PORTABLE IN-SITU OXYGENATION AND HYDROGENATION REMEDIAL SYSTEM

Methods and systems are presented for in-situ remediation of contaminated groundwater utilizing a body deployed in a groundwater well in communication with groundwater to be treated. At least two electrodes positioned are within the body and are supplied with DC current for electrolyzing groundwater to produce a beneficial gas, to be entrained in the groundwater, and an exhaust gas. A collector may be provided for exhaust gas evolved at the second electrode during electrolysis. A conduit in flow communication with the collector for channeling exhaust gas away from the electrodes and groundwater may also be included.
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PORTABLE IN-SITU OXYGENATION AND HYDROGENATION REMEDIAL SYSTEM

[001] This application claims the benefit of U.S. Provisional Application No. 60/813,419, filed June 14, 2006, which is hereby incorporated by reference in its entirety.

[002] Provided are certain systems and methods for the treatment of groundwater, and more specifically, to systems and methods for in-situ decontamination of groundwater by infusing contaminated soil with hydrogen or oxygen.

[003] Groundwater treatment systems may employ anaerobic or aerobic biodegradation to remove contaminants from subterranean water sources. Contaminated soil may be infused with gas to create an environment suitable for anaerobic or aerobic biodegradation. Current in-situ groundwater treatment systems are typically large-scale systems that require sophisticated technical expertise to install and maintain, a considerable area on the ground surface to be dedicated to system controllers and other equipment, and a traditional alternating current (AC) electrical power connection to be available at the treatment site. Many current systems require digging in order to access contaminated soil and groundwater or for subterranean placement of treatment equipment. Most current treatment systems focus on aerobic biodegradation.

[004] Provided are systems and methods for in-situ treatment of groundwater using a body configured to be disposed below ground level in communication with the groundwater to be treated. The body includes at least one first electrode and at least one second electrode positioned inside the body for electrolyzing groundwater to provide an exhaust gas and a beneficial gas. The beneficial gas is entrained in the groundwater of a remedial area. Some
embodiments further include a conduit for channeling the exhaust gas away from the electrodes and groundwater. Some embodiments further include a groundwater pump deployed in a well or housed within the body of the system for circulating groundwater.

[005] A method of treating groundwater in-situ at a location below ground level is provided, including installing at the location a treatment system having at least one first electrode and at least one second electrode. The method further includes providing polarized power to the electrodes to stimulate electrolysis, evolving a beneficial and an exhaust gas at the electrodes, and entraining the beneficial gas in the groundwater. Some embodiments further include channeling the exhaust gas away from the electrodes and groundwater. Some embodiments further include flowing groundwater through the system past the first and second electrodes

**BRIEF DESCRIPTION OF THE FIGURES**

[006] Figure 1 shows a detailed sectional view of an exemplary system for in-situ treatment of groundwater.

[007] Figure 2 shows a cross-sectional view of the exemplary system of Fig. 1.

[008] Figure 3 shows a local environmental view of two exemplary systems deployed in a groundwater well.

[009] Figure 4 shows an environmental view of a chain of exemplary systems installed in a groundwater well and connected to a solar power supply.

[010] Figure 5 shows a sectional view of another exemplary system for the in-situ treatment of groundwater.
[011] Reference will now be made in detail to one or more exemplary embodiments of the present invention as illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[012] Figure 1 shows a detailed sectional view of an exemplary system for in-situ treatment of groundwater. In some embodiments, system 1 includes a single hollow body 2. In some embodiments, body 2 is cylindrical. In some embodiments, system 1 is closed off at one or both ends by an end cap 11. In some embodiments, the end cap 11 is secured with screws 12. Body 2 is constructed of any non-conducting material. In some embodiments, body 2 is made of acrylic. In some embodiments, body 2 is made of PVC or another plastic material. In some embodiments, end cap 11 is made of the same material as body 2. In some embodiments, end cap 11 is made of a different non-conducting material than body 2.

[013] In some embodiments, groundwater enters system 1 through one or more inlet ports 8 near the base of body 2 and flows into filter chamber 6. In some embodiments, filter chamber 6 is filled with filter material 7. In some embodiments filter material 7 comprises one or more materials capable of removing particulate and/or contaminant material from groundwater. In some embodiments, filter material 7 comprises granular-activated carbon. In some embodiments, filter material 7 comprises calcium salts or another salt or salts. In some embodiments, groundwater flows through filter material 7 and through chamber divider 14 into electrolysis chamber 5. In some embodiments, groundwater flows directly into electrolysis chamber 5 without passing through any filter material or chamber divider 14.
[014] Electrolysis chamber 5 contains a plurality of électrodes, including at least one cathode 3 and at least one anode 4 for producing hydrogen and oxygen, respectively. System 1 is powered by electrical power delivered by line cord 9, which in some embodiments extends from the system to a power source above the ground surface. In some embodiments, line cord 9 is connected to a battery, which may be located anywhere within the monitoring well, within body 2, or otherwise attached to system 1. In some embodiments, line cord 9 is terminated at each end by waterproof connector plugs 13. Anodes 4 are connected to the positive lead of line cord 9, while cathodes 3 are connected to the negative lead of line cord 9. Cathodes 3 and anodes 4 are made of a conductive material. In some embodiments, cathodes 3 and anodes 4 are made of a noble and/or transitional metal such as graphite or a carbon-graphite composite; however, many different conductive materials may be suited for this application. In some embodiments, cathodes 3 and anodes 4 may be made of the same material, while in some embodiments, cathodes 3 and anodes 4 may be made of different noble and/or transitional metals.

[015] In some embodiments, an even number of cathodes 3 and anodes 4 is arranged in a pattern of alternating polarity. In some embodiments, each anode 4 and cathode 3 is separated from other electrodes in electrolysis chamber 5 by screen 15. In some embodiments, screen 15 is made of nylon, e.g., fine-mesh nylon. Screen 15 allows electrons, but not gas, to pass through. Screen 15 keeps the hydrogen and oxygen gasses created by electrolysis separated and ensures each will be funneled to its appropriate tube.

[016] When power is supplied to cathodes 3 and anodes 4, the process of electrolysis splits groundwater in electrolysis chamber 5 into its separate molecular
parts of oxygen and hydrogen. During electrolysis, small bubbles of oxygen gas form on anodes 4 and small bubbles of hydrogen gas form on cathodes 3. When the bubbles become large enough, they break free from the anodes 4 and cathodes 3 and travel upwards in electrolysis chamber 5. In some embodiments, the oxygen gas is funneled through electrolysis chamber gas outlet tube 16, into exhaust tube 10, and ultimately above the ground surface to be released into the atmosphere.

The hydrogen gas is funneled through electrolysis chamber gas outlet port 17 and released into the groundwater and infused in the surrounding soil. Bacteria in the surrounding soil may then use the hydrogen gas to perform anaerobic biodegradation of groundwater contaminants, thus remediating the soil and groundwater surrounding system 1. In some embodiments, groundwater circulation may be improved by use of a pump (not shown) installed inside the well or within system 1 (not shown).

[017] In some embodiments, if oxygen is the desired gas for remediating soil and groundwater, the polarity of line cord 9 is reversed. In some embodiments, polarity is reversed using a switch on system 1 or the power supply. In some embodiments, polarity is reversed by inverting the position of connector plug 13. When polarity has been reversed, electrodes 3, which were previously hydrogen-accumulating cathodes, become oxygen-accumulating anodes 4, and electrodes 4, which were previously oxygen-accumulating anodes, become hydrogen-accumulating cathodes 3. Accordingly, when polarity has been reversed, hydrogen gas is now funneled through electrolysis chamber gas outlet tube 16 and exhaust tube 10; into the atmosphere. Oxygen gas is funneled through electrolysis chamber gas outlet port 17 into the well, and thus into the surrounding groundwater and soil. This infusion of oxygen allows bacteria in surrounding soil to perform aerobic
biodegradation of groundwater contaminants. In some embodiments, both oxygen and hydrogen are released into the groundwater well at different depths.

[018] In some embodiments, a low-voltage DC power supply at 12 volts or less is sufficient to support operation of system 1. In some embodiments, the power source is located above ground surface. The power source may use direct current and may be a generator or a solar panel or array. In some embodiments, a power source such as a battery is located within a well or within system 1 itself. In some embodiments, power may be supplied to system 1 by an AC rectified power source via line cord 9 and converted to DC power to support operation of system 1.

[019] Many different size combinations of a power supply, system 1, and electrodes 3, 4 are possible. However, as an example, an embodiment of system 1 employing a 12-volt direct current (DC) power supply and four 5-inch electrodes (two anodes 4 and two cathodes 3) produces approximately 2 cubic inches (32.78 cubic centimeters) of hydrogen gas, and 1 cubic inch (16.39 cubic centimeters) of oxygen in one hour. In some embodiments, system 1 employing four 5-inch electrodes (two anodes 4 and two cathodes 3) may produce between 11 cubic centimeters and 58 cubic centimeters of hydrogen, and 5.5 cubic centimeters and 29 cubic centimeters of oxygen in one hour as voltage is varied between 6-volt DC to 30-volt DC current. In some embodiments, system 1 employing four 7.5-inch electrodes (two anodes 4 and two cathodes 3) may produce between 17 cubic centimeters and 127 cubic centimeters of hydrogen, and 8.5 cubic centimeters and 63.5 cubic centimeters of oxygen in one hour as voltage is varied between 6-volt DC to 30-volt DC current. In some embodiments, system 1 employing four 10-inch electrodes (two anodes 4 and two cathodes 3) may produce between 19 cubic centimeters and 147 cubic centimeters of hydrogen, and 9.5 cubic centimeters and 73.5 cubic centimeters of
oxygen in one hour as voltage is varied between 6-volt DC to 30-volt DC current. The increase of hydrogen and oxygen production observed with increasing voltage applied to a fixed electrode length may be approximately linear. Increasing electrode length at a fixed voltage may result in an observed logarithmic increase in hydrogen and oxygen production.

[020] Some embodiments may rely solely on bacteria native to the soil to perform the remediation process. In some embodiments, useful bacteria strains may be deployed into soil surrounding system 1 before or during operation of system 1.

[021] In some embodiments, two or more systems 1 are connected together, or “chained” within a well in order to facilitate faster remediation or remediation of a larger soil and groundwater area. In some embodiments, waterproof connector plug 13 of a first system 1 is connected to waterproof connector plug 13 of a second system 1 to chain the two systems together. In some embodiments, exhaust tubes 10 of two or more systems 1 screw or slide together in order to chain two or more systems 1. In some embodiments, a slip coupling is used to connect exhaust tubes 10 between two or more systems 1.

[022] In some embodiments, system 1 is self-contained and small enough to fit in existing monitoring wells. For example, many gasoline stations are equipped with monitoring wells as small as two inches in diameter. According to some embodiments, system 1 is small enough to be easily transported to a contaminated site and utilize such pre-existing wells. Further, according to some embodiments, system 1 is capable of operating on low-voltage DC current, making groundwater treatment possible at remote sites where no standard electricity connections are available. In some embodiments, a solar panel or array may provide enough power to operate a system or array of systems.
According to some embodiments, system 1 is installed by a person without any special skill or knowledge of groundwater treatment, as the only requirements for effective operation are that system 1 be placed in a contaminated groundwater source and be plugged into a power source in much the same manner as any common electrical system. In some embodiments, the system is unobtrusive compared to previous groundwater treatment systems in that it requires only a small exhaust tube and line cord to extend above ground level.

Figure 2 shows a cross-sectional view of the exemplary system of Fig. 1. According to some embodiments, within body 2, filter material 7 forms a layer, through which groundwater may pass before flowing through chamber divider 14 and entering electrolysis chamber 5 (as shown in Fig. 1). Anodes 4 and cathodes 3 are arranged around exhaust tube 10, which is within body 2 and runs beyond the length of body 2 at each end. Barrier 15 provides separation between electrodes 3, 4 and in some embodiments, prevents mixing of the gases created by electrolysis. The positive lead of line cord 9 connects to anodes 4, while the negative lead of line cord 9 connects to cathodes 3.

Figure 3 shows a local environmental view of an exemplary remediation system comprising two systems 1 deployed in a groundwater well in some embodiments. Respective line cords 9 are connected to each other via waterproof connector plugs 13. In some embodiments, exhaust tubes 10 are connected via slip couplings 21 to effectively form one long exhaust tube reaching from beneath the last system 1 in the chain to above ground surface. In some embodiments, exhaust tube 10 of the last (bottom) system 1 in the chain is capped by plug 19.
[026] In some embodiments, one or more remediation systems are deployed in a groundwater monitoring well between 2 and 4 inches in diameter. In some embodiments, a top portion of the walls of the monitoring well is solid tubing constructed of a material such as schedule 40 PVC or another water-impervious material, while a permeable member such as slotted well screen 18 forms the walls of the monitoring well below the water table 22. In some embodiments, slotted well screen 18 may be perforated with openings, which may be, e.g., between 0.01 and 0.02 inches in wide to allow water to enter the well and to allow the passage of gas or other injected material out of the well into surrounding remedial area 24. According to some embodiments, during electrolysis, gas bubbles 20 of the desired gas are released directly into the well and surrounding groundwater and seep through a permeable member such as slotted well screen 18 in Fig. 3 into surrounding soil, facilitating anaerobic or aerobic biodegradation.

[027] FIG. 4 shows an environmental view of chained groundwater treatment systems 1 deployed in a groundwater well 26. In some embodiments, the chained systems are held below the water table 22 by a bob 23 at the bottom of well 26. An exhaust tube 10 and line cord 9 extend up well 26 to above the ground surface. Above the surface, line cord 9 is connected to an electrical power supply 25. In some embodiments, the power supply is a solar panel or array 25. In some embodiments, power supply 25 is any DC electrical source, including, for example, an external power source connected to available electric service, a battery, or a generator. Once in operation, enriched groundwater produced by the system or systems deployed in the well passes from groundwater well 26 into the surrounding remedial area 24. Within remedial area 24, bacteria will use the beneficial gas in the enriched groundwater to break down contaminants in soil and groundwater to their
less harmful components, thereby remediating the surrounding soil and groundwater in remedial area 24. Some embodiments may rely solely on bacteria native to the soil to perform the remediation process. In some embodiments, useful bacteria strains may be deployed into remedial area 24 before or during operation of systems 1.

[028] FIG. 5 provides a detailed sectional view of another embodiment of system 1. According to some embodiments, system 1 is contained in body 2. Groundwater enters system 1 through one or more inlet ports 8 near the base of the system, into the filter chamber 6 filled with filter material 7. In some embodiments, groundwater passes through filter material 7, removing particulate and contaminant material. From filter chamber 6, groundwater passes through the divider 14a, and through the electrolysis chamber inlet 29 into the electrolysis chamber 5. In some embodiments, filter chamber 6 and filter material 7 may not be present, meaning divider 14a either does not exist or is effectively the base of the system, and groundwater passes directly into the electrolysis chamber 5.

[029] In some embodiments, in electrolysis chamber 5, electrodes 3 and 4 are positioned in a circular pattern around the inside of electrolysis chamber 5 surrounding exhaust tube 10. In some embodiments, an even number of electrodes is arranged in an alternating pattern of anodes and cathodes. Electrodes 3 are made of conductive materials. In some embodiments, electrodes are made of noble or transitional metals. Power is supplied to the electrodes 3 and 4 by a line cord 9 that extends from system 1 to the ground surface where it is connected to a power supply. In some embodiments, system 1 operates on direct current power. When power is supplied to the system, electrodes 3 and 4 split groundwater inside electrolysis chamber 5 into its molecular parts of oxygen and hydrogen through the
process of electrolysis. Oxygen is produced at the anode, which is the electrode 4 connected to the positive lead of the line cord 9, while hydrogen is produced at the cathode, which is the electrode 3 connected to the negative lead of the line cord 9.

[030] As water is split into its molecular parts, bubbles of oxygen and hydrogen form on the surface of the anodes and cathodes, respectively. These bubbles grow in size until they separate from their respective electrodes 4 and 3 and travel upwards in electrolysis chamber 5. In some embodiments, the bubbles eventually encounter the chamber divider 14b between the electrolysis chamber 5 and diffusion chamber 32. In some embodiments, above each electrode, respective funnels formed in the chamber divider 14b direct at least a portion of gas produced by each respective electrode upward into diffusion chamber 32 or past the diffusion chamber 32 through outlet tube 16 and into exhaust chamber 30. In some embodiments, the beneficial gas—either oxygen or hydrogen—to be used for remedial action is directed into a gas diffuser 28. In the system depicted in Fig. 5, hydrogen gas from cathode 3 would be directed into diffusion chamber 32, while oxygen from anode 4 would be directed to exhaust chamber 30. Diffusion chamber 32 is open to the surrounding groundwater well by the outlet ports 17. In some embodiments, beneficial gas passes through gas diffuser 28 and mix with groundwater in diffusion chamber 32, enriching the surrounding groundwater with the dissolved beneficial gas. In some embodiments, gas diffuser 28 is not included, and the beneficial gas entering diffusion chamber 32 is dissolved directly into groundwater. The enriched groundwater flows from the system 1 into the groundwater well, and eventually into the saturated soil surrounding the well. In some embodiments, native bacteria in the surrounding soil will then use the beneficial gas in the enriched groundwater to break down contaminants in soil and
groundwater to their less harmful components, thereby remediating the surrounding soil and groundwater. In some embodiments, useful bacteria may be introduced into the contaminated area before or during operation of system 1.

[031] In some embodiments, at least a portion of the gas that is not currently being used for remediation—either oxygen or hydrogen—will pass from electrolysis chamber 5 through electrolysis chamber outlet tube 16, which passes through diffusion chamber 32 and chamber divider 14c to the exhaust chamber 30. From exhaust chamber 30 the gas passes through the exhaust tube inlet port 27 into the exhaust tube 10, then up the exhaust tube 10 to ground surface where the unused gas is released to the atmosphere. Some embodiments include a partition, such as partition 31 at the top of the system in Fig. 5, to center and isolate the system in the groundwater well.

[032] Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosure herein. It is intended that the specification and examples be considered as exemplary only, and not an exhaustive list of every combination of features that may comprise the invention described herein.
WHAT IS CLAIMED IS:

1. An in-situ groundwater treatment system comprising:
   a body configured to be disposed below ground level in communication with
   the groundwater to be treated, the body including at least one groundwater inlet, and
   at least one groundwater outlet;
   at least one first electrode positioned inside the body for electrolyzing
   groundwater to provide a beneficial gas;
   at least one second electrode positioned inside the body for electrolyzing
   groundwater to provide an exhaust gas
   an electrical power source operatively connected to supply current of one
   polarity to the first electrode and current of an opposite polarity to the second
   electrode;
   a collector for the exhaust gas evolved at the second electrode during
   electrolysis; and
   a conduit in flow communication with the collector for channeling the exhaust
   gas away from electrodes and the groundwater,
   wherein the beneficial gas is entrained in the groundwater leaving the outlet.

2. The system of claim 1, wherein the power source comprises a line cord
   for supplying power to the at least one first electrode and at least one second
   electrode.

3. The system of claim 2, wherein the at least one first electrode and at
   least one second electrode are arranged in even-numbered pairs.

4. The system of claim 3, wherein each first or second electrode is
   separated from all other first or second electrodes by an electrode isolation screen to
   avoid mixing gases.
5. The system of claim 4, wherein the electrode isolation screen is made of a fine-mesh nylon.

6. The system of claim 3, wherein the first electrode pairs and the second electrode pairs are arranged in a circular pattern.

7. The system of claim 1, further comprising a groundwater pump for increasing groundwater circulation in a remedial area.

8. The system of claim 1, wherein the beneficial gas is disposed at a body inlet.

9. The system of claim 1, wherein the system is portable.

10. The system of claim 1, wherein the conduit is configured to channel the exhaust gas for release to the atmosphere above ground level.

11. The system of claim 1, wherein the first electrode is a cathode, and wherein hydrogen is the beneficial gas.

12. The system of claim 1, wherein the first electrode is an anode, and wherein oxygen is the beneficial gas.

13. The system of claim 1, further comprising an electrolysis chamber that houses the first electrode and the second electrode.

14. The system of claim 1 wherein the first electrode and the second electrode are constructed of a conductive material.

15. The system of claim 2 wherein the line cord further comprises at least one waterproof connector plug.

16. The system of claim 1 wherein the power source comprises at least one of:

   a low-voltage direct current (DC) power source;

   a solar cell;
a solar array;
a battery; and
an electrical generator..

17. The system of claim 1 wherein the first electrode and the second electrode are constructed of at least one of:
   graphite;
a carbon-graphite composite;
a noble metal; and
a transitional metal.

18. The system of claim 1, further comprising a partition connected to the body and configured to hold the system in place in a treatment area.

19. The system of claim 1, wherein a main body of the groundwater treatment system is constructed of one or more nonconductive materials.

20. The system of claim 1, wherein a main body of the groundwater treatment system is constructed of PVC.

21. The system of claim 1, wherein a main body of the groundwater treatment system is constructed of a plastic.

22. The system of claim 1, further comprising filter material through which groundwater passes before being electrolyzed.

23. The system of claim 22 wherein the filter material comprises at least one of:
   activated carbon; and
   a calcium salt.
24. The system of claim 22, wherein the body further comprises a filter chamber in flow communication with the at least one groundwater inlet port and containing the filter material.

25. The system of claim 24, further comprising a filter chamber divider separating the filter material from an area where electrolysis is performed.

26. The system of claim 1, further comprising a gas screen disposed between the first electrode and the second electrode.

27. The system of claim 26, wherein the screen is a fine-mesh nylon screen.

28. The system of claim 1, wherein at least two groundwater treatment systems are connected to form a chain.

29. The system of claim 28, wherein the line cords of the at least two groundwater treatment systems are coupled to each other.

30. The system of claim 28, wherein the exhaust conduits of the at least two groundwater treatment systems are coupled to each other.

31. The system of claim 28, wherein the bottom of the exhaust conduit of the last groundwater treatment system in the chain is plugged with a stopper.

32. The system of claim 1, further comprising a diffusion chamber.

33. The system of claim 32, wherein the diffusion chamber further comprises at least one beneficial gas outlet port.

34. The system of claim 32, wherein the diffusion chamber contains a gas diffuser connected to the first electrode or the second electrode that generates the beneficial gas.

35. The system of claim 1, further comprising an exhaust chamber.
36. The system of claim 35, wherein the exhaust chamber further comprises at least one outlet port to the exhaust conduit.

37. The system of claim 35, further comprising at least one exhaust chamber partition separating the exhaust chamber from at least one of:

- a filter chamber;
- an electrolysis chamber; and
- a diffusion chamber.

38. The system of claim 1, wherein the exhaust conduit comprises at least one inlet for receiving exhaust gas.

39. A method of treating groundwater in-situ at a location below ground level comprising:

- installing at the location at least one treatment system having at least one first electrode and at least one second electrode;
- flowing groundwater through the system past the first and second electrodes;
- providing polarized power to the electrodes for electrolysis;
- evolving a beneficial gas from the groundwater at the first electrode and an exhaust gas at the second electrode;
- collecting the exhaust gas evolved from the second electrode;
- channeling the collected exhaust gas away from the electrodes and flowing groundwater; and
- entraining the beneficial gas in the flowing groundwater.

40. The method of claim 39 wherein the at least one treatment system is installed in a pre-existing well.

41. The method of claim 39 further comprising drilling a treatment well in a section of contaminated groundwater.
42. The method of claim 41 wherein the at least one treatment system is installed in the drilled treatment well.

43. The method of claim 39 further comprising reversing the electrical polarity of the supplied power.

44. The method of claim 39 further comprising coupling together a plurality of groundwater treatment systems.

45. The method of claim 39, further comprising filtering groundwater before flowing it through the system.

46. The method of claim 39, wherein entraining the beneficial gas includes diffusing the beneficial gas into the groundwater.

47. The method of claim 39, wherein flowing groundwater includes pumping groundwater through the system.

48. The method of claim 39, further comprising separating the evolved gases with an ion-permeable membrane.

49. The method of claim 39, further comprising disposing beneficial bacteria into the well at the location of the groundwater to be treated.
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 07/13862

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8)- C02F 1/00 (2007.01)
USPC - 210/170.07; 204/553, 562, 247
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 210/170.07; 204/553, 562, 247

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

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
Electronic Databases Searched: USPTO WEST (PGPUB, EPAB, JPA6, USPT), Google patent, Google Scholar. Search Terms Used: nylon, electrospinning, adj water, groundwater, beneficial adj gas, inlet and outlet, electrode, body, below adj ground, commu115, treatment, greater or lower or less, in-situ, exhaust.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>Y</td>
<td>US 2003/0075435 A1 (Kemner et al.) 24 April 2003 (24.04.2003) especially figure 1-2; para [0005]-[0006]; [0029]</td>
<td>5-6, 10, 27, 32-34, 37, 46</td>
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Further documents are listed in the continuation of Box C.

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