

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
1 December 2016 (01.12.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/190857 A1

(51) International Patent Classification:

C05D 1/00 (2006.01) *C05D 9/00* (2006.01)
C05D 3/04 (2006.01) *C05G 3/00* (2006.01)

(21) International Application Number:

PCT/US2015/032610

(22) International Filing Date:

27 May 2015 (27.05.2015)

(25) Filing Language:

English

(26) Publication Language:

English

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))



WO 2016/190857 A1

(54) Title: IONIC AGRICULTURAL PARTICLE, IONIC AGRICULTURAL COMPOSITION, AND PROCESS OF FORMING AN IONIC AGRICULTURAL COMPOSITION

(57) Abstract: An ionic agricultural particle, an ionic agricultural composition and a process of forming an ionic agricultural composition are described. The ionic agricultural particle includes an anionic inorganic industrial by-product and a cationic organic binder which are electrostatically aggregated. The ionic agricultural composition includes a plurality of ionic agricultural particles having an arrangement. The process of forming the ionic agricultural composition comprises blending the anionic inorganic industrial by-product and the cationic organic binder to form a plurality of ionic agricultural particles.

**IONIC AGRICULTURAL PARTICLE, IONIC AGRICULTURAL
COMPOSITION, AND PROCESS OF FORMING AN IONIC
AGRICULTURAL COMPOSITION**

FIELD OF THE INVENTION

[0001] The present invention is directed to ionic agricultural powders, ionic agricultural compositions and processes of forming ionic agricultural compositions. More specifically, the present invention is directed to electrostatically aggregated cationic organic binder and anionic inorganic industrial by-product.

BACKGROUND OF THE INVENTION

[0002] Specific minerals are known to stimulate plant growth in agriculture. For example, fertilizers and other additives sometimes contain silicon compounds, such as, calcium silicate, magnesium silicate, potassium silicate, and sodium silicate. In some cases, fertilizers and the other additives deliver these minerals, these compounds, or combinations of these minerals and these compounds to a plant or to soil. The method of delivering the minerals or compounds, the crystal structure of the minerals or compounds, and the combination of the minerals or compounds impacts the efficacy of the fertilizers and other additives, for example, by impacting the solubility of them. Soluble compounds are able to travel through soil, plants, and/or portions of plants (such as a cell wall) better than insoluble compounds.

[0003] The minerals or compounds in the fertilizers or other additives are produced in several forms. For example, the minerals or compounds in the fertilizers or other additives are natural (for example, mined) or synthetic (for example, a by-product of an industrial process). Utilizing synthetic minerals or compounds, such as, by-products, is potentially environmentally beneficial by reducing waste and economically beneficial by creating economic value to existing waste.

[0004] One such by-product is slag. Slag is generally perceived as a waste material. However, most slag is suitable for use in road surfaces, roofing, or

cementitious products. The source of slag impacts the composition of the slag and, thus, the end-use of the slag or portions of the slag. For example, blast furnace slag is known to be used in roads and cementitious products; however, it has previously been perceived as undesirable for agricultural products due to its composition. Stainless steel slag (greater than 10.5 weight % Chromium is indicative of a stainless steel product) has been used for roads and cementitious products as well as agricultural products due to its compositions. However, stainless steel slag is in some instances limited in availability.

[0005] Additionally or alternatively, making of agricultural compositions from slag sources, especially pelletized agricultural compositions, potentially involves difficulty in dispersion during blending, pellet strength, and combinations thereof.

[0006] Applying such agricultural compositions is sometimes difficult. Silicon from different sources, such as different composition slags, have potentially different structures. In addition, silicon has different structures based upon process parameters, such as, the cooling rate of the slag, and/or based upon physical characteristics, such as granular size of the compound. These different structures in some cases affect solubility of compounds containing silicon. Solubility impacts the ability for silicon to be processed by plants and/or the ability to sequester heavy metals. Thus, information about silicon that fails to identify whether the silicon is in a soluble compound could be misleading or unreliable by failing to properly identify the impact of including such silicon. In addition, lacking such information prevents proper identification of preferred ranges of silicon from soluble compounds.

[0007] Ionic agricultural particles, ionic agricultural compositions, and processes of forming ionic agricultural compositions that include one or more improvements in comparison to the prior art would be desirable.

BRIEF DESCRIPTION OF THE INVENTION

[0008] In an exemplary embodiment, an ionic agricultural particle includes an anionic inorganic industrial by-product and a cationic organic binder. The anionic

inorganic industrial by-product and the cationic organic binder are electrostatically aggregated.

[0009] In another exemplary embodiment, an ionic agricultural composition includes a plurality of ionic agricultural particles. Each of the plurality of ionic agricultural particles includes an anionic inorganic industrial by-product and a cationic organic binder. The anionic inorganic industrial by-product and the cationic organic binder are electrostatically aggregated. The ionic agricultural composition further includes an arrangement of the plurality of ionic agricultural particles.

[0010] In another exemplary embodiment, a process of forming an ionic agricultural composition includes blending an anionic inorganic industrial by-product and a cationic organic binder to form a plurality of ionic agricultural particles.

[0011] Other features and advantages of the present invention will be apparent from the following more detailed description, which illustrates, by way of example, the principles of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Provided are ionic agricultural particles, ionic agricultural compositions, and processes of forming an ionic agricultural composition.

[0013] Embodiments of the present disclosure, for example, in comparison to concepts failing to include one or more of the features disclosed herein, permit environmental benefits by utilizing waste or by-product streams from one or more industrial processes, permit the ability for calcium silicate and/or magnesium silicate to be retained in agricultural substances for longer periods of time, are capable of increasing soil pH, are capable of decreasing metal toxicity (for example, from Al, Mn, or heavy metals), improve cation exchange capacity, improve crop tolerance (for example, to drought, frost, disease, and/or insects by increasing strength of cell wall and/or by further protecting from disease/pathogen attack), improve plant productivity (for example, by increasing the rate and/or amount of photosynthesis through increased production of chlorophyll and/or carbohydrates), increase fertilization by

introduction of nitrogen, phosphorous and/or potassium, decrease lodging (for example, by increasing structural integrity with increased silicon in roots, shoots, and/or leaves), reduce or eliminate till utilization (for example, by increasing lateral and vertical movement), improve handling (for example, by 25%), improving flow ability (for example, by 15%), improve storability (for example, by 30%), provide increased soluble silicon (for example, greater than 10 lbs/ton), and permit combinations thereof.

[0014] In one embodiment, an ionic agricultural particle includes an anionic inorganic industrial by-product and a cationic organic binder. The anionic inorganic industrial by-product and the cationic organic binder are electrostatically aggregated. In another embodiment, an ionic agricultural composition includes a plurality of ionic agricultural particles.

[0015] The cationic organic binder includes any suitable materials. Such suitable materials include, but are not limited to, denatured soy bean particles, denatured corn particles, or combinations thereof. As used herein, "denatured soy bean particles" are particles resulting from the treatment of soy bean meal to remove vegetable oil and water soluble compounds. "Denatured corn particles" are particles resulting from the treatment of corn meal to remove vegetable oil and water soluble compounds.

[0016] The ionic agricultural particle includes any suitable amount of the cationic organic binder. Suitable amounts include, but are not limited to, between 1 weight % to 10 weight % of the ionic agricultural particle, between 2 weight % to 7 weight %, between 3 weight % to 6 weight %, between 4 weight % to 5 weight %, or any suitable combination, sub-combination, range, or sub-range therein.

[0017] In one embodiment, the cationic organic binder includes a yeast extract. Without being bound by theory, it is believed that the yeast extract enhances organic matter decomposition for accelerated nutrient availability of nutrients in the cationic organic binder, such as, but not limited to, nitrogen. Commercially available yeast extracts include yeast extracts and autolysates sold under the trademark HY-YEST 455 by Quest International Company (Hoffman Estates, Illinois).

[0018] The anionic inorganic industrial by-product includes any suitable materials. Such suitable materials include, but are not limited to, slag from metal production. The slag is produced by a suitable process, including, but not limited to, an industrial process or a blast furnace in a unitary process or a combination of processes linked, for example, by transportation of materials. In one embodiment, the slag is a silicon-containing by-product including silicon in one or more compounds. The silicon is in a soluble compound or a combination of a soluble compound and an insoluble compound.

[0019] The total silicon in an ionic agricultural particle includes all soluble silicon and insoluble silicon. In some embodiments, the total silicon of the ionic agricultural particle is less than 30 atomic % or greater than 39 atomic %. In some embodiments, the total silicon of the ionic agricultural particle is less than 25 atomic %, less than 15 atomic %, between 5 atomic % and 25 atomic %, between 15 atomic % and 25 atomic %, between 20 atomic % and 25 atomic %, between 1 atomic % and 5 atomic %, or any suitable combination or sub-combination thereof. Alternatively, in other embodiments, the total silicon of the ionic agricultural particle is between 40 atomic % and 53 atomic %, between 45 atomic % and 50 atomic %, between 50 atomic % and 53 atomic %, greater than 45 atomic %, greater than 50 atomic %, or any suitable combination, sub-combination, range, or sub-range therein.

[0020] Additionally or alternatively, in some embodiments, the silicon from the soluble compound within an ionic agricultural particle is at or above a specific amount. For example, in one embodiment, the silicon from the soluble compound in the ionic agricultural particle is between 10 atomic % and 20 atomic %, between 10 atomic % and 15 atomic %, between 15 atomic % and 20 atomic %, between 12 atomic % and 15 atomic %, between 10 atomic % and 12 atomic %, greater than 10 atomic %, greater than 12 atomic %, greater than 15 atomic %, greater than 20 atomic %, or any suitable combination, sub-combination, range, or sub-range therein.

[0021] The soluble compound in an ionic agricultural particle is any suitable composition containing silicon and capable of being in solution. For example, in some

embodiments, the soluble compound includes a monosilic acid, a polysilic acid, an organosilicon, calcium silicate, calcium inosilicate, or other suitable forms of silicon capable of being in solution. In one embodiment, the soluble compound is any suitable compound having a solubility that is greater than or equal to the least soluble form of calcium silicate. In one embodiment, the soluble compound is any suitable compound capable of travelling through a cell wall of a plant or otherwise available to the plant due to its ability to dissolve. In contrast, in some embodiments, the insoluble compound is silic acid (quartz in solution), amorphous silica, magnesium silicate, coarse or crystalline silicates, or other similar forms of silicon generally incapable of being in solution. In one embodiment, the insoluble compound is any suitable compound having a solubility that is less than or equal to the most soluble form of magnesium silicate. In one embodiment, the insoluble compound is any suitable compound incapable of travelling through a cell wall of a plant or is otherwise unavailable to the plant due to its inability to dissolve.

[0022] The content and/or source of the slag producing an ionic agricultural particle potentially impacts the compositions of the ionic agricultural particle. In one embodiment, the slag is formed by a process for forming a product such as carbon steel, aluminum, phosphate, copper, zinc, non-ferrous material, alloy steel, iron, combustion products and energy (such as from coal), any product that has less than 10 weight % chromium (greater than 10.5 weight % being indicative of a stainless steel product), or any other suitable product. In further embodiments, the product of the slag-producing process has less than 8% chromium, less than 6% chromium, less than 4% chromium, between 2% and 8% chromium, between 2% and 6% chromium, between 4% and 8% chromium, between 4% and 6% chromium, or any suitable combination, sub-combination, range, or sub-range therein.

[0023] In one embodiment, the slag from the slag-producing process is a metal slag, such as, carbon steel slag, aluminum slag, copper slag, zinc slag, non-ferrous slag, argon oxygen decarburization slag (AOD slag), alloy steel slag, stainless steel slag (for heavy metal sequestration or combined by-products), blast furnace slag (for example, from the production of iron), blast oxygen furnace slag (BOFS), or

combinations thereof. In one embodiment, the slag from the slag-producing process is a non-metal slag, such as, phosphate slag or coal slag.

[0024] In one embodiment, the slag from the slag-producing process is copper slag and/or has a general composition including, by weight, between 30% and 40% SiO₂, between 5% and 10% CaO, between 1% and 5% MnO, between 2% and 4% Al₂O₃, between 2% and 3% Zn, a balance of Fe, and incidental impurities.

[0025] In one embodiment, the slag from the slag-producing process is zinc slag and/or has a general composition including, by weight, 20% FeO, 15% CaO, 20% SiO₂, 5% Al₂O₃, 10% PbO, a balance ZnO, and incidental impurities.

[0026] In one embodiment, the slag from the slag-producing process is non-ferrous slag and/or has a general composition including, by weight, 15% CaO, 15% SiO₂, 5.4% Al₂O₃, 1.3% MgO, 1.1% K₂O, 0.9% Na₂O, 4.8% Zn, 2.0% Pb, a balance FeO, and incidental impurities. In a further embodiment, the slag 104 includes, by weight, 15% CaO, 15% SiO₂, 5.4% Al₂O₃, 1.3% MgO, .1% K₂O, 0.9% Na₂O, 4.8% Zn, 2.0% Pb, 0.7% C, 0.6% Cu, 0.4% SO₄²⁻, 0.4% MnO, 0.2% TiO₂, 0.2% PO₄³⁻, trace components (such as, 0.1% B, 0.04% SrO, and 0.04% Cl) a balance FeO, and incidental impurities.

[0027] In one embodiment, the slag from the slag-producing process is blast furnace slag and/or has a general composition including, by weight, between 32% and 45% CaO, between 5% and 15% MgO, between 32% and 42% SiO₂, between 7% and 16% Al₂O₃, between 1% and 2% S, between 0.1% and 1.5% Fe₂O₃, between 0.2% and 1.0% MnO, and incidental impurities. In a further embodiment, the slag 104 has a composition including, by weight, of between 5% and 15% MgO, between 32% and 42% SiO₂, between 7% and 16% Al₂O₃, between 1% and 2% S, between 0.1% and 1.5% Fe₂O₃, between 0.2% and 1.0% MnO, a balance of CaO, and incidental impurities.

[0028] In one embodiment, the slag from the slag-producing process is coal slag and/or has a general composition including, by weight, 48% SiO₂, 10% Al₂O₃, 14% CaO, 7.4% Fe₂O₃, 6.2% MgO, 1.6% Na₂O, 1.6% K₂O, and incidental impurities.

[0029] In one embodiment, the slag from the slag-producing process is phosphate slag and/or has a general composition including, by weight, 16% to 19% P₂O₅ (for example, in the form 4CaO·P₂O₅·CaSiO₃), 4% to 12% MgO, a balance CaO, and incidental impurities. In another embodiment, the slag 104 from the slag-producing process is phosphate slag and/or has a general composition including, by weight, between 39% and 42% SiO₂, up to 3.5% Al₂O₃, up to 0.5% Fe₂O₃, up to 2% P₂O₅, a balance CaO, and incidental impurities.

[0030] In one embodiment, the slag from the slag producing process is a steel slag and/or has a general composition including, by weight, between 10% and 19% SiO₂, between 1% and 3% Al₂O₃, between 5% and 10% MgO, between 10% and 40% Fe (for example, from FeO or Fe₂O₃), between 5% and 8% MnO, a balance CaO, and incidental impurities. In a further embodiment, the slag includes, by weight, between 10% and 19% SiO₂, between 1% and 3% Al₂O₃, between 5% and 10% MgO, between 10% and 40% Fe (for example, from FeO or Fe₂O₃), between 5% and 8% MnO, 0.5% TiO₂, between 0.5% and 1% P₂O₅, a balance CaO, and incidental impurities.

[0031] In one embodiment, the slag from the slag producing process is AOD slag and/or has a general composition including, by weight, between 6% and 8% Al₂O₃, between 1% and 3% Cr₂O₃, up to 1% Fe₂O₃, between 0.5% and 6% FeO, between 4% and 6% MgO, between 22% and 29% SiO₂, a balance CaO, and incidental impurities. In a further embodiment, the slag includes, by weight, between 6% and 8% Al₂O₃, between 1% and 3% Cr₂O₃, up to 1% Fe₂O₃, between 0.5% and 6% FeO, between 4% and 6% MgO, between 0.8% and 1% MnO, between 22% and 29% SiO₂, a balance CaO, and incidental impurities.

[0032] In one embodiment, the slag from the slag producing process is BOFS and/or has a general composition including, by weight, between 15% and 35% FeO,

between 10% and 20% SiO₂, up to 10% Al₂O₃, up to 10% MgO, up to 10% MnO, up to 2% P₂O₅, up to 2% Cr₂O₃, a balance CaO, and incidental impurities.

[0033] In one embodiment, the anionic inorganic industrial by-product includes silicon, calcium, and magnesium, for example, as a combination of calcium silicate and magnesium silicate. In one embodiment, the anionic inorganic industrial by-product further includes calcium between 26 atomic % and 28 atomic % and magnesium between 6 atomic % and 8 atomic %, with the balance being other constituents from the slag.

[0034] In one embodiment, the anionic inorganic industrial by-product includes a sulfate source and calcium silicate. The sulfate source is suitably any non-hazardous sulfate source including, but not limited to, gypsum. The gypsum is be mined, synthetic, or a combination thereof. Using mined gypsum, synthetic gypsum, and combinations of mined gypsum and synthetic gypsum permits the effects of the structure of the gypsum to be controlled and/or adjusted.

[0035] In one embodiment, the sulfate source is further processed to achieve desired physical properties prior to being introduced to the ionic agricultural composition. For example, in one embodiment, the sulfate source is filtered through one or more mesh stages. In one embodiment, 99% of the by-product is smaller than #20 mesh, 90% of the by-product is smaller than #60 mesh, 75% of the by-product is smaller than #100 mesh. Additionally or alternatively, in one embodiment, moisture content of the sulfate source is adjusted to a specific range (for example, by mechanical watering devices, filters, centrifuges, or combinations thereof). In one embodiment, the specific range of moisture content is between 10% and 18%, between 10% and 15%, between 7% and 12%, between 5% and 7%, or at 5%, or any suitable combination, sub-combination, range, or sub-range therein. In one embodiment, the lime or limestone forms 90% to 99%, 90% to 95%, 94% to 99%, 92% to 97%, or any suitable combination, sub-combination, range, or sub-range therein, of the sulfate source. In another embodiment, the gypsum forms 90% to 99%,

90% to 95%, 94% to 99%, 92% to 97%, or any suitable combination, sub-combination, range, or sub-range therein, of the sulfate source.

[0036] In one embodiment, the anionic inorganic industrial by-product includes synthetic gypsum. Suitable processes for forming the synthetic gypsum include, but are not limited to, a sulfate-producing process which is a portion of a slag-producing process or a separate process. For example, in one embodiment, the sulfate-producing process forming the synthetic gypsum is a by-product of flue gas desulfurization in a coal combustion process. Additionally or alternatively, in one embodiment, the sulfate source is a by-product of another industrial process. For example, in one embodiment, the sulfate source is a by-product formed from slag in a coal combustion process, a by-product formed from bottom-boiler ash in a coal combustion process, a by-product formed from hydrogen sulfide produced from a pickling liquor, or any suitable combination thereof. The anionic inorganic industrial by-product includes any suitable amount of synthetic gypsum or no synthetic gypsum. In one embodiment, the anionic inorganic industrial by-product includes 40 weight % to 60 weight % synthetic gypsum, alternatively 50 weight % synthetic gypsum.

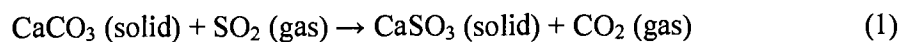
[0037] In one embodiment, the anionic inorganic industrial by-product includes 75 weight % to 95 weight %, 75 weight % to 85 weight %, 80 weight % to 90 weight %, 85 weight % to 95 weight %, 85 weight % to 90 weight %, or any suitable combination, sub-combination, range, or sub-range therein, being the sulfate source and 5 weight % to 25 weight %, 5 weight % to 15 weight %, 10 weight % to 20 weight %, 15 weight % to 25 weight %, 10 weight % to 15 weight %, or any suitable combination, sub-combination, range, or sub-range therein, being the calcium silicate or the silicon-containing by-product of the slag. In a further embodiment, the anionic inorganic industrial by-product includes 88.5 weight % being the sulfate source and 12.5 weight % calcium silicate or the silicon-containing by-product of the slag.

[0038] In one embodiment, a combined wet blend of the anionic inorganic industrial by-product includes 5 atomic % to 6 atomic % H₂O, 4 atomic % to 6 atomic % magnesium, 17 atomic % to 19 atomic % sulfur, and a balance calcium. In one

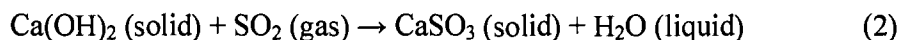
embodiment, the combined wet blend includes 5.6 atomic % H₂O, 22.2 atomic % calcium, 0.05 atomic % magnesium, and 17.5 atomic % sulfur. In one embodiment, a combined dry blend of the ionic agricultural composition includes 22 atomic % to 26 atomic % calcium, 0.04 atomic % to 0.06 atomic % magnesium, and 17.5 atomic % to 19.5 atomic % sulfur. In one embodiment, the dry blend includes 23.5 atomic % calcium, 0.05 atomic % magnesium, and 18.5 atomic % sulfur. In one embodiment, the pH of the ionic agricultural composition is 7.5 to 8.5, or 8.1. However, in another embodiment, the pH is greater than 8.5 by including additional ammonium sulfate as described below.

[0039] In one embodiment, the sulfate source includes ammonium sulfate. In this embodiment, ammonia is used as a reactant in the sulfate-producing process (such as, flue gas desulfurization in coal combustion) to yield (NH₄)₂SO₄ (ammonium sulfate). The pH of the resulting ionic agricultural composition is higher than embodiments with the sulfate source being from gypsum, thereby permitting a blending to achieve a desired pH.

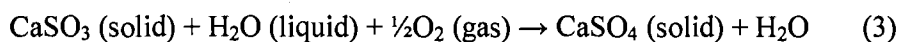
[0040] In one embodiment, the sulfate-producing process is coal combustion. Coal includes sulfur oxides (SO_x). Monitoring emissions in coal combustion involves monitoring whether SO_x is being emitted. To reduce SO_x, various scrubbers or other systems remove sulfur, sulfates, sulfites, sulfur trioxide, sulfur dioxide, or other sulfur-containing compounds. The SO_x reduced and/or removed by flue gas desulfurization includes circulating of a flue gas to remove sulfur from the flue gas and generating a sulfur-containing by-product. There are two different methods of performing flue gas desulfurization that produce the sulfate source. In a first method (assuming ideal operating conditions), wet scrubbing is performed with a CaCO₃ slurry (for example, a limestone slurry) to produce CaSO₃ (calcium sulfite):



[0041] In a second method (assuming ideal operating conditions), wet scrubbing is performed with a Ca(OH)₂ slurry (for example, a lime slurry) to produce CaSO₃ (calcium sulfite):



[0042] After the CaSO_3 (calcium sulfite) is formed (either under the first method or the second method), it undergoes a forced oxidation process which converts it to the sulfate source, CaSO_4 (for example, synthetic gypsum):



[0043] In operation, the lime or limestone slurry is present with the synthetic gypsum after the flue gas desulfurization. Depending upon the concentration of sulfur in the coal and the other limiting aspects of the reactions, the sulfate source includes a specific amount of synthetic gypsum and lime or limestone. In one embodiment, the sulfate source includes 90 weight % to 95 weight % calcium sulfate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), 1 weight % to 2 weight % calcium sulfite ($\text{CaSO}_3 \cdot \frac{1}{2}\text{H}_2\text{O}$), and 2 weight % to 3 weight % calcium carbonate (CaCO_3). In one embodiment, the remaining portion includes magnesium sulfate/sulfite.

[0044] In one embodiment, each of at least a portion of the plurality of ionic agricultural particles includes a dimension of 250 μm to 1,000 μm , alternatively 400 μm to 750 μm , alternatively 450 μm to 600 μm , alternatively at least 250 μm , alternatively at least 400 μm , alternatively at least 500 μm , alternatively greater than 500 μm . In a further embodiment, each of the plurality of ionic agricultural particles includes a dimension of 250 μm to 1,000 μm , alternatively 400 μm to 750 μm , alternatively 450 μm to 600 μm , alternatively at least 250 μm , alternatively at least 400 μm , alternatively at least 500 μm , alternatively greater than 500 μm , or any suitable combination, sub-combination, range, or sub-range therein.

[0045] In one embodiment, the cationic organic binder includes particles of any suitable size, including, but not limited to, particles having a size of between 100 μm to 500 μm , between 100 μm to 300 μm , between 200 μm to 400 μm , between 300 μm to 500 μm , between 100 μm to 200 μm , between 200 μm to 300 μm , between 300 μm to 400 μm , between 400 μm to 500 μm , between 225 μm to 275 μm , between 240 μm

to 260 μm , 250 μm , or any suitable combination, sub-combination, range, or sub-range therein.

[0046] In one embodiment, a process of forming the ionic agricultural composition includes blending the anionic inorganic industrial by-product and the cationic organic binder to form a plurality of ionic agricultural particles, for example, by a high-speed blender. In another embodiment, the plurality of ionic agricultural particles are further subjected to a mechanical processing technique. The mechanical processing technique is be any suitable technique, including, but not limited to, powdering, agglomerating, granulating, pelletizing, and combinations thereof.

[0047] In one embodiment, the plurality of ionic agricultural particles are arranged in any suitable form, including, but not limited to, a powder, agglomerates, granules, pellets, a dispersion in a liquid carrier, or combinations thereof. As used herein, a “powder” is an arrangement of particles, wherein a majority of the particles are present as individual particles. In a further embodiment, a minority of the particles are loosely aggregated through adhesive force. An “agglomerate” is an arrangement of particles wherein the particles are aggregated into a cluster of particles in which each particle retains its individual form and is visually distinguishable from the other particles. A “granule” is an arrangement of particles wherein the particles are progressively enlarged by combination with one another until the particles lose their individual forms and are no longer visually distinguishable from one another. A “pellet” is an arrangement of particles wherein the particles are aggregated into a specific geometry. The specific geometry is any suitable geometry, including, but not limited to, a sphere, spheroid, cone, frustoconical section, ellipsoid, cube, cuboid, triangular prism, tetrahedron, square pyramid, pentagonal prism, hexagonal prism, cylinder, octahedron, pentagonal trapezohedron, decahedron, dodecahedron, icosohedron, or combinations thereof. As used herein, “specific geometry” indicates that the geometry will substantially conform to the desired geometry rather than requiring that the geometry will be mathematically precise.

[0048] As used herein, a “dispersion in a liquid carrier” is any suitable heterogeneous mixture, including, but not limited to, a colloid, colloidal suspension, suspension, sol, or a combination thereof. The liquid carrier is any suitable liquid, including, but not limited to, water, beet juice, or a combination thereof. In one embodiment, the liquid carrier includes 2% to 10%, 2% to 5%, 4% to 7%, 6% to 10%, 5%, or any suitable combination, sub-combination, range, or sub-range therein, by weight beet juice.

[0049] In one embodiment, the ionic agricultural particles are pelletized or agglomerated, for example, by introducing a binder system to the ionic agricultural particles and pelletizing with a pelletizing disc capable of varying speed and angle of rotation, thereby forming a pelletized ionic agricultural composition. The binder system includes a property of promoting pellet strength when used for forming a pelletized ionic agricultural composition, includes a property of promoting dispersion when used for blending ionic agricultural particles, includes a property of being compatible with calcium silicate, includes other suitable properties, and combinations thereof.

[0050] In one embodiment, the pellet strength is a dry crush strength at least 5 pounds-force.

[0051] In one embodiment, the ionic agricultural composition includes or is formed using the binder system. The binder system includes a dry binder, a wet binder, or a combination thereof. The dry binder is be any suitable material, including, but not limited to, carboxymethyl cellulose, polyvinylpyrrolidone, calcium stearate, starch, guar gum, and combinations thereof. In one embodiment, the ionic agricultural composition includes an appropriate amount of dry binder. In another embodiment, the ionic agricultural composition includes 1 weight % to 5 weight %, 1.5 weight %, 3.5 weight percent, 4 weight percent, 4.5 weight %, or any suitable combination, sub-combination, range, or sub-range therein, dry binder.

[0052] In one embodiment the wet binder is a carbohydrate sugar such as beet juice, corn starch, molasses, calcium citrate, condensed fermentation residual, soy

polymer, or combinations thereof, mixed with water. In a further embodiment, the carbohydrate sugar also includes protein.

[0053] The wet binder includes a volumetric concentration of carbohydrate sugar and water. In one embodiment, the volumetric concentration of the binder system includes between 15 volume % and 50 volume %, between 15 volume % and 25 volume %, between 20 volume % and 30 volume %, between 25 volume % and 35 volume %, between 30 volume % and 40 volume %, between 35 volume % and 45 volume %, between 40 volume % and 50 volume %, between 22 volume % and 27 volume %, between 37 volume % and 42 volume %, or any suitable combination, sub-combination, range, or sub-range therein, being carbohydrate sugar.

[0054] In one embodiment, the ionic agricultural composition includes a green ball % moisture of 5% to 40%, 5% to 15%, 10% to 20%, 15% to 25%, 20% to 30%, 25% to 35%, 30% to 40%, or any suitable combination, sub-combination, range, or sub-range therein. In another embodiment, the ionic agricultural composition includes a pin mixer moisture of 5 % to 20%, 5% to 10%, 10% to 15%, 15% to 20%, or any suitable combination, sub-combination, range, or sub-range therein.

[0055] Additionally or alternatively, in some embodiments, other components, additives, micronutrient packets, sulfate sources, or combinations thereof are introduced to the ionic agricultural composition.

[0056] In one embodiment, a micronutrient packet is added to the ionic agricultural composition during the formation of the ionic agricultural composition and/or after the formation of the ionic agricultural composition. In one embodiment, the micronutrient packet includes boron, copper, zinc, iron, manganese, and molybdenum. Additionally or alternatively, in other embodiments, macronutrients (such as, nitrogen, phosphorus, and/or potassium) and/or nutrients (such as, calcium, magnesium, and/or sulfur) are added to the ionic agricultural composition. In one embodiment, the micronutrient packet, the macronutrients, and/or the nutrients are added by a second by-product from a process, such as those described above.

[0057] For example, in one embodiment, a nutrient such as sulfate from the sulfate source from a sulfate-producing process is added to the ionic agricultural composition during the formation of the ionic agricultural composition and/or after the formation of the ionic agricultural composition.

[0058] The application of the ionic agricultural particles treats soil to form treated soil. In one embodiment, the ionic agricultural particle increases the rate of plant growth in the treated soil. The ionic agricultural particles are applied to the soil by any suitable technique to form the treated soil and are absorbed by the plant (for example, in one embodiment, at a concentration substantially equal to that of the concentration of the silicon from the soluble compound in the treated soil). In one embodiment, the ionic agricultural particles are applied through a spreader. In one embodiment, the ionic agricultural particles are applied by banding, for example, by depositing the ionic agricultural particles along with a seed into a furrow in the soil prior to the furrow being closed. In this embodiment, plant growth is unexpectedly at a rate that is even faster than plant growth based upon spreading the ionic agricultural particles without banding.

[0059] In one embodiment, the ionic agricultural particles provide silicon to soil, a plant, or a portion of a plant (such as through a cell wall or into a cell wall) that is measurable, for example, through a regulatory body. In one embodiment, the ionic agricultural particles provide silicon that is measurable by an analytical technique approved by the American Association of Plant Food Controlled Officials and/or the Association of Official Analytical Chemists.

[0060] In one embodiment, the applying of the ionic agricultural particles to the soil sequesters one or more heavy metals, such as non-toxic metals (for example, iron, cobalt, nickel, copper, manganese, molybdenum, and zinc), toxic metals (for example, mercury, plutonium, barium, and lead), selectively toxic metals (for example, vanadium, tungsten, arsenic, chromium, and cadmium), any other metal having a specific gravity above 5, or any suitable combination or sub-combination thereof. The heavy metals are sequestered by forming substantially inert particles including the

ionic agricultural particles and the heavy metals. For example, the ionic agricultural particles interact with and treat the soil such that the heavy metals form inert particles, thereby sequestering the heavy metals.

[0061] In one embodiment, the ionic agricultural particles are applied under conditions for increased effect. For example, in one embodiment, the ionic agricultural particles are applied under acidic soil conditions. In one embodiment, the ionic agricultural particles are applied during a period of increased growth during the life-cycle of the plants in the soil, for example, the spring or the fall, a one-month period, two-month period, or three-month period with higher amounts of moisture and/or sunlight than other periods of similar durations. In one embodiment, the ionic agricultural particles are applied under alkaline soil conditions, for example, when the ionic agricultural particles include sulfates. In one embodiment, the ionic agricultural particles are applied during a period, such as, a pre-growth period, a post-dormancy period, a dormancy period, a post-harvest period, a fallow period, any other suitable period, or combinations thereof.

[0062] While the invention has been described with reference to one or more embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. In addition, all numerical values identified in the detailed description shall be interpreted as though the precise and approximate values are both expressly identified.

CLAIMS

What is claimed is:

1. An ionic agricultural particle, comprising:
 - an anionic inorganic industrial by-product; and
 - a cationic organic binder,wherein the anionic inorganic industrial by-product and the cationic organic binder are electrostatically aggregated.
2. The ionic agricultural particle of claim 1, wherein the ionic agricultural particle includes a dimension of at least 500 μm .
3. The ionic agricultural particle of claim 1, wherein the cationic organic binder includes denatured soy bean particles.
4. The ionic agricultural particle of claim 1, wherein the anionic inorganic industrial by-product includes slag from metal production.
5. The ionic agricultural particle of claim 1, wherein the anionic inorganic industrial by-product includes synthetic gypsum.
6. An ionic agricultural composition, comprising:
 - a plurality of ionic agricultural particles, wherein each of the plurality of ionic agricultural particles includes:
 - an anionic inorganic industrial by-product; and
 - a cationic organic binder,
 - wherein the anionic inorganic industrial by-product and the cationic organic binder are electrostatically aggregated; and
 - an arrangement of the plurality of ionic agricultural particles.
7. The ionic agricultural composition of claim 6, wherein the arrangement of the plurality of ionic agricultural particles includes a powder.
8. The ionic agricultural composition of claim 6, wherein the arrangement of the plurality of ionic agricultural particles includes agglomerates.

9. The ionic agricultural composition of claim 6, wherein the arrangement of the plurality of ionic agricultural particles includes granules.
10. The ionic agricultural composition of claim 6, wherein the arrangement of the plurality of ionic agricultural particles includes pellets.
11. The ionic agricultural composition of claim 6, wherein the arrangement of the plurality of ionic agricultural particles includes a dispersion in a liquid carrier.
12. The ionic agricultural composition of claim 11, wherein the liquid carrier includes water.
13. The ionic agricultural composition of claim 11, wherein the liquid carrier includes beet juice.
14. The ionic agricultural composition of claim 6, wherein each of at least a portion of the plurality of ionic agricultural particles includes a dimension of at least 500 μm .
15. The ionic agricultural composition of claim 6, wherein each of the plurality of ionic agricultural particles includes a dimension of at least 500 μm .
16. The ionic agricultural composition of claim 6, wherein the cationic organic binder includes denatured soy bean particles.
17. The ionic agricultural composition of claim 6, wherein the anionic inorganic industrial by-product includes slag from metal production.
18. The ionic agricultural composition of claim 6, wherein the anionic inorganic industrial by-product includes synthetic gypsum.
19. A process of forming an ionic agricultural composition, comprising blending an anionic inorganic industrial by-product and a cationic organic binder to form a plurality of ionic agricultural particles.
20. The process of claim 20, wherein the plurality of ionic agricultural particles are subjected to a mechanical processing technique selected from the group consisting of powdering, agglomerating, granulating, pelletizing, and combinations thereof.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/032610

A. CLASSIFICATION OF SUBJECT MATTER

INV. C05D1/00 C05D3/04 C05D9/00 C05G3/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C05D C05G B01J A01N C05B C05F C21B C22B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2001/042494 A1 (WELSHIMER JAMES W [US] ET AL) 22 November 2001 (2001-11-22) paragraph [0013] paragraph [0022] - paragraph [0027] paragraph [0037] claims	1-3, 5-10, 14-20
X	-----	
Y	US 2013/269405 A1 (MIRANDA STEPHEN R [US] ET AL) 17 October 2013 (2013-10-17) paragraph [0009] - paragraph [0011] paragraph [0034] - paragraph [0040] paragraph [0046] - paragraph [0048] paragraph [0052] - paragraph [0056] claims	1,2, 4-10,14, 15,17-20 13
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

8 February 2016

Date of mailing of the international search report

16/02/2016

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INTERNATIONAL SEARCH REPORT

International application No PCT/US2015/032610

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/333428 A1 (MIRANDA STEPHEN R [US] ET AL) 19 December 2013 (2013-12-19)	1,2, 4-10,14, 15,17-20
Y	paragraph [0009] - paragraph [0011] paragraph [0034] - paragraph [0043] paragraph [0047] - paragraph [0056] paragraph [0061] claims	13
X	----- WO 2014/023988 A1 (PLANTACO LOGISZTIKAI ES SZOLGALTATO KFT [HU]) 13 February 2014 (2014-02-13)	1,6-9, 11,12, 19,20
Y	page 4, line 12 - line 22 page 11, line 19 - page 12, line 22 page 15, line 9 - line 34 claims	13
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X	----- US 2007/266824 A1 (STEIN JOSEPH L [US] ET AL) 22 November 2007 (2007-11-22)	1,2, 6-10,14, 15,17, 19,20
	paragraph [0018] - paragraph [0019] paragraph [0032] claims	

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