



## (51) International Patent Classification:

*C09D 5/00* (2006.01) *F16L 58/04* (2006.01)  
*C23F 13/00* (2006.01)

## (21) International Application Number:

PCT/US2015/020141

## (22) International Filing Date:

12 March 2015 (12.03.2015)

## (25) Filing Language:

English

## (26) Publication Language:

English

## (30) Priority Data:

61/969,310 24 March 2014 (24.03.2014) US  
62/002,255 23 May 2014 (23.05.2014) US

(71) Applicant: **BOARD OF REGENTS, THE UNIVERSITY OF TEXAS SYSTEM** [US/US]; 201 West 7th Street, Austin, TX 78701 (US).

(72) Inventor: **BAHADUR, Vaibhav**; The University of Texas at Austin, 204 E. Dean Keeton Street, Stop C2201, Austin, TX 78712-1591 (US).

(74) Agent: **VOIGT, JR., Robert, A.**; Winstead, P.C., P.O. Box 131851, Dallas, TX 75313 (US).

(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, BN, 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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, 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, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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, KM, ML, MR, NE, SN, TD, TG).

## Published:

— with international search report (Art. 21(3))

(54) Title: ELIMINATING FOULING IN HYDROCARBON PIPELINES BY ELECTRICAL TECHNIQUES

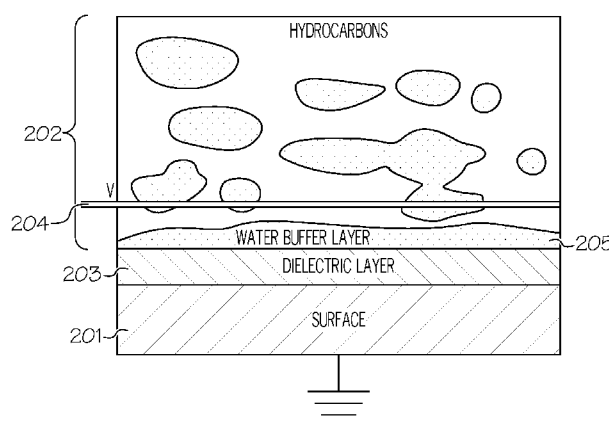


FIG. 2B

(57) Abstract: A method for eliminating hydrocarbon fouling and reducing pumping power during hydrocarbon transportation. A dielectric layer covers the inner surface of a pipeline for transporting a water-hydrocarbon mixture. A proximity electrode is immersed in the water-hydrocarbon mixture, and an electrical voltage is applied across the dielectric layer. A buffer layer of water is formed on the dielectric layer since water is electrically attracted from the water-hydrocarbon mixture. This water layer, located between the dielectric layer and the water-hydrocarbon mixture, eliminates hydrocarbon fouling on the inner surface of the pipeline or any other internal surface that needs fouling protection. Alternatively, the dielectric layer covers an outer surface of the pipeline and is covered by an external conducting layer. Applying a potential difference between the proximity electrode and the external conducting layer still forms a water buffer layer between the inner surface and the water-hydrocarbon mixture, which eliminates hydrocarbon fouling.

## ELIMINATING FOULING IN HYDROCARBON PIPELINES BY ELECTRICAL TECHNIQUES

## CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 62/002,255, "Eliminating Hydrocarbon Fouling and Reducing Pumping Power for Pipeline Oil Transport," filed May 23, 2014 as well as claims priority to U.S. Provisional Patent Application Serial No. 61/969,310, "Eliminating Hydrocarbon Fouling and Reducing Pumping Power for Pipeline Oil Transport," filed March 24, 2014, which are both incorporated by reference herein in their entirety.

## TECHNICAL FIELD

[0002] The present invention relates generally to hydrocarbon fouling and pumping power for pipeline oil transport, and more particularly to eliminating hydrocarbon fouling and reducing the pumping power for pipeline oil transport.

## BACKGROUND

[0003] Hydrocarbon (organic) fouling in the oil and gas industry is a significant flow assurance concern and has huge implications on efficiency, reliability and safety. Hydrocarbon fouling refers to the accumulation of unwanted material (e.g., asphaltenes, waxes, hydrates, scales, biofoulants, etc.) on solid surfaces (e.g., pipelines, risers, production tubing, valves, chokes, manifolds, separators, surface facilities and in refinery components and heat exchangers) and is a serious operational concern in conventional as well as unconventional (e.g., hydraulic fracturing, deepwater, heavy oil) oil and gas production. Unfortunately, existing fouling mitigation techniques involve the use of environmentally unfriendly chemical inhibitors, mechanical pigging, and expensive monitoring and maintenance operations.

[0004] Furthermore, pipelines are the most effective way of transporting hydrocarbons over long distances. However, transporting very high viscosity oil (e.g., heavy oil) necessitates very high pressure drops and pumping power requirements. The currently used technologies to reduce pumping power involve heating pipelines (to reduce the viscosity) or the addition of copious amounts of diluents to the crude stream. Both of these options are expensive to implement and have limited effectiveness.

## BRIEF SUMMARY

[0005] In one embodiment of the present invention, a method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture comprises covering an inner surface of a pipeline for transporting and storing the water-hydrocarbon mixture with a dielectric layer. The method further comprises applying a potential difference across the dielectric layer established by applying an electrical potential to a proximity electrode immersed in a solution of the water-hydrocarbon mixture and applying an electrical potential to the pipeline. The method additionally comprises forming a buffer layer of water on top of the dielectric layer by electrically attracting water from the water-hydrocarbon mixture to the buffer layer by applying the potential difference across the dielectric layer, where the water buffer layer is located between the dielectric layer and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on the inner surface of the pipeline.

[0006] In another embodiment of the present invention, a transportation mechanism for transporting hydrocarbons comprises a pipeline for transporting a water-hydrocarbon mixture. The transportation mechanism further comprises a dielectric layer covering an inner surface of the pipeline. The transportation mechanism additionally comprises a proximity electrode immersed in the water-hydrocarbon mixture, where a potential difference is applied across the dielectric layer established by applying an electrical potential to the proximity electrode and applying an electrical potential to the pipeline. In addition, the transportation mechanism comprises a buffer layer of water on top of the dielectric layer, where the water buffer layer comprises water electrically attracted from the water-hydrocarbon mixture by applying the potential difference across the dielectric layer and where the water buffer layer is located between the dielectric layer and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on an inner surface of the pipeline.

[0007] In another embodiment of the present invention, a method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture comprises covering an outer surface of a pipeline for transporting and storing the water-hydrocarbon mixture with a dielectric layer. The method further comprises covering the dielectric layer with an external conducting layer. The method additionally comprises applying a potential difference across the dielectric layer established by applying an electrical potential to a proximity electrode immersed in a

solution of the water-hydrocarbon mixture and applying an electrical potential to the external conducting layer. In addition, the method comprises forming a buffer layer of water on top of an inner surface of the pipeline by electrically attracting water from the water-hydrocarbon mixture to the buffer layer by applying the potential difference across the dielectric layer, where the water buffer layer is located between the inner surface of the pipeline and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on the inner surface of the pipeline.

**[0008]** In another embodiment of the present invention, a transportation mechanism for transporting hydrocarbons comprises a pipeline for transporting a water-hydrocarbon mixture. The transportation mechanism further comprises a dielectric layer covering an outer surface of the pipeline. The transportation mechanism additionally comprises an external conducting layer covering the dielectric layer. Furthermore, the transportation mechanism comprises a proximity electrode immersed in the water-hydrocarbon mixture, where a potential difference is applied across the dielectric layer established by applying an electrical potential to the proximity electrode and applying an electrical potential to the external conducting layer. Additionally, the transportation mechanism comprises a buffer layer of water on top of an inner surface of the pipeline, where the water buffer layer comprises water electrically attracted from the water-hydrocarbon mixture by applying the potential difference across the dielectric layer and where the water buffer layer is located between the inner surface of the pipeline and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on the inner surface of the pipeline.

**[0009]** In a further embodiment of the present invention, a method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture comprises covering an outer surface of a pipeline for transporting the water-hydrocarbon mixture with an external capacitance. The method further comprises applying a potential difference across the external capacitance established by applying an electrical potential to a proximity electrode immersed in a solution of the water-hydrocarbon mixture and applying an electrical potential to the external capacitance. Additionally, the method comprises forming a buffer layer of water on top of an inner surface of the pipeline by electrically attracting water from the water-hydrocarbon mixture to the buffer layer by applying the potential difference across the external capacitance, where the water buffer layer is located between the inner surface of the pipeline and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on the inner surface of the pipeline.

[0010] In another embodiment of the present invention, a transportation mechanism for transporting hydrocarbons comprises a pipeline for transporting a water-hydrocarbon mixture. The transportation mechanism further comprises an external capacitance covering an outer surface of the pipeline. Furthermore, the transportation mechanism comprises a proximity electrode immersed in the water-hydrocarbon mixture, where a potential difference is applied across the external capacitance established by applying an electrical potential to the proximity electrode and applying an electrical potential to the external capacitance. In addition, the transportation mechanism comprises a buffer layer of water on top of an inner surface of the pipeline, where the water buffer layer comprises water electrically attracted from the water-hydrocarbon mixture by applying the potential difference across the external capacitance and where the water buffer layer is located between the inner surface of the pipeline and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on the inner surface of the pipeline.

[0011] In a further embodiment of the present invention, a method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture comprises covering an inner surface of a pipeline for transporting the water-hydrocarbon mixture with a dielectric layer. The method further comprises applying a potential difference across the dielectric layer established by applying an electrical potential to an electrode mesh covering the dielectric layer and applying an electrical potential to the pipeline. Additionally, the method comprises forming a buffer layer of water on top of the electrode mesh by electrically attracting water from the water-hydrocarbon mixture to the buffer layer by applying the potential difference across the dielectric layer, where the water buffer layer is located between the electrode mesh and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on the inner surface of the pipeline.

[0012] In another embodiment of the present invention, a transportation mechanism for transporting hydrocarbons comprises a pipeline for transporting a water-hydrocarbon mixture. The transportation mechanism further comprises a dielectric layer covering an inner surface of the pipeline. The transportation mechanism additionally comprises an electrode mesh covering the dielectric layer, where a potential difference is applied across the dielectric layer established by applying an electrical potential to the electrode mesh and applying an electrical potential to the pipeline. Furthermore, the transportation mechanism comprises a buffer layer of water on top of the dielectric layer, where the water buffer layer comprises water electrically attracted

from the water-hydrocarbon mixture by applying the potential difference across the dielectric layer, where the water buffer layer is located between the electrode mesh and the water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on an inner surface of the pipeline.

**[0013]** The foregoing has outlined rather generally the features and technical advantages of one or more embodiments of the present invention in order that the detailed description of the present invention that follows may be better understood. Additional features and advantages of the present invention will be described hereinafter which may form the subject of the claims of the present invention.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0014] A better understanding of the present invention can be obtained when the following detailed description is considered in conjunction with the following drawings, in which:

[0015] Figure 1 is a method for preventing hydrocarbon fouling from an oil-water mixture, where the target surface is covered with a dielectric layer, in accordance with an embodiment of the present invention;

[0016] Figure 2A is a schematic illustrating the method for preventing hydrocarbon fouling from an oil-water mixture, where the target surface is covered with a dielectric layer, in accordance with an embodiment of the present invention;

[0017] Figure 2B is a schematic illustrating the application of a potential difference between the substrate and a proximity electrode in the liquid that selectively attracts water towards the surface thereby eliminating hydrocarbon fouling in accordance with an embodiment of the present invention;

[0018] Figure 3 is an alternative method for preventing hydrocarbon fouling from an oil-water mixture, where the dielectric layer is not required to be placed between the target surface and the hydrocarbon-water mixture, in accordance with an embodiment of the present invention;

[0019] Figure 4A is a schematic illustrating an alternative embodiment in which the dielectric layer is not coated on the target internal surface, but instead, on the corresponding external surface in accordance with an embodiment of the present invention;

[0020] Figure 4B illustrates protecting the pipeline internal walls from hydrocarbon fouling in accordance with an embodiment of the present invention;

[0021] Figure 5 is a schematic illustrating a further alternative embodiment in which the dielectric layer and the outer conducting layer are replaced with an external capacitance in accordance with an embodiment of the present invention;

[0022] Figure 6 illustrates the use of an electrode mesh sleeve along the surface of a pipeline as opposed to using a proximity electrode in accordance with an embodiment of the present invention;

[0023] Figure 7 illustrates the concept of core annular flow, where the viscous oil is transported as a core in a pipeline, surrounded in a lubricating layer of much less viscous water in accordance with an embodiment of the present invention; and

[0024] Figure 8 is a graph illustrating the change in pressure drop versus the thickness of the water layer in accordance with an embodiment of the present invention.

## DETAILED DESCRIPTION

[0025] While the following discusses the present invention in connection with eliminating hydrocarbon fouling and reducing the pumping power for pipeline oil transport, the principles of the present invention may be applied to other areas of technology, including, but not limited to, enhanced boiling heat transfer applications (e.g., eliminating film boiling by forcing water to wet the surface), fluid flow applications (enabling annular flows with water electrowetted walls) and nuclear applications (e.g., preventing dryout and controlling instability). A person of ordinary skill in the art would be capable of applying the principles of the present invention to such implementations. Further, embodiments applying the principles of the present invention to such implementations would fall within the scope of the present invention.

[0026] Furthermore, it is noted that the principles of the present invention described herein can be applied to protect any internal surface from fouling (e.g., surfaces inside pipelines, tubes, risers, valves, chokes, pumps, heat exchangers) regardless of the shape of the surface. A person of ordinary skill in the art would be capable of applying the principles of the present invention to such implementations. Further, embodiments applying the principles of the present invention to such implementations would fall within the scope of the present invention.

[0027] The principles of the present invention describe new methods to prevent fouling and contamination of surfaces by hydrocarbons during oil and gas production, transportation and refining. Hydrocarbon fouling in the oil and gas industry is a significant operational concern and has huge implications on efficiency, reliability and safety. The methods described herein can also be used to reduce the pumping power needed to transport highly viscous oils or other fluids via pipelines.

[0028] In one embodiment, the present invention relies on the contrast in the electrical properties of hydrocarbons and water to eliminate hydrocarbon contact with the surface that needs to be protected from fouling. By artificially forcing water to wet the surface (e.g., pipeline inner surfaces), hydrocarbon contact is eliminated (minimized) and the surface stays protected from fouling. Furthermore, in one embodiment, the present invention relies on electrically attracting water to form a water buffer layer at the surface which prevents hydrocarbon molecules from touching the surface. All types of hydrocarbon fouling (e.g., asphaltenes, waxes, hydrates) can be addressed by the methods described herein.

[0029] Referring now to the Figures, Figure 1 is a method 100 for preventing hydrocarbon fouling from an oil-water mixture, where the target surface is covered with a dielectric layer, in accordance with an embodiment of the present invention. Figure 1 will be discussed in conjunction with Figures 2A-2B. Figure 2A is a schematic illustrating the method for preventing hydrocarbon fouling from an oil-water mixture, where the target surface is covered with a dielectric layer, in accordance with an embodiment of the present invention. Figure 2B is a schematic illustrating the application of a potential difference between the substrate and a proximity electrode in the liquid that selectively attracts water towards the surface thereby eliminating hydrocarbon fouling in accordance with an embodiment of the present invention.

[0030] Referring to Figure 1, in conjunction with Figures 2A and 2B, in step 101, an inner wall of a pipeline 201 for transporting a water-hydrocarbon mixture 202 is covered with a dielectric layer 203. As illustrated in Figures 2A-2B, a surface 201, such as an inner wall of a pipeline, needs fouling protection from water-hydrocarbon mixture 102 (typical of oil and gas production streams). In one embodiment, surface 201 is covered by dielectric layer 203 (e.g., oxide, polymer, ceramic, etc.). In one embodiment, dielectric layer 203 has a range in thickness from a few nanometers to a few inches depending on the application. Furthermore, dielectric layer 203 can be smooth, textured (rough) naturally or textured artificially. Additionally, the surface energy of dielectric layer 203 can range from very high to very low. Furthermore, the water wettability of dielectric layer 203 can range from superhydrophilic to superhydrophobic. The oil wettability of dielectric layer 203 can range from superoleophilic to superoleophobic. In one embodiment, dielectric layer 203 is made of a single material. In another embodiment, dielectric layer 203 is made from multiple materials. In one embodiment, dielectric layer 203 is multilayered. Furthermore, dielectric layer 203 may be corrosion resistant coating or an antifouling coating.

[0031] In step 102, an electrical potential difference is applied across dielectric layer 203 established by applying an electrical potential to a proximity electrode 204 immersed in the solution of the water-hydrocarbon mixture 202 and applying an electrical potential to surface 201. In one embodiment, the applied electrical potential corresponds to a DC voltage (positive or negative) or an AC voltage. Furthermore, the applied electrical potential can be any other complex electrical waveform. In one embodiment, proximity electrode 204 can be continuous (as shown in Figure 2) or it can be intermittent. Proximity electrode 204 can be axially aligned

with pipeline 201 (as shown in Figure 2) or it could protrude radially into pipeline 201 via electrical feedthroughs. Proximity electrode 204 can be made of any conducting material. Furthermore, multiple proximity electrodes 204, as opposed to a single electrode, could be used to get the same performance and the spacing between the electrodes can vary greatly.

[0032] In step 103, a buffer layer 205 is formed of water on top of dielectric layer 203 by electrically attracting water from water-hydrocarbon mixture 202 to buffer layer 205 by applying the potential difference across dielectric layer 203. The externally applied voltage will selectively attract water from the water-hydrocarbon mixture 202 (shown in Figure 2B) and maximize surface-water contact to form a water rich buffer layer 205 at surface 201.

[0033] The formation of this water buffer layer 205 is expected to significantly eliminate the propensity of hydrocarbon fouling on that surface 201. In other words, the application of an electrical voltage will make it energetically unfavorable for hydrocarbon molecules to touch dielectric layer 203. It should be noted that the principles of the present invention described herein can be applied for a variety of hydrocarbons, such as asphaltenes, waxes and hydrates, which have very different electrical properties than water. It should also be noted that the surface to be protected from hydrocarbon fouling requires the attachment of a dielectric layer 203 (which establishes the capacitive system for attracting water). In another embodiment of the present invention, dielectric layer 203 itself has antifouling chemical properties and low surface energy and will further aid the antifouling action of the present invention.

[0034] An alternative method for preventing hydrocarbon fouling from an oil-water mixture is discussed below in connection with Figure 3. Figure 3 is an alternative method 300 for preventing hydrocarbon fouling from an oil-water mixture, where the dielectric layer is not required to be placed between the target surface and the hydrocarbon-water mixture, in accordance with an embodiment of the present invention. Figure 3 will be discussed in conjunction with Figures 4A-4B, using the same element numbers for the same elements described in Figures 2A and 2B. Figure 4A is a schematic illustrating an alternative embodiment in which the dielectric layer is not coated on the target internal surface, but instead, on the corresponding external surface in accordance with an embodiment of the present invention. Figure 4B illustrates protecting the pipeline internal walls from hydrocarbon fouling in accordance with an embodiment of the present invention.

[0035] Referring now to Figure 3, in conjunction with Figures 4A-4B, in step 301, an outer surface of a pipeline wall 201 is covered with a dielectric layer 203. In this manner, surface 201 to be protected can be in intimate contact with hydrocarbon-water mixture 202.

[0036] In step 302, dielectric layer 203 is covered with an external conducting (metallic) layer 401. In this manner, the side of dielectric layer 203 opposite pipeline wall 201 can be protected.

[0037] In step 303, an electrical potential difference is applied across dielectric layer 203 established by applying an electrical potential to a proximity electrode 204 immersed in a solution of the water-hydrocarbon mixture 202 and applying an electrical potential to external conducting layer 401.

[0038] In step 304, a buffer layer of water 205 is formed on top of an inner surface of pipeline wall 201 by electrically attracting water from water-hydrocarbon mixture 202 to buffer layer 205 by applying the potential difference across dielectric layer 203 thereby protecting surface 201 from fouling.

[0039] The embodiment shown in Figures 4A and 4B has clear benefits over the embodiment shown in Figures 2A and 2B. The embodiment of Figures 4A and 4B does not rely on dielectric layer deposition directly on the target surface (e.g., surface 201); this has benefits for antifouling applications for internal surfaces, like the insides of pipelines. Dielectric layer deposition on such internal surfaces is often a manufacturing challenge. Such surfaces can still be protected from hydrocarbon fouling by coating the corresponding external surfaces with the dielectric layer and then forming the water buffer layer as illustrated in Figures 4A and 4B. Other practical issues (e.g., dielectric degradation) associated with hydrocarbon-dielectric interaction are also completely avoided as dielectric layer 203 is never in intimate contact with liquid 202. The embodiment of Figures 4A and 4B also makes this technology very amenable to retrofitting existing equipment and pipelines since no changes to internal surfaces are needed (making changes to external surfaces is relatively easier and less expensive).

[0040] A further alternative embodiment for preventing hydrocarbon fouling from an oil-water mixture is discussed below in connection with Figure 5. Figure 5 is a schematic illustrating a further alternative embodiment for preventing hydrocarbon fouling from an oil-water mixture in which the dielectric layer 203 and the outer conducting layer 401 of Figures 4A and 4B are replaced with an external capacitance 501 in accordance with an embodiment of the present

invention. In this manner, a dielectric layer is no longer needed to be deposited to the inner or outer surface. The principles of the present invention as discussed above in connection with Figures 3 and 4A-4B apply to the embodiment of Figure 5 except that a potential difference is applied across external capacitance 501 established by applying an electrical potential to proximity electrode 204 immersed in a solution of the water-hydrocarbon mixture 202 and applying an electrical potential to external capacitance 501. All the other aspects discussed above in connection with Figures 3 and 4A-4B apply to Figure 5 and will not be reiterated for the sake of brevity.

[0041] Referring to Figure 5, the capacitive action of a dielectric layer (either on the inside or outside) can be obtained by adding a solid state capacitor 501 to surface 201 to be protected. In one embodiment, capacitor 501 would be electrically connected in series to surface 201, and would have the same working action as the capacitance of a dielectric layer. As a result, such an embodiment is advantageous since the deposition and durability of dielectric layers can be expensive and often needs development of new manufacturing technologies. Also, the technical risks due to dielectric layer degradation are completely eliminated with this embodiment. Furthermore, capacitor 501 can be mounted far away from the actual surface 201 which makes this technology more practical in certain applications (e.g., boiler tubes, wherein having a capacitor mounted on a hot surface is not desirable). This embodiment of adding a solid state capacitor 501 has been tested and the obtained results are similar to the results obtained by a surface dielectric layer.

[0042] A further alternative embodiment is to replace proximity electrode 204 of Figures 2A-2B, 4A, 4B and 5 with an electrode mesh sleeve along the pipeline as illustrated in Figure 6.

[0043] Figure 6 illustrates the use of an electrode mesh sleeve 601 along the surface of pipeline 201 as opposed to using proximity electrode 204 in accordance with an embodiment of the present invention. The use of an electrode mesh sleeve 601 is easier to implement than the use of a proximity electrode 204 and hence will aid in the implementation of this technology. As illustrated in Figure 6, a potential difference is applied across dielectric layer 203 established by applying an electrical potential to electrode mesh sleeve 601 and applying an electrical potential to surface 201. As a result, a buffer layer 205 of water is formed on top of electrode mesh sleeve 601 by electrically attracting water from water-hydrocarbon mixture 202 to buffer layer 205.

The externally applied voltage will selectively attract water from the water-hydrocarbon mixture 202 and maximize surface-water contact to form a water rich buffer layer 205 at surface 201.

[0044] While Figure 6 illustrates the replacement of proximity electrode 204 in Figures 2A and 2B with electrode mesh sleeve 601, proximity electrode 204 may be replaced with the use of electrode mesh sleeve 601 in any of the embodiments discussed herein, including the embodiments of Figures 4A, 4B and 5.

[0045] Furthermore, the principles of the present invention can also be utilized to reduce the pumping power required to transport viscous oils through pipelines. The viscosity of certain heavy oils can be 1,000 times greater than the viscosity of water, which leads to very high pressure drop requirements and power consumption by the pipeline. By electrically forcing water to wet the surface (e.g., surface 201 of Figures 2A-2B, 4A-4B, 5 and 6), a buffer water layer (e.g., water buffer layer 205 of Figures 2B, 4A-4B, 5 and 6) can be created at the pipeline walls which will act as a lubricant for oil transport as shown in Figure 7.

[0046] Figure 7 illustrates the concept of core annular flow, where viscous oil 701 is transported as a core in a pipeline 700, surrounded in a lubricating layer 702 of much less viscous water in accordance with an embodiment of the present invention. As illustrated in Figure 7, pipeline 700 will still transport oil 701 in its core, but the pumping power will be substantially reduced because of the lubricating aspect of water layer 702. This concept of transporting oil in a water sheath is termed herein as “core annular flow.” A practical challenge in present day core annular flow technology is the generation and maintenance of water buffer layers. The present invention can generate and maintain a stable water layer at the interface by keeping the interior walls of the pipeline water wetted using any of the three configurations depicted in Figures 2A-2B, 4A-4B, 5 and 6.

[0047] Furthermore, by generating and maintaining a lubricating water layer at the wall to enable low pumping power transport of viscous oil, the pumping pressure drop can be reduced  $\geq 10$  times by using a core annular flow pumping scheme (water-oil) as compared with pumping of viscous oil alone as shown in Figure 8. Figure 8 is a graph 800 illustrating the change in pressure drop versus the thickness of the water layer (water layer 702 of Figure 7) in accordance with an embodiment of the present invention. As illustrated in Figure 8, in conjunction with Figure 7, depending on the thickness of the lubricating water layer 702, significant reduction in

pressure drop can be realized for the core annular flow (2 fluid) pumping scheme as compared to the baseline oil pumping scheme.

[0048] The descriptions of the various embodiments of the present invention have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

## CLAIMS:

1. A method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture, the method comprising:
  - covering an inner surface of a pipeline for transporting and storing said water-hydrocarbon mixture with a dielectric layer;
  - applying a potential difference across said dielectric layer established by applying an electrical potential to a proximity electrode immersed in a solution of said water-hydrocarbon mixture and applying an electrical potential to said pipeline; and
  - forming a buffer layer of water on top of said dielectric layer by electrically attracting water from said water-hydrocarbon mixture to said buffer layer by applying said potential difference across said dielectric layer, wherein said water buffer layer is located between said dielectric layer and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on said inner surface of said pipeline.
2. The method as recited in claim 1, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes, hydrates and scales.
3. The method as recited in claim 1, wherein said dielectric layer has antifouling chemical properties and/or low surface energy.
4. The method as recited in claim 1, wherein said dielectric layer comprises one of the following: an oxide, a polymer and a ceramic.
5. A transportation mechanism for transporting hydrocarbons, the mechanism comprises:
  - a pipeline for transporting a water-hydrocarbon mixture;
  - a dielectric layer covering an inner surface of said pipeline;
  - a proximity electrode immersed in said water-hydrocarbon mixture, wherein a potential difference is applied across said dielectric layer established by applying an electrical potential to said proximity electrode and applying an electrical potential to said pipeline; and
  - a buffer layer of water on top of said dielectric layer, wherein said water buffer layer comprises water electrically attracted from said water-hydrocarbon mixture by applying said potential difference across said dielectric layer, wherein said water buffer layer is located

between said dielectric layer and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on an inner surface of said pipeline.

6. The transportation mechanism as recited in claim 5, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes and hydrates.

7. The transportation mechanism as recited in claim 5, wherein said dielectric layer has antifouling chemical properties and/or low surface energy.

8. The transportation mechanism as recited in claim 5, wherein said dielectric layer comprises one of the following: an oxide, a polymer and a ceramic.

9. A method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture, the method comprising:

covering an outer surface of a pipeline for transporting and storing said water-hydrocarbon mixture with a dielectric layer;

covering said dielectric layer with an external conducting layer;

applying a potential difference across said dielectric layer established by applying an electrical potential to a proximity electrode immersed in a solution of said water-hydrocarbon mixture and applying an electrical potential to said external conducting layer; and

forming a buffer layer of water on top of an inner surface of said pipeline by electrically attracting water from said water-hydrocarbon mixture to said buffer layer by applying said potential difference across said dielectric layer, wherein said water buffer layer is located between said inner surface of said pipeline and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on said inner surface of said pipeline.

10. The method as recited in claim 9, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes and hydrates.

11. The method as recited in claim 9, wherein said dielectric layer comprises one of the following: an oxide, a polymer and a ceramic.

12. A transportation mechanism for transporting hydrocarbons, the mechanism comprises:  
a pipeline for transporting a water-hydrocarbon mixture;

a dielectric layer covering an outer surface of said pipeline;  
an external conducting layer covering said dielectric layer;  
a proximity electrode immersed in said water-hydrocarbon mixture, wherein a potential difference is applied across said dielectric layer established by applying an electrical potential to said proximity electrode and applying said electrical potential to said external conducting layer;  
and

a buffer layer of water on top of an inner surface of said pipeline, wherein said water buffer layer comprises water electrically attracted from said water-hydrocarbon mixture by applying said potential difference across said dielectric layer, wherein said water buffer layer is located between said inner surface of said pipeline and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on said inner surface of said pipeline.

13. The transportation mechanism as recited in claim 12, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes and hydrates.

14. The transportation mechanism as recited in claim 12, wherein said dielectric layer comprises one of the following: an oxide, a polymer and a ceramic.

15. A method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture, the method comprising:

covering an outer surface of a pipeline for transporting said water-hydrocarbon mixture with an external capacitance;

applying a potential difference across said external capacitance established by applying an electrical potential to a proximity electrode immersed in a solution of said water-hydrocarbon mixture and applying an electrical potential to said external capacitance; and

forming a buffer layer of water on top of an inner surface of said pipeline by electrically attracting water from said water-hydrocarbon mixture to said buffer layer by applying said potential difference across said external capacitance, wherein said water buffer layer is located between said inner surface of said pipeline and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on said inner surface of said pipeline.

16. The method as recited in claim 15, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes and hydrates.
17. The method as recited in claim 15, wherein said external capacitance comprises a solid-state capacitor.
18. A transportation mechanism for transporting hydrocarbons, the mechanism comprises:  
a pipeline for transporting a water-hydrocarbon mixture;  
an external capacitance covering an outer surface of said pipeline;  
a proximity electrode immersed in said water-hydrocarbon mixture, wherein a potential difference is applied across said external capacitance established by applying an electrical potential to said proximity electrode and applying an electrical potential to said external capacitance; and  
a buffer layer of water on top of an inner surface of said pipeline, wherein said water buffer layer comprises water electrically attracted from said water-hydrocarbon mixture by applying said potential difference across said external capacitance, wherein said water buffer layer is located between said inner surface of said pipeline and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on said inner surface of said pipeline.
19. The transportation mechanism as recited in claim 18, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes and hydrates.
20. The transportation mechanism as recited in claim 18, wherein said external capacitance comprises a solid-state capacitor.
21. A method for eliminating hydrocarbon fouling in transporting and storing a water-hydrocarbon mixture, the method comprising:  
covering an inner surface of a pipeline for transporting said water-hydrocarbon mixture with a dielectric layer;  
applying a potential difference across said dielectric layer established by applying an electrical potential to an electrode mesh covering said dielectric layer and applying an electrical potential to said pipeline; and

forming a buffer layer of water on top of said electrode mesh by electrically attracting water from said water-hydrocarbon mixture to said buffer layer by applying said potential difference across said dielectric layer, wherein said water buffer layer is located between said electrode mesh and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on said inner surface of said pipeline.

22. The method as recited in claim 21, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes and hydrates.

23. A transportation mechanism for transporting hydrocarbons, the mechanism comprises:  
a pipeline for transporting a water-hydrocarbon mixture;  
a dielectric layer covering an inner surface of said pipeline;  
an electrode mesh covering said dielectric layer, wherein a potential difference is applied across said dielectric layer established by applying an electrical potential to said electrode mesh and applying an electrical potential to said pipeline; and

a buffer layer of water on top of said dielectric layer, wherein said water buffer layer comprises water electrically attracted from said water-hydrocarbon mixture by applying said potential difference across said dielectric layer, wherein said water buffer layer is located between said electrode mesh and said water-hydrocarbon mixture thereby eliminating hydrocarbon fouling on an inner surface of said pipeline.

24. The transportation mechanism as recited in claim 23, wherein hydrocarbons in said water-hydrocarbon mixture comprise one or more of the following: asphaltenes, waxes and hydrates.

1 / 6

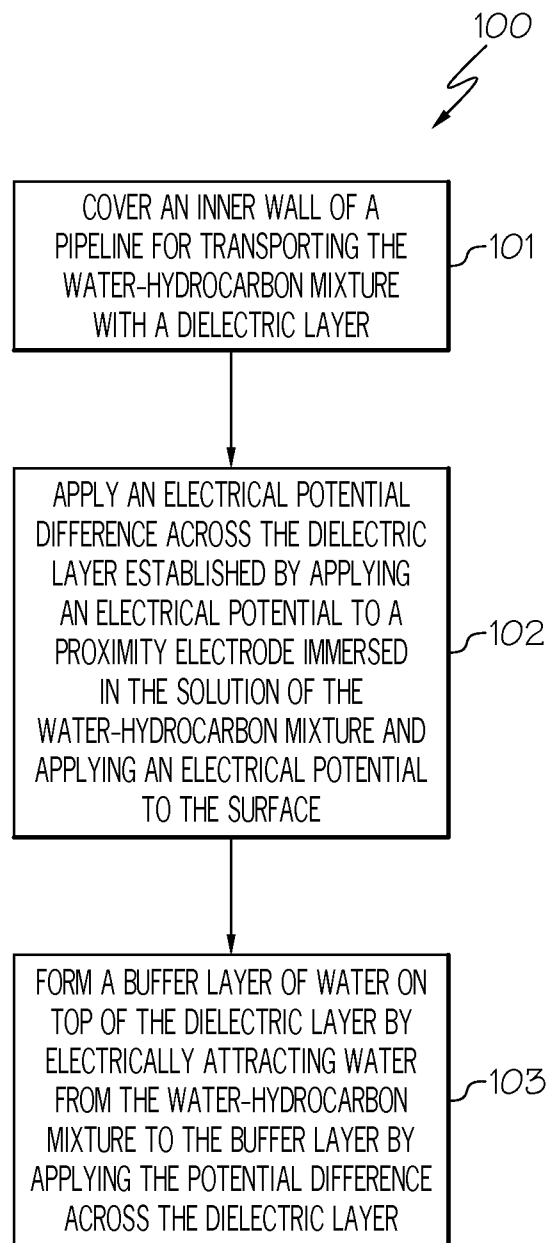


FIG. 1

2 / 6

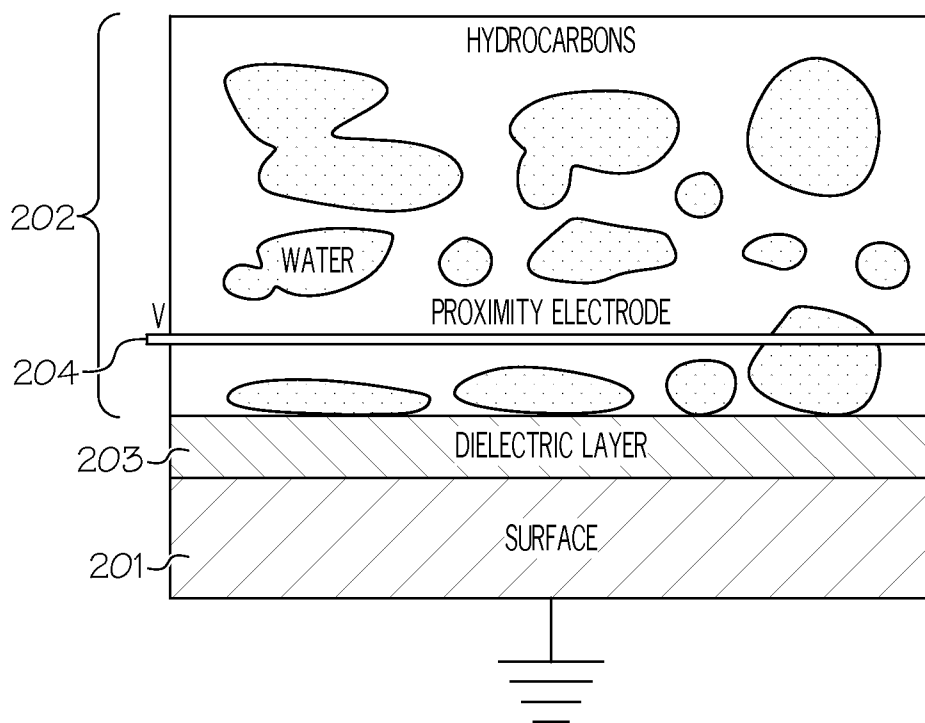


FIG. 2A

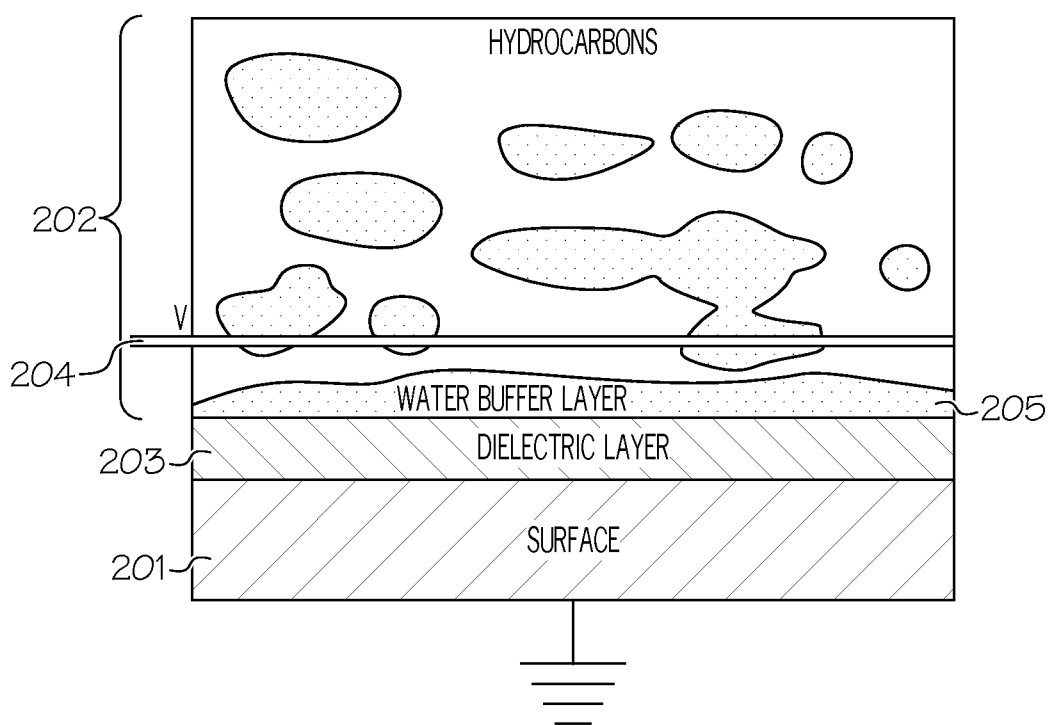


FIG. 2B

3 / 6

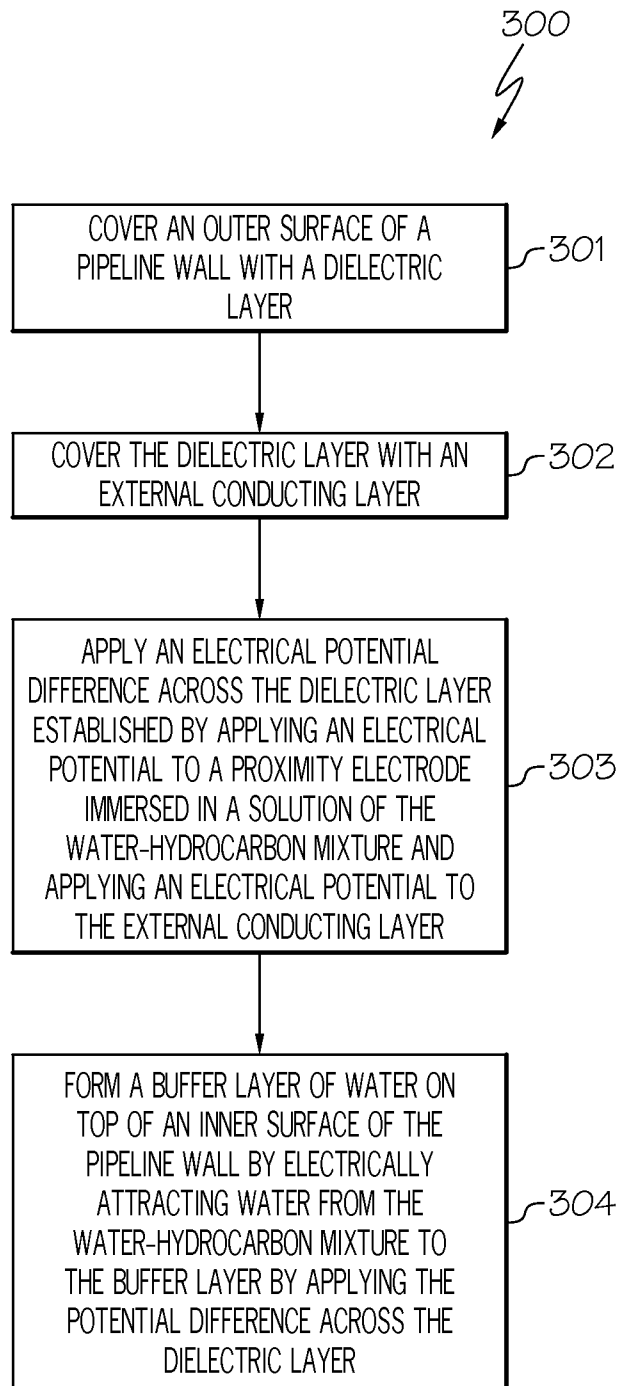


FIG. 3

4 / 6

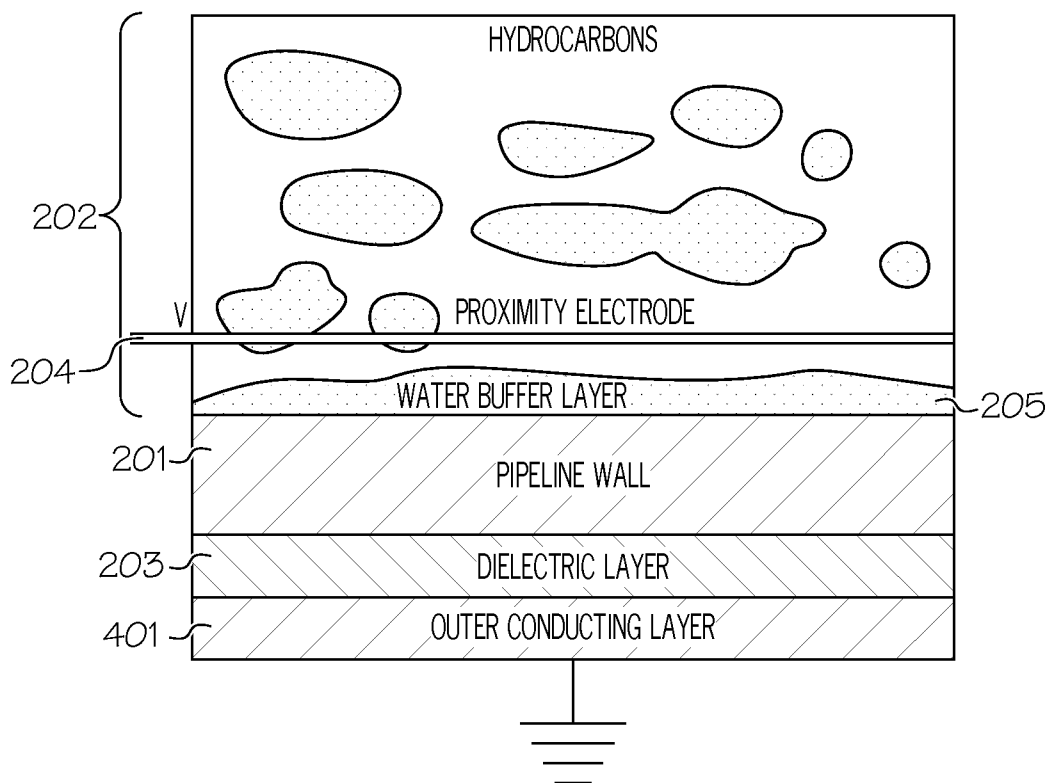


FIG. 4A

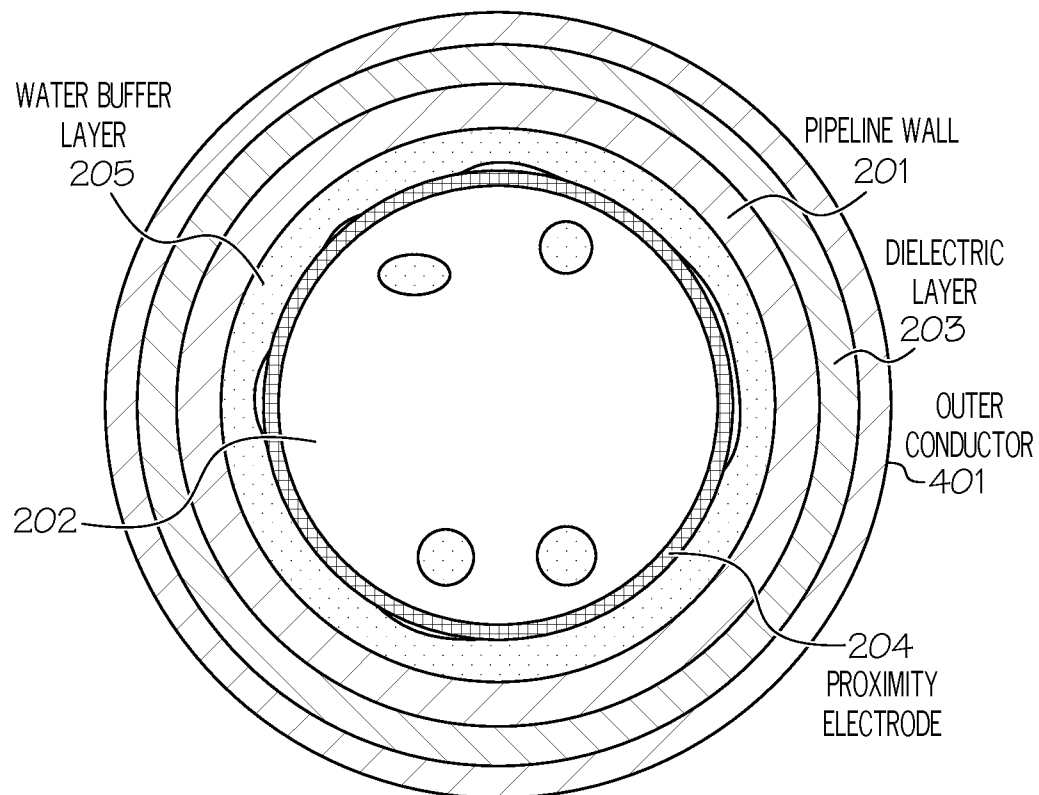


FIG. 4B

5 / 6

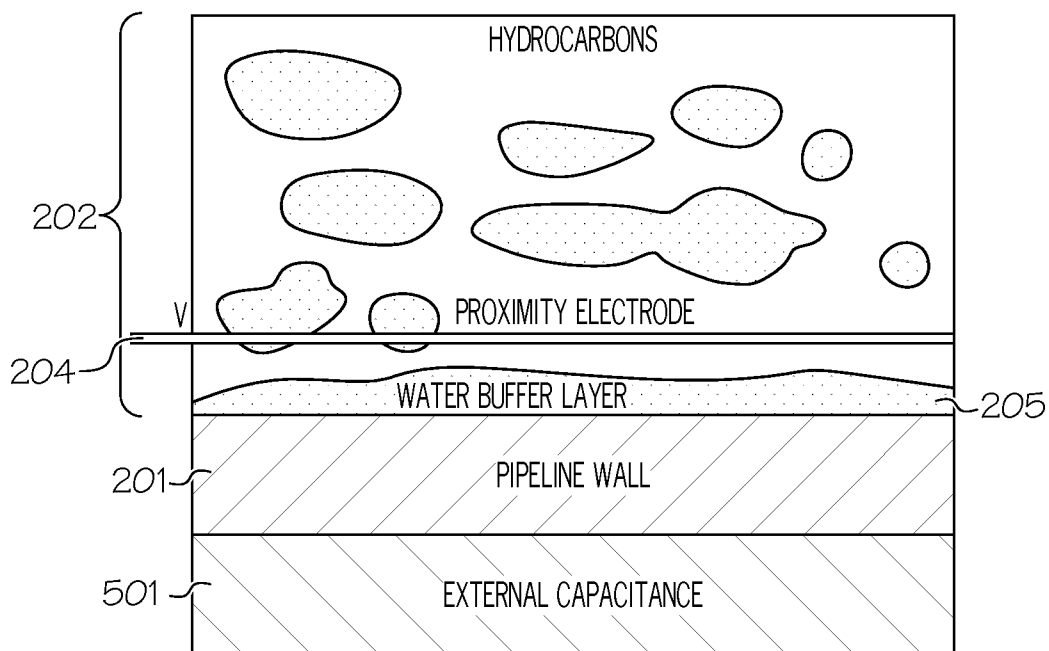


FIG. 5

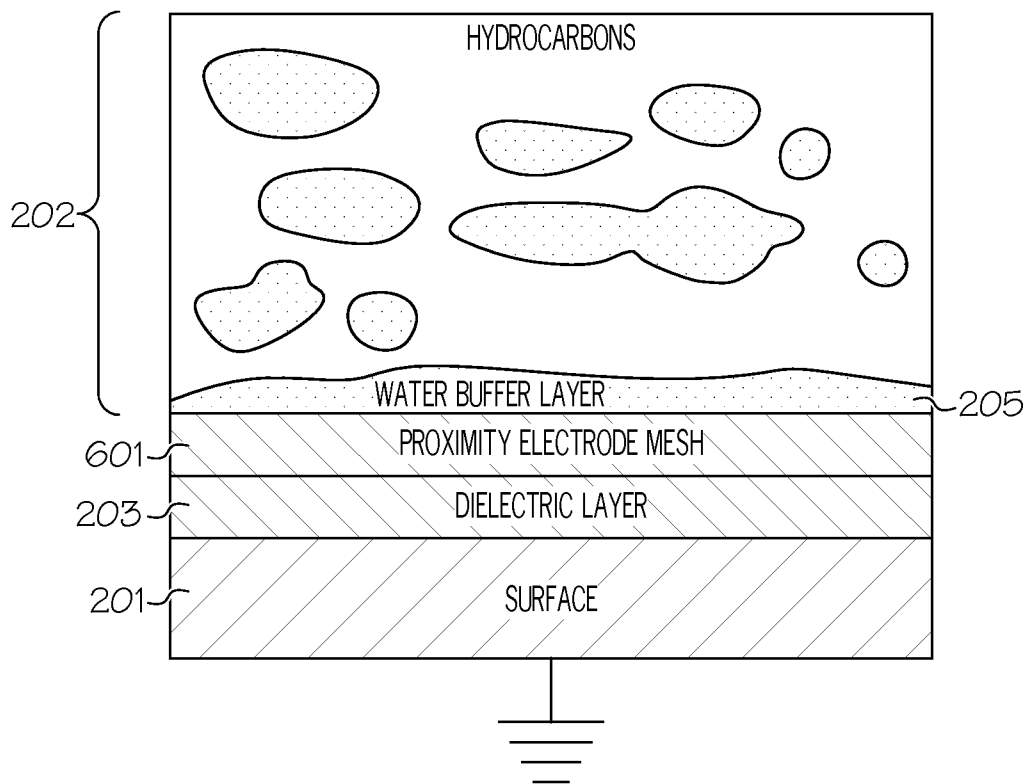


FIG. 6

6 / 6

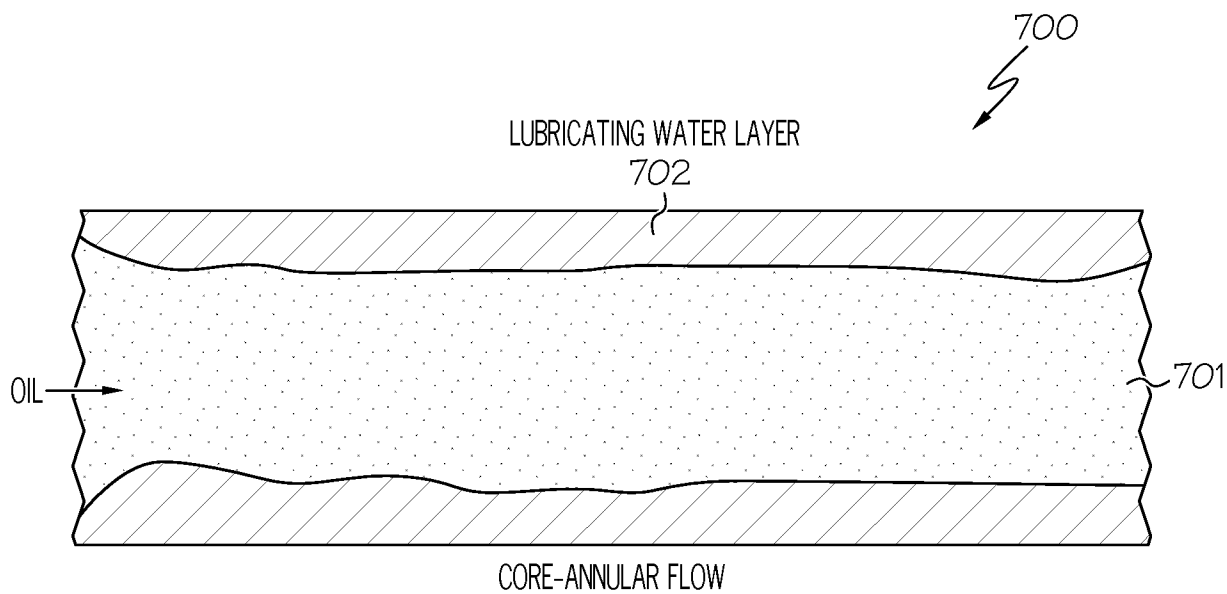


FIG. 7

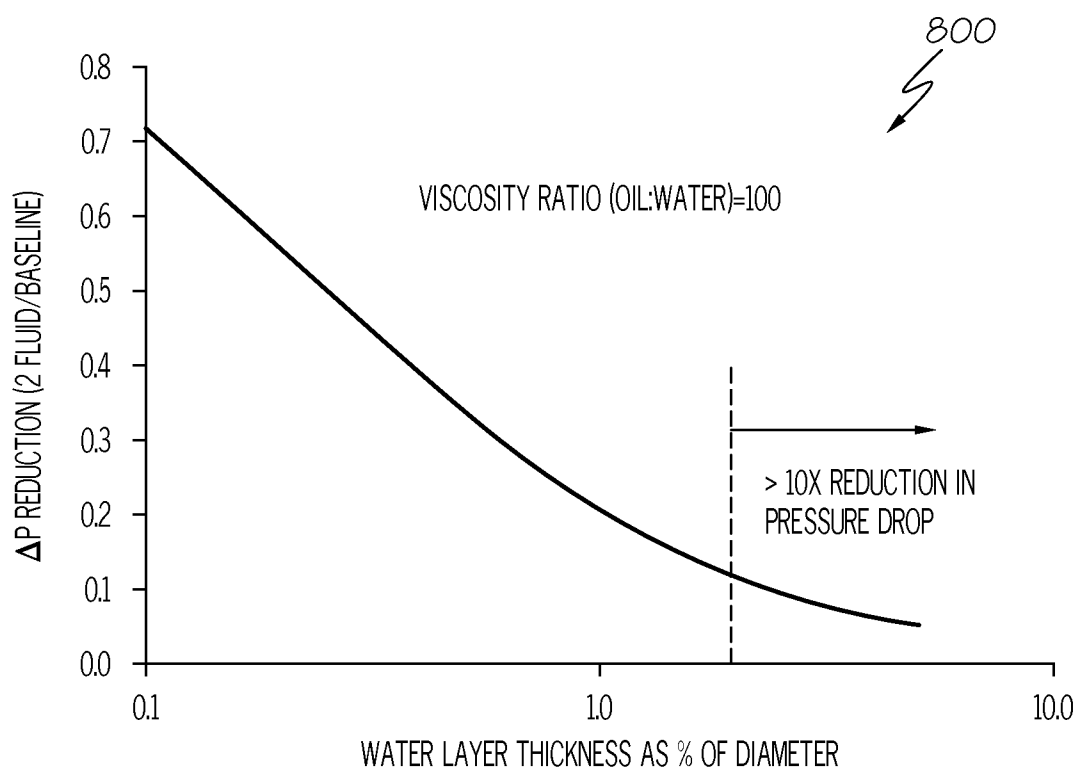


FIG. 8

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US15/20141

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - C09D 5/00; C23F 13/00; F16L 58/04 (2015.01)

CPC - C09D 5/00; C23F 13/00; F16L 58/04

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): C09D 5/00, 5/16, 7/00, 7/12; C23F 11/00, 13/00; F16L 58/00, 58/04, 58/10 (2015.01); CPC: C09D 5/00, 5/16, 7/00, 7/12; C23F 11/00, 13/00; F16L 58/00, 58/04, 58/10; USPC: 204/196.01, 196.16; 205/80, 687, 724, 729

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); EBSCO; Google Scholar; ProQuest; IP.com; petroleum, hydrocarbon, crude, transport, storage, tank, pipeline, dielectric, coating, antifouling, water, lubrication, layer, electrode, current

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category*    | Citation of document, with indication, where appropriate, of the relevant passages                                                   | Relevant to claim No.           |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|
| Y<br>--<br>A | US 2014/0020783 A1 (ZAZOVSKY, A et al.) 23 January 2014; figure 1A; paragraphs [0022], [0032], [0042], [0051]-[0052], [0093]         | 1-8, 15-20<br>--<br>9-14, 21-24 |
| Y<br>--<br>A | US 2014/0034504 A1 (CAMERON SOLUTIONS, INC) 06 February 2014; figures 8-12; paragraphs [0004], [0006], [0027], [0042], [0053]-[0054] | 1-8, 15-20<br>--<br>9-14, 21-24 |
| Y            | US 2010/0112378 A1 (DEININGER, MA et al.) 06 May 2010; paragraphs [0007], [0015], [0053]                                             | 2, 6, 16, 19                    |
| Y            | WO 2014/018991 A2 (MBJ WATER PARTNERS) 30 January 2014; figures 20-21; page 34, lines 15-30                                          | 17, 20                          |
| A            | US 2013/0186669 A1 (CHABAS, JA et al.) 25 July 2013; entire document                                                                 | 9-14                            |
| A            | US 2004/0211659 A1 (VELEV, O) 28 October 2004; entire document                                                                       | 9-14, 21-24                     |
| A            | US 3,567,619 A (BROWN, RN et al.) 02 March 1971; entire document                                                                     | 21-24                           |

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

## \* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

15 May 2015 (15.05.2015)

Date of mailing of the international search report

16 JUN 2015

Name and mailing address of the ISA/

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Shane Thomas

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774