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3,273,960

CAKING RESISTANT MONOCALCIUM PHOSPHATE, MONOHYDRATE AND PROCESS FOR ITS MANUFACTURE

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This invention relates to new and unexpectedly advantageous mixtures of alkaline earth metal phosphate salts, to processes for preparing them, and to methods for their use.

The tendency for particulated salts such as monocalcium orthophosphate monohydrate (MCP), sodium chloride, sodium tripolyphosphate, etc., to cake, or to form large, hard lumps when they are exposed to a highly humid atmosphere and/or to high pressures for an extended period of time is well known. In the past, many efforts have been made to find a suitable method for the prevention or inhibition of this tendency to cake without complete success, particularly with respect to phosphate salts such as MCP which have a very strong caking tendency.

It is an object of this invention to provide materials for significantly reducing the normal tendency of particulated phosphate salts such as MCP to cake when a small amount of the material is blended with the salt which has the tendency to cake.

It is another object of this invention to provide improved methods for reducing the normal tendency of particulated salts, such as those described above, to cake when they are exposed to conditions of high humidity and/or pressure.

It is still another object of this invention to provide methods for the preparation of materials having the ability to significantly reduce the normal tendency of particulated salts such as those described above to cake.

These objects, as well as others, can be attained in accordance with the present invention by preparing and properly utilizing mixtures of orthophosphate and polyphosphate salts that result from the reaction of inorganic alkaline earth metal bases with superphosphoric acids that contain a fairly large proportion of polyphosphoric acids.

It has been found that when certain superphosphoric acids are reacted with a sufficient quantity of a reactive alkaline earth metal base, the resulting water-insoluble mixture of alkaline earth metal phosphate salts is unexpectedly proficient as an anti-caking agent. In fact, for some systems, such as for monocalcium orthophosphate monohydrate, for example in which conventional anti-caking agents such as commercial tricalcium phosphate (hydroxylapatite), sodium silico aluminate, etc., do not perform efficiently, it has been found that the products from the aforesaid reaction are particularly efficacious in this respect.

In order to simplify the detailed discussion of the present invention, the unexpectedly useful products from the reaction of these certain superphosphoric acids and alkaline earth metal bases or carbonates will be termed "hyperphosphate" salts or "hyperphosphates" throughout the remainder of the present specification and the appended claims. Although it is not known with certainty why the alkaline earth metal hyperphosphates are so outstandingly effective as anti-caking agents, it is believed that they function in this improved manner because their polyphosphate moiety is apparently predominantly amorphous (non-crystalline) in character. It is believed that this amorphous moiety of the alkaline earth metal hyperphosphates makes it possible for the products of the present invention

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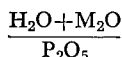
to perform so much better as anti-caking agents than would any otherwise similar blends of crystalline alkaline earth metal phosphate salts. Thus the alkaline earth metal hyperphosphates of this invention can be characterized in one respect by the fact that their polyphosphate moiety is at least about 65 weight percent, and preferably is substantially entirely amorphous.

The superphosphoric acids useful in the practice of the present invention are those which contain, in addition to orthophosphoric acid, at least about 10, and preferably at least about 30, weight percent of polyphosphoric acids. (The polyphosphoric acids are those phosphoric acids that contain more than one phosphorous atom in each molecule or phosphorous "chain." Depending upon the actual concentration of phosphorous in the superphosphoric acids, polyphosphoric acids contained therein have from 2 to 12, or even more, phosphorous atoms per molecule. The more concentrated (in P_2O_5) superphosphoric acids contain relatively more of the higher polymers.) Stated otherwise, the superphosphoric acids with which this invention is concerned are those that contain at least about 71 weight percent, and preferably at least about 75 weight percent of phosphorous, calculated as P_2O_5 . Because they are somewhat easier to handle in the liquid state, it is also preferred that the superphosphoric acids that are utilized in the practice of the present invention be liquid, or at least semi-fluid at some temperature below about 75° C. Consequently, preferred superphosphoric acids are those that contain less than about 85 weight percent of phosphorous, calculated as P_2O_5 . Thus, the alkaline earth metal "hyperphosphates" of the present invention can be characterized as being the reaction products of alkaline earth metal bases or carbonates with superphosphoric acids that contain from about 71 to 85 weight percent of phosphorous, calculated as P_2O_5 , which reaction products also contain at least about 10 weight percent, and preferably at least about 30 weight percent, of polyphosphates (i.e., phosphates having more than one P atom in their molecules). This polyphosphate portion of the alkaline earth metal "hyperphosphates" of the present invention is further characterized by being at least about 65 weight percent (and preferably substantially all) in the amorphous (non-crystalline) condition.

Ordinarily, superphosphoric acids are manufactured by simply absorbing a certain amount of phosphorous pentoxide (in the form of P_2O_5 vapor which usually results from burning elemental phosphorous) into water, or into a relatively dilute solution of orthophosphoric acid, until the desired amount of phosphorous is contained in the aqueous, syrupy absorption medium. For purposes of the present invention it has been discovered that satisfactory reagents containing large superphosphoric acid moiety can also be made by dissolving some alkali metal salts of the polyphosphoric acids (such as, for example, tetrasodium pyrophosphate, tetrapotassium pyrophosphate, sodium acid pyrophosphate, lithium acid pyrophosphate, sodium tripolyphosphate, potassium tripolyphosphate, sodium trimetaphosphate, potassium trimetaphosphate, sodium and/or potassium "glassy" phosphates, etc.) into orthophosphoric acid, or even into one of the superphosphoric acids. In this manner, the polyphosphoric acid fraction of the particular phosphoric acid which is being utilized can be changed to some extent without having to dilute the superphosphoric acid with water, or having to handle highly dangerous P_2O_5 . Because the polyphosphate salts are soluble in orthophosphoric acid and in superphosphoric acid to only a limited degree, the amount of alkali metal polyphosphate salts that can be utilized in preparing the particular superphosphoric acid that is to be neutralized with the alkaline earth metal base or carbonate according to the present

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invention, will be limited to that amount which can be dissolved into the superphosphoric acid. Ordinarily, when such alkali metal polyphosphate salts as those described above are employed as solubilized components in the reagents containing large superphosphoric acid moiety of the invention, they will be present in the superphosphoric acids only to the extent that the ratio of the total cation (hydrogen plus alkali metal) moiety of the acid composition to phosphorous, calculated as



is between about 3.1 and about 1.2, but it is preferred that this ratio be between about 2.6 and about 1.7. M, in the foregoing formula is an alkali metal cation.

The alkaline earth metal bases and carbonates which can be reacted with the above-described superphosphoric acids in the practice of this invention are those which have measurably higher solubilities in water than do their corresponding alkaline earth metal phosphate salts. Since almost all of the alkaline earth metal orthophosphate and alkaline earth metal polyphosphate salts (particularly those containing calcium and magnesium) are extremely insoluble in water, a fairly wide variety of alkaline earth metal bases and all of the alkaline earth metal carbonates can be utilized in the practice of this aspect of the invention. For example, calcium, magnesium, strontium, and barium carbonate, hydroxide, oxide, as well as mixtures of these, can be utilized in the practice of this invention. Because of problems relating to toxicity that sometimes arise when barium and strontium salts are utilized for certain purposes, and since barium and strontium bases are not readily available, the alkaline earth metal bases and carbonates which are preferred are the calcium and magnesium bases and carbonates. Of these, still further preferred are the hydroxides.

The above-described superphosphoric acids and alkaline earth metal bases and/or carbonates can be brought into contact with one another in any particular manipulative manner desired without having a substantial effect upon the benefits which result from practicing the invention, or varying from the spirit of the invention. All that is necessary, for example, is that sufficient alkaline earth metal base and/or carbonate be supplied to neutralize essentially all of the superphosphoric acids contained therein. It is preferred, however, that the superphosphoric acid be intermixed with the particular alkaline earth metal base and/or carbonate employed only in the presence of sufficient water to provide both an efficient transfer of heat through the system and adequate ease of agitation. (This particular aspect of the invention will be described in more detail below.) Thus, the desired reaction of alkaline earth metal base or carbonate with superphosphoric acid must ordinarily be made to occur in a fairly fluid, aqueous medium.

Perhaps the best way in which superphosphoric acid, water, and alkaline earth metal base and/or carbonate can be brought together under the desired conditions is by first diluting the superphosphoric acid with water (preferably concurrently removing heat from the resulting dilute solution by any appropriate conventional means in order to minimize hydrolysis of the polyphosphoric acids), and then mixing the resulting relatively dilute aqueous solution of superphosphoric acid (containing polyphosphoric acids) into a slurry of the appropriate alkaline earth metal base or carbonate. In this particular procedure the base or carbonate can be dispersed in water prior to the mixing step, or can be added directly to the dilute aqueous superphosphoric acid solution. Also, via a preferred procedure, fairly concentrated superphosphoric acid can be added slowly (drop-wise or in a slow stream, for example) to an agitated solution or suspension of the appropriate alkaline earth metal base or carbonate in water. In this manner, the hydrolysis rate of

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the polyphosphoric acids can be minimized, since it has been found that their hydrolysis occurs more slowly in basic solutions. The heat of dilution (of the superphosphoric acid) as well as the heat evolved from the desired reaction can be removed as the reaction proceeds. Thus, the superphosphoric acid can be maintained at a relatively low temperature until it has been completely reacted with the particular alkaline earth metal base or carbonate employed.

It should be noted that when superphosphoric acids containing a significant quantity of any of the polyphosphoric acids described above are diluted with water, the relative proportions of orthophosphoric acid to the various polyphosphoric acids (as well as the relative proportions of the various polyphosphoric acids, one to another) in the diluted aqueous system remain substantially unchanged from those which existed in the original superphosphoric acid unless or until the polyphosphoric acids are degraded by hydrolysis. Thus, an alkaline earth hyperphosphate prepared by reacting a particular alkaline earth metal base with a diluted superphosphoric acid (that has not been hydrolytically degraded) is substantially identical to the hyperphosphate which results from reacting the alkaline earth metal base or carbonate with the superphosphoric acid in a concentrated, undiluted state (assuming that reaction conditions were such that the concentrated superphosphoric acid was not degraded). Hence, the present invention can be said to involve the reaction of one of the alkaline earth metal bases or carbonates described above with a mixture of orthophosphoric acid and polyphosphoric acids, which mixture is similar to that contained in any of the desirable superphosphoric acids described above.

Ordinarily the reaction or neutralization of superphosphoric acid with alkaline earth metal base or carbonate should be permitted to proceed until substantially no unreacted superphosphoric acid remains in the aqueous reaction medium. Because the presence of a significant amount of unreacted phosphoric acids in the final alkaline earth metal hyperphosphate products is not desirable, the pH (measured at the 1 weight percent level in distilled water) of the aqueous reaction medium should be between about 5 and about 9, and preferably between about 6 and about 8 when the reaction has proceeded to the optimum extent. On the other hand, up to about 10 weight percent of alkaline earth metal base or carbonate can be present in the final hyperphosphate products without detracting substantially from the benefits that can be derived from practicing the present invention.

The reaction of superphosphoric acid and one or more of the above-described alkaline earth metal bases or carbonates can be conducted in an aqueous medium in conventional mixing equipment, preferably while the materials are being continuously stirred. The temperature of the aqueous medium during the above-described reaction or neutralization should generally be maintained between about 2° C. and about 50° C., but should preferably be between about 10° C. and about 35° C., although even higher temperatures can be utilized. Where higher temperatures are employed, careful consideration must be given to the effect of the increase in the rate of hydrolysis of the polymeric fraction of superphosphoric acid, which rate of hydrolysis increases considerably when the reaction temperature is raised.

Since the reaction rate (of superphosphoric acid with an alkaline earth metal base or carbonate) is interdependent to some extent upon not only the temperature of the reaction medium, but also the particular base or carbonate employed (for example, calcium carbonate ordinarily reacts more slowly with superphosphoric acid than does calcium hydroxide), a concise definition of all of the elements relating to the preferred conditions under which the invention should be carried out cannot be made. It should be noted, however, that the reaction conditions must be such that the alkaline earth metal hyperphosphate

salts always contain at least about 10 weight percent, and preferably at least about 30 weight percent of polyphosphate salts.

In order to provide practically efficient ease by which heat can be transferred through the reaction medium (wherein superphosphoric acid is reacted with an alkaline earth metal base or carbonate, as described above) and also in order to provide adequate ease of agitation (so that conventional mixing equipment can be utilized for the processes of this invention), it has been found that it is best to use at least about 70 weight percent of water (based on the combined weight of water plus final alkaline earth metal hyperphosphate product), and sometimes as much as 90 weight percent of water, or even more. As a practical matter, however, because of the expense of removing the water from the hyperphosphate product (which removal must be undertaken subsequently), usually not more than about 85 weight percent of water will be utilized in these processes.

The water can be removed from the above-described final slurry or paste by any particular procedure desired. For example, conventional drum-driers or spray-drying facilities can readily be utilized. The dried product resulting from the application of conventional drying techniques to the slurries or pastes which in turn resulted from the above-described reaction is generally in the form of loosely agglomerated flakes or granules, which are usually larger than desired for the product's optimum performance as an anti-caking agent. When such lumping or agglomeration occurs, usually a single pass of the dried product through a conventional powder mill, such as for example a hammer mill, is sufficient to reduce the relatively larger particles to a more desirable size. It has been found that, although hyperphosphate products having particles that barely pass through a U.S. Standard 30-mesh screen are effective to some extent as anti-caking agents, for highest efficiency as an anti-caking agent, most of the particles of hyperphosphate product, produced according to this invention, should be finely divided: that is, the particles should be small enough so that at least about 80 weight percent of them can be passed through a U.S. Standard 100-mesh screen. Preferably, the particles should be small enough so that at least about 70 weight percent of them can be passed through a U.S. Standard 325-mesh screen.

When the finely divided alkaline earth metal hyperphosphate salts are to be utilized as anti-caking agents, they need only be interspersed reasonably well through the particulated material which is to be prevented from caking excessively. Sufficiently good dispersion of the above-described hyperphosphate salts can be accomplished, for example, in practically any conventional mixer or blender. Thus, the particulated material (which will ordinarily have a tendency to cake under certain conditions) and the finely divided alkaline earth metal hyperphosphate need only be intermixed in the appropriate proportions in a conventional ribbon type mixer, for example for about 5 minutes, in order to achieve an excellent degree of dispersion of the anti-caking additive through said particulated material.

While, in order to reduce the caking tendencies of materials such as MCP, sodium chloride, sugar, sodium tripolyphosphate, etc., very small amounts of finely divided alkaline earth metal hyperphosphates are effective (for example, some observable anti-caking effectiveness can be observed when they are present at a level as low as about 0.2 weight percent), usually at least about 0.5 weight percent (based on the weight of the material being treated) of one or more of the hyperphosphates of this invention is ordinarily utilized. For optimum results, usually at least about 1 weight percent of one of these hyperphosphates should be interspersed through the particulated material being treated. There is no critical upper limitation as to the amount of alkaline earth metal hyperphosphate that can be utilized in order to reduce

the caking tendency of any given material. However, as practical matter, usually not more than about 10 weight percent should be used.

As it was stated above, the apparent reason that the alkaline earth metal hyperphosphates which are produced according to this invention perform so efficiently as anti-caking agents is that the polyphosphate fraction of these materials is amorphous in character. X-ray analysis of calcium hyperphosphate, for example, gave patterns which indicated that the only crystalline material present was tricalcium orthophosphate. Thus, since the calcium polyphosphates gave no X-ray diffraction pattern, it is concluded that they are amorphous or non-crystalline in form. Another factor that tends to support the conclusion that the hyperphosphates of this invention are unique is their excellent performance as anti-caking agents for, for example, MCP, as compared to the performance in the same application of a physical blend of (crystalline) phosphate salts, which blend is made up to simulate as closely as possible the hyperphosphate. For example, calcium hyperphosphate made from 105% H_3PO_4 (76% P_2O_5) according to Example I, below, is a significantly superior anti-caking agent for particulated (powdered) MCP as compared with a physical blend of 42 weight percent of crystalline tricalcium orthophosphate, 42 weight percent of crystalline calcium pyrophosphate, 8.5 weight percent of crystalline calcium tripolyphosphate, and 0.5 weight percent of crystalline calcium tetraphosphate, even though the particle size distribution of this physical blend of crystalline salts is almost identical to that of the calcium hyperphosphate. Relative performance data for these materials are given in Table I, below.

In the following examples, all parts are by weight unless otherwise specified.

EXAMPLE I.—PREPARATION OF CALCIUM HYPERPHOSPHATE

Into 2330 parts of water in a conventional glass-lined, jacketed mixing tank are blended one hundred parts of superphosphoric acid containing 75.5 weight percent of phosphorous, calculated as P_2O_5 . The acid is added slowly in order to avoid localized overheating and the unnecessary hydrolysis of the polymeric phosphoric acids that might otherwise result from a quick dilution of the superphosphoric acid. The temperature of the water during the addition of the superphosphoric acid is maintained below about 35° C. by circulating cool water through the jacket of the mixing tank. Into another, similar mixing tank are poured 5460 parts of water. To this water are added 1132 parts of calcium hydroxide. The resulting slurry is agitated while the diluted superphosphoric acid, prepared above, is added slowly to the slurry. The temperature of the aqueous reaction mixture is maintained below about 35° C. during and subsequent to the addition of the superphosphoric acid. The formation of calcium hyperphosphate is completed within a period of about thirty minutes after the superphosphoric acid is introduced into the calcium hydroxide slurry. The pH of the resulting slurry is then adjusted to about 7 by the incremental addition of small amounts of lime and superphosphoric acid. Other acids and/or bases can be used for this final adjustment of the pH of the slurry to the desired value.

The resulting slurry is then dried on a 36 inch diameter stainless steel drum dryer which is heated with steam under 80 pounds per square inch gauge pressure and rotating at 6 revolutions per minute. The drum-dried product contacts about 5 weight percent of moisture and is in the form of fairly large flakes and agglomerates. This product is then passed once through a conventional hammer mill. Its particles are thereby reduced in size so that about 95 weight percent of them can be passed through a U.S. Standard 325-mesh screen. X-ray diffraction analysis of this product reveals that tricalcium orthophosphate is the only crystalline material present.

EXAMPLE II.—PREPARATION OF MAGNESIUM HYPERPHOSPHATE

The procedure shown in Example I is followed except that 810 parts of magnesium hydroxide is used in place of the calcium hydroxide. The calcium and magnesium hyperphosphates from Examples I and II, respectively are both excellent anti-caking agents for MCP, sodium chloride, sodium tripolyphosphate, as well as many other materials that have a tendency to cake when they are exposed to conditions of high humidity and/or pressure.

Anti-caking properties of the alkaline earth metal hyperphosphates

Ten thousand parts of powdered commercial monocalcium orthophosphate monohydrate (MCP) are blended in a conventional ribbon-type mixer for about 15 minutes with 150 parts of the finely-divided calcium hyperphosphate prepared according to Example I, above. Thirty grams of the resulting blend are then placed loosely in a 3 cm. by 3½ cm. rigid-walled "exposure" cylinder, which is then covered (top and bottom) with a moisture permeable fabric and exposed for 48 hours at 90° F., under 6.7 p.s.i.g. pressure to an atmosphere at 80% relative humidity. The results of this test (to determine the resistance of the treated MCP to caking) are listed in Table I, below, along with comparative data for both conventionally known anti-caking agents, and for other alkaline earth salts of superphosphoric acid (hyperphosphates). Note that results in Table I are given in terms of "caking numbers" which represent the pounds of force required to be applied uniformly to the top surface of the "cake" of MCP in order to break it. The lower "caking numbers" indicate better resistance to the normal caking tendency of MCP. "Caking numbers" lower than about 20 are considered desirable. Generally, it has been found that those products which yield "caking numbers" lower than about 20 will not cake appreciably under ordinary conditions of handling and shipping.

TABLE I.—"CAKING NUMBERS" FOR VARIOUS ANTI-CAKING AGENTS

Agent	Concentration ⁴	
	1%	2%
(a) Control-powdered monocalcium orthophosphate monohydrate.....	45	
(b) Calcium hyperphosphate—Example I (from 105% H ₃ PO ₄) ¹	10	5
(c) Calcium hyperphosphate (from 110% H ₃ PO ₄) ¹	8	(⁵)
(d) Magnesium hyperphosphate—Example II (from 105% H ₃ PO ₄) ¹	12	9
(e) Simulated calcium hyperphosphate ^{1, 2}		30
(f) Commercial powdered tricalcium orthophosphate ³		36
(g) Microcrystalline tricalcium orthophosphate ³		32
(h) Sodium silico aluminate ⁴ (commercial "flow-conditioner").....	21	(dusty) 11

¹ Average particle size = <10μ.
² Blended salts, combined to the relative proportions present in agent (b), above.
³ Average particle size = <1μ.
⁴ In powdered monocalcium orthophosphate monohydrate.
⁵ Cake broke before weight applied.

Note that the "caking number" test is a very severe one, and that the alkaline earth metal hyperphosphates of the present invention are unexpectedly superior as anti-caking agents for MCP, compared to products that are presently commercially recommended for this purpose. Also of interest is the fact that, although the largest single chemical component of the calcium hyperphosphate from 105% H₃PO₄ ("b" in Table I), is tricalcium orthophosphate, the hyperphosphate performs significantly better in this test than does a product that consists essentially of tricalcium orthophosphate ("f" in Table I).

What is claimed is:

1. A process for manufacturing a particulated monocalcium orthophosphate monohydrate composition which is resistant to caking, which process comprises intermixing with said monocalcium orthophosphate monohydrate from about 0.2 to about 10 weight percent of a finely divided alkaline earth metal hyperphosphate, whereby the normal tendency of said monocalcium orthophosphate monohydrate to cake is inhibited; at least about 80 weight percent of the particles of said finely divided alkaline earth metal hyperphosphate being small enough to pass through a U.S. Standard 100 mesh screen; said alkaline earth metal hyperphosphate being the product resulting from reacting together a material selected from the group consisting of alkaline earth metal bases and alkaline earth metal carbonates with a superphosphoric acid containing initially from about 71 to about 85 weight percent of phosphorus, calculated as P₂O₅; said product being characterized as containing at least about 30 weight percent polyphosphates having more than one phosphorus atom in their molecules, and being at least about 65 weight percent in the amorphous condition.
2. A process as in claim 1, wherein said alkaline earth metal is selected from the group consisting of calcium and magnesium.
3. A process for manufacturing a particulated monocalcium orthophosphate monohydrate composition which is resistant to caking, which process comprises intermixing with said monocalcium orthophosphate monohydrate between about 0.2 and 10 weight percent of finely divided alkaline earth metal hyperphosphate; at least about 70 weight percent of the particles of said finely divided alkaline earth metal hyperphosphate being small enough to pass through a U.S. Standard 325 mesh screen; said alkaline earth metal hyperphosphate being the product resulting from reacting together a material selected from the group consisting of alkaline earth metal bases and alkaline earth metal carbonates with a superphosphoric acid containing initially from about 71 to about 85 weight percent of phosphorus, calculated as P₂O₅; said product being characterized as containing at least about 30 weight percent polyphosphates having more than one phosphorus atom in their molecules, and being substantially entirely amorphous.
4. Particulated monocalcium orthophosphate monohydrate having intimately dispersed therein from about 0.5 to about 10 weight percent of finely divided calcium hyperphosphate; at least about 70 weight percent of said finely divided calcium hyperphosphate being small enough to pass through a U.S. Standard 325 mesh screen; said alkaline earth metal hyperphosphate being the product resulting from reacting together a material selected from the group consisting of alkaline earth metal bases and alkaline earth metal carbonates with a superphosphoric acid containing initially from about 71 to about 85 weight percent of phosphorus, calculated as P₂O₅; said product being characterized as containing at least about 30 weight percent polyphosphates having more than one phosphorus atom in their molecules, and being at least about 65 weight percent in the amorphous condition.

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