S. Pat. No. 4,407,761 describes a synthesis of 4-amino-1-hydroxybutylidene-1,1-bisphosphonic acid (alendronic acid) and other bisphosphonic acids. The reaction can be carried out in the presence of a diluent, especially chlorinated hydrocarbons, especially chlorobenzene, which does not solubilize the reaction components and serves only as a heat carrier. The reaction starts as a two-phase system, in which the melted phase gradually thickens into a non-stirtable mass. This semi-solid sticky mass finally turns into a hard, rigid material, coating the walls of the reaction vessel, fouling the reactor and preventing smooth heat transfer and complicating product work-up. This process might be suitable for laboratory preparation of gram quantities of the product however, for commercial production it is not acceptable.

A solution to this caking and fouling problem is clearly required before the reaction can be economically practiced on a commercial scale.

[0006] The above-described flaws of the process of the '761 patent were acknowledged by Kieczkowski et al. See, e.g. Kieczkowski et al., *J. Org. Chem.*, 60(25) 8310, 8311 (1995). In application for Canadian Patent 2,018,477 and 2,044,923, Kieczkowski et al. revealed a solution to the solidification and fouling problem. Methanesulfonic acid (MSA) was used to solubilize the reaction components and keep the reaction mixture fluid up to completion of the reaction. Although the problems with physical characteristics of the reaction appeared solved, a safety problem surfaced.

[0007] Methanesulfonic acid reacts with phosphorous trichloride and, under adiabatic conditions, the reaction becomes self-heating at 85° C. and an uncontrolled exotherm occurs at reaction temperatures >140° C. Kieczkowski et al. acknowledged this safety issue and raised it in Example 1 of both above-cited Canadian applications. The safety concern is mentioned by the authors in somewhat more detail in the above cited article in the *Journal of Organic Chemistry*.

[0008] U.S. Pat. No. 5,908,959 (corresponding to WO 98/34940), assigned to Apotex Inc., describes a process for preparing alendronic acid comprising reacting 4-aminobutyric acid (GABA) with phosphorous acid and phosphorous trichloride in the presence of a polyalkylene(glycol) or derivatives thereof. However, it was reported that large quantities of polyalkylene(glycol), as well as toluene, are required for the reaction, making it inefficient for use on a large scale.

[0009] There remains a need for a safe and efficient industrial process for preparing bisphosphonic acids, especially risedronic acid, alendronic acid, and zoledronic acid that is free of the solidification problem.

[0010] The present inventors have surprisingly found that yield is improved and fouling caused by solidification problems is reduced if, in the reaction between a carboxylic acid (e.g. 3-pyridyl acetic acid or its hydrochloride), H₃PO₃, and, for example, POCl₃, an aromatic hydrocarbon such as toluene, especially in the presence of ortho-phosphoric acid as codiluent, or a silicon oil such as polydimethylsiloxane, is used as a diluent instead of previously used halogenated hydrocarbons. The present inventors have also surprisingly found that the solidification and reactor fouling problem can be eliminated if the reaction between carboxylic acid, phosphorous acid, and, for example, POCl₃, is carried out in a diluent that is an aromatic hydrocarbon (e.g. toluene) in the presence of a heterogeneous solid support.

SUMMARY OF THE INVENTION

[0011] The present invention relates to a method of making a bisphosphonic acid and crystalline hydrates thereof including the step of combining a carboxylic acid with phosphorous acid and phosphorous oxychloride (POCl₃) in the presence of a diluent that is other than a halogenated hydrocarbon.

[0012] The diluents of the present invention include aromatic hydrocarbons such as toluene, xylene, and benzene, and inert silicone fluids such as polydimethylsiloxane ("PDMS") and polymethylphenylsiloxane ("PMPS"). The aromatic hydrocarbon diluents are not used with polyalkylene glycol codiluents.

[0013] In one aspect, the present invention relates to a method of making a bisphosphonic acid comprising the step of combining a carboxylic acid, phosphorous acid, and a halophosphorous compound selected from PCl₃, PCl₅,

POCl_3 , PBr_3 , POBr_3 , and PBr_5 , especially POCl_3 , in the presence of a diluent that is an aromatic hydrocarbon, especially toluene, or a silicone fluid, especially a poly(dimethylsiloxane) with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture.

[0014] In another aspect, the present invention relates to a method of making a bisphosphonic acid comprising the step of combining a carboxylic acid, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid, and a codiluent that is ortho-phosphoric acid, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture.

[0015] In another aspect, the present invention relates to a method of making a bisphosphonic acid comprising the step of combining a carboxylic acid, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture, and in the presence of a heterogeneous solid support.

[0016] In yet another aspect, the present invention relates to method of making a bisphosphonic acid comprising the step of combining a carboxylic acid, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture, wherein the phosphorous acid and the second phosphorous compound that is a halophosphorous compound are added in at least first and second portions.

[0017] In another aspect, the present invention relates to a method of making a bisphosphonic acid comprising the step of combining a carboxylic acid selected from 4-aminobutanoic acid, (3-pyridyl)ethanoic acid, (1-imidazolyl)ethanoic acid, N-(n-pentyl)-N-methyl-3-aminopropanoic acid, 2(imidazo[1,2-a]pyridin-3-yl)ethanoic acid, and 6-aminohexanoic acid, and the hydrochlorides thereof, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 , especially POCl_3 , in the presence of a diluent that is an aromatic hydrocarbon, especially toluene, or a silicone fluid, especially poly(dimethylsiloxane) with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture. When the diluent is an aromatic hydrocarbon, a heterogeneous solid support and/or ortho-phosphoric acid can also be advantageously included in the combination.

[0018] In still a further aspect, the present invention relates to a method of making alendronic acid monohydrate comprising the steps of:

[0019] a) combining 4-aminobutanoic acid, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 at a temperature of about 80°C . to about 100°C . in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid to form a reaction mixture, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in

the reaction mixture, optionally including ortho-phosphoric acid codiluent, or, when the diluent is an aromatic hydrocarbon, a heterogeneous solid support

[0020] b) combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,

[0021] c) separating the aqueous phase,

[0022] d) combining the aqueous phase with ethanol whereby a suspension comprising alendronic acid is formed, and

[0023] e) isolating alendronic acid monohydrate from the suspension.

[0024] In another aspect, the present invention relates to a method of making risedronic acid monohydrate comprising the steps of:

[0025] a) combining (3-pyridyl)ethanoic acid or its hydrochloride salt, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 at a temperature of about 80°C . to about 100°C . in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid to form a reaction mixture, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture, optionally including ortho-phosphoric acid codiluent or, when the diluent is an aromatic hydrocarbon, a heterogeneous solid support,

[0026] b) combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,

[0027] c) separating the aqueous phase,

[0028] d) combining the aqueous phase with ethanol whereby a suspension comprising risedronic acid is formed, and

[0029] e) isolating risedronic acid monohydrate from the suspension.

[0030] In a further aspect, the present invention relates to a method of making zoledronic acid monohydrate comprising the steps of:

[0031] a) combining (1-imidazolyl)ethanoic acid or its hydrochloride, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 at a temperature of about 80°C . to about 100°C . in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid to form a reaction mixture, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture, optionally including ortho-phosphoric acid codiluent or, when the diluent is an aromatic hydrocarbon, a heterogeneous solid support,

[0032] b) combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,

[0033] c) separating the aqueous phase,

[0034] d) combining the aqueous phase with ethanol whereby a suspension comprising zoledronic acid is formed, and

[0035] e) isolating zoledronic acid monohydrate from the suspension.

[0036] In another aspect, the present invention relates to a method of making ibandronic acid comprising the steps of:

[0037] a) combining N-methyl-N-(n-pentyl)-3-aminopropanoic acid, phosphorous acid, and a halophospho-

rous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 at a temperature of about 80°C . to about 100°C . in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid to form a reaction mixture, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture, optionally including ortho-phosphoric acid codiluent or, when the diluent is an aromatic hydrocarbon, a heterogeneous solid support,

[0038] b) combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,

[0039] c) separating the aqueous phase,

[0040] d) combining the aqueous phase with ethanol whereby a suspension comprising ibandronic acid is formed, and

[0041] e) isolating ibandronic acid from the suspension.

[0042] In still a further aspect, the present invention relates to a method of making minodronic acid hemihydrate comprising the steps of:

[0043] a) combining 2-(imidazo[1,2-a]pyridin-3-yl) ethanoic acid, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 at a temperature of about 80°C . to about 100°C . in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid to form a reaction mixture, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture, optionally including ortho-phosphoric acid codiluent or, when the diluent is an aromatic hydrocarbon, a heterogeneous solid support,

[0044] b) combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,

[0045] c) separating the aqueous phase,

[0046] d) combining the aqueous phase with ethanol whereby a suspension comprising minodronic acid is formed, and

[0047] e) isolating minodronic acid from the suspension.

[0048] In yet a further aspect, the present invention relates to method of making neridronic acid comprising the steps of:

[0049] a) combining 6-aminohexanoic acid, phosphorous acid, and a halophosphorous compound selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 at a temperature of about 80°C . to about 100°C . in the presence of a diluent that is an aromatic hydrocarbon or a silicone fluid to form a reaction mixture, with the proviso that, when the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not present as a codiluent in the reaction mixture, optionally including ortho-phosphoric acid codiluent or a heterogeneous solid support,

[0050] b) combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,

[0051] c) separating the aqueous phase,

[0052] d) combining the aqueous phase with ethanol whereby a suspension comprising neridronic acid is formed, and

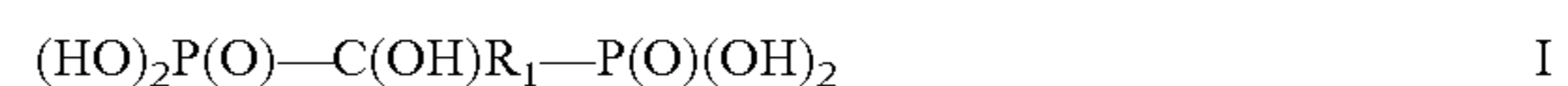
[0053] e) isolating minodronic acid from the suspension.

DETAILED DESCRIPTION OF THE INVENTION

[0054] As used herein in connection with a measured quantity, the term about refers to that variation in the measured quantity as would be expected by the skilled artisan making the measurement and exercising a level of care commensurate with the objective of the measurement and the precision of the measuring equipment used.

[0055] As used herein, the abbreviation TGA refers to the well-known technique of thermogravimetric analysis. The results of TGA analysis disclosed herein were obtained using a Mettler-Toledo Star^e system at a heating rate of 10° per minute with 40 mL/min nitrogen purge gas. Sample weights were approximately 10 mg.

[0056] The present invention provides a method for making bisphosphonic acids of general formula:



[0057] In preferred embodiments, R_1 is R_2CH_2- and R_2 can be C1 to C8 linear or branched alkyl, optionally bearing one or more substituents selected from amino, hydroxy, halo, aryl, heteroaryl, haloaryl, haloheteroaryl; or R_2 can be aryl or heteroaryl, optionally substituted with one or more substituents selected from amino, hydroxy, halo, aryl, heteroaryl, haloaryl, and haloheteroaryl. In particularly preferred embodiments, R_2 is either 2-aminoethyl (i.e. I is alendronic acid), 3-pyridyl (i.e. I is risedronic acid), imidazol-1-yl (i.e. I is zoledronic acid), $n\text{-C}_5\text{H}_{11}-\text{N}(\text{CH}_3)\text{CH}_2-$ (i.e. I is ibandronic acid), imidazo[1,2-a]pyridine-3-yl (i.e. I is minodronic acid), or 4-aminobutyl (i.e. I is neridronic acid).

[0058] When R_2 is either 2-aminoethyl, 3-pyridyl, or 1H-imidazol-1-yl, the product obtained from the practice of the method of the present invention is a crystalline monohydrate of the bisphosphonic acid. The crystalline monohydrates of risedronic acid, alendronic acid, and zoledronic acid are particular embodiments of the present invention.

[0059] In the method of the present invention, I are made by reacting a carboxylic acid (or, in the case of an amino acid or other acid having a quaternarizable nitrogen atom, optionally the hydrochloride) with phosphorous acid (H_3PO_3) and a second phosphorous compound that is preferably a halophosphorous compound (phosphorous halide) selected from PCl_3 , PCl_5 , POCl_3 , PBr_3 , POBr_3 , and PBr_5 , in the presence of a diluent that is other than a halogenated hydrocarbon. Phosphorous oxychloride, POCl_3 , is the preferred halophosphorous compound. Any carboxylic acid can be used in the practice of the present invention. 4-Aminobutanoic acid (γ -aminobutyric acid), 2-(pyridin-3-yl)ethanoic acid (3-pyridine acetic acid), 1-carboxymethylimidazole (1H-imidazol-1-yl acetic acid), N-pentyl-N-methyl-3-aminopropanoic acid, 2(imidazo[1,2-a]pyridin-3-yl)ethanoic acid, and 6-aminohexanoic acid, or hydrochlorides thereof, are preferred carboxylic acids in the practice of the present invention.

[0060] Preferably, 1.25 to 4 equivalents of H_3PO_3 and about 2 to about 4 equivalents of second phosphorous compound are used per equivalent of carboxylic acid. The diluent, which can also be referred to as a slurring agent, can be used in an amount between about 5 and about 8 volumes per weight [volumes per weight is milliliters per gram or liters per kilogram] of carboxylic acid, preferably about 5.5 volumes per weight [i.e. mL per g] of carboxylic acid. The skilled artisan will know to adjust the amount of diluent according to, among other things, the particular reactor being used and the viscosity of the reaction mixture.

[0061] The diluents of the present invention are selected from the group consisting of the aromatic hydrocarbons or from the group consisting of inert silicon oils, also called silicone fluids. Aromatic hydrocarbons are normally liquid at about 25° C. Toluene is a preferred aromatic hydrocarbon diluent of the present invention. Other aromatic hydrocarbons useful in the practice of the present invention include benzene and the xylenes. Toluene is the preferred aromatic hydrocarbon for use in the present invention.

[0062] When the diluent is an aromatic hydrocarbon, a polyalkylene glycol is not used as a codiluent (combined with the aromatic hydrocarbon). Polyalkylene glycols have the general structure $R_1-(Q-CH_2-O-)_n-R_2$, where R_1 and R_2 are the same or different and equal to hydrogen, lower alkyl, and lower acyl; Q is $CH(CH_3)$ or $-CH_2-$; and n is about 4 to about 250.

[0063] The silicon oils of the present invention include poly(dimethylsiloxane), "PDMS", a polymeric compound composed of repeating dimethylsiloxane units: $-[Si(CH_3)_2-O-]_n-$. PDMS is the preferred silicon oil of the present invention. Another type of silicon oil included in the present invention is poly(methylphenylsiloxane), "PMPS", a compound composed of repeating methylphenylsiloxane units: $-[(CH_3)(C_6H_5)Si-O-]_n-$.

[0064] Silicon oils, also known as silicone fluids, are particularly suited as diluents or slurring agents in the present invention because they are stable over a wide temperature range and are also non-toxic and therefore useful in the pharmaceutical industry. Silicon oil effectively dissolves the phosphorus acid and halophosphorous compound, however it does not dissolve the carboxylic acid in the reaction. The carboxylic acid remains suspended in the silicon oil; thus at least one reactant is in suspension.

[0065] The silicon oils useful in the practice of the present invention are miscible with benzene, toluene, carbon tetrachloride and other organic solvents, but are insoluble in water and are therefore easily removed before hydrolysis in the present invention. Separation of silicon oil is also facilitated by adding toluene at the end of the reaction. Examples of silicone fluids useful in the practice of this invention include, but are not limited to, polydimethylsiloxane ("PDMS"), poly[oxy(dimethylsilene)], dimethicone, methylsilicone oil, Dow Corning® 200 fluid (a poly(dimethylsiloxane)); Wacker SWS101 fluid (a poly(dimethylsiloxane)); Baysilone® MPH 350 fluid; poly[oxy(methylphenylsilylene)]; methylphenyl silicone oil; and Dow Corning® 710 fluid (phenyl methylsiloxane)

[0066] A heterogeneous solid support is a particulate solid, essentially insoluble in aliphatic or aromatic hydrocarbons, chlorinated aliphatic or aromatic hydrocarbons, or polar aprotic solvents, having sufficient adsorptive capacity so that when used in a deposition inhibiting effective amount in combination with a diluent that is an aromatic hydrocarbon, fouling of the reactor and agitator with solid of intermediate products in the heterogeneous synthesis of bisphosphonic acids according to the present invention from a carboxylic acid, H_3PO_3 , and a second phosphorous compound in the presence of a diluent that is an aromatic hydrocarbon, e.g. toluene, chlorobenzene and the like as described below, does not occur.

[0067] Preferred heterogeneous solid supports have a porous structure and include fumed silica, silica xerogels, and diatomaceous silica. Diatomaceous silica having a median pore size between about 5 μ and about 9 μ , preferably about 7 μ ,

is a particularly preferred heterogeneous solid support. Hyflo Super-Cel, available from World Minerals, Santa Barbara, Calif., USA, is an example of a preferred heterogeneous solid support.

[0068] The skilled artisan will know to adjust the amount of heterogeneous solid support used according to, among other things, the porosity and effective surface area of the heterogeneous solid support. When the heterogeneous solid support has a nominal pore size of about 7 μ , the support will be used in a amount between about 30 wt-% and about 50 wt-% of the combined weight of all reactants.

[0069] In one embodiment, the present invention provides a method of making a bisphosphonic acid that includes the step of combining—in a two-phase system—a carboxylic acid, phosphorous acid (H_3PO_3), and a second phosphorous compound that is a halophosphorous compound in the presence of a diluent that is an aromatic hydrocarbon, preferably toluene, in the substantial absence of a polyalkylene glycol. It is preferred to slowly add the second phosphorous compound (e.g. $POCl_3$) in small aliquots (or dropwise) to a mixture of carboxylic acid, H_3PO_3 , and diluent.

[0070] The combining is carried out in a suitable reactor with good agitation at a temperature between about 65° C. and about 100° C., preferably at about 100° C., for a time between about 1 and about 4 hours. A time of about 2.5 hours is usually sufficient and is preferred. During the reaction, a solid forms and the reaction mixture can be multi-phased.

[0071] Following the reaction, water is combined with the reaction mixture, whereby aqueous and nonaqueous phases are formed, and the resulting combination is heated to a temperature between about 60° C. and about 80 C to dissolve the solid. The amount of water can be from about one to about three times the volume, preferably one, of diluent used. The aqueous phase is then separated and heated to a temperature between about 90° C. and about 100° C. for about 8 to about 24 hours, preferably 16 hours, whereafter the product bisphosphonic acid can be isolated from the aqueous phase by any means known in the art.

[0072] The product bisphosphonic acid can be isolated, for example, by combining the aqueous phase with ethanol to precipitate the product and, optionally cooling the resulting suspension to about 5° C. The product bisphosphonic acid can then be separated from the suspension by any means known in the art, for example by filtration (gravity or suction) or centrifugation/decanting, to mention just two. The yield of dried product in this embodiment can be 70% to 80% or more, an improvement relative to known methods.

[0073] In another embodiment, the present invention provides a method of making a bisphosphonic acid that includes the step of combining—in a two-phase system—a carboxylic acid, phosphorous acid, and a second phosphorous compound in the presence of a diluent that is an inert silicon oil, preferably polydimethylsiloxane (PDMS). It is preferred to slowly add the second phosphorous compound (e.g. $POCl_3$) in small aliquots (or dropwise) to a mixture of carboxylic acid, H_3PO_3 , and diluent.

[0074] The combining is carried out in a suitable reactor with good agitation at a temperature between about 65° C. and about 100° C., preferably at about 80° C., for a total time between about 15 and about 30 hours. A time greater than 20 hours is preferred and about 25 hours is particularly preferred.

[0075] Following the reaction, water and, optionally, toluene are combined with the reaction mixture, whereby aqueous and nonaqueous phases are formed, and the resulting

combination is heated to a temperature between about 70° C. and about 80° C. to dissolve the solid. The amount of water and, when used, toluene are not critical and can be from about one to about three, preferably one, times the volume of diluent used. The mixture is then stirred vigorously for about 10 to 40 minutes. The aqueous phase is then separated from the toluene phase (containing the silicon oil) and heated to a temperature between about 90° C. and about 100° C. for about 4 to about 20 hours, preferably 16 hours, whereafter the product bisphosphonic acid can be isolated from the aqueous phase by any means known in the art.

[0076] The product bisphosphonic acid can be isolated, for example, by adding ethanol to the aqueous phase to precipitate the product and, optionally and preferably, cooling the resulting suspension to about 5° C. The product bisphosphonic acid can then be separated from the suspension by any means known in the art, for example by filtration (gravity or suction) or centrifugation/decanting, to mention just two. The yield of dried product in this embodiment can be 60% to 80% or more, an improvement relative to known methods.

[0077] In another embodiment, the present invention provides a method of making a bisphosphonic acid including the step of combining a carboxylic acid, H_3PO_3 , and a second phosphorous compound that is a halophosphorous compound in the presence of a diluent that is an aromatic hydrocarbon, essentially free of polyalkylene glycol, and ortho-phosphoric acid (H_3PO_4) codiluent, whereby the reaction mixture remains stirrable and the reactor remains substantially free of fouling deposits during the reaction. It is preferred to add the second phosphorous compound (e.g. $POCl_3$) in small aliquots (or dropwise) to a mixture of carboxylic acid, H_3PO_3 , H_3PO_4 , and diluent.

[0078] The diluent can be used in an amount between about 5 and about 8 volumes per weight of carboxylic acid, preferably about 7.2 volumes per weight of carboxylic acid. The skilled artisan will know to adjust the amount of diluent according to, among other things, the particular reactor being used.

[0079] The ortho-phosphoric acid is used in amount equal to between about 3 and about 6, preferably 5, equivalents, based on the amount of carboxylic acid used.

[0080] The combining is carried out in a suitable reactor with good agitation at a temperature between about 65° C. and about 100° C., preferably 100° C., for a time of about 2 hours or more, preferably 16 to 20 hours.

[0081] Following the reaction, water is combined with the fluid reaction mixture at a temperature between about 60° C. and about 90° C., whereby aqueous and nonaqueous phases are formed, and the combined reaction mixture and water are stirred until no solid is visible in the combination. The amount of water can be from about one to about three, preferably one, times the volume of diluent used. The aqueous phase is separated and stirred for a time at a temperature between about 90° C. and about 100° C., preferably 95° C. The time is not critical as long as it is sufficient to allow formation of the desired product. A time of 5 to 20 hours is typically sufficient.

[0082] The desired bisphosphonic acid product can be isolated from the aqueous phase by any means known in the art. For example, the bisphosphonic acid can be isolated by adding ethanol to the aqueous phase and, optionally, cooling the suspension so obtained to a temperature of about 5° C. The bisphosphonic acid can be separated from the suspension by any means known to the skilled artisan, for example filtration

(gravity or suction), or centrifugation/decanting, to mention just two. In this embodiment, the yield can be 68% or more.

[0083] In yet another and preferred embodiment, the present invention provides a method of making a bisphosphonic acid including the step of combining a carboxylic acid, H_3PO_3 , and a second phosphorous compound that is a halophosphorous compound (preferably $POCl_3$), in the presence of a diluent that is an aromatic hydrocarbon, and a heterogeneous solid support, preferably diatomaceous silica.

[0084] The diluent, preferably toluene, can be used in an amount between about 5 and about 8 volumes per weight of carboxylic acid, preferably about 7.2 volumes per weight of carboxylic acid. The skilled artisan will know to adjust the amount of diluent according to the particular reactor being used. The heterogeneous solid support can be used in an amount equal to between 30 and about 50 percent of the total weight of carboxylic acid, H_3PO_3 , and second phosphorous compound.

[0085] The combining is carried out in a suitable reactor having good agitation at a temperature between about 65° C. and about 100° C., preferably 100° C., for a time of about 4 to about 8 hours. It is convenient to add the second phosphorous compound in small portions or dropwise to a suspension of heterogeneous solid support in diluent and the remaining reactants. The reactor remains essentially free of fouling deposits.

[0086] Following the reaction, water is combined with the suspension, whereby aqueous and nonaqueous phases form and the combination of water and suspension is held at about 65° C. for a time sufficient to bring the product into aqueous solution, typically 20 minutes to one hour. The liquid phases (aqueous and nonaqueous) are separated from the heterogeneous solid support. The aqueous phase is separated. If desired, the heterogeneous solid support can be washed with additional aliquots of hot water and the washings combined with the separated aqueous phase. The aqueous phase (and washings if any) is heated at 90° C. to 95° C. and stirred at this temperature for 5 to 20 hours.

[0087] The product bisphosphonic acid can be isolated from the aqueous phase by any means known in the art. For example, ethanol (1 to 2 times the volume of the aqueous phase) can be added to cooled (25° C.) aqueous phase and, optionally and preferably, the resulting suspension is cooled to about 5° C. The bisphosphonic acid can be separated from the suspension by any means known in the art, for example filtration (gravity or suction) or centrifugation/decanting, to mention just two. The yield of dried product in this embodiment can be 56% or more.

[0088] In still another and preferred embodiment, the present invention provides a method of making a bisphosphonic acid that includes the step of combining a carboxylic acid, first and second portions of phosphorous acid (H_3PO_3) and first and second portions of a second phosphorous compound that is a halophosphorous compound (preferably $POCl_3$) in the presence of a diluent that is an aromatic hydrocarbon, preferably toluene. This embodiment includes the additional step of adding a second portion (amount) of phosphorous acid (H_3PO_3) and a second portion (amount) of second phosphorous compound that is a halophosphorous compound in a stepwise or incremental manner. A stepwise or incremental manner means that a part of the second portion of H_3PO_3 and second portion of second phosphorous compound or both is added, then the resultant reaction mixture is heated (between 65° C. and 100° C.), for a time increment of between 1 and 4

hours. The cycle is repeated until the desired total second amount of H_3PO_3 and second phosphorous compound has been added.

[0089] It is preferred to add the second phosphorous compound (e.g. POCl_3) in small aliquots (or dropwise) initially to a mixture of carboxylic acid, H_3PO_3 , and diluent, to form the initial reaction mixture. It is also preferred to add to the initial reaction mixture a second amount of both H_3PO_3 and the second phosphorous compound in a stepwise or incremental manner, and to add them in two or more increments.

[0090] The combining is carried out in a suitable reactor with good agitation and at a temperature between about 65°C . and 100°C ., preferably at about 100°C . The initial reaction mixture, formed by the dropwise addition of the second phosphorous compound to a mixture of carboxylic acid, H_3PO_3 , and diluent, is then heated for an initial time increment between about 1 and about 3 hours, preferably about 2 hours.

[0091] In preferred embodiments, the H_3PO_3 and the second phosphorous compound are added in at least first and second portions. After addition of a first portion, a second portion of H_3PO_3 and a second portion of second phosphorous compound that is a halophosphorous compound are then added in aliquots (dropwise) in an incremental manner, with time increments of between 1 and about 4 hours between slow addition of first and second portions. The total reaction time, obtained from adding each incremental time to the initial time increment, is preferably between about 3 and 6 hours. It is preferred to add a second portion of both H_3PO_3 and second phosphorous compound in two distinct steps. The preferred amount of a second amount of H_3PO_3 added in each increment is equal to about one-third of the volume of H_3PO_3 present in the initial reaction mixture. The preferred amount of a second portion of second phosphorous compound is equal to about one-third of the volume of second phosphorous compound added to the initial reaction mixture.

[0092] Following the reaction, water is combined with the reaction mixture, whereby aqueous and nonaqueous phases form, and the resulting combination is heated to a temperature between about 60°C . and about 70°C . to dissolve the solid. The amount of water can be from about one to about three, preferably one, times the volume of diluent used. The aqueous phase is then separated and heated to a temperature between about 90°C . and about 100°C . for about 8 to about 24 hours, preferably 16 hours, whereafter the product bisphosphonic acid can be isolated from the aqueous phase by any means known in the art.

[0093] For example, the product bisphosphonic acid can be isolated by combining the aqueous phase with ethanol to precipitate the product and, optionally, cooling the resulting suspension to about 5°C . The product bisphosphonic acid can then be separated from the suspension by any means known in the art, for example by filtration (gravity or suction) or centrifugation/decanting, to mention just two. The yield of dried product in this embodiment can be 70% to 80% or more, an improvement relative to known methods.

[0094] In another preferred embodiment, the present invention provides a method of making a bisphosphonic acid that includes the step of combining a carboxylic acid, a phosphorous acid (H_3PO_3) and a second phosphorous compound that is a halophosphorous compound (preferably POCl_3) in the presence of a diluent selected from inert silicon oils, preferably PDMS, and the additional step of adding a second portion of phosphorous acid (H_3PO_3) and a second portion of

second phosphorous compound. The temperature of the reaction mixture can be cycled between additions.

[0095] It is preferred to add the second phosphorous compound (e.g. POCl_3) in small aliquots (or dropwise) initially to a mixture of carboxylic acid, H_3PO_3 , and diluent, to form the initial reaction mixture. It is also preferred to add to the initial reaction mixture a second amount of both H_3PO_3 and the second phosphorous compound in a stepwise or incremental manner, and to add them in two or more increments.

[0096] The combining is carried out in a suitable reactor with good agitation and at a temperature between about 65°C . and 100°C ., preferably at about 70°C . The initial reaction mixture, formed by the dropwise addition of the second phosphorous compound to a mixture of carboxylic acid, H_3PO_3 , and diluent, is then heated for an initial time increment between about 2 and about 20 hours, preferably about 4 hours.

[0097] A second portion (amount) of H_3PO_3 and a second portion (amount) of second phosphorous compound or both are then slowly added in small aliquots in an incremental manner with time increments of between 2 and about 20 hours between the additions of the second portion of H_3PO_3 and the second portion of halophosphorous. The total reaction time, obtained from adding each incremental time to the initial time increment, is preferably between about 20 and 30 hours. It is preferred to add a second portion of both H_3PO_3 and second phosphorous compound in two steps. The preferred second portion of H_3PO_3 added in each increment is equal to about one-third of the volume of H_3PO_3 present in the initial reaction mixture. The preferred second amount of second phosphorous compound is equal to about one-third of the volume of second phosphorous compound added dropwise to form the initial reaction mixture.

[0098] Following the reaction, water and, if desired, toluene are combined with the reaction mixture, whereby aqueous and nonaqueous phases form, and the resulting combination is heated to a temperature between about 60°C . and about 80°C . to dissolve the solid. Addition of toluene is advantageous if the viscosity of the reaction mixture is too high. When used, the amount of toluene is adjusted according to the viscosity of the reaction mixture. The amount of water can be from about one to about three, preferably one, times the volume of diluent used. The mixture is then stirred vigorously for about 10 to 40 minutes. The aqueous phase is then separated and heated to a temperature between about 90°C . and about 100°C . for about 8 to about 24 hours, preferably 16 hours, whereafter the product bisphosphonic acid can be isolated from the aqueous phase by any means known in the art.

[0099] For example, the product bisphosphonic acid can be isolated by combining the aqueous phase with ethanol to precipitate the product and, optionally, cooling the resulting suspension to about 5°C . The product bisphosphonic acid can then be separated from the suspension by any means known in the art, for example by filtration (gravity or suction) or centrifugation/decanting, to mention just two. The yield of dried product in this embodiment can be 70% to 80% or more, an improvement relative to known methods.

[0100] When 4-aminobutanoic acid is used in the method of the present invention, in any of its embodiments discussed above, the product is a crystalline monohydrate of alendronic acid. When 2-(3-pyridin-3-yl)ethanoic acid is used in the method of the present invention, in any of its embodiments discussed above, the product is a crystalline monohydrate of risedronic acid. When 1H-imidazole-1-yl acetic acid is used in the method of the present invention, in any of its embodi-

ments, the product is a crystalline monohydrate of zoledronic acid. When the carboxylic acid is N-(n-pentyl)-N-methyl-3-aminopropanoic acid is used, the isolated bisphosphonic acid is ibandronic acid. When 2-(imidazo[1,2-a]pyridin-2-yl) ethanoic acid is used in the method of the present invention, in any of its embodiments, minodronic hemihydrate acid is obtained. When 6-aminohexanoic acid is used in the practice of the present invention, in any of its embodiments, neridronic acid is obtained.

[0101] The present invention can be illustrated with the following non-limiting examples.

Example 1

[0102] A 250 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was charged with 3-pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and toluene (50 ml). The suspension was heated to 85° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 20 minutes. The reaction mixture was then heated to 95° C. for 2.5 hours. Water (50 ml) was added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously until the solidified product dissolved completely. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 16 hours. Then aqueous phase was cooled to 25° C. and absolute ethanol (100 ml) was added to precipitate the final product. The suspension was cooled to 5° C. and held at that temperature for 1 hour. The white product was filtered, washed with absolute ethanol (2×50 ml) and dried in a vacuum oven at 50° C. for 20 hours to obtain 9.34 g (82%) of risedronic acid monohydrate.

Example 2

[0103] A 250 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was charged with 3-pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and silicon oil (Aldrich) (50 ml). The suspension was heated to 85° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 45 minutes. The reaction mixture was then heated to 95° C. for 25 hours. Then another amount of phosphorous oxychloride (3.73 ml, 0.04 mole) was added dropwise and the reaction mixture was heated for an additional 5 hours at 95° C. Water (50 ml) and toluene (50 ml) were added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously for 30 minutes. Then the toluene phase (containing the silicon oil) and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 16 hours. Then the aqueous phase was cooled to 5° C. and was stirred at this temperature for 5.5 hours. The white product was filtered, washed with water (2×50 ml) and dried in a vacuum oven at 50° C. for 11 hours to obtain 7.19 g (59%) of risedronic acid monohydrate.

[Remark: The yield of the above process is calculated on dry base].

Example 3

[0104] A 250 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was loaded with 3-Pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and silicon oil (silicon fluid M-350) (50 ml). The

suspension was heated to 85° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 30 minutes. The reaction mixture was then heated to 95° C.-100° C. After 4 hours at 95° C.-100° C., another amount of phosphorous oxychloride (3.73 ml, 0.04 mole) and phosphorous acid (3.28 g, 0.04 mole) was added and the reaction mixture was heated at 95° C.-100° C. for additional 17 hours. Water (50 ml) and toluene (50 ml) were added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously for 10 minutes. Then the toluene phase (containing the silicon oil) and the aqueous phase were separated and the aqueous phase was heated at 95° C. for 18 hours. Then it was cooled to 5° C. and absolute ethanol (50 ml) was added. The mixture was stirred at this temperature for 4 hours. The white product was then filtered, washed with absolute ethanol (2×50 ml) and dried in a vacuum oven at 50° C. for 22 hours to give 6.18 g (51%) of risedronic acid monohydrate.

[0105] [Remark: The yield of the above process is calculated on dry base].

Example 4

[0106] A 250 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was loaded with 3-pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and silicon oil (Merck) (50 ml). The suspension was heated to 84° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 30 minutes. After 4 hours at 84° C., another amount of phosphorous oxychloride (3.73 ml, 0.04 mole) and phosphorous acid (3.28 g, 0.04 mole) was added and the reaction mixture was heated at 84° C. for additional 20 hours. Water (50 ml) and toluene (50 ml) were added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously for 20 minutes. Then the toluene phase (containing the silicon oil) and the aqueous phase were separated and the aqueous phase was heated at 95° C. for 16 hours. Then it was cooled to 5° C. and absolute ethanol (50 ml) was added. The mixture was stirred at this temperature for 4 hours. The white product was then filtered, washed with absolute ethanol (2×75 ml) and dried in a vacuum oven at 50° C. for 26 hours to give 9.30 g (76%) of risedronic acid monohydrate.

[0107] [Remark: The yield of the above process is calculated on dry base].

Example 5

[0108] A 250 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was loaded with 3-Pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and silicon oil (Merck) (50 ml). The suspension was heated to 70° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 20 minutes. After 4 hours at 70° C., another amount of phosphorous oxychloride (3.73 ml, 0.04 mole) and phosphorous acid (3.28 g, 0.04 mole) was added and the reaction mixture was heated at 70° C. for additional 2 hours. Then another amount of phosphorous oxychloride (3.73 ml, 0.04 mole) and phosphorous acid (3.28 g, 0.04 mole) was added and the reaction mixture was heated at 70° C. for additional 16 hours. Water (50 ml) and toluene (50 ml) were added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously for 10 minutes. Then the toluene phase (containing the silicon oil) and the

aqueous phase were separated and the aqueous phase was heated at 95° C. for 16 hours. Then it was cooled to 25° C. and absolute ethanol (50 ml) was added. The mixture was cooled to 5° C. and was stirred at this temperature for 3 hours. The white product was then filtered, washed with absolute ethanol (2×45 ml) and dried in a vacuum oven at 50° C. for 24 hours to give 9.41 g (77%) of risedronic acid monohydrate.

[0109] [Remark: The yield of the above process is calculated on dry base].

Example 6

[0110] A 500 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was charged with 3-pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole), ortho-phosphoric acid (11.80 g, 0.12 mole) and toluene (50 ml). The suspension was heated to 90° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 20 minutes. The reaction mixture was then heated to 95° C. for 20.5 hours. Water (50 ml) was added after cooling the reaction mixture to 80° C. The mixture was stirred vigorously until the solidified product dissolved completely. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 5.5 hours. The aqueous phase was cooled to 25° C. and absolute ethanol (50 ml) was added to precipitate the final product. The suspension was cooled to 5° C. for 1 hour. The white product was filtered, washed with absolute ethanol (2×20 ml) and dried at 65° C. for 5 hours to obtain 7.70 g (68%) of risedronic acid monohydrate.

Example 7

[0111] A 2 L cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was charged with 3-pyridine acetic acid hydrochloride (27.7 g, 0.16 mole), phosphorous acid (39.4 g, 0.48 mole), ortho-phosphoric acid (47.2 g, 0.48 mole) and toluene (200 ml). The suspension was heated to 90° C. and phosphorous oxychloride (44.8 ml, 0.48 mole) was added dropwise during 20 minutes. The reaction mixture was then heated to 95° C. for 20.5 hours. Water (200 ml) was added after cooling the reaction mixture to 80° C. The mixture was stirred vigorously until the solidified product dissolved completely. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 5.5 hours. The aqueous phase was cooled to 25° C. and absolute ethanol (200 ml) was added to precipitate the final product. The suspension was cooled to 5° C. for 1 hour. The white product was filtered, washed with absolute ethanol (2×80 ml) and dried at 65° C. for 5 hours to obtain 38.2 g (84%) of risedronic acid monohydrate.

Example 8

[0112] A 500 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was charged with 3-pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and toluene (50 ml). The suspension was heated to 90° C. Hyflo Super-Cel diatomaceous silica (17.50 g, 50% w/w of all the reagents) was added in portions after the mixture of 3-pyridyl acetic acid and H₃PO₃ was melted, to obtain an heterogeneous suspension. Phosphorous oxychloride (11.2 ml, 0.12 mole) was then added dropwise during 12

minutes. The reaction mixture was then heated to 95° C. for 3 hours. Water (75 ml) was added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously for 30 minutes and then the Hyflo was removed by filtration. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 16 hours. The aqueous phase was cooled to 25° C. and absolute ethanol (75 ml) was added to precipitate the final product. The suspension was cooled to 5° C. for 1 hour. The white product was filtered, washed with absolute ethanol (2×20 ml) and dried in a vacuum oven at 50° C. for 24 hours to obtain 6.30 g (56%) of risedronic acid monohydrate.

Example 9

[0113] A 2 L cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was charged with 3-pyridine acetic acid hydrochloride (27.7 g, 0.16 mole), phosphorous acid (39.4 g, 0.48 mole) and toluene (200 ml). The suspension was heated to 90° C. Hyflo Super-Cel diatomaceous silica (70 g, 50% w/w of all the reagents) was added in portions after the mixture of 3-pyridyl acetic acid and H₃PO₃ was melted, to obtain an heterogeneous suspension. Phosphorous oxychloride (44.8 ml, 0.48 mole) was then added dropwise during 12 minutes. The reaction mixture was then heated to 95° C. for 3 hours. Water (300 ml) was added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously for 30 minutes and then the Hyflo was removed by filtration. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 16 hours. The aqueous phase was cooled to 25° C. and absolute ethanol (300 ml) was added to precipitate the final product. The suspension was cooled to 5° C. for 1 hour. The white product was filtered, washed with absolute ethanol (2×80 ml) and dried in a vacuum oven at 50° C. for 24 hours to obtain 31.7 g (71%) of risedronic acid monohydrate.

Example 10

[0114] A 250 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was loaded with 3-pyridine acetic acid hydrochloride (6.94 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and toluene (50 ml). The suspension was heated to 90° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 20 minutes. The reaction mixture was then heated to 95° C. for 3.5 hours. Water (50 ml) was added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously till the solidified product dissolved completely. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 16 hours. Then it was cooled to 5° C. during 3 hours and stirred at this temperature for an additional 40 hours. The white product was filtered, washed with water (2×25 ml) and dried in a vacuum oven at 50° C. for 24 hours to obtain 6.38 g (56%) of risedronic acid monohydrate.

Example 11

[0115] A 250 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was loaded with 4-amino butyric acid (GABA) (4.12 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and toluene (50 ml). The suspension was heated to 85° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 20 minutes. The reaction mixture was

then heated to 95° C. for 2.5 hours. Water (50 ml) was added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously till the solidified product dissolved completely. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 16 hours. The aqueous phase was cooled to 25° C. and absolute ethanol (100 ml) was added to precipitate the final product. The suspension was cooled to 5° C. for 1 hour. The white product was filtered, washed with absolute ethanol (2×50 ml) and dried in a vacuum oven at 50° C. for 20 hours to obtain 8.20 g (82%) of alendronic acid monohydrate.

Example 12

[0116] A 500 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was loaded with GABA (4.12 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole), ortho-phosphoric acid (11.80 g, 0.12 mole), and toluene (50 ml). The suspension was heated to 90° C. and phosphorous oxychloride (11.2 ml, 0.12 mole) was added dropwise during 20 minutes. The reaction mixture was then heated to 95° C. for 20.5 hours. Water (50 ml) was added after cooling the reaction mixture to 80° C. The mixture was stirred vigorously till the solidified product dissolved completely. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 5.5 hours. The aqueous phase was cooled to 25° C. and absolute ethanol (50 ml) was added to precipitate the final product. The suspension was cooled to 5° C. for 1 hour. The white product was filtered, washed with absolute ethanol (2×20 ml) and dried at 65° C. for 5 hours to obtain 6.80 g (68%) of alendronic acid monohydrate.

Example 13

[0117] A 500 ml cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, was loaded with GABA (4.12 g, 0.04 mole), phosphorous acid (9.84 g, 0.12 mole) and toluene (50 ml). The suspension was heated to 90° C. Hyflo Super-Cel diatomaceous silica (17.50 g, 50% w/w of all the reagents) was added in portions after the mixture of 3-pyridyl acetic acid HCL and H₃PO₃ was melted to obtain an heterogeneous suspension. Phosphorous oxychloride (11.2 ml, 0.12 mole) was

then added dropwise during 12 minutes. The reaction mixture was then heated to 95° C. for 3 hours. Water (75 ml) was added after cooling the reaction mixture to 65° C. The mixture was stirred vigorously for 30 minutes and then the Hyflo was removed by filtration. The toluene and the aqueous phases were separated and the aqueous phase was heated at 95° C. for 16 hours. The aqueous phase was cooled to 25° C. and absolute ethanol (75 ml) was added to precipitate the final product. The suspension was cooled to 5° C. for 1 hour. The white product was filtered, washed with absolute ethanol (2×20 ml) and dried in a vacuum oven at 50° C. for 24 hours to obtain 5.60 g (56%) of alendronic acid monohydrate.

Example 14

Preparation of Zoledronic Acid Monohydrate (ZLD-Ac)

[0118] Six experiments were run reacting imidazoleacetic acid (IAA), phosphorous acid (H₃PO₃) and phosphorous oxychloride (POCl₃) according to the following the general procedure. The specific conditions of each experiment, and the results obtained, are given in Table I.

[0119] A cylindrical reactor equipped with a mechanical stirrer, a thermometer, a reflux condenser and a dropping funnel, is loaded with 1-imidazole acetic acid (IAA), phosphorous acid and a diluent (silicon oil). The obtained suspension is heated to 75° C.-80° C. and phosphorous oxychloride is added drop-wise. The reaction mixture is then heated to 75° C.-100° C. for 1-34 hours. Water is added at 80° C.-100° C. The resulting mixture is stirred vigorously for about 15 minutes. [N.b. in some cases, when silicon oil is used as a diluent, there is a need to add toluene in order to improve the separation between the oily phase and the aqueous phase]. Then the phases are separated. The aqueous phase is put in a clean reactor and heated to 95° C.-100° C. for 13.5-19 hours. The aqueous phase is then cooled to 5° C. and absolute ethanol is added to obtain a precipitate after stirring at 5° C. for 2.5-4 hours. The white product is then filtered, washed with absolute ethanol and dried in a vacuum oven at 50° C. for 17-24 hours to obtain zoledronic acid.

[0120] After recrystallization from water (26 volumes), zoledronic acid monohydrate is obtained (LOD by TGA=6.3%-9.3%).

TABLE 1

Preparation of ZLD-Ac Monohydrate starting from IAA, H ₃ PO ₃ and POCl ₃											
Example	Raw material (grams of IAA)	Ratio of reactants (equivalents) IAA/H ₃ PO ₃ /POCl ₃	Diluent/ volumes per grams of IAA	Temp. of reaction	Time of reaction	Amount of water for the hydrolysis step	Addition of Toluene to improve phases separation	Time of hydrolysis step	Amount of abs.EtOH/ Acetone for the precipitation of ZLD-Ac	LOD by TGA	Yield (grams of ZLD-Ac)
1	IAA · HCl (5.4 g)	1/3.6/4.5	Silicon oil/ 6.5 vol.	80° C.	24 hrs	45 ml	50 ml	19 hrs	90 ml(EtOH)	9.1%	79% (7.8 g)
4	IAA · HCl (4.9 g)	1/3/3.75	Silicon oil/ 5.5 vol.	80° C.	22 hrs	54 ml	54 ml	19 hrs	54 ml(EtOH)	6.8%	76% (6.7 g)
6	IAA · HCl (5.9 g)	1/2/3	Silicon oil/ 5.5 vol.	80° C.	23 hrs	33 ml	—	16 hrs	200 ml(EtOH)	7.9%	38% (4.0 g)
7	IAA · HCl (6.0 g)	1/4/4	Silicon oil/ 5.5 vol.	80° C.	11 hrs	33 ml	33 ml	16 hrs	33 ml(EtOH)	9.3%	74% (8.2 g)
8	IAA (12.0 g)	1/3/3.75	Silicon oil/ 6.0 vol.	80° C.	17 hrs	72 ml	—	16 hrs	—	7.7%	72% (20.0 g)

TABLE 1-continued

Preparation of ZLD-Ac Monohydrate starting from IAA, H ₃ PO ₃ and POCl ₃											
Example	Raw material (grams of IAA)	Ratio of reactants (equivalents) IAA/H ₃ PO ₃ /POCl ₃	Diluent/ volumes per grams of IAA	Temp. of reaction	Time of reaction	Amount of water for the hydrolysis step	Addition of Toluene to improve phases separation	Time of hydrolysis step	Amount of abs.EtOH/ Acetone for the precipitation of ZLD-Ac	LOD by TGA	Yield (grams of ZLD-Ac)
9	IAA (70 g)	1/3/3.75	Silicon oil/ 7.0 vol.	80° C.	34 hrs	490 ml	490 ml	16 hrs	490 ml(EtOH) (addition of EtOH at reflux temp.)	6.3%	59% (95.1 g) Purity by HPLC 98.3%*

*HPLC method:

Column: Phenomenex Phenyl-Hexyl 5 um, 250 × 4.6 mm

Mobile phase: 40 mM Octansulfonic acid sodium salt in 1% HClO₄, 0.2% H₃PO₄; Methanol (85:15)

Detection: 220 nm

1. A method of making a bisphosphonic acid comprising the steps of:

- combining, to form a reaction mixture, a carboxylic acid selected from the group consisting of (1-imidazolyl)ethanoic acid, and N-(n-pentyl)-N-methyl-3-aminopropanoic acid, with phosphorous acid and a halophosphorous compound selected from PCl₃, PCl₅, POCl₃, PBr₃, POBr₃, and PBr₅ in the presence of a diluent, and optionally in the presence of a codiluent,
- combining the reaction mixture with water or a water solution of a non-oxidizing acid, whereby at least aqueous and non-aqueous phases are formed,
- separating the aqueous phase,
- combining the aqueous phase with ethanol, whereby a precipitate of the bisphosphonic acid is formed, and, optionally,
- isolating the bisphosphonic acid;

wherein the diluent includes i) an aromatic hydrocarbon and ortho-phosphoric acid, or ii) a silicone fluid, with the proviso that when the diluent includes an aromatic hydrocarbon and ortho-phosphoric acid, the co-diluent, if present, is not a polyalkylene glycol.

2. The method of claim **1** wherein the phosphorous acid and the halophosphorous compound are each combined together in at least a first portion and a second portion.

3. The method of claim **1** wherein the diluent comprises an aromatic hydrocarbon and ortho-phosphoric acid and the reaction is conducted in the presence of a heterogeneous solid support.

4. The method of claim **3** wherein the heterogeneous solid support is diatomite silica.

5. The method of claim **3** wherein the aromatic hydrocarbon is toluene.

6. The method of claim **1** wherein the silicone fluid is a poly(dimethylsiloxane).

7. The method of claim **1** wherein the halophosphorous compound is POCl₃.

8. (canceled)

9. The method of claim **1** wherein the carboxylic acid is (1-imidazolyl)ethanoic acid or its hydrochloride and the isolated bisphosphonic acid is zoledronic acid monohydrate.

10. The method of claim **1** wherein the carboxylic acid is N-(n-pentyl)-N-methyl-3-aminopropanoic acid or its hydrochloride and the isolated bisphosphonic acid is ibandronic acid.

11. (canceled)

12. (canceled)

13. A method of making zoledronic acid monohydrate comprising the steps of:

- combining, to form a reaction mixture, (1-imidazolyl)ethanoic acid or its hydrochloride, phosphorous acid, and a halophosphorous compound selected from PCl₃, PCl₅, POCl₃, PBr₃, POBr₃, and PBr₅ at a temperature of about 80° C. to about 100° C. in the presence of a diluent, and optionally in the presence of a codiluent,
- combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,
- separating the aqueous phase,
- combining the aqueous phase with ethanol whereby a suspension comprising zoledronic acid monohydrate is formed, and, optionally,
- isolating the zoledronic acid monohydrate from the suspension,

wherein the diluent includes i) an aromatic hydrocarbon and ortho-phosphoric acid, or ii) a silicone fluid, with the proviso that when the diluent includes an aromatic hydrocarbon and ortho-phosphoric acid, the co-diluent, if present, is not a polyalkylene glycol.

14. (canceled)

15. The method of claim **13** wherein the diluent is an aromatic hydrocarbon and ortho-phosphoric acid and a heterogeneous solid support is combined in the reaction mixture and wherein the method further comprises the step of filtering the aqueous and non-aqueous phases before the aqueous phase is separated.

16. A method of making ibandronic acid comprising the steps of:

- combining, to form a reaction mixture, N-methyl-N-(n-pentyl)-3-aminopropanoic acid, phosphorous acid, and a halophosphorous compound selected from PCl₃, PCl₅, POCl₃, PBr₃, POBr₃, and PBr₅ at a temperature of about 80° C. to about 100° C. in the presence of a diluent, and optionally in the presence of a codiluent,
- combining the reaction mixture with water, whereby an aqueous and a non-aqueous phase are formed,

c) separating the aqueous phase,
d) combining the aqueous phase with ethanol whereby a suspension comprising ibandronic acid is formed, and, optionally,
e) isolating the ibandronic acid from the suspension, wherein the diluent includes i) an aromatic hydrocarbon and ortho-phosphoric acid, or ii) a silicone fluid, with the proviso that when the diluent includes an aromatic hydrocarbon and ortho-phosphoric acid, the co-diluent, if present, is not a polyalkylene glycol.

17. (canceled)

18. The method of claim 16 wherein the diluent is an aromatic hydrocarbon and ortho-phosphoric acid and a heterogeneous solid support is combined in the reaction mixture and wherein the method further comprises the step of filtering the aqueous and non-aqueous phases before the aqueous phase is separated.

19-24. (canceled)

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