AIR-FREIGHTABLE SUBSEA WELL CONTAINENT TOOLING PACKAGE

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ABSTRACT

A system for supplying a chemical dispersant to a subsea hydrocarbon discharge site comprises a surface vessel including a dispersant storage tank and a dispersant pump configured to pump dispersant from the storage tank. In addition, the system comprises a first flow line coupled to the pump and extending subsea from the vessel. Further, the system comprises a subsea dispersant distribution system coupled to the first flow line. Still further, the system comprises a dispersant injection device coupled to the distribution system and configured to inject dispersant from the tank into a subsea hydrocarbon stream.
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CROSS-REFERENCE TO RELATED APPLICATIONS


STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND

[0003] 1. Field of the Invention

[0004] The invention relates generally to a tooling package deployed as an initial response to a subsea hydrocarbon discharge. More particularly, the invention relates to an air-freightable tooling package including a subsea dispersant injection system for delivering chemical dispersants to a subsea hydrocarbon discharge stream.

[0005] 2. Background of the Technology

[0006] In offshore drilling operations, a blowout preventer (BOP) is often installed on a wellhead at the sea floor and a lower marine riser package (LMRP) mounted to the BOP. In addition, a drilling riser extends from a flex joint at the upper end of the LMRP to a drilling vessel or rig at the sea surface. A drill string is then suspended from the rig through the drilling riser, LMRP, and the BOP into the well bore.

[0007] During drilling operations, drilling fluid, or mud, is delivered through the drill string, and returned up an annulus between the drill string and casing that lines the well bore. In the event of a rapid influx of formation fluid into the annulus, commonly known as a "kick," the BOP and/ or LMRP may actuate to seal the annulus and control the well. In particular, BOPs and LMRPs comprise closure members capable of sealing and closing the well in order to prevent the release of gas or liquids from the well. However, if the wellbore is not sealed in response to a surge of formation fluid pressure in the annulus, a "blowout" may occur. The blowout may result in the discharge of hydrocarbons into the surrounding sea water. The subsea release of hydrocarbons may present environmental issues. In addition, the subsea release of hydrocarbons may potentially present a hazardous environment at the surface. Consequently, the more time it takes to respond to a subsea blowout and subsea discharge of hydrocarbons, the more hydrocarbons are likely discharged into the surrounding water.

[0008] Chemical dispersing agents, or simply dispersants, are specially formulated chemical products containing surfactant-active agents and a solvent. Dispersants aid in breaking up hydrocarbon solids and liquids by reducing the interfacial tension between the oil and water, thereby promoting the migration of finely dispersed water-soluble micelles that are rapidly diluted. As a result, the hydrocarbons are effectively spread throughout a larger volume of water, and the environmental impact may be reduced. In addition, dispersants are believed to facilitate and accelerate the digestion of hydrocarbons by microbes, protozoa, nematodes, and bacteria. Moreover, the use of dispersants reduces the risk to responders at the surface by minimizing the accumulation of oil, associated volatile organic compounds (VOCs) and hydrocarbon vapors. Dispersants can also delay the formation of persistent oil-in-water emulsions.

[0009] Traditionally, 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. Since dispersants may comprise chemicals, there is generally a desire to minimize the quantity and distribution of dispersants that are used. However, since oil released from a subsea well diffuses and spreads out at 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.

[0010] To minimize "overspray" and limit the application of dispersants to the oil slick itself, distribution at the surface typically involves the visualization of the oil slick at the surface. Accordingly, the clock surface distribution may not be possible (e.g., at night the location and boundaries of the oil slick at the surface may not be visible). However, there is usually a limited time-frame in which dispersants can be successfully applied at the surface. In particular, certain oil constituents evaporate quickly at the surface, leaving waxy residues or "weathered" oil that are often unresponsive to dispersants.

[0011] It should also be appreciated that some turbulence at the surface (e.g., wave action) is preferred during surface application of dispersants to sufficiently mix the dispersant into the oil and the treated oil into the water. Depending on the weather and sea conditions, surface turbulence may be less than adequate. Moreover, 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.

[0012] Accordingly, there remains a need in the art for improved systems and methods for the offshore application of chemical dispersant to discharged hydrocarbons. Such systems and methods would be particularly well received if they were rapidly sourced and easily transported to the offshore location, and further, offered the potential to minimize the quantity of dispersants emitted, enhance dissipation of the discharged oil before it reaches the surface, operate around the clock (e.g., 24 hours a day), and facilitate increased microbial digestion of oil.

BRIEF SUMMARY OF THE DISCLOSURE

[0013] These and other needs in the art are addressed in one embodiment by a system for supplying a chemical dispersant to a subsea hydrocarbon discharge site. In an embodiment, the system comprises a surface vessel including a dispersant storage tank and a dispersant pump configured to pump dispersant from the storage tank. In addition, the system comprises a first flow line coupled to the pump and extending subsea from the vessel. Further, the system comprises a subsea dispersant distribution system coupled to the flow line. The dispersant distribution system includes a modular subsea manifold assembly including a base, a frame remov-
ably coupled to the base, and a chemical dispersant manifold coupled to the frame. Still further, the system comprises a dispersant injection device coupled to the distribution system and configured to inject dispersant from the tank into a subsea hydrocarbon stream.

These and other needs in the art are addressed in another embodiment by a subsea manifold assembly. In an embodiment, the manifold assembly comprises a base including a plate and a plurality of posts extending perpendicularly from the plate. In addition, the manifold assembly comprises a frame removably coupled to the base. The frame has an upper end, a lower end, and a plurality of parallel posts extending from the upper end to the lower end. Each post has a receptacle at the lower end that slidingly receives one of the posts of the base. Further, the manifold assembly comprises a chemical dispersant manifold coupled to the frame. The chemical dispersant manifold includes a plurality of dispersant inlets and a plurality of dispersant outlets.

These and other needs in the art are addressed in another embodiment by a method for responding to a subsea hydrocarbon discharge at an offshore location. In an embodiment, the method comprises (a) storing a base of a subsea manifold assembly, a frame of a subsea manifold assembly, a chemical dispersant manifold of the subsea manifold assembly, a flying lead, and a dispersant application device at a common geographical location. In addition, the method comprises (b) transporting the base, the frame, the dispersant manifold, the flying lead, and the application device to the offshore location. Further, the method comprises (c) assembling the base, the frame, and the dispersant manifold into the manifold assembly. Still further, the method comprises (d) lowering the manifold assembly subsea after (c).

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**

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

**FIG. 1** is a schematic view of an embodiment of a subsea dispersant injection system in accordance with the principles described herein;

**FIG. 2** is a perspective front view of the subsea dispersant manifold of FIG. 1;

**FIG. 3** is a perspective rear view of the subsea dispersant manifold of FIG. 1;

**FIG. 4** is a top view of the subsea dispersant manifold of FIG. 1;

**FIG. 5** is a front view of the subsea dispersant manifold of FIG. 1;

**FIG. 6** is a rear view of the subsea dispersant manifold of FIG. 1;

**FIG. 7** is an exploded assembly view of the subsea dispersant manifold of FIG. 1;

**FIG. 8** is a schematic view of the subsea dispersant manifold of FIG. 1;

**FIG. 9A** is a perspective view of one of the dispersant application devices of FIG. 1;

**FIG. 9B** is a side view of the dispersant application device of FIG. 9A;

**FIG. 10** is a schematic view of the dispersant application device of FIGS. 9A and 9B deployed with a subsea remotely operated vehicle and used in conjunction with the subsea dispersant injection system of FIG. 1 to inject dispersant into a subsea hydrocarbon stream at a subsea hydrocarbon discharge site;

**FIGS. 11A-11E** are side views of embodiments of dispersant injection wands that may be employed with the base of FIGS. 9A and 9B; and

**FIG. 12** is a schematic view of a plurality of components maintained at a common geographic location for deployment as a first response to a subsea hydrocarbon discharge.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

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 suggest that the scope of the disclosure, including the claims, is limited to that embodiment.

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.

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 part), 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.

Referring now to FIG. 1, an embodiment of a system 100 for distributing and injecting chemical dispersants subsea is schematically shown. System 100 extends from the sea surface 102 to the sea floor 103 and delivers chemical dispersants to one or more subsea hydrocarbon discharge sources or sites 110. In general, a discharge site 110 may be any subsea location at which hydrocarbons are emitted into the surrounding sea water including, without limitation, a subsea BOP, a subsea manifold, a subsea pipe or conduit, a
riser, etc. 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 emitted into the surrounding sea water from a damaged or broken subsea oil conduit or other subsea equipment. At discharge site 110, hydrocarbons are emitted as a stream 111 that slowly diffuses and spreads out as it rises to the sea surface 102 to form a hydrocarbon plume 112. As will be described in more detail below, system 100 is employed to inject a chemical dispersant directly into the hydrocarbon stream 111 at discharge site 110 to facilitate its breakup, dissipation, and microbial digestion.

[0035] In this embodiment, system 100 includes an offshore support vessel 120 at the sea surface 102, a dispersant distribution system 130 extending along the sea floor 103, and a plurality of subsea dispersant application devices 200 coupled to distribution system 130. In general, support vessel 120 stores chemical dispersants at the sea surface 102 and pumps the chemical dispersants to the distribution system 130. Dispersant in system 130 is then supplied to application devices 200, which are employed by one or more subsea remotely operated vehicles (ROVs) 290 to inject the dispersant into the hydrocarbon stream 111 emitted at discharge site 110.

[0036] Vessel 120 includes a plurality of chemical dispersant storage tanks 121, a plurality of dispersant injection pumps 122 coupled to tanks 121, and a dispersant flow line 124 extending from pumps 122 to distribution system 130. In this embodiment, flow line 124 is coiled tubing mounted to a coiled tubing reel or unit 123 that supplies the dispersants to distribution system 130 and application devices 200. In other embodiments, flow line 124 may be a subsea umbilical that supplies the dispersants to distribution system 130 and application devices 200, and may also supply electrical power and pressurized hydraulic fluid to system 130. Such an umbilical may be mounted to a reel or stored and deployed in another suitable fashion.

[0037] Tanks 121 store chemical dispersants at the sea surface 102 on vessel 120. In this embodiment, three tanks 121 are provided, each tank 121 being the same. Namely, each tank 121 comprises a five-thousand gallon dispersant storage vessel. However, in general, tanks 121 may comprise any suitable number and size dispersant storage tanks. Further, the chemical dispersant stored in tanks 121 and supplied to system 130 may comprise any suitable chemical dispersant including, without limitation, a surfactant or mixture of fluids including surfactants. One example of a suitable chemical dispersant is Corexit® EC9500A available from Nalco Company of Naperville, Ill.

[0038] Pumps 122 supply dispersant in tanks 121 to coiled tubing 124 of coiled tubing unit 123. In this embodiment, one fluid pump 122 is provided for each storage tank 121, and thus, each pump 122 pulls dispersant from one tank 121 and supplies it to coiled tubing unit 123 and associated coiled tubing 124. In addition, in this embodiment, each pump 122 includes a flowmeter to measure and monitor the volumetric flow rate of dispersant through that pump 122. Pumps 122 preferably operate at pressures and flow rates suitable for the downstream components of system 100. In this embodiment, each pump 122 is configured to output dispersant at a pressure less than or equal to 5,000 psi and flow rate less than or equal to 12 gpm. However, in other embodiments, the pressure and flow rate of dispersant from pumps 122 may be increased or decreased depending on the limitations of the downstream components. Coiled tubing 124 extends from coiled tubing unit 123 and vessel 120 at the sea surface 102 to subsea distribution system 130.

[0039] Referring still to FIG. 1, distribution system 130 extends between coiled tubing 124 and application devices 200 and supplies dispersant therebetween. In this embodiment, distribution system 130 includes a subsea manifold assembly 140 coupled to tubing 124 and a plurality of flexible dispersant flow lines or flying leads 190 extending between manifold assembly 140 and application devices 200. Each flying lead 190 has a first or inlet end 190a coupled to manifold assembly 140 and a second or outlet end 190b coupled to one application device 200. In this embodiment, each flying lead 190 is a flexible hose preferably rated for at least 5,000 psi, and more preferably rated for at least 10,000 psi.

[0040] During dispersant injection operations, dispersant is pumped from vessel 120 via pumps 122 down coiled tubing 124 to manifold assembly 140, which distributes the dispersant to one or more flying leads 190. Each flying lead 190 supplies dispersant to one application device 200. Thus, pumps 122 on vessel 120 facilitate the flow of dispersant through system 100 from storage tanks 121 to application devices 200.

[0041] One or more subsea ROVs 290 are employed to install the subsea components of system 100 and operate the subsea components of system 100 during dispersant injection operations. In this embodiment, each ROV 290 includes an arm 291 from a claw 292, a subsea camera 293 for viewing the subsea operations, and an umbilical 294. Streaming video and/or images from cameras 293 are communicated to the surface or other remote location via umbilical 294 for viewing on a live or periodic basis. Arms 291 and claws 292 are controlled via commands sent from the surface or other remote location to ROV 290 through umbilical 294. As will be described in more detail below, arms 291 and claws 292 enable ROVs 290 to grasp, manipulate, install, actuate, and position various subsea components.

[0042] Referring now to FIGS. 2-8, manifold assembly 140 is positioned at the sea floor 103 and includes a base 141, a support frame 150 coupled to base 141, a plurality of arms 160 extending from frame 150, a chemical dispersant manifold 170 supported by frame 150, and a hydraulic fluid manifold 180 supported by frame 150. As will be described in more detail below, base 141 supports manifold assembly 140 on the sea floor 103, frame 150 supports manifolds 170, 180, which route and control the flow of dispersant and hydraulic fluid, respectively, through manifold assembly 140, and arms 160 support flying leads 190 during deployment of manifold assembly 140. For example, in FIG. 5, one flying lead 190 is shown wrapped around one set of arms 160.

[0043] In this embodiment, base 141 comprises a generally rectangular plate 142 mounted on a plurality of elongate, parallel joists 143 and a plurality of parallel cross-members 144 extending between adjacent joists 143. Plate 142 extends beyond the periphery of frame 150 and provides a relatively large surface area for engaging the sea floor 103. Consequently, base 141 functions as a “mud mat” that distributes the weight of manifold assembly 140 along the sea floor 103, thereby restricting and/or preventing manifold assembly 140 from sinking into the sea floor 103. As best shown in FIG. 7, in this embodiment, plate 142 includes a central rectangular opening 145 and a plurality of circular holes 146 disposed about opening 145. In addition, base 141 includes four par-
allel posts 147 extending upwardly and perpendicularly from plate 142 and generally positioned at the four corners of opening 145. Each post 147 has a first or upper end 147a, a second or lower end 147b, and a shoulder 148 positioned between ends 147a, b. Shoulder 148 extends about the entire perimeter of its corresponding post 147. Each post 147 also includes a male extension 149 extending from shoulder 148 to end 147a. Each extension 149 is configured to engage a mating receptacle in frame 150. Lower ends 147b are fixed to cross members 144.

[0044] Referring again to FIGS. 2-7, frame 150 has a vertically oriented central or longitudinal axis 155, a first or upper end 150a distal base 141, and a second or lower end 150b releasably coupled to base 141. In addition, frame 150 has a rectangular prismatic shape, and thus, may generally be described as having vertical, parallel front and rear sides 151a, b, respectively; vertical, parallel lateral sides 151c, d, respectively; and horizontal, parallel top and bottom sides 151e, f, respectively. Each lateral side 151a, b extends between sides 151c, d and between sides 151e, f; sides 151c, d extend between sides 151a, b and sides 151e, f; and sides 151e, f extend between sides 151a, b and between sides 151c, d. Top and bottom sides 151e, f are perpendicular to axis 155, and sides 151a, c, e are orthogonal.

[0045] In this embodiment, frame 150 includes four vertical posts 152, a first plurality of horizontal stringers or cross-members 153 extending between posts 152 at upper end 150a, and a second plurality of horizontal cross-members 153 extending between posts 152 at lower end 150b. Each post 152 is coaxially aligned with one post 147 of base 141 and is positioned at the intersection of one side 151a, b and one lateral side 151c, d. In addition, each post 152 has a first or upper end 152a disposed at frame upper end 150a, and a second or lower end 152b disposed at frame lower end 150b and releasably connected to a post 147 of base 141. In particular, each lower end 152b comprises a receptacle 154 that slidingly receives one extension 149, thereby coupling frame 150 to base 141. In this embodiment, one cross-member 153 extends perpendicularly between each pair of adjacent posts 152 at upper end 150a and lower end 150b, and one cross-member 153 extends between diagonally opposed posts 152 at upper end 150a and lower end 150b.

[0046] A plurality of handles 156 are coupled to posts 152 and cross-members 153. Handles 156 facilitate the grasping and manipulation of frame 150 at the surface and subsea. In this embodiment, each handle 156 is a generally U-shaped handle. Frame 150 also includes an umbilical connection plate 157 coupled to cross-members 152 at upper end 150a. Connection plate 157 includes a central, circular opening 158 that allows the inner lines and cables of a subsea umbilical to extend through plate 157 and into frame 150. As best shown in FIG. 7, frame 150 also includes a plurality of cylindrical arm mounts 159—four mounts 159 extend perpendicularly from front side 151a and four mounts 159 extend perpendicularly from rear side 151b. One mount 159 is positioned at upper end 150a and lower end 150b of each corner of frame 150.

[0047] Referring still to FIG. 7, one arm 160 is releasably coupled to each mount 159. In this embodiment, arms 160 are cylindrical tubulars, each arm 160 having a first end 160a attached to one mount 159 and a free end 160b distal frame 150. In particular, first end 160a of each arm 160 defines a receptacle 161 that slidingly receives one mating mount 159. In addition, each arm 160 includes a distal portion 162 extending from end 160b and oriented perpendicular to lateral sides 151c, d. In particular, a first set of four arms 160 have parallel distal portions 162 extending perpendicularly away from side 151c, and a second set of four arms 160 have parallel distal portions 162 extending perpendicularly away from side 151d.

[0048] Each arm 160 comprises a finger 163 rotatably coupled to free end 160b of each arm 160. More specifically, each finger 163 is pivotally coupled to one end 160b and configured to rotate about an axis 164 oriented perpendicular to distal portion 162 of the corresponding arm 160, perpendicular to a plane containing front side 151a, and parallel to plate 142. Each finger 163 coupled to each arm 160 connected to frame 150 at upper end 150a extends vertically upward from its corresponding end 160b, and each finger 163 coupled to each arm 160 connected to frame 150 at lower end 150b extends vertically downward from its corresponding end 160b. In addition, each finger 163 has a first position generally perpendicular to distal portion 162 of the corresponding arm 160 and plate 142, and a second position extending axially from distal portion 162 of the corresponding arm 160 and parallel to plate 142. Fingers 163 are biased to the first position, but may be transitioned to the second position by application of a force generally parallel to distal portion 162 of the corresponding arm 160 and perpendicular to a plane containing lateral side 151c.

[0049] As shown in FIG. 5, arms 160 generally provide a means for storing flying leads 190 during deployment of manifold assembly 140 and when manifold assembly 140 is not in use. In particular, one or more flying leads 190 may be looped or wrapped around the distal portions 162 of the four arms 160 extending from side 151c, and one or more flying leads 190 may be looped or wrapped around the distal portions 162 of the other four arms 160 extending from side 151d. Once leads 190 are wound around distal portions 162, fingers 163 restrict and/or prevent the leads 190 from being inadvertently pulled off arms 160.

[0050] Dispersant manifold 170 is coupled to and supported by a dispersant control panel 171 positioned on front side 151a and extending between adjacent posts 152. In general, dispersant manifold 170 controls and routes the flow of dispersant pumped from vessel 120 through coiled tubing 124 to manifold assembly 140. As best shown in FIG. 8, dispersant manifold 170 includes a first dispersant inlet 172, a pair of second dispersant inlets 173, and a pair of dispersant outlets 174. In this embodiment, inlet 172 and each outlet 174 comprises an API 17H Hi Flow “hot stab” receptacle or connector 175 configured to releasably engage a mating hot stab connector coupled to the end of coiled tubing, and each inlet 173 comprises a JIC connector 176 configured to releasably engage a mating connector at the end of a dispersant flow line carried within an umbilical. Accordingly, inlet 172 may also be described as a “coiled tubing” or “hot stab” inlet, each outlet 174 may also be described as a “coiled tubing” or “hot stab” outlet, and each inlet 173 may also be described as an “umbilical” inlet. Thus, dispersant manifold 170 enables the delivery of dispersant via coiled tubing (e.g., coiled tubing 124) or umbilical, thereby enhancing the versatility of manifold assembly 140. As shown in FIG. 1, in this embodiment, the subsea, lower end of coiled tubing 124 is releasably connected to coiled tubing inlet 172.

[0051] Referring still to FIG. 8, each inlet 172, 173 is coupled to each outlet 174 via flow lines 177. However, fluid communication between each inlet 172, 173 and each outlet
174 is controlled by a plurality of valves 178. Each valve 178 has an open position allowing fluid flow through that valve 178 and a closed position restricting and/or preventing fluid flow through that valve 178. In this embodiment, each inlet 172, 173 includes a valve 178 that controls the flow of fluid (e.g., dispersant) through that particular inlet 172, 173, and further, each outlet 174 includes a valve 178 that controls the flow of fluid through that particular outlet 174. Valves 178 are positioned along flow lines 177 between inlets 172, 173 and outlets 174. Thus, fluid communication between any one inlet 172, 173 and any one outlet 174 requires the valve 178 of that particular inlet 172, 173 to be opened and the valve 178 of the particular outlet 174 to be opened. For example, if valve 178 of inlet 172 is opened and valve 178 of one outlet 174 is open, fluid communication between inlet 172 and that particular outlet 174 is permitted. However, if a valve of any inlet 172, 173 is closed or a valve 178 of an outlet 174 is closed, fluid communication between that particular inlet 172, 173 and that particular outlet 174 is restricted and/or prevented. Thus, fluid communication between any inlet 172, 173 and any outlet 174 requires at least two valves 178 to be open.

[0052] In this embodiment, each valve 178 is a quarter-turn ball valve that is manually actuated by one or more subsea ROVs 290. However, in general, each valve 178 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 include, without limitation, gate valves, ball valves, and butterfly valves. In addition, although valves 178 are manual valves operated by subsea ROVs 290 in this embodiment, in other embodiments, valves 178 may be actuated by other suitable means including, without limitation, hydraulically actuation, electrical actuation, pneumatic actuation, or combinations thereof. To minimize and/or eliminate the inadvertent emission of chemical dispersants into the surrounding sea water prior to venting or discharge of hydrocarbons subsea, valves 178 of outlets 174 are preferably closed until it is time to inject the dispersant into the subsea hydrocarbon stream. Inlet 172 and each outlet 174 also includes a pressure gauge 179 that measures the pressure of fluid within that particular inlet 172 and outlet 174, respectively.

[0053] As shown in FIGS. 5 and 8, coiled tubing inlet 172, coiled tubing outlets 174, and gauges 179 are generally located on the front or outward facing side of panel 171, whereas umbilical inlets 173 are located on the rear or inward facing side of panel 171. Thus, for umbilical dispersant supply connections, the lower end of the outer sheath of a subsea umbilical is attached to umbilical connection plate 157, and the dispersant supply lines within the umbilical pass through hole 158 to the interior of frame 150 where they are routed and connected to inlets 173 on the backside of panel 171. In addition, each valve 178 may accessed and transitioned between the open and closed positions by a rotatable member or handle 178a positioned on the front side of panel 171.

[0054] Referring now to FIGS. 3, 6, and 8, hydraulic fluid manifold 180 is coupled to and supported by a hydraulic fluid control panel 181 positioned on rear side 151b and extending between adjacent posts 152. In general, hydraulic fluid manifold 180 controls and routes the flow of pressurized hydraulic fluid through manifold assembly 140. Thus, pressurized fluid may be supplied to manifold assembly 140 and delivered to other subsea components such as hydraulic accumulators, etc.

[0055] As best shown in FIG. 8, hydraulic fluid manifold 180 includes a pair of hydraulic fluid inlets 182 and a pair of hydraulic fluid outlets 183; a flow line 185 extends from each inlet 182 to one of the outlets 183. In this embodiment, each inlet 182 comprises a JIC connector 176 configured to releasably engage a mating coupling at the end of a dispersant flow line carried within an umbilical, and each outlet 183 comprises a port disposed within an API 17H dual port “hot stab” receptacle or connector 184 configured to releasably engage a mating connector coupled to the end of a hydraulic fluid flow line. Accordingly, each inlet 182 may also be described as an “umbilical” inlet, and each outlet 183 may also be described as a “hot stab” outlet.

[0056] Referring still to FIG. 8, each inlet 182 is coupled to one outlet 183 via a single dedicated flow line 185. However, fluid communication between each inlet 182 and each outlet 183 is controlled by a valve 186 disposed in each flow line 185. Valves 186 are similar to valves 178 previously described. Namely, each valve 186 has an open position allowing fluid flow through that valve 186 and a closed position restricting and/or preventing fluid flow through that valve 186. In this embodiment, each flow line 185 includes one valve 186 that controls the flow of fluid (e.g., hydraulic fluid) through that flow line 185 and corresponding inlet 182 and outlet 183. Thus, fluid communication between each inlet 182 and its corresponding outlet 183 requires the valve 186 of the corresponding flow line to be opened. In this embodiment, each valve 186 is a quarter-turn ball valve that is manually actuated by one or more subsea ROVs 290. However, in general, each valve 186 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 include, without limitation, gate valves, ball valves, and butterfly valves. In addition, although valves 186 are manual valves operated by subsea ROVs 290 in this embodiment, in other embodiments, valves 186 may be actuated by other suitable means including, without limitation, hydraulically actuation, electrical actuation, pneumatic actuation, or combinations thereof. Each flow line 185 also includes a pressure gauge 179 as previously described that measures the pressure of fluid within that particular flow line 185.

[0057] As shown in FIGS. 3, 6, and 8, outlets 183 and gauges 179 are generally located on the front or outward facing side of panel 181, whereas umbilical inlets 182 are located on the rear or inward facing side of panel 181. Thus, the lower end of the outer sheath of a subsea umbilical is attached to umbilical connection plate 157, and the hydraulic fluid supply lines within the umbilical pass through hole 158 to the interior of frame 150 where they are routed and connected to inlets 182 on the backside of panel 181. In addition, each valve 186 may accessed and transitioned between the open and closed positions by a rotatable member or handle 186a positioned on the front side of panel 181.

[0058] Referring to FIGS. 1 and 8, each outlet 174 of dispersant manifold 170 supplies dispersant to one dispersant application device 200 via one flying lead 190. In this embodiment, dispersant manifold 170 includes two outlets 174 as previously described, and thus, manifold 170 can be used to simultaneously supply dispersant to two dispersant application devices 200. Inlet end 190a of each flying lead 190 comprises a coupling 191 sized and configured to releasably connect to one coiled tubing connector 175, thereby placing that flying lead 190 in fluid communication with the
corresponding outlet 174. Similarly, outlet end 190b of each flying lead 190 comprises a coupling 192 sized and configured to releasably connect to one dispersant application device 200. In general, each device 200 may comprise any device that allows dispersant to be injected into the hydrocarbon stream at discharge site 110. Exemplary embodiments of dispersant application devices (e.g., devices 200) are described in more detail below. In general, devices 200 are operated, manipulated, and maneuvered by subsea ROVs 290.

[0059] Referring now to FIGS. 9A and 9B, an embodiment of a dispersant application device 200 for injecting dispersants into a subsea stream of hydrocarbons is shown. Device 200 is connected to outlet end 190b of one dispersant flow line 190 previously described and shown in FIG. 1 to inject dispersant into subsea hydrocarbon discharge site 110. In this embodiment, dispersant application device 200 comprises a base 201 and an elongate dispersant application wand 210 extending from base 201. Wand 210 is a tubular having a central or longitudinal axis 215, a first or base end 210a coupled to base 201, and a second or free end 210b opposite end 210a and distal base 201. In this embodiment, wand 210 and axis 215 extend linearly from base 201. Distal end 210b of wand 210 comprises an orifice defining a nozzle 211 for injecting dispersants into the hydrocarbon stream at discharge site 110. In general, dispersant from distribution system 130 flows through flow line 190 to base 201, and is then supplied through wand 210 to nozzle 211.

[0060] Device 200 also includes a dispersant inlet 202 and an inlet valve 203, each mounted to base 201. Inlet 202 is in fluid communication with one flow line 190 previously described. In particular, inlet 202 is releasably connected to outlet end 190b of one flow line 190 with a coupling 192 as previously described. Inlet valve 203 controls the flow of dispersant through inlet 202 and wand 210. Specifically, when inlet valve 203 is opened, inlet 202 and flow line 190 are in fluid communication with wand 210. However, when valve 203 is closed, fluid communication between inlet 202 and wand 210 is restricted and/or prevented. In this embodiment, inlet valve 203 is a quarter-turn ball valve that is manually actuated by one or more subsea ROVs 290. However, in general, valve 203 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 include, without limitation, gate valves, ball valves, and butterfly valves. In addition, although valve 203 is a manual valve operated by subsea ROVs 290 in this embodiment, in other embodiments, valve 203 may be actuated by other suitable means including, without limitation, hydraulic actuation, electrical actuation, pneumatic actuation, or combinations thereof. To minimize and/or eliminate the inadvertent emission of chemical dispersants into the surrounding sea water prior to venting or discharge of hydrocarbons subsea, valve 203 is preferably closed until it is time to inject the dispersant into the subsea hydrocarbon stream. In general, dispersant flows through flying lead 190 into inlet 202, and then through valve 203 to wand 210. For purposes of clarity, the flow lines connecting inlet 202 and valve 203, and wand 210 and valve 203 are not shown in FIGS. 9A and 9B. A pair of handles 204 extend from base 201 and enable one or more ROVs 290 to grasp, manipulate, and position device 200.

[0061] Referring now to FIG. 10, device 200 is shown injecting dispersant into a subsea hydrocarbon stream 111 at a subsea hydrocarbon discharge site 110. In this embodiment, discharge site 110 is a subsea BOP stack 300 including a subsea blowout preventer (BOP) 320 mounted to a wellhead 330 at the sea floor 103, and a lower marine riser package (LMRP) 340 including a riser flex joint 345. Casing 341 extends from wellhead 330 into subterranean wellbore 301. Typically, a riser extends from LMRP 340 to a platform or vessel at the sea surface 102, however, in this embodiment, the riser has been removed to provide direct access to BOP stack 300.

[0062] BOP 320 and LMRP 340 are configured to selectively seal wellbore 301 and contain hydrocarbon fluids therein with a plurality of sets of opposed rams 321 in BOP 320 (e.g., opposed blind shear rams or blades, opposed pipe rams, etc.) and/or an annular blowout preventer 341 in LMRP 340 (i.e., an annular elastomeric sealing element that is mechanically squeezed radially inward). During a “kick” or surge of formation fluid pressure in wellbore 301, one or more sets of rams 321 and/or annular BOP 341 are normally actuated to seal in wellbore 301. However, if the wellbore 301 is not sealed, a blowout may result. Such a blowout may compromise the ability to contain wellbore 301 and the hydrocarbon fluids therein. In FIG. 10, stack 300 is shown after a subsea blowout. As a result, hydrocarbon fluids flowing upward in wellbore 301 pass through BOP 320 and LMRP 340, and are discharged into the surrounding sea water proximal the sea floor 103, thereby resulting in hydrocarbon stream 111 and plume 112.

[0063] Referring now to FIGS. 1 and 10, to inject chemical dispersants into stream 111, device 200 is connected to outlet end 190b of one flow line 190 with ROV 290, and then positioned and oriented with ROV 290 such that free end 210b is disposed in hydrocarbon stream 111 at discharge site 110. Using system 100, dispersant is pumped from tanks 121 to application device 200. With valve 203 opened, the dispersant flows through inlet 202 and wand 210 to end 210b where it is injected into stream 111 through nozzle 211.

[0064] As shown in FIGS. 9A and 9B, wand 210 has a linear central axis 215, and distal end 210b includes a single nozzle 211. However, in general, the wand (e.g., wand 210) may have any suitable geometry and the distal end or portion (e.g., end 210b) may include any suitable number of nozzles. In FIGS. 11A–11E, a variety of exemplary wands that may be used in connection with application device 200 in place of wand 210 previously described are shown. In FIG. 11A, a wand 310 having a linear central axis 315 and a free end 312 having a fan geometry including a plurality of dispersant injection nozzles 313 is shown. In FIG. 11B, a wand 320 having a linear central axis 325 and a free end 322 having a trident geometry including three dispersant injection nozzles 323 is shown. In FIG. 11C, a hook-shaped wand 330 having an arcuate central axis 335, a free end 332, and a distal portion 333 including a plurality of axially and circumferentially spaced dispersant injection nozzles 334 is shown. In FIG. 11D, a wand 340 having a linear central axis 345 and a C-shaped distal portion 342 including a plurality of dispersant injection nozzles 343 is shown. In FIG. 11E, a wand 350 having a linear central axis 355 and a Y-shaped distal portion 352 including a plurality of dispersant injection nozzles 353 is shown. Embodiments of dispersant application devices (e.g., device 200) including wands 310, 320, 330, 340, 350 may be deployed in the same manner device 200 previously described and shown in FIG. 10. Other examples of dispersant injection devices are described in U.S. Provisional Patent Application No. 61/479,
Regardless of the geometry of the wand of the dispersant application device (e.g., straight wand 210, hook-shaped wand 330, C-shaped wand 340, Y-shaped wand 350, etc.), in embodiments, the dispersant nozzles may be positioned and oriented to generate a vortex to enhance mixing of the dispersant and the discharged hydrocarbons. In addition, the nozzles may also be configured to enhance the contact surface area between the discharged dispersant and the hydrocarbons. For example, the nozzles may be configured to discharge relatively small droplets of dispersant.

Referring now to FIG. 12, the various components of distillation system 130, one or more dispersant injection devices 200, as well as various tools 502 for installing system 130 and preparing the discharge site and/or sea floor 103 for the installation of system 130 are preferably stored and inventoried together in a common warehouse or geographic location 505 for use as an emergency or first response package for containing a subsea hydrocarbon discharge. In this embodiment, manifold assembly 140 has been broken down to facilitate transport to the offshore location. In particular, manifold assembly 140 has been broken down into base 141, frame 150, arms 150, and panels 171, 181, which comprise manifolds 170, 180, respectively. A plurality of flying leads 190, application devices 200, and tools 502 are preferably inventoried with the components of manifold assembly 140 to provide a complete response package that contains all the necessary hardware for implementing system 130. In general, tools 502 may include any tool suitable for deploying and installing system 130 as well as clearing debris in preparation for installation of system 130 including, without limitation, subsea ROV operated saws (e.g., chop saws), torque tools, grinders, grapple tools, cleaning tools, riser/piper shears (e.g., shears available from Prime Marine Services Inc. of Broussard, La.), stud removal tools, impact wrenches, acoustic modems and pressure transducers, diamond wires, etc.

In this embodiment, the components of manifold assembly 140 (e.g., base 141, frame 150, arms 160, and panels 171, 181) shown in FIG. 12 are sized and configured to be air-freightable on their own or in conjunction with other components. In other words, each component of manifold assembly 140 has a weight and dimensions suitable for air transport. Conventional cargo aircraft such as the Antonov AN124-100 and Boeing 747 have a maximum payload capacity of about 120 tons (2.4x10^7 lbs.), and cargo bays sized to accommodate cargo having a maximum weight of up to about 21 ft. and a maximum height of up to about 14 ft. In embodiments described herein, manifold assembly 140 has a total weight of about 7 tons (7x10^3 lbs.), and all of the components of the exemplary response package have a total combined weight less than 120 tons. In addition, although a fully assembled manifold assembly 140 may not be sized to fit within a standard heavy lift cargo bay, the ability to break down manifold assembly 140 into base 141, frame 150, and arms 160 enables the air transportability of manifold assembly 140. Specifically, base 141, frame 150, arms 160, and panels 171, 181 are each sized such that they can be oriented to have a width less than 21 ft. and a height less than 14 ft. Accordingly, manifold assembly 140 may be broken down into the components shown in FIG. 12, which may then be transported together by air in a single cargo aircraft. Flying leads 190, devices 200, and tools 502 may be transported in the same cargo aircraft with the components of manifold assembly 140 or transported in a separate cargo aircraft. In this embodiment, all the components of the response package fit securely within four standard 20 ft. cargo containers or vans configured for transportation in a single cargo aircraft (e.g., Boeing 747 or Antonov AN124-100).

Most conventional subsea manifolds are not sized and configured to be transported by air because their weight exceeds the payload capacity of conventional cargo aircraft and/or their dimensions cannot be accommodated by conventional aircraft cargo bays. Consequently, transport of such conventional manifolds is typically accomplished by land and/or sea vessel, which may be time consuming depending on the total transported distance. For example, if there is a subsea blowout in the Gulf of Mexico, and the most suitable manifold for routing dispersants subsea is located in the Middle East, it may take days or even weeks to transport the manifold by land and sea to the offshore location in the Gulf of Mexico. However, embodiments of dispersant manifold assemblies described herein (e.g., manifold assembly 140) are air-freightable, and thus, may be transported around the globe in a matter of hours or short number of days (e.g., 1-2 days maximum). As a result, embodiments described herein offer the potential to more efficiently and timely contain a subsea blowout, thereby potentially reducing the total volume of subsea hydrocarbon emissions.

Referring now to FIGS. 1 and 12, the centrally stored or warehoused components shown in FIG. 12 are transported via land, sea or combinations thereof to the offshore site. One or more tools 502 may be employed to prepare the subsea discharge site 110, the sea floor 103, and/or the anticipated landing site of manifold assembly 140 for the installation of system 130. For example, ROVs 290 may utilize one or more tools 502 to cut and clear debris surrounding discharge site 110 so that hydrocarbon stream 111 can be accessed with dispersant application devices 200. Once the sea floor 103 and discharge site 110 have been prepared for installation of system 130, manifold assembly 140, flying leads 190, and application devices 200 are lowered subsea. For air transport, manifold assembly 140 may have been broken down, and thus, manifold assembly 140 is preferably assembled at the sea surface 102 and lowered subsea with wireline or pipestream. During subsea deployment, fluid leads 190 are preferably wrapped about arms 160 as shown in FIG. 5.

Once manifold assembly 140 is sufficiently positioned on the sea floor 103, ROVs 290 are employed to facilitate the connection of dispersant flow line 124 to manifold inlet 172 (or to connect one or two umbilical dispersant line(s) to inlet(s) 173), the connection of inlet end 190a of each flying lead 190 to one outlet 174, the connection of outlet end 190b of each flying lead 190 to one dispersant application device 200, and the connection of any hydraulic fluid flow lines to manifold 180. Next, dispersants are pumped from vessel 120 to distribution system 130, and the appropriate valves 178 are manipulated (e.g., opened or closed) to direct the dispersants to application devices 200. Subsea ROV's 290 maneuver and manipulate devices 200 to inject chemical dispersants directly into stream 111 at discharge site 110.

As previously described, most conventional dispersant techniques rely on the application of dispersants to the relatively spread out oil slick at the sea surface. However, embodiments described herein enable the direct injection of chemical dispersants into the hydrocarbon stream at its sub-
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. For example, it is believed that direct subsea application of dispersants prior to substantial mixing of oil and sea water may reduce the volume of dispersant necessary for effective oil dispersion by up to 70%. In addition, injecting dispersant at the point of subsea hydrocarbon release offers the potential to minimize VOCs at the surface, enhance microbial digestion/breakdown of the hydrocarbons, subsea, and enable continuous 24 hour application of dispersants over a range of weather conditions and sea states. Further, direct injection into “fresh” oil at the discharge site reduces and/or eliminates problems associated with dispersant application to weathered crude oil.

[0072] It should be appreciated that embodiments described herein may be used in combination with other subsea dispersant injection systems such as the subsea autonomous dispersant injection systems described in U.S. Patent Application Ser. No. 61/445,357, entitled “Subsea Autonomous Dispersant Injection System and Methods” filed Feb. 22, 2011, which is hereby incorporated herein by reference in its entirety for all purposes.

[0073] 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. Unless expressly stated otherwise, the steps in a method claim may be performed in any order. The recitation of identifiers such as (a), (b), (c) or (i), (2), (3) before steps in a method claim are not intended to and do not specify a particular order to the steps, but rather are used to simplify subsequent reference to such steps.

What is claimed is:

1. A system for supplying a chemical dispersant to a subsea hydrocarbon discharge site, comprising:
   a surface vessel including a dispersant storage tank and a dispersant pump configured to pump dispersant from the storage tank;
   a first flow line coupled to the pump and extending subsea from the vessel;
   a subsea dispersant distribution system coupled to the first flow line;
   a dispersant injection device coupled to the distribution system and configured to inject dispersant from the tank into a subsea hydrocarbon stream.

2. The system of claim 1, wherein the subsea dispersant distribution system comprises:
   a subsea manifold assembly positioned at the sea floor, wherein the manifold assembly includes a base, a frame coupled to the base, and a chemical dispersant manifold coupled to the frame;
   wherein the chemical dispersant manifold includes a plurality of dispersant inlets and a plurality of dispersant outlets, wherein the first flow line is connected to one of the dispersant inlets; and
   a second flow line extending from one of the outlets of the chemical dispersant manifold to the injection device.

3. The system of claim 2, wherein each outlet of the chemical dispersant manifold includes a valve configured to control the flow of dispersant through the outlet, and
   wherein each inlet of the chemical dispersant manifold includes a valve configured to control the flow of dispersant through the inlet.

4. The system of claim 3, wherein at least a first of the inlets of the chemical dispersant manifold is configured to releasably connect with coiled tubing;
   wherein at least a second of the inlets of the chemical dispersant manifold is configured to releasably connect with an umbilical line.

5. The system of claim 4, wherein each outlet of the chemical dispersant manifold is configured to releasably connect with hot stab connector.

6. The system of claim 2, wherein the dispersant injection device includes a base and an elongate wand extending from the base;
   wherein the wand includes at least one nozzle configured to inject dispersant into the subsea hydrocarbon stream.

7. The system of claim 2, wherein the subsea manifold assembly comprises a plurality of arms connected to the frame, wherein a third flow line is wrapped around at least some of the plurality of arms.

8. The system of claim 2, wherein the subsea manifold assembly further comprises a hydraulic fluid manifold coupled to the frame;
   wherein the hydraulic fluid manifold includes a plurality of inlets and a plurality of outlets, each inlet of the hydraulic manifold coupled to one outlet of the hydraulic manifold with a hydraulic flow line;
   wherein each hydraulic flow line includes a valve configured to control the flow of hydraulic fluid through the hydraulic flow line.

9. The system of claim 1, wherein the base has a first weight and the frame has a second weight, wherein the sum of the first weight and the second weight is less than 120 tons.

10. The system of claim 1, wherein the base and the frame are each configured to be air freightable.

11. A method for responding to a subsea hydrocarbon discharge at an offshore location, comprising:
   (a) storing a subsea manifold assembly, a flying lead, and a dispersant application device together at a common location;
   (b) transporting the manifold assembly, the flying lead, and the application device to the offshore location;
   (c) lowering the manifold assembly subsea after (b).

12. The method of claim 11, further comprising:
   (d) connecting a first end of the flying lead to an outlet of the dispersant manifold after (c); and
   (e) connecting a second end of the flying lead to an inlet of the application device after (c).

13. The method of claim 12, further comprising:
   (f) connecting a lower end of a dispersant flow line to an inlet of the dispersant manifold after (c).

14. The method of claim 13, wherein (d), (e), and (f) are performed with one or more subsea ROVs.
15. The method of claim 13, further comprising:
   (g) flowing a chemical dispersant from a surface vessel through the dispersant flow line to the dispersant manifold;
   (h) flowing the chemical dispersant from the dispersant manifold through the flying lead to the application device.

16. The method of claim 15, further comprising:
   (i) injecting the chemical dispersant into a stream of hydrocarbons emitted at a source of the hydrocarbon discharge.

17. The method of claim 13, wherein (b) comprises transporting the manifold assembly, the flying lead, and the application device by air.

18. The method of claim 13, wherein (a) further comprises storing a plurality of flying leads, a plurality of dispersant application devices, and a plurality of tools together at the common location.

19. The method of claim 18, wherein the plurality of tools comprise ROV operated tools for clearing debris subsea selected from the group consisting of saws, grinders, and diamond wires.

20. The method of claim 11, further comprising:
   storing a chemical dispersant in a storage tank at the sea surface;
   pumping the chemical dispersant from the storage tank through a dispersant flow line to the dispersant manifold.