



(51) International Patent Classification: Not classified

(21) International Application Number:
PCT/US2011/055744(22) International Filing Date:
11 October 2011 (11.10.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/392,443 12 October 2010 (12.10.2010) US
61/392,899 13 October 2010 (13.10.2010) US
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

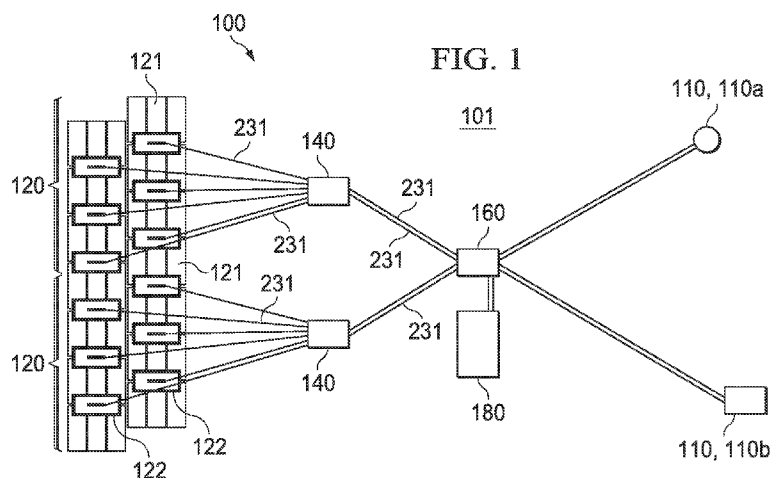
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

[Continued on next page]

(54) Title: SUBSEA AUTONOMOUS DISPERSANT INJECTION SYSTEM AND METHODS



(57) Abstract: A system for autonomously supplying a chemical dispersant to a subsea hydrocarbon discharge site which comprises a subsea storage vessel configured to store the chemical dispersant subsea is described herein. The storage vessel includes a dispersant outlet in fluid communication with the subsea hydrocarbon discharge site.



Published:

- *without international search report and to be republished
upon receipt of that report (Rule 48.2(g))*

SUBSEA AUTONOMOUS DISPERSANT INJECTION SYSTEM AND METHODS**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims priority to US Provisional Patent Application No. 61/445,357, filed February 22, 2011, entitled "Subsea Autonomous Dispersant Injection System and Methods," US Provisional Patent Application No. 61/392,899, filed October 13, 2010, entitled "Marine Subsea Free Standing Riser Apparatus, Systems and Methods" and US Provisional Patent Application No. 61/392,443, filed October 12, 2010, entitled "Marine Containment and Disposal Systems and Methods," which are hereby incorporated by reference herein in their entireties for all purposes.

**STATEMENT REGARDING FEDERALLY SPONSORED
RESEARCH OR DEVELOPMENT**

[0002] Not applicable.

BACKGROUNDField of the Invention

[0003] The invention relates generally to subsea dispersant systems and methods. More particularly, the invention relates to autonomous dispersant systems and methods for managing the subsea release or venting of hydrocarbons.

Background of the Technology

[0004] Chemical dispersing agents, or simply dispersants, aid in breaking up hydrocarbon solids and liquids, and dissipating oil slicks on the surface of water by forming water-soluble micelles that are rapidly diluted. As a result, the hydrocarbons are effectively spread throughout a larger volume of water. In addition, dispersants are believed to facilitate and accelerate the digestion of oil by microbes. Dispersants can also delay the formation of persistent oil-in-water emulsions.

[0005] Traditionally, oil dispersants have been sprayed onto the oil at the surface of the water. Normally, this process is controlled and delivered from surface vessels or from the air immediately above the oil at the surface. For example, aircraft may be employed to spray oil dispersant over an oil slick on the surface of the sea. In general, minimizing the quantity and distribution of dispersants is generally preferred. However, since oil released from a subsea well diffuses and spreads out as it rises to the surface, oil at the surface is often spread out over a relatively large area (e.g., hundreds or thousands of square miles). To sufficiently cover all or substantially all of the oil that reaches the surface, relatively large quantities of dispersant must be distributed over the relatively large area encompassed by the oil slick. Further, by limiting distribution of dispersants

to the surface, only those microbes at or proximal the surface have an opportunity to begin digestion of the oil. In addition, it may occasionally be necessary to evacuate due to anticipated hurricane activity. Since distribution of dispersants at the surface typically involves human intervention, it may not be possible during such evacuations.

[0006] Accordingly, there remains a need in the art for chemical dispersant distribution systems and methods that can operate autonomously during periods when surface operations are not feasible. Such systems and methods would be particularly well received if they offered the potential to minimize the quantity dispersants emitted, enhance dissipation of oil, and facilitate increased microbial digestion of oil.

BRIEF SUMMARY OF THE DISCLOSURE

[0007] These and other needs in the art are addressed in one embodiment by a system for autonomously supplying a chemical dispersant to a subsea hydrocarbon discharge site. In an embodiment, the system comprises a subsea storage vessel configured to store the chemical dispersant subsea. The storage vessel includes a dispersant outlet in fluid communication with the subsea hydrocarbon discharge site.

[0008] These and other needs in the art are addressed in another embodiment by a method for autonomously supplying a chemical dispersant to a subsea hydrocarbon discharge site. In an embodiment, the method comprises (a) installing a system on the sea floor, the system comprising a plurality of subsea storage vessels, each storage vessel including a dispersant outlet. In addition, the method comprises (b) storing a chemical dispersant in the subsea storage vessels. Further, the method comprises (c) flowing the chemical dispersant from one or more of the subsea storage vessels to the subsea hydrocarbon discharge site.

[0009] Thus, embodiments described herein comprise a combination of features and advantages intended to address various shortcomings associated with certain prior devices, systems, and methods. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a detailed description of the preferred embodiments of the invention, reference will now be made to the accompanying drawings in which:

[0011] Figure 1 is a schematic top view of an embodiment of an autonomous subsea dispersant system in accordance with the principles described herein;

[0012] Figure 2 is a schematic top view of the dispersant storage assemblies of Figure 1;

- [0013] Figure 3 is a perspective view of one of the storage vessels of Figure 2;
- [0014] Figure 4 is a schematic top view of one of the storage assemblies and corresponding distribution manifold of Figure 1;
- [0015] Figure 5 is a perspective view of the distribution manifold of Figure 4;
- [0016] Figure 6 is an enlarged schematic top view of the delivery manifold, pump system, and discharge sites of Figure 1;
- [0017] Figure 7 is a perspective view of the delivery manifold of Figure 6;
- [0018] Figure 8 is a schematic view of the pump system of Figure 6;
- [0019] Figure 9 is a front view of the manifold discharge site of Figures 1 and 6; and
- [0020] Figure 10 is a cross-sectional view of the venturi eductor of Figures 6 and 9.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] The following discussion is directed to various embodiments of the invention. Although one or more of these embodiments may be preferred, the embodiments disclosed should not be interpreted, or otherwise used, as limiting the scope of the disclosure, including the claims. In addition, one skilled in the art will understand that the following description has broad application, and the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to intimate that the scope of the disclosure, including the claims, is limited to that embodiment.

[0022] Certain terms are used throughout the following description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but not function. The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

[0023] In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to... ." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection via other devices, components, and connections. In addition, as used herein, the terms "axial" and "axially" generally mean along or parallel to a central axis (e.g., central axis of a body or a port), while the terms "radial" and "radially" generally mean perpendicular to the central axis. For instance, an axial distance refers

to a distance measured along or parallel to the central axis, and a radial distance means a distance measured perpendicular to the central axis.

[0024] Referring now to Figure 1, an embodiment of a subsea dispersant distribution system 100 in accordance with the principles described herein is schematically shown. System 100 is disposed along the sea floor 101 and delivers chemical dispersants to one or more subsea oil emission or discharge sites 110. As will be described in more detail below, the chemical dispersant is directly injected into a subsea stream of oil to facilitate its breakup, dissipation, and microbial digestion at the one or more subsea ejection sites 110. As shown in Figure 1, one discharge site 110, also labeled 110a, is a subsea BOP, and a second discharge site 110, also labeled 110b, is a preinstalled subsea manifold (e.g., chimney). However, in general, a given discharge site (e.g., discharge site 110) may be any subsea site or location where oil is vented, emitted, or ejected (intentionally or unintentionally) into the surrounding sea water including, without limitation, a subsea BOP, a subsea pipeline or conduit, a subsea manifold, or combinations thereof. For example, for well pressure control purposes, a well may be intentionally vented into the surrounding sea water from a subsea BOP or manifold upon evacuation of associated surface operations in anticipation of a hurricane. As another example, oil may be unintentionally emitted into the surrounding sea water from a damaged or broken subsea oil conduit or BOP.

[0025] In this embodiment, system 100 includes a plurality of dispersant storage assemblies 120, one dispersant distribution manifold 140 coupled to each storage assembly 120, a dispersant delivery manifold 160 coupled to each distribution manifold 140, and a pumping system 180 coupled to delivery manifold 160. In general, each storage assembly 120 stores chemical dispersants subsea, each distribution manifold 140 collects the dispersant from its corresponding storage assembly 120 and supplies the dispersant to delivery manifold 160, and delivery manifold 160 supplies the dispersant to one or more discharge sites 110. Pump system 180 facilitates the flow of dispersant through system 100 from storage assemblies 120 to discharge sites 110. As will be described in more detail below, the various components of system 100 (e.g., storage assemblies 120, distribution manifold 140, and delivery manifold 160) include a plurality of valves that enable control over the flow of dispersant from each storage assembly 120 to one or more discharge sites 110, thereby reducing the potential for the inadvertent discharge of dispersant into the surrounding sea water.

[0026] The components of system 100 are delivered subsea, coupled together subsea, and operated subsea with one or more remotely operated vehicles (ROVs). Due to the time and effort that may be necessary to install system 100, it is preferably implemented as part of the

long-term plan for the development of an offshore field. For example, if system 100 is not already installed, it may be too late to do so once a specific hurricane risk has been identified.

[0027] Referring now to Figure 2, the two storage assemblies 120 of system 100 are shown. In this embodiment, each storage assembly 120 is identical. Specifically, each storage assembly 120 includes a plurality of mud mats 121 disposed along the sea floor 101 and a plurality of dispersant storage vessels 122 supported by mud mats 121. Mud mats 121 distribute the weight of storage vessels 122 along the sea floor 101, thereby restricting and/or preventing storage vessels 122 from sinking into the sea floor 101. In addition, mud mats 121 cover and shield the sea floor 101 from turbulence induced by ROV thrusters, thereby reducing visibility loss due to disturbed mud during installation and operation. In Figure 2, each storage assembly 120 includes six total storage vessels 122 arranged in two staggered rows of three vessels 122 each. However, in general, the storage assemblies (e.g., storage assemblies 120) may comprise any number of storage vessels (e.g., vessels 122) arranged in any suitable configuration.

[0028] Referring now to Figure 3, one storage vessel 122 is shown, it being understood that each storage vessel 122 of system 100 is configured the same. In general, storage vessels 122 are devices designed to contain chemical dispersants subsea, and supply the chemical dispersants to the remainder of system 100. In this embodiment, each storage vessel 122 includes a stand or support structure 123 and a flexible dispersant storage bladder 130 supported within structure 123. Support structure 123 has a lower rectangular base 124, a plurality of guide columns or rails 125 extending perpendicularly upward from base 124, and a rectangular upper compression plate or member 126 slidably mounted to rails 125. Specifically, each guide rail 125 is fixed to and extends vertically upward from one corner of base 124, and each corner of upper plate 126 includes an annular sleeve or collar 127 slidably disposed about one rail 125. The upper end of each guide rail 125 includes a stop 128 extending radially outward from its respective rail 125; each stop 128 restricts and/or prevents a corresponding collar 127 from sliding off and disengaging rail 125. Otherwise, upper plate 126 is free to move up and down along rails 125 relative to base 124.

[0029] Storage bladder 130 is positioned between base 124 and upper plate 126, and is disposed within the four guide rails 125. In this embodiment, bladder 130 is generally configured to assume a rectangular shape within support structure 123 when filled with dispersants. To reduce and/or eliminate inadvertent leaking or discharge of chemical dispersant contained in bladder 130 into the surrounding sea water, bladder 130 is preferably made from flexible, durable material(s) suitable for storing chemical dispersants in a subsea environment. Examples of suitable materials include, without limitation, PVC coated fabrics and EVA coated fabrics. As the volume of dispersant in bladder 130 decreases, bladder 130 will collapse between upper

plate 126 and base 124, and upper plate 126 will move downward toward base 124 under the force of gravity. To enhance compression of bladder 130 (to facilitate the flow of dispersant from bladder 130 to the remainder of system 100), upper plate 126 may include added weight. Upper plate 126 generally remains in contact with the top of bladder 130, and thus, the position and movement of plate 126 relative to base 124 will depend, at least in part, on the volume of dispersant within bladder 130. To further protect the bladder (e.g., bladder 130), in other embodiments, the frame (e.g., support structure 123) may include outer walls extending between the upper plate (e.g., plate 126) and the base (e.g., base 124), and extending between adjacent guide rails (e.g., rails 125), to prevent the bladder from extending outward beyond the periphery of the frame. Such walls may comprise any suitable material such as coated steel, a polypropylene mesh, or a wire mesh.

[0030] Although this embodiment of storage vessel 122 includes upper plate 126 slidably coupled to guide rails 125, in other embodiments, the upper member (e.g., plate 126) of the bladder support structure (e.g., structure 123) may be fixed to support posts extending perpendicularly from the base (e.g., similar to rails 125 extending from base 124). In such embodiments, the bladder (e.g., bladder 130) may be suspended from the upper member. During operations, the slightly buoyant dispersant stored within the bladder rises upward within the bladder as its volume decreases.

[0031] Referring now to Figures 3 and 4, each storage vessel 122 also includes a dispersant conduit or flow line 132 that is coupled to upper plate 126 and provides access to bladder 130. In particular, conduit 132 includes a T-connector 133 releasably connected to a bladder coupling 131 that defines an inlet/outlet passage or port in bladder 130. Bladder coupling 131 extends vertically from the top of bladder 130 through a throughbore 129 in upper plate 126 and is releasably coupled to T-connector 133. Thus, dispersant may be flowed into or out of bladder 130 via conduit 132, T-connector 133, and coupling 131.

[0032] Dispersant conduit 132 has a first end 132a defining an inlet 134 to conduit 132 and a second end 132b defining an outlet 135 to conduit 132. In general, bladder 130 is filled with dispersant via inlet 134, and bladder 130 supplies dispersant to the remainder of system 100 via outlet 135. In this embodiment, each end 132a, b comprises a male coupling 200 configured to releasably connect to a mating female coupling 201. In addition, conduit 132 includes an outlet valve 210 positioned between outlet 135 and T-connector 133, an inlet valve 211 positioned between inlet 134 and T-connector 133, and a check valve 212 positioned between inlet valve 211 and T-connector 133. Check valve 212 is configured and oriented to allow one-way fluid flow from inlet 134 through valve 211 to T-connector 133 and bladder 130. In other words, check valve 212 prevents dispersant in bladder 130 and conduit 132 from exiting conduit 132

via inlet 134. A pressure gauge or sensor 220 is provided to measure the pressure of dispersant in conduit 132 and bladder 130.

[0033] In this embodiment, each valve 210, 211 is a quarter-turn butterfly valve that is physically and directly actuated by one or more subsea remotely operated vehicles (ROVs). However, in general, each valve 210, 211 may comprise any suitable valve capable of being transitioned between an open position allowing fluid flow therethrough and a closed position preventing fluid flow therethrough. Examples of suitable valves including, without limitation, ball valves and butterfly valves. In addition, although valves 210, 211 are manual valves operated by subsea ROVs in this embodiment, in general, valves 210, 211 may be actuated by other suitable means including, without limitation, hydraulically actuation, electrical actuation, pneumatic actuation, or combinations thereof.

[0034] Referring still to Figures 3 and 4, to minimize and/or eliminate the inadvertent emission of chemical dispersants into the surrounding sea water prior to venting or discharge of hydrocarbons subsea, outlet valve 210 and inlet valve 211 of each vessel 122 are preferably closed until it is time to inject the dispersant into the subsea hydrocarbon stream. To fill a bladder 130 with dispersant, one or more subsea ROVs are employed to releasably connect the female receptacle or coupling 201 on the end of a dispersant supply line 230 to mating male coupling 200 at inlet end 132a, and then open inlet valve 211. With outlet valve 210 in the closed position, dispersant is pumped through supply line 230 through inlet 134, inlet valve 211, check valve 212, T-connector 133, and bladder coupling 131 into bladder 130. To minimize the risk of overinflating bladder 130, which may potentially tear or damage bladder 130, the pressure of dispersant in conduit 132 and bladder 130 is monitored with pressure gauge 220 while filling. The pressure may be monitored with a subsea ROV and/or communicated to the sea surface via telemetry (e.g., acoustic telemetry), and then communicated by satellite to a remote location for periodic or real time monitoring of dispersant pressure within bladder 130. In the event coupling 201 on supply line 230 inadvertently decouples or disconnects from coupling 200 at inlet end 132a while inlet valve 211 is open and bladder 130 is being filled, check valve 212 restricts and/or prevents dispersant within bladder 130 from back flowing through valve 211 and exiting conduit 132 through end 132a, thereby limiting and/or preventing the inadvertent release of dispersant to the surrounding environment. Once bladder 130 is sufficiently filled, inlet valve 211 is closed and female coupling 201 of dispersant supply line 230 is disconnected from coupling 200 at inlet end 132a. Each bladder 130 is filled in a similar manner.

[0035] Referring now to Figures 1 and 4, one distribution manifold 140 is provided for each storage assembly 120. In general, each distribution manifold 140 collects the dispersant

supplied by each vessel 122 of one storage assembly 120, and then supplies the collected dispersant to delivery manifold 160. Although Figure 4 shows only one distribution manifold, each distribution manifold 140 is configured the same.

[0036] A plurality of dispersant pipelines or conduits 231 supply dispersant stored in storage vessels 122 to manifold 140 - each conduit 231 extends from one storage vessel 122 of storage assembly 120 to manifold 140. In particular, each conduit 231 has a first or inlet end 231a comprising a female coupling 201 releasably connected to a mating male coupling 200 at outlet 135 of one storage vessel flow line 143, and a second or outlet end 231b comprising a female coupling 201 that is releasably coupled to a mating male coupling 200 of manifold 140. In general, each conduit 231 may comprise any suitable rigid or flexible tubular or pipe for flowing chemical dispersants. Each conduit 231 is preferably made from a material suitable for both the harsh subsea conditions and the chemical properties of the dispersant such as a hydrogenated nitrile butadiene rubber (HNBR) liner with a neoprene cover. The diameter of conduits 231 may be increased or decreased as desired to decrease or increase, respectively, the internal friction and associated resistance to fluid flow therethrough. In this embodiment, each conduit 231 comprises a four inch diameter flexible hose.

[0037] Referring now to Figures 4 and 5, a stand or support structure 150 supports manifold 140 above the sea floor 101. Structure 150 includes a frame 151, a generally horizontal lower plate 152 coupled to the bottom of frame 151 and disposed along the sea floor 101, and a generally horizontal upper plate 153 coupled to the top of frame 151 and spaced above lower plate 152. Similar to mud mats 121 previously described, lower plate 152 distributes the weight of structure 150 and manifold 140 along the sea floor 101, thereby restricting and/or preventing structure 150 from sinking into the sea floor 101. In addition, parallel plates 152, 153 cover and shield mud along the sea floor 101 from turbulence induced by ROV thrusters, thereby reducing visibility loss due to disturbed mud.

[0038] Manifold 140 is secured to upper plate 153 and comprises a plurality of dispersant inlets 141 and a pair of dispersant outlets 142. Each inlet 141 is in fluid communication with one storage vessel 122, and each outlet 142 is in fluid communication with delivery manifold 160. Specifically, each inlet 141 comprises a male coupling 200 that releasably connects to mating female coupling 201 on outlet end 231b of one conduit 231 extending from one storage vessel 122, and each outlet 142 comprises a male coupling 200 that releasably connects to a mating female coupling 201 on inlet end 231a of one conduit 231 extending to delivery manifold 160. As best shown in Figure 4, each inlet 141 includes a check valve 212 configured and oriented to allow one-way fluid flow from supply conduit 231 through inlet 141 into manifold 140. Thus, dispersant can flow from storage vessels 122 through conduits 231 into manifold 140, however,

dispersant is restricted and/or prevented by check valves 212 from flowing from manifold 140 through one or more conduits 231 to storage vessels 122. Consequently, in the event a subsea bladder 130 tears or ruptures, dispersant flowing through manifold 140 from other bladders 130 is prevented from back-flowing from manifold 140 to the torn bladder 130, thereby limiting and/or preventing further emission of dispersant into the surrounding sea through the tear in the damaged bladder 130.

[0039] Referring still to Figures 4 and 5, each outlet 142 includes an outlet valve 210 and a pressure gauge or sensor 220 to measure the pressure of dispersant flowing therethrough. Inlets 141 are in fluid communication with each outlet 142 that has its corresponding outlet valve 210 opened. Thus, if both outlet valves 210 are opened, each inlet 141 is in fluid communication with both outlets 142; if one outlet valve 210 is opened and the other outlet valve 210 is closed, each inlet 141 is in fluid communication with outlet 142 associated with the opened valve 210 and is not in fluid communication with outlet 142 associated with the closed valve 210; and if both outlet valves 210 are closed, no inlet 141 is in fluid communication with either outlet 142.

[0040] Referring now to Figures 1 and 6, each distribution manifold 140 supplies dispersant to delivery manifold 160 via conduits 231 extending from outlets 142. In general, delivery manifold 160 collects the dispersant supplied by each distribution manifold 140, and then delivers the collected dispersant to one or more subsea hydrocarbon discharge sites 110.

[0041] A plurality of dispersant conduits 231 as previously described supply dispersant from distribution manifold 140 to delivery manifold 160 - each conduit 231 extends from one distribution manifold outlet 142 to manifold 160. In particular, female coupling 201 at inlet end 231a of each conduit 231 is releasably connected to mating male coupling 200 at one outlet 142, and female coupling 201 at outlet end 231b of each conduit 231 is releasably coupled to a mating male coupling 200 of manifold 160.

[0042] Referring now to Figure 7, a stand or support structure 170 supports manifold 160 above the sea floor 101. Structure 170 is similar to structure 151 previously described. Namely, support structure 170 includes a frame 171, a generally horizontal lower plate 172 coupled to the bottom of frame 171 and disposed along the sea floor 101, and a generally horizontal upper plate 173 coupled to the top of frame 171 and spaced above lower plate 172. Similar to mud mats 121 previously described, lower plate 172 distributes the weight of structure 170 and manifold 160 along the sea floor 101, thereby restricting and/or preventing structure 170 from sinking into the sea floor 101. In addition, parallel plates 172, 173 cover and shield mud along the sea floor 101 from turbulence induced by ROV thrusters, thereby reducing visibility loss due to disturbed mud.

[0043] Referring now to Figures 6 and 7, manifold 160 is secured to upper plate 173 and comprises a plurality of dispersant inlets 161, a pump outlet 162a, a pump inlet 162b, and a plurality of discharge outlets 163. Inlets 161 receive dispersant from distribution manifolds 140 via conduits 231, pump outlet 162a supplies dispersant from manifold 160 to subsea pumping system 180, pump inlet 162b receives dispersant from pumping system 180, and outlets 163 supply dispersant to discharge sites 110. In this embodiment, system 100 is configured to supply dispersant to subsea BOP 110a and subsea manifold 110b - one pair of outlets 163, also labeled as outlets 163a, provide dispersant to BOP 110a, and a second pair of outlets 163, also labeled as outlets 163b, provide dispersant to manifold 110b. Inclusion of multiple outlets 163 for each discharge site 110 provides redundancy in the event delivery of dispersant through one outlet 163 is interrupted or obstructed for any reason. In this embodiment, each inlet 161, 162b, and each outlet 162a, 163 comprises a male coupling 200 that releasably connects to a mating female coupling 201 of a dispersant conduit or pipeline. For example, coupling 200 at each inlet 161 is releasably connected to female coupling 201 at outlet end 231b of one conduit 231 extending from distribution manifold 140. In addition, each outlet 163 includes an outlet valve 210 as previously described.

[0044] Referring still to Figures 6 and 7, each inlet 161 includes an inlet valve 211 as previously described. Downstream of valves 211, inlets 161 merge together and the dispersant flowing through inlets 161 passes through a single gate valve 213 that controls the flow of dispersant through the remainder of manifold 160 and system 100. To minimize supplying an excessive quantity of dispersant, a flowmeter 221 measures the total flow rate of dispersant passing through gate valve 213, manifold 171, and system 100. The flow rate of dispersant measured by flowmeter 221 may be monitored with a subsea ROV and/or communicated to the sea surface via telemetry (e.g., acoustic telemetry), and then communicated by satellite to a remote location for periodic or real time monitoring of the total dispersant flowrate. The flowmeter 221 also records the flowrate for later retrieval and analysis. In addition, a pressure gauge or sensor 220 is provided to measure the pressure of dispersant in delivery manifold 171.

[0045] Manifold 160 also includes a valve 214 positioned between pump outlet 162a and pump inlet 162b, an outlet valve 210 associated with pump outlet 162a, and an inlet valve 211 associated with pump inlet 162b. When valve 214 is closed and valves 210, 211 of pump outlet 162a and pump inlet 162b, respectively, are open, dispersant flows from flowmeter 221 through pump outlet 162a to pump system 180, and dispersant returns to manifold 160 from pump system 180 through pump inlet 162b. In general, pump system 180 creates a pressure differential between the dispersant in outlet 162a and inlet 162b (i.e., across valve 214) that facilitates the movement of dispersant through system 100 from storage assemblies 120 to

discharge sites 110. Similar to valves 210, 211 previously described, in this embodiment, valve 214 is a quarter-turn butterfly valve that is manually actuated by one or more subsea remotely operated vehicles (ROVs). However, in general, valve 214 may comprise any suitable valve capable of being transitioned between an open position allowing fluid flow therethrough and a closed position preventing fluid flow therethrough. Examples of suitable valves including, without limitation, ball valves and butterfly valves. In addition, although valve 214 is a manual valve operated by subsea ROVs in this embodiment, in general, valve 214 may be actuated by other suitable means including, without limitation, hydraulically actuation, electrical actuation, pneumatic actuation, or combinations thereof.

[0046] Referring now to Figures 6-8, pump system 180 includes a dispersant inlet 181, a dispersant outlet 182, a primary pump 183, a first backup pump 184, and a second backup pump 185. In this embodiment, inlet 181 comprises a supply conduit 232a releasably connected to male coupling 200 of delivery manifold outlet 162a with a mating female coupling 201, and outlet 182 comprises a return conduit 232b releasably connected to male coupling 200 of delivery manifold inlet 162b with a mating female coupling 201. Thus, supply conduit 232a flows dispersant from delivery manifold 160 to pump system 180 and a return conduit 232b flows dispersant from pump system 180 to manifold 160.

[0047] As best shown in Figure 8, each pump 183, 184, 185 is configured similarly. Specifically, each pump 183, 184, 185 comprises a dispersant inlet 186, a dispersant outlet 187, a power and control system 188, and a drive mechanism 189. During operation of pump system 180, each inlet 186 is in fluid communication with conduit 232a and supplies dispersant to its respective pump 183, 184, 185, and each outlet 187 is in fluid communication with conduit 232b and returns dispersant from its respective pump 183, 184, 185 to delivery manifold 160. In this embodiment, each outlet 187 includes a check valve 212 as previously described to allow one-way fluid flow from outlet 187 to return conduit 232b. In other words, check valves 212 in pump system 180 prevent dispersant in return conduit 232b from back flowing into pumps 183, 184, 185.

[0048] Referring still to Figure 8, each power and control system 188 includes a plurality of batteries in two independent circuits 188a that supply electrical power to drive mechanism 189, and a controller 188b that monitors and regulates power delivery and the operation of drive mechanism 189 (e.g., on/off, speed, dispersant flowrate.). For instance, controllers 188b may measure and record the dispersant delivery profile during dispersant delivery operations for later retrieval and analysis. When operating, each drive mechanism 189 creates a pressure differential between the dispersant in corresponding inlet 186 and corresponding outlet 187, thereby moving dispersant therethrough. In general, each drive mechanism 189 may comprise

any suitable device capable of creating a pressure differential to move a fluid including, without limitation, a positive displacement pump (e.g., gear pump, progressive cavity pump, reciprocating piston pump, etc.), a velocity pump (e.g., centrifugal pump, radial flow pump, axial flow pump, etc.), or combinations thereof.

[0049] Pumps 183, 184, 185 provide multiple levels of redundancy - pump 184 serves as a backup to pump 183, and pump 185 serves as a backup to pump 184. In this embodiment, pumps 183, 184, 185 are arranged and configured such that pump 183 initiates pumping operations with pumps 184, 185 off, first backup pump 184 kicks in when the output of primary pump 183 is insufficient (e.g., primary pump 183 fails or begins to run out of power, etc.), and second backup pump 185 kicks in when the output of primary pump 183 and first backup pump 184 are both insufficient. In particular, system 180 includes a plurality of pressure sensors 221 that communicate with controllers 188b. Outlet 187 of primary pump 183 includes two pressure sensors 221 that measure the pressure of dispersant therein, and outlet 187 of first backup pump 184 includes one pressure sensor 221 that measures the pressure of dispersant therein. One pressure sensor 221 on outlet 187 of primary pump 183 communicates with controller 188b of first backup pump 184, the other pressure sensor 221 on outlet 187 of primary pump 184 is in series with pressure sensor 221 on outlet 187 of first backup pump 184 and communicates with controller 188b. When the pressure in outlet 187 of primary pump 183 is sufficiently low, one sensor 221 closes a circuit that instructs controller 188b of first backup pump 184 to begin pumping operations, and the other sensor 221 partially closes a circuit that may eventually instruct controller 188b of second backup pump 185 to begin pumping operations. When the pressure in outlet 187 of first backup pump 184 is sufficiently low, sensor 221 fully closes a circuit that instructs controller 188b of second backup pump 185 to begin pumping operations.

[0050] Referring still to Figure 8, pump system 180 also includes a pressure control bypass system 190 disposed between outlets 187 of pumps 183, 184, 185 and return conduit 232b. In general, pressure control bypass system 190 protects pumps 183, 184, 185 from excessive backpressures and allows pumps 183, 184, 185 to be bypassed in the event pumps 183, 184, 185 have failed, are not being used, or are pumping insufficiently. System 190 includes an "inactive open" hydraulic valve 215 extending between conduits 232a, b, a first variable pressure controlled valve or regulator 216 in fluid communication with valve 215, pump outlets 187, and conduit 232b, and a second variable pressure controlled valve or regulator 217 in fluid communication with valve 215, regulator 216, and pump outlets 187. In general, regulators 216, 217 allow dispersant to pass therethrough above a certain predetermined threshold pressure. As a result, regulators 216, 217 generate backpressure in system 190. The backpressure in system 190 resulting from regulators 216, 217 transitions hydraulic valve 215 from its normally open

position to a closed position. In the open position, valve 215 allows direct fluid communication between conduits 232a, b, thereby allowing dispersant flowing therethrough to effectively bypass pump system 180 and pumps 183, 184, 185. However, in the closed position, valve 215 restricts and/or prevents direct fluid communication between conduits 232a, b, thereby forcing dispersant in supply conduit 232a to flow through pump system 180 and pumps 183, 184, 185 before passing into return conduit 232b.

[0051] As previously described, regulators 216, 217 allow dispersant to pass therethrough above a certain predetermined threshold pressure. In this embodiment, regulator 216 has a predetermined pass-through threshold pressure that is less than the predetermined pass-through threshold pressure of regulator 217. Thus, as the pressure of dispersant in outlets 187 increases, regulator 216 will allow dispersant to pass therethrough before regulator 217. As dispersant is allowed to pass through regulator 216, the pressure of dispersant in outlets 187 will generally be maintained at or slightly above the predetermined pass-through threshold pressure of regulator 216. As a result, the higher predetermined pass-through threshold pressure of regulator 217 may not be attained. However, should the pressure of dispersant in outlets 187 continue to rise after dispersant is flowing through regulator 216, there is a risk of generating excessive backpressure, which may damage pumps 183, 184, 185. Accordingly, regulator 217 is configured such that its predetermined pass-through threshold pressure of is below the pressure at which damage to pumps 183, 184, 185 may occur. When the pressure of dispersant in outlets 187 meets or exceeds the predetermined pass-through threshold pressure of regulator 217, regulator 217 will open and allow dispersant to vent to the sea, thereby protecting pump system 180 from damage.

[0052] Referring again to Figure 6, delivery manifold outlets 163a supply dispersant to BOP 110a via a pair of BOP supply conduits 233. Each conduit 233 has an inlet end 233a comprising a female coupling 201 releasably connected to one outlet 163a, and an outlet end 233b comprising a male coupling 200 releasably connected to a BOP injection member 190. In general, BOP injection member 190 may comprise any device that allows dispersant to be injected into the hydrocarbon stream being vented at BOP 110. In this embodiment, BOP injection member 190 comprises a ring mounted to BOP 110a that includes an injection port in fluid communication with the hydrocarbons flowing through BOP 110a. In this embodiment, injection member 190 includes a pair of inlets 191, an injection outlet or port 192, and a pair of outlet valves 210. Each inlet 191 comprising a female coupling 201 coupled to one outlet end 233b.

[0053] Delivery manifold outlets 163b supply dispersant to manifold 110b via a pair of manifold supply conduits 234. In this embodiment, each conduit 234 comprises a plurality of conduits or hoses releasably connected end-to-end. Each conduit 234 has an inlet end 234a comprising a

female coupling 201 releasably connected to one outlet 163b, an outlet end 234b comprising a male coupling 200 releasably connected to a venturi eductor 195 mounted to manifold 110b. Each conduit 234 also includes an outlet valve 210. A pressure gauge or sensor 222 measures the differential pressure between conduits 234.

[0054] Referring now to Figures 9 and 10, venturi eductor 195 is mounted to the upper end of subsea manifold 110b and includes a hydrocarbon inlet 196, a dispersant inlet 197, and an outlet 198. Dispersant inlet 197 is positioned at the intersection of hydrocarbon inlet 196 and outlet 198. Hydrocarbon inlet 196 includes a converging frustoconical flow path 196a that extends to dispersant inlet 197, and outlet 198 includes a diverging frustoconical flow path 198a extending from dispersant inlet 197. Thus, together, paths 196a, 198a define a converging-diverging nozzle that results in a fluid pressure decrease in outlet 198 that draws dispersant into eductor 195 via inlet 197. Within outlet 198, dispersant mixes with the hydrocarbon stream.

[0055] In this embodiment, venturi eductor 195 is used in conjunction with subsea manifold 110a. However, embodiments of venturi eductor 195 may be used in conjunction with other subsea devices that emit or vent hydrocarbons subsea. Since venturi eductor 195 relies on the venturi effect to intake dispersant, it is preferably employed in single phase flow environments. Depending on the desired flow rate of dispersant through system 100, the pressure drop generated by venturi eductor 195 may be sufficient to drive dispersant through system 100 without the need for pump system 180. Alternatively, in embodiments that do not leverage a venturi eductor (e.g., venturi eductor 195) or where the pressure drop induced by venturi eductor 195 is insufficient to drive system 100, pump system 180 may be relied upon to drive the flow of dispersant through system 100.

[0056] Referring now to Figures 1, 4, 6, and 8, as previously described, system 100 is preferably installed subsea with ROVs as part of the long term development plan. The ROVs may be used to position the components of system 100 subsea (e.g., manifolds 140, 160 and associated stands 150, 170, storage vessels 122, etc.) and make the connections between the various components (e.g., connect conduits 231 between storage vessels 122 and distribution manifolds 140, connect conduits 231 between manifolds 140 and manifold 160, etc.). Following installation, system 100 is placed in "stand-by" until the time it is needed to inject chemical dispersants into a subsea hydrocarbon stream or leak. Dispersant storage bladders 130 may be filled as described above upon installation or on an as needed basis (i.e., once a decision to operate system 100 has been made).

[0057] After installation, but prior to use of system 100 (i.e., while system 100 is on stand-by), the various valves of system 100 are preferably configured to minimize the risk of an inadvertent leak or discharge of dispersant into the surrounding sea water. For example, outlet valve 210 of each

storage vessel 122 is preferably closed. Select downstream valves may be left open prior to use of system 100 to minimize the time and effort required for ROVs to open the numerous valves necessary for the operation of system 100 once it is needed. For example, outlet valves 210 of each distribution manifold 140; and inlet valves 211, gate valve 213, and outlet valves 210 of delivery manifold 160 may be configured in their open positions prior to actual use of system 100. However, to reduce the potential for allowing hydrocarbons in BOP 110a and/or manifold 110b to backflow into system 100, when system 100 is not in operation, valves 210 in BOP supply conduits 233 and manifold supply conduits 234 are preferably configured in their closed positions. Since system 100 may be driven by pump system 180, venturi eductor(s) 195, or combinations thereof, there are several possible configurations for valve 214, outlet valve 210 of pump outlet 162a, and inlet valve 211 of pump inlet 162b. For example, to drive system 100 solely with one or more venturi eductors 195, valve 214 is opened, outlet valve 210 of pump outlet 162a is closed, and inlet valve 211 of pump inlet 162b is closed. However, to drive system 100 with pump system 180 as well as one or more venturi eductors 195, valve 214 is closed, outlet valve 210 of pump outlet 162a is opened, and inlet valve 211 of pump inlet 162b is opened.

[0058] Referring still to Figures 1, 4, 6, and 8, system 100 may be transitioned from the "stand-by" mode to an "operating" or activated" mode, in which dispersant is supplied from storage vessels 122 to discharge sites 110, upon the subsea discharge and/or venting of hydrocarbons at one or more discharge sites 110. For example, in anticipation of an approaching hurricane, hydrocarbons may be intentionally vented from one or more discharge sites 110 for pressure control during subsequent evacuation of surface operations and surface facilities associated with discharge sites 110. Prior to evacuation of such surface operations and facilities, system 100 is activated to inject dispersant into the subsea hydrocarbon streams. In particular, once a decision has been made to operate system 100, one or more ROVs may be employed to fill bladders 130 (if not filled upon installation) and configure the valves of system 100, as appropriate, to allow dispersant to be flowed through system 100 from bladders 130 to discharge sites 110. In cases where pump system 180 is relied upon to pump dispersant to sites 110, ROVs may be employed to initiate pumping operations with pump system 180. Alternatively, pump system 180 may be adapted for remote activation from the surface or other location.

[0059] Once system 180 has been activated, it can operate autonomously (i.e., without human intervention or intervention from the surface) and continuously to flow dispersant to sites 110. For example, as long as hydrocarbons are flowing through venturi eductor 195, the low pressure region in venturi eductor 195 will pull dispersant from storage vessels 122 through system 100. In addition, power and control systems 188 of pump system 180 can operate pumps 183, 184, 185 as long as associated batteries in circuits 188a provide sufficient power to drive pumps 183, 184, 185.

Thus, in general, system 100 can deliver dispersant to sites 110 until bladders 130 have been emptied or ROVs shut down system 100 (e.g., turn off pump system 180, close valves that allow dispersant to flow through system 100, etc.).

[0060] During operation of system 100, dispersant is supplied from storage vessels 122 to distribution manifolds 140 with conduits 231, and then supplied from distribution manifolds 140 to delivery manifold 160 with conduits 231. From delivery manifold 160, the dispersant may be pumped through supply conduits 233 to site 110b, and pumped and/or be pulled through supply conduits 234 to venturi eductor 195 at site 110a. Accordingly, system 100 may also be described as including one or more dispersant storage assemblies that store dispersant subsea (e.g., assembly 120), one or more subsea hydrocarbon discharge sites that emit a hydrocarbon stream subsea (e.g., sites 110), and a dispersant delivery system that delivers the dispersant from the storage assemblies to the discharge sites (e.g., conduits 231, distribution manifolds 140, delivery manifold 160, pump system 180, and supply conduits 233, 234). Although the dispersant delivery system in system 100 includes a plurality of interconnected conduits (e.g., conduits 231, 233, 234) and manifolds (e.g., manifolds 140, 160), in other embodiments, other suitable connections, components, etc. may be provided to deliver the dispersant from the storage assemblies to the discharge sites. For example, distribution manifolds 140 could be eliminated and storage assemblies 120 directly connected to inlets 161 of delivery manifold 160.

[0061] As previously described, most conventional dispersant techniques rely on the distribution of dispersants over hydrocarbons at the sea surface. However, embodiments of system 100 enable the direct injection of chemical dispersants into one or more subsea hydrocarbon streams. Without being limited by this or any particular theory, injecting dispersant at the point of subsea hydrocarbon release offers the potential to greatly improve dispersant efficiency, as compared to spreading dispersant over an oil slick on the surface of the sea, by maximizing mixing of the dispersant and hydrocarbons before substantial diffusion of the hydrocarbons. In addition, injecting dispersant at the point of subsea hydrocarbon release offers the potential to minimize VOCs at the surface.

[0062] In the manner described, embodiments described herein provide systems and methods for autonomously and continuously flowing chemical dispersants to one or more subsea hydrocarbon discharge sites, even when surface operations are not feasible. In addition, inclusion and specific placement of outlet valves 210, gate valve 214, check valves 212, flowmeter 221, and pressure gauges 220, 222 in embodiments described herein offers the potential to reduce the likelihood of an inadvertent subsea dispersant leak or discharge, undesirable tear or damage to storage bladders, and damage to the pump system (e.g., pump system 180).

[0063] While preferred embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teachings herein. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the systems, apparatus, and processes described herein are possible and are within the scope of the invention. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

CLAIMS

What is claimed is:

1. A system for autonomously supplying a chemical dispersant to a subsea hydrocarbon discharge site, comprising:
 - a subsea storage vessel configured to store the chemical dispersant subsea, wherein the storage vessel includes a dispersant outlet in fluid communication with the subsea hydrocarbon discharge site.
2. The system of claim 1, further comprising a first subsea manifold including a dispersant inlet in fluid communication with the dispersant outlet of the storage vessel and a dispersant outlet in fluid communication with the subsea hydrocarbon discharge site.
3. The system of claim 2, further comprising:
 - a plurality of subsea storage vessels, wherein each storage vessel is configured to store the chemical dispersant subsea and includes a dispersant outlet;
 - wherein the first subsea manifold includes a plurality of dispersant inlets, each dispersant inlet in fluid communication with the dispersant outlet of one of the storage vessels.
4. The system of claim 3, wherein each storage vessel comprises:
 - the dispersant outlet;
 - a dispersant inlet;
 - an outlet valve configured to control the flow of dispersant through the dispersant outlet;
 - an inlet valve configured to control the flow of dispersant through the dispersant inlet; and
 - a check valve configured to allow one-way fluid communication of the dispersant through the inlet valve to the storage vessel.
5. The system of claim 4, wherein each storage vessel further comprises:
 - a support structure;
 - a flexible bladder disposed within the support structure, wherein the bladder is configured to store the dispersant and is in fluid communication with the dispersant outlet of the storage vessel.

6. The system of claim 5, wherein the support structure of each storage vessel includes a lower base, a plurality of guide rails extending perpendicularly from the base, and an upper plate slidably mounted to the guide rails;

wherein the flexible bladder of each storage vessel is disposed between the lower base and the upper plate.

7. The system of claim 5, wherein the support structure of each storage vessel includes a lower base, a plurality of support posts extending perpendicularly from the base, and an upper plate fixed to the support posts;

wherein the flexible bladder of each storage vessel is suspended from the upper plate.

8. The system of claim 2, further comprising:

a first plurality of subsea storage vessels;

a second plurality of subsea storage vessels;

wherein each storage vessel is configured to store the chemical dispersant subsea and includes a dispersant outlet;

wherein the first subsea manifold includes a plurality of dispersant inlets, each dispersant inlet of the first subsea manifold in fluid communication with the dispersant outlet of one of the storage vessels of the first plurality of subsea storage vessels;

a second subsea manifold including a plurality of dispersant inlets and a dispersant outlet, each dispersant inlet of the second subsea manifold in fluid communication with the dispersant outlet of one of the storage vessels of the first plurality of subsea storage vessels;

a delivery manifold including a plurality of dispersant inlets and at least one dispersant outlet, wherein each dispersant inlet of the delivery manifold is in fluid communication one of the dispersant outlets of the first subsea manifold or the second subsea manifold;

wherein the at least one dispersant outlet of the delivery manifold is in fluid communication with the subsea hydrocarbon discharge site.

9. The system of claim 8, further comprising a venturi eductor mounted to the discharge site, wherein the venturi eductor includes a converging-diverging nozzle adapted to flow a stream of hydrocarbons and a dispersant inlet in fluid communication with the diverging nozzle;

wherein the dispersant inlet of the venturi eductor is in fluid communication with the at least one outlet of the delivery manifold.

10. The system of claim 8, further comprising a subsea pump system configured to pump the chemical dispersant from the storage vessels to the subsea hydrocarbon discharge site;

wherein the subsea pump system comprises:

a dispersant inlet in fluid communication with a pump outlet of the delivery manifold;

a dispersant outlet in fluid communication with a pump inlet of the delivery manifold;

a primary pump in fluid communication with the dispersant inlet of the pump system and the dispersant outlet of the pump system;

a first backup pump in fluid communication with the dispersant inlet of the pump system;

a first plurality of batteries configured to power the primary pump; and

a second plurality of batteries configured to power the first backup pump.

11. The system of claim 8, wherein each dispersant inlet of the delivery manifold includes a check valve configured to allow one-way fluid flow through the inlet into the delivery manifold.

12. The system of claim 8, wherein the delivery manifold includes a plurality of dispersant outlets, each dispersant outlet of the delivery manifold configured to flow the dispersant to the subsea discharge site;

Wherein each dispersant outlet of the delivery manifold includes an outlet valve configured to control the flow of dispersant through its corresponding dispersant outlet.

13. A method for autonomously supplying a chemical dispersant to a subsea hydrocarbon discharge site, comprising:

(a) installing a system on the sea floor, the system comprising a plurality of subsea storage vessels, each storage vessel including a dispersant outlet;

(b) storing a chemical dispersant in the subsea storage vessels;

(c) flowing the chemical dispersant from one or more of the subsea storage vessels to the subsea hydrocarbon discharge site.

14. The method of claim 13, further comprising:

placing the system in stand-by after (a) and before (c);

activating the system to flow the chemical dispersant from one or more of the subsea storage vessels in (c).

15. The method of claim 14, further comprising evacuating a surface facility or surface operation after activating the system.
16. The method of claim 15, wherein (c) is performed without human intervention.
17. The method of claim 13, wherein the system further comprises a first manifold including a plurality of dispersant inlets and a dispersant outlet; and
wherein (c) comprises:
(c1) flowing the chemical dispersant from one or more of the subsea storage vessels to the first manifold; and
(c2) flowing the chemical dispersant from the first manifold to the subsea hydrocarbon discharge site.
18. The method of claim 17, wherein (c) comprises pumping the chemical dispersant from one or more of the subsea storage vessels to the first manifold; and
wherein (d) comprises pumping the chemical dispersant from the first manifold to the subsea hydrocarbon discharge site.
19. The method of claim 17, wherein (a) comprises mounting a venturi eductor to the subsea discharge site, the venturi eductor including a converging-diverging nozzle and a dispersant inlet.
20. The method of claim 19, further comprising:
flowing a stream of hydrocarbons through the converging-diverging nozzle of the venturi eductor;
generating a low pressure region in the venturi eductor while flowing the stream of hydrocarbons through the converging-diverging nozzle of the venturi eductor;
relying on the low pressure region in the venturi eductor to flow the chemical dispersant from one or more of the subsea storage vessels to the first manifold and to flow the chemical dispersant from the first manifold to the subsea hydrocarbon discharge site.
21. The method of claim 13, further comprising filling each storage vessel with the chemical dispersant subsea.
22. The method of claim 21, wherein each storage vessel comprises:

a dispersant inlet including an inlet valve and a check valve;
a support structure;
a flexible bladder disposed within the support structure, wherein the bladder is configured to store the dispersant;
wherein the dispersant outlet of each storage vessel includes an outlet valve.

23. The method of claim 22, wherein filling each storage vessel comprises:
opening the inlet valve of the storage vessel;
flowing the dispersant through the inlet and check valve of the storage vessel into the bladder; and
expanding the bladder.

24. The method of claim 17, further comprising restricting the flow of dispersant from the first manifold to one or more of the storage vessels.

25. The method of claim 17, wherein the system further comprises:
a first plurality of subsea storage vessels;
a second plurality of subsea storage vessels;
a second manifold including a plurality of dispersant inlets and a dispersant outlet;
wherein each storage vessel includes a dispersant outlet;
a delivery manifold including a plurality of dispersant inlets and a dispersant outlet;
wherein (c) further comprises flowing the chemical dispersant from each storage vessel of the first plurality of storage vessels to the first manifold and flowing the chemical dispersant from each storage vessel of the second plurality of storage vessels to the second manifold;
wherein (d) further comprises flowing the chemical dispersant from the first manifold and the second manifold to the delivery manifold and flowing the chemical dispersant from the delivery manifold to the subsea hydrocarbon discharge site.

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FIG. 1

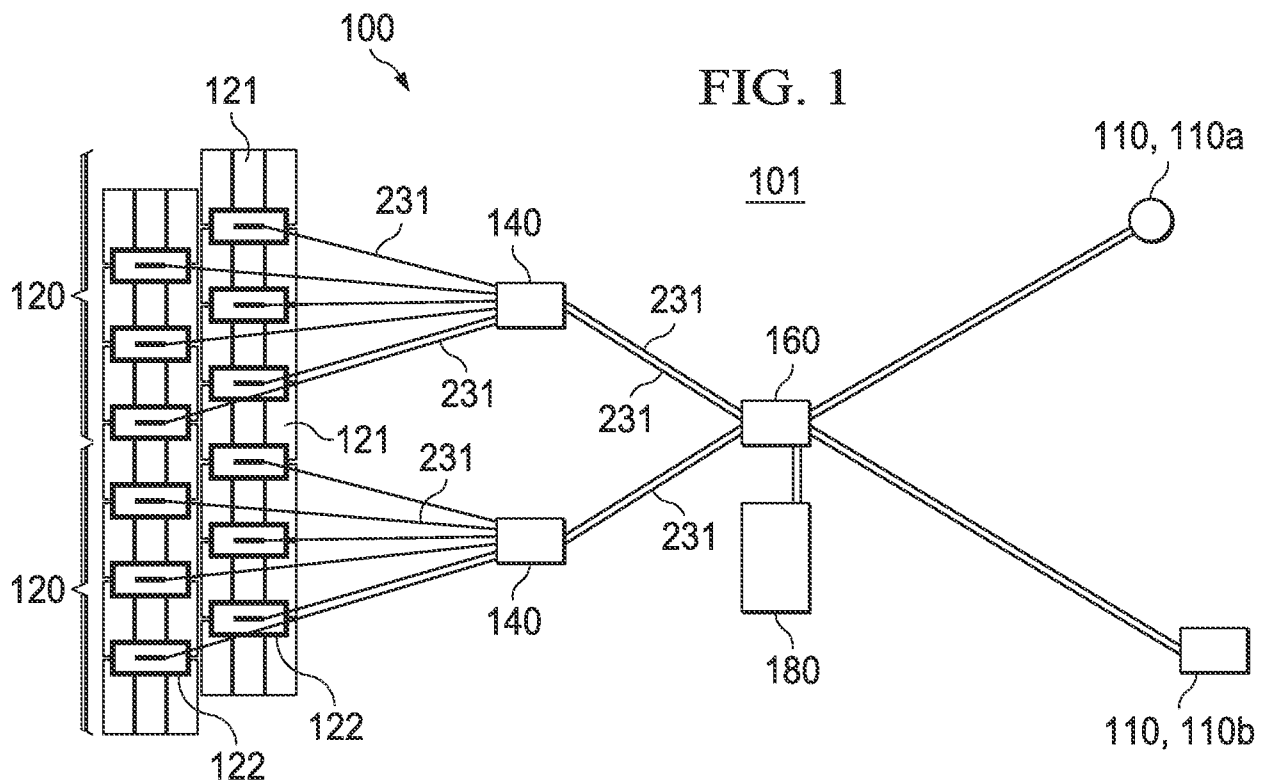


FIG. 2

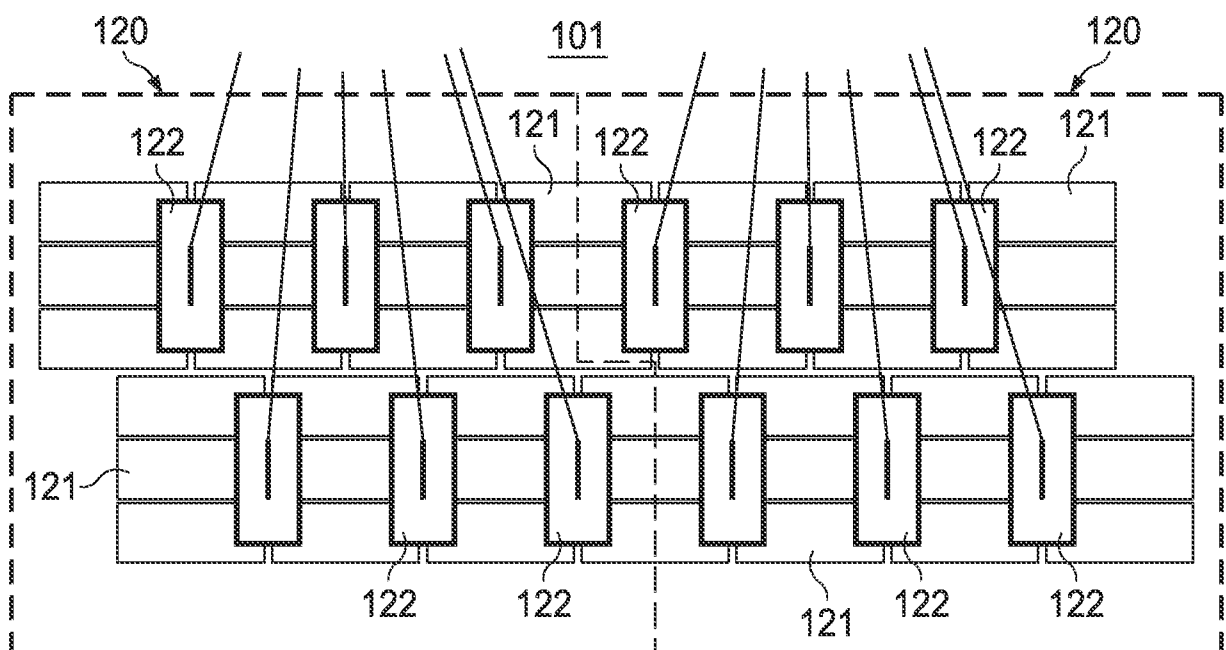
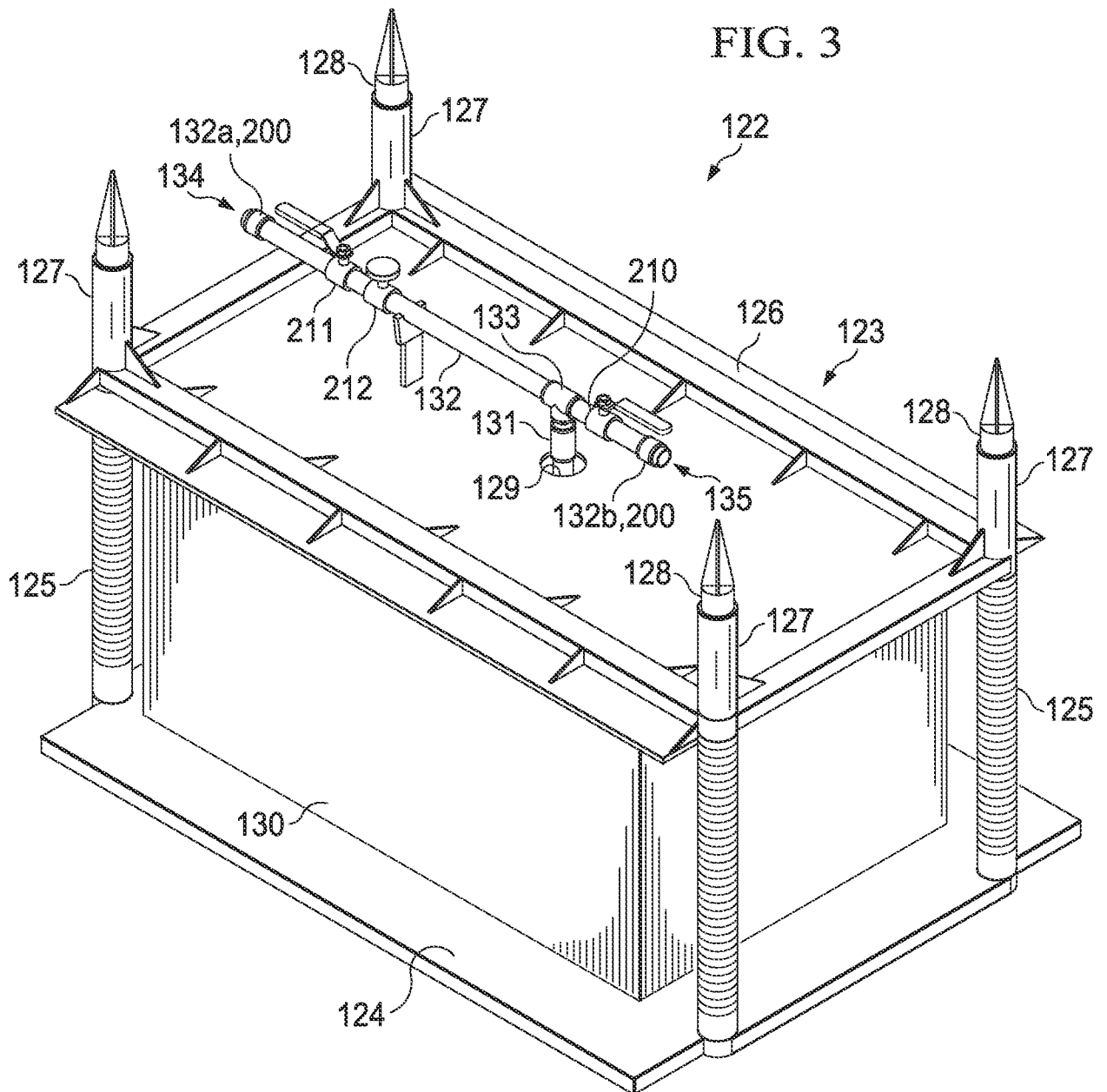
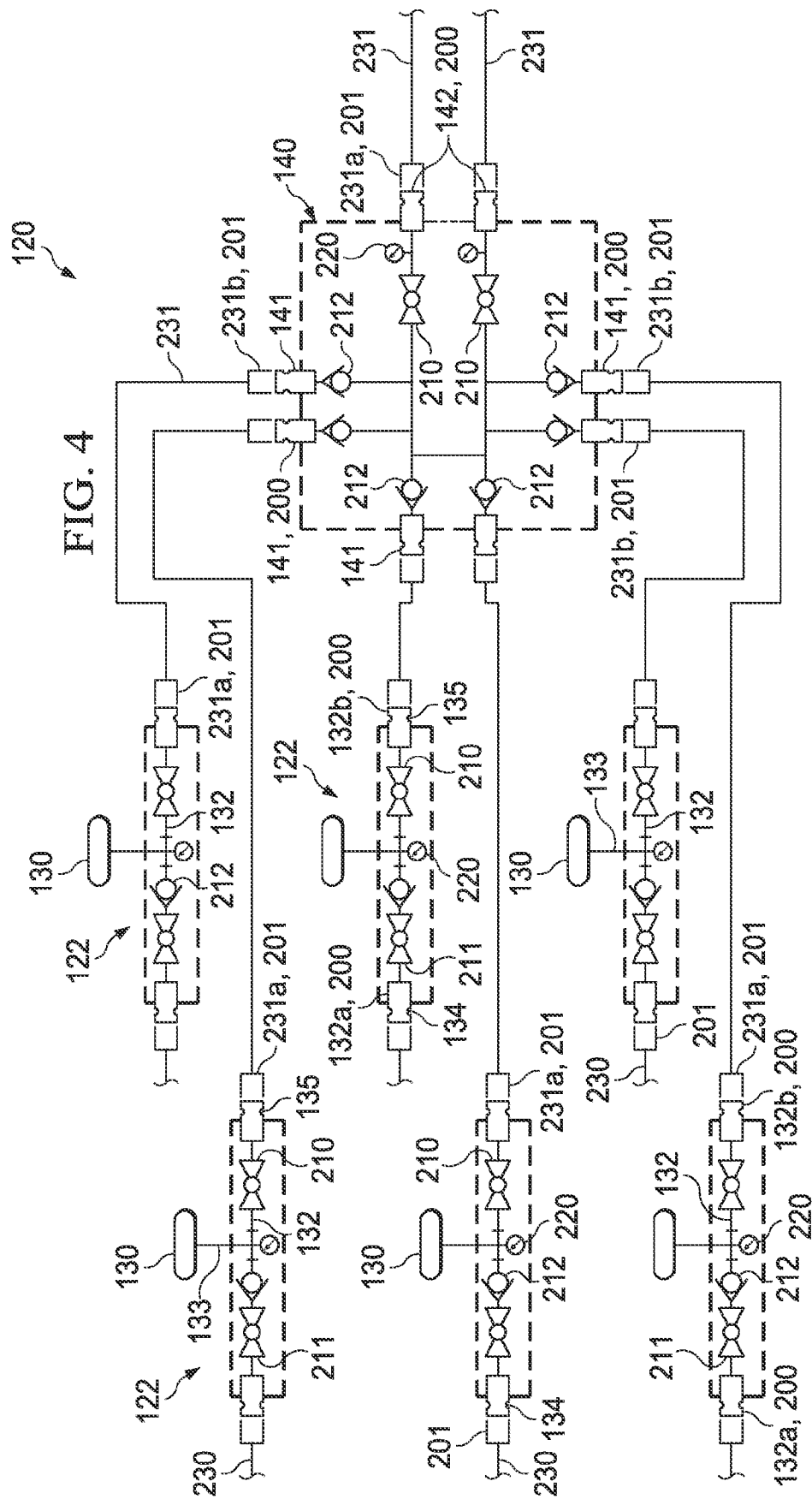


FIG. 3



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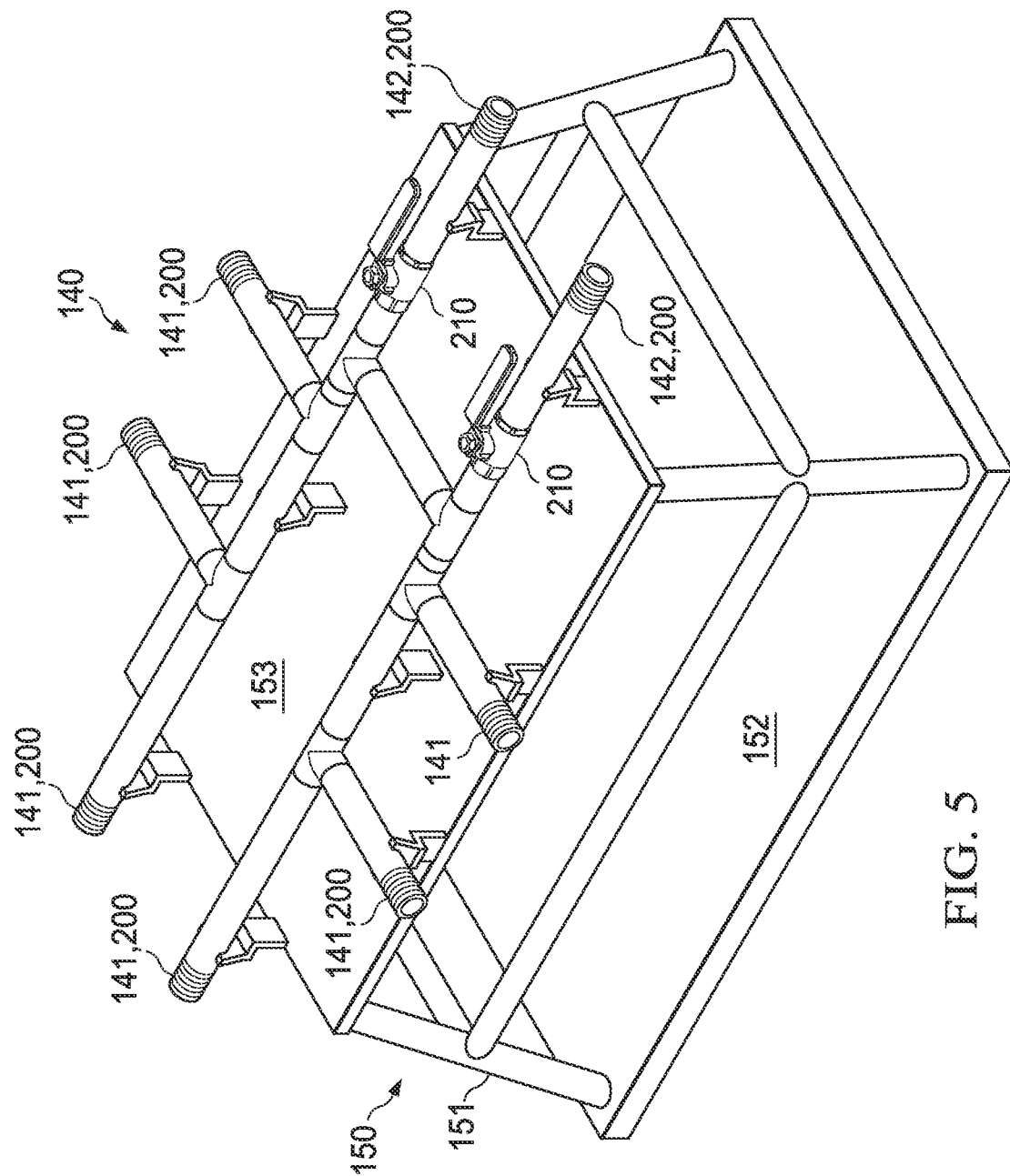


Fig. 5

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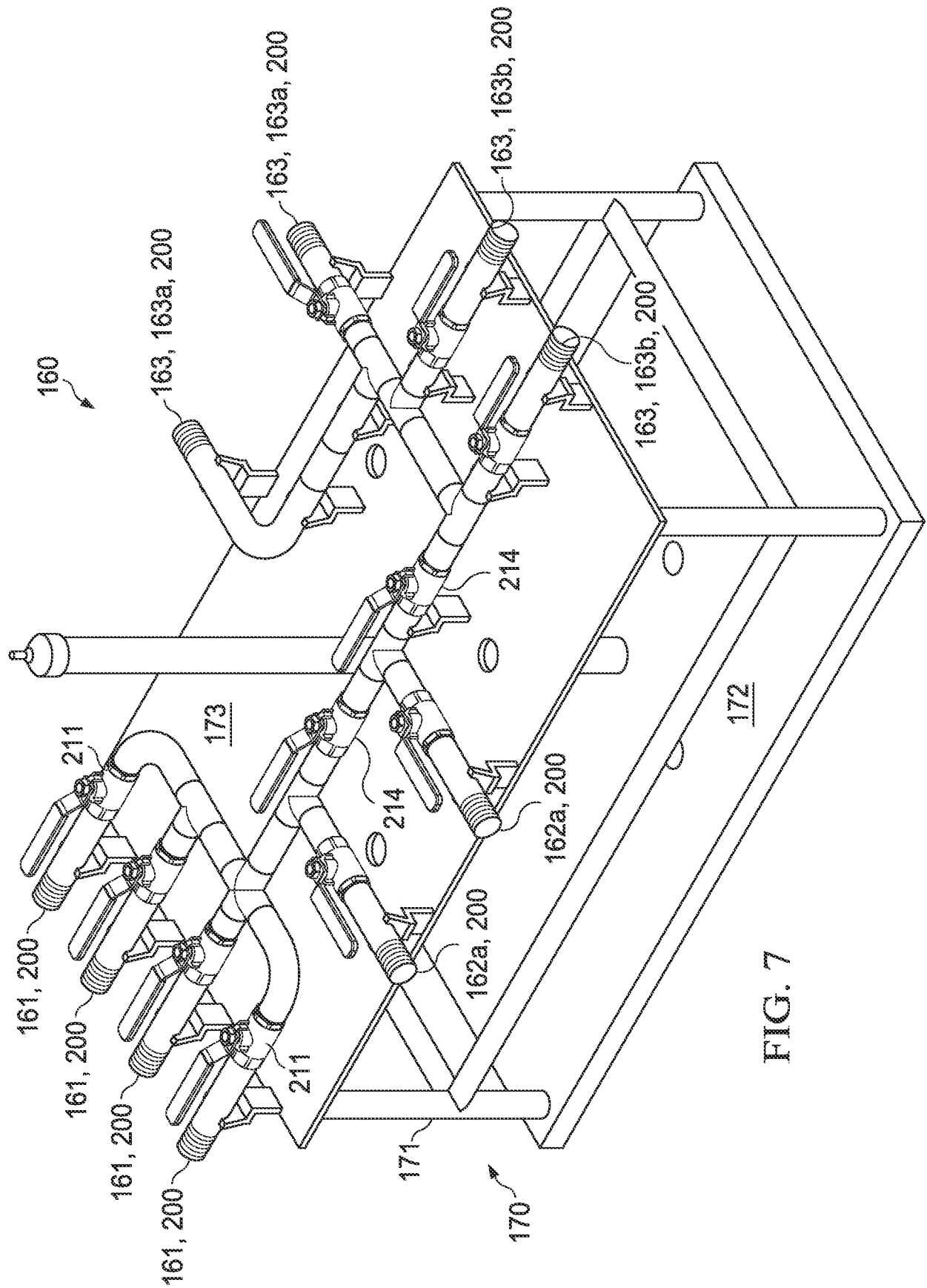


Fig. 7

Fig. 8

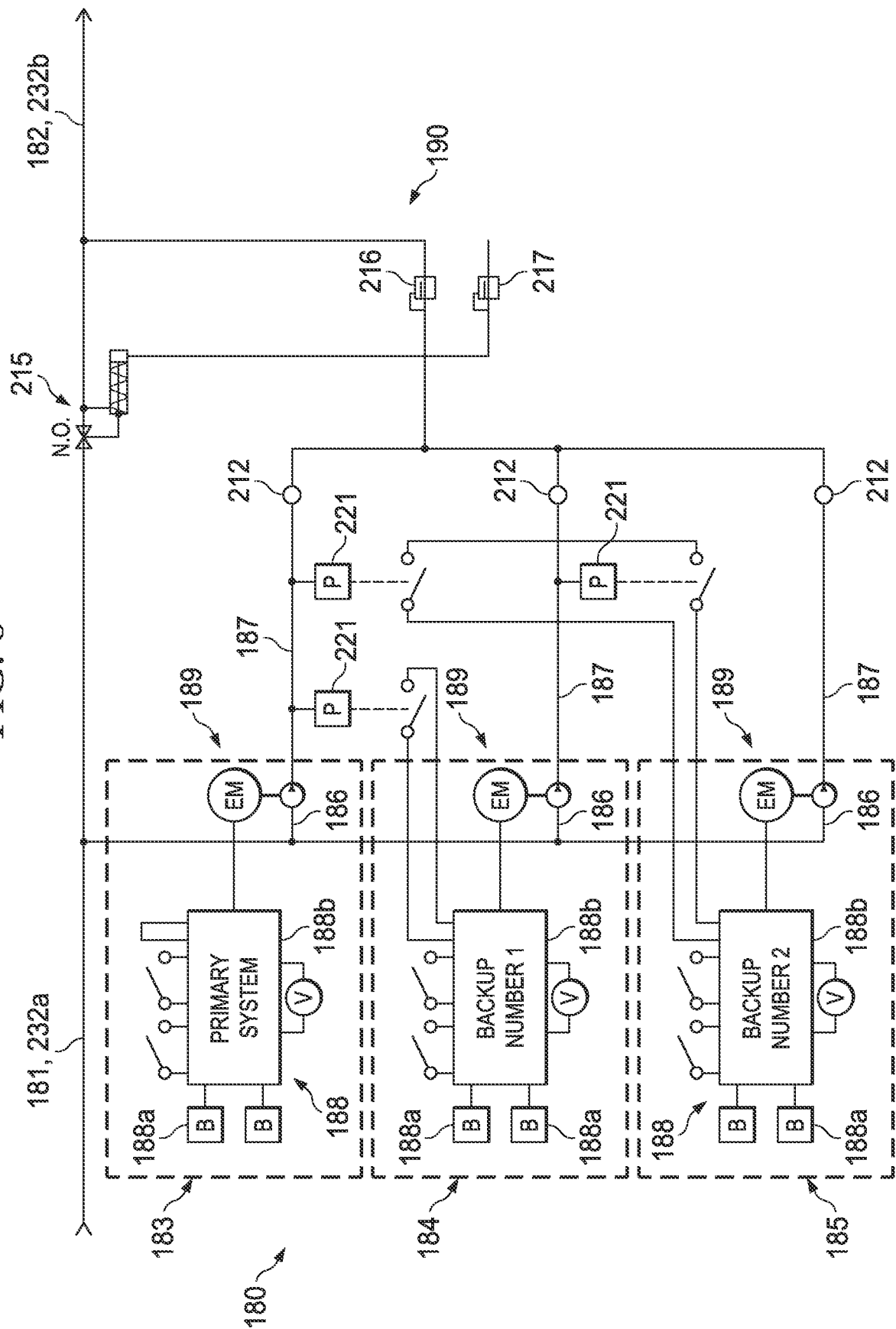


FIG. 9

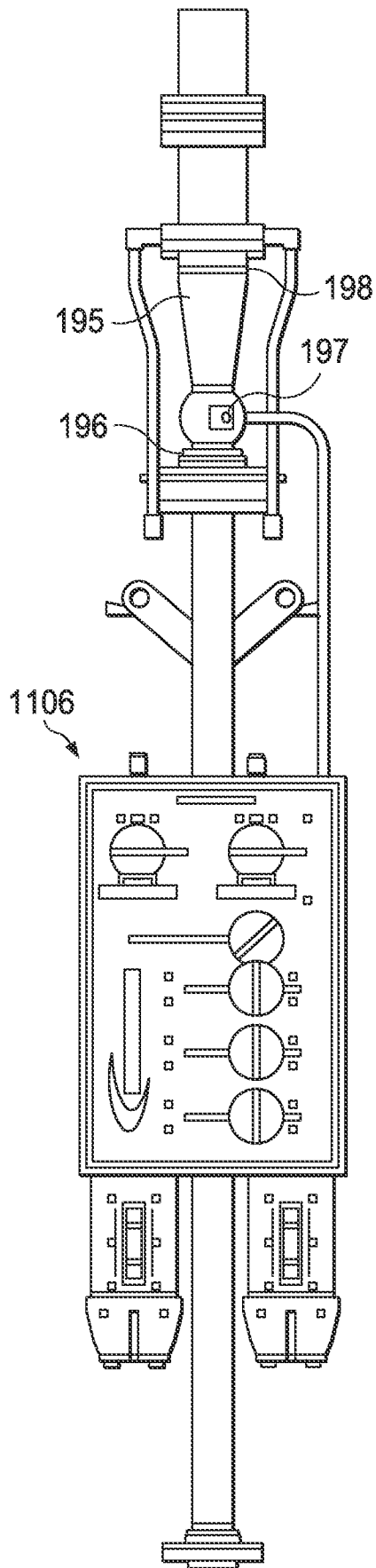


FIG. 10

