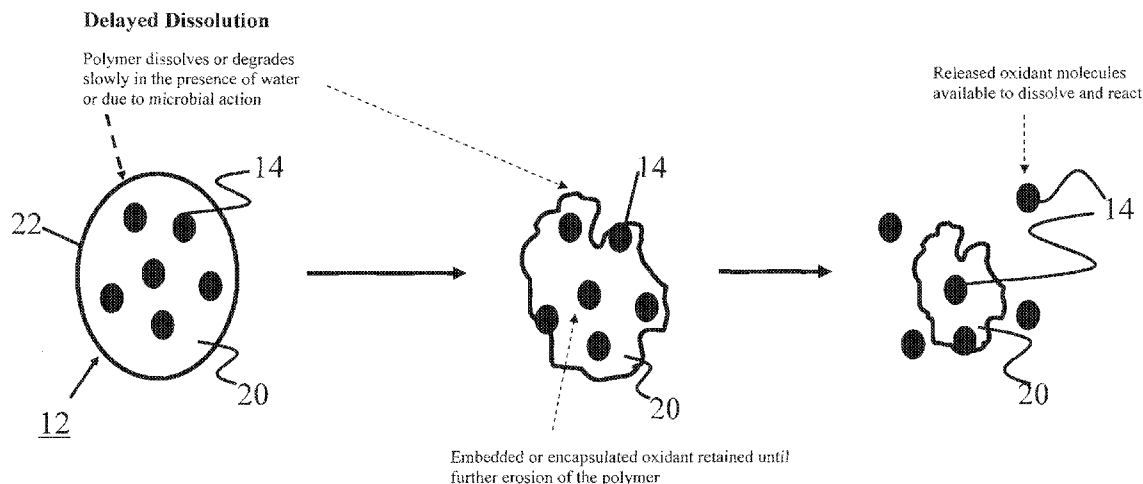




US 20090105371A1

(19) **United States**(12) **Patent Application Publication**
Luster-Teasley(10) **Pub. No.: US 2009/0105371 A1**(43) **Pub. Date: Apr. 23, 2009**(54) **CONTROLLED RELEASE REMEDIATION
SYSTEM AND COMPOSITION**(52) **U.S. Cl. 523/124**(76) **Inventor: Stephanie Luster-Teasley,**
Greensboro, NC (US)**Correspondence Address:**
SMITH MOORE LEATHERWOOD LLP
P.O. BOX 21927
GREENSBORO, NC 27420 (US)(21) **Appl. No.: 11/873,961**(22) **Filed: Oct. 17, 2007****Publication Classification**(51) **Int. Cl.**
C08J 3/20 (2006.01)(57) **ABSTRACT**

A controlled release remediation composition or compositions, a method making such composition(s), a method of using such composition(s), and a remediation system including such composition(s) are disclosed. The disclosed controlled release remediation composition or compositions include at least one chemical oxidant agent, optionally, at least two chemical oxidant agents; at least one encapsulant polymer; and, optionally, at least one matrix polymer. The disclosed controlled release remediation composition or compositions are capable of substantially constantly releasing an amount of the at least one chemical oxidant agent, optionally, amounts of the at least two chemical oxidant agents, for example, into an aqueous system such as may be found at a contaminated site, over at least about a one month period up to over about a three month period.



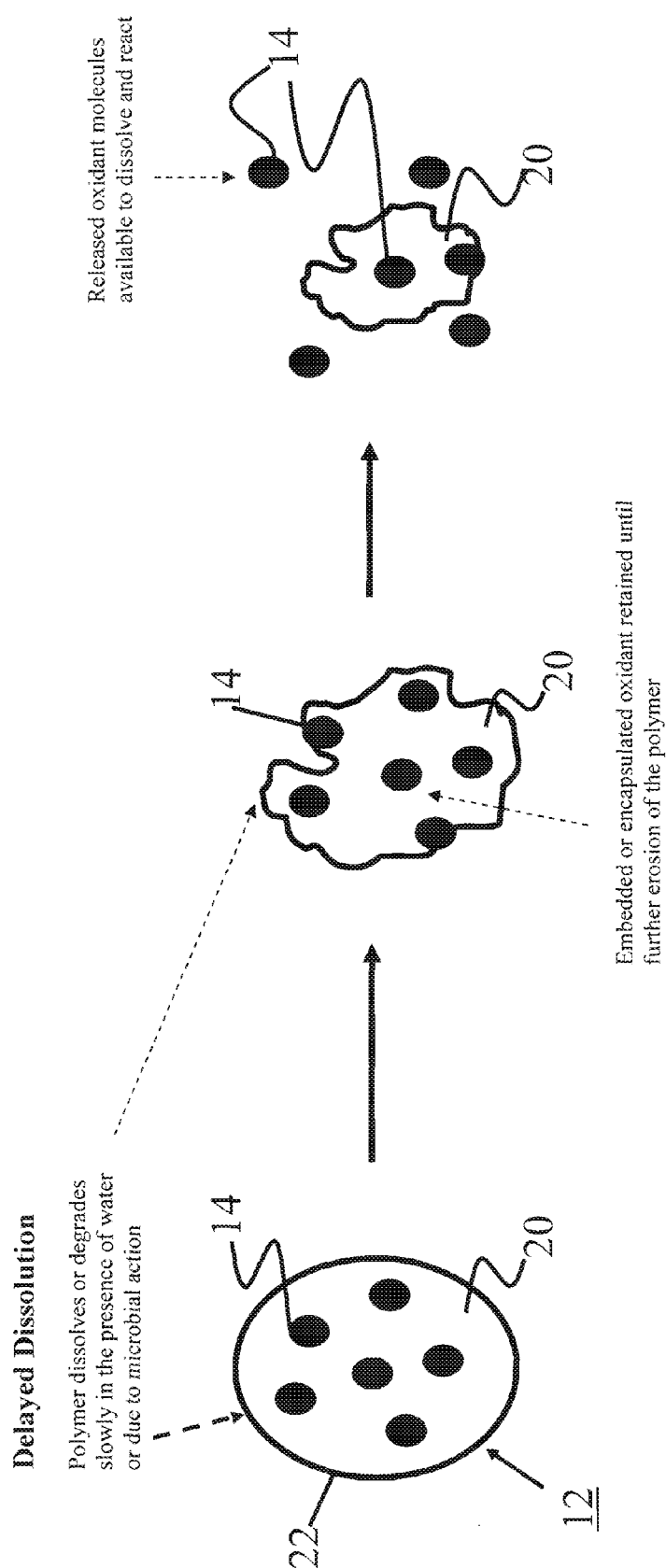
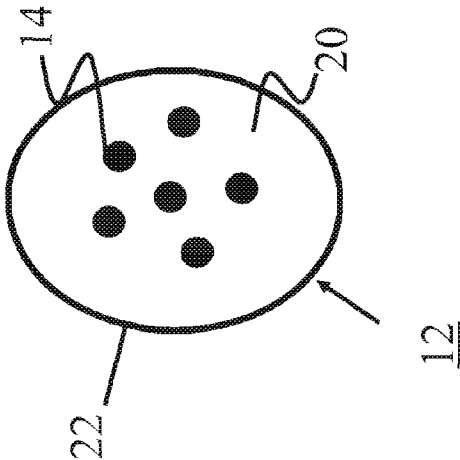


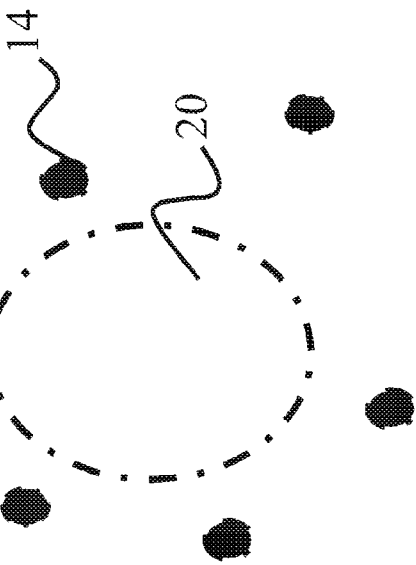
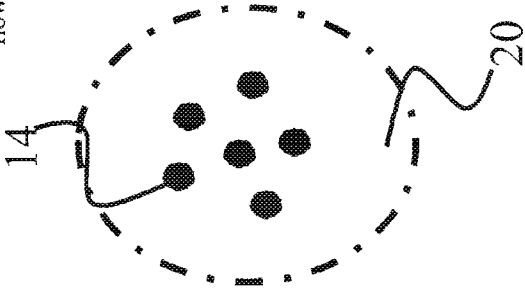
FIG. 1

Diffusion Controlled

Moderately soluble polymer shell with small pore openings created by water flow or microbes (degradation) OR semi-permeable membrane



Oxidant molecules diffuse with water flow into the environment to react



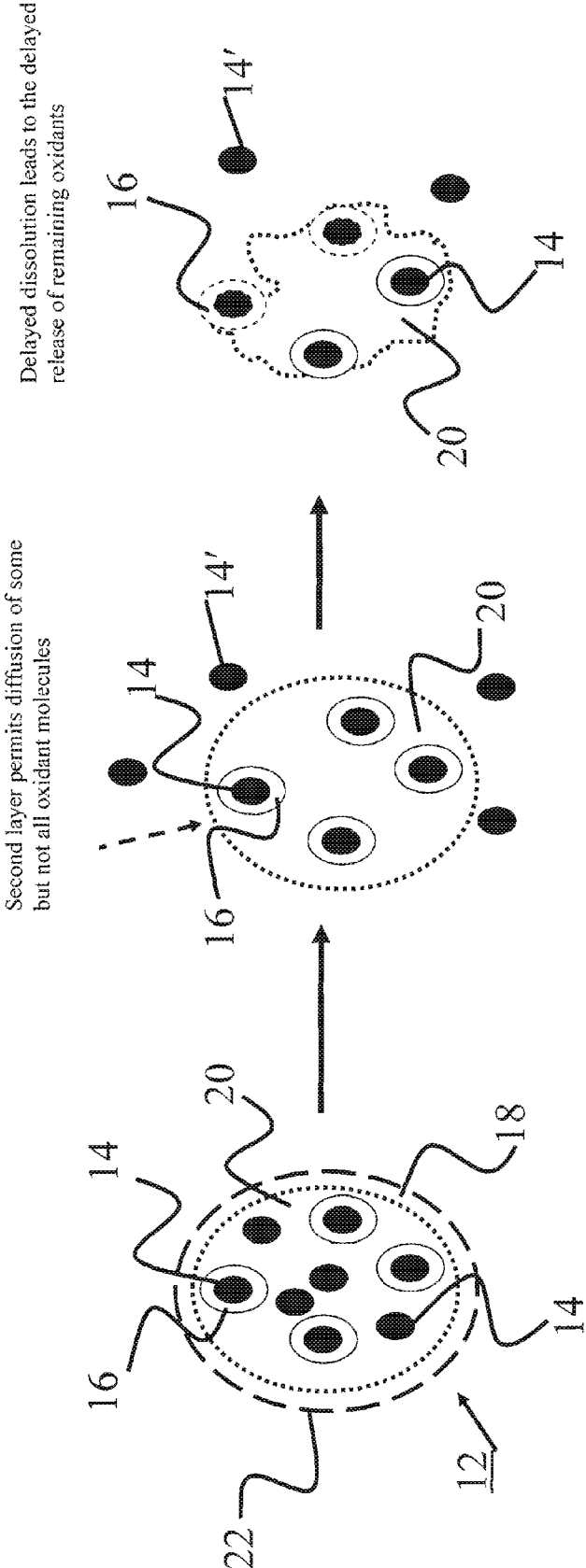
Oxidant treatment released and polymer shell naturally degrades over time

FIG. 2

Combined Control

A layering of delayed dissolution and diffusion controlled mechanisms. Polymer dissolves or degrades slowly in the presence of water or due to microbial action

FIG. 3



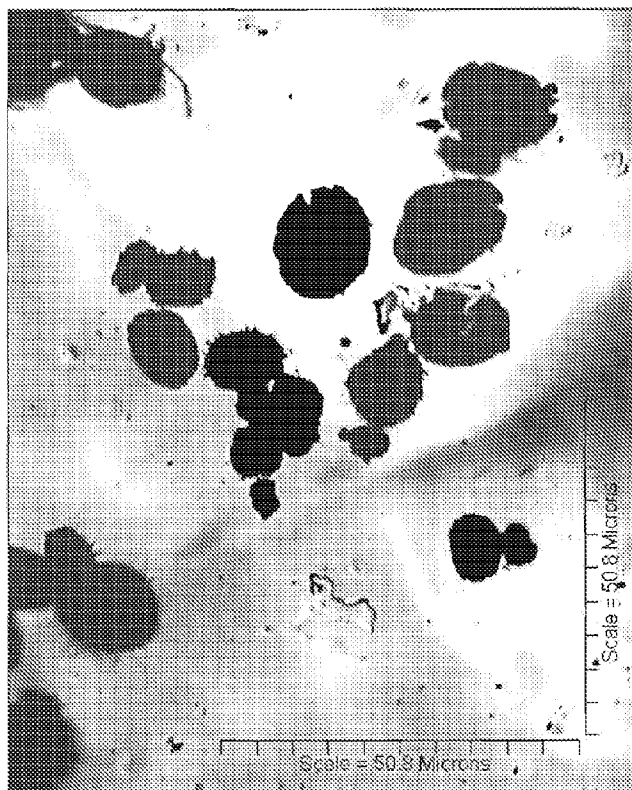


FIG. 4b

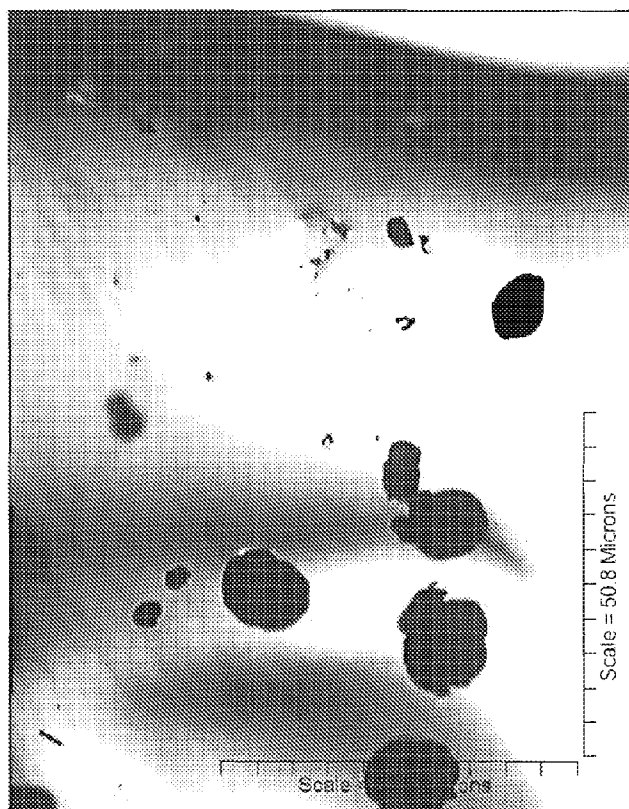


FIG. 4a

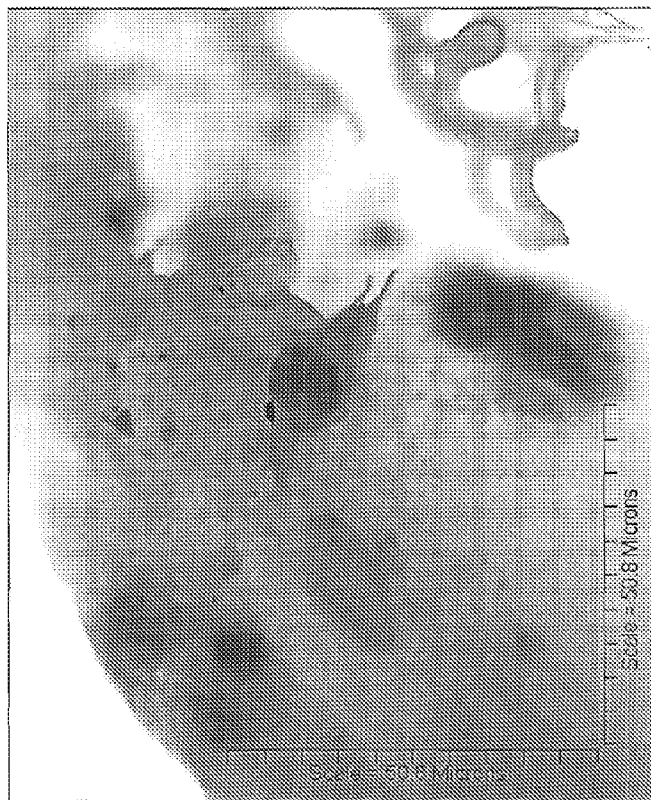


FIG. 5b

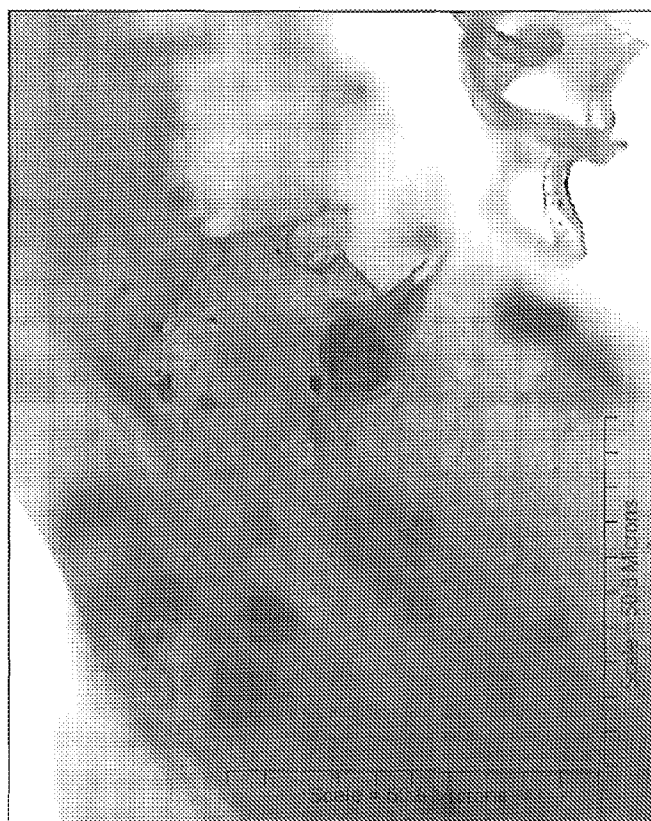
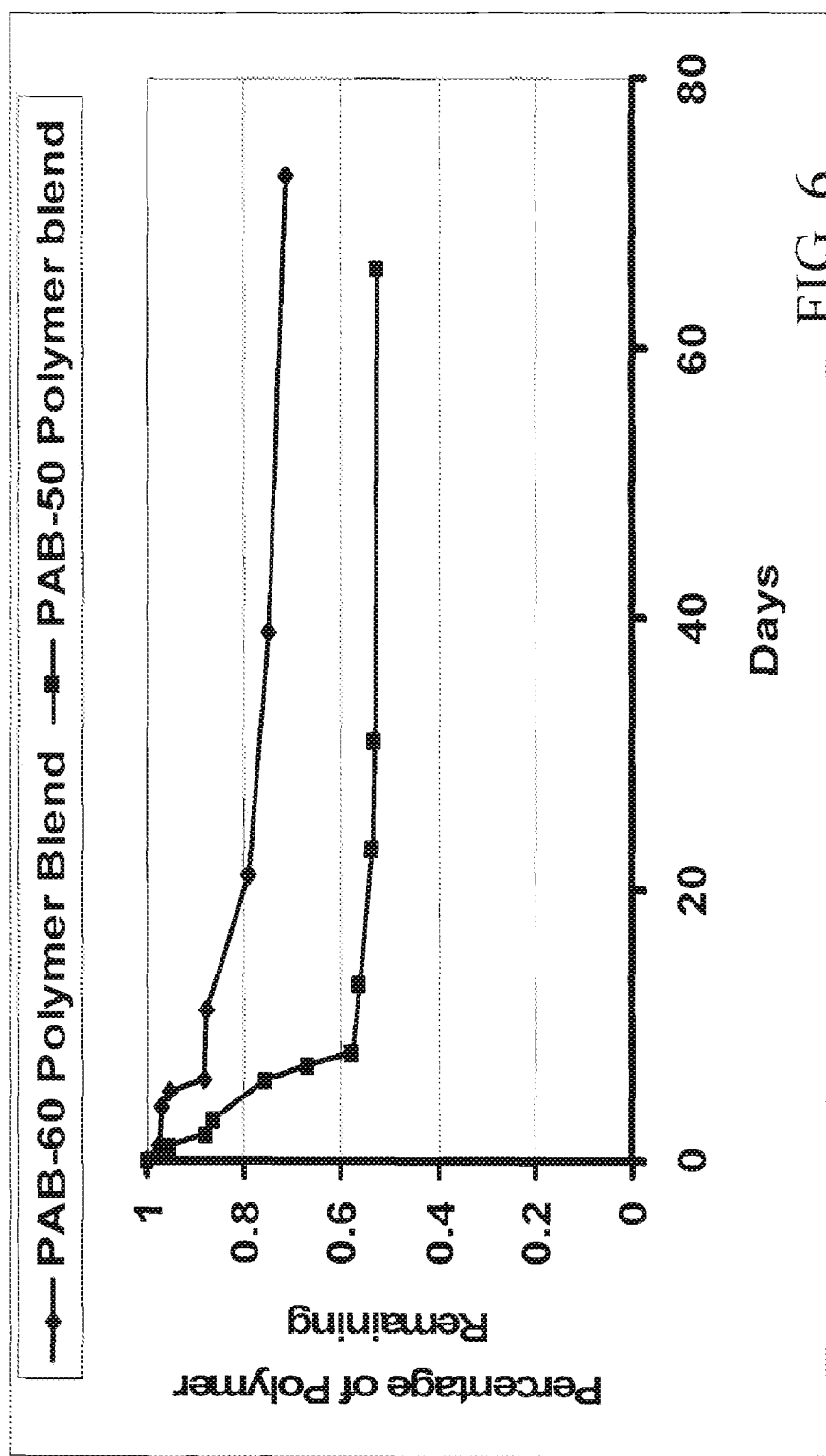
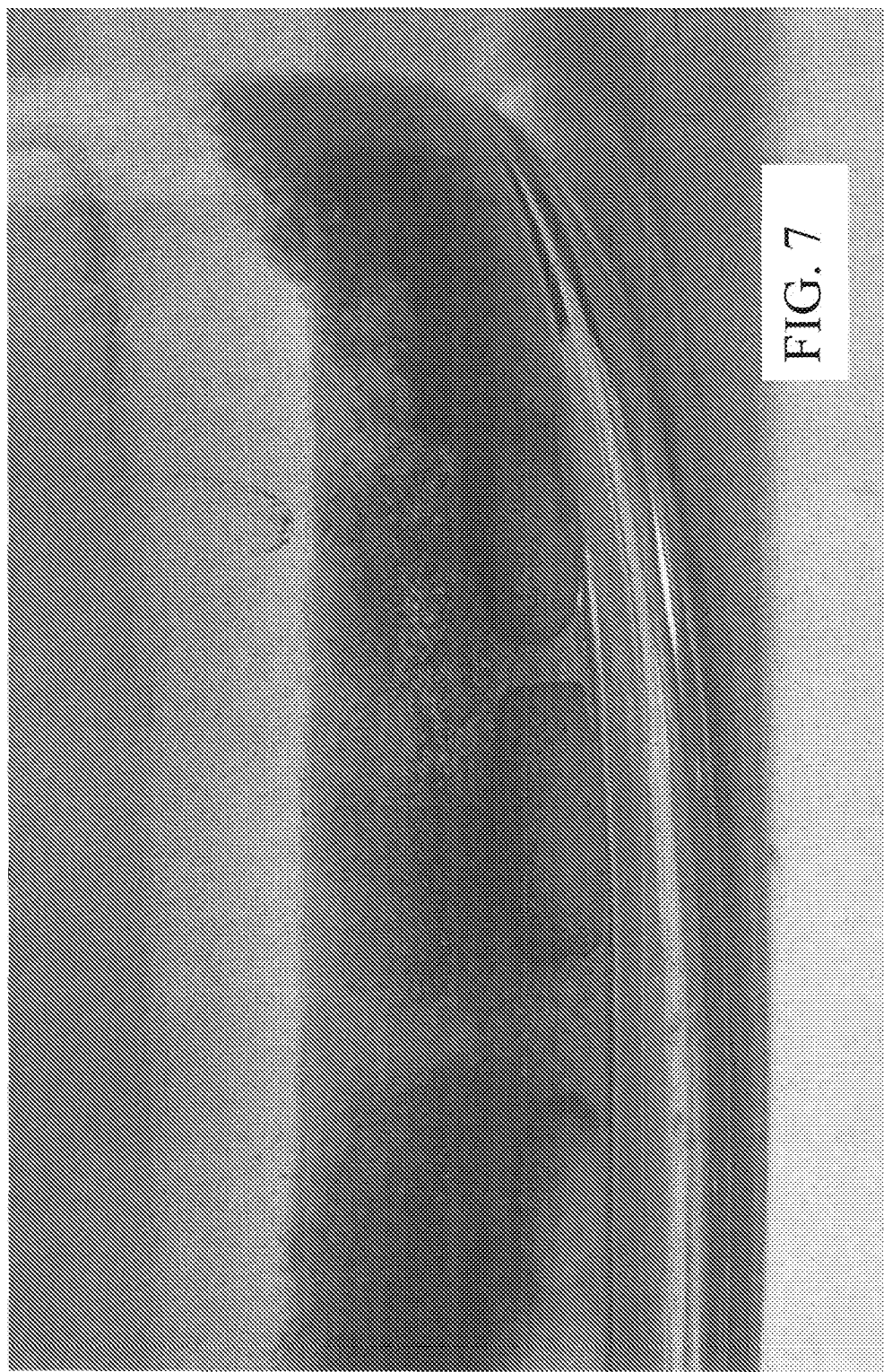


FIG. 5a





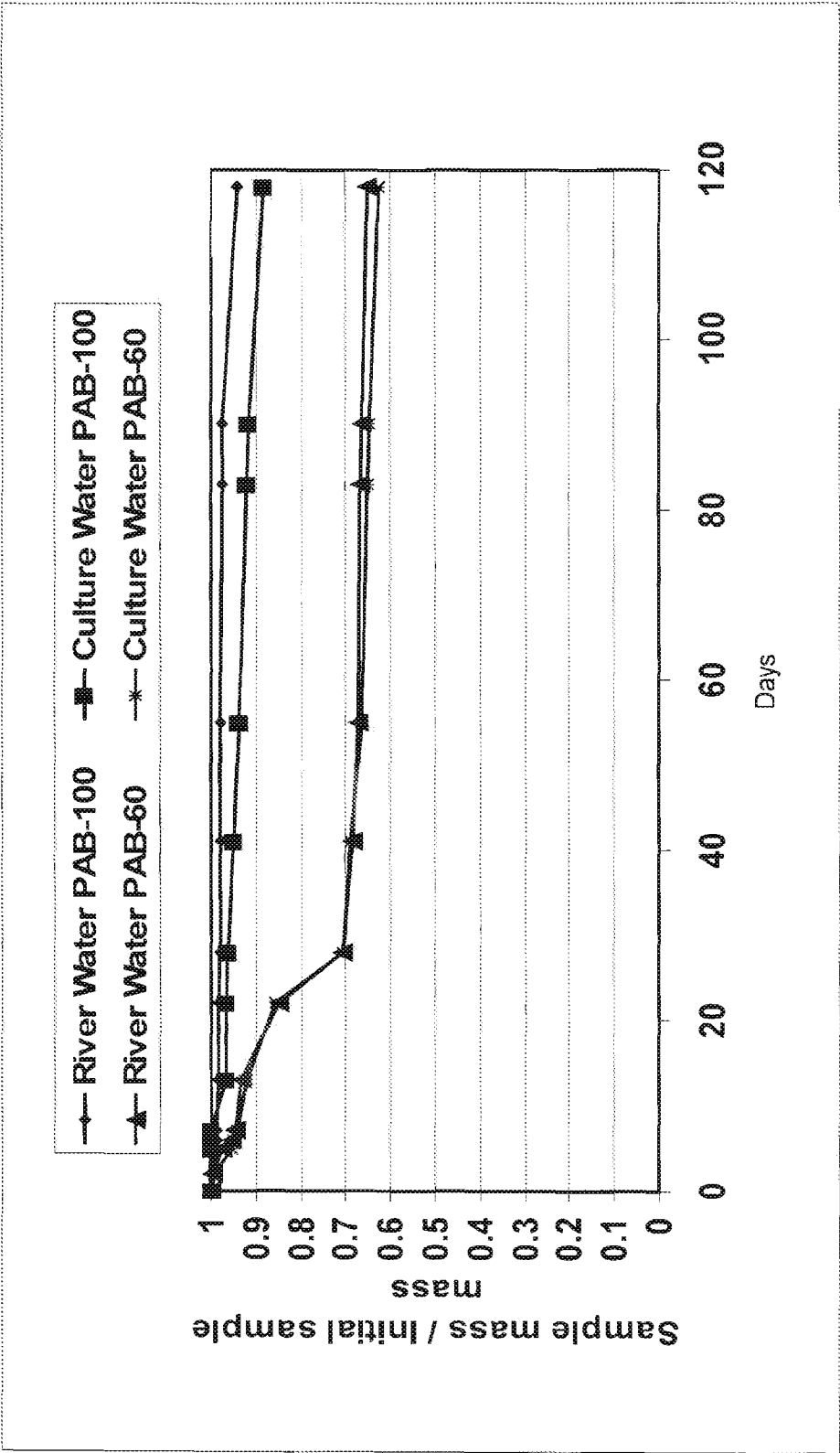


FIG. 8

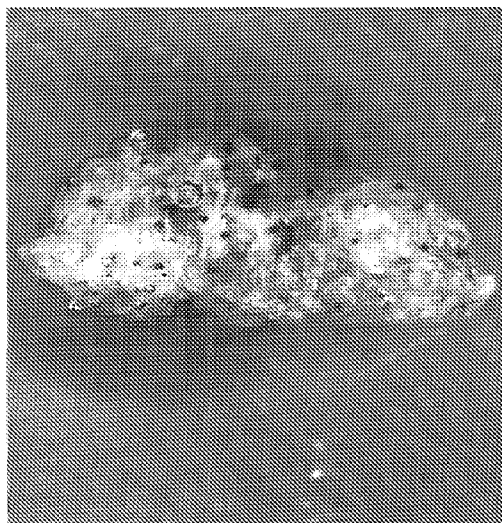


FIG. 9c

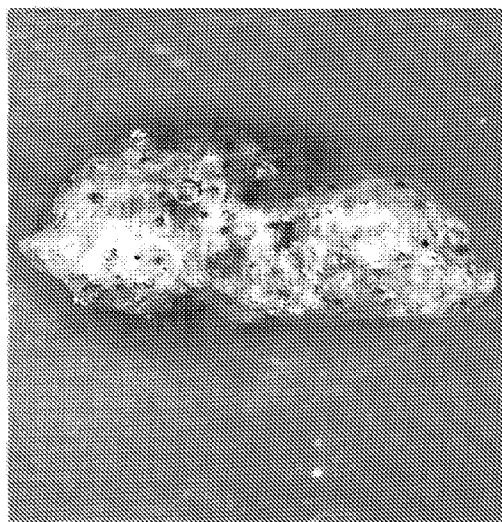


FIG. 9b

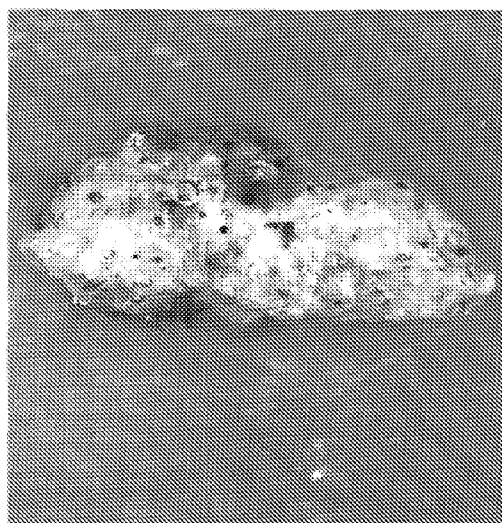


FIG. 9a

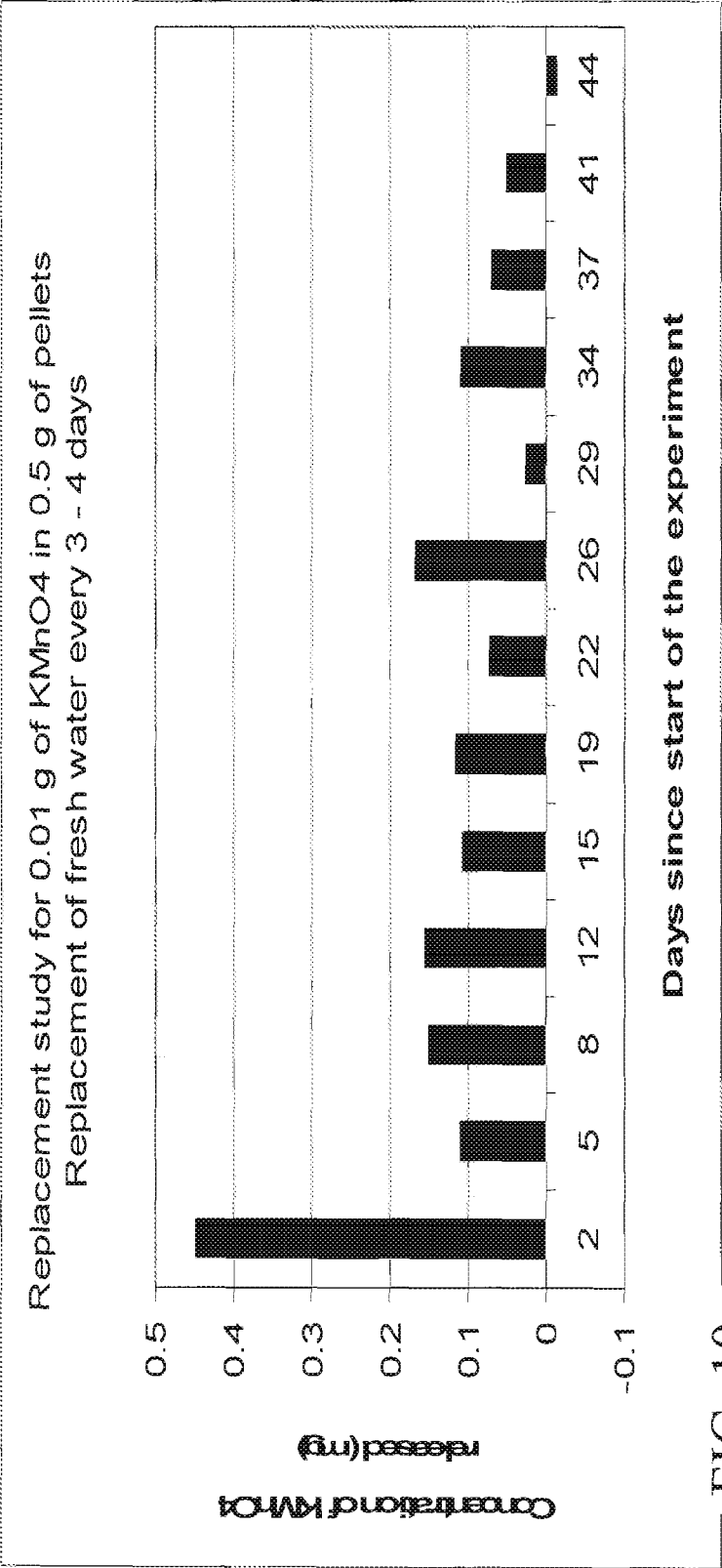


FIG. 10

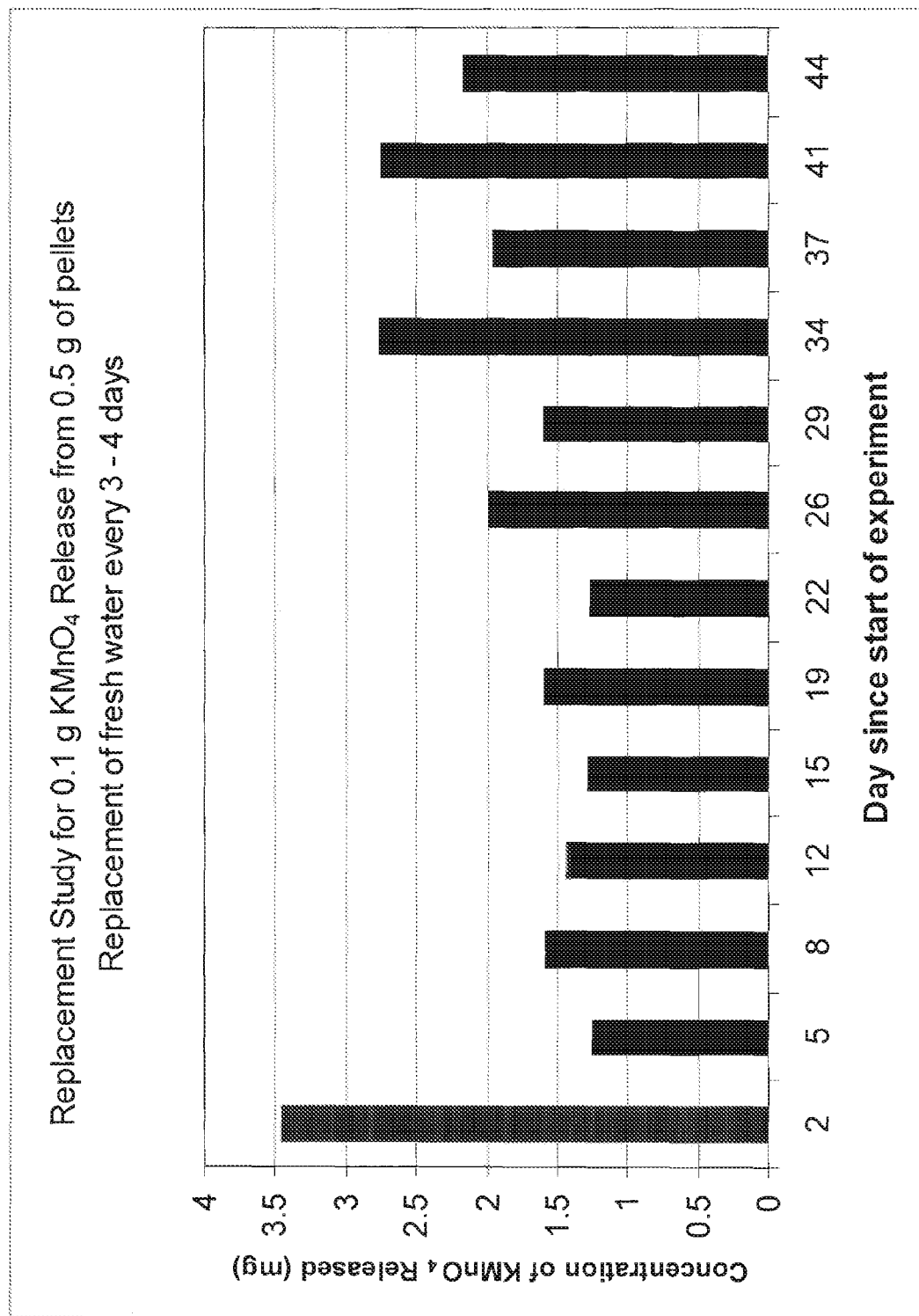


FIG. 11

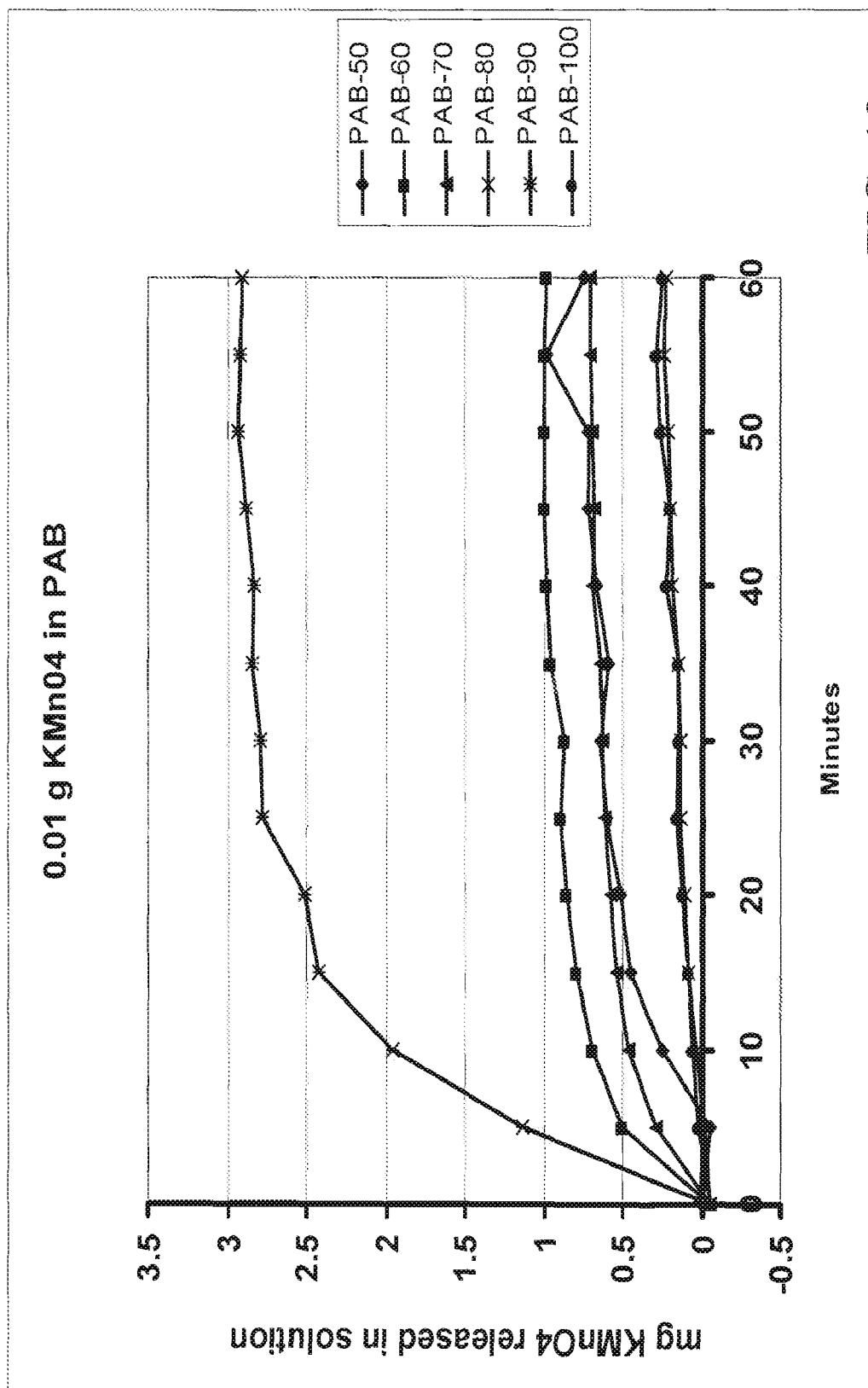


FIG. 12

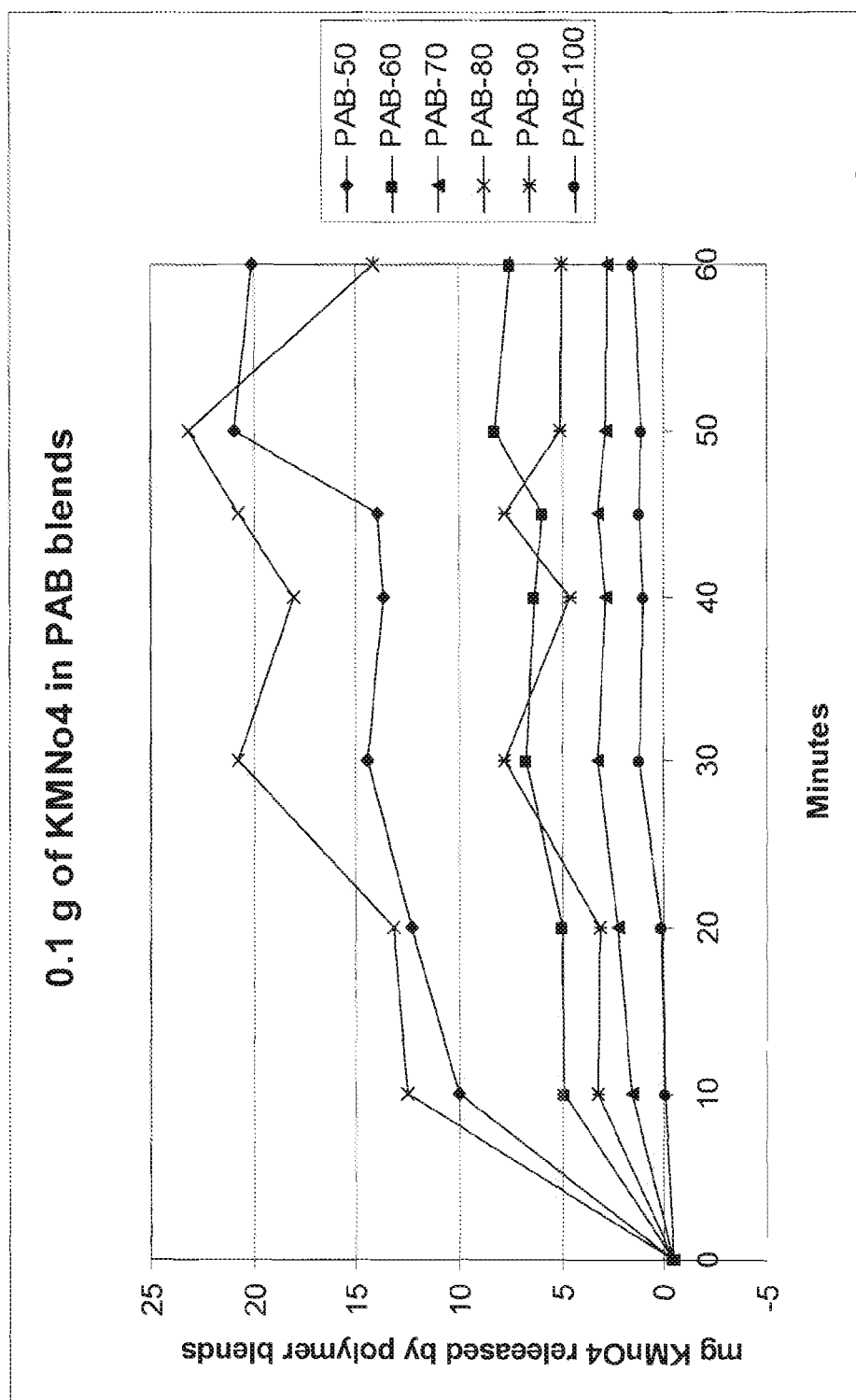


FIG. 13

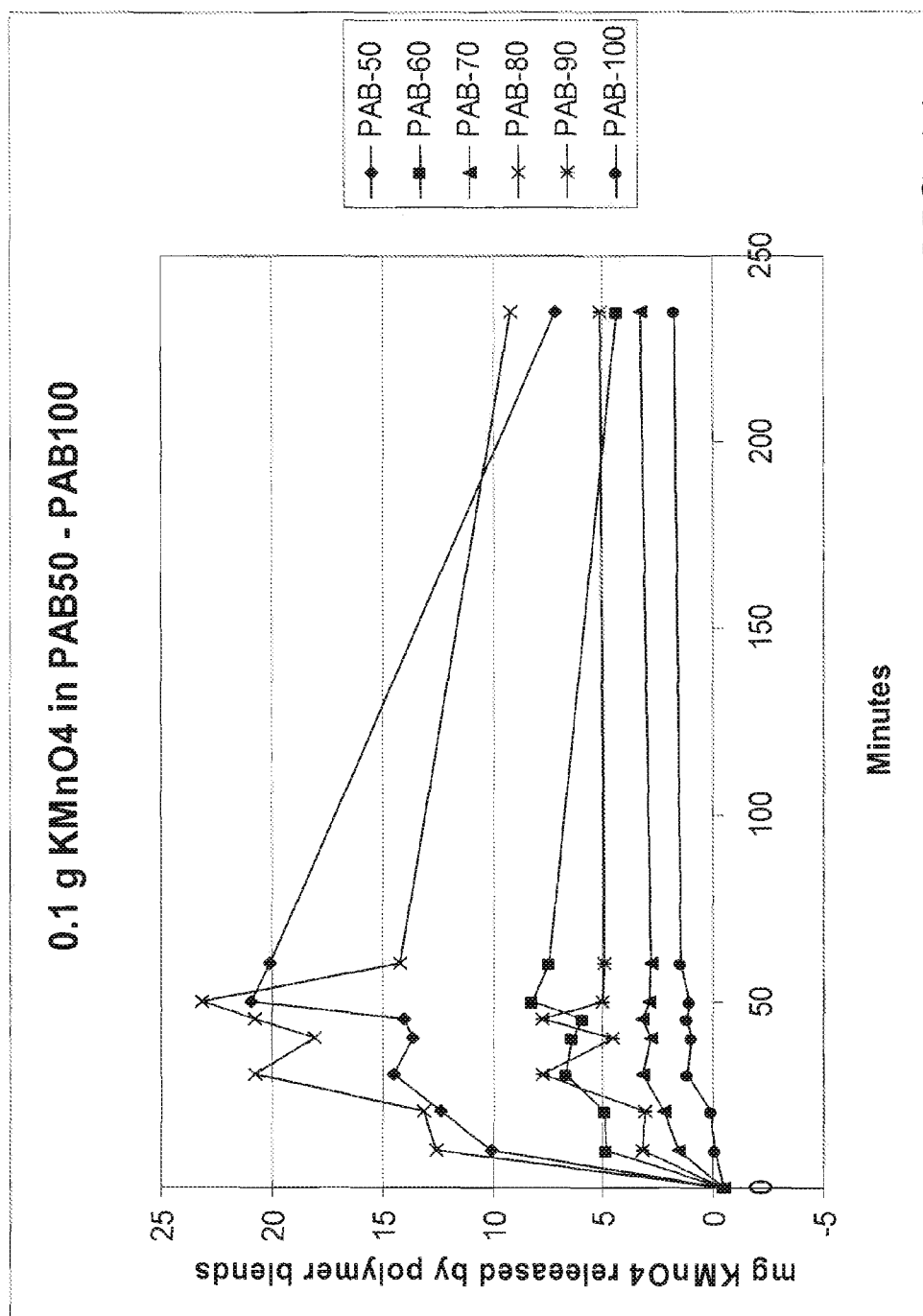


FIG. 14

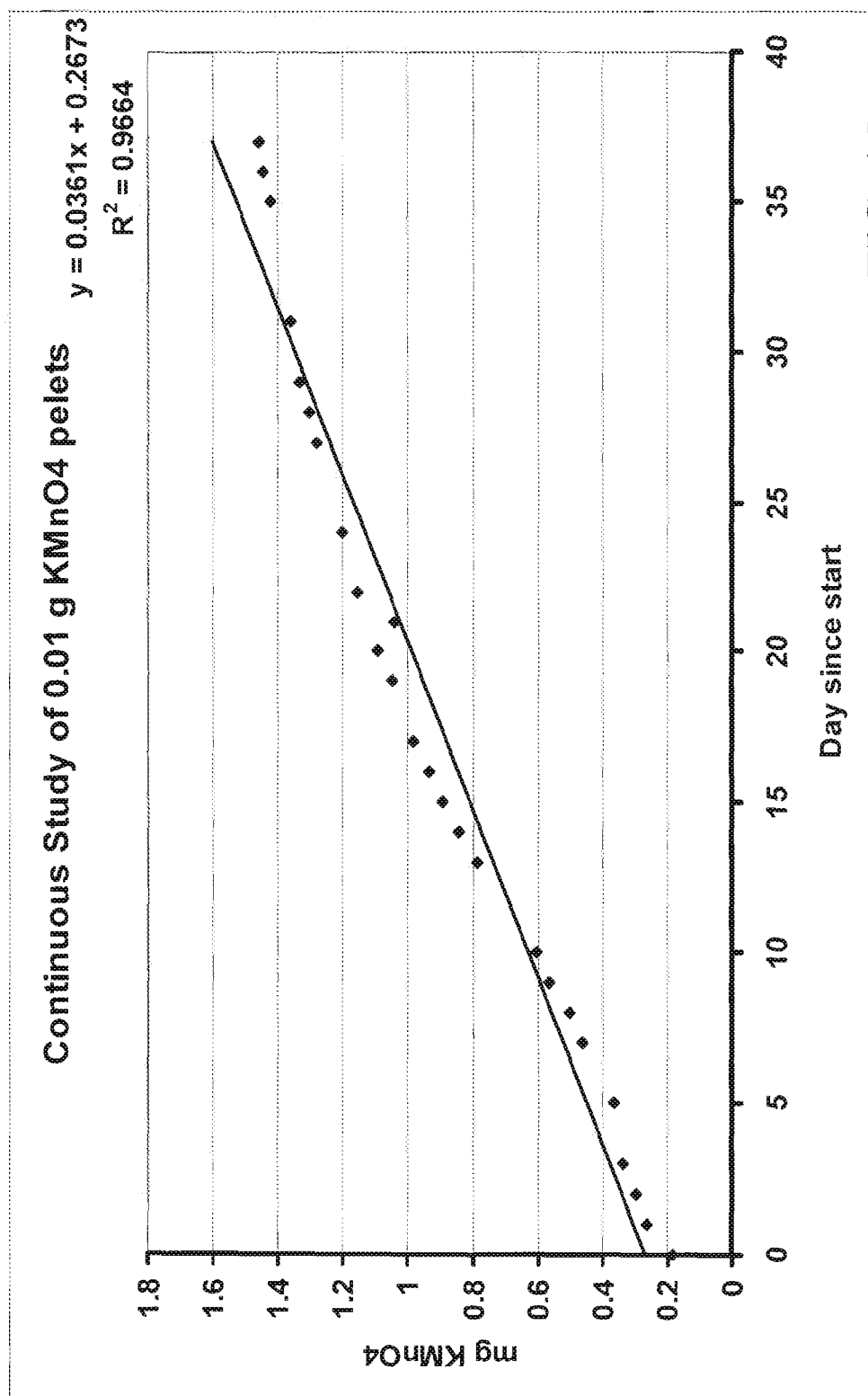


FIG. 15

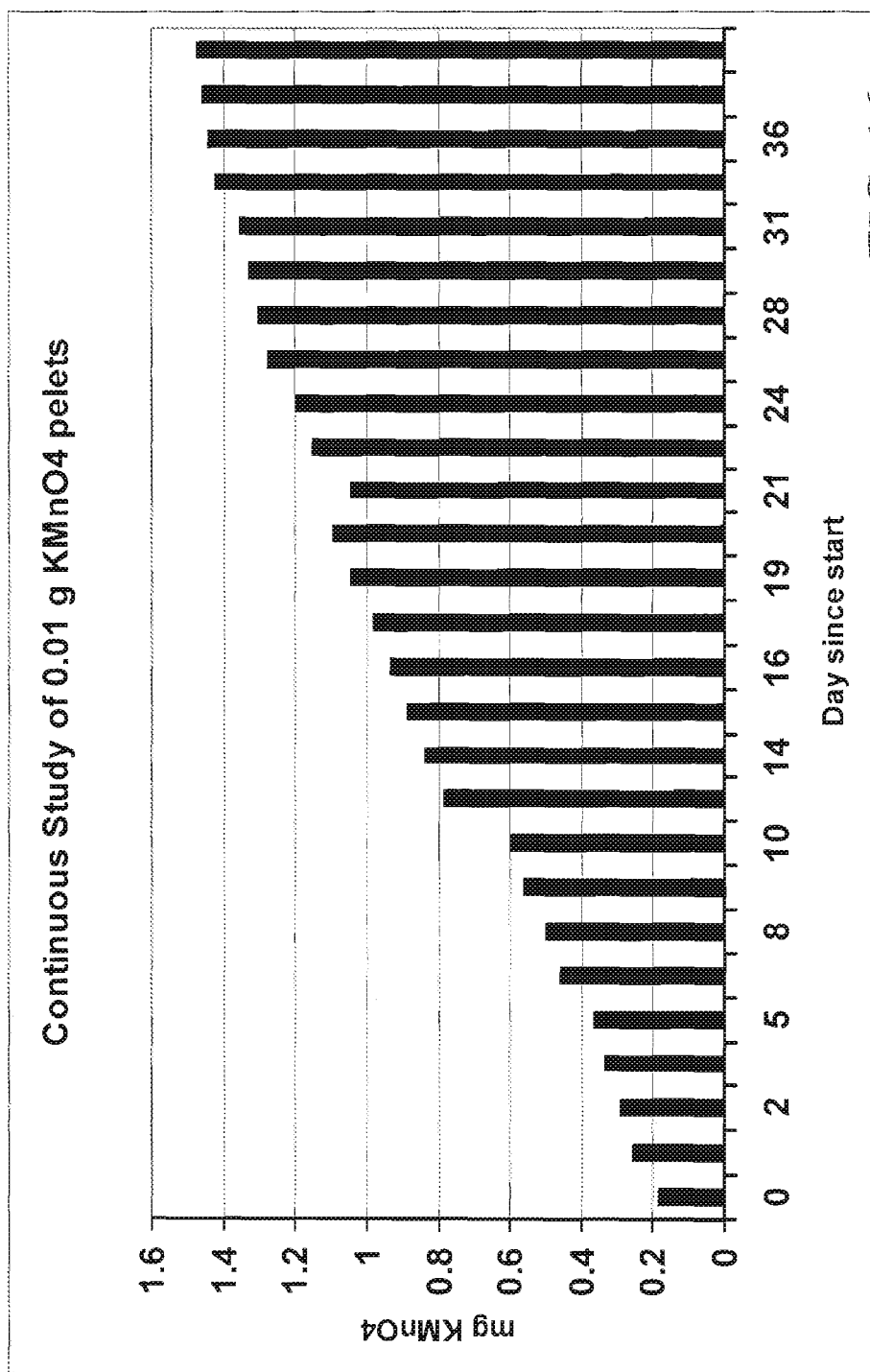


FIG. 16

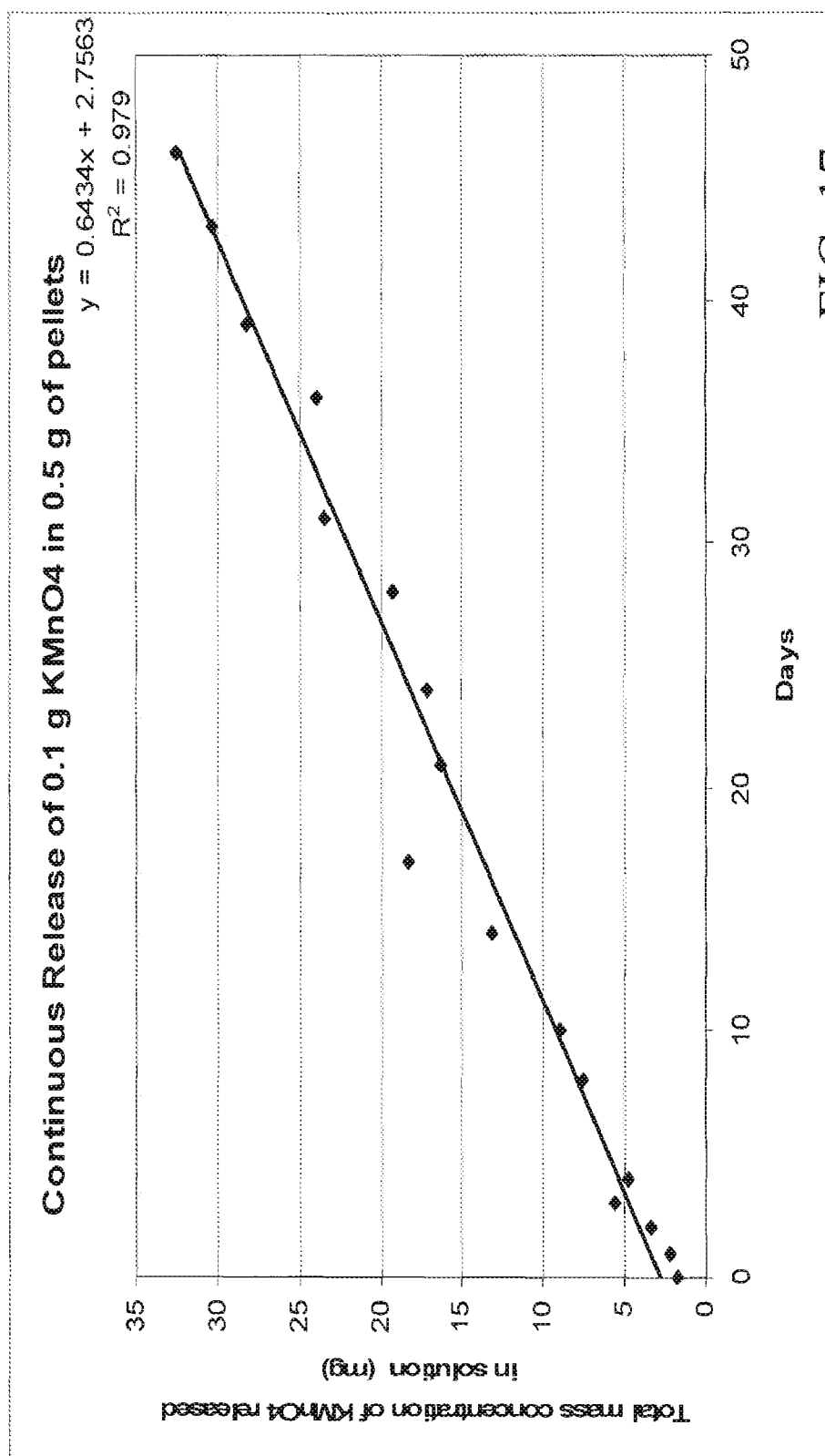


FIG. 17

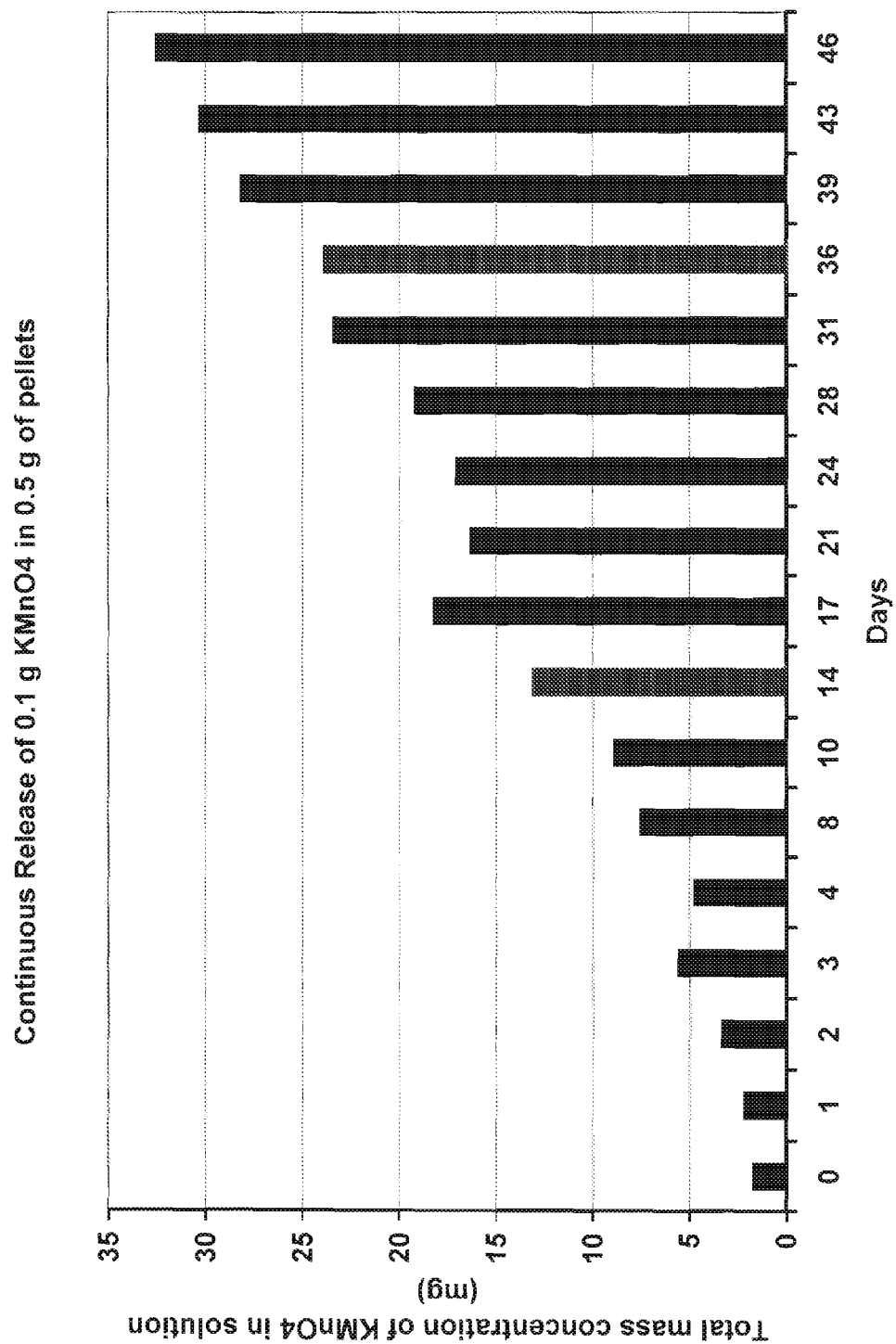


FIG. 18

CONTROLLED RELEASE REMEDIATION SYSTEM AND COMPOSITION

FIELD OF THE INVENTION

[0001] The present invention relates to a controlled release remediation system including at least one controlled release remediation composition. Also, the present invention relates to a method for manufacturing a controlled release remediation composition usable in a controlled release remediation system. Further, the present invention relates to a method for remediating a contaminated site using a controlled release remediation composition.

BACKGROUND

[0002] The United States has more than 200,000 sites with contaminated groundwater and subsurface soils due to leaking underground storage tanks, industrial wastes, and accidental spills. These contaminated sites contain over 1.7 million gallons of chemical and foreign microbial waste; the ability to conduct subsurface remediation is essential for controlling and reducing potential spread of contaminants within an aquifer's watershed.

[0003] Subsurface remediation proves to be challenging because most sites require treatment of both groundwater and subsurface soils. Conventional methods for in-situ remediation include pump-and-treat, thermal desorption, use of surfactants, and air venting. Each method has benefits and limitations, but all of these methods require a long time, many months to years, before significant remediation is accomplished at a contaminated site.

[0004] Chemical oxidants are highly reactive gases and liquids that can be injected into the ground to remediate both groundwater and soils in-situ. Current oxidant delivery methods are effective in remediating recalcitrant compounds; however, these methods are costly, require high maintenance, and can be dangerous to workers. Examples of chemical oxidation hazards include contact with strong oxidizing solutions and acids, explosions, and worker injuries due to the use of more risky techniques such as direct-push injections for liquid delivery.

[0005] Thus there remains a need for a new and improved remediation system and a controlled release remediation composition or compositions that address the problems of conventional methods for in-situ remediation.

SUMMARY

[0006] The present invention meets these and other needs by providing a controlled release remediation composition or compositions, a method making such composition(s), a method of using such composition(s), and a remediation system including such composition(s). According to various aspects of embodiments of the present invention, a controlled release remediation composition or compositions include at least one chemical oxidant agent, optionally, at least two chemical oxidant agents; at least one encapsulant polymer; and, optionally, at least one matrix polymer. To that end according to various aspects of embodiments, a controlled release remediation composition or compositions are capable of substantially constantly releasing an amount of the at least one chemical oxidant agent, optionally, amounts of the at least two chemical oxidant agents, for example, into an aque-

ous system such as may be found at a contaminated site, over at least about a one month period up to over about a three month period.

[0007] Numerous other features and advantages of aspects of embodiments and embodiments of the invention will appear from the following description. In the description, reference is made to exemplary aspects of embodiments and embodiments of the invention. Such aspects of embodiments and embodiments do not represent the full scope of the invention. Reference should therefore be made to the claims herein for interpreting the full scope of the invention. In the interest of brevity and conciseness, any ranges of values set forth in this specification contemplate all values within the range and are to be construed as support for claims reciting any sub-ranges having endpoints which are real number values within the specified range in question. By way of a hypothetical illustrative example, a disclosure in this specification of a range of from 1 to 5 shall be considered to support claims to any of the following ranges: 1-5; 1-4; 1-3; 1-2; 2-5; 2-4; 2-3; 3-5; 3-4; and 4-5.

[0008] In one example of an aspect of an embodiment, a controlled release remediation composition comprises at least one pellet. As will be appreciated by those in the art, such pellet might comprise one or more variety of shapes and/or sizes, for example, to control a rate of release and/or a concentration of oxidant that is released. Some examples of one or more variety of shapes of pellets include spheres, cylinders, "wagon wheels", gear-shapes, saddles, disks, bricks, coils, columns, hollow-elbows, chips, fibers, or shapes of any two or more of the preceding. Also, some examples of one or more variety of sizes of pellets might include one of more dimensions ranging from about a micron (μm) to multiple tens of millimeters (mm). In aspects of an embodiment, sizes can comprise in one aspect a largest dimension of about 1 millimeter (mm, about -18 mesh); in another aspect, between about 500 microns (μm) and about 1.0 μm (about -35, +1000 mesh), and, in yet another aspect, between about 300 microns (μm) and about 1.0 μm (about -50, +635 mesh).

[0009] Examples of an at least one chemical oxidant agent includes at least one of a photo-oxidants agent, an electron transfer reaction agent, a free radical agent, or combinations of any two or more of the preceding. Other examples of an at least one chemical oxidant agent include at least one of a persulfate agent, a permanganate agent, or combinations of any two or more of the preceding. Such examples can include at least one of a titanium oxide agent, a molybdenum sulfide agent, zinc sulfide agent, a sodium permanganate agent, a potassium permanganate agent, a sodium persulfate agent, an ammonium persulfate agent, a potassium persulfate agent, or a combination of any two or more of the preceding. Again, it will be appreciated that more than at least one chemical oxidant agent can be used, for example, at least two or even plurality. It will be appreciated that an at least one chemical oxidant agent can come in a variety of shapes and/or sizes. Such shapes can be a particle size comprising not greater than about 125 μm (-120 mesh), optionally between about 75 microns (μm) and about 1.0 μm (About -200, +1000 mesh), and optionally between about 50 microns (μm) and about 1.0 μm (about -270, +1000 mesh).

[0010] When a controlled release remediation composition includes a matrix polymer in combination with an encapsulant polymer, the matrix polymer can be selected to have a degradation rate less than the release rate of the at least one chemical oxidant agent and greater than the encapsulant deg-

radiation rate the at least one encapsulant polymer. Also, a controlled release remediation composition can further include at least one additional encapsulant polymer that encapsulates at least a portion of the matrix polymer embedding at least a portion of the encapsulated chemical oxidant agent.

[0011] When a controlled release remediation composition includes at least one matrix polymer in combination with at least one encapsulant polymer, the at least one chemical oxidant agent can be between about 1 wt % to about 60 wt % of the controlled release remediation composition; the at least one encapsulant polymer can be between about 1 wt % to about 99 wt % of the controlled release remediation composition; and the at least one matrix polymer can be the balance of the controlled release remediation composition.

[0012] Some examples of environmentally degradable polymer and/or the biodegradable polymer include at least one of a polylactide, a polyglycolide, a polylactide-co-glycolide, a polylactic acid, a polyglycolic acid, a polylactic acid-co-glycolic acid, a polycaprolactone, a polycarbonates, a polyesteramides, a polyanhydrides, a polyamino acid, a polyorthoester, a polyacetyls, a polycyanoacrylates, a polyetheresters, a polydioxanone, a polyalkylene alkylate, a copolymer of a polyethylene glycol and a polylactid or polylactide-co-glycolide, a biodegradable polyurethane, a polysaccharide, a blend of any two or more of the preceding, or a copolymer of any two or more of the preceding. Blends of such polymers can include, for example, between 0 wt % to about 100 wt % of a first polymer; between 0 wt % to about 60 wt % of a second polymer; and a balance of a third polymer. Alternatively, copolymers of such polymers can include, for example, between 0 wt % to about 100 wt % of a first polymer; between 0 wt % to about 60 wt % of a second polymer; and a balance of a third polymer.

[0013] Among examples of environmentally degradable polymer and/or the biodegradable polymer, polylactic acid, polyvinyl alcohol, polycaprolactone, a blend of any two or more of the preceding, or a copolymer of any two or more of the preceding have been found to work satisfactorily. Blends of such polymers can include, for example, between 0 wt % to about 60 wt % of a polylactic acid; between 0 wt % to about 60 wt % of a polyvinyl alcohol; and between 0 wt % to about 100 wt % of a polycaprolactone. In an aspect of an embodiment concerning polycaprolactone blends, an amount of polycaprolactone is not less than about 40 wt % of the blend. Alternatively, copolymers of such polymers can include, for example, between 0 wt % to about 60 wt % of a polylactic acid; between 0 wt % to about 60 wt % of a polyvinyl alcohol; and between 0 wt % to about 100 wt % of a polycaprolactone. In an aspect of an embodiment concerning polycaprolactone copolymers, an amount of polycaprolactone is not less than about 40 wt % of the copolymers.

[0014] Some examples of chemical pollutants include at least one of a chlorinated organic compound (e.g., polychlorinated biphenyls (PCBs), chlorinated benzenes (CBs)), a compound containing at least one unsaturated carbon-carbon bond, an aromatic hydrocarbon (AH: e.g., benzene, toluene, ethylbenzene, xylene, [note that BTEX is an acronym that stands for Benzene, Toluene, Ethylbenzene, and Xylene], mesitylene, phenol, . . . etc.), a polycyclic aromatic hydrocarbon (PAH: e.g., anthracene, chrysene, naphthalene, phenanthrene, benzo[a]pyrene, pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, coronene, dibenz[a,h]anthracene

(C₂₀H₁₄), indeno[1,2,3-cd]pyrene (C₂₂H₁₂), ovalene, . . . etc.), methyl tertiary-butyl ether (also known as MTBE), a munitions constituent (e.g., cyclotrimethylenetrinitramine, also known as RDX, cyclonite, hexogen, and T4; trinitrotoluene, also known as TNT; cyclotetramethylene-tetranitramine, also known as HMX, and octogen; . . . etc.), an organic pesticide, wastewater, a drinking water treatment, a pathogen (e.g., bacteria, viruses, protozoa, fungi, proteins, . . . etc.), or any combination of two or more of the preceding.

[0015] Accordingly, one aspect of an embodiment the present invention is to provide a controlled release remediation composition that includes at least one chemical oxidant agent, at least one encapsulant polymer, and at least one matrix polymer. The at least one chemical oxidant agent is selected to be capable of remediating at least one chemical pollutant. Also, the at least encapsulant polymer is selected to be substantially compatible with at least one chemical oxidant agent. At least a portion of the encapsulant polymer encapsulates at least a portion of the chemical oxidant agent. Also, at least a portion of the encapsulant polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. As to the matrix polymer, at least a portion of it embeds at least a portion of the encapsulated chemical oxidant agent. As with the encapsulant polymer, at least a portion of the matrix polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. In this manner, the controlled release remediation composition is capable of substantially constantly releasing an amount of the at least one agent chemical oxidant agent, for example, into an aqueous system such as may be found at a contaminated site, over at least about a one month period up to over about a three month period.

[0016] Another aspect of an embodiment the present invention is to provide a controlled release remediation composition comprising a plurality of chemical oxidant agents and a polymer. At least two of the plurality chemical oxidant agents are capable of remediating at least two different chemical pollutants. At least a portion of the polymer encapsulates at least a portion of the plurality of chemical oxidant agents. Also, at least a portion of the polymer comprises a biodegradable polymer. The controlled release remediation composition is capable of substantially constantly releasing an amount of the at least two of the plurality chemical oxidant agents into an aqueous system over at least a one month period up to over about a three month period.

[0017] Yet another aspect of an embodiment the present invention is to provide a method of making controlled release remediation composition. Steps of the method can include one or more selecting and combining steps. For example, at least one chemical oxidant agent capable of remediating at least one chemical pollutant is selected. As another example, at least one encapsulant polymer that is substantially compatible with the at least one chemical oxidant agent is selected. Such at least one encapsulant polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. As yet another example, at least one matrix polymer is selected. As with the at least one encapsulant polymer, such at least one matrix polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. The at least one encapsulant

polymer and the at least one matrix polymer may be the same, different, or include components that are related, such as, by a starting monomer or monomers. As to one example of combining steps, at least a portion of the chemical oxidant agent is encapsulated using the encapsulant polymer. As to another example of combining steps, the encapsulated chemical oxidant agent is combined with the at least one matrix polymer so that at least a portion of the matrix polymer embeds at least a portion of the encapsulated chemical oxidant agent.

[0018] Still another aspect of an embodiment of the present invention is to provide a remediation system including at least one controlled release remediation composition that includes at least one chemical oxidant agent, at least one encapsulant polymer, and at least one matrix polymer. The at least one chemical oxidant agent is selected to be capable of remediating at least one chemical pollutant. Also, the at least encapsulant polymer is selected to be substantially compatible with at least one chemical oxidant agent. At least a portion of the encapsulant polymer encapsulates at least a portion of the chemical oxidant agent. Also, at least a portion of the encapsulant polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. As to the matrix polymer, at least a portion of it embeds at least a portion of the encapsulated chemical oxidant agent. As with the encapsulant polymer, at least a portion of the matrix polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. In this manner, the remediation product is capable of substantially constantly releasing a sufficient amount of the at least one agent chemical oxidant agent into a contaminated site over at least about a one month period up to over about a three month period so as to remediate at least a portion of the at least one chemical pollutant.

[0019] Still yet another aspect of an embodiment of the present invention is to provide a method of using a controlled release remediation composition. Steps of the method can include one or more determining, selecting, combining, and providing steps. For example, at least one chemical pollutant to be remediated at a contaminated site is identified. Then, at least one chemical oxidant agent capable of remediating the at least one chemical pollutant is selected. Another selecting example includes selecting at least one encapsulant polymer that is substantially compatible with the at least one chemical oxidant agent is selected. Such at least one encapsulant polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. As yet another example, at least one matrix polymer is selected. As with the at least one encapsulant polymer, such at least one matrix polymer includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. The at least one encapsulant polymer and the at least one matrix polymer may be the same, different, or include components that are related, such as, by a starting monomer or monomers. As to one example of combining steps, at least a portion of the chemical oxidant agent is encapsulated using the encapsulant polymer. As to another example of combining steps, the encapsulated chemical oxidant agent is combined with the at least one matrix polymer so that at least a portion of the matrix polymer embeds at least a portion of the encapsulated chemical oxidant agent to form a controlled release remediation composition. Further steps involve shaping, sizing, and/or providing. For example, the controlled release remediation composition is shaped, sized, or shaped and sized so as to be capable of substantially constantly releasing an amount of the at least one chemical oxidant agent, for example, into an aqueous system of a contamination site, over at least about a one month period up to over about a three month period. As to an example of providing, a sufficient amount of the shaped, sized, or shaped and sized controlled release remediation composition is provided to the contaminated site in manner that remediates at least a portion of the at least one chemical pollutant at the contaminated site.

[0020] These and other aspects, advantages, and salient features of the present invention will become apparent from the following detailed description, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0021] FIG. 1 is a schematic illustrating a controlled release remediation composition constructed according to an aspect of an embodiment of the present invention;

[0022] FIG. 2 is a schematic illustrating a controlled release remediation composition constructed according to another aspect of an embodiment of the present invention;

[0023] FIG. 3 is a schematic illustrating a controlled release remediation composition constructed according to yet another aspect of an embodiment of the present invention;

[0024] FIGS. 4a and 4b are photos of the KMnO_4 in a PLA polymer photographed after it was made (FIG. 4a) and approximately seven months later (FIG. 4b);

[0025] FIGS. 5a and 5b are photos of the KMnO_4 in a polycaprolactone (PCL) polymer photographed after it was made (FIG. 5a) and approximately seven months later (FIG. 5b);

[0026] FIG. 6 is a plot comparing degradation of a PAB-50 and a PAB-60 polymer blend for pellet design;

[0027] FIG. 7 is a photograph showing visible attachment of plant material growing on pellets after about six months;

[0028] FIG. 8 is a plot comparing degradation in river water and culture water of pellets made using a PAB-100 and a PAB-60 polymer blend for;

[0029] FIGS. 9a, 9b, and 9c are time series photographs of a chemical oxidant agent diffusing from a controlled release remediation composition;

[0030] FIG. 10 is a plot showing the time release of a chemical oxidant agent;

[0031] FIG. 11 is a plot showing the time release of a chemical oxidant agent;

[0032] FIG. 12 is a plot comparing the short-term time release of a chemical oxidant agent using different polymers;

[0033] FIG. 13 is a plot comparing the short-term time release of a chemical oxidant agent using different polymers;

[0034] FIG. 14 is a plot comparing the short-term time release of a chemical oxidant agent using different polymers;

[0035] FIG. 15 is a plot showing the release rate of a chemical oxidant agent for a controlled release remediation composition;

[0036] FIG. 16 is a plot showing the release rate of a chemical oxidant agent for a controlled release remediation composition;

[0037] FIG. 17 is a plot showing the release rate of a chemical oxidant agent for a controlled release remediation composition; and

[0038] FIG. 18 is a plot showing the release rate of a chemical oxidant agent for a controlled release remediation composition.

DETAILED DESCRIPTION

[0039] In the following description, like-referenced characters designate like or corresponding parts throughout the several views shown in the figures. It is also understood that terms such as “top,” “bottom,” “outward,” “inward,” and the like are words of convenience and are not to be construed as limiting terms.

[0040] Referring to the drawings in general and to FIGS. 1, 2, and 3 in particular, it will be understood that the illustrations are for the purpose of describing one or more aspects of and/or one or more embodiments of the invention and are not intended to limit the invention thereto. In FIGS. 1, 2, and 3, a controlled release remediation composition is generally designated 12. Such composition 12 includes at least one chemical oxidant agent 14 and at least one matrix polymer 20. Such composition 12 can include at least one encapsulant polymer 16. The at least one chemical oxidant agent 14 is selected to be capable of remediating at least one chemical pollutant 22 (not depicted in FIGS. 1, 2, and 3). A matrix polymer 20 is selected to be substantially compatible with at least one chemical oxidant agent 14 and at least a portion of it embeds at least a portion of the chemical oxidant agent 14. At least a portion of the matrix polymer 20 includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. In this manner, the controlled release remediation composition 12 can be capable of substantially constantly releasing an amount of the at least one agent chemical oxidant agent 14, for example, into an aqueous system such as may be found at a contaminated site, over at least about a one month period up to over about a three month period. Also, the at least one encapsulant polymer 16 is selected to be substantially compatible with at least one chemical oxidant agent 14.

[0041] In some aspects of embodiments of the present invention as shown in FIG. 3, at least a portion of an encapsulant polymer 16 encapsulates at least a portion of a chemical oxidant agent 14. Such encapsulant polymer 16 can include at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. In such case, at least a portion of a matrix polymer 20 embeds at least a portion of the encapsulated chemical oxidant agent 14. As with the matrix polymer 20, at least a portion of the encapsulant polymer 16 includes at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer. In this manner, the controlled release remediation composition is capable of substantially constantly releasing an amount of the at least one agent chemical oxidant agent, for example, into an aqueous system such as may be found at a contaminated site, over at least about a one month period up to over about a three month period.

[0042] “Degradable” or “degradation” is intended to mean that the polymer undergoes an irreversible process that leads to a significant change in the chemical and/or physical structure of the material that is typically characterized by a loss of physical and/or chemical properties, such as integrity, molecular weight, molecular structure, mechanical strength,

and/or fragmentation. In an aspect, a polymer degrades to a benign non-toxic material that is not harmful to the environment.

[0043] A degradation of a polymer can be by a process that involves one or more of, for example, photodegradation, chemical degradation, physical degradation or, biodegradation. Photodegradation includes a process of degradation that can be initiated by exposure of the polymer to natural or artificial light. Chemical degradation includes a process of degradation wherein chemical bonds in the polymer are broken as a result of one or more chemical reactions such as, for example, hydrolysis, thermal cleavage, or oxidation. Chemical degradation is thus more encompassing than photodegradation, since the reactions are not limited to those initiated by exposure to light. Physical degradation can include forces such as erosion that may help a polymer to degrade. Biodegradation includes a process of degradation that occurs as a result of the action of enzymes, derived from the metabolic processes of microorganisms or other living species, on the polymer. It is possible that a given mechanism of degradation may be classified as more than one of the above-described processes.

[0044] “Biodegradable” means that a polymer or polymer component is susceptible to being assimilated by microorganisms when buried in the ground or otherwise contacted with the organisms under conditions conducive to their growth.

[0045] “Environmentally degradable” means that a polymer or polymer component is capable of being degraded by surrounding environmental elements (e.g., chemical, physical, thermal, and/or light) without microorganisms to a form that ultimately may be biodegradable when it mineralizes, for example, biodegrades to carbon dioxide, water and biomass.

[0046] Conditions that enable the chemical, physical, thermal and/or biological degradation of a polymer or polymer component may vary. A polymer or polymer component of this invention are especially adapted to be degradable in soil and/or subterranean applications.

[0047] It will be appreciated that in aspects of embodiments of the present invention, a controlled release remediation composition 12 might be used in an alone process or in conjunction with another engineered system as a remediation system 10. For example, a controlled release remediation composition 12 might comprise at least one pellet 22, a plurality of which is capable of being packed into a screened well or mix into the soil to form a permeable barrier layer at a contamination site. Such a barrier layer of controlled release remediation composition 12 would be capable of releasing one or more chemical oxidant agents 14 as groundwater flows through it to react with contaminated water and chemical pollutants 24 present in the soil and/or subterranean level.

[0048] As noted, a controlled release remediation composition 12 might comprise at least one pellet 22. As will be appreciated by those in the art, such pellet might comprise one or more variety of shapes and/or sizes, for example, to control a rate of release and/or a concentration of oxidant that is released. Some examples of one or more variety of shapes of pellets include spheres, cylinders, “wagon wheels”, gear-shapes, saddles, disks, bricks, coils, columns, hollow-elbows, chips, fibers, or shapes of any two or more of the preceding. Also, some examples of one or more variety of sizes of pellets might include one of more dimensions ranging from about a micron (μm) to multiple tens of millimeters (mm). In one aspect of an embodiment, sizes can comprise in one aspect a

largest dimension of about 1 millimeter (mm, about -18 mesh); in another aspect, between about 500 microns (μm) and about 1.0 μm (about -35, +1000 mesh), and, in yet another aspect, between about 300 microns (μm) and about 1.0 μm (about -50, +635 mesh).

[0049] Examples of an at least one chemical oxidant agent **14** includes at least one of a photo-oxidants agent, an electron transfer reaction agent, a free radical agent, or combinations of any two or more of the preceding. Other examples of an at least one chemical oxidant agent include at least one of a persulfate agent, a permanganate agent, or combinations of any two or more of the preceding. Such examples can include at least one of a titanium oxide agent, a molybdenum sulfide agent, a zinc sulfide agent, a sodium permanganate agent, a potassium permanganate agent, sodium persulfate agent, ammonium persulfate agent, potassium persulfate agent, or a combination of any two or more of the preceding. Again, it will be appreciated that more than at least one chemical oxidant agent **14** can be used, for example, at least two (e.g., a first chemical oxidant agent **14** and a second chemical oxidant agent **14'**) or even plurality (e.g., chemical oxidant agent **14**, a second chemical oxidant agent **14'**, . . . a n^{th} chemical agent **14''**). It will be appreciated that an at least one chemical oxidant agent can come in a variety of shapes and/or sizes. Such shapes can be a particle size comprising not greater than about 125 μm (-120 mesh), optionally between about 75 microns (μm) and about 1.0 μm (About -200, +1000 mesh), and optionally between about 50 microns (μm) and about 1.0 μm (about -270, +1000 mesh).

[0050] When a controlled release remediation composition **12** includes a matrix polymer **20** in combination with an encapsulant polymer **16**, the matrix polymer **20** can be selected to have a degradation rate less than the release rate of the at least one chemical oxidant agent **14** and greater than the degradation rate of the at least one encapsulant polymer **16**. Also, a controlled release remediation composition **12** can further include at least one additional encapsulant polymer **18** that encapsulates at least a portion of the matrix polymer **20** embedding at least a portion of the encapsulated chemical oxidant agent **14**.

[0051] When a controlled release remediation composition **12** includes at least one matrix polymer **20** in combination with at least one encapsulant polymer **16**, the at least one chemical oxidant agent **14** can be between about 1 wt % to about 60 wt % of the controlled release remediation composition **12**; the at least one encapsulant polymer **16** can be between about 1 wt % to about 99 wt % of the controlled release remediation composition **12**; and the at least one matrix polymer **20** can be the balance of the controlled release remediation composition **12**.

[0052] Some examples of environmentally degradable polymer and/or the biodegradable polymer include at least one of a polylactide, a polyglycolide, a polylactide-co-glycolide, a poly(lactic acid), polyglycolic acid, poly(lactic acid-co-glycolic acid), polycaprolactone, a polycarbonates, a polyesteramides, a polyanhydrides, a polyamino acid, a polyorthoester, a polyacetyls, a polycyanoacrylates, polyetheresters, a polydioxanone, a polyalkylene alkylate, a copolymer of a polyethylene glycol and a polylactid or polylactide-co-glycolide, a biodegradable polyurethane, a polysaccharide, a blend of any two or more of the preceding, or a copolymer of any two or more of the preceding. Blends of such polymers can include, for example, between 0 wt % to about 100 wt % of a first polymer; between 0 wt % to about 60 wt % of a

second polymer; and a balance of a third polymer. Alternatively copolymers of such polymers can include, for example, between 0 wt % to about 100 wt % of a first polymer; between 0 wt % to about 60 wt % of a second polymer; and a balance of a third polymer.

[0053] Among examples of environmentally degradable polymer and/or the biodegradable polymer, polylactic acid, polyvinyl alcohol, polycaprolactone, a blend of any two or more of the preceding, or a copolymer of any two or more of the preceding have been found to work satisfactorily. Blends of such polymers can include, for example, between 0 wt % to about 60 wt % of a polylactic acid; between 0 wt % to about 60 wt % of a polyvinyl alcohol; and between 0 to about 100 wt % of a polycaprolactone. Alternatively copolymers of such polymers can include, for example, between 0 wt % to about 100 wt % of a polylactic acid; between 0 wt % to about 60 wt % of a polyvinyl alcohol; and between 0 wt % to about 100 wt % of a polycaprolactone.

[0054] Some examples of chemical pollutants **24** include at least one of a chlorinated organic compound (e.g., polychlorinated biphenyls (PCBs), chlorinated benzenes (CBs)), a compound containing at least one unsaturated carbon-carbon bond, an aromatic hydrocarbon (AH: e.g., benzene, toluene, ethylbenzene, xylene, [note that BTEX is an acronym that stands for Benzene, Toluene, Ethylbenzene, and Xylene], mesitylene, phenol, . . . etc.), a polycyclic aromatic hydrocarbon (PAH: e.g., anthracene, chrysene, naphthalene, phenanthrene, benzo[a]pyrene, pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, coronene, dibenz[a,h]anthracene ($\text{C}_{20}\text{H}_{14}$), indeno[1,2,3-cd]pyrene ($\text{C}_{22}\text{H}_{12}$), ovalene, . . . etc.), methyl tertiary-butyl ether (also known as MTBE), a munitions constituent (e.g., cyclotrimethylenetrinitramine, also known as RDX, cyclonite, hexogen, and T4; trinitrotoluene, also known as TNT; cyclotetramethylene-tetranitramine, also known as HMX, and octogen; . . . etc.), an organic pesticide, wastewater, a drinking water treatment, a pathogen (e.g., bacteria, viruses, protozoa, fungi, proteins, . . . etc.), or any two or more of the preceding.

[0055] In an operation according an aspect of an embodiment relating to delayed dissolution as shown to FIG. 1, polymer matrix **20** environmentally degrades (e.g., dissolves in the presence of water or degrades slowly in the presence of water) and/or biologically degrades (e.g., due to microbial action). Some embedded and/or encapsulated chemical oxidant agent **14** is retained until further degradation of the polymer. Released chemical oxidant agent **14** is available to dissolve and react with one or more chemical pollutants **24**.

[0056] In an operation according an aspect of an embodiment relating to diffusion controlled as shown to FIG. 2, polymer matrix **20** environmentally degrades (e.g., moderately water soluble with small pore openings created by water flow) and/or biologically degrades (e.g., due to microbial action). Chemical oxidant agent **14** diffuses with water flow into the environment to react one or more chemical pollutants **24**. FIG. 2 explains diffusion controlled release of the encapsulated oxidant. For example, the polymer matrix **20** may be moderately soluble and/or have small pore openings created due to the semi-permeable property for the polymer, water flow or microbial degradation. This enables a chemical oxidant agent **14** to diffuse across a shell boundary.

[0057] In an operation according an aspect of an embodiment relating to delayed dissolution in combination with diffusion controlled as shown to FIG. 3, additional encapsu-

lant polymer **18** environmentally degrades (e.g., moderately water soluble with small pore openings created by water flow) and/or biologically degrades (e.g., due to microbial action). Polymer matrix **20** permits diffusion of some but not all of chemical oxidant agent **14'**. Delayed dissolution leads to the delayed release of remaining chemical oxidant agent **14** that eventually diffuses with water flow into the environment to react with one or more chemical pollutants **24**.

EXAMPLES

[0058] Certified ACS KMnO_4 (Fisher Chemical, Fair Lawn, N.J.) was used as the oxidant encapsulated in an environmentally degradable polymer, a biodegradable polymer, an environmentally degradable polymer and biodegradable polymer, a copolymer thereof, or a blend thereof Poly-lactic acid (NatureWorks LLC, Minnetonka, Minn.), polyvinyl alcohol (Aldrich Chemical, Milwaukee, Wis.), and polycaprolactone (Dow Chemical, Midland Mich.) were evaluated.

[0059] To produce controlled release remediation compositions, pure polymers and polymer blends were combined to produce about 0.3 to about 0.5 cm solid pellets. Molten polymer was created by heating a polymer above its melting point in an aluminum dish or Pyrex® beaker using a hot plate stirrer. KMnO_4 was stirred into the molten polymer to suspend KMnO_4 . Pellets were then formed by placing the viscous molten suspension in a mold to solidify and form the pellets.

[0060] Those skilled in the art will appreciate that other methods might be used to make a controlled release remediation composition according to aspects of embodiments and/or embodiments of the present invention. For example, an extrusion process might be used to incorporate one or more chemical oxidant agents with matrix polymer with the elongate extrudant being chopped to form pellets. Other methods might include fiber spinning, injection molding, mixing and compounding, pultrusion, and reaction injection molding.

[0061] Criteria for an environmentally degradable polymer or a biodegradable polymer selection includes a compatibility with a selected chemical oxidant agent, in the examples KMnO_4 , an ability to form solid pellet structures. In an aspect of an embodiment of the invention, a largest dimension of a pellet might comprises about 1 millimeter (mm, about -18 mesh), optionally between about 500 microns (μm) and about 1.0 μm (about -35, +1000 mesh), and optionally between about 300 microns (μm) and about 1.0 μm (about -50, +635 mesh), and an ability of such polymer to degrade or dissolve to release the chemical oxidant agent.

[0062] Applicant contemplates controlled release remediation compositions that exhibited delayed dissolution delivery, diffusion controlled delivery, or combined delayed/diffusion delivery of a chemical oxidant agent, in the examples KMnO_4 . In a controlled release remediation composition exhibiting delayed diffusion, a polymer either dissolves in water or degrades due to microbial action to release chemical oxidant agent, in the examples KMnO_4 . In a controlled release remediation composition exhibiting diffusion control, a chemical oxidant agent, in the examples KMnO_4 , is able to diffuse through the matrix polymer into water. FIGS. 1, 2, and 3 depict designs to enable the controlled release of oxidants from a biodegradable polymer.

[0063] Evaluated polymers included polylactic acid (PLA), polyvinyl alcohol (PVOH), and polycaprolactone (PCL). Polylactic acid (PLA), an aliphatic polyester, is a hydrophobic, biodegradable polymer that can be degraded by aerobic

or anaerobic. Polylactic acid has a thermal melting point at about 193° C., therefore the melting point for the polymer is less than the melting point of potassium permanganate (270° C.). Polyvinyl alcohol (PVOH) is a hydrophilic polymer selected for use as a polymer blend and has a melting temperature of about 200° C. Applicant believes that PVOH could be used in blends to provide a method to increase the diffusion of KMnO_4 into water. Polycaprolactone (PCL) is a biodegradable polymer having a melting temperature of about 60° C. and is degradable under aerobic and anaerobic conditions.

[0064] Polylactic acid, polyvinyl alcohol, and polycaprolactone were tested for reactivity with KMnO_4 . One concern for encapsulant polymer and/or matrix polymer is that a chemical oxidant agent is adversely affected by an interaction or reaction. For example, if the KMnO_4 is reactive with polymer, visible evidence would be a brown discoloration caused by MnO_2 from KMnO_4 degradation or visible degradation of the polymer. For this test, KMnO_4 was encapsulated using PLA, PVOH blends, and PCL matrices to form pellets and mounted on a glass slide. Photos at 40 \times and 100 \times were taken of the pellets using a digital microscope to observe any reactions or discoloration of the matrix. Little to no reactivity was seen in PLA, PVOH blends, and PCL matrices. FIGS. 4(a) and 4(b) show that KMnO_4 appears to be stable and non-reactive when in contact with PLA. FIG. 4a is a photo of the KMnO_4 in the PLA polymer photographed after it was made and FIG. 4b shows the same sample photographed approximately seven month later. FIGS. 4a and 4b show that KMnO_4 appears to be stable and non-reactive when in contact with PLA. FIG. 5a is a photo of the KMnO_4 in the PCL polymer photographed after it was made and FIG. 5b shows the same sample photographed approximately seven months later. FIGS. 5a and 5b show that KMnO_4 appears to be stable and non-reactive when in contact with PCL.

[0065] Six controlled release remediation compositions met the criteria (e.g., (1) polymer compatibility with the chemical oxidant agent, (2) the ability for diffusion of the chemical oxidant agent through the polymer, and (3) the ability to form pellet structures using the polymer that is feasible for use as fill material for a permeable reactive barrier or in a reactor system). Identification numbers were assigned to the polymer and polymer blends, namely, PAB-50, PAB-60, PAB-70, PAB-80, PAB-90, and PAB-100 were PAB stand for a blend of polycaprolactone (PCL) and polyvinyl alcohol (PVOH) and -X stand for the amount in weight percent of PCL blended with PVOH. These samples were mixtures of hydrophilic and hydrophobic polymers blended to create pellets that would dissolve and/or degrade in the presence of water to release the chemical oxidant agent.

[0066] Water evaluated included water collected from Reedy Fork Ranch Creek (Greensboro, N.C.), culture water containing **12** aerobic microorganisms from the PolyTox cultures (Fisher Scientific Company, Fair Lawn, N.J.), and deionized water over a period of six months. These tests were conducted to determine dissolution and degradation of the pellet blends in aqueous media. The FIG. 6 summarizes data from an experiment over a 70 day period using the hydrophilic polymer (in this case PVOH) blended in with the polycaprolactone in samples PAB-50 and PAB-60.

[0067] The PAB-50 controlled release remediation composition had an increased dissolution rate in aqueous media compared to PAB-60. This result provided data for designing controlled release remediation compositions to release the

chemical oxidant agent at slower or faster rates. That is blends with higher concentrations of the hydrophilic polymer (i.e., PAB-50) dissolve to yield a rapid release of oxidant. Slower, controlled release rates are therefore feasible in polymer blends with less hydrophilic polymer blended in the matrix (i.e., PAB-60).

[0068] Dissolution and Degradation experiments of Polymer blends over a 90 day period were designed to investigate dissolution and degradation of the polymer in natural water such as river water and aqueous, aerobic mixed culture. In the lab, the polymers were evaluated in a batch system with 100 ml of river water or culture water. The table below represents the experiment carried out in the lab over a period of 118 days to show how two different polymer blends (PAB-60 and PAB-100) blends dissolved or degraded in aqueous media (Table 1).

TABLE 1

	<u>Dissolution and degradation - Days of Degradation</u>									
	SAMPLES									
	0	2	7	13	22	41	55	83	90	118
	Percent Reduction in Mass									
<u>DI Water (PAB-100)*</u>										
River Water (PAB-100)	0	0.4	1.3	1.6	1.8	2.1	2.2	2.3	2.5	5.7
Mixed Culture (PAB-100)	0	0	0	3.2	3.5	5.2	6.3	8.0	8.5	11.7
DI water (non-sterile) (PAB-60)	0	0.3	6.5	7.5	18.0	30.5	33.1	33.6	33.7	35.0
River Water (PAB-60)	0	0.2	5.6	6.5	15.2	31.7	32.8	33.4	34.7	33.5
Mixed Culture (PAB-60)	0	1	6.0	8.1	14.2	31.2	33.8	35.1	35.3	37.5

*data not available at time of filing

[0069] Biological growth was seen on the PAB-100 pellets after about six-months in the batch water (See e.g., FIG. 7). No biological growth was evident on the PAB-60 samples. The pH for the batches, both PAB-60 and PAB-100, ranged from about 6.7-7.5 suggesting the pH level was not the cause for the lack of biological growth in the bottles. Perhaps the lack of growth was due to the addition of the second polymer in the pellet. FIG. 8 includes the results of a study of polymer and polymer blends PAB-100 and PAB-60 normalized to show degradation over 2-months in river water and mixed microbial culture water.

[0070] The profile in FIGS. 9a, 9b and 9c shows a controlled release remediation composition and a chemical oxidant agent diffusing therefrom. The chemical oxidant agent is embedded in a polymer matrix; this also shows the slow release of the oxidant from pellets of controlled release remediation composition over time, the purple color residue coming out of the matrix is the chemical oxidant agent, potassium permanganate.

[0071] Biphasic KMnO_4 release was observed in our KMnO_4 release studies. A rapid release of KMnO_4 occurred during the initial about 1-3 days followed by a controlled and slower release of KMnO_4 for an extended period of time. (See e.g., FIGS. 10 & 11).

[0072] FIG. 10 relates to a replacement media study of 0.5 g of pellets containing 0.01 g of oxidant. Also, FIG. 11 relates to a replacement media study of 0.5 g of pellets containing 0.1 g of oxidant. The oxidant concentration was measured every 2-4 days. After each measurement, the pellets and bottles were rinsed to remove residual oxidant and fresh water added

to the reaction bottles. The process of measuring the oxidant concentration was then repeated 2-3 days later.

[0073] FIG. 12 relates to a one-hour release study of 0.5 g of pellets containing 0.01 g oxidant in the polymer and polymer blends PAB-50, PAB-60, PAB-70, PAB-80, PAB-90, and PAB-100. FIG. 13 relates to a one-hour release study of 0.5 g of pellets containing 0.1 g oxidant in the polymer and polymer blends PAB-50, PAB-60, PAB-70, PAB-80, PAB-90, and PAB-100. FIG. 14 relates to a four-hour release study of 0.5 g of pellets containing 0.1 g oxidant in the polymer and polymer blends PAB-50, PAB-60, PAB-70, PAB-80, PAB-90, and PAB-100.

[0074] FIG. 15 is a linear-fit for release data from 0.5 g of pellets containing 0.01 g oxidant to determine the release rate. FIG. 16 is a bar chart presenting continuous release concentration measurements of oxidant release from 0.5 g of pellets containing 0.01 g of oxidant.

[0075] FIG. 17 is a linear-fit for release data from 0.5 g of pellets containing 0.1 g oxidant to determine the release rate. FIG. 18 is a bar chart presenting continuous release concentration measurements of oxidant release from 0.5 g of pellets containing 0.1 g of oxidant

[0076] Controlled release remediation compositions based on the polymer blends were made. Chemical oxidant agent release was delayed by increasing the amount of PCL in the polymer blends. PAB-50, PAB-60 and PAB-70 contained 50%, 60% and 70% PCL in the polymer blend respectively. These polymers released KMnO_4 faster than PAB-80 and PAB-100. It was also observed that homogenous mixing of the polymers for the blends was beneficial. PVOH is hydrophilic and will readily dissolve in water leaving pores in the hydrophobic PCL matrix. When PVOH is not homogeneously mixed in the interior of the matrix and PVOH crystals are located on the surface of the pellet, KMnO_4 will be released in to the water at a faster rate. This was observed in PAB-90 which demonstrated a significantly higher release rate for the oxidants.

[0077] Controlled release remediation composition PAB-50 which is a 50/50 and controlled release remediation composition PAB-60 which is as a 60/40 mix of two polymers released KMnO_4 at a faster rate than PAB-80 and PAB-100. Controlled release remediation composition PAB-90 exhibited a higher than expected release rate for KMnO_4 compared to the other samples. Applicant believes that the polymer blend was not homogeneously distributed throughout the pellet. Either more dissolution polymer was present at the surface of the pellet or surface imbedded KMnO_4 was present on the surface of the pellet and caused a rapid release of the oxidant.

[0078] While typical embodiments have been set forth for the purpose of illustration, the foregoing description should not be deemed to be a limitation on the scope of the invention. Accordingly, various modifications, adaptations, and alternatives may occur to one skilled in the art without departing from the spirit and scope of the present invention. It should be understood that all such modifications and improvements have been deleted herein for the sake of conciseness and readability but are properly within the scope of the following claims.

1. A controlled release remediation composition comprising:

A) at least one chemical oxidant agent, wherein the at least one chemical oxidant agent is capable of remediating at least one chemical pollutant;

B) an encapsulant polymer, wherein:

i) at least a portion of the encapsulant polymer encapsulates at least a portion of the chemical oxidant agent, and

ii) at least a portion of the encapsulant polymer comprises at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer; and

C) a matrix polymer, wherein:

i) at least a portion of the matrix polymer embeds at least a portion of the encapsulated chemical oxidant agent, and

ii) at least a portion of the matrix polymer comprises at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer,

Wherein the controlled release remediation composition is capable of substantially constantly releasing an amount of the at least one agent chemical oxidant agent into an aqueous system over least about a one month period up to over about a three month period.

2. The controlled release remediation composition according to claim 1, wherein the composition comprises at least one pellet.

3. The controlled release remediation composition according to claim 2, wherein the at least one pellet comprises one of more dimensions ranging from about a micron (μm) to multiple tens of millimeters (mm).

4. The controlled release remediation composition according to claim 3, wherein the at least one pellet comprises a largest dimension of about 1 millimeter (mm), about -18 mesh), optionally between about 500 microns (μm) and about $1.0\ \mu\text{m}$ (about -35 , $+1000$ mesh), and optionally between about 300 microns (μm) and about $1.0\ \mu\text{m}$ (about -50 , $+635$ mesh).

5. The controlled release remediation composition according to claim 1, wherein the at least one pellet comprises any one of a sphere, a cylinder, a wagon wheel, gear-shape, a saddle, a disk, a brick, a coil, a column, a hollow-elbow, a chip, a fiber, or any two or more of the preceding.

6. The controlled release remediation composition according to claim 1, wherein the at least one chemical oxidant agent comprises at least one of a photo-oxidants agent, an electron transfer reaction agent, a free radical agent, or combinations of any two or more of the preceding.

7. The controlled release remediation composition according to claim 1, wherein the at least one chemical oxidant agent

comprises at least one of a persulfate agent, a permanganate agent, or combinations of any two or more of the preceding.

8. The controlled release remediation composition according to claim 1, wherein the at least one chemical oxidant agent comprises at least one of a titanium oxide agent, a molybdenum sulfide agent, a molybdenum sulfide agent, zinc sulfide agent, a sodium permanganate agent, a potassium permanganate agent, sodium persulfate agent, ammonium persulfate agent, potassium persulfate agent, or a combination of any two or more of the preceding.

9. The controlled release remediation composition according to claim 1, wherein the matrix polymer comprised a degradation rate less than the release rate of the at least one chemical oxidant agent and greater than the encapsulant degradation rate the at least one encapsulant polymer.

10. The controlled release remediation composition according to claim 1, further comprising at least one additional encapsulant polymer, wherein at least a portion of the at least one additional encapsulant polymer encapsulates at least a portion of the matrix polymer embedding at least a portion of the encapsulated chemical oxidant agent.

11. The controlled release remediation composition according to claim 1, wherein the environmentally degradable polymer or the biodegradable polymer comprises at least one of a polylactide, a polyglycolide, a polylactide-co-glycolide, a polylactic acid, polyglycolic acid, polylactic acid-co-glycolic acid, a polycaprolactone, a polycarbonates, a polyesteramides, a polyanhydrides, a polyamino acid, a polyorthoester, a polyacetyls, a polycyanoacrylates, polyetheresters, a polydioxanone, a polyalkylen alkylate, a copolymer of a polyethylene glycol and a polylactid or polylactide-co-glycolide, a biodegradable polyurethane, a polysaccharide, a blend of any two or more of the preceding, or a copolymer of any two or more of the preceding.

12. The controlled release remediation composition according to claim 11, wherein the blend comprises:

b1) between 0 wt % to about 100 wt % of a first polymer;

b2) between 0 wt % to about 60 wt % of a second polymer; and

b3) a balance of a third polymer.

13. The controlled release remediation composition according to claim 11, wherein the copolymer comprises:

c1) between 0 wt % to about 100 wt % of a first polymer;

c2) between 0 wt % to about 60 wt % of a second polymer; and

c3) a balance of a third polymer.

14. The controlled release remediation composition according to claim 1, wherein the environmentally degradable polymer or the biodegradable polymer comprises at least one of a polylactic acid, polyvinyl alcohol, polycaprolactone, a blend of any two or more of the preceding, or a copolymer of any two or more of the preceding.

15. The controlled release remediation composition according to claim 14, wherein the blend comprises:

b11) between 0 wt % to about 60 wt % of a polylactic acid;

b12) between 0 wt % to about 60 wt % of a polyvinyl alcohol; and

b13) between 0 wt % to about 100 wt % of a polycaprolactone.

16. The controlled release remediation composition according to claim 14, wherein the copolymer comprises:

c11) between 0 wt % to about 100 wt % of a polycaprolactone

c12) between 0 wt % to about 60 wt % of a polyvinyl alcohol; and

c13) a balance of at least one of a polylactide, a polyglycolide, a polylactide-co-glycolide, a polylactic acid, polyglycolic acid, polylactic acid-co-glycolic acid, a polycarbonates, a polyesteramides, a polyanhydrides, a polyamino acid, a polyorthoester, a polyacetyls, a polycyanoacrylates, polyetheresters, a polydioxanone, a polyalkylen alkylate, a copolymer of a polyethylene glycol and a polylactid or polylactide-co-glycolide, a biodegradable polyurethane, a polysaccharide, a blend of any two or more of the preceding, or a copolymer of any two or more of the preceding.

17. The controlled release remediation composition according to claim 1, wherein the at least one chemical pollutant comprises at least one of a chlorinated organic compound, a compound containing at least one unsaturated carbon-carbon bond, an aromatic hydrocarbon, a polycyclic aromatic hydrocarbon, a munitions constituent, an organic pesticide, wastewater, a drinking water treatment, a pathogen, or any combination of two or more of the preceding.

18. The controlled release remediation composition according to claim 1, wherein:

- α) the at least one chemical oxidant agent comprises between about 1 wt % to about 60 wt % of the controlled release remediation composition;
- β) encapsulant polymer comprises between about 1 wt % to about 99 wt % of the controlled release remediation composition; and
- γ) matrix polymer comprises the balance of the controlled release remediation composition.

19. The controlled release remediation composition according to claim 1, wherein the at least one chemical oxidant agent comprises a particle size comprising about 125 μm (−120 mesh), optionally between about 75 microns (μm) and about 1.0 μm (About −200, +1000 mesh), and optionally between about 50 microns (μm) and about 1.0 μm (about −270, +1000 mesh).

20. A method of making controlled release remediation composition, the method comprising the steps of:

- A) selecting at least one chemical oxidant agent capable of remediating at least one chemical pollutant;
- B) selecting an encapsulant polymer that is substantially compatible with the at least one chemical oxidant agent and comprises at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer;
- C) encapsulating at least a portion of the chemical oxidant agent using the encapsulant polymer;
- D) selecting a matrix polymer comprising at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer; and
- E) combining the encapsulated chemical oxidant agent and the matrix polymer so that at least a portion of the matrix polymer embeds at least a portion of the encapsulated chemical oxidant agent.

21. A remediation system comprising:

- A) at least one controlled release remediation composition comprising:
 - i) at least one chemical oxidant agent, wherein the at least one chemical oxidant agent is capable of remediating at least one chemical pollutant;

- ii) an encapsulant polymer, wherein:

- a) at least a portion of the encapsulant polymer encapsulates at least a portion of the chemical oxidant agent, and
- b) at least a portion of the encapsulant polymer comprises at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer; and

- iii) a matrix polymer, wherein:

- a) at least a portion of the matrix polymer embeds at least a portion of the encapsulated chemical oxidant agent, and
- b) at least a portion of the matrix polymer comprises at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer; and

B) an amount of at least one controlled release remediation composition capable of being provided such that the remediation product is capable of substantially constantly releasing a sufficient amount of the at least one chemical oxidant agent into a contaminated site over at least about a one month period up to over about a three month period so as to remediate at least a portion of the at least one chemical pollutant.

22. A method of using a controlled release remediation composition, the method comprising the steps of:

- A) determining at least one chemical pollutant to be remediated at a contaminated site;
- B) selecting at least one chemical oxidant agent capable of remediating the at least one chemical pollutant;
- C) selecting an encapsulant polymer that is substantially compatible with the at least one chemical oxidant agent and comprises at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer;
- D) encapsulating at least a portion of the chemical oxidant agent using the encapsulant polymer;
- E) selecting a matrix polymer comprising at least one of an environmentally degradable polymer, a biodegradable polymer, or an environmentally degradable polymer and biodegradable polymer;
- F) combining the encapsulated chemical oxidant agent and the matrix polymer so that at least a portion of the matrix polymer embeds at least a portion of the encapsulated chemical oxidant agent to form a controlled release remediation composition;
- G) shaping, sizing, or shaping and sizing the controlled release remediation composition so as to be capable of substantially constantly releasing an amount of the at least one chemical oxidant agent into an aqueous system from over at least about a one month period up to over about a three month period; and
- H) providing a sufficient amount of the shaped, sized, or shaped and sized controlled release remediation composition to the contaminated site in manner that remediates at least a portion of the at least one chemical pollutant at the contaminated site.

23. A controlled release remediation composition comprising:

- A) a plurality of chemical oxidant agents, wherein at least two of the plurality chemical oxidant agents are capable of remediating at least two different chemical pollutants; and
- B) a polymer, wherein:
 - i) at least a portion of the polymer encapsulates at least a portion of the plurality of chemical oxidant agents, and

- ii) at least a portion of the polymer comprises a biodegradable polymer.

Wherein the controlled release remediation composition is capable of substantially constantly releasing amounts of the at least two of the plurality chemical oxidant agents into an aqueous system from over at least a one month period up to over about a three month period.

* * * * *