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(54) Title: ANTIMICROBIAL CHEMICAL COMPOSITIONS

(57) Abstract: Antimicrobial chemical compositions comprise an aluminum phosphate (AlP) solid dispersed within a binding polymer, wherein one or more bioactive materials are disposed within AlP forming a bioactive-AlP complex. The complex may comprise the bioactive material chemically bonded with the AlP, physically combined with the AlP, or a combination of both. The complex may be formed according to precipitation, condensation and sol-gel methods of forming. The complex is engineered to provide a controlled delivery of the bioactive material or a constituent thereof upon exposure to moisture to give a desired level of antimicrobial resistance to a film or composite formed from the composition of at least about 30 μg/m2, and may also provide a desired degree of corrosion resistance through the release of passivating phosphate anion. Such antimicrobial chemical compositions provide an improved degree of active, long-term resistance to a broad range of micro-organisms when compared to known antimicrobial chemical compositions.

ANTIMICROBIAL CHEMICAL COMPOSITIONS

FIELD OF THE INVENTION

This invention relates to chemical compositions having antimicrobial properties and, more specifically, to chemical compositions that are specially formulated to include an aluminum phosphate complex comprising one or more antimicrobial agents, and methods for making the same.

BACKGROUND OF THE INVENTION

Chemical compositions formulated to include one or more antimicrobial agents to provide antimicrobial properties, e.g., provided in the form of a coating composition or the like for forming a film layer on an underlying substrate surface, are known in the art. Such antimicrobial chemical compositions make use of antimicrobial agents known to provide some degree of protection against unwanted micro-organisms.

Conventional antimicrobial chemical compositions known in the art, e.g., formulated products such as water-based paints and coatings, include biocides incorporated therein to preserve the liquid composition during storage from spoilage by micro-organisms. Antimicrobial protection is afforded from such conventional paints and coatings by the incorporation of agents that prevent defacement of the applied, dry film in service by mold and/or mildew growth.

While conventional antimicrobial chemical compositions are known to provide some protection against unwanted microorganisms, the protection afforded is somewhat limited in both the degree of its activity, and the length in time of its being able to offer a desired level of resistance to unwanted microorganisms. This is largely due to the nature of the formulation and the limited activity of the antimicrobial agent disposed therein, and the resulting inability to provide a highly-active and long-lasting resistance to unwanted microorganisms. Thus, while such conventional antimicrobial chemical compositions are capable of providing some degree of resistance to microorganisms, they are unable to provide a desired or needed level of microorganisms control sufficient to meet the demands of certain end-use applications.

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There is an unmet need to provide active, long-term resistance to a broad range of bacteria, mold, mildew, and other harmful micro-organisms to prevent collateral effects of illness and/or product spoilage due to infection. Examples of target end-use applications where it is critical to prevent infection and product spoilage from surface contact in sensitive environments includes: hospitals and health care facilities; kitchens and food processing and storage areas; dairies; breweries; bathroom and rest room facilities; hotels; school, recreation, amusement, and sports facilities. While existing anti-microbial additives may provide some degree of anti-microbial action, their effectiveness in such formulated products as paints and coatings is limited by the amounts ofmaterial required to achieve anti-microbial action, which exceeds: (1) cost constraints for the formulated product; (2) usage limitations relative to non-target toxicity; (3) the practical limits for incorporation in the formulated product; and (4) which may be limited by the mechanism for delivery to the surface of the article to be protected.

It is, therefore, desired that antimicrobial chemical compositions be formulated in a manner that provide a desired active, long-term resistance to a broad range of microorganisms, including bacteria, mold, mildew, and other micro-biological species to prevent collateral effects of illness and product spoilage, when compared to known antimicrobial chemical compositions, thereby meeting the needs of certain end-use applications. It is desired that such antimicrobial chemical compositions be engineered in a manner facilitating the ability to effectively customize, adjust and/or tailor changes in the performance characteristics of the formulations for the purpose of effectively addressing the specific antimicrobial needs associated with different end-use applications. It is further desired that such antimicrobial chemical compositions be formulated from readily available materials, and/or be made by methods, that facilitate manufacturing the chemical compositions in a manner that does not require the use of exotic equipment, that is not unduly labor intensive, and that is economically feasible.

SUMMARY OF THE INVENTION

In a first aspect, the present invention provides an antimicrobial chemical composition comprising: a complex comprising a bioactive constituent that is a metal ion, wherein the complex releases the bioactive constituent at a rate upon contact of the complex with moisture; and a binder polymer forming a bulk matrix of the composition, wherein the complex is disposed within bulk matrix, and wherein the bulk matrix enables the bioactive constituent that is released from the complex to diffuse therethrough at a rate; wherein the rate of release of the

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bioactive constituent from the complex is the same or different from the rate of diffusion of the bioactive constituent through the bulk matrix, wherein the complex comprises amorphous aluminum phosphate, wherein the complex has a porosity, and wherein the rate of release of the bioactive constituent is a function of the porosity.

In a second aspect, the present invention provides a antimicrobial chemical composition comprising: a binding polymer; and a bioactive-aluminum phosphate complex dispersed within the binding polymer, the complex comprising an aluminum phosphate polymer and a bioactive material comprising a bioactive constituent that is a metal ion; wherein the aluminum phosphate complex has an engineered porosity that, when the composition is cured, provides a controlled delivery of the bioactive constituent when exposed to moisture, wherein the aluminum phosphate polymer comprises amorphous aluminum phosphate.

In a third aspect, the present invention provides a system for providing antimicrobial protection comprising a coating composition applied to substrate and cured to form a film, the coating composition comprising a binding polymer with a bioactive-aluminum phosphate complex dispersed therein, wherein the complex comprises an amorphous aluminum phosphate combined with a bioactive material, and wherein the complex is engineered to provide a controlled delivery of a bioactive constituent that is a metal ion when exposed to moisture.

In a fourth aspect, the present invention provides a method for making an antimicrobial chemical composition, wherein the composition when cured provides a controlled delivery of a bioactive constituent derived from the bioactive material upon exposure to moisture, the method comprising adding a polymer binding material to a bioactive-aluminum phosphate complex prepared according to a method for making a bioactive-aluminum phosphate complex comprising the steps of: forming an amorphous aluminum phosphate by combining an aluminum source, with a phosphate source in an aqueous solution at suitable pH to form a dispersion of aluminum phosphate; and adding a bioactive material during or after the step of forming so that the bioactive material is combined with the aluminum phosphate to form the bioactive-aluminum phosphate complex, the complex being capable of releasing a bioactive constituent that is a metal ion, wherein during the step of forming, the dispersion comprises amorphous aluminum phosphate.

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In a fifth aspect, the present invention provides a method for making an antimicrobial chemical composition comprising a bioactive material dispersed within an aluminum phosphate, the method comprising the steps of: forming an aluminum phosphate by combining an aluminum source, with a phosphate source in an aqueous solution at suitable pH to form a dispersion of aluminum phosphate; adding a bioactive material during or after the step of forming so that the bioactive material is disposed in the aluminum phosphate forming a bioactive-aluminum phosphate complex; and combining a polymer binding material with the bioactive-aluminum phosphate complex to form the antimicrobial chemical composition; wherein the composition when cured provides a controlled delivery of a bioactive constituent that is a metal ion derived from the bioactive material upon exposure to moisture of from 10 to 900 ppm, wherein during the step of forming, the dispersion comprises amorphous aluminum phosphate.

In a sixth aspect, the present invention provides a method for making an antimicrobial chemical composition comprising a bioactive material combined with an aluminum phosphate, the method comprising the steps of: forming an aluminum phosphate by combining an aluminum source, with a phosphate source in an aqueous solution at suitable pH to form a dispersion of aluminum phosphate; adding a bioactive material to the amorphous aluminum phosphate after the step of forming to provide a complex wherein the bioactive material is physically incorporated in the aluminum phosphate to form a bioactive-aluminum phosphate complex; and combining a polymer binding material with the complex to form the antimicrobial chemical composition; wherein the composition when cured provides a controlled delivery of a bioactive constituent that is a metal ion derived from the bioactive material of 100 ppm or greater upon exposure to moisture, wherein during the step of forming, the dispersion comprises amorphous aluminum phosphate.

In a seventh aspect, the present invention provides a method for making an antimicrobial chemical composition comprising a bioactive material combined with aluminum phosphate, the method comprising the steps of: combining aluminum hydroxide and phosphoric acid to form a solution comprising an acidic aluminum phosphate condensate; combining a bioactive material during or after the step of forming the acidic aluminum phosphate condensate to form mixture comprising a bioactive-aluminum phosphate complex comprising the bioactive material that is a metal ion; and and further comprising the step of adding a neutralizing agent to the acidic aluminum phosphate complex to increase its pH; and combining a polymer binding material

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with the complex to form the chemical composition, wherein the complex comprises amorphous aluminum phosphate.

In an eighth aspect, the present invention provides a method for making an antimicrobial chemical composition comprising a bioactive material combined with aluminum phosphate, wherein the bioactive material comprises a metal salt, the method comprising the steps of: combining a bioactive material with aluminum hydroxide to form a mixture, and wherein before the step of combining, a complex is formed by combining the metal salt with a ligand; adding the mixture to phosphoric acid to form a bioactive-aluminum phosphate complex comprising the bioactive material; and combining a polymer binding material with the complex to form the chemical composition, wherein the complex comprises amorphous aluminum phosphate.

In a ninth aspect, the present invention provides an antimicrobial chemical complex comprising a bioactive constituent in the form of metal ions chemically bonded with and incorporated into a polymer backbone of an amorphous aluminum phosphate, the complex having an engineered porosity to provide a controlled release of the metal ions therefrom of from about 10 to 1,000 ppm upon contact of the complex with moisture, wherein the porosity is characterized by at least one of: a total intrusion volume of 0.5 to 2 mL/g; an average pore diameter of from about 0.02 to 0.6 μm; or a BET surface area from about 2 to 250 m^2/g.

In a tenth aspect, the present invention provides a bioactive-aluminum phosphate complex comprising amorphous aluminum phosphate and a bioactive material including a complexed metal material, wherein the complexed metal material comprises silver ions combined with a ligand, wherein the complexed metal material is chemically bonded with and incorporated into a polymer backbone of the amorphous aluminum phosphate.

Antimicrobial chemical compositions as described herein generally comprise an aluminum phosphate (AlP) solid that is dispersed within a binding polymer. One or more bioactive materials are disposed within or combined with the AlP to form a bioactive-AlP complex. A feature of the complex is that it is specifically engineered such that, when the composition is provided in the form of a dried film or composite, it

provides a controlled delivery of a bioactive constituent (derived from the bioactive material upon exposure to moisture) to the film or composite surface to provide a desired level of antimicrobial resistance. The AlP used to form the complex may be in amorphous form, in crystalline form, or in a combination thereof. In an example embodiment, the AlP comprises amorphous AlP.

The bioactive material or a bioactive constituent derived therefrom, used to form the complex may either be chemically bonded with, e.g., provided in the backbone of, the AlP polymer, or may be physically incorporated, enmeshed, encapsulated, or intertwined with the AlP polymer, depending on the particular method used to make the complex. The bioactive material can be organic and/or can be a metal salt or oxide such as those including silver salts, copper salts, zinc salts, calcium salts, and combinations thereof, and/or can be a metal ion such as those including silver, copper, zinc, calcium, and combinations thereof. Additionally, the bioactive material may comprise one or more metal oxides, which may include and are not limited to oxides of zinc, copper, magnesium, barium, calcium and combinations thereof, and which may add to the antimicrobial effectiveness and/or light stability of the bioactive material. Further, the bioactive material may be complexed before being combined to form the bioactive-AlP complex, which may add to the color or light stability of the bioactive material. In an example, where the bioactive material comprises a metal salt such as silver nitrate, the metal salt can be complexed with a ligand such as ammonia, imidazole, substituted imidazole, and combinations thereof before the complexed metal salt is combined with other ingredients used to form the bioactive-AlP complex. Binding polymers used to form the composition can include polyurethanes, polyesters, solvent-based epoxies, solventless epoxies, water-borne epoxies, epoxy copolymers, acrylics, acrylic copolymers, silicones, silicone copolymers, polysiloxanes, polysiloxane copolymers, alkyds and combinations thereof.

In an example embodiment, the AlP is engineered to provide a controlled delivery of the bioactive constituent when the chemical composition is in a cured form, e.g., in the form of a coating film or a composite structure, of from about 5 to 1,000 ppm, preferably about 10 to 900 ppm, and most preferably from about 15 to 800 ppm. In an example embodiment, it is desired to provide at controlled delivery of at least 100 ppm or greater of the bioactive constituent. The amount of the bioactive material, e.g., Ag, in

the complex may be in the range of from about 1 to 10 percent by weight, preferably from about 2 to 8 percent by weight, and more preferably from about 3 to 6 percent by weight based on the total weight of the complex. The ratio of phosphate to aluminum in the complex is in the range of from about 0.5:1 to 1.5:1. The bioactive-AlP complex in the chemical composition comprises from about 0.1 to 2 percent of the dry film weight, or 20 to 1,000 ppmw of bioactive constituent, e.g., Ag in the paint. In a preferred embodiment, an effective leaching rate, that is, amount of bioactive constituent, e.g., Ag, released on the surface of a cured coating or cured composite comprising the bioactive-AlP complex is at least about 30 $\mu g/m^2$, and is preferably about 36.9$\mu g/m^2$ or >2$\mu g/L$ in a rinse for bioactivity.

In an example embodiment, the antimicrobial chemical composition may also provide a desired degree of corrosion resistance, e.g., when formulated as a coating for use with metallic substrates. In such embodiment, the AlP is formulated to provide, in addition to the controlled release/delivery of bioactive constituent, a controlled delivery of passivating anion such as phosphate anion upon exposure to moisture. In an example embodiment, such antimicrobial chemical composition may provide a controlled delivery of phosphate anion of greater than about 100 ppm.

Antimicrobial chemical compositions as described herein are made by first forming the bioactive-AlP complex, which comprises forming an AlP by combining a desired aluminum source, with a desired phosphate source under suitable reaction conditions, e.g., in an aqueous solution at suitable pH and suitable temperature, to form the AlP. The bioactive material is added to the AlP during and/or after the step of forming the AlP so that the bioactive material is dispersed or combined with the AlP, thereby forming the bioactive-AlP complex. If desired, further AlP can be added to the bioactive-AlP complex before combining the complex with the binding polymer.

According to one example method of making, the bioactive material is added to the AlP after it has been formed, in which case the resulting bioactive-AlP complex comprises the bioactive material physically incorporated, enmeshed, encapsulated, or intertwined with the AlP polymer. According to another example method of making, the bioactive material is added to the AlP during formation of the AlP, in which case the resulting bioactive-AlP complex is formed in-situ with the ALP and comprises a

bioactive constituent of the bioactive material chemically bonded to the AlP polymer, e.g., as part of the ALP polymer backbone.

In an example, a bioactive-aluminum phosphate complex is made by combining an aluminum source (such as aluminum hydroxide in amorphous and/or in crystalline form) with a phosphate source (such as phosphoric acid) in the presence of a bioactive material to form a reaction mixture. The bioactive material can be provided as a separate ingredient or in a premixed form in combination with one or both of the aluminum source and the phosphate source. One or both of the aluminum source and phosphate source can be provided in the form of an aqueous solution. The reaction mixture is allowed to undergo reaction (e.g., at room temperature) to form a bioactive-aluminum phosphate complex, wherein the bioactive material is bonded with the aluminum phosphate. In an example, the bioactive material can be silver nitrate that may be complexed with imidazole or ammonia, and/or that may be combined with an oxide of zinc and/or copper. The so-formed bioactive-aluminum phosphate complex is combined with a desired polymer binder to form the antimicrobial chemical composition as disclosed herein.

Antimicrobial chemical compositions as described herein are specifically engineered to provide active, long-term resistance to a broad range of micro-organisms, including bacteria, mold, mildew, and other micro-biological species to prevent collateral effects of illness and product spoilage, when compared to known antimicrobial chemical compositions, thereby meeting the needs of certain formulated end-use applications, wherein such applications include paints, coatings, adhesives, composites, cements, plastics and the like. These antimicrobial chemical compositions are made from readily available materials and/or by methods that facilitate manufacturing in a manner avoiding exotic equipment, which is not unduly labor intensive, and that is economically feasible.

DETAILED DESCRIPTION

Antimicrobial chemical compositions as described herein generally comprise an aluminum phosphate (AlP) that is dispersed within a binding polymer that forms the bulk matrix of the composition. One or more bioactive materials are disposed within the aluminum phosphate, thereby forming a bioactive-AlP complex, and the aluminum phosphate is specifically engineered to provide controlled delivery or release of a bioactive constituent derived from the bioactive material upon exposure to moisture. Such antimicrobial chemical compositions are made by a number of methods described herein, and can be formulated for use as paints, coatings, adhesives, composites, cements, plastics, and the like.

Aluminum phosphates useful in this regard include amorphous aluminum phosphates, crystalline aluminum phosphate, and combinations thereof. Example aluminum phosphates useful in this regard are amorphous aluminum phosphates (AAlPs), and preferred AAlPs are amorphous aluminum orthophosphates. While the use of AAlPs is desired because AAlPs have been shown to have certain characteristic properties, making them well suited for use as a carrier to the bioactive material, crystalline AlPs and combinations of amorphous and crystalline AlPs are also understood to be useful in this regard and within the scope of the antimicrobial chemical compositions as disclosed herein.

In an example embodiment, the amorphous aluminum orthophosphates are amorphous aluminum hydroxy phosphates. Amorphous aluminum hydroxy phosphates provide uniform dispersion properties within the composition and the dispersion remains stable throughout the shelf-life of the formulation. The hydroxyl content of the amorphous aluminum hydroxy phosphate provides matrix stability by providing hydrogen bonds with suitable groups of the binding polymer of the formulation, e.g., such as carboxyl groups, amino groups, hydroxyl groups, acid groups and the like. This feature is unique to the amorphous aluminum hydroxy phosphate, and is not present in crystalline or other types of amorphous phosphates, and for this reason help to provide uniform dispersion properties

AlPs used to form antimicrobial chemical compositions disclosed herein are specially designed to have a high level of compatibility with a variety of different binding polymers or binding polymer systems useful for formulating such end-use applications, thereby providing a high degree of flexibility and choice in formulating such compositions to meet the needs and conditions of a variety of end-use applications in a number of different end-use industries.

Controlled delivery and/or release of the bioactive constituent within the chemical composition is largely dependent on the diffusion rate of the bioactive constituent through the bulk matrix of the composition, whether in the form of a coating or a composite. The diffusion rate of the bioactive constituent is dependent on the structural features of the bulk matrix that control bioactive constituent and water transport. These features include, but are not limited to, cross-link density, pigment to volume ratio (PVC), nature of the bioactive material carrier, hydrophilicity of components, and the polarity of the components.

Antimicrobial chemical compositions as disclosed herein use AlP as the bioactive carrier material, which AlP is engineered to provide a controlled diffusion of both moisture to the bioactive material contained therein, and a diffusion or delivery or release of the bioactive constituent to the surface of a coating or composite comprising such AlP, for purposes of providing a desired degree of antimicrobial resistance. Accordingly, the bioactive material is incorporated into the AlP, which has been specifically made to moderate and control the solubility of the bioactive constituent, and to control the diffusion of the dissolved bioactive constituent through the composition film or composite bulk matrix.

A characteristic/parameter of the AlP discovered to have an influence over the diffusion of moisture and delivery of the bioactive constituent is the porosity of the AlP molecule. A feature of AlP complexes as disclosed herein is the ability to engineer the morphology and the porosity of such complexes by choice of synthesis method. As used herein, the term "engineered porosity" is defined as the volume of space existing within a solid material consisting of particle voids, interstitial space between particles in particle aggregates, and interstitial space between aggregates in agglomerates. Mercury

porosimetry is used to characterize the porosity properties of solids and pigments. Key measurements include:

1. Total intrusion volume (ml/g) - measures the overall space in the sample into which mercury can be absorbed as a function of pressure.
2. Total pore area (m^2/g) - converts volume to area and defines how much area is occupied by the total intrusion volume.
3. Average pore volume (4V/A=μ) - shows the distribution of volume by area, i.e., how much volume on the average goes into different pore sizes.
4. BET (m^2/g) - is the measure of total surface area accessible to nitrogen gas under test conditions. BET and porosity correlate.

AlP complexes comprising a metal salt or metal ion, e.g., such as silver, as the bioactive material and formed by sol-gel method (as described in better detail below) result in the formation of nano-sized primary particles incorporated into aggregates of very-high surface area and porosity. An advantage of having such high surface area and porosity is that it ensures optimum diffusion contact with water and subsequent release of the silver ion in the film formed by the binding polymer bulk matrix, thereby promoting uniform distribution of the complex throughout the film or composite, and promoting a relatively rapid release of the bioactive material from the complex upon contact with water.

AlP complexes comprising a metal salt or metal ion, e.g., such as silver, as the bioactive material and prepared by the sol-gel method have BET surface areas ranging from about 100 and 250 m^2/g, and preferably between about 125 and 200 m^2/g, and most preferably between about 140 and 160 m^2/g. Such AlP complexes have a total intrusion volume of between about 1 and 2 mL/g, and preferably between about 1.3 and 1.8 mL/g. Such AlP complexes have an average pore volume of from about 0.02 to 0.06 μm, and preferably between about 0.04 and 0.05 μm.

In contrast, AlP complexes comprising a metal salt or metal ion, e.g., such as silver, as the bioactive material and formed by precipitation or condensation method (as described in better detail below) result in the formation of nano-sized primary particles incorporated into aggregates of relatively low surface area and low porosity. An

advantage of having low surface area and porosity is that it ensures reduced degree of diffusion contact with water and subsequent release of the silver ion in the film or composite formed by the binding polymer bulk matrix, thereby promoting uniform distribution of the complex throughout the film or composite, and promoting a relatively slow release of the bioactive material from the AlP complex upon contact with water.

AlP complexes comprising a metal salt or metal ion, e.g., such as silver, as the bioactive material and prepared by precipitation or condensation method have BET surface areas ranging from about 2 to 10 m^2/g, total intrusion volumes ranging from about 0.5 to 0.9 mL/g, and have average pore volumes ranging from about 0.4 to 0.6 μm.

Thus, a feature of AlPs useful for making antimicrobial chemical compositions is that they have an engineered porosity calculated to provide the desired rates of moisture diffusion and delivery of bioactive constituent that promotes a desired degree of activity and antimicrobial resistance when placed in an end-use application.

Thus, the desired porosity of the AlP is understood to vary depending on the certain requirements called for by each different end-use application. However, it is generally desired that the porosity of the AlP be not so great so as to rapidly extinguish the bioactive constituent upon exposure to moisture, e.g., be highly active but provide a greatly reduced effective service life. The loading of the bioactive material and/or the type of bioactive material that is used will also influence the activity and effective service life. Accordingly, the porosity of the AlP reflects a balance or compromise between a desired degree of antimicrobial activity and a desired effective service life for a given amount or general loading range of a given bioactive material.

The porosity of the AlP is engineered during the process of making the AlP and/or during post formation processing, e.g., drying and/or other heat treatment, as described in greater detail below.

AlPs as disclosed herein, in addition to serving as the bioactive material carrier to provide desired controlled delivery/release of the bioactive constituent, provide anticorrosion protection through the delivery of phosphate anion when exposed to moisture. Accordingly, for those end-use applications calling for both antimicrobial and

anticorrosion properties, e.g., in the case where the composition is formulated for use as a coating on a metal substrate, the AlP can also be engineered to provide a controlled delivery of the phosphate anion to provide a desired degree of corrosion protection through passivation to a metal substrate.

In an example embodiment, wherein such corrosion resistance is also desired, the AlP is engineered to release in the range of from about 50 to 500 ppm, and preferably 100 to 200 ppm of the passivating phosphate anion when present in a cured film or composite placed into an end-use application. The amount of passivating anion to be delivered depends on a number of different factors such as the loading or amount of the AlP used, the type of binding polymer that is used, the type of metallic substrate being protected, and the type of environment present in the end-use application. In a preferred embodiment, where the metallic substrate being protected comprises iron and the corrosion environment comprises water, oxygen, and other corrosive salts, the AlP is engineered to release approximately 160 ppm of the passivating phosphate anion.

Example binding polymers include those currently used for making known antimicrobial chemical compositions, and can be selected from the general group including water-borne polymers, solvent-borne polymers, hybrids and combinations thereof. Example water-borne polymers useful for making anticorrosion coating compositions include acrylic and acrylic copolymers, alkyd, epoxy, polyurethane, and silicone, and polysiloxane polymers. Example solvent-borne and/or non-aqueous polymers useful for making anticorrosion coating compositions include acrylic and acrylic copolymers, epoxy, polyurethane, silicone, polysiloxane, polyester, and alkyd. Preferred binding polymers include acrylic copolymer latex, alkyd, polyurethane and epoxy polymers.

In an example embodiment, antimicrobial chemical compositions comprise in the range of from about 15 to 75 weight percent, preferably in the range of from about 20 to 60 weight percent, and more preferably in the range of from about 20 to 35 weight percent of the binding polymer based on the total weight of the chemical composition when in a pre-cured or wet state. An antimicrobial chemical composition comprising less than about 15 percent by weight of the binding polymer may include a greater amount of the bioactive material (present as the bioactive-AlP complex) than necessary

to provide a desired degree of antimicrobial protection. An antimicrobial chemical composition comprising greater that about 75 percent by weight of the binding polymer may include an amount of the bioactive material (present as the bioactive-AlP complex) that is insufficient to provide a desired degree of antimicrobial resistance. While certain amounts of the binding polymer have been provided, it is to be understood that the exact amount of the binding polymer that is used to formulate antimicrobial chemical compositions will vary depending on such factors as the type of binding polymer used, the types and amounts of other materials used to form the chemical composition, the type and/or quantity of bioactive material that is used, and/or the particular end-use antimicrobial application.

Bioactive materials or agents useful in forming antimicrobial chemical compositions described herein can be selected from a variety of bioactive materials and/or species including, but not limited to: (1) antimicrobial additives comprising organic molecules that are either biocidal (kill microbes) or biostatic (inactivate microbes); (2) bio-pesticides, typically peptides that have biostatic or biocidal effects on microbes; (3) natural products that inhibit or prevent the growth of the target organisms naturally; (4) "friendly" bacteria that interfere with the growth and/or development of target microbes; (5) minerals and metals that release or produce antimicrobial species in response to certain environmental conditions; and (6) combinations thereof. Organic antimicrobial additives and metal-based biocides have most commonly been used to impart antimicrobial properties to formulated products.

Metal-based materials useful as bioactive materials or agents include metal ions and metal salts. Suitable metal ions include those selected from the group consisting of silver, copper, zinc, calcium, and combinations thereof. Suitable metal salts include salts of the above-identified metal ions. In an example embodiment, silver is a desired bioactive material because it has several advantages, provided that it can be made compatible with the formulation of the binding polymer in which is it incorporated, and provided that the silver can be maintained in an active state within the formulation for delivery to the surface upon exposure to moisture in a consistent and cost effective manner. Silver is advantageous over organic materials because it has higher degree of thermal stability, a lower level of toxicity to non-target organisms than typical organic biocides, and has a higher level of UV stability.

Silver ion (Ag^+) is bioactive, and in sufficient concentration kills a variety of microorganisms. Silver has proven anti-microbial activity and is known to be effective against certain antibiotic-resistant bacteria. It has broad spectrum anti-microbial activity and minimal toxicity toward mammalian cells. Silver is typically formulated or incorporated as an active ingredient in a carrier component (at concentration levels typically <5% by weight) such as glass, silica, or zeolite. The mechanism of action by which silver-based materials control micro-organisms involves the release of silver ion in response to ambient moisture. The silver ion is formed by contact with water, and the ion contacts the organism and interacts with multiple binding sites in the organism. As the silver ion is transferred into the cells of the target organism metabolic, the respiratory functions of the cell are altered and eventually cease, causing the cell to die.

Suitable sources of silver for use as the bioactive material include silver salts such a silver nitrate and silver chloride, wherein silver nitrate ($AgNO_3$) is preferred. Silver nitrate is extremely soluble (122 grams per 100 milliliters of water at 0°C) and this solubility presents a special challenge for controlled delivery of the bioactive material from a formulated product, such as an antimicrobial coating or composite. Silver nitrate is useful as a bioactive material as long as the delivery of silver ion from the formulated coating or composite to the surface is controlled at a rate and in a concentration balanced to supply the minimum control level for the target service life. Too rapid of a delivery will result in excessive concentration of silver ion on the surface to be protected, causing a discoloration of the surface and/or a rapid depletion the available reserves of silver nitrate in the bulk matrix, thereby reducing effective service life.

As discussed above, the AlP is made having an engineered porosity to provide a controlled diffusion rate and release/delivery of the bioactive constituent, e.g., silver ion, through the bulk matrix of the coating or composite. The incorporation of silver nitrate directly into a coating as a free component will not allow for controlled release. It is necessary to incorporate the silver nitrate (or silver ion source) in the AlP as engineered to moderate and control the solubility of the silver salt, control the diffusion of the dissolved silver ion through the film or composite matrix, and to control the resulting delivery of the silver ion to the surface.

As noted above, the porosity properties of AlP are engineered to provide a mechanism to control such reactions as hydrolysis and dissolution. Additionally, the AlP can be made hydroscopic so that it attracts water to itself specifically in a bulk matrix, thereby providing a medium for dissolution interactions. The feature of engineered porosity is the basis for controlled dissolution and ion release. In the case of silver ion, the diffusion rate of silver ion is dependent on the surface area and the porosity of the AlP. This also moderates the overall transport rate of the silver ion through the bulk matrix. Specifically, when water contacts the bulk matrix it is absorbed, and when the water in the bulk matrix contacts the highly soluble silver disposed within the bioactive-AlP complex (either as silver nitrate physically encapsulated within the AlP or as a silver ion chemically bonded to the AlP) the silver species is dissolved and the silver ion undergoes diffusion through the bulk matrix to the surface.

A feature of antimicrobial compositions as disclosed herein is that such compositions comprise the use of the AlP complex disposed within the bulk matrix of the binder polymer, wherein the AlP complex has a rate of bioactive constituent delivery that can be the same or different than the rate of bioactive constituent (released from the complex) migration or diffusion through the binder polymer. Thus, a formulator can engineer the porosity of the AlP complex to provide a desired release rate of the bioactive constituent therefrom, and can further engineer the formulation (by use of different binding polymers, fillers and the like) to influence the migration or diffusion rate of the bioactive constituent through the composition to meet certain end-use application demands. The combination of these features, i.e., the release rate of the bioactive constituent from the AlP complex, and the migration or diffusion rate of such released bioactive constituent through the binder polymer bulk matrix, provide for an enhanced level of antimicrobial composition customization not otherwise available. Such customization of release rates and migration/diffusion rates operate to provide a vast range of antimicrobial compositions that can be specifically tailored to address a variety of end-use applications.

The amount or concentration of the bioactive material that is incorporated into the AlP can and will vary depending on such factors as the type of bioactive material used,

the nature of the binding polymer used to form the coating or composite matrix, the type of AlP (amorphous, crystalline, or a combination thereof), and the engineered porosity of the AlP. Thus, the properties of the bioactive-AlP complex, such as the bioactive material concentration and the AlP engineered porosity can be controlled to address various exposure conditions such as temperature, relative humidity, ultra-violet exposure and the like.

In an example embodiment, it is desired that a sufficient amount of the bioactive material be present, and that the AlP have an engineered porosity that will result in the composition, when provided in the form of a dried film or composite, to provide a controlled delivery of the bioactive constituent (derived from contacting the bioactive material with moisture) of from about 5 to 1,000 ppm, preferably of from about 10 to 900 ppm, and more preferably in the range of from about 15 to 800 ppm. In a particular embodiment, where the bioactive constituent is silver ion, a desired optimum controlled delivery of the silver ion is greater than about 100 ppm, and most preferably about 120 ppm. In a preferred embodiment, an effective leaching rate, that is, amount of bioactive constituent, e.g., Ag, released on the surface of a cured coating or cured composite comprising the bioactive-AlP complex is at least about 30 $\mu g/m^2$, and is preferably about 36.9$\mu g/m^2$ or >2$\mu g/L$ in a rinse for bioactivity.

In order to provide the desired controlled delivery of the bioactive constituent, it is desired that certain amount of the bioactive material be used when forming the bioactive-AlP complex. In an example embodiment, the AlP complex comprises from about 1 to 10 percent by weight of the bioactive material, preferably from about 2 to 8 percent by weight of the bioactive material, and more preferably from about 3 to 6 percent by weight of the bioactive material based on the total weight of the bioactive-AlP complex.

Additionally, it has been discovered that mixed anti-microbial complexes based on silver and other bio-active materials can be synthesized which have synergistic effects. For example, in addition to silver-AlP complexes, other bio-active metals as copper and/or zinc can be introduced into the complex by their inclusion in the synthesis process as better described below. Further, certain organic bio-active molecules can be introduced into the complex through physical adsorption/encapsulation or by actual

reaction/condensation with the phosphate group of the complex. This provides a controlled release mechanism through subsequent hydrolysis in the bulk film by the diffusion of water.

AlPs can be made through the selective combination the materials noted above. The following selected methods of preparation are provided below as examples, and it is to be understood that other methods of preparation other than those specifically disclosed may be used. While the methods disclosed herein for making AlPs may reference and disclose the formation of amorphous aluminum phosphate (AAlP), it is to be understood that such methods may also produce or be adapted to produce other forms of AlP, such as the various crystalline aluminum phosphate forms and/or mixtures of amorphous and crystalline aluminum phosphates, depending on the end-use antimicrobial application performance properties. Example crystalline forms of AlPs formed as disclosed herein include and are not limited to orthorhombic and triclinic aluminum orthophosphates. Accordingly, the methods disclosed herein are understood to be useful for making different forms of AP, depending on the particular end-use applications and performance properties.

Binary Condensation Methods of Making

Generally, the AlP is an aluminum phosphate complex that is prepared by combining a suitable aluminum salt, such as aluminum hydroxide, aluminum sulfate and the like with phosphoric acid or other phosphorus-containing compound or material, depending on the particular type of aluminum salt selected for forming the aluminum phosphate. In an example embodiment, a preferred aluminum salt is aluminum hydroxide (ATH or $Al(OH)_3$), and a preferred source of the phosphorus-containing ingredient is phosphoric acid (H_3PO_4). Example methods as disclosed herein comprise forming AlP by a condensation process, wherein the AlP is formed by the condensation reaction of the aluminum salt ingredient with the phosphorous-containing ingredient to produce AlP particles in slurry form. The composition of the condensed solid resulting from such process of making depends on the ratio of the aluminum metal to phosphate anion. The properties of the resulting complex, i.e., the AlP, depends on the processing parameters employed during the condensation reaction, including choice of aluminum salt, temperature, the physical state of the reactants, order of addition of reactants, rate

of addition of reactants, the degree and duration of agitation, pretreatment of one or more of the reactants, and post treatment of the resulting condensation product.

Generally speaking, the condensed solid that results from this method of making, even after milling, has a very low oil absorption property and low surface area (as measured by BET method) when compared to aluminum phosphate prepared by other known methods. Oil absorption is defined as the amount (grams or pounds) of linseed oil required to wet out and fill the voids spaces around a pigment, ASTM – D-281-84, which is a measure of the binder demand or the amount of binder resin that a pigment may absorb in a given formulation. High binder demand adds to formulation cost and can affect certain barrier properties of the dry film. This is further surprising because the aluminum phosphate made by the binary condensation process disclosed herein also displays the controlled release property and water adsorption property usually associated with high surface area particles.

In an example embodiment, the condensed aluminum phosphate prepared herein has an oil absorption of less than about 50, preferably in the range of between about 10 to 40, and more preferably in the range of between about 20 to 30. In contrast, AlP that is made by other methods has an oil absorption of greater than about 50, and typically in the range of about 50 to 110.

In an example embodiment, the AlP prepared herein has a surface area of less than about 20 m^2/g, and preferably less than about 10 m^2/g. In an example embodiment, the surface area is in the range of between about 2 to 8 m^2/g, and more preferably in the range of between about 3 to5 m^2/g. In contrast, AlP made by other methods has a surface area greater than 20 m^2/g, e.g., from about 30 to 135 m^2/g.

AlPs made as a binary condensation product can be produced according to least five different methods, wherein two of which involve adding a base reactant to an acid reactant, one of which involves adding an acid reactant to a base reactant, one of which involves base-to-acid in-situ aggregation, and one of which involves acid-to-base in-situ aggregation. In such methods, selected starting materials including an aluminum source and a phosphorous source are combined under specific conditions of controlled material delivery, temperature, and agitation. The judicious selection of starting materials and

processing conditions produces AlPs having a material content and chemical structure intentionally created with the purpose of producing the above-noted engineered characteristics to provide the desired controlled delivery/release of the bioactive constituent when formulated into a coating composition or composite.

As noted above, aluminum sources useful for forming AlP by binary condensation method include aluminum salts, such as aluminum hydroxide, aluminum chloride, aluminum nitrate, aluminum sulfate, and the like. Preferred aluminum sources include aluminum hydroxide and aluminum sulfate. Phosphorous sources useful for forming AlP by condensation include phosphoric acid, and salts of phosphorus as orthophosphates or as polyphosphates. A suitable source of phosphorus is fertilizer grade phosphoric acid, from any origin, that has been clarified and discolored. For example, a commercial phosphoric acid containing approximately 54% of P_2O_5 may be chemically treated and/or diluted with treated water resulting in a concentration of approximately 20% of P_2.

AlPs useful for forming antimicrobial chemical compositions described herein can be made according to a number of different methods, which includes at least five variations of the binary condensation process. The following selected methods of preparation are provided below as examples, and it is to be understood that other methods of preparation other than those specifically disclosed may be used.

Example No. 1 – Binary Condensation Formation of the AlP (base-to-acid route)

In an example embodiment, AlP is prepared by adding aluminum hydroxide ($Al(OH)_3$) to phosphoric acid (H_3PO_4). The H_3PO_4 was diluted with water before being combined with the $Al(OH)_3$ and, prior to addition, the $Al(OH)_3$ was not wetted with water, although wetted $Al(OH)_3$ can be used. The reactants were quickly combined at room temperature without heating to produce a white slurry. However, if desired, the reaction can be heated. The H_3PO_4 was 85wt% in water provided by Sigma-Aldrich, and the $Al(OH)_3$ was reagent grade provided by Sigma-Aldrich. Specifically, approximately 57.3 g (0.5 mole) H_3PO_4 was diluted with 50 g of water before being combined with $Al(OH)_3$. Approximately 39 g (0.5 mole) of $Al(OH)_3$ was added to the solution quickly and the mixture was stirred slowly at room temperature to wet the powder. An AlP condensed solid was formed and existed as a dispersion of solid AlP

particles in water. In this particular embodiment, the AlP particles existed primarily in the form of amorphous aluminum phosphate (AAlP). Diluting the H_3PO_4 prior to addition of the $Al(OH)_3$ thereto is believed to contribute to forming exclusively AAlP, e.g., wherein there is little to no crystalline form produced. The suspension was filtered to isolate the AlP particles. The particles were washed and dried to an appropriate temperature, which may be less than about 300°C, and preferably from about 100°C to 200°C. A feature of the AlP so formed is that it may be combined with a binding polymer, e.g., used for formulating an antimicrobial coating composition, without the need for further heat treatment, tempering, or calcining. While heating the AlP at the extreme temperatures noted above may be useful for driving off water, such may also initiate conversion of the AlP from an amorphous form to a crystalline form. It may be desired to subject the AlP to elevated temperatures above 200°C, e.g., of between 300°C to 800°C, to either remove unwanted constituents therefrom and/or to influence physical characteristics of the AlP that may influence its end-use performance properties or characteristics in the antimicrobial composition. If a crystalline form of AlP is desired, the AlP so formed can be further heat treated or calcined to produce the desired crystalline AlP.

Alternatively, the AlP was prepared by adding the $Al(OH)_3$ to the H_3PO_4. However, unlike the example embodiment disclosed above, the H_3PO_4 was not diluted before combining with the $Al(OH)_3$. However, before combining, the H_3PO_4 was heated. Additionally, prior to combining with the H_3PO_4, the $Al(OH)_3$ was wetted with water. A feature of this method of preparing is that it does not include the addition of free water after combination of the reactants, although it is to be understood that the AlP can be made according to this method by including the addition of free water. In an example embodiment, the H_3PO_4 was 85wt% in water provided by Sigma-Aldrich, and the $Al(OH)_3$ was reagent grade provided by Sigma-Aldrich. Specifically, approximately 57.6 g H_3PO_4 was heated to a temperature of about 80°C. Approximately 39 g of $Al(OH)_3$ was wetted with about 2 g water and the wetted $Al(OH)_3$ was quickly added to the H_3PO_4 under fast mechanical stirring. An AALP solid was formed and existed as a dough-like ball that was removed and stored at room temperature. A feature of the AlP so formed is that further treatment in the form of filtering and washing was not necessary to isolate and obtain the desired AlP. Like the example embodiment

disclosed above, such AlP was dried and formed into the desired particle size useful for forming the antimicrobial chemical composition.

Example No. 2 – Binary Condensation Formation of the AlP (base-to-acid route)

In an example embodiment, AlP having the above-noted engineered physical properties or characteristics, e.g., porosity, is prepared by adding aluminum hydroxide ($Al(OH)_3$) to phosphoric acid (H_3PO_4) at an elevated temperature, e.g., at about 60°C, to form the desired AlP. The H_3PO_4 was diluted with water before being combined with the $Al(OH)_3$ and, prior to addition, the $Al(OH)_3$ was combined with water to form a slurry comprising between about 10 to 25 percent by weight, and in some cases up to about 40 percent by weight $Al(OH)_3$, depending on the grade of the $Al(OH)_3$. In preparing the $Al(OH)_3$ slurry, the water may be heated to facilitate dispersion of the aluminum hydroxide powder, e.g., to overcome certain properties of a specific grade of aluminum hydroxide. The heated slurry may be maintained at an elevated temperature and added to the acid. With very high-grade aluminum hydroxide, having a high degree of purity and small particle size and distribution, the $Al(OH)_3$ slurry can be made by adding to room temperature water.

The $Al(OH)_3$ slurry was added slowly to the diluted H_3PO_4 for the purpose of controlling the kinetics of the condensation reaction. In an example embodiment, the $Al(OH)_3$ slurry was added in a controlled manner, e.g., in a drop-wise fashion or the like, to the H_3PO_4 over a period of approximately 10 minutes to about one hour. The combined reactants were heated to a temperature of approximately 95°C, and the reactants were mixed together for a sufficient period of time, typically about 3 hours. In an example embodiment, the reaction takes place in a constant volume system that is essentially closed, e.g., a reflux condenser may be attached to maintain constant solvent volume (water) in the reaction system. In an example embodiment, the H_3PO_4 was 85wt% in water provided by Sigma-Aldrich, and the $Al(OH)_3$ was reagent grade, provided by Sigma-Aldrich. Specifically, approximately 864 g of 85% dilute H_3PO_4 was used, and the slurry was formed by combining 585 g of $Al(OH)_3$ with 1,650 g of deionized water. The combined reactants were contained in a mixing vessel and mixed at 1,300 to 1,500 rpms. Further water was added to the reactants and the combination was mixed for approximately 30 minutes to about 3 hours, e.g., more typically the latter.

If desired, a suitable chemical agent can be added to the reactants for the purpose of reducing the solubility of the components of the mother liquor, thereby providing still further increased control over the outcome of the reaction. In an example embodiment, such chemical agent can be calcium hydroxide ($Ca(OH)_2$), soluble amines such as diethylenetriamine (DETA), or the like.

An AlP condensed solid was formed and existed as a dispersion of solid acidic AlP particles in water. The suspension was filtered to isolate the acidic AlP particles. The particles were washed with water one or more times, and then filtered again. In an example embodiment, after the initial filtering, the particles were washed with a volume of water approximately six times the volume of the precipitate before being refiltered. Successive washings operate to remove unreacted starting material and any soluble byproducts from production. After being refiltered, the acidic AlP particles were reslurried by the addition of water, and were further treated in accordance with one of the following three different techniques.

In a first technique, the slurry is filtered to isolate the acidic AlP particles and the particles are heated. In an example embodiment, the AlP particles are heated to a temperature of about 110°C for about 24 hours to drive off the water, and produce acidic AlP particles. Alternatively, the AlP particles are heated to a temperature of about 250°C for about 12 to 48 hours, and produce acidic AlP particles that are both free of water and any by-products that decompose below 250°C. In addition, heat treatment at either temperature, but especially at the elevated temperature, provides the driving force to complete the conversion of any intermediates that may remain in the complex.

In a second technique, the slurry containing the acidic AlP is neutralized by adding a suitable neutralizing agent thereto. In an example embodiment, the neutralizing agent is ammonium hydroxide (NH_4OH) that is added to the slurry in a sufficient amount to increase the pH and to neutralize the AP to a desired pH, typically 5.5 to 7.0. The resulting slurry is filtered and the isolated AP particles are heated. In one example embodiment, the AlP particles are heated to a temperature of about 110°C for about 24 hours to drive off the water, and produce AlP particles. Alternatively, the AlP particles are heated to a temperature of about 250°C for about 24 hours to both drive off water

and other unwanted chemical constituents, to produce AlP particles and to effect any final conversion or neutralization of surface adsorbed or bulk absorbed reactive species such as phosphate anion or hydrogen phosphate anion. Any reactive amine may be used for this conversion or neutralization step, including but not limited to diethylenetriamine, triethylenetetramine, 2-amino-2-methyl-1-propanol.

In a third technique, the slurry containing the acidic AlP is neutralized by adding a suitable neutralizing agent thereto. In an example embodiment, the neutralizing agent is calcium hydroxide ($Ca(OH)_2$) that is added to the slurry in a sufficient amount to increase the pH and neutralize the acidic AlP. The resulting slurry is filtered and the isolated AlP particles are heated. In one example embodiment, the AlP particles are heated to a temperature of about 110°C for about 24 hours to drive off the water, and produce AlP particles. Alternatively, the AlP particles are heated to a temperature of about 250°C for about 24 hours to both drive off water and other unwanted chemical constituents, and produce AlP particles. Other hydroxide compounds of such divalent cations as barium, and magnesium may be used in place of calcium to effect the neutralization or pH adjustment.

As described above in Example 1, the AlP produced according to the methods disclosed in Example 2 comprised AAlP. However, it is to be understood that crystalline AlP and/or combinations of AAlP and crystalline AlP can be produced according to the methods disclosed, e.g., by running the condensation reaction at temperatures for periods of time of less than 3 hours above 90°C. Maintaining the reaction temperature between about 45 and 90°C, and preferably between about 60 and 70°C will produce AlP that is a combination of crystalline and amorphous forms. Running the reaction at a temperature below about 45°C will produce primarily AlP in the amorphous form.

Example No. 3 – Binary Condensation Formation of the AlP (acid-to-base route)

It has been discovered that changing the order of addition changes the nature of the catalysis of the condensation reaction, i.e., adding the acid to the basic slurry results in slower localized pH change and the reaction is primarily base catalyzed. The AlP particles form slower and are smaller in localized areas in solution. The particles that

form tend to have higher surface areas than particles formed by acid catalysis, and are less aggregated and agglomerated. In an example embodiment, the order of addition in Example 2 is reversed, that is, the required amount of phosphoric acid is added slowly to the aluminum hydroxide slurry. The slurry is prepared as described in Example 2. Phosphoric acid is added slowly to the slurry over a period of approximately 30 minutes to one hour, and the resulting mixture is mechanically stirred and heated to about 95°C for at least 3 hours. The AlP particles are isolated and purified, and dried as described in Example 2.

In addition to the acid-to-base route disclosed immediately above, it has been discovered that such acid-to-base route can be further enhanced by first dissolving a certain amount of the aluminum hydroxide in the phosphoric acid before adding the acid solution to the slurry. In an example embodiment, an amount of aluminum hydroxide, e.g., up to the solubility limit of aluminum hydroxide, is dissolved separately in the phosphoric acid. In an example embodiment, AlP is prepared according to a two-step process. In a first step, a portion of the aluminum hydroxide, typically one third of the stoichiometric amount, is first dissolved in phosphoric acid to form an acidic AlP solution. This acidic AlP solution contains all the phosphoric acid and phosphate needed to satisfy the stoichiometry of the reaction for a product having the desired 1:1 P to Al ratio. In a second step, the acidic AlP solution is then added to a slurry containing the remaining amount of aluminum hydroxide required for stoichiometry. The combination undergoes reaction at ambient temperature to form an AlP condensed solid comprising a dispersion of solid acidic AlP particles in water. Alternatively, the reaction can occur at elevated temperature conditions, e.g., of about 95°C, which is preferred for reaction efficiency and kinetic control of product forms. An advantage of this two-step approach is that part of the aluminum hydroxide required for the reaction is dissolved and pre-reacted before the acid solution is added to the slurry, thereby providing a subsequent heterogeneous reaction that is less viscous and requires less agitation, to thereby ensure more complete condensation.

Like the method disclosed in Example 2 above, such acid-to-base reaction routes are ones that are preferably conducted under constant volume conditions. The suspension was filtered to isolate the acidic AlP particles. The particles were washed with water one or more times, and then filtered again. In an example embodiment, after the initial

filtering, the particles were washed with a volume of water approximately six times the volume of the precipitate before being refiltered. In a preferred embodiment, the sequence is to filter and wash, which can be repeated any number of times to achieve the desired degree of purity. The resulting rewashed AlP particles can then be filtered and dried at a temperature of approximately 110°C for about 24 hours to provide acidic AlP particles.

Alternatively, after rewashing, the AlP particles can be reslurried and then neutralized by adding a suitable neutralizing agent, e.g., such as those described above, thereto. In an example embodiment, a sufficient quantity of ammonium hydroxide (NH_4OH) was added to the reslurried AP, and the resulting mixture was filtered to isolate the AlP particles, and the particles are heated. In an example embodiment, the AlP particles are heated to a temperature of about 110°C for about 24 hours to drive off the water, and produce solid AAlP particles. Additionally, as described above, it is to be understood that the method disclosed herein can also be used to produce crystalline AlP or combinations of AAlP and crystalline AlP, e.g., by running the reaction at temperatures in excess of about 90°C.

Example 4 – Binary Condensation Formation of the AlP (base-to-acid in-situ aggregation)

In an example embodiment, AlP is prepared by adding aluminum hydroxide ($Al(OH)_3$) to phosphoric acid (H_3PO_4) to form the desired AlP, e.g., in the manner disclosed above in Examples 1 and 2. However, unlike Examples 1 and 2, the reaction is allowed to occur in an open system, wherein the reaction system is left open so as to allow solvent water to continuously evaporate, thereby causing the concentration of the reaction system to increase and its pH to decrease over time. At periodic intervals during the condensation reaction process, the water level is replenished to the initial volume. The reaction slurry is then diluted with an additional 50 g of water and stirred for 30 minutes to further facilitate dispersion of the AlP particles in the reaction slurry. The slurry is then filtered, washed with a volume of water approximately six times the volume of the precipitate, and filtered again. This filter-wash-filter cycle can be repeated until the desired purity level is achieved. Usually one to three cycles is sufficient to remove unreacted starting material and unwanted reaction by-products.

It has been discovered that by allowing the volume to vary as described, the resulting change in system concentration and pH causes sequential precipitation of AlP "oligomers" in solution onto AlP particles already formed and agglomerated. This sequential precipitation of AlP oligomers onto already-formed and agglomerated AlP particles operates to seal the surface porosity of the pre-existing AlP aggregates and particles, e.g., causing in-situ particle layering, which thereby reduces the surface porosity of such AlP aggregate and reduces such related properties as oil absorption. In an example embodiment, the AlP oligomers are AAlP and the AlP particles already formed are AAlP.

As noted above, allowing water levels to cycle during the condensation causes a change in the pH proportional to the concentration of the $Al(OH)_3$. When the volume decreases, the pH increases due to the higher concentration of the $Al(OH)_3$, and the solubility decreases allowing AlP oligomers to agglomerate. Adding $Ca(OH)_2$ to the condensation medium may also effect a similar change in pH, causing the precipitation of AlP and subsequent coating of pre-existing AlP particles. This process would also incorporate the alkaline earth metal cations as counter-ions for residual acid phosphate groups either adsorbed on the AlP particle surface or bonded as a pendant component.

A condensed solid was formed and existed as a dispersion of solid acidic-coated AAlP particles in water. The suspension was filtered to isolate the acidic coated AlP particles. The particles were washed with water one or more times, and then filtered again. In an example embodiment, after the initial filtering the particles were washed with a volume of water approximately six times the volume of the precipitate before being refiltered. Successive washings remove unreacted starting material and any byproducts from production. After being refiltered, the acidic-coated AlP particles were reslurried by the addition of water, and were further heat treated. In an example embodiment, the slurry is filtered to isolate the acidic coated AlP particles and the particles are heated to a temperature of about 110°C for about 24 hours to drive off the water, and produce acidic coated AlP particles. Alternatively, the coated AlP particles are heated to a temperature of about 250°C for about 12 to 48 hours, to produce dry acidic coated AP particles that are both free of water and any by-products that decompose below 250°C. Additionally, as described above, it is to be understood that

the method disclosed herein can be used to produce crystalline AlP, or a combination of AAlP and crystalline AlP.

Example 5 - Binary Condensation Formation of AlP (acid-to-base in-situ aggregation)

In an example embodiment, AlP is prepared by adding phosphoric acid (H_3PO_4) to aluminum hydroxide ($Al(OH)_3$) to form the desired AlP, e.g., in the manner disclosed above in Example 3. However, unlike Example 3, the reaction is allowed to occur in an open system, wherein the reaction system is left open so as to allow solvent water to continuously evaporate, thereby causing the concentration of the reaction system to increase and its pH to decrease over time. At periodic intervals during the condensation reaction process, the water level is replenished to the initial volume. The reaction slurry is then diluted with an additional 50 g of water and stirred for 30 minutes to further facilitate dispersion of the AlP particles in the reaction slurry. The slurry is then filtered, washed with a volume of water approximately six times the volume of the precipitate, and filtered again. This filter-wash-filter cycle can be repeated until the desired purity level is achieved. Usually one to three cycles is sufficient to remove unreacted starting material and unwanted reaction by-products.

As noted above in Example 4, it has been discovered that by allowing the volume to vary as described during the reaction, the resulting change in system concentration and pH causes sequential precipitation of AlP "oligomers" in solution onto AlP particles already formed and agglomerated. This sequential precipitation of AlP oligomers onto already-formed and agglomerated AlP particles operates to seal the surface porosity of the pre-existing AlP aggregates and particles, e.g., causing in-situ particle layering, which thereby reduces the surface porosity of such AP aggregate and reduces such related properties as oil absorption. In an example embodiment, the AP oligomers are AAlP and the AlP particles already formed are AAlP. Additionally, as described above, it is to be understood that the method disclosed herein can be used to produce crystalline AlP, or combinations of AAlP and crystalline AlP.

Example No. 6 – Formation of the Bioactive-AlP Complex (physical incorporation)

The AlP made as a binary condensation product, e.g., as set forth in Example Nos. 1 to 5, was constituted as a 34 percent by weight slurry, and was mixed with appropriate concentration silver nitrate solution. The later solution was made so that a 1.0% percent

and a 10% percent silver-to-AlP slurry solution was prepared. The combined slurry was mixed for approximately 5 minutes and then atomized in a spray drier under nitrogen, and dried at temperatures ranging from about 180°C inlet to about 79°C outlet. The solid powder was collected and analyzed. The resulting powder was a bioactive-AlP complex where the bioactive material was physically incorporated, enmeshed, encapsulated, or intertwined in the AlP polymer.

Alternatively, the AlP made as a binary condensation product, e.g., as set forth in Example Nos. 1 to 5, was constituted as a 34 percent by weight slurry, and was mixed with appropriate concentration silver nitrate solution. After stirring the combined slurry was filtered and washed once with hot water at a temperature of 40 to 60°C. The filtrate was dried at approximately 110°C for approximately 12 hours, divided into portions, and each heat treated for approximately 24 hours at approximately 250°C. Yields were the same regardless of heat treatment temperature, and the resulting powder was a bioactive-AlP complex where the bioactive material was physically incorporated, enmeshed, encapsulated, or intertwined in the AlP polymer.

Example No. 7 – Formation of the Bioactive-AlP Complex (chemical bonding)

AlPs were prepared by the binary condensation routes described above in Example Nos. 1 to 5, except that a silver nitrate solution of appropriate concentration was combined at the same time as the phosphoric acid and aluminum hydroxide where brought together. The resulting suspension comprised the bioactive-AlP complex condensate in solution, wherein the bioactive material, in the form of silver ion, was chemically bonded with the AlP polymer, e.g., incorporated into the AlP polymer backbone. The suspension was filtered in the manner described above, to isolate the bioactive-AlP complex particles. The particles were washed and dried at the temperatures described in the above-noted Examples to provide the desired engineered physical properties or characteristics, e.g., porosity.

In these example processes, a chemical reaction results in the formation of amorphous aluminum orthophosphate or of aluminum orthophosphates ($Al_2(HPO_4)_3$ or $Al(H_2PO_4)_3$. The reaction, is carried out through the mixture of the two ingredients (when forming the AlP separately), or through the mixture of the three ingredients

(when directly forming the bioactive-AlP complex). The reagents are dosed in a reactor equipped with a stirring device, and allowed to react for a short period of time, e.g., less than about 10 minutes.

Variables for forming AlP by the binary synthesis process that affect product outcome may include: (a) the type of ATH used; (b) the method of dispersing the ATH in the reaction slurry and the temperature at which it is done; (c) the concentration of the ATH in the reaction slurry; (d) the order and rate of combination (addition) of the ATH slurry to the phosphoric acid; that is acid to base (A to B) or base to acid (B to A); (e) the concentration of the reaction slurry; (f) the temperature at which the condensation reaction is run (e.g., room temperature or an elevated temperature such as 95°C); (f) the duration (time) of the reaction at temperature (e.g., 30 minutes or up to 4 hours); (g) the type of agitation (e.g., simple mixing or dispersion); and (h) post reaction treatment such as: filtration, followed by washing and drying of the condensate to a dry powder; or concentration of the condensate slurry to a gel or paste by partial evaporation of solvent (with or without pH adjustment).

With respect to the type of ATH used, it was discovered that the physical form of the AlP produced by the binary synthesis process depends on both the nature of the ATH used as starting material, and reaction conditions that control kinetics. Broadly two types of ATH are available; amorphous and crystalline. Crystalline ATH may exist in a variety of specific crystalline forms and mineral compositions. It has been discovered that certain of these types require considerable energy input in the form of heat and agitation to undergo the phosphate condensation reaction. The resulting AlP product produced using crystalline ATH is typically crystalline also (one of many are possible structures).

The use of amorphous ATH allows rapid room temperature reaction kinetics, and the resulting AlP formed therefrom is virtually always amorphous also. It has been discovered that to preserve desired silver functionality (when using silver as the antimicrobial agent) it is useful to run reactions at the lowest temperatures possible. It has been discovered that amorphous ATH is suitable for such use. It has also been discovered that moderately reactive crystalline ATH (characterized by DSC as having

an endothermic transition at around 310°C as opposed to lesser reactive ATH materials which have the endothermic transition at around 340°C), when condensed with phosphoric acid at room temperature, yields AlP made up of around 50% amorphous content (which contains the silver-aluminum-phosphate component) and around 50% unreacted ATH. This is actually a higher level of amorphous conversion than detected when using typical crystalline ATH and combining with phosphoric acid at room temperature and allowing for condensation where typically less than 10% conversion occurs. The so-formed AlP is amorphous and it is theorized that its composition is primarily ATH with a surface coating of phosphate. The higher levels of amorphous AlP conversion in the chemistry described herein are attributed to the presence of the other ingredients that facilitate surface reaction and/or inhibit the crystallization process (so that any AlP formed remains amorphous). It has been discovered in testing that this composition provides effective levels of antimicrobial activity as well as light stability.

An additional variable relating to the formation of the bioactive-AlP complex, e.g., Ag-AlP, may include the point of introduction of the bioactive agent (e.g., silver source such as silver nitrate) being: (a) to the ATH slurry before condensation (ATH + AgX + water); (b) to the phosphoric acid before condensation; (c) to the mixed condensate at the beginning of mixing as a solution; and (d) to the condensate at the end of mixing as a solution. While the variable of bioactive agent point of introduction is discussed above in the context of the binary condensation process, it is to be understood that this variable applies equally to the remaining methods of making the bioactive-AlP complex as disclosed herein.

Precipitation Methods of Making

The AlP is a phosphate complex prepared by dissolving a suitable salt, such as aluminum hydroxide, magnesium hydroxide, calcium hydroxide, aluminum sulfate and the like in phosphoric acid in molar amounts to achieve complete dissolution of the salt. The phosphate complex is precipitated from the acid solution by neutralizing with an alkaline solution or base such as sodium hydroxide, potassium hydroxide, ammonium hydroxide, sodium aluminate, potassium aluminate and the like. The composition of the resulting precipitated solid depends on the ratio of the metal to the phosphate anion. The properties of the precipitated complex, i.e., AlP, depend on the processing parameters employed during the dissolution of the salt in the acid and on the conditions

of the precipitation/neutralization, including choice of neutralizing agent, temperature, order of addition of reactants, rate of addition of reactants, and the degree and duration of agitation.

AlPs are made as a precipitation product by combining selected starting materials including an aluminum source and a phosphorous source under specific conditions of controlled material delivery, temperature, agitation, and pH. The judicious selection of starting materials and process conditions produces AlPs having a material content and chemical structure intentionally created with the purpose of producing the above-noted engineered physical property or characteristic, e.g., porosity, the provides the desired controlled delivery/release of the bioactive constituent.

Aluminum sources useful for forming AlP by-precipitation include aluminum salts, such as aluminum chloride, aluminum nitrate, aluminum sulfate and the like. Aluminum sources useful for forming AlP also include aluminate compounds, such as sodium aluminate and the like, aluminum hydroxide, or aluminum in metallic form. Phosphorous sources useful for forming AlP by precipitation include phosphoric acid, and salts of phosphorus as orthophosphates or as polyphosphates. An alkaline solution is used to control the pH or neutralize the reaction of the main ingredients. In an example embodiment, the alkaline solution can include ammonium hydroxide, sodium hydroxide, sodium carbonate, and combinations thereof. In an example embodiment, sodium hydroxide is used as the alkaline solution. Useful aluminum sources, phosphate sources, and alkaline sources include those disclosed in Published US Patent Applications 2006/0045831 and 2008/0038556, which are each incorporated herein by reference in their entirety.

AlPs can be made through the selective combination of the materials noted above. The following selected methods of preparation are provided below as examples, and it is to be understood that other methods of preparation other than those specifically disclosed may be used. While AlPs produced according to the precipitation route as better disclosed below comprise amorphous AlPs, it is to be understood that the precipitation methods of making AlP as disclosed herein can also be used or adapted to produce crystalline AlP or combinations of amorphous and crystalline AlP depending on the particular desired antimicrobial chemical composition properties.

Example No. 8 - Aluminum Sulfate Method of Making AlP

In an example embodiment, AlP having the above-noted engineered properties is prepared by combining aluminum sulfate, phosphoric acid and sodium hydroxide as disclosed in US Patent No. 7,951,309, which is incorporated herein by reference. The process steps used in this example process generally include: preparing the main reagents, such as a diluted solution of phosphoric acid, a diluted solution of aluminum sulfate, and a diluted solution of sodium hydroxide or ammonium hydroxide; simultaneous and controlled adding of the reagents in a reactor equipped with a sloshing system to keep the homogeneity of the mixture during the process; and controlling, during the addition of the reagents in the reactor, of the temperature and pH (acidity) of the mixture and the reaction time.

The main reagents in this example process can be prepared as follows. A source of phosphorus is fertilizer grade phosphoric acid, from any origin, that has been clarified and discolored. For example, a commercial phosphoric acid containing approximately 54% of P_2O_5 may be chemically treated and/or diluted with treated water resulting in a concentration of approximately 20% P_2O_5. Another reagent useful for this example process is commercial aluminum sulfate, which may be obtained by reaction between alumina (hydrate aluminum oxide) and concentrated sulfuric acid (98% H_2SO_4), that is clarified and stored at an approximate 28% concentration of Al_2O_3. For the reaction to have favorable kinetics, the aluminum sulfate is diluted with water treated at approximately 5% of Al_2O_3.

Neutralization of the reaction is carried out with a sodium hydroxide solution, which may be commercially purchased in different concentrations. A concentration of approximately 50% of NaOH may be purchased and diluted. For example, in a first phase of the reaction, when the initial reagents are being mixed, the sodium hydroxide may be used in the concentration of approximately 20% of NaOH. In a second phase of the reaction, to fine tune the product acidity, a sodium hydroxide solution with approximately 5% of NaOH may be used. As an alternative neutralizer, ammonium hydroxide or sodium carbonate (soda ash) may be used.

In this example process, a chemical reaction results in the formation of amorphous aluminum orthophosphate or of aluminum orthophosphates ($Al_2(HPO_4)_3$ or $Al(H_2PO_4)_3$. The reaction is carried out through the mixture of the three reagents, i.e., phosphoric acid solution, aluminum sulfate solution, and sodium hydroxide solution. The reagents are dosed in a reactor, typically containing a sloshing system, during about a 30 minute period. During the addition of the reagents in the reactor, the pH of the mixture is controlled within a 4 to 4.5 range and a reaction temperature, between 35°C and 40°C. The reaction is completed after about 15 minutes of the reagent mixture. In this period, the pH of the mixture may be adjusted to 5, with the addition of more diluted sodium hydroxide. In this example process, the temperature is preferably maintained below approximately 40°C. At the end of the reaction, the suspension formed should contain a P:Al molar ratio of between about 0.8:1 to 1.2:1.

After the formation of the AlP, the suspension containing around 6.0% to 10.0% of solids, with a maximum approximate temperature of about 45°C, and density of about 1.15 to 1.25 g/cm^3, is processed for separation. In an example embodiment, the suspension is pumped to a conventional filter press. In the filter press, the liquid phase (sometimes referred to as the "liquor") is separated from the solid phase (sometimes referred to as the "cake"). The wet cake, containing approximately 35% to 45% of solids is kept in the filter for washing cycle. The filtered concentrate, which is basically a concentrated solution of sodium sulfate, is extracted from the filter and stored for future usage. While the use of a filter press has been disclosed as a separating technique, it is to be understood that other types of separating techniques can be used.

In an example embodiment, washing of the wet cake is performed in the filter itself and in multiple process steps. In a first washing ("displacement washing") the largest part of the filtered substance contaminating the cake is removed. The washing step is performed using treated water over the cake flowing at a preselected flow rate. A second washing step, also with treated water, may be carried out to further reduce, if not eliminate, the contaminants. A third washing step using a slightly alkaline solution may be used to neutralize the cake and to keep its pH in the 7.0 range. The cake may be blown with compressed air for a period of time. Preferably, the solids content of the wet product is between about 35% to 45%. While the use of a particular washing

technique and sequence has been disclosed, it is to be understood that other types of washing techniques can be used.

The cake dispersion may be processed in such a way that the filter cake, wet and washed, and containing approximately 35% of solids, is extracted from the press filter by a conveyor belt and transferred to a reactor/disperser. The dispersion of the cake is aided by the addition of a dilute solution of sodium tetrapyrophosphate.

After the dispersion step, the product is then dried, when the AAlP "mud," with a percentage of solids of between about 30% to 50%, is pumped to the drying unit. In an example embodiment, water removal from the material can be carried out with drying equipment, such as a "turbo dryer" type through an injection of a hot air stream, at a temperature of less than about 300°C, preferably temperatures of from about 100°C to 200°C as noted above to obtain the desired engineered porosity. While the use of a particular drying technique has been disclosed, it is to be understood that other types of drying techniques can be used.

Example No. 9 - Sodium Aluminate Method of Making AlP

In another example process, the AlP is prepared by using sodium aluminate as an aluminum source as disclosed in US Patent No. 7,951,309. In one such embodiment, the AAlP is prepared by a reaction between phosphoric acid and aluminum hydroxide. The process may further comprise a step of neutralizing that can be carried out by using sodium aluminate. In certain embodiments, the process for making an AlP comprises reacting phosphoric acid, aluminum hydroxide and sodium aluminate. In one embodiment, the process for making an amorphous sodium aluminum phosphate comprises reacting aluminum phosphate and sodium aluminate.

In one embodiment, the reaction comprises two steps. In a first step, phosphoric acid reacts with aluminum hydroxide to produce aluminum phosphate at an acidic pH. In one embodiment, AlP is produced as a water soluble aluminum phosphate. In certain embodiments, the pH of water soluble AlP is less than about 3.5. In certain embodiments, the pH is about 3, 2.5, 2, 1.5 or 1. In certain embodiments, AAlP is produced as a fine solid-liquid dispersion at a higher pH. In one embodiment, the pH is about 3, 4, 5 or 6.

In a second step, the acidic aqueous aluminum phosphate solution or dispersion from the first chemical step is reacted with sodium aluminate. In certain embodiments, the sodium aluminate is used as an aqueous solution at a pH greater than about 10. In one embodiment, the pH of the aqueous sodium aluminate solution is about 11, 12 or 13. In one embodiment, the pH of the aqueous sodium aluminate solution is greater than about 12. The AAlP is generated as a solid precipitate. In one embodiment, the solid aluminum-sodium phosphate has a molar ratio of P:Al of about 0.85, and a molar ratio of Na:Al of about 0.50. In one embodiment, the solid AAlP has a molar ratio of P:Al of about 1, and a molar ratio of Na:Al of about 0.76. In certain embodiments, the molecules with other formulation ratios can be obtained by the same procedure.

In one embodiment, the solid hydrated aluminum hydroxide is added to the phosphoric acid in the first chemical step. In another embodiment, the solid hydrated aluminum hydroxide is added to the purified liquid sodium aluminate solution to form a colloidal solution. In another embodiment, the solid hydrated aluminum hydroxide is added directly as solid or solid-liquid suspension in water in the second reaction step. In certain embodiments, the reaction is carried out in a single step.

Sodium aluminates useful for this example process include those that can be obtained by methods known to those skilled in the art. For example, the sodium aluminate can be provided in solution form as a standard chemical product resulting from the first step in the Bayer process in the alumina (Al_2O_3) extraction from Bauxite ore, often called "purified sodium pregnant solution". This liquid aqueous sodium aluminate solution is saturated at ambient temperature and stabilized with sodium hydroxide, NaOH. It's typical compositions are: sodium aluminate, 58 to 65% mass (25 to 28% mass of Al_2O_3) and sodium hydroxide, 3.5 to 5.5% mass (2.5 to 4% mass of free Na_2O). In certain embodiments, it has a molar ratio of Na:Al of from about 1.10 to 2.20 and low impurities (depending on the Bauxite origin: Fe=40 ppm, Heavy metals=20 ppm, and small amount of anions, Cl^- and SO_4^{2-}). In certain embodiments, the sodium aluminate water solution has a molar ratio of Na:Al of about 1.1 0, 1.15, 1.20, 1.25, 1.30, 1.35, 1.40, 1.45, 1.50, 1.55, 1.60, 1.65, 1.70, 1.75, 1.80, 1.85, 1.90, 1.95, 2.0, 2.05, 2.10, 2.15 or 2.2. The solution color, in certain embodiments, is amber. In certain embodiments, the viscosity of the solution is approximately 100 cP. In certain aspects,

the sodium aluminate solution is purified by polishing filtration. In certain embodiments, the sodium aluminate solution is regenerated from solid aluminum hydroxide and sodium hydroxide.

The solid hydrated aluminum hydroxide can be obtained by methods known to one of skill in the art. In one embodiment, aluminum hydroxide is an industrial chemical produced by the Bayer process. The solid hydrated aluminum hydroxide can be obtained from the "purified sodium aluminate pregnant solution" by precipitation which is accomplished via cooling the solution. In one embodiment, the sodium aluminate thus produced has a low level of impurities and a variable amount of humidity (cations about 70 ppm, chlorates about 0.85% mass and sulfates about 0.60% mass (these impurities are determined by the purification level of the "Purified Sodium Aluminate pregnant solution) and the total water, hydration and humidity, about 22.0 to 23.5% mass. In one aspect, both raw materials are standard primary industrial products, just first and second step from the bauxite processing, (commodities) produced in huge amounts by the ~~B~~ bauxite processors.

In one embodiment, the chemical reaction results in the formation of aluminum sodium phosphate ($Al(OH)_7Na_7(PO_4).1.7H_2O$). After the formation of aluminum sodium phosphate, the suspension containing around 6% to 10% of solids, with a maximum approximate temperature of 45°C, and density in a 1.15 to 1.25 g/cm^3 range, is pumped to a conventional filter press.

In a preferred embodiment, AlP prepared by the precipitation process is prepared by using sodium aluminate. It has been discovered that the sodium aluminate process provides for an improved degree of control over the desired characteristics of the AlP that does not otherwise exist in the aluminum sulfate process.

Example No. 10 - Formation of the Bioactive-AlP Complex (physical incorporation)

The AlP made by the precipitation methods described above in Example Nos. 8 and 9, was constituted as a 34 percent by weight slurry, and was mixed with appropriate concentration silver nitrate solution. The later solution was made so that a 1.0 percent and a 10 percent by weight silver-to-AlP complex was made and a slurry solution was prepared. The combined slurry was mixed for approximately 5 minutes and then

atomized in a spray drier under nitrogen, and dried at temperatures ranging from about 180°C inlet to about 79°C outlet. The solid powder was collected and analyzed. The resulting powder was a bioactive-AlP complex where the bioactive material was physically incorporated, enmeshed, encapsulated, or intertwined in the AlP polymer.

Alternatively, the AlP made by the precipitation processes disclosed above was constituted as a 34 percent by weight slurry, and was mixed with appropriate concentration silver nitrate solution. After stirring the combined slurry was filtered and washed once with hot water at a temperature of 40 to 60°C. The filtrate was dried at approximately 110°C for approximately 12 hours, divided into portions, and each heat treated for approximately 24 hours at approximately 250°C. Yields were the same regardless of heat treatment temperature, and the resulting powder was a bioactive-AlP complex where the bioactive material was physically incorporated, enmeshed, encapsulated, or intertwined in the AlP polymer.

Example No. 11 – Formation of the Bioactive-ALP Complex (chemical bonding)

An AlP was prepared similar to the precipitation process described above in Example Nos. 8 and 9, except that a silver nitrate solution of appropriate concentration was combined with the acidic aluminum phosphate solution (P:Al ratio of 3:1) and then neutralized with an appropriate amount of sodium aluminate. The resulting dispersion comprised the bioactive-AlP complex, wherein the bioactive material, in the form of silver ion, was chemically bonded with, e.g., incorporated into the polymer backbone of, the AlP polymer. The dispersion was filtered to isolate the bioactive-AALP complex particles. The particles were washed and dried at the temperatures described above to provide the desired engineered porosity.

Sol Gel Method of Making

AlP prepared by a sol-gel process involves the creation of inorganic molecular networks from molecular or ionic precursors through the formation of a colloidal suspension (sol) and the gelation of such sol to form a solid network in a continuous liquid phase (gel). The precursors for synthesizing these colloids typically comprise a metal or metalloid element surrounded by various reactive groups. Stated another way, in the sol gel process, simple molecular or ionic precursors are converted into nano-sized particles to form a colloidal suspension (sol). The colloidal nano-particles are

then linked with one another in a three-dimensional liquid filled solid network (gel). This transformation to a gel can be initiated in a number of ways, but the most convenient approach is to change the pH of the reaction solution.

The method used to remove the liquid from the solid will affect the sol gel's properties. For example, supercritical drying will maintain the three-dimensional structure in the dried solid, whereas slow drying in a fluid evaporation process collapses the network structure creating a high density material.

Advantages to preparing the AlP via a sol gel synthesis process include process versatility and simplicity resulting in the possibility to obtain highly pure and/or tailored materials, uniform particle size distribution, substantially spherical-shaped aggregate particles, nano-sized particles, and custom engineered compositions. While AlP as disclosed herein comprises substantially spherical aggregate particles, it is understood that some small amount of nonspherical particles may unintentionally be produced and may be present in the resulting antimicrobial chemical compositions.

As used herein, the term "gel" is understood to be a three-dimensional cage structure formed of linked large molecular mass polymers or aggregates in which liquid is trapped. The network of the structure typically consists of weak and/or reversible bonds between the core particles. The term "sol" as used herein is understood to be a colloidal dispersion of solids in a liquid. The solids comprise aluminum phosphate having nanometer scale average particle sizes. The gel comprises an aluminum phosphate sol as a dispersed phase in a semi-rigid mass enclosing all of the liquid. Post treatment of product produced by the sol gel process by filtration, washing, drying, and combinations thereof leads to aggregation of the colloidal solids in a controlled fashion to form a larger solid complex.

Generally, the sol gel process includes the following process steps: (1) nucleation or polymerization or condensation of the molecular precursors to form primary particles, e.g., nanometer in scale, to form the sol (colloidal dispersion or suspension); (2) growth of the particles or gelation; (3) linkage of the particles to form chains and the extension of such chains throughout the liquid medium to form a thickened gel; and (4) treating the sol gel material to remove the liquid to give a desired solid end-product.

In an example embodiment, the precursor solution is prepared by combining a suitable aluminum source, with a phosphorous source. Suitable aluminum sources can be selected from the group of aluminum salts such as aluminum chloride, aluminum nitrate, aluminum sulfate and the like. A preferred aluminum source is aluminum nitrate. Phosphorous sources useful for forming AAlP by sol gel process include phosphoric acid, and salts of phosphorus as orthophosphates or as polyphosphates. A source of phosphorus is fertilizer grade phosphoric acid, from any origin, that has been clarified and discolored.

The primary ingredients of the precursor solution are combined together in an aqueous environment with a gelling agent to produce a colloidal dispersion of solid aluminum phosphate particles in solution. In an example embodiment, the precursor solution is formed by combining aluminum nitrate with phosphoric acid (85% by weight) in the presence of water. Water can be present in one or more of the aluminum nitrate, the phosphoric acid, or as added water independent of either ingredient.

After the precursor ingredients are combined, the resulting system is stirred and a suitable alkaline ingredient is added to the stirred solution. Alkaline ingredients useful for this purpose include those conventionally used to change the pH of the system, e.g., increase the pH of the acidic system, and in an example embodiment is ammonium hydroxide. The presence of the ammonium hydroxide increases the pH and drives the process of nucleation and condensation forming a colloidal dispersion or sol. Depending on the concentration of nucleating agent, this step can be intermediate or final. Further addition of nucleating agent causes the primary aluminum phosphate particles to link together forming a gel, e.g., results in gelation, and further results in the colloidal particles being linked into the gel structure to form a sol gel.

In an example embodiment, it may be desired to control the sol gel process to isolate the colloidal dispersion before gelation. This can be done by controlling the reaction conditions so that only colloidal dispersion occurs (i.e., formation of a sol) and not full gelation. Controlling the process in this manner may provide certain manufacturing advantages and/or provide certain advantages relating to handling of the end-product.

The colloidal dispersion from this process can be filtered to recover the solids, and then thermally treated and/or washed as described below.

In an example embodiment, the phosphoric acid, aluminum nitrate, and/or ammonium hydroxide can be heated prior to being combined with one another, or can be heated after combination, e.g., during stirring. Additionally, the amount of water present and/or the rate of addition of the ammonium hydroxide, can be adjusted to produce a desired reaction product having a desired yield of AAlP.

In an example embodiment that amount of ammonium hydroxide, NH_4OH, that is added to the acid solution is sufficient to neutralize the acid system to initiate formation of colloidal aluminum phosphate particles, and for gelation exceeds the stoichiometric amount to form ammonium nitrate, $NH_4NO_{3,}$. The range can be from the stoichiometric amount of NH_4OH needed to form the NH_4NO_3 (1.0 stoichiometry) to about 3.0 stoichiometry, preferably between about 1.1 and 2.0, and more preferably between about 1.2 and 1.5.

The order of addition (i.e., base solution to acid precursor solution or vice versa) has been found to control the rate and extent of gelation. When base is added to stirred precursor solution in stoichiometric concentration ranges stated above (1.0 to 3.0) virtually instantaneous gelation occurs. It has been discovered that reversing the order of addition, i.e., adding the precursor solution to the base solution, provides control over the extent of growth from colloidal dispersion to full gelation. As discussed below, it has also been discovered that particle morphology can be controlled by the method of addition.

It has been found that concentrations of ammonia in excess of the 1.1 stoichiometric ratio are useful to minimize unreacted aluminum in the resulting complex. For the end-use application as an inhibitive pigment, it is desirable that the phosphate release rate from the complex when contacted with water be in the 200 to 400 ppm range. Testing has determined that phosphate anion elution is in the target range when the ammonia level in the reaction is around 1.2 to 3 stoichiometric ratio and after the solid has been thoroughly washed and/or thermally treated to remove the soluble by-products as described below.

In an example process, the sol gel is next subjected to post gelation treatment which may comprise heating, washing, and/or sizing. In an example embodiment, the sol gel powder formed is isolated by collapsing the dispersion or gel by driving off the liquid constituent. Various types of gels can be formed from the sol gel such as; xerogels that are solids formed by unhindered drying of the sol gel so as to yield high porosity and surface area (150 – 1,000 m^2/g) in solid form, aerogels that are solids formed by supercritical drying (e.g., freeze drying), hydrogels that are water insoluble colloidal polymer particles dispersed in water, and organogels that are amorphous, non-glassy solids comprising a liquid organic phase trapped in the solid matrix.

The sol gel consists of solid $AlPO_4$ connected through various pH dependent (amino, water, phosphate) linkages to form a solid dispersed phase as a mass enveloping all the liquid, the latter consisting of water and dissolved salts. Heating the gel, to a temperature above about 100°C, evaporates the water and any ammonia and collapses the mass to a solid consisting of aluminum phosphate, $AlPO_4$, and ammonium nitrate, NH_4NO_3. Heating the gel or the collapsed gel solid, to a temperature above about 215°C, thermally decomposes the ammonium nitrate, NH_4NO_3, thereby eliminating it from the powder product. Heating to temperatures above about 215°C leads to a decrease in pH, indicating that residual amino groups remaining after thermal decomposition of the ammonium nitrate, NH_4NO_3, most likely as substituent's on the PO group, are also thermally decomposed and replaced by hydrogen atoms thereby making the complex acidic. The solid product resulting from this treatment has been shown by analysis to be pure AAlP having a phosphate release rate of around 240 ppm and surface area greater than 125 m^2/gram.

Accordingly, the post gelation heat treatment can comprise a single step of heating the sol gel to a relatively high temperature above about 250°C for a period of time sufficient to achieve water evaporation, collapsing of the mass, and thermally decomposing the ammonium nitrate, NH_4NO_3. In an example embodiment, this can be done at about 250°C for approximately 12 to 72 hours. The resulting product from this heat treatment is substantially aluminum phosphate, i.e., there is very little if any ammonium phosphate or ammonium nitrate.

Alternatively, the post gelation heat treatment can comprise a single step of heating the sol gel at a lower temperature of about above about 100 to 150°C for a period of time sufficient to achieve water evaporation. In an example embodiment, this can be done at about 110°C for approximately 1 to 24 hours. The resulting product from this heating or drying treatment is AAlP and ammonium phosphate and ammonium nitrate.

This drying step can be followed by a heat treatment step at a temperature of between about 215 to 300°C. In a preferred embodiment, the drying step is at about 110°C for about 24 hours, and the heat treatment is about 250°C for up to 1 to 3 days (16 to 72 hours). The resulting AAlP has a moisture content of from about 5 to 20 percent by weight and the desired engineered porosity. The pH of the heat treated material can be adjusted by re-dispersing the complex and adjusting the pH with ammonium hydroxide solution. The resulting complex is then dried at 100 to 110°C to remove water and ammonia.

If desired, before drying or heat treatment, the sol gel material can be filtered to separate the solid particles from solution, and the separated solid, e.g., in the form of a cake, can be subjected to one or more wash cycles. The wash cycles use water and operate to rid the solid aluminum phosphate particles of any unwanted solubles, e.g., ammonium compounds such as ammonium nitrate, and ammonium phosphate that have been formed as a reaction by- product. The washed sample can then be dried and/or heat treated in the manner disclosed above to further evaporate water and/or thermally decompose any residual ammonium nitrate and ammonium phosphate in the washed aluminum phosphate, and densify the aluminum phosphate particles.

If desired, the sol material can be dried at about 100°C to evaporate water and collapse the mass, and the collapsed powder can be washed with water to remove ammonium nitrate , NH_4NO_3, to thereby recover instead of thermally decompose the by-product. The washed and dried mass can be heat treated above about 215°C to thermally decompose any residual ammonium nitrate, NH_4NO_3 , thereby providing substantially pure AAlP.

The basic chemistry of the sol gel process for forming only the AAlP is presented below as follows:

1. Precursor solution - Combination of all ingredients

$Al(NO_3)_3 \cdot 9H_2O + H_3PO_4 + H_2O$

2. Gelling Agent

$3NH_4OH + H_2O$

3. Sol-gel reaction

$AlPO_4 + (NH_4)_3PO_4 + H_2O \longrightarrow AlPO_4 + NH_4OH$

Reaction to form AAlP sol gel: as NH_4OH (28% NH_3 in water) is added, it neutralizes the acid system and drives formation of insoluble $AlPO_4$, that takes Al^{+3} out of the reaction and allows more NH_4^{+1} to combine with NO_3^{-1} to form soluble NH_4NO_3. Depending on the concentration and rate of addition of the NH_4OH colloidal particles of $AlPO_4$ will form. Adding more NH_3 to the reaction allows the $AlPO_4$ colloidal particles to aggregate and to eventually form bonds between the particles to form the gel structure.

The amount of NH_3 added must exceed the stoichiometric amount required to form NH_4NO_3 in order to have sufficient NH_3 to control pH and facilitate gel bridging. Depending on the amount of NH_3 added, the rate of addition, and the concentration, the gel will consist of a mass of $AlPO_4$ solid particles linked forming a cage, three-dimensional structure encapsulating ammonium nitrate, NH_4NO_3, dissolved in water. Ammonium phosphate may also be present as an intermediate, and extending reaction conditions (i.e., by further heating) will lead to full reaction with the aluminum in the system to condense to aluminum phosphate.

4. Filtration and washing - Optional to supplement or replace thermal purification to remove soluble ammonium salts.

5. Dehydration and drying - Drying at above at least 100°C to evaporate water and collapse the sol gel structure to form a densified solid.

$AlPO_4 + NH_4NO_3$

6. Thermal purification - Thermal treatment at 215 to 250°C to thermally decompose ammonium nitrate.

$AlPO_4$ (amorphous aluminum phosphate)

If desired, the order of ingredient addition can be changed from that disclosed above. For example, the acid solution may be added to a solution of the ammonium hydroxide in order to control the viscosity of the reaction system and/or impact the surface area of the colloidal solids. Such flexibility in the order of ingredient addition may be advantageous, e.g., for the scale-up of manufacturing where it may be desirable to avoid gelation in favor of the formation of a suspension of colloidal primary particles. The resulting composition after washing, drying and/or thermal treatment is essentially chemically the same regardless of the order of addition. However product morphology is affected by these processing parameters. Adding acid to base results in higher surface area and greater porosity. The sol gel process disclosed herein produces an aluminum phosphate composition consisting essentially of AAlP.

Base-to-acid sequencing causes rapid pH change and the rapid formation of sol particles followed by rapid gelation to form interlinked particles in the gel matrix. This reduces molecular mobility and prevents any further particle growth or morphological change. When acid is added to base, the pH change is slower and localized colloidal aluminum phosphate particles form. No gelation occurs so the system mobility allows for continued competing side reactions (increased solublization of ammonium nitrate and ammonium phosphate) allowing intermediate species to survive. When dehydration and thermal decomposition occur, small particles of aluminum phosphate exist in the presence of departing water and decomposition products (of ammonium nitrate), leading to more porosity in small aggregated aluminum phosphate particles.

The basic chemistry of the sol gel process for forming only the bioactive-AAlP complex (which involves adding the bioactive material, e.g., in the form of silver nitrate, to the aluminum nitrate and aqueous phosphoric acid) is presented below as follows:

1. Precursor solution - Combination of all ingredients

   $Al(NO_3)_3 \cdot 9H_2O + H_3PO_4 + H_2O + AgNO_3$

2. Gelling Agent

   $3NH_4OH + H_2O$

3. Sol-gel reaction

$AgAlPO_4 + (NH_4)_3NO_3 + H_2O + NH_3$

4. Filtration and washing - Optional to supplement or replace thermal purification to remove soluble ammonium salts.

5. Dehydration and drying - Drying at above at least 100°C to evaporate water and collapse the sol gel structure to form a densified solid.

$AgAlPO_4 + NH_4NO_3$

6. Thermal purification - Thermal treatment at 215 to 250°C to thermally decompose ammonium nitrate.

$AgAlPO_4$ (amorphous silver aluminum phosphate)

Example No. 12 - Formation of the Bioactive-AlP Complex (physical incorporation)

The AAlP made by the sol gel process as described above, was constituted as a 34 percent by weight slurry, and was mixed with appropriate concentration silver nitrate solution. The later solution was made so that a 1.0 percent and a 10 percent silver-to-AgAlP complex were prepared. The combined slurry was mixed for approximately 5 minutes and then atomized in a spray drier under nitrogen, and dried at temperatures ranging from about 180°C inlet to about 79°C outlet. The solid powder was collected and analyzed. The resulting powder was a bioactive-AlP complex where the bioactive material was physically incorporated, enmeshed, encapsulated, or intertwined in the AlP polymer.

Alternatively, the AAlP made by the sol gel process was constituted as a 34 percent by weight slurry, and was mixed with appropriate concentration silver nitrate solution. After stirring the combined slurry was filtered and washed once with hot water at a temperature of 40 to 60°C. The filtrate was dried at approximately 110°C for approximately 12 hours, divided into portions, and each heat treated for approximately 24 hours at approximately 250°C. Yields were the same regardless of heat treatment temperature, and the resulting powder was a bioactive-AlP complex where the bioactive material was physically incorporated, enmeshed, encapsulated, or intertwined in the AlP polymer.

Example No. 13 – Formation of the Bioactive-AAlP Complex (chemical bonding)

An AAlP was prepared similar to the sol gel process described above, except that a silver nitrate solution of appropriate concentration was combined at the same time as the aluminum nitrate and aqueous phosphoric acid. The resulting gel comprised the bioactive-AlP complex, wherein the bioactive material, in the form of silver ion, was chemically bonded with the AlP polymer. The dispersion was filtered, washed, and dried at the temperatures described above to provide the desired engineered porosity.

AlPs/bioactive-AlP complexes formed by the above-noted methods have a P:Al ratio of from about 0.5:1 to 1.5:1. It is desired that the AlPs/bioactive-AlP complexes have a P:Al ratio in this range because this provides a suitable range of particle morphology and properties that are compatible with desired formulation chemistries.

If desired, the bioactive-AlP complex as described herein can be initially made in the form of a concentrate, wherein an amount of the bioactive material is initially combined with a first amount of the AlP (in the case where the bioactive material is physically incorporated with the AlP polymer) or a first amount of the precursor materials used to form the AlP (in the case where the bioactive material is chemically bonded with the AlP polymer). This initially stage results in the formation of a bioactive-AlP complex condensate, i.e., having a high concentration of the bioactive material present. This complex condensate can then be used as feedstock to formulate a number of different formulations to meet different end-use applications. In an example embodiment, the complex condensate may be combined with further AlP to provide a bioactive-AlP complex having a relatively lower bioactive material content that is well suited for a certain end-use application. The ability to make such a complex condensation thereby adds a desired degree of flexibility to the process of obtaining different antimicrobial formulations for meeting different antimicrobial end-use applications.

AlP and bioactive-AlP complexes made in the manner described herein are provided in solid form as a white powder having a desired particle size or size distribution. The particle size will depend on such factors such as the binding polymer, and the particular end-use application. In an example embodiment, the AlP may have a particle size

distribution of D50 from about 0.5 to 8 microns. In an example embodiment, it is desired that the AlP have a P:Al ratio of from about 0.9 to 1, and have a particle size distribution of D50 of about 1 micron and D90 less than about 4 microns. For use in an antimicrobial chemical composition it is desired that the AlP have a particle size of less than about 20 microns, and preferably in the range of from about 0.5 to 10 microns, and more preferably in the range of from about 1.0 to 8.0 microns. Particle sizes of less than about 0.5 microns may interfere with the processing of certain chemical formulations and adversely affect film properties by increasing binder resin absorption.

AlP and bioactive-AlP complexes prepared in the manner described above may not be subjected to high-temperature drying or other thermal treatment for the purpose of retaining an amorphous structure and avoiding conversion to a crystalline structure. It has been discovered that AlPs formed in this manner retain the desired amorphous structure, even after low temperature drying. AlPs formed as disclosed herein have a structure comprising an engineered porosity that enables it to serve as a carrier for the bioactive material to provide the desired controlled delivery/release of the bioactive constituent for use in an antimicrobial chemical composition.

AAlPs as produced herein display a markedly increased water adsorption potential or degree of rehydration, when compared to crystalline AlP, that permits such AAlPs, once dehydrated by drying, to be rehydrated to contain up to about 25 percent by weight water. This feature is especially useful when the AlP is used in end-use applications calling for some degree of protection against corrosion, and wherein the AlP is present in a nonwater-borne binding polymer. In such application, the AlP acts, in addition to being a carrier for the bioactive material and being an corrosion inhibiting pigment, as a moisture scavenger to both slow water intrusion into the cured film and restrict water diffusion through the cured film.

Additionally, the rehydration feature of AlPs disclosed herein can be beneficial when placed in low humidity end-use applications. In such applications, AlPs can be used having a high or saturated moisture content that can operate to drive the bioactive constituent, e.g., have a built-in transport mechanism, to a surface of the cured antimicrobial chemical composition or composite to promote the presence of such bioactive constituent at the surface in the absence of surrounding moisture. Engineered

in this manner, antimicrobial chemical compositions comprising such AlP can function to provide a desired level of bioactive constituent at the surface in low humidity/moisture applications.

Antimicrobial chemical compositions described herein are prepared by combining a selected binding polymer with the AlP and the bioactive material in the manner and in the amounts described above. The resulting bioactive-AlP complex can be provided for composition formulation in the form of a dried powder or can be provided in the form of a slurry or liquid suspension depending on the formulation conditions or preferences.

Antimicrobial chemical compositions described herein, comprising the bioactive-AlP complex, comprise from about 5 to 1000 ppm, preferably 10 to 900 ppm, and 15 to 800 ppm of the bioactive material based on the total weight of the chemical composition. Such antimicrobial chemical compositions may comprise other materials, agents, and/or additives (in addition to the bioactive-AlP complex and the binding polymer), such as pigments, fillers, rheological agents, flow stabilizers, light-control stabilizers, and the like. For example, antimicrobial chemical compositions comprising a silver bioactive material may comprise an additive designed to inhibit the photo reduction of the silver, to thereby preserve the active state of the silver, contained within the composition, dried film and/or composite formed therefrom, to help ensure its effective service life.

Complexing the Bioactive Agent

It has been discovered that complexing the bioactive agent (when such is silver salt) with any of a number of organic complexing agents has an unexpected benefit on both the stabilization of the silver ion in the Ag-AlP complex and in enhancing its antimicrobial properties. Ag^+ will complex with a variety of ligands such as ammonia, imidazole (IMI), substituted IMI, and combinations thereof. The most common coordination number (the number of groups with which a metal may bond) for Ag^+ is 2, indicating that, in the simplest case, the structure for silver complexed with ammonia will be: $[Ag(NH_3)_2]^{+2}$. The reduction potential of Ag^+ is +0.799V and this provides a strong thermodynamic driving force for the reduction of Ag^+ ion to silver metal. However, complexing the silver ion with ammonia changes the reduction potential to 0.37V, making reduction harder. Hence stabilizing the silver ion by complexation

operates to increase its resistance to reduction and resulting discoloration and deactivation.

Further, chelated Ag^+ was found to be more effective by several orders of magnitude than free silver ion in antimicrobial activity. It is believed that Ag^+ ions are actively transported in the organism intracellularly by the chelating ligand in a protected complex and not by the free ion. Hence, successful complexation of the silver ion in Ag-AlP not only protects the silver ion (in the formulated product) from reduction and discoloration, but may also render it a more effective antimicrobial agent. This gives the product formulator more flexibility concerning loading levels, service scope and life, and price points.

The silver-ammonium complex is a simple linear structure: $[NH_3---Ag---NH_3]^{+2}$. In an example embodiment, IMI was selected as a complexing ligand for silver. Studies were conducted using IMI to determine whether benefits in stabilization and increased efficacy would accrue to the AlP system incorporating this complexed silver compound. IMI is a cyclic, planar, five membered ring exhibiting aromaticity. The non-protonated nitrogen atom has a lone pair of electrons that are not part of the aromatic pi (π) cloud that describes the electronic bonding structure of the molecule. These electrons provide a point of attack for protons or electrophilic groups (e.g., silver ion). It is believed that the silver ion will bond with two IMI molecules through their non-protonated nitrogen groups. However, there may also be weak bonding between silver atoms, in effect, aggregating more than one Ag-IMI complex together. Therefore, the different ratios of IMI to silver content were evaluated.

With respect to the nature of any interaction between the phosphate groups present in the various AlP compositions with silver ion or silver ion complexes, by analogy to the behavior of chlorates (which have four electronegative oxygen groups similar to phosphate), it is theorized that electrostatic attraction occurs between the oxygen in phosphate and the hydrogen in IMI as well as directly with the silver ion (where IMI is not present or where kinetic factors allow first interaction between the $P-O^-$ and the Ag^+).

In an example embodiment, the following factors relating to forming the silver complex and an Ag-AlP complex comprising the same were evaluated: (a) the ratio between silver ion and IMI in the system (two levels were picked at 1:2 and 1:4, Ag:IMI molar ratio); (b) preparing the complex in advance of the AlP condensation reaction (referred hereafter as "pre-mix") vs. in situ formation during AlP condensation; (c) order and point of addition of the silver-IMI complex (before or after AlP condensation); (d) temperature of the condensation reaction (room temperature or an elevated temperature such as 95°C); (e) effect of post-condensation neutralization (with ammonia) on the product; (f) overall order of addition for the condensation reaction (B to A, or A to B); and (g) presentation of the silver-IMI-phosphate product as a powder or a gel/slurry.

The testing showed that, changes to the binary condensation process as disclosed above for making Ag-AlP may provide certain desired improvements, wherein such changes may include: (a) reducing the addition time for all steps, which operated to provide improved properties of color stability and/or silver content retention after processing; (b) hot conditions in any step typically led to lower silver retention (because side reactions were enhanced that lead to such undesirable by-products as silver phosphate or silver oxide); (c) preparing each component separately (e.g., silver-IMI complex; aluminum hydroxide (ATH) slurry) and then combining them together and finally combining that combination with phosphoric acid gave the best possible result. It is believed that preparing the components separately rather than in situ allows each to form completely and in its purest form. Hence, when the aluminum phosphate condensation reaction occurs, the silver ion or the silver ion complex is already formed and it will be trapped within the forming AlP complex for maximum interaction with the AlP.

It was discovered that the addition of either Ag-IMI (1:2) or Ag-IMI (1:4) solution to 85% phosphoric acid gave a white slurry. Subsequent neutralization with ammonium hydroxide gave a white precipitate that could be dried to a white powder at about 110°C for 24 hours. This result is theorized to indicate that there is a fundamental chemical interaction between the silver complex and phosphate that leads to a discrete product (other than silver phosphate which is a yellow solid).

It was also discovered that the addition of slurry consisting of ATH and silver nitrate in the appropriate proportions to 85% phosphoric acid gave a stable white gel-like composition. The stability of this product is based on the uniform entrapment of the silver ion within the AlP matrix. Such stabilization is believed to be due to the formation of an ionic complex between the silver ion and the phosphate groups of the AlP in the slurry.

In view of the above test results, an example synthesis route for forming an Ag-AlP complex comprising the above-described Ag complex is as follows: (a) Pre-make a silver-IMI-nitrate complex [Ag-IMI] by the simple combination of silver nitrate with IMI in water at room temperature with stirring; (b) Pre-make an ATH slurry (20% solids be weight) by dispersing ATH in water at room temperature; (c) combine the ATH slurry with the Ag-IMI complex at room temperature by stirring to form a mixture; (d) add the ATH/Ag-IMI mixture (base) to 85% phosphoric acid at room temperature with stirring for a period of time, e.g., about one hour (in this order of addition, the acid pH operates to stabilize the silver ion in the complex); (e) allow the mixture to react at room temperature for an additional amount of time, e.g., one hour, after combining; and (f) the reaction mixture becomes a viscous gel-like composition, wherein the gel can either be isolated for use in water-based application, or can be dried to a white powder by heating, e.g., at about 110°C for a period of time, e.g., about 24 hours.

While the feature of forming an Ag-AlP complex comprising a complexed silver salt has been disclosed in the context of using the binary condensation process of making the Ag-AlP complex, it is to be understood that complexed bioactive material, e.g., silver salts, as disclosed herein can be used to form Ag-AlP complexes according to the other remaining methods or process of making Ag-AlP complexes as disclosed herein, wherein in such other methods the bioactive material, e.g., silver salt is replaced with the complexed bioactive material, e.g., complexed silver salt.

Also, while an example of combining the complexed bioactive material with the aluminum source prior to forming the AlP complex has been disclosed, it is to be understood that the complexed bioactive material can be added separately while the aluminum source and phosphate source are combined together, or can be precombined with the phosphate source as an alternative to precombining with the aluminum source.

Addition of Oxides of Metal

Various oxides of metals such as zinc and/or copper and the like may be incorporated into bioactive-AlP complexes as disclosed herein. In an example, it is theorized that the presence of zinc oxide in the bioactive-AlP complex may be useful for the purpose of absorbing ultraviolet light and providing inherent antimicrobial properties. In an example, zinc oxide was added to the ATH slurry pre-make (from step (b) above) and the chemical composition and performance properties were determined. XRD analysis of product from this reaction showed no crystal structures due to any zinc oxide or zinc phosphate crystalline component, indicating that the zinc was included in the amorphous component as part of the Ag-AlP complex. As noted above, the presence of the zinc component operates to both enhance the light stability and expand the antimicrobial activity of the composition.

While zinc oxide has been noted as an example metal oxide for incorporating into bioactive-AlP complexes as disclosed herein, it is to be understood that other oxides of metal including and not limited to copper, magnesium, barium, calcium, and combinations thereof, are intended to be within the scope of antimicrobial compositions as disclosed herein. Additionally, it is to be understood that the addition of one or more metal oxides to form bioactive-AlP complexes as disclosed herein can be performed by any one of the different methods or processes of making the bioactive-AlP complex as disclosed herein.

The metal oxide can be introduced during the process of making the bioactive-AlP complex prior to the step of forming the AlP, during the step of forming the AlP, or after the step of forming the AlP. In an example, the metal oxide is present at the time of forming the AlP, which means it may be precombined with the bioactive material or may be combined separately from the bioactive material at the time that the AlP is being formed. The metal oxide may be presented separately, may be presented in combination with the bioactive material, e.g., silver salt, and/or may be precombined with one or both of the aluminum source and phosphate source. In an example where the bioactive material is complexed, the metal oxide may be added to the bioactive material before or after complexing. In an example embodiment, the metal oxide is added after the bioactive material has been complexed.

Further Examples of Bioactive-AlP Complexes

Further examples of bioactive-AlP complexes as disclosed herein are provided for reference. These examples were prepared as described and tested for antimicrobial efficacy by determining the minimum inhibitory concentration (MIC) against the micro-organisms noted below, and were tested for light stability as described below.

Further Example 1: [CL20] Ag-AlP Complex

Preparation of ATH slurry – approximately 98.3 grams of ATH was dispersed in 560 grams of distilled water. In a separate vessel, approximately 11 grams of $AgNO_3$ was dissolved in 60 grams of distilled water. The $AgNO_3$ solution was added drop wise to the ATH slurry with stirring.

Condensation reaction – approximately 144 grams of 85% phosphoric acid was added to a reaction flask. The ATH/$AgNO_3$ slurry was added drop wise to the acid with stirring. The reaction mixture was stirred for two hours at room temperature in the dark. When the reaction was complete it formed an Ag-AlP complex, and the mixture was a wet cake without a distinct liquid layer. The percent solids of the cake was measured, and the Ag-AlP complex was suitable for use directly as an antimicrobial additive in water based formulations.

Further Example 2: [CL21] AgIMI(1:2)-AlP Complex

Preparation of pre-mixed components – approximately 14.1 grams of IMI was combined with 50 grams of distilled water. In a separate container, approximately 17.7 grams of $AgNO_3$ was dissolved in 50 grams of distilled water (run and store reaction in dark). The IMI solution was added drop wise to the $AgNO_3$ solution, and the solution was stirred for 30 minutes at room temperature in the dark forming an Ag-IMI complex. In a separate container, approximately 157.3 grams of ATH was dispersed in 560 grams of distilled water. The Ag-IMI complex solution was added drop wise with stirring to the ATH slurry, and the resulting mixture was mixed at room temperature in the dark for 30 minutes.

Condensation reaction – approximately 230 grams of 85% phosphoric acid was added to a reaction flask. The ATH and Ag-IMI complex mixture was added to the acid

drop wise with stirring at room temperature. The reaction mixture was stirred for two hours at room temperature in the dark. When the reaction was complete, the mixture was a wet cake made of AgIMI-AlP complex without a distinct liquid layer. The percent solids of the cake was measured, and the AgIMI-AlP complex was suitable for use directly as an antimicrobial additive in water based formulations.

Further Example 3: [CL22] AgIMI(1:4)-AlP Complex

The procedure of Further Example 2 was followed except that approximately 28.3 grams of IMI was used.

Further Example 4: [CL47] AgIMI(1:4)-ZnO-AlP Complex

Preparation of pre-mixed components – approximately 27.2 grams of IMI was combined with 50 grams of distilled water. In a separate vessel, approximately 17.7 grams of $AgNO_3$ was dissolved in 50 grams of distilled water. The IMI solution was added drop wise to the $AgNO_3$ solution and the mixture was stirred for 30 minutes at room temperature in the dark forming an AgIMI complex. In a separate vessel, approximately 157.3 grams of ATH and 53.1 grams of ZnO were combined with 550 grams of distilled water and dispersed for 30 minutes at room temperature. The AgIMI solution was added drop wise to the ATH-ZnO slurry and mixed for 30 minutes at room temperature.

Condensation reaction - the ATH-ZnO and AgIMI slurry was added drop wise to approximately 227.8 grams of 85% phosphoric acid. The glassware was washed with 50 grams of distilled water and the wash was added to the reaction mixture. The reaction mixture is stirred for two hours at room temperature in the dark forming an AgIMI-ZnO-AlP Complex.

Neutralization option to adjust pH - the resulting reaction slurry was titrated with approximately 28% NH_4OH to the target pH. Typically the pH of the slurry at the end of the reaction is between about 2.5 and 3.0. In the example, approximately 174.7 grams of 28% NH_4OH was used to bring the pH of the slurry to 7.03.

Post processing option - the slurry mixture resulting from the reaction and comprising the AgIMI-ZnO-AlP complex may be used directly as the gel (some

concentration by water evaporation may helpful to reach a specified solids content). Or the reaction slurry may be filtered, and the filter cake dried to a white powder at an elevated temperature, e.g., of about 110°C for 24 hours, or as low as about 60°C under vacuum for 24 hours.

Further Example 5: [CL50] Ag-ZnO-AlP Complex

Preparation of pre-mixed components – approximately 1 gram of $AgNO_3$ was dissolved in 50 grams of distilled water. Separately, approximately 84.5 grams of ATH and approximately 20.8 grams of ZnO were combined with 560 grams of distilled water and dispersed at room temperature for 30 minutes. The $AgNO_3$ solution was added drop wise to the ATH-ZnO slurry and mixed for 30 minutes at room temperature in the dark.

Condensation reaction - the ATH-ZnO-$AgNO_3$ slurry was added drop wise to approximately 122.5 grams of 85% phosphoric acid. Glassware was washed with 50 grams of distilled water and added to the reaction mixture. The mixture is stirred for two hours at room temperature in the dark forming an Ag-ZnO-AlP complex.

Post processing option – same as disclosed above in Further Example 4.

Further Example 6: [CL49] AgIMI(1:2)-ZnO-AlP Complex

Preparation of pre-mixed components – approximately 13.6 grams of IMI was dissolved in 50 grams of distilled water. Separately, approximately 17.7 grams of $AgNO_3$ was dissolved in 50 grams of distilled water. The IMI solution was added drop wise to the $AgNO_3$ solution and was stirred for 30 minutes in the dark at room temperature forming an AgIMI complex. Separately, approximately 123.9 grams of ATH and 33.5 grams of ZnO were combined with 560 grams of distilled water and dispersed at room temperature for 30 minutes. The AgIMI solution was added drop wise to the ATH-ZnO slurry and stirred for 30 minutes at room temperature in the dark.

Condensation reaction - the ATH-AgIMI-ZnO slurry was added drop wise at room temperature to approximately 179.4 grams of 85% phosphoric acid. Glassware was washed with 50 grams of distilled water and added to the reaction mixture. The

reaction slurry is stirred for two hours at room temperature in the dark producing an AgIMI-ZnO-AlP Complex.

Post processing option – same as disclosed above in Further Example 4.

Further Example 7: [CL48] AgIMI(1:4)-ZnO-AlP Complex

The procedure of Further Example 6 was followed except that approximately 27.2 grams of IMI was used.

Further Example 8: [CL51/52] AgIMI(1:4)-Cu_2O(Ag:Cu=1:1)-AlP Complex

Preparation of pre-mixed components – approximately 27.2 grams of IMI was dissolved in 50 grams of distilled water. Separately, approximately 17.7 grams of $AgNO_3$ was dissolved in 50 grams of distilled water. The IMI solution was added drop wise to the $AgNO_3$ solution and was stirred for 30 minutes in the dark at room temperature to form an AgIMI complex. Separately, approximately 153.3 grams of ATH and approximately 12.7 grams of Cu_2O were mixed with 560 grams of water and dispersed for 30 minutes. The AgIMI solution was added drop wise to the ATH-Cu_2O slurry and mixed for 30 minutes in the dark at room temperature.

Condensation reaction - the ATH-AgIMI-Cu_2O slurry was added drop wise at room temperature to approximately 222.1 grams of 85% phosphoric acid. Glassware was washed with 50 grams of distilled water and added to the reaction mixture. The reaction slurry was stirred for two hours at room temperature in the dark producing a AgIMI-Cu_2O-AlP complex.

The reaction mixture was filtered and dried at an elevated temperature, e.g., of about 110°C for 24 hours, to form a white powder. [CL51].

Neutralization option to adjust pH - procedure of Further Example 4. [CL52] – treated with ammonia.

Further Example 9: [CL53/54] Ag-ZnO-Cu_2O(Ag:Cu 1:0.5; Ag:Zn 1:3)-AlP Complex

Preparation of pre-mixed components – approximately 17.7 grams of $AgNO_3$ was dissolved in 50 grams of distilled water. Separately, approximately 153.3 grams of ATH and approximately 41.8 grams of ZnO and approximately 6.3 grams of Cu_2O were combined with 560 grams of distilled water and dispersed at room temperature for 30 minutes. The $AgNO_3$ solution was added drop wise to the ATH-ZnO-Cu_2O slurry and mixed for 30 minutes at room temperature in the dark.

Condensation reaction - the ATH-$AgNO_3$-ZnO-Cu_2O slurry was added drop wise at room temperature to approximately 222.1 grams of 85% phosphoric acid. Glassware was washed with 50 grams of distilled water and added to the reaction mixture. The reaction slurry was stirred for two hours at room temperature in the dark producing an Ag-ZnO-Cu_2O-AlP complex.

Cl53 is not filtered - the condensation reaction mixture is dried to a white powder at an elevated temperature, e.g., of about 110°C for 24 hours.

CL54 is filtered – the condensation reaction mixture is filtered and dried at an elevated temperature, e.g., of about 110°C for 24 hours, to form a white powder.

Further Example 10: [CL55/56/57] AgIMI(1:4)-ZnO-Cu_2O(Ag:Cu 1:0.5; Ag:Zn 1:3)-AlP Complex

Preparation of pre-mixed components – approximately 27.2 grams of IMI was dissolved in 50 grams of distilled water. Separately, approximately 6.3 grams of Cu_2O was dissolved in 50 grams of distilled water. The IMI solution was added drop wise to the Cu_2O solution and was stirred for 30 minutes in the dark at room temperature. Separately, approximately 17.7 grams of $AgNO_3$ was dissolved in 50 grams of distilled water. The $AgNO_3$ solution was added drop wise to the Cu_2O-IMI solution and stirred for 30 minutes at room temperature in the dark producing an AgIMI-Cu complex.

Separately, approximately 137.6 grams of ATH and approximately 41.8 grams of ZnO were mixed with 560 grams of distilled water and dispersed for 30 minutes.

The AgIMI-Cu_2O solution was added drop wise to the ATH-ZnO slurry and mixed for 30 minutes in the dark at room temperature forming an ATH-AgIMI-Cu_2OZnO solution.

Condensation reaction - the ATH-AgIMI-Cu_2O-ZnO slurry was added drop wise at room temperature to approximately 199.4 grams of 85% phosphoric acid. Glassware was washed with 50 grams of distilled water and added to the reaction mixture. The reaction slurry was stirred for two hours at room temperature in the dark producing an AgIMI-Cu_2OZnO-AlP complex.

CL55 - half of the final reaction mixture was filtered and dried at an elevated temperature, e.g., of about 110°C for 24 hours, to form a white powder.

The remaining half of the reaction was neutralized as described above.

CL56 – the final reaction mixture was neutralized and dried at an elevated temperature, e.g., of about 110°C for 24 hours, but not filtered.

CL57- the final reaction mixture was neutralized, filtered, and dried at an elevated temperature, e.g., of about 110°C for 24 hours.

Compositional Effects on Antimicrobial Activity (MIC)

The antimicrobial efficacy of the further examples was determined by measuring the MIC for each against the following: (a) Pseudomonas aeruginosa (bacteria); (b) Escherichia coli (bacteria); (c) Staphylococcus aureus; (d) Candida albicans (yeast); and (d) Aspergillus niger (fungi). MIC is the lowest concentration (ppm) of active ingredient at which organism growth is inhibited. The standard dilution method was used.

As illustrated in Table 1 below, series examples CL20 through CL50 demonstrated the effect of AgAlP, AgIMI complexation, and ZnO inclusion on MIC performance, which is summarized as follows:

1. All examples of AgAlP are effective in inhibiting bacterial growth at less than about 4 ppm, and in several cases, below about 1 ppm;

2. The addition of ZnO to the composition significantly decreases the MIC required to control yeast and fungi;
3. The combination of AgIMI complex and ZnO further minimize fungal growth.

Series CL51 through CL57 were a test of the effect of copper (as Cu_2O) on the properties of the system. At the concentration levels tested, copper had no significant effect on the antimicrobial performance of the Ag-IMI-AlP-Zn system [CL47=CL57=CL54]. However, the inclusion of these levels of copper in the composition had a surprising and beneficial effect on the color stability of formulations containing the composition, as discussed below.

Table 1.

Summary of MIC Testing

		AP Complex Type	Comment	pH	report	MIC - ppm p. aerug	e. coli	s. aureus	yeast	fungi
CL20	gel	$AgNO_3$	Ag-AP control	2.5	#1		2	<1	63	16
			acidic							
CL21	gel	AgIMI (1:2)	Ag-IMI complex in AP	2.6	#1		<1	<1	125	63
			acidic							
CL22	gel	AgIMI (1:4)	Ag-IMI complex in AP	2.6	#1		<1	<1	125	63
CL47	pwdr	AgIMI (1:4) NH_3 ZnO	Ag-IMI complex and ZnO in AP	7.6	#1		2	2	7.8	125
			neutralized with NH_4		#2	0.78	3	0.78	12.5	100
CL48	slurry	AgIMI (1:4) ZnO	Ag-IMI complex and ZnO in AP	3.1	#1		3.8	2	7.8	16
			higher IMI level							
CL49	slurry	AgIMI (1:2) ZnO	Ag-IMI complex and ZnO in AP	2.9	#1		<1	<1	<1	7.8
					#2	0.39	1.5	0.39	12.5	50
CL50	slurry	$AgNO_3$ ZnO	Ag with ZnO in AP	2.6	#1		<1	<1	<1	16
					#2	0.78	3	0.78	12.5	25
CL51	pwd	AgIMI(1:4)-Ag:Cu (1:1)	Ag-IMI complex with Cu_2O in AP	6.7						
CL52	pwd	AgIMI(1:4)-Ag:Cu (1:1)	Ag-IMI complex with Cu_2O in AP	6.8	#2	12.5	12.5	12.5	100	100
			neutralized with NH_4							
CL53	pwd	$AgNO_3$ -AgCu(1:0.5)-AgZn(1:3)	AgAP complex with ZnO and Cu_2O	5.4	#2	50	100	100	50	100
			no IMI complex; not filtered							
CL54	pwd	$AgNO_3$ -AgCu(1:0.5)-AgZn(1:3)	AgAP complex with ZnO and Cu_2O	4.7	#2	25	50	25	25	100
			no IMI complex; filtered							
CL55	pwd	AgIMI(1:4)-AgCu(1:0.5)-AgZn(1:3)	AgIMI complex with ZnO and Cu_2O	6.3	#2					
			in AP;not filtered;not neutralized							
CL56	pwd	AgIMI(1:4)-AgCu(1:0.5)-AgZn(1:3)	AgIMI complex with ZnO and Cu_2O	6.6	#2	0.78	3.1	1.56	12.5	100
			in AP;not filtered;neutralized							
CL57	pwd	AgIMI(1:4)-AgCu(1:0.5)-AgZn(1:3)	AgIMI complex with ZnO and Cu_2O	6.7	#2	0.78	3.1	0.78	12.5	100
			in AP;filtered;not neutralized							

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Compositional Effects on Light Stability/Color Change – UV Stability Testing

Sample chemical compositions in the form of paints were prepared using latex as the binding polymer in an amount within the ranges presented above. The property of the Ag-AlP complexes incorporated in such paint formulation was tested at two levels, 100 ppm and 500 ppm of silver in the dry film.

Color Stability data are summarized in Table 2 presented below.

TABLE 2

COLOR STABILITY ΔE - QUV (B bulb) - 28 days exposure			
Sample	Composition	ΔE	ΔE
		100 ppm	500 ppm
CL42	AgIMI (no ZnO)	12.41	
CL47	AgIMI + ZnO	3.5	
CL50	AgAP + ZnO (no IMI)	5.4	
CL52	CL47 + Cu_2O (high)	1.91	5.43
CL53	CL50 + Cu_2O(low)	4.02	10.77
CL56	CL47 + Cu_2O (low) NF	2.26	10.11
CL57	CL47 + Cu_2O(low)F	2.52	
NF - not filtered; F - filtered			

The data presented in Table 2 shows color change (measured as ΔE using BYK Spectro-Guide Sphere Gloss Spectrophotometer) after exposure to UV light in a QUV chamber (UV B bulb) for 28 days. Color changes of less than about 2.0 are barely visible to the eye, while color changes of about 5.0 or less show very slight shading difference compared to the initial condition of the sample and would be considered acceptable in most applications.

Comparing CL42 and CL47, the positive effect of ZnO on color stability is clearly demonstrated. The color change is reduced from 12.41 to barely a perceptible 3.5.

The addition of cuprous oxide adds to this benefit, and is seen as a function of its concentration (i.e., the higher the level of cuprous oxide the better the effect). This trend is further illustrated for the results of CL51 (1.91), CL56 (2.26), and CL57 (2.52).

Generally, the presence of ZnO in the Ag-AlP complex is shown to provide further enhanced light stabilization. IMI-Ag complexation contributes a secondary/complementary light stabilization effect. While the inclusion of cuprous oxide contributes still further to light stabilization.

Antimicrobial chemical compositions disclosed herein may be provided in the form of a coating composition for applying to a desired substrate surface to provide a desired level of antimicrobial resistance. Such antimicrobial coating compositions can be formulated for use as a primer, a mid coat, or a top coat. Additionally such antimicrobial coating compositions may be used with or without a primer, as a mid or a top coat. Further, antimicrobial chemical compositions as disclosed herein may be formulated as a clear coating for placement over an existing substrate surface or underlying coating that may or may not be colored, thereby facilitating use of such clear coating over a variety of substrates or underlying coating surface to provide antimicrobial resistance without the need for special pigmenting to match existing substrate colors or the like.

Bioactive-AlP complexes as described herein provide bioactive components in a manner that ensures surface antimicrobial efficacy while permitting ease of formulation to meet a variety of end-use applications. The bioactive-AlP complex provides for uniform distribution of the bioactive ingredient, e.g., silver ion, throughout the chemical composition, dried film, composite, or formulated article. The bioactive-AlP complex provides the formulated bulk matrix with properties engineered to accommodate moisture induced transport: absorption, adsorption, desorption, diffusion of water and dissolved species in bulk. The bioactive-AlP complex is specifically engineered to release one or more bioactive constituent, e.g., silver ion, based on the concentration of the bioactive material incorporated and by the hydrophilicity and morphology of the complex (surface area and porosity). The bioactive-AlP complex as described herein can be introduced into formulated products such as pigments, or as an additive through bonding the phosphate functionality to certain functional groups of the binder matrix of

the bulk composite or film. Additionally, the bioactive-AlP complexes in thermally stable form can be incorporated into powder coating formulations to render such surfaces antimicrobial.

In one example embodiment, antimicrobial chemical compositions as described herein can be formulated into a film in which the bulk of the article serves as a reservoir or depot for the bioactive material or its constituent, e.g., silver ion. Such formulation can be engineered to optimize the following aspects of the antimicrobial mechanism: water diffusion into the film, water absorption and adsorption into the bioactive-AlP complex, salt dissolution within the complex, ion transport out of the complex, and bioactive material or its constituent transport through the matrix to the surface to be protected.

Alternatively, antimicrobial chemical compositions as described herein can be formulated into an enriched thin film (e.g., having a film thickness of less than about 25μ, and preferably less than about 10μ) engineered for physical durability balanced with water diffusion/bioactive material or its constituent transport properties to impart antimicrobial properties to a surface without incorporating the antimicrobial into the bulk of the article, e.g., where such incorporation may not be practical from a cost standpoint, or where the operative control mechanism may not be possible, e.g., a water impermeable plastic.

As described above, the combined AlP and bioactive material is provided in the form of a bioactive-AlP complex, where the bioactive material is either chemically bonded with, e.g., provided in the backbone of the AlP polymer, or is physically incorporated, enmeshed, encapsulated, or intertwined with the AlP polymer, depending on the particular method used to make the complex. Additionally, the bioactive material or its constituent may be present in the AlP polymer both chemically and physically. For example, when the bioactive-AlP complex is formed by combining the desired bioactive material at the time of forming the AlP, thereby facilitating chemical bonding between the bioactive material or its constituent with the AlP, a stoichiometric excess of the additional bioactive material may result in it being physically incorporated into the AlP molecule, in which case the resulting bioactive-AlP complex would include the

bioactive material or its constituent present in both chemically-bonded and physically-incorporated form.

As demonstrated above, embodiments of the invention provide a novel antimicrobial chemical compositions, novel bioactive-AlP complexes, and novel methods for making the same. While each has been described with respect to a limited number of embodiments, the specific features of one embodiment should not be attributed to other embodiments of the invention. No single embodiment is representative of all aspects of the invention. In some embodiments, the compositions or methods may include numerous compounds or steps not mentioned herein.

For example, if desired, antimicrobial chemical compositions can be prepared to additionally include one or more bioactive materials separately or in combination other than those specifically described that are known to have bioactive value. Any such additional bioactive material may or may not be incorporated with the bioactive-AlP complex, e.g., can exist as a separate dispersion with the binding polymer, and can operate to increase or complement or provide a synergistic antimicrobial effect of the chemical composition.

Additionally, while antimicrobial chemical compositions as presented in the examples provided herein have been described as comprising AlP in amorphous form, it is to be understood that antimicrobial chemical compositions as described herein can additionally comprise AlP in its known crystalline forms, and can comprise AlP in a combination of amorphous and crystalline forms.

In other embodiments, the compositions or methods do not include, or are substantially free of, any compounds or steps not enumerated herein. Variations and modifications from the described embodiments exist. The method of making the chemical compositions and/or AlP is described as comprising a number of acts or steps. These steps or acts may be practiced in any sequence or order unless otherwise indicated. Finally, any number disclosed herein should be construed to mean approximate, regardless of whether the word "about" or "approximately" is used in describing the number. The appended claims intend to cover all those modifications and variations as falling within the scope of the invention.

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CLAIMS

1. An antimicrobial chemical composition comprising;

a complex comprising a bioactive constituent that is a metal ion, wherein the complex releases the bioactive constituent at a rate upon contact of the complex with moisture; and

a binder polymer forming a bulk matrix of the composition, wherein the complex is disposed within bulk matrix, and wherein the bulk matrix enables the bioactive constituent that is released from the complex to diffuse therethrough at a rate;

wherein the rate of release of the bioactive constituent from the complex is the same or different from the rate of diffusion of the bioactive constituent through the bulk matrix,

wherein the complex comprises amorphous aluminum phosphate, wherein the complex has a porosity, and wherein the rate of release of the bioactive constituent is a function of the porosity.

2. The chemical composition as recited in claim 1 wherein the aluminum phosphate essentially consists of amorphous aluminum phosphate, or wherein the aluminum phosphate is a combination of amorphous and crystalline aluminum phosphate.

3. The chemical composition as recited in claim 1 wherein the rate of release of the bioactive constituent is different from the rate of diffusion of the bioactive constituent.

4. The chemical composition as recited in claim 1 wherein the bioactive constituent is present in a bioactive material comprising a complexed silver material.

5. The chemical composition as recited in claim 4 wherein the complexed silver material comprises a complexing agent selected from the group consisting of ligands.

6. The chemical composition as recited in claim 5 wherein the ligands are selected from the group consisting of imidazole, substituted imidazole, ammonia, and combinations thereof.

7. The chemical composition as recited in claim 6 wherein the wherein the silver material comprises a silver salt and the ligand is imidazole.

8. The chemical composition as recited in claim 4 wherein the bioactive material further comprises a metal oxide.

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9. The chemical composition as recited in claim 8 wherein the metal oxide is selected from the group of oxides that include metals consisting of copper, zinc, and combinations thereof.

10. An antimicrobial chemical composition comprising:

a binding polymer; and

a bioactive-aluminum phosphate complex dispersed within the binding polymer, the complex comprising an aluminum phosphate polymer and a bioactive material comprising a bioactive constituent that is a metal ion;

wherein the aluminum phosphate complex has an engineered porosity that, when the composition is cured, provides a controlled delivery of the bioactive constituent when exposed to moisture,

wherein the aluminum phosphate polymer comprises amorphous aluminum phosphate.

11. The chemical composition as recited in claim 10 wherein the aluminum phosphate polymer essentially consists of amorphous aluminum phosphate, or wherein the aluminum phosphate polymer is a combination of amorphous and crystalline aluminum phosphate.

12. The chemical composition as recited in claim 10 wherein the controlled delivery of the bioactive constituent is in the range of from 15 to 800 ppm, or wherein the controlled delivery of the bioactive constituent is at least 30 $\mu g/m^2$.

13. The chemical composition as recited in claim 10 wherein the amount of the bioactive material present in the complex is in the range of from 1 to 10 percent of the total weight of the complex.

14. The chemical composition as recited in claim 10 wherein the ratio of phosphate to aluminum is in the range of from 0.5:1 to 1.5:1.

15. The chemical composition as recited in claim 10 wherein the bioactive material is physically interspersed in the aluminum phosphate polymer.

16. The chemical composition as recited in claim 10 wherein the bioactive material:

a) is a metal salt selected from the group consisting of metal ions of silver, calcium, copper, zinc, silver salts, copper salts, zinc salts, calcium salts, and combinations thereof; or

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b) is selected from the group consisting of silver ion, silver salts, and silver compounds capable of releasing silver ion when contacted by water, and combinations thereof.

17. The chemical composition as recited in claim 10 wherein the bioactive material is chemically bonded with the aluminum phosphate polymer.

18. The chemical composition as recited in claim 17 wherein the bioactive material is incorporated into the backbone of the aluminum phosphate polymer.

19. The chemical composition as recited in claim 10 wherein the complex has a surface area:
a) greater than 100 m^2/g; or
b) less than 100 m^2/g; or
c) less than 20 m^2/g.

20. The chemical composition as recited in claim 10 wherein the controlled delivery of the bioactive constituent is different than a diffusion rate of the bioactive constituent through the binder polymer.

21. The chemical composition as recited in claim 10 comprising from 0.01 to 1 weight percent of the bioactive material based on the total weight of the chemical composition.

22. The chemical composition as recited in claim 10 comprising from 0.05 to 5 weight percent of the complex based on the total weight of the chemical composition.

23. The chemical composition as recited in claim 22 comprising from 0.1 to 2 weight percent of the complex based on the total weight of the chemical composition.

24. The chemical composition as recited in claim 10 wherein the binding polymer is selected from the group consisting of polyurethanes, polyesters, solvent-based epoxies, solventless epoxies, water-borne epoxies, epoxy copolymers, acrylics, acrylic copolymers, silicones, silicone copolymers, polysiloxanes, polysiloxane copolymers, alkyds and combinations thereof.

25. The chemical composition as recited in claim 10 wherein the bioactive-aluminum phosphate complex has:
a) a water adsorption potential of up to 25 percent by weight water; or

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b) a controlled delivery of phosphate anion of less than 1,500 ppm upon exposure to moisture.

26. The chemical composition as recited in claim 10 wherein the bioactive aluminum phosphate complex has a controlled delivery of phosphate anion of between 100 to 500 ppm.

27. The chemical composition as recited in claim 10 wherein the bioactive material comprises a metal salt, and wherein the metal salt is combined with a material selected from the group consisting of ligands, metal oxides, and combinations thereof.

28. The chemical composition as recited in claim 27 wherein the metal salt is silver nitrate and the ligand is selected from the group consisting of ammonia, imidazole, substituted imidazole, and combinations thereof.

29. The chemical composition as recited in claim 28 wherein the wherein the metal salt is combined with a metal oxide.

30. A system for providing antimicrobial protection comprising a coating composition applied to substrate and cured to form a film, the coating composition comprising a binding polymer with a bioactive-aluminum phosphate complex dispersed therein, wherein the complex comprises an amorphous aluminum phosphate combined with a bioactive material, and wherein the complex is engineered to provide a controlled delivery of a bioactive constituent that is a metal ion when exposed to moisture.

31. The system as recited in claim 30 wherein the bioactive material is combined with a further material selected from the group consisting of ligands, metal oxides, and combinations thereof.

32. The system as recited in claim 30 wherein the bioactive material is a soluble silver salt and is complexed with a ligand.

33. The system as recited in claim 32 wherein the ligand is selected from the group consisting of ammonia, imidazole, substituted imidazole, and combinations thereof.

34. The system as recited in claim 32 wherein the bioactive material is combined with a metal oxide.

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35. The system as recited in claim 34 wherein the metal oxide is selected from the group including oxides of metals consisting of copper, zinc, and combinations thereof.

36. The system as recited in claim 30 wherein the controlled delivery from the complex occurs at a release rate, and wherein the binding polymer has a diffusion rate for the bioactive constituent released from the complex, and wherein the release rate is different from the diffusion rate.

37. The system as recited in claim 30 wherein the controlled delivery of the bioactive constituent is from 5 to 1,000 ppm.

38. The system as recited in claim 37 wherein the controlled delivery of the bioactive constituent is from 10 to 900 ppm.

39. The system as recited in claim 30 wherein the bioactive material is a metal ion selected from the group consisting of silver, copper, zinc, calcium, and combinations thereof.

40. The system as recited in claim 39 wherein the metal ion is incorporated in the backbone of the aluminum phosphate.

41. The system as recited in claim 39 wherein the metal ion is chemically bonded in the aluminum phosphate complex.

42. The system as recited in claim 30 wherein the bioactive material is a metal salt selected from the group consisting of silver salts, copper salts, zinc salts, calcium salts, and combinations thereof.

43. The system as recited in claim 42 wherein the metal salt is incorporated with the aluminum phosphate.

44. The system as recited in claim 30 comprising a controlled release rate of phosphate anion of from 100 and 1,500 ppm upon exposure to moisture.

45. The system as recited in claim 30 wherein the binding polymer is selected from the group consisting of polyurethanes, polyesters, solvent-based epoxies, solventless epoxies, water-borne

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epoxies, epoxy copolymers, acrylics, acrylic copolymers, silicones, silicone copolymers, polysiloxanes, polysiloxane copolymers, alkyds and combinations thereof.

46. A method for making an antimicrobial chemical composition, wherein the composition when cured provides a controlled delivery of a bioactive constituent derived from the bioactive material upon exposure to moisture, the method comprising adding a polymer binding material to a bioactive-aluminum phosphate complex prepared according to a method for making a bioactive-aluminum phosphate complex comprising the steps of:

forming an amorphous aluminum phosphate by combining an aluminum source, with a phosphate source in an aqueous solution at suitable pH to form a dispersion of aluminum phosphate; and

adding a bioactive material during or after the step of forming so that the bioactive material is combined with the aluminum phosphate to form the bioactive-aluminum phosphate complex, the complex being capable of releasing a bioactive constituent that is a metal ion,

wherein during the step of forming, the dispersion comprises amorphous aluminum phosphate.

47. A method for making an antimicrobial chemical composition comprising a bioactive material dispersed within an aluminum phosphate, the method comprising the steps of:

forming an aluminum phosphate by combining an aluminum source, with a phosphate source in an aqueous solution at suitable pH to form a dispersion of aluminum phosphate;

adding a bioactive material during or after the step of forming so that the bioactive material is disposed in the aluminum phosphate forming a bioactive-aluminum phosphate complex; and

combining a polymer binding material with the bioactive-aluminum phosphate complex to form the antimicrobial chemical composition;

wherein the composition when cured provides a controlled delivery of a bioactive constituent that is a metal ion derived from the bioactive material upon exposure to moisture of from 10 to 900 ppm,

wherein during the step of forming, the dispersion comprises amorphous aluminum phosphate.

48. A method for making an antimicrobial chemical composition comprising a bioactive material combined with an aluminum phosphate, the method comprising the steps of:

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forming an aluminum phosphate by combining an aluminum source, with a phosphate source in an aqueous solution at suitable pH to form a dispersion of aluminum phosphate;

adding a bioactive material to the amorphous aluminum phosphate after the step of forming to provide a complex wherein the bioactive material is physically incorporated in the aluminum phosphate to form a bioactive-aluminum phosphate complex; and

combining a polymer binding material with the complex to form the antimicrobial chemical composition;

wherein the composition when cured provides a controlled delivery of a bioactive constituent that is a metal ion derived from the bioactive material of 100 ppm or greater upon exposure to moisture,

wherein during the step of forming, the dispersion comprises amorphous aluminum phosphate.

49. A method for making an antimicrobial chemical composition comprising a bioactive material combined with aluminum phosphate, the method comprising the steps of:

combining aluminum hydroxide and phosphoric acid to form a solution comprising an acidic aluminum phosphate condensate;

combining a bioactive material during or after the step of forming the acidic aluminum phosphate condensate to form mixture comprising a bioactive-aluminum phosphate complex comprising the bioactive material that is a metal ion; and

and further comprising the step of adding a neutralizing agent to the acidic aluminum phosphate complex to increase its pH; and

combining a polymer binding material with the complex to form the chemical composition, wherein the complex comprises amorphous aluminum phosphate.

50. A method for making an antimicrobial chemical composition comprising a bioactive material combined with aluminum phosphate, wherein the bioactive material comprises a metal salt, the method comprising the steps of:

combining a bioactive material with aluminum hydroxide to form a mixture, and wherein before the step of combining, a complex is formed by combining the metal salt with a ligand;

adding the mixture to phosphoric acid to form a bioactive-aluminum phosphate complex comprising the bioactive material; and

combining a polymer binding material with the complex to form the chemical composition, wherein the complex comprises amorphous aluminum phosphate.

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51. An antimicrobial chemical complex comprising a bioactive constituent in the form of metal ions chemically bonded with and incorporated into a polymer backbone of an amorphous aluminum phosphate, the complex having an engineered porosity to provide a controlled release of the metal ions therefrom of from about 10 to 1,000 ppm upon contact of the complex with moisture, wherein the porosity is characterized by at least one of:

a total intrusion volume of 0.5 to 2 mL/g;

an average pore diameter of from about 0.02 to 0.6 μm; or

a BET surface area from about 2 to 250 m^2/g.

52. A bioactive-aluminum phosphate complex comprising amorphous aluminum phosphate and a bioactive material including a complexed metal material, wherein the complexed metal material comprises silver ions combined with a ligand, wherein the complexed metal material is chemically bonded with and incorporated into a polymer backbone of the amorphous aluminum phosphate.

53. A bioactive-aluminum phosphate complex as recited in claim 52 wherein the ligand is selected from the group consisting of imidazole, substituted imidazole, ammonia, and combinations thereof.

54. The bioactive-aluminum phosphate complex as recited in claim 52, wherein the complex has an engineered porosity to provide a controlled release of the metal ions therefrom of from about 10 to 1,000 ppm upon contact of the complex with moisture, wherein the porosity is characterized by at least one of:

a total intrusion volume of 0.5 to 2 mL/g;

an average pore diameter of from about 0.02 to 0.6 μm; and

a BET surface area from about 2 to 250 m2/g.

55. The bioactive-aluminum phosphate complex as recited in claim 52 further comprising a metal oxide.

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56. The bioactive-aluminum phosphate complex as recited in claim 55 wherein the metal oxide is selected from the group of oxides that include metals consisting of copper, zinc, and combinations thereof.

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