ABSTRACT

A system for forming a permeable reactive barrier includes a source conduit for providing a substantially dry barrier-forming material at an initial flow velocity. A delivery conduit arrangement is in fluid communication with the source conduit and includes a first delivery conduit and a second delivery conduit. The first and second delivery conduits each have an outlet end for being positioned proximate a bottom of respective spaced-apart boreholes in the ground. The first and second delivery conduits each have one or more openings defined in respective sidewalls thereof proximate the outlet ends thereof, for venting air that is entrained in the flow of the material. A total cross-sectional area of a flow path increases between the source conduit and the outlet ends of the first and second delivery conduits. During operation a final flow velocity of the barrier-forming material is at least about 30% less than the initial flow velocity.

METHOD AND SYSTEM FOR FORMING A PERMEABLE REACTIVE BARRIER IN THE GROUND

FIELD

The present invention relates generally to methods and systems for *in situ* construction of a subsurface containment region for containing hazardous waste or contaminated soil buried under in the ground, and more particularly to a method and system for forming an underground permeable reactive barrier.

BACKGROUND

Dr. Robert Gillham of the University of Waterloo, decades ago, discovered a method of in-situ treatment of chlorinated solvents by introducing iron filings into a polluted ground source of ground water.

Sayles et al. (Environmental Science and Technology, 1997) investigated the utility of using zero-valent iron (e.g., granular iron filings and the like) to dechlorinate DDT and related compounds in an anaerobic aqueous environment. Sayles et al. also acknowledged the importance of providing for a large surface-area of reactive iron, such as that which could be facilitated by the use of a fine particulate or powdered forms of iron. This method became popular and was used later by mixing iron filings with sand.

Currently, various techniques are known for forming zero-valent iron permeable reactive barriers. These known techniques can be classified based on whether placement of the barrier requires digging a trench or is achieved without digging a trench. Those techniques that do not require digging a trench may be further classified based on whether a continuous or discontinuous barrier is formed.

As will be apparent, barrier placements that require digging a trench are limited to relatively shallow depths, cause considerable disruption of the surface and subsurface, and are not well suited for areas in which the subsurface contains large cobbles or consolidated rock formations. On the other hand, barrier placements involving the drilling of boreholes into the ground can be used to form barriers to deeper depths than is possible using trenched techniques, and the presence of cobbles or consolidated rock formations is not a major concern.

One approach involves drilling a series of large diameter boreholes, which are spaced closely together such that adjacent boreholes overlap with one another. When a barrier material is placed into the boreholes, the resulting barrier is continuous along the length of the series of boreholes. Alternatively, a series of smaller diameter boreholes may be drilled in a spaced-apart arrangement and fracturing techniques may be used to open a space between the adjacent boreholes. Once again, when a barrier material is placed into the boreholes, the resulting barrier is continuous along the length of the series of boreholes. Yet another approach involves drilling an array of spaced-apart boreholes, which is arranged in a plurality of staggered rows. When a barrier material is placed into the boreholes, the resulting barrier is discontinuous, but the array is designed such that contaminated groundwater must flow through the barrier material in at least one of the boreholes in at least one of the rows.

The use of staggered rows of boreholes to form a permeable reactive barrier is particularly attractive because greater depths may be reached, the barrier may be constructed close to property lines, and the subsurface composition is not problematic. Unfortunately, the boreholes tend to be relatively small in diameter (e.g., 6 inches), which causes problems when filling the boreholes with a substantially dry barrier-forming material, such as for instance a sand/iron filing mixture with a humidity level of about 20%. Typically, the substantially dry barrier-forming material is fed through a conduit that is inserted into the borehole. The borehole is filled from the bottom up, and the conduit is withdrawn as the level of the substantially dry barrier-forming material in the borehole rises. The barrier-forming material is normally entrained in a flow of a gas, such as for instance air, and is fed into the borehole with a high flow velocity. This may result in a significant amount of the barrier-forming material being blown back up the borehole and into the surrounding environment. In addition, the height of the barrier-forming material in the borehole may rise faster than the conduit is being withdrawn from the borehole, causing the outlet end of the conduit to become stuck in the borehole.

The need thus exists for an improved method and system that addresses the above-mentioned drawbacks.

SUMMARY

In accordance with an aspect of at least one embodiment there is provided a method of forming a permeable reactive barrier in the ground for remediating groundwater, comprising: drilling a plurality of holes in the ground; and introducing a substantially dry barrier-forming material into two holes of the plurality of holes in a simultaneous fashion, comprising: positioning a filling tool relative to the two holes such that an outlet end of a first conduit of the filling tool is proximate a bottom of a first one of the two holes and an outlet end of the second conduit of the filling tool is proximate a bottom of a second one of the two holes; providing a flow of the substantially dry barrier-forming material at an initial flow velocity through a source conduit and into a flow divider, the flow divider having a first outlet in fluid communication with an inlet end of the first conduit and a second outlet in fluid communication with an inlet end of the second conduit; and withdrawing the filling tool out of the two holes while continuing to introduce the substantially dry barrier-forming material into the two holes, wherein a final flow velocity of the substantially dry barrier-forming material exiting from the outlet ends of the first and second conduits is at least about 30% less than the initial flow velocity, and wherein withdrawing the filling tool is performed at a rate that is substantially equal to a rate of filling the two holes with the substantially dry barrier-forming material.

In accordance with an aspect of at least one embodiment there is provided a system for forming a permeable reactive barrier in the ground for remediating groundwater, comprising: a source conduit for providing a substantially dry barrier-forming material at an initial flow velocity; a flow divider having an inlet in fluid communication with an outlet end of the source conduit, and having a first outlet and a second outlet, wherein the flow of the substantially dry barrier-forming material exits the flow divider via the first and second outlets at a flow velocity that is lower than the initial flow velocity; a first conduit having an inlet end in fluid communication with the first outlet and having an outlet end opposite the inlet end thereof; a second conduit having an inlet end in fluid communication with the second outlet and having an outlet end opposite the inlet end thereof; wherein the first and second conduits each comprise one or more openings defined in respective sidewalls thereof for venting air that is entrained in the flow of the substantially dry barrier-forming material for reducing the flow velocity of the substantially dry barrier-forming material from the intermediate flow velocity to a final flow velocity.

In accordance with an aspect of at least one embodiment there is provided a system for forming a permeable reactive barrier in the ground for remediating groundwater, comprising: a source conduit for providing a substantially dry barrier-forming material at an initial flow velocity; and a delivery conduit arrangement in fluid communication with the source conduit and having a first delivery conduit and a second delivery conduit, the first and second delivery conduits each having an outlet end for being positioned proximate a bottom of respective spaced-apart holes drilled into the ground, and the first and second delivery conduits each having one or more openings defined in respective sidewalls thereof proximate the outlet ends thereof for venting air that is entrained in the flow of the substantially dry barrier-forming material, wherein a total cross-sectional area of a flow path of the substantially dry barrier-forming material increases between the source conduit and the outlet ends of the first and second delivery conduits, and wherein during operation a final flow velocity of the substantially dry barrier-forming material exiting via the outlet ends of the first and second delivery conduits is at least about 30% less than the initial flow velocity.

BRIEF DESCRIPTION OF THE DRAWINGS

The instant disclosure will now be described by way of example only, and with reference to the attached drawings, in which:

FIG. 1 is a simplified diagram of a system or filling tool according to an embodiment.

FIG. 2 is an enlarged partial view of the system or filling tool of FIG. 1.

FIG. 3 is a simplified view showing the system or filling tool of FIG. 1 positioned within two adjacent boreholes of an array of boreholes.

FIG. 4 is a simplified side view showing the system or filling tool of FIG. 1 positioned within two boreholes prior to filling with substantially dry barrier-forming material.

FIG. 5 is a simplified side view showing the system or filling tool of FIG. 1 positioned within two boreholes during filling with substantially dry barrier-forming material.

FIG. 6 is a simplified side view showing the system or filling tool of FIG. 1 positioned within two boreholes after filling with substantially dry barrier-forming material.

DETAILED DESCRIPTION

While the present teachings are described in conjunction with various embodiments and examples, it is not intended that the present teachings be limited to such embodiments. On the contrary, the present teachings encompass various alternatives and equivalents, as will be appreciated by those of skill in the art. All statements herein reciting principles, aspects, and embodiments of this disclosure, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure.

As used herein, the terms "first", "second", and so forth are not intended to imply sequential ordering, but rather are intended to distinguish one element from another, unless explicitly stated. Similarly, sequential ordering of method steps does not imply a sequential order of their execution, unless explicitly stated.

Referring now to FIG. 1, shown is a simplified diagram of a system or filling tool according to an embodiment. The system 100 includes a source conduit 102 as well as a delivery conduit arrangement, which is shown generally at 104. The delivery conduit arrangement 104 includes a flow divider 106, a first delivery conduit 108 and a second delivery conduit 110, each of which has a wall thickness of about 0.6 cm. The flow divider 106 has an inlet 112 that is in fluid communication with the source conduit 102 for receiving a flow of a substantially dry barrier-forming material. The flow divider 106 divides the flow of the substantially dry barrier-forming material into two, approximately equal flows out of first and second outlets 114 and 116 and into the first and second delivery conduits 108 and 110, respectively.

A first sensing ring 118 is provided proximate the outlet end of the first delivery conduit 108 and a second sensing ring 120 is provided proximate the outlet end of the second delivery conduit 110. In an embodiment, the sensing rings 118 and 120 are approximately 30 cm in length and have a wall thickness of 2.5 to 3 cm. Since the sensing rings 118 and 120 have the same inside diameter as the first and second delivery conduits 108 and 110, the sensing rings 118 and 120 protrude outwardly from the outer surface of the first and second delivery conduits 108 and 110. The sensing rings 118 and 120 may be joined to the outlet end of the first and second delivery conduits 108 and 110 by a weld bead.

A first plurality of openings 122 is provided through the sidewall along a length of the first delivery conduit 108 that is above the sensing ring 118. Similarly, a second plurality of openings 124 is provided through the sidewall along a length of the second delivery conduit 110 that is above the sensing ring 120. Additional openings (not illustrated) are also formed on the sides of the first and second delivery conduits that are opposite the openings 122 and 124 shown in FIG. 1. Alternatively, the openings 122 and 124 are provided in the form of elongated slots, or the number and/or size and/or distributions of the openings 122 and 124 may be selected for a particular application.

Attachment points 126 and 128 are provided for the purpose of attaching lifting cables (not shown in FIG. 1), which allow a crane to be used to lower and raise the system 100 along a substantially vertically path. Preferably, the source conduit 102 is flexible and the delivery conduits 108 and 110 are rigid and parallel to one another, to facilitate a straight up-and-down insertion and withdrawal of the system 100 into and out of boreholes that are to be filled with the substantially dry barrier-forming material.

Referring now to FIG. 2, shown is an enlarged partial view of the system or filling tool 100 of FIG. 1, which shows more detail of the flow divider 106 and first delivery conduit 108. During operation, an inlet end (not shown in FIG. 2) of the source conduit 102 is in fluid communication with a source of the substantially dry barrier-forming material. By way of a specific and non-limiting example, the substantially dry barrier-forming material comprises sand, such as for instance silica sand or quartz sand, mixed with iron particles and a thixotropic rheology modifier such as for instance attapulgite or Acti-Gel® (purified magnesium aluminosilicate). In a specific implementation, 4 parts sand are mixed with 1 part iron particles and thixotropic rheology modifier. By way of a specific and non-limiting example, the source conduit 102 has an inside diameter of approximately 5 cm and provides an initial flow f_T of the substantially dry barrier-forming material with an initial velocity v_i. The flow f_T enters the flow divider 106 via inlet 112 and is divided into two approximately equal flows f_1 and f_2. In the example that is shown in FIG. 2, the flow divider 106 has an inside diameter of approximately 7.5 cm. The combined effect of i) dividing the initial flow f_T into two flows f_1 and f_2 and ii) providing a larger inside diameter within the flow divider 106 compared to the source conduit 102 is to increase the total cross-sectional area of a flow path of the substantially dry barrier-forming material. In the instant example, the total cross-sectional area increases from about 19.5 cm^2 in the source conduit 102 to about 88.3 cm^2 in the flow divider 106. According to Bernoulli's principle, since the total volumetric flow rate of the substantially dry barrier-forming material is constant along the flow path, the flow velocity of the two flows f_1 and f_2 in the flow divider 106 will be lower than the flow velocity within the source conduit 102, i.e., reduced from v_i to an intermediate velocity v_{in}.

Referring still to FIG. 2, the flow f_1 passes along the length L of the first delivery conduit, which is typically 5 m to 15 m, through sections 200 and 202, each of which has an inside diameter approximately equal to the inside diameter of the flow divider 106, i.e., an inside diameter of about 7.5 cm. The plurality of openings 122 defined through the sidewall of section 202 vent a portion of the gas G within which the substantially dry barrier-forming material is entrained. In some embodiments, the openings 122 are about 2.5 cm in diameter and are spaced apart from one another by about 15 cm. In some embodiments, two rows of openings 122 are provided along opposite sides of the section 202. Venting gas G via the openings 122 further reduces the velocity of the two flows f_1 and f_2 from the intermediate velocity v_{in} to a final velocity v_f. By way of a few non-limiting examples, the final velocity v_f of the flows f_1 and f_2 exiting from the outlet ends of the first and second delivery conduits 108 and 110, respectively, is at least 30% less, at least 40% less, at least 50% less, or at least 60% less than the initial flow velocity v_i within the source conduit 102.

Now referring also to FIG. 3, the system or filling tool 100 may be used for forming a permeable reactive barrier in the ground for remediating groundwater, in which an array of boreholes 300 is formed in a plurality of staggered rows r_1-r_3 and then filled with a barrier-forming material. By way of a specific and non-limiting example, the bore holes are approximately 15 cm in diameter and are separated by a center-to-center distance *d* of approximately 45 cm. As will be apparent, the boreholes in the array 300 are formed, e.g., by drilling, such that the center-to-center separation corresponds to the center-to-center separation between the substantially parallel first and second delivery conduits 108 and 110 of the system 100. If the system 100 has a different configuration, such as for instance a flow divider that spaces the first and second delivery conduits 108 and 110 either more closely together or further apart, then the spacing between the adjacent boreholes in the array 300 is adjusted accordingly.

Of course, the depth of the boreholes in the array 300 depends on various factors that are specific to the site that is being remediated. A depth of about 5 m to 15 m below ground surface is typical. As will be apparent, one or more of the diameter, the spacing, and the depth of the boreholes may be smaller or larger than the above-mentioned example dimensions, e.g., depending on the particular constraints and requirements. The boreholes 300 may be drilled or bored etc. through various types of subsurface structures, including consolidated rock formations or soils that contain cobbles of various sizes. The formation of a suitable array 300 of boreholes may be achieved using techniques that are generally well known to one of ordinary skill in the art and will not be discussed further herein.

Now referring also to FIGS. 4-6, the system or filling tool 100 is positioned within two adjacent boreholes 302 and 304, such that the sensing rings 118 and 120 at the outlet ends of the first and second delivery conduits 108 and 110 are proximate the bottoms 400 and 402 of the boreholes 302 and 304, respectively (FIG. 4). The boreholes 302 and 304 are filled with a substantially dry mixture of sand, iron particles, granular iron or iron filings, and a thixotropic rheology modifier suspension stabilizer such as Acti-Gel®. Some water may be added to mixture to dampen it, however the dry mixture will over time acquire moisture *in-situ* in the ground after the boreholes 302 and 304 are filled. Preferably quartz sand, or silica sand is used in the mixture. In operation the mixture may be added to a hopper and fed into the source conduit 102 using e.g., a not illustrated shotcrete compressed air delivery system capable of moving the mixture with the high initial velocity v_i.

As the boreholes 302 and 304 are filled with the substantially dry barrier-forming material 500 (FIGS. 5 and 6), the system 100 is withdrawn substantially vertically upwards, as indicated by the block arrow, at a rate that is approximately the same as the filling rate of the boreholes 302 and 304. For instance, cables 404 and 406 are attached to the system 100 via the attachment points 126 and 128, respectively, and a not illustrated crane is used to lift the system 100 out of the boreholes 302 and 304.

Referring again to FIGS. 1 and 2, the sensing rings 118 and 120 have the same inside diameter as the first and second delivery conduits 108 and 110, respectively, but a larger outside diameter. For instance, the outside diameter of the sensing rings 118 and 120 is approximately 2.5 cm larger than the outside diameter of the first and second delivery conduits 108 and 110. The sensing rings 118 and 120 therefore protrude outwardly from the outer surfaces of the first and second delivery conduits 108 and 110. If the crane operator raises the system 100 at a rate that is slower than the rate at which the boreholes 302 and 304 are being filled, then the protruding sensing rings 118 and 120 will become buried in the substantially dry barrier-forming material and the crane operator will sense an increased resistance to continued raising of the system 100. With experience, the crane operator will learn to vary the rate of raising the system 100 in response to sensed feedback provided by the sensing rings 118 and 120.

Advantageously, the reduced flow velocity that is achieved using the system 100, combined with vertically lifting the system 100 during filling of the boreholes 302 and 304, results in the simultaneous formation of void-free columns of the substantially dry barrier-forming material within the boreholes 302 and 304. The system 100 may then be positioned into another pair of adjacent boreholes, such as for instance boreholes 306 and 308, and the boreholes 310 and 312 are filled, etc., and the process is repeated until all of the boreholes of the array 300 are filled. Advantageously, two boreholes may be filled at the same time, which may reduce the total time required to construct the permeable reactive barrier, since the system 100 does not need to be lowered into and withdrawn from each borehole individually.

As discussed above, the depth of the boreholes in the array 300 depend on the constraints and requirements of the site that is being remediated. Typical depths are in the range of 5 m to 15 meters, but other depths are possible. The system 100 may be made in different sizes to accommodate different depth boreholes, for instance the length L in FIG. 2 may be 5 m or the length L may be 10 m or the length L may be 15 m. The relative sizes of the sections 200 and 202 may be different in systems 100 having different lengths L. For instance, the section 202 may have a length of about 3 m, and the section 200 may have a length that is selected to provide the desired total length L, e.g., 2 m or 7 m or 12 m. Alternatively, the relative sizes of the sections 200 and 202 may be the same in different systems 100 having different lengths L.

Optionally, the system 100 may be disassembled to allow sections 200 and/or 202 of different lengths to be used to suit the requirements for a particular application. For instance, boreholes having a depth of 15 m may be filled when the system 100 is assembled using a section 200 of 12 m in length and a section 202 of 3 m in length. When it becomes necessary to fill boreholes that are only 10 m in depth, the section 200 of 12 m in length may be “swapped out” for a different section 200 of only 7 m in length. A kit of parts may include a flow divider, a pair of sections 202 of 3 m in length, and a plurality of pairs of sections 200 of various lengths. Optionally, the kit of parts further includes additional pairs of sections 202 of various lengths.

Throughout the description and claims of this specification, the words “comprise”, “including”, “having” and “contain” and variations of the words, for example “comprising” and “comprises” etc., mean “including but not limited to”, and are not intended to, and do not exclude other components.

It will be appreciated that variations to the foregoing embodiments of the disclosure can be made while still falling within the scope of the disclosure. Each feature disclosed in this specification, unless stated otherwise, may be replaced by alternative features serving the same, equivalent or similar purpose. Thus, unless stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

All of the features disclosed in this specification may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. In particular, the preferred features of the disclosure are applicable to all aspects of the disclosure and may be used in any combination. Likewise, features described in non-essential combinations may be used separately (not in combination).

CLAIMS

What is claimed is:

1. A method of forming a permeable reactive barrier in the ground for remediating groundwater, comprising:

drilling a plurality of boreholes in the ground; and

introducing a substantially dry barrier-forming material into two boreholes of the plurality of boreholes in a simultaneous fashion, comprising:

positioning a filling tool relative to the two boreholes such that an outlet end of a first delivery conduit of the filling tool is proximate a bottom of a first one of the two boreholes and an outlet end of the second delivery conduit of the filling tool is proximate a bottom of a second one of the two boreholes;

providing a flow of the substantially dry barrier-forming material at an initial flow velocity v_i through a source conduit and into a flow divider, the flow divider having a first outlet in fluid communication with an inlet end of the first delivery conduit and a second outlet in fluid communication with an inlet end of the second delivery conduit; and

withdrawing the filling tool out of the two boreholes while continuing to introduce the substantially dry barrier-forming material into the two boreholes,

wherein a final flow velocity v_f of the substantially dry barrier-forming material exiting from the outlet ends of the first and second delivery conduits is at least about 30% less than the initial flow velocity v_i, and wherein withdrawing the filling tool is performed at a rate that is substantially equal to a rate of filling the two boreholes with the substantially dry barrier-forming material.

2. The method of claim 1, wherein the flow divider has an inside diameter that is larger than an inside diameter of the source conduit, and wherein the flow of the substantially dry barrier-forming material exits the flow divider via the first and second outlets at a flow velocity v_{in} that is intermediate the initial flow velocity v_i and the final flow velocity v_f.

3. The method of claim 2, wherein the first and second delivery conduits each include one or more openings defined in sidewalls thereof for venting gas that is entrained in the flow of the substantially dry barrier-forming material, thereby reducing the flow velocity of the substantially dry barrier-forming material from the intermediate flow velocity v_{in} to the final flow velocity v_f.

4. The method of claim 1, wherein the substantially dry barrier-forming material comprises a mixture of sand, granular iron or iron filings, and a thixotropic rheology modifier.

5. The method of claim 4, wherein the thixotropic rheology modifier comprises purified magnesium aluminosilicate, wherein the substantially dry mixture has less than 20% moisture content, and wherein the ratio of sand and thixotropic rheology modifier suspension stabilizer to granular iron or iron filings is at least 3:1.

6. The method of claim 4, wherein the thixotropic rheology modifier comprises purified attapulgite.

7. The method of claim 4, wherein the sand is silica sand or quartz sand.

8. A method as defined in claim 1, wherein each one of the first and second delivery conduits has a sensing ring disposed at or about the respective outlet end thereof, and further comprising a step of adjusting a rate of withdrawing the filling tool from the two boreholes based on sensed feedback relating to interaction between the sensing rings and the substantially dry barrier-forming material within the boreholes.

9. A system for forming a permeable reactive barrier in the ground for remediating groundwater, comprising:

a source conduit for providing a substantially dry barrier-forming material at an initial flow velocity v_i;

a flow divider having an inlet in fluid communication with an outlet end of the source conduit, and having a first outlet and a second outlet, wherein the flow of the substantially dry barrier-forming material exits the flow divider via the first and second outlets at an intermediate flow velocity v_{in} that is lower than the initial flow velocity v_i;

a first delivery conduit having an inlet end in fluid communication with the first outlet and having an outlet end opposite the inlet end thereof;

a second delivery conduit having an inlet end in fluid communication with the second outlet and having an outlet end opposite the inlet end thereof;

wherein the first and second delivery conduits each comprise one or more openings defined in respective sidewalls thereof for venting gas that is entrained in the flow of the substantially dry barrier-forming material for reducing the flow velocity of the substantially dry barrier-forming material from the intermediate flow velocity v_{in} to a final flow velocity v_f.

10. The system of claim 9, wherein the flow divider has an inside diameter that is larger than an inside diameter of the source conduit.

11. The system of claim 9, wherein the first and second delivery conduits each have a respective inside diameter that is larger than an inside diameter of the source conduit.

12. The system of claim 9, wherein each one of the first and second delivery conduits has a respective outside diameter and further comprise a sensing ring disposed at or about the respective outlet end thereof, the sensing ring having an outside diameter that is larger than the outside diameter of the respective one of the first and second conduits.

13. The system of claim 9, wherein the first and second delivery conduits are substantially parallel to one another and are spaced-apart by a center-to-center distance d, and wherein during operation the first and second delivery conduits are positioned within respective boreholes that are drilled into the ground and spaced-apart by approximately the same center-to-center distance d.

14. The system of claim 13, wherein the center-to-center distance d is between about 30 cm and about 90 cm.

15. A system for forming a permeable reactive barrier in the ground for remediating groundwater, comprising:

a source conduit for providing a substantially dry barrier-forming material at an initial flow velocity v_i; and

a delivery conduit arrangement in fluid communication with the source conduit and having a first delivery conduit and a second delivery conduit, the first and second delivery conduits each having an outlet end for being positioned proximate a bottom of respective spaced-apart boreholes drilled into the ground, and the first and second delivery conduits each having one or more openings defined in respective sidewalls thereof proximate the outlet ends thereof for venting gas that is entrained in the flow of the substantially dry barrier-forming material,

wherein a total cross-sectional area of a flow path of the substantially dry barrier-forming material increases between the source conduit and the outlet ends of the first and second delivery conduits, and wherein during operation a final flow velocity v_f of the substantially dry barrier-forming material exiting via the outlet ends of the first and second delivery conduits is at least about 30% less than the initial flow velocity v_i.

16. The system of claim 15, wherein the delivery conduit arrangement comprises a flow divider section having an inside diameter that is larger than an inside diameter of the source conduit, the flow divider section having a first outlet in fluid communication with an inlet end of the first delivery conduit and a second outlet in fluid communication with an inlet end of the second delivery conduit.

17. The system of claim 15, wherein the first and second delivery conduits each have a respective inside diameter that is larger than an inside diameter of the source conduit.

18. The system of claim 15, wherein each one of the first and second delivery conduits has a respective outside diameter and further comprise a sensing ring disposed at or about the respective outlet end thereof, the sensing ring having an outside diameter that is larger than the outside diameter of the respective one of the first and second delivery conduits.

19. The system of claim 15, wherein the first and second delivery conduits are substantially parallel to one another and are spaced-apart by a center-to-center distance *d*, and wherein during operation the first and second delivery conduits are positioned within respective holes that are drilled into the ground and spaced-apart by approximately the same center-to-center distance *d*.

20. The system of claim 19, wherein the center-to-center distance *d* is between about 30 cm and about 90 cm.

Statement under 84.1 (b) of the Patent Rules

This invention provides a method and system for in situ construction of a subsurface containment region for containing hazardous waste or contaminated soil buried under in the ground, and more particularly to a method and system for forming an underground permeable reactive barrier which uses iron filings and sand to neutralize hazardous chemicals within the ground. This green solution to neutralize these toxic chemicals is especially suited to areas where it is not practicable to dig a trench to address this environmental problem.

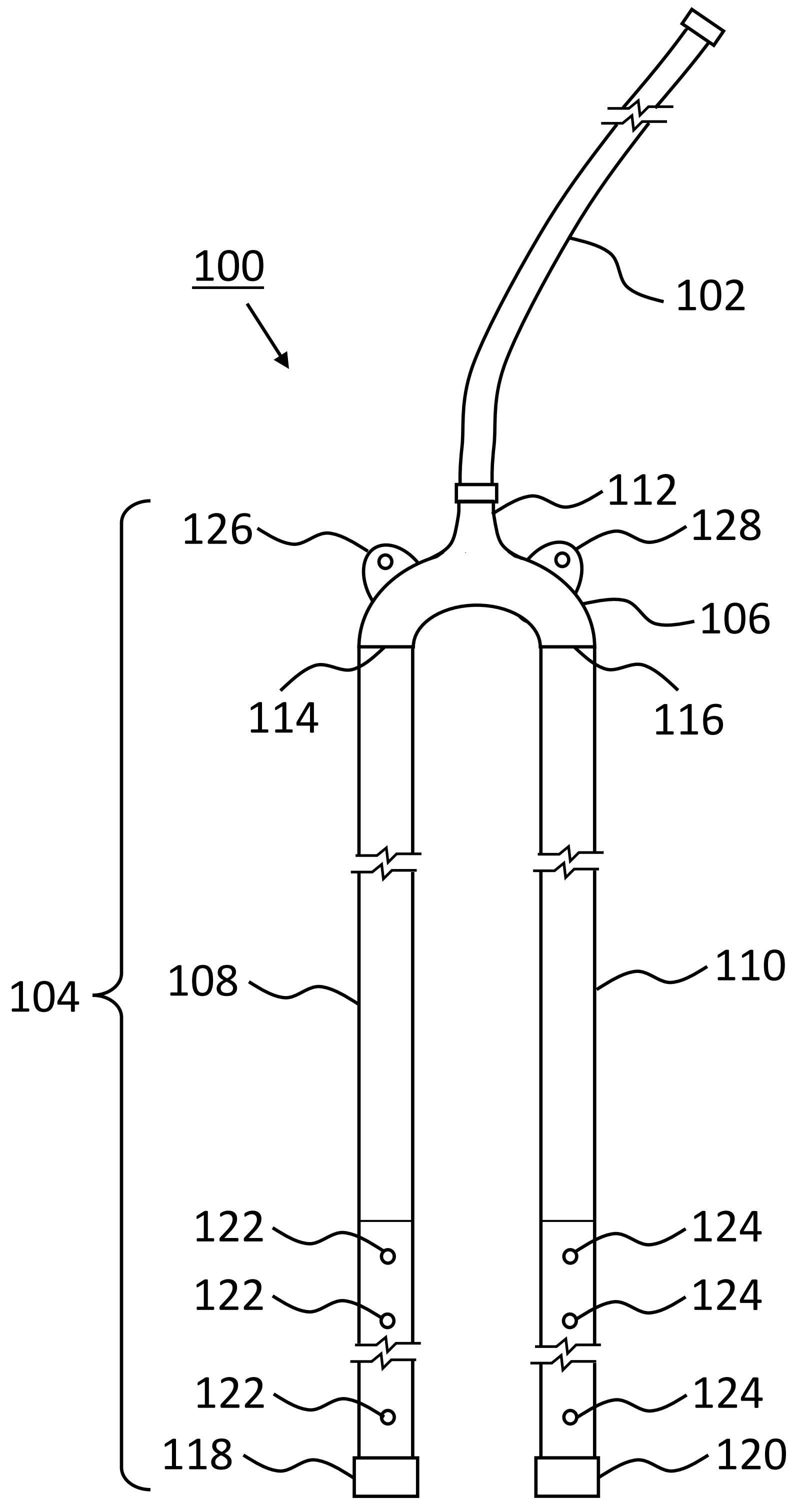
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Figure 1

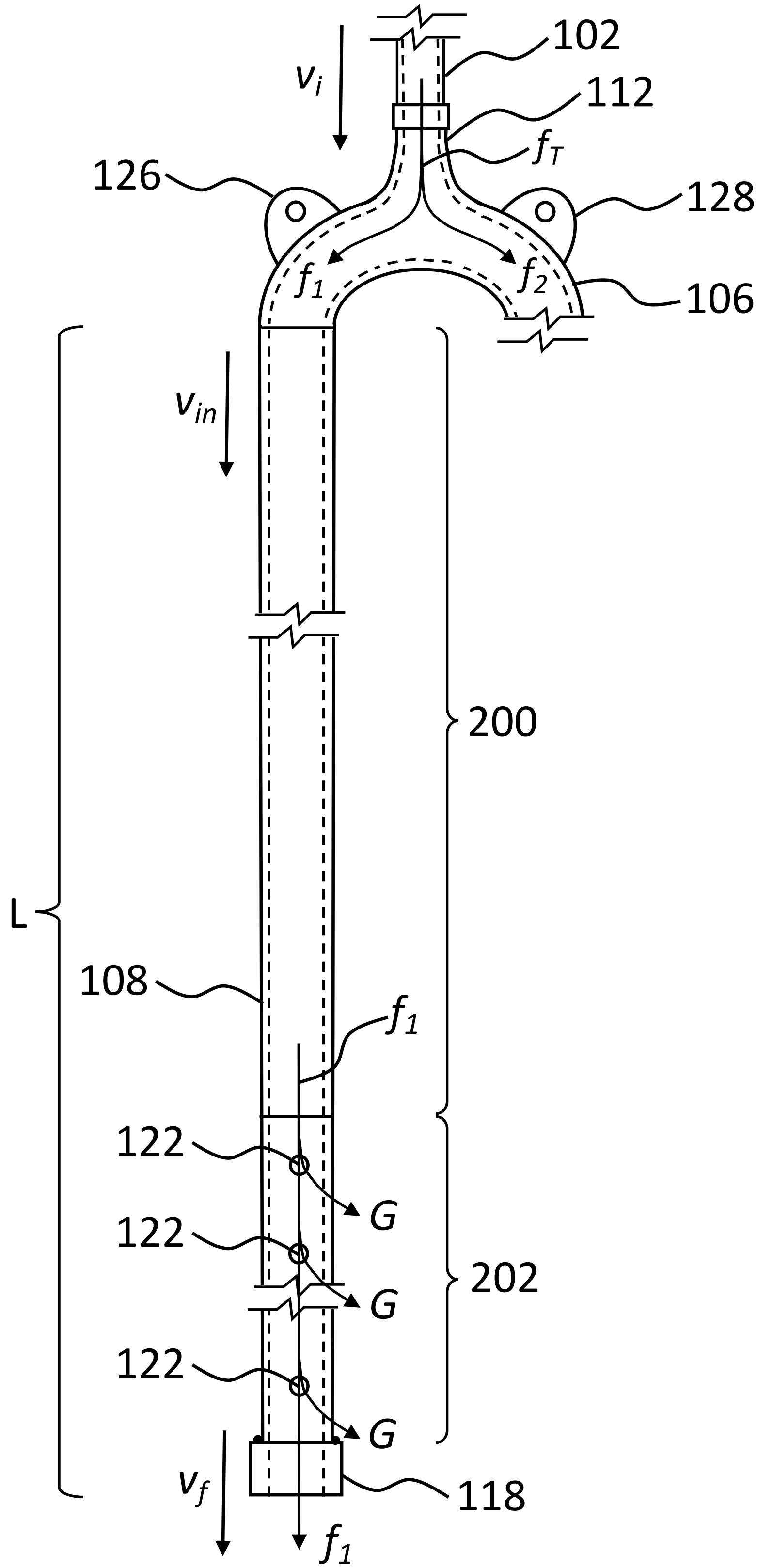

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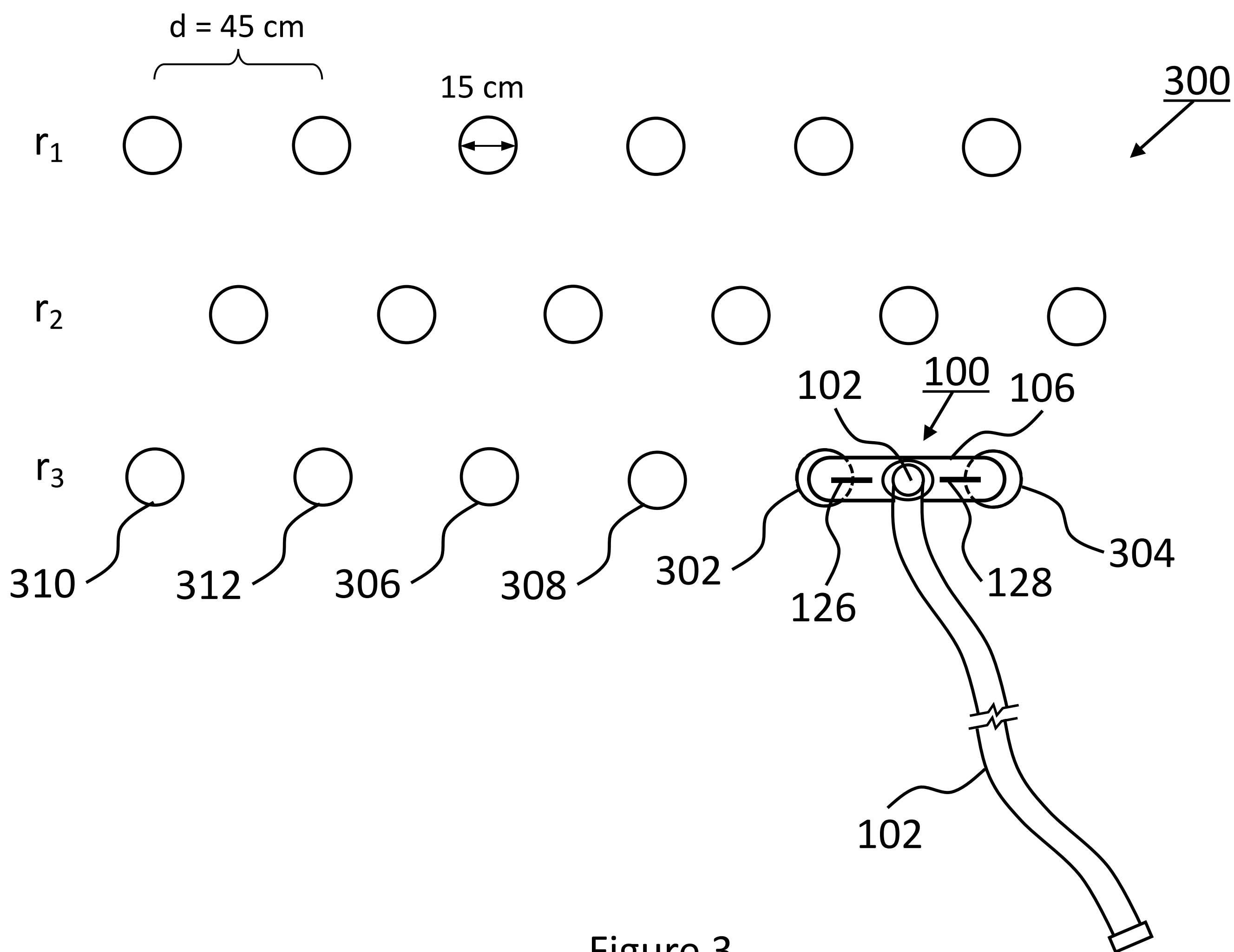
Figure 2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302
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128
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102

Figure 3

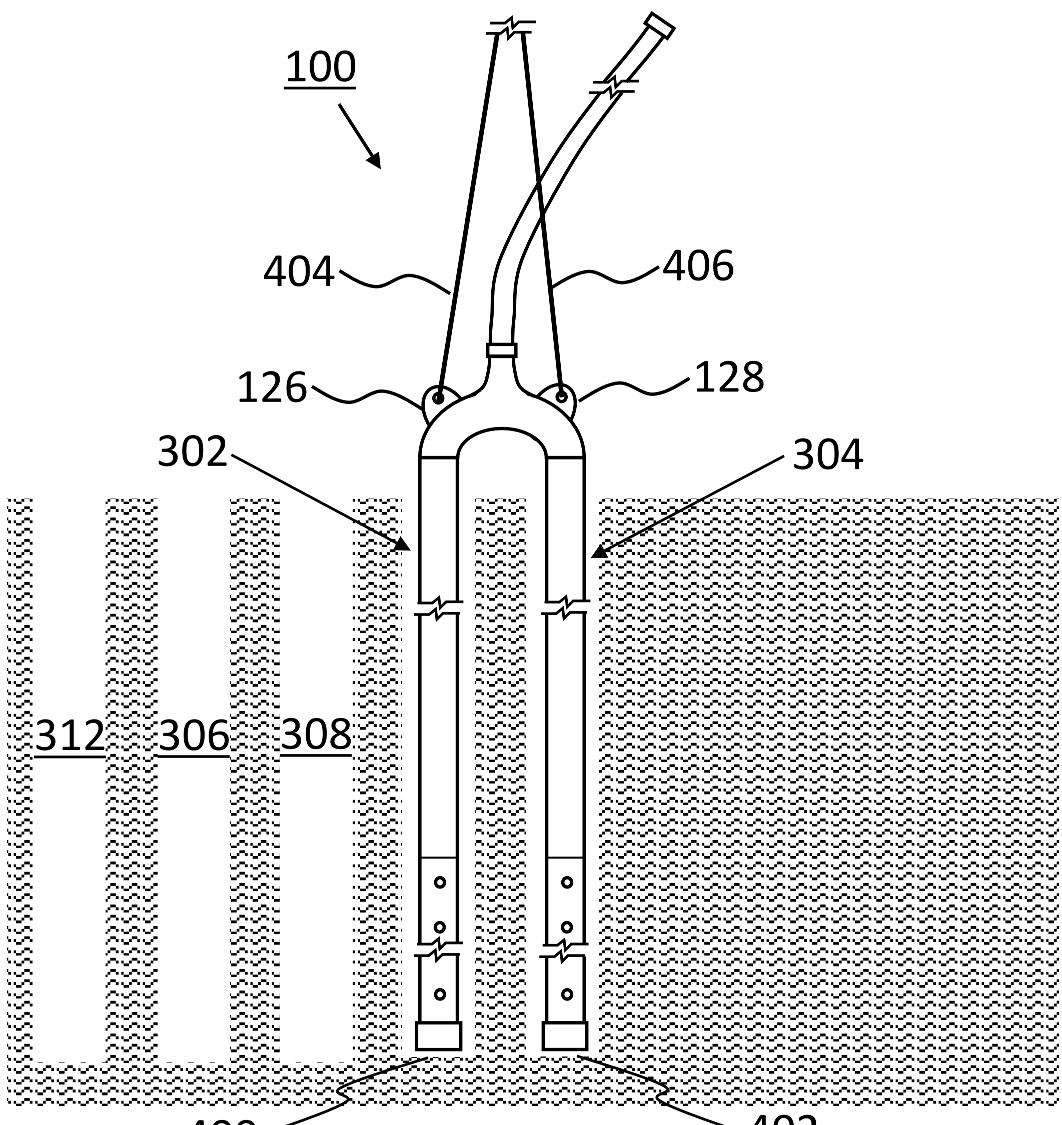

Figure 4

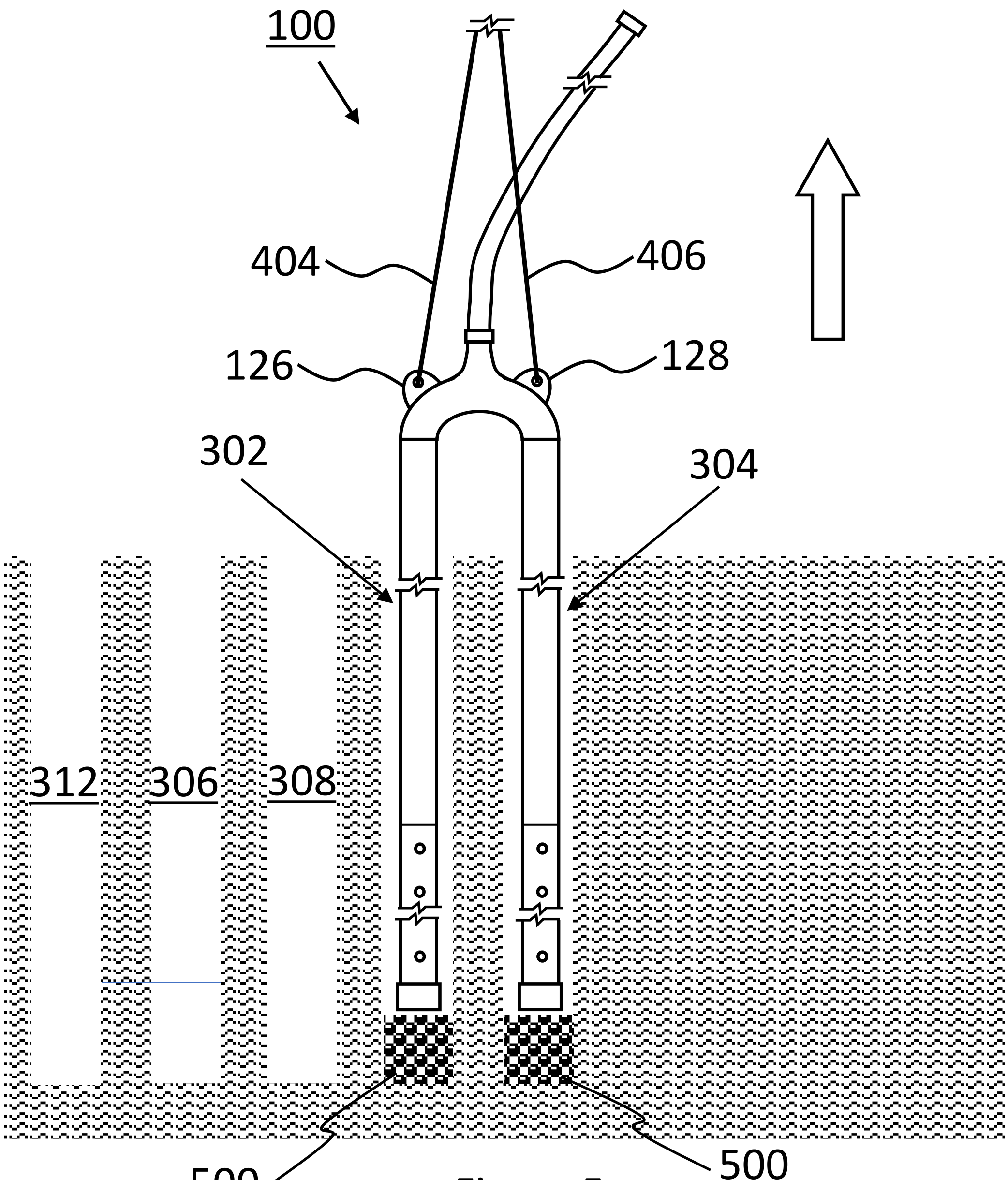

Figure 5

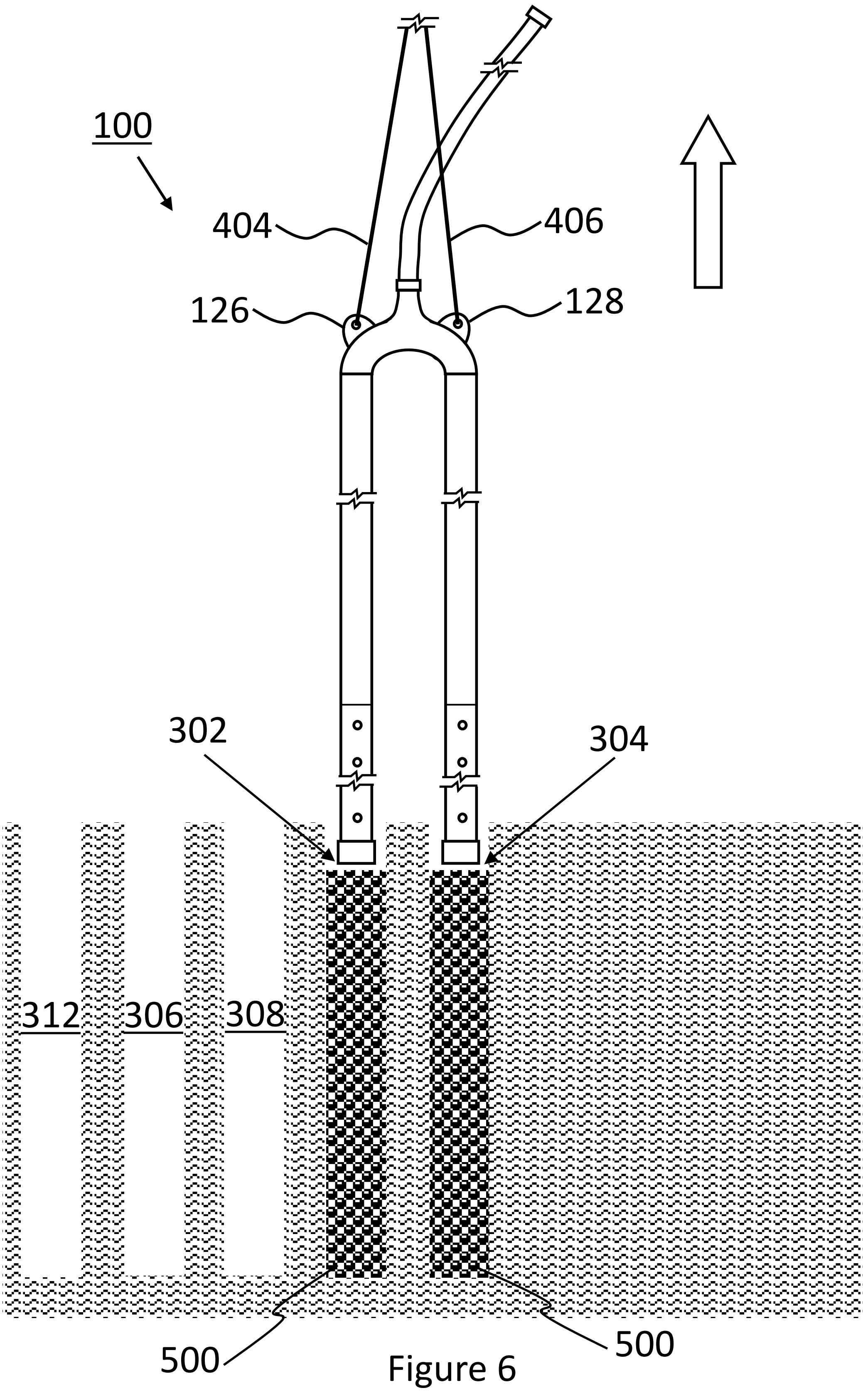

Figure 6