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(71) Applicant: **DONALDSON COMPANY, INC.** [US/US]; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US).

(72) Inventors: **MORAVEC, Davis, B.**; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US). **DALLAS, Andrew, J.**; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US). **BLOCK, Joseph, M.**; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US). **HAUSER, Bradly, G.**; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US). **HALL, Cullen, E.**; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US). **SHEPHERD, Mark, C.**; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US). **MADSEN, Mike, J.**; 1400 West 94th Street, P.o. Box 1299, Minneapolis, MN 55440-1299 (US).

(74) Agent: **WHIPPS, Brian, C.**; Mueting, Raasch & Gebhardt, P.A., P.O. Box 581336, Minneapolis, MN 55458-1336 (US).

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(54) **Title**: HYDROCARBON-IN-WATER PURIFICATION SYSTEM

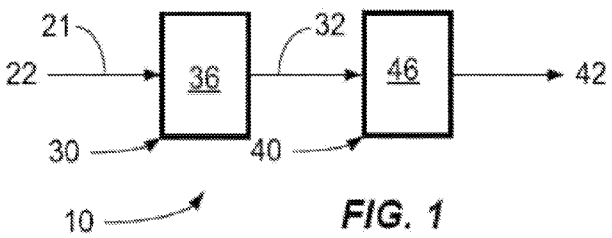

FIG. 1

(57) **Abstract**: A hydrocarbon-in-water purification system includes a high capacity hydrocarbon absorber stage having a high capacity hydrocarbon absorber material and an inlet configured to receive a hydrocarbon-in-water dispersion from a fuel system. A polishing hydrocarbon absorber stage is in liquid communication and downstream of the high capacity hydrocarbon absorber stage including polishing activated carbon. The high capacity hydrocarbon absorber material has a greater saturation capacity than the polishing activated carbon and the polishing activated carbon has a greater polishing capacity than the high capacity hydrocarbon absorber material. A method for controlling and managing the evacuation of water from the hydrocarbon-in-water purification system includes tracking the purification state of water volumes and the bed loading states of purification beds defined in the water filter.

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HYDROCARBON-IN-WATER PURIFICATION SYSTEM

[0001] The present disclosure relates to hydrocarbon-in-water purification systems and methods, and particularly those that remove hydrocarbons from water with a high capacity absorber element upstream from a polishing absorber element.

BACKGROUND

[0002] Water contamination in fuel is a concern as it affects the performance and operation of engines. Water contamination can cause various problems including fuel filter plugging, fuel starvation, damage of engine components through cavitation and corrosion, and promotion of microbiological growth, for example.

[0003] Various devices have been employed to reduce water contamination in fuel. By way of example, coalescing and separating devices have been employed to first cause the emulsified water to coalesce into larger droplets and then remove the enlarged droplets from the fuel stream. A removed or drained hydrocarbon-in-water dispersion or emulsion stream is an output from this water from fuel separator system.

[0004] Recent efforts have been focused on reducing air pollution caused by the combustion of hydrocarbon fluids. Diesel fuels have been refined with reduced amounts of sulphur to meet diesel engine emission control regulations. However, these low-sulphur diesel fuels have necessitated the use of other additives. By way of example, surfactants have been added to low-sulphur diesel fuels to maintain sufficient lubricity of the diesel fuel for the engine. Surfactants have also the effect of stabilizing hydrocarbon-in-water emulsions or dispersions as they lower the interfacial tension between water and hydrocarbons.

SUMMARY

[0005] The present disclosure relates to hydrocarbon-in-water purification systems and methods, and particularly to those that remove hydrocarbons from water with a high capacity absorber element upstream from a polishing absorber element, among other aspects.

[0006] In many embodiments a hydrocarbon-in-water purification system includes a high capacity hydrocarbon absorber stage having a high capacity hydrocarbon absorber material and an inlet configured to receive a hydrocarbon-in-water dispersion from a fuel system. A polishing hydrocarbon absorber stage is in liquid communication and downstream of the high capacity hydrocarbon absorber stage. The polishing hydrocarbon absorber stage includes polishing activated carbon. The high capacity hydrocarbon absorber material has a greater saturation capacity than the polishing activated carbon and the polishing activated carbon has a greater polishing capacity than the high capacity hydrocarbon absorber material.

[0007] In further embodiments, an engine fuel and water separation system includes a fuel and water separator system fluidly connected to an engine fuel line and having a water drain outlet. A hydrocarbon-in-water purification system, described herein, is in fluid communication with the water drain outlet.

[0008] In still further embodiments, a method includes forming a hydrocarbon-in-water dispersion from a fuel system and passing the hydrocarbon-in-water dispersion through a high capacity hydrocarbon absorber stage. The high capacity hydrocarbon absorber stage includes a high capacity hydrocarbon absorber material that removes at least a portion of hydrocarbon from the dispersion to form a permeate that is substantially water. Then, passing the permeate through a polishing hydrocarbon absorber stage. The polishing hydrocarbon absorber stage includes polishing activated carbon to adsorb hydrocarbon and form a polished water stream. The high capacity hydrocarbon absorber material has a greater saturation capacity than the polishing activated carbon and the polishing activated

carbon has a greater polishing capacity than the high capacity hydrocarbon absorber material.

[0009] In various embodiments, a method includes determining whether a purification state of a dischargeable water volume in a final purification bed in a water filter is clean or not clean. The water filter contains one or more water volumes and a plurality of purification beds arranged from a first purification bed to the final purification bed such that the first purification bed receives new water introduced into the water filter from a water collection reservoir and the final purification bed discharges water from the water filter. The one or more water volumes reside in the plurality of purification beds. The method further includes introducing a new water volume into the first purification bed in response to determining that the dischargeable water volume is clean. Introducing the new water volume may move each of the one or more water volumes in the water filter such that the dischargeable water volume leaves the final purification bed and a next dischargeable water volume of the one or more water volumes enters the final purification bed. The method also includes tracking a purification state associated with the next dischargeable water volume in response to a residence time of the next dischargeable water volume in at least one of the purification beds, and tracking a bed loading state associated with the at least one of the purification beds in response to the residence time.

[0010] In additional embodiments, a method includes introducing a new water volume into a first purification bed of a water filter. The water filter contains one or more water volumes and a plurality of purification beds arranged from the first purification bed to a final purification bed such that the first purification bed receives new water introduced into the water filter from a water collection reservoir and the final purification bed discharges water from the water filter. The one or more water volumes may reside in the plurality of purification beds. The method may further include updating a purification bed tracker defining an associated purification bed corresponding to one of the plurality of

purification beds. The purification bed tracker maintains a current residence time of a current water volume residing in the associated purification bed, a current purification state of the current water volume, and a current bed loading state of the associated purification bed. Each of the plurality of purification beds is associated with a different purification bed tracker and a different water volume. Also, the method includes updating the current purification state of the purification bed tracker associated with the first purification bed to unclean.

[0011] In various further embodiments, a method includes introducing a new water volume into a first purification bed of a water filter. The water filter contains one or more water volumes and a plurality of purification beds arranged from the first purification bed to a final purification bed such that the first purification bed receives new water introduced into the water filter from a water collection reservoir and the final purification bed discharges water from the water filter. The one or more water volumes reside in the plurality of purification beds. The method further includes updating a water volume tracker defining an associated water volume corresponding to one of the water volumes. The water volume tracker maintains a current residence time of the associated water volume, a current purification state of the associated water volume, a current purification bed in which the associated water volume resides, and a current bed loading state of the current purification bed. Each of the one or more water volumes is associated with a different water volume tracker and a different purification bed. Still further, the method includes creating a water volume tracker associated with the new water volume with the current purification state of the new water volume set to unclean.

[0012] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The disclosure may be more completely understood in consideration of the following detailed description of various embodiments of the disclosure in connection with the accompanying drawings, in which:

[0014] **FIG. 1** is a schematic diagram view of a hydrocarbon-in-water purification system;

[0015] **FIG. 2** is a schematic diagram view of an engine fuel and water separation system; and

[0016] **FIG. 3** is a schematic diagram view of another hydrocarbon-in-water purification system.

[0017] **FIG. 4** is a schematic diagram view of an engine system having a hydrocarbon-in-water purification system.

[0018] **FIG. 5** is a schematic diagram view of a process for managing the evacuation of water from the engine system of **FIG. 4**.

[0019] **FIG. 6** is a schematic diagram view of a fuel water separator and a water filter of the engine system of **FIG. 4**.

[0020] **FIG. 7** is a schematic diagram view of a controller of the engine system of **FIG. 4**.

[0021] **FIG. 8** is a schematic diagram view of a process for checking water evacuation conditions of the process of **FIG. 5**.

[0022] **FIG. 9** is a schematic diagram view of a process for maintaining a purification bed tracker.

[0023] **FIG. 10** is a schematic diagram view of a process for maintaining a water volume tracker.

[0024] The schematic drawings presented herein are not necessarily to scale. Like numbers used in the figures refer to like components, steps and the like. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labeled with the same number. In addition, the use of

different numbers to refer to components is not intended to indicate that the different numbered components cannot be the same or similar.

DETAILED DESCRIPTION

[0025] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration several specific embodiments of devices, systems and methods. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense.

[0026] All scientific and technical terms used herein have meanings commonly used in the art unless otherwise specified. The definitions provided herein are to facilitate understanding of certain terms used frequently herein and are not meant to limit the scope of the present disclosure.

[0027] As used in this specification and the appended claims, the singular forms “a”, “an”, and “the” encompass embodiments having plural referents, unless the content clearly dictates otherwise.

[0028] As used in this specification and the appended claims, the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise.

[0029] As used herein, “have”, “having”, “include”, “including”, “comprise”, “comprising” or the like are used in their open ended sense, and generally mean “including, but not limited to.” It will be understood that the terms “consisting of” and “consisting essentially of” are subsumed in the term “comprising,” and the like.

[0030] Any direction referred to herein, such as “top,” “bottom,” “left,” "right," "upper," "lower," “above,” below,” and other directions and orientations are described herein for

clarity in reference to the figures and are not to be limiting of an actual device or system or use of the device or system. Many of the devices, articles or systems described herein may be used in a number of directions and orientations.

[0031] The term "hydrocarbon" refers to oil or fuel materials that are primarily formed of saturated or unsaturated molecules with thirty or less carbon atoms.

[0032] The phrase "hydrocarbon-in-water emulsion" refers to an emulsion or dispersion where water is the continuous phase and hydrocarbon is the dispersed or discontinuous phase.

[0033] The term "absorption" refers to the removal process of hydrocarbons from water and includes absorption, adsorption, or the like processes of removal of hydrocarbons from water.

[0034] The phrases "high capacity hydrocarbon absorber material" and "high capacity material" refer to a material that does not need to clean water to the intended cleanliness, but instead has properties that lead to high saturation capacities. For example, when challenged with 2500 ppm B5-in-water emulsion or dispersion (B5=5% biodiesel blend) the saturation capacity of these materials is preferably greater than 750 mg of hydrocarbon per gram of material or greater than 1000 mg of hydrocarbon per gram of material. Preferred saturation capacities will vary depending on the challenge fluid concentration and makeup.

[0035] The phrase "polishing hydrocarbon absorber material" and "polishing material" refer to a material that can purify water down to the intended cleanliness over a wide range of incoming challenge water concentrations. Preferably, these materials have high loading characteristics at the intended target cleanliness. For example, when challenged with 2500 ppm B5-in-water emulsions or dispersions, with a target cleanliness of 2 ppm, these materials have a preferred loading or polishing capacity of greater than 25 mg of hydrocarbons per gram of material or greater than 50 mg of hydrocarbon per gram of

material. Preferred loading characteristics depend on challenge fluid concentration and makeup, and on target cleanliness

[0036] The present disclosure describes water purification systems and particularly to systems that remove hydrocarbons from water with a high capacity absorber element upstream from a polishing absorber element, among other aspects. The high capacity absorber element removed at least a portion of the hydrocarbon from a hydrocarbon in water dispersion to form a permeate. The permeate is then passed through the polishing absorber element to form a polished water stream. The polished water stream can have less than 5 ppm of hydrocarbons or less than 2 ppm or hydrocarbons or less than 1 ppm of hydrocarbons. In many embodiments the high capacity absorber element is activated carbon and/or a polymeric material such as polyurethane and the polishing absorber stage is activated carbon. The high capacity hydrocarbon absorber material has a greater saturation capacity than the polishing activated carbon and the polishing activated carbon has a greater polishing capacity than the high capacity hydrocarbon absorber material. The high capacity hydrocarbon absorber stage and the polishing hydrocarbon absorber stage may be contained within a single housing. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples provided below.

[0037] Fuel cleanliness requirements for fuel injection systems are demanding in order to ensure reliable engine performance. To a large degree, fuel filtration is responsible for meeting the fuel cleanliness requirements associated with the control of abrasive particles and non-dissolved water. These fuel filters can coalesce at least a portion of the entrained water from the fuel stream and form a fuel-in-water dispersion or emulsion waste stream.

[0038] **FIG. 1** is a schematic diagram view of a hydrocarbon-in-water purification system **10**. **FIG. 3** is a schematic diagram view of another hydrocarbon-in-water purification system **100**. The hydrocarbon-in-water purification system **10** includes high capacity

hydrocarbon absorber stage **30** containing a high capacity hydrocarbon absorber material **36** and an inlet **21** configured to receive a hydrocarbon-in-water dispersion **22** from a hydrocarbon-in-water dispersion source. The high capacity hydrocarbon absorber material **36** removes at least a portion of the hydrocarbon and forms a permeate that is substantially water. Permeate exits the high capacity hydrocarbon absorber stage **30.** A polishing hydrocarbon absorber stage **40** is in liquid communication and downstream of the high capacity hydrocarbon absorber stage **30**. Permeate **32** enters the polishing hydrocarbon absorber stage **40** that includes a polishing hydrocarbon absorber material **46.** The polishing hydrocarbon absorber material **46** removes the remaining hydrocarbon to achieve a purified water stream **42** exiting the polishing hydrocarbon absorber stage **40**. The polishing hydrocarbon absorber stage **40** can include activated carbon, for example.

[0039] Preferably, the high capacity hydrocarbon absorber material **36** has a greater saturation capacity (q_{sat}) than the polishing activated carbon **46** and the polishing activated carbon **46** has a greater loading or polishing capacity (q_t) than the high capacity hydrocarbon absorber material **36**. The high capacity hydrocarbon absorber material **36** may have an, at least 10% greater or at least 25% or greater or at least 50% greater or at least 100% greater saturation capacity (q_{sat}) than the polishing activated carbon **46**. The polishing activated carbon **46** may have an, at least 10% a greater or at least 25% greater loading or greater or at least 50% greater or at least 100% greater polishing capacity (q_t) than the high capacity hydrocarbon absorber material **36**.

[0040] **FIG. 3** illustrates an embodiment of a dual absorber **100** where the high capacity hydrocarbon absorber stage material **36** forms a container defining a void space and the polishing hydrocarbon absorber material **46** (for example, activated carbon) is disposed in the void space. The high capacity hydrocarbon absorber stage material **36** forming the container can be contained in a housing **13** having an inlet **22** (supplying the fuel in water dispersion) and an outlet **42** (purified water stream). In many of these embodiments the

high capacity hydrocarbon absorber stage material **36** is a non-woven fiber or fabric layer that is formed of a polymeric material described below.

[0041] **FIG. 2** is a schematic diagram view of an engine fuel and water separation system **11**. The engine fuel and water separation system **11** includes a fuel and water separator system **50** (fuel water separator) fluidly connected to an engine fuel line **12** and having a water drain outlet **23** and a filtered fuel outlet **24**. A hydrocarbon-in-water purification system **10, 100** is in fluid communication with the water drain outlet **23**.

[0042] In many embodiments the hydrocarbon-in-water dispersion source is fuel filter element **50** that can filter out particulates from the fuel flow and coalesce water and form a hydrocarbon-in-water dispersion stream. The fuel filter element **50** forms a portion of a fuel system such as those used in a diesel engine such as a vehicle engine, for example.

[0043] The hydrocarbon-in-water purification system **10, 100** may be contained within a single housing. The high capacity hydrocarbon absorber stage **30** and the polishing hydrocarbon absorber stage **40** are contained within a single housing **13**, a filter housing, for example. The high capacity hydrocarbon absorber stage **30** may defines a first volume **36** (of high capacity material) and the polishing hydrocarbon absorber stage **40** may define a second volume **46** (of polishing material) and the first volume **36** and the second volume **46** are contained within a filter housing **13**.

[0044] The high capacity hydrocarbon absorber stage **30** and the polishing hydrocarbon absorber stage **40** may be physically separated from each other when contained within a single housing **13**. A porous dividing element **15** may separate the first volume **36** from the second volume **46**.

[0045] The porous dividing element **15** may prevent or reduce mixing or diffusion of the first volume **36** (of high capacity material) with the second volume **46** (of polishing material). The porous dividing element **15** may be fixed to the filter housing **13**. The porous dividing element **15** may include a plurality of apertures. The apertures may be sized to

prevent the high capacity material and the polishing material from passing through the porous dividing element **15**. The apertures may be smaller than the particle size of the high capacity material and the polishing material. The porous dividing element **15** may be a screen element or porous metal layer.

[0046] The porous dividing element **15** may be a porous non-woven layer or non-woven fabric layer. The non-woven layer **15** may be formed of a polymeric material such as polyethylene, polypropylene, polyurethane, polyester, and combinations thereof. These polymeric materials may also absorb hydrocarbons and be a hydrocarbon absorber material. The porous dividing element **15** may be a polyurethane non-woven layer. The porous dividing element **15** may be an extruded layer such as a polymeric screen formed of a polymeric material such as polyethylene, polypropylene, polyurethane, polyester, and combinations thereof. These polymeric materials may also absorb hydrocarbons and be a hydrocarbon absorber material.

[0047] The hydrocarbon-in-water purification system **10, 100** includes a high capacity hydrocarbon absorber stage **30** containing a high capacity hydrocarbon absorber material **36** and an inlet **23** (fluidly coupled to the water drain outlet **23** of the fuel and water separator system **50)** to receive a hydrocarbon-in-water dispersion **22** from a hydrocarbon-in-water dispersion source **50**. The high capacity hydrocarbon absorber material **36** removes at least a portion of the hydrocarbon and forms a permeate that is substantially water. Permeate exits the high capacity hydrocarbon absorber stage **30.** A polishing hydrocarbon absorber stage **40** is in liquid communication and downstream of the high capacity hydrocarbon absorber stage **30**. Permeate enters the polishing hydrocarbon absorber stage **40** that includes a polishing hydrocarbon absorber material **46.** The polishing hydrocarbon absorber material **46** removes the remaining hydrocarbon to achieve a purified water stream **42** exiting the polishing hydrocarbon absorber stage **40**. The polishing hydrocarbon absorber stage **40** can include activated carbon, for example.

[0048] In some embodiments, the hydrocarbon-in-water purification system **10**, **100** can include an antimicrobial agent. For example, one or more of the high capacity hydrocarbon absorber stage **30** or polishing hydrocarbon absorber stage **40** can include an antimicrobial agent. The antimicrobial agent can be any useful material or compound that inhibits microbe growth or kills microbes. Exemplary antimicrobial agents include silver, copper, organic biocides (such as quaternary amines, for example), ozone, or UV light.

[0049] In many embodiments, the hydrocarbon-in-water dispersion or emulsion has a hydrocarbon content of at least 500 ppm or at least 1000 ppm or at least 2,000 ppm or at least 5,000 ppm. The permeate has a hydrocarbon content of less than 500 ppm or less and 250 ppm or less than 100 ppm. The polished water stream has a hydrocarbon content of less than 5 ppm or less than 2 ppm, or less than 1 ppm.

[0050] In other embodiments, the hydrocarbon-in-water dispersion or emulsion has a hydrocarbon content of at least 100 ppm or at least 250 ppm or is in a range from 100 ppm to 500 ppm. The permeate has a hydrocarbon content of less than the hydrocarbon-in-water dispersion or emulsion. The polished water stream has a hydrocarbon content of less than 5 ppm or less than 2 ppm, or less than 1 ppm.

[0051] **Hydrocarbon Absorbing Material**

[0052] The hydrocarbon absorbing material includes any material capable of absorbing hydrocarbons. Exemplary hydrocarbon absorbing material includes polymeric material, activated carbon, or both. The hydrocarbon-in-water dispersion first contacts a high capacity hydrocarbon absorbing material prior to contacting a polishing hydrocarbon absorbing material. It has been found that the overall life of the hydrocarbon absorbing element can be prolonged by having the high capacity hydrocarbon absorbing material upstream of the polishing hydrocarbon absorbing material.

[0053] The relationship between equilibrium concentration and carbon loading can be described by an adsorption isotherm. Three of the most widely used models of adsorption are the Freundlich, Langmuir, and BET (Brunauer, Emmett, and Teller) isotherms. Of these, the empirical Freundlich Isotherm expression best describes the loading behavior of activated carbon over a wide range of challenge conditions and loading amounts. The Freundlich isotherm expression is:

$$q = \frac{x}{m} = K_f c_e^{\frac{1}{n}}$$

where **q** is the adsorbent loading in milli-grams of adsorbate per gram of adsorbent (**x/m**), $\mathbf{c_e}$ is the equilibrium adsorbate concentration in solution, and $\mathbf{K_f}$ and **1/n** are the isotherm parameters that are dependent on the adsorbate, adsorbent, and temperature.

[0054] The Freundlich Isotherm expression can be used to determine the adsorbent loading at a particular target equilibrium adsorbate concentration. When the equilibrium adsorbate concentration ($\mathbf{c_e}$) is equal to the incoming adsorbate concentration ($\mathbf{c_o}$) the material is exhausted. The loading capacity under these conditions is called the saturation capacity or $\mathbf{q_{sat}}$. The saturation capacity of a material varies with different incoming adsorbate concentrations. A material that has high saturation capacity is called a high capacity hydrocarbon absorber material or high capacity material.

[0055] In most purification applications the target adsorbate concentration leaving the element ($\mathbf{c_t}$) is less than the incoming adsorbate concentration. In this case, the adsorbent loading determined from the Freundlich Isotherm expression at the intended target adsorbate concentration is deemed the polishing capacity or $\mathbf{q_t}$. The polishing capacity of a material varies with different incoming adsorbate concentrations and target adsorbate concentrations. The polishing capacity is generally less than the saturation capacity. A material that has high polishing capacity is called a polishing hydrocarbon absorber material or polishing material.

[0056] Preferably, the high capacity hydrocarbon absorber material has a greater saturation capacity (q_{sat}) than the polishing hydrocarbon absorber material and the polishing hydrocarbon absorber material has a greater polishing capacity (q_t) than the high capacity hydrocarbon absorber material. The saturation capacity (q_{sat}) and polishing capacity (q_t) is determined with the same incoming adsorbate concentration.

[0057] A hydrocarbon-in-water purification system containing separate sections of a high capacity material followed by a polishing material has an increased lifetime over a similar sized system of a single material. In particular, a filter housing containing separate sections of a high capacity material followed by a polishing material can have an increased lifetime over a similar sized filter housing of a single material. The high capacity material and the polishing material are configured in serial flow orientation to each other where the polishing material is downstream from the high capacity material.

[0058] Activated carbon is a fine-grained carbon with an extremely large surface area and a highly porous structure. Its adsorption capacity is therefore especially high and is especially pronounced for hydrocarbons in particular. Activated carbon consists primarily of carbon (mostly >90%) with a strongly porous structure. In addition, the internal surface area of the activated carbon is between 500 and 2000 m^2/g carbon, which explains the high adsorption capacity of the activated carbon.

[0059] A "high capacity" activated carbon is a material that has a loading at saturation (q_{sat}) of at least 25% or at least 50% or at least 75% greater than a control sample of activated carbon (referred to herein as polishing hydrocarbon absorbing material). Generally, the high capacity hydrocarbon absorber material has a greater saturation capacity (q_{sat}) than the polishing hydrocarbon absorber material.

[0060] In some embodiments the high capacity hydrocarbon absorbing polymeric material includes hydrocarbon absorbing polymeric polyethylene, polypropylene, polyurethane, polyester, and combinations thereof. These absorbing polymeric materials can be in the

form of a non-woven fabric layer, nanofiber layer, a sponge or polymer foam element or layer. In other embodiments the high capacity hydrocarbon absorbing material is an activated carbon. In some embodiments, the high capacity hydrocarbon absorbing material includes both a high capacity hydrocarbon absorbing polymeric material and a high capacity hydrocarbon absorbing activated carbon material.

[0061] The high capacity hydrocarbon absorbing material includes one or more or two or more different types or kinds of high capacity hydrocarbon absorbing material. The two or more high capacity hydrocarbon absorbing materials may be mixed together within a single volume or separated from each other by a divider or spacer element where they are in serial flow orientation to each other.

[0062] In some embodiments the high capacity hydrocarbon absorbing material includes two or more high capacity hydrocarbon absorbing activated carbon materials. The two or more high capacity hydrocarbon absorbing activated carbon material may be mixed together within a single volume or separated from each other by a divider or spacer element where they are in serial flow orientation to each other.

[0063] In some embodiments the high capacity hydrocarbon absorbing material includes two or more high capacity hydrocarbon absorbing polymeric materials. The two or more high capacity hydrocarbon absorbing polymeric materials may be mixed together within a single volume or separated from each other by a divider or spacer element where they are in serial flow orientation to each other.

[0064] In some embodiments the high capacity hydrocarbon absorbing material includes a high capacity hydrocarbon absorbing polymeric material and a high capacity hydrocarbon absorbing activated carbon material. The high capacity hydrocarbon absorbing polymeric material and the high capacity hydrocarbon absorbing activated carbon material may be mixed together within a single volume or separated from each other by a divider or spacer element where they are in serial flow orientation to each other. In these embodiments, the high capacity hydrocarbon absorbing polymeric material may represent

from 10 to 90 wt% of the total high capacity hydrocarbon absorbing material and a high capacity hydrocarbon absorbing activated carbon material may represent from 90 to 10% of the total high capacity hydrocarbon absorbing material. The high capacity hydrocarbon absorbing polymeric material may represent from 25 to 50 wt% of the total high capacity hydrocarbon absorbing material and a high capacity hydrocarbon absorbing activated carbon material may represent from 75 to 50% of the total high capacity hydrocarbon absorbing material. The high capacity hydrocarbon absorbing polymeric material may represent from 75 to 50 wt% of the total high capacity hydrocarbon absorbing material and a high capacity hydrocarbon absorbing activated carbon material may represent from 25 to 50% of the total high capacity hydrocarbon absorbing material.

[0065] In many embodiments the polishing hydrocarbon absorber material is an activated carbon. In some embodiments the polishing hydrocarbon absorbing material includes two or more polishing hydrocarbon absorbing activated carbon materials. The two or more polishing hydrocarbon absorbing activated carbon material may be mixed together within a single volume or separated from each other by a divider or spacer element where they are in serial flow orientation to each other.

[0066] It is understood that the high capacity hydrocarbon absorbing material and the polishing hydrocarbon absorber material are different materials. For example both the hydrocarbon absorbing material and the hydrocarbon absorber material can be activated carbon, however, they are different types of activated carbon that have different absorption properties. Generally, the polishing activated carbon has a greater loading or polishing capacity ($\mathbf{q_t}$) than the high capacity hydrocarbon absorber material.

[0067] In some embodiments the hydrocarbon-in-water purification system has about an equal weight or volume amount of high capacity hydrocarbon absorber material as compared to polishing hydrocarbon absorber material. The high capacity hydrocarbon absorber material represents from 45 to 55 wt% of the total absorber material (contained within the

hydrocarbon-in-water purification system) and the polishing hydrocarbon absorber material is about 55% to 45% of the total absorber material.

[0068] In some embodiments having a greater wt% of high capacity hydrocarbon absorber material as compared to polishing hydrocarbon absorber material has been shown to improve the lifetime of the overall hydrocarbon in water purification system. In some of these embodiments the high capacity hydrocarbon absorber material represents from 55% to 95% wt of the total absorber material and the polishing hydrocarbon absorber material is about 45% to 5% of the total absorber material.

[0069] In other embodiments having a greater wt% of polishing hydrocarbon absorber material as compared to high capacity hydrocarbon absorber material has been shown to improve the lifetime of the overall hydrocarbon in water purification system. In some of these embodiments the high capacity hydrocarbon absorber material represents from 15% to 45% wt of the total absorber material and the polishing hydrocarbon absorber material is about 85% to 55% wt of the total absorber material.

[0070] In some embodiments the hydrocarbon-in-water purification system has about 2/3 high capacity hydrocarbon absorber material and 1/3 polishing hydrocarbon absorber material. The high capacity hydrocarbon absorber material represents from 60 to 75 wt% of the total absorber material (contained within the hydrocarbon-in-water purification system) and the polishing hydrocarbon absorber material is about 40% to 25% of the total absorber material.

[0071] As used herein, terms such as “inside”, “outside”, “vertical”, “horizontal”, “above”, “below”, “left” , “right”, “upper” and “lower”, “clockwise” and “counter clockwise” and other similar terms, refer to relative positions as shown in the figures. In general, a physical embodiment can have a different orientation, and in that case, the terms are intended to refer to relative positions modified to the actual orientation of the device.

[0072] **FIG. 4** is a schematic diagram view of an engine system **150** showing various components that can be used to provide and control fluid flow from a source of fuel having a potential need for fuel water separation. As shown, the engine system **150** includes a fuel source **152**, fuel water separator **154**, a water filter **156**, a fuel pump **158**, an engine **160**, a controller **162**, a fuel line **164**, and a water line **166**. A fuel line valve **170**, a water line valve **172**, a water-in-fuel (WIF) sensor **174**, a temperature sensor **176**, are also included in this illustrated embodiment of the engine system **150**.

[0073] Although these components are included in the illustrated embodiment, it should be understood that the disclosure is not limited to including each component shown, and furthermore, other components may be included that are not shown or may be found in other arrangements that may also be used with control techniques described herein for separating water from fuel and purifying the separated water to remove hydrocarbons. For example, the engine system **150** may also be configured as described in European Patent Application 2,878,352, filed 29 November 2013, and titled "Fuel Filter Assembly, Filter Element and Method for Draining Water from a Fuel Filter Assembly," which is incorporated herein for all purposes.

[0074] During operation, the engine system **150** may separate water from fuel. Water may be present in the fuel, for example, due to atmospheric condensation or non-ideal fuel management. In some cases, fuel in the fuel source **152** may be mixed with water. The engine system **150** preferably removes water from the fuel before it reaches the engine **160**.

[0075] The water in the engine system **150** may not be useful, however, and in various embodiments, the water is preferably evacuated out of the engine system **150**, which may enter into the environment **180**. In at least one embodiment, water may evaporate into the environment **180**.

[0076] The separated water may be unclean, however. As used herein, "unclean water" means water that may contain or is considered to contain contaminants, such as hydrocarbons. Accordingly, "clean water" means water that does not have contaminants or is considered to be sufficiently free of contaminants. Preventing the release of unclean water into the environment **180** may be preferable, for example, to comply with jurisdictional requirements. In various embodiments, a threshold level of contaminants may be determined in response to jurisdictional requirements. In many cases, "unclean water" is preferably purified into "clean water" that may enter into the environment **180** in compliance with jurisdictional requirements.

[0077] In various illustrative embodiments, the engine system **150** preferably purifies the unclean water separated before leaving the engine system **150**. The various components of the engine system **150** and their operations related to purifying unclean water are described herein in further detail.

[0078] The fuel source **152** may be a fuel tank capable of containing and providing a fuel to the engine **160** through fuel line **164**. The engine **160** may be an internal combustion engine, for example, which combusts the fuel (for example, diesel) to provide mechanical energy (for example, torque for automotive power) during normal operation. During normal operation of the engine **160**, the fuel line **164** is typically in fluid communication with the fuel source **152**, the fuel water separator **174**, the fuel pump **158**, and the engine **160**.

[0079] Fluid communication along the fuel line **164** may be interrupted by the fuel line valve **170**, which can be open or closed. A closed fuel line valve **170** preferably prevents fluid communication across the valve in either direction. In at least the illustrated embodiment, the fuel line valve **170** is positioned between the fuel source **152** and the fuel water separator **154** along the fuel line **164**. During normal operation of the engine **160**, the fuel line valve **170** is preferably open.

[0080] Fuel is preferably drawn by the fuel pump **158** upstream or downstream along the fuel line **164**. As used herein to describe the engine system **150**, the term "upstream" along the fuel line **164** means a direction toward the fuel source **152**. Accordingly, the opposite term "downstream" along the fuel line **164** means a direction toward the engine **160**.

[0081] The fuel pump **158** may provide a pressure differential along the fuel line **164**. During normal operation, the fuel pump **158** provides a relatively higher pressure downstream (+) and a relatively lower pressure upstream (-) to draw fuel downstream.

[0082] In some embodiments, the fuel pump **158** may operate in reverse. For example, the fuel pump **158** may provide a relatively lower pressure upstream and a relatively higher pressure upstream to draw fuel upstream.

[0083] The fuel water separator **154** preferably removes a sufficient amount of water from the fuel to prevent or mitigate harm to the engine **160**. As shown, the fuel water separator **154** is positioned downstream of the fuel source **152** and upstream of the fuel pump **158** and the engine **160**.

[0084] In many embodiments, the fuel water separator **154** is similar to fuel filter element **50** in **FIG. 2**. In various illustrative embodiments, the fuel water separator **154** receives fuel mixed with water in an upstream inlet, filters water from the fuel, provides the filtered fuel to a downstream outlet to the fuel line **164**, and provides water to the water line **166**.

[0085] The water line **166** may provide fluid communication between the environment **180** and the fuel water separator **154**. In the illustrated embodiment, the water line **166** typically provides fluid communication among the fuel water separator **154**, the water filter **156**, and the environment **180**. As shown, the water filter **156** is positioned downstream of the fuel water separator **154** and upstream of the environment **180**.

[0086] As used herein, "upstream" along the water line **166** means a direction toward to the fuel water separator **154**. Accordingly, the opposite term "downstream" along the water line **166** means a direction toward the environment **180**.

[0087] In many embodiments, the water provided from the fuel water separator **154** to the water line **166** is considered unclean water and may include a hydrocarbon-in-water dispersion. Unclean water is preferably purified by the water filter **156** to provide clean water to the environment **180**. For example, the water filter **156** may include the hydrocarbon-in-water purification system **10, 100** of **FIGS. 1** or **3**, which absorbs hydrocarbons into a hydrocarbon absorbing material to purify water.

[0088] Fluid communication along the water line **166** may be restricted by the water line valve **172**, which may allow fluid to flow in only one direction along the water line **166**. For example, the water line valve **172** may be a check valve, which may be pressure sensitive to open and allow flow in one direction and to close and prevent fluid flow in the other direction. In at least one embodiment, the water line valve **172** is a passive check valve. In the illustrated embodiment, the water line valve **172** is positioned along the water line **166** between the fuel water separator **154** and the water filter **156**.

[0089] During normal operation, the fuel pump **158** may create a lower upstream pressure than the pressure of the environment **180** (for example, atmospheric pressure), which may cause a pressure differential across the water line valve **172** that is lower upstream (-) and higher downstream (+) along the water line **166**. In the illustrated embodiment, the water line valve **172** tends to close in response this pressure differential and prevents fluid from flowing upstream along the water line **166**.

[0090] Water is preferably evacuated from the engine system **150** by flowing water downstream through water line valve **172**. The separated water may flow from the fuel water separator **154**, through to the water filter **156**, and out of the engine system **150**, in some

embodiments, via a pressure differential. For example, water may be evacuated by building a sufficient pressure differential builds across the water line valve **172**, particularly a higher pressure upstream than downstream, to open it and allow water to flow downstream along the water line **166** to evacuate water. In many embodiments, the water line valve **172** preferably allows fluid to flow only downstream along the water line **166**.

[0091] In the illustrated embodiment, the fuel pump **158** may be used to provide the pressure differential needed to evacuate water. For example, the fuel pump **158** can operate in reverse to create a higher upstream pressure than the pressure of the environment **180**, which is sufficient to open the water line valve **172**. In particular, the fuel line valve **170** may also be closed to facilitate the build-up of pressure in the fuel water separator **154**, for example, by preventing fuel pumped upstream from flowing back into the fuel source **152**. Once opened due to a sufficient pressure differential, the open water line valve **172** allows fluid to flow downstream along the water line **166** across the pressure differential toward the environment **180**.

[0092] In many embodiments, the engine **160** is preferably not operating (for example, not consuming fuel) while the fuel pump **158** is reversed. Accordingly, the engine **160** may preferably be turned off before evacuating water. In other embodiments, however, another component other than the fuel pump **158** may be used to provide pressure to evacuate water, or a different valve other than a check valve, such as an active one-way valve that is not necessarily responsive to pressure in the fuel line **164**, may be used to allow water to flow downstream for evacuation.

[0093] In various embodiments, the unclean water (for example, hydrocarbon-in-water dispersion) may be described as being separated in a continuous manner by the fuel water separator **154** as fuel flows through it. When an engine **160** is running, an amount of water separated may be modeled and estimated in response to one or more parameters.

Non-limiting examples of water separation parameters include: the type of filter material in the fuel water separator **154**, the "saturation" of such filter material (for example, the amount of filter loading), the concentration of water in the fuel, the temperature of the fuel, and the flow rate of fuel, among others.

[0094] While the engine **160** is running, however, the fuel pump **158** is preferably in normal operation and water is not being evacuated. It may be beneficial to collect and store the water until it can be evacuated. Accordingly, the unclean water may be described as being evacuated from the fuel water separator **154** in batches. The process of continuously separating water and evacuating it in batches may be described as a "multi-batch" process. In some illustrative embodiments, the fuel water separator **154** includes a reservoir for collecting the unclean water until it is evacuated into the water filter **156**.

[0095] In many illustrative embodiments, the unclean water preferably is purified while residing in the water filter **156**. A required or minimum amount of time in the water filter **156** to sufficiently purify the unclean water for evacuation from the engine system **150** may be modeled or estimated in response to one or more parameters. For example, the water purification parameters may include the kinetic parameters, such as adsorbent loading, ratio of adsorbate to adsorbent, equilibrium adsorbate concentration, adsorbate characteristics, adsorbent characteristics (for example, physical characteristics such as surface area), and temperature. In many embodiments, a kinetic profile based on a particular set of kinetic parameters that models the concentration of hydrocarbons in water versus the amount time in the water filter **156** may be used to determine a residence time threshold, as well as other aspects of the control technique, as described herein elsewhere.

[0096] In many embodiments, it may be preferable to maximize or optimize the amount of time unclean water spends in the water filter **156**, which may be evacuated in batches out of the fuel water separator **154** and into the water filter **156**. On the other hand, it may also

be preferable to minimize or optimize the frequency that the engine system **150** is turned off for evacuating water from the fuel water separator **154** (in other words, minimizing the interruption of operating time). The technique described herein defines a technique for optimizing the purification and the evacuation of water that may be used with engine system **150**.

[0097] In many illustrative embodiments, the engine system **150** evacuates a predetermined water volume from the fuel water separator **154** and into the water filter **156**. The water filter **156** is preferably designed for receiving and storing a target number of predetermined water volumes (for example, one, two, three, or more). The target number of predetermined water volumes may be selected to facilitate enough residence time of the water in the water filter **156** based on an estimated water separation rate in the fuel water separator **154** according to a particular application.

[0098] In one illustrative automotive application, for example, the estimated rate of water separation by the fuel water separator **154** may be determined to be about 40 mL per hour of engine operation under typical conditions. In the same engine system **150**, the estimated rate of water purification by the water filter **156** may be determined to be about 40 mL per hour of residence time under typical conditions. Furthermore, the predetermined water volume for evacuation may be about 40 mL by design, which means three water volumes would be evacuated over a 3 hour period (for example, entering into the water filter at the 0, 1, and 2 hour marks). To facilitate the desired residence time in the water filter **156** for all three water volumes, the water filter **156** may be designed to store multiple predetermined water volumes (for example, at least three). By the time of a fourth evacuation at the 3 hour mark, the first water volume will have at least 3 hours of residence time in the water filter **156** and may be considered to be clean for evacuation out of the water filter **156**.

[0099] The water filter **156** may be designed to receive and evacuate the predetermined water volumes according to a first-in, first-out process (FIFO). A FIFO process preferably maximizes the amount of time a water volume resides in a water filter **156** capable of containing multiple water volumes by evacuating water that has spent the most time in the water filter **156** from the engine system **150**. In the illustrative automotive application described, for example, the first 40 mL water volume evacuated into the water filter **156** at the 0 hour mark may reside in the water filter **156** for 3 hours and be evacuated from the water filter **156** before the second and third water volumes (for example, at the 3 hour mark when a fourth water volume is evacuated into the water filter **156**).

[00100] The engine system **150** may include a control system for managing the flow of fuel and water through the water filter **156**. In the illustrated embodiment, the control system includes the controller **162** in operative communication with various components in the engine system **150** to manage and control, in particular, the evacuation of water. In many illustrative embodiments, the controller **162** also tracks the residence time of unclean water in the water filter **156** to facilitate the management of water evacuation. The controller **162** may be configured to implement various illustrative methods to manage and control water evacuation described herein elsewhere.

[00101] Many aspects of this disclosure are described in terms of receivers, timers, managers, operators, or controllers that include sequences of actions to be performed by components of a control and/or a communication system, which can be a computer system or other hardware capable of executing programmed instructions. These components can be embodied in a controller of an engine system (for example, an engine control module/unit (ECM/ECU)), multiple controllers, or a controller separate from the engine system communicating with the engine controller. In at least one embodiment, depicted and described components can be part of a wired or wireless network, such as a controller area network (CAN), in which the controller, sensor, actuators communicate via digital messages. It will be recognized that in embodiments consistent with the present

disclosure, each of the various actions could be performed by specialized circuits (for example, discrete logic gates interconnected to perform a specialized function), by program instructions being executed by one or more processors (for example, a central processing unit (CPU) or microprocessor), or by a combination, all of which can be implemented in the controller **162** and/or another controller(s). A controller may utilize a processor or share a processor with another component to perform actions required. Logic of embodiments consistent with the disclosure can be implemented in any suitable data processor, which may be configured to execute instructions on a computer readable medium. A computer readable medium may include tangible forms of media, for example, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (for example, EPROM, EEPROM, or Flash memory), an optical fiber, and a portable compact disc read-only memory (CD-ROM), or any other solid-state, magnetic, and/or optical disk medium capable of storing information. Thus, various aspects can be embodied in many different forms, and all such forms are contemplated to be consistent with this disclosure.

[00102] The controller **162** may be in operative communication with the fuel line valve **170** and the fuel pump **158**. In many illustrative embodiments, the controller **162** provides signals to command the fuel pump **158** to operate normally and to operate in reverse. Further, the controller **162** may provide signals to command the fuel line valve **170** to open or to close. In this manner, the controller **162** is configured to control the evacuation of water.

[00103] Also, the controller **162** may be in operative communication with sensors to receive sensor data. In some illustrative embodiments, the controller **162** is operatively coupled to the WIF sensor **174** and the temperature sensor **176** to receive various sensor signals representing sensor data. The controller **162** may use sensor data may to facilitate the management of water evacuation.

[00104] The WIF sensor **174** preferably provides a signal indicating that the predetermined water volume is ready to evacuate from the fuel water separator **154**. In various illustrative embodiments, the WIF sensor **174** may be in fluid communication with the water collection reservoir of the fuel water separator **154** and positioned to be triggered when the water level (for example, fuel-water interface) in the reservoir meets or exceeds a predetermined trigger volume.

[00105] In many embodiments, the predetermined trigger volume is preferably related to the predetermined water volume by a safety factor to prevent separated fuel from flowing into the water filter **156**. For example, the WIF sensor **174** position may trigger when at least 50 mL of water has been collected in the fuel water separator **154** and only 40 mL of water may be evacuated into the water filter **156**.

[00106] In various embodiments, one WIF sensor **174** is included. However, two or more WIF sensors **174** may be included in various embodiments.

[00107] In some illustrative embodiments, the controller **162** controls evacuation by commanding the fuel pump **158** to reverse for a predetermined amount of time in response to the WIF sensor **174** being triggered (for example, and the engine **160** being off). In at least one embodiment, the controller **162** reverses the fuel pump **158** for a predetermined amount of time estimated to evacuate the predetermined amount of water under typical operating conditions.

[00108] The temperature sensor **176** preferably provides a signal indicating a temperature along the water line. The water temperature may affect the ability of the water to be evacuated from the engine system **150**. For example, the temperature sensor **176** may provide a low-temperature signal indicating a possible build-up of ice that may restrict the flow of water. The water temperature may also affect the kinetics of the water filter **156**, or its capacity to filter hydrocarbons from water. In response to receiving the low-temperature

signal, the controller **162** may update a fault state to indicate that water should not be evacuated until a later time, for example, to facilitate water evacuation management.

[00109] The temperature sensor **176** may be dedicated for indicating water temperature or may be a temperature sensor typically present in the engine system **150** for indicating other temperatures. In many illustrative embodiments, the water line **166** is positioned in close proximity to the engine **160** such that the temperature of the water in the water line **166** is within 5 degrees Celsius of the engine **160**. In such embodiments, a dedicated sensor for water temperature may not be needed. For example, the temperature sensor **176** may be the engine block sensor, which may already be used to provide the engine block temperature, for example, to an ECU. In such cases, the controller **176** may receive the signal indicating the temperature along the water line from the ECU. This configuration has the further benefit of normalizing the temperature of the water line **166** to about the engine block temperature, which may prevent freezing and ice-buildup when warmed up.

[00110] Referring now to **FIGS. 4** and **5** together, a schematic diagram view of an illustrative process **200** for managing the evacuation of water is shown. The process **200** may be implemented in controller **162**, for example.

[00111] In step **202**, an indication that water is ready to evacuate is determined. The indication may be determined in response to a WIF sensor **172** being triggered indicating a predetermined water volume is ready to evacuate from the fuel water separator **154**. In such embodiments, the engine system **150** operator may also be notified (for example, by light lamp in instrument cluster) that the WIF sensor **172** has been triggered.

[00112] In step **204**, water evacuation conditions are checked. In various embodiments, an engine operation state is checked. For example, if the engine key is in the "off" position, the engine **160** is determined to be not operating (for example, in an off state and not

running). In some illustrative embodiments, the water evacuation conditions are checked in response to the engine key being turned to the "off" position.

[00113] On the other hand, if the engine key is in the "on" position, indicating that the engine **160** is operating, a timer may be started. After a predetermined duration, the timer may expire indicating that the WIF sensor **174** has been triggered for the predetermined duration. The predetermined duration may correspond to an estimated amount of water separated by the fuel water separator **154** over the predetermined duration that exceeds the size of the water collection reservoir and/or exceeds the capacity of the water filter **156** to purify within a particular time limit.

[00114] The operator of the engine system **150** may be notified that water must be evacuated within a particular period of time, and a second timer may be started. Upon expiration of the second timer, the engine system **150** may take severe measures to preserve the ability of the water filter **156** to sufficiently purify the water until the operator turns off the engine **160** (for example, pulls over) so that water can be evacuated. Non-limiting examples of severe measures include: derating the engine output, flashing the instrument lamp, and activating an audible alarm.

[00115] In further embodiments, a water temperature is checked prior to evacuation. If the water temperature is determined to be below a threshold level, then water may not be evacuated to the potential of freezing water. For example, if the temperature sensor **176** indicates a low water temperature (for example, less than 10 degrees Celsius), the water may not be evacuated.

[00116] In additional embodiments, the purification progress of the water volume to be evacuated from the water filter **156** is checked. If the water volume to be evacuated is determined to be not clean, then the water may not be evacuated from the water filter **156**. The purification of the water volume is preferably tracked from the entry of the water volume

into the water filter **156** until the water volume is evacuated from the water filter **156** to facilitate this determination.

[00117] In step **206**, water is evacuated from the fuel water separator **154** into the water filter **156** if the evacuation conditions are satisfactory. If the water filter **156** is filled with water before the evacuation, an older water volume may be evacuated from the water filter **156**.

[00118] In step **208**, parameters indicating the state of the filter are updated. For example, fault states may be determined and set. Non-limiting examples of fault states include a low temperature fault, an excess restriction fault, a valve failure fault, an excess water fault, and a filter expired fault. The fault states preferably indicate that the evacuation attempt failed and that water was not evacuated. The absence of any fault states indicates that the evacuation was successful. The engine operator may be notified accordingly.

[00119] In one example, a low temperature fault may be determined and set in response to a low temperature signal from the temperature sensor **176**, which may impact the ability to evacuate water due to freezing water. In a second example, an excess restriction fault may be determined and set in response to an excessive variation in fuel pump characteristics during reverse operation (for example, during evacuation), which may impact the ability to evacuate water due to a potential restricted flow. In a third example, a valve failure fault may be determined and set in response to an excessive variation in fuel pump characteristics during operation in reverse (for example, during evacuation, the fuel line valve **170** not being closed or water line valve **172** not opening), which may impact the ability to evacuate water due to the undesirable loss of pressure or build-up of pressure. In a fourth example, an excess water fault may be determined and set in response to water collected by the fuel water separator **154** exceeding the capability of the water filter **156** to purify within a particular time limit, which may result in undesirable evacuation of unclean water. In a fifth example, a filter expired fault may be determined and set in response to the water filter **156** or a purification bed **300** reaching

the end of a useful service life, which may result in insufficient purification of unclean water despite residence time. In at least one embodiment, the filter expired fault is determined in response to the final purification bed **300** reaching the end of its useful service life (for example, its bed loading threshold).

[00120] **FIG. 6** is a schematic diagram view of the illustrative fuel water separator **154** and the illustrative water filter **156**. In the illustrated embodiment, the fuel water separator **154** removes water **192** from the fuel **190**. The separated fuel **190** may continue downstream in normal operation. The separated water **192** may collect in a water collection reservoir **194**, preferably at the bottom of the fuel water separator **154**.

[00121] In some illustrative embodiments, the fuel **190** and the water **192** may reside in the same volume after separation. The separated fuel **190** may float above the separated water **192** as a separate phase, for example. The water collection reservoir **194** may be defined as a lower portion of a volume in the fuel water separator **154**. Although the water collection reservoir **194** is schematically shown as a cylinder, any suitable shape capable of separating and containing water and fuel is contemplated within this disclosure.

[00122] Also, as shown, the WIF sensor **174** is positioned in the water collection reservoir **194**. The WIF sensor **174** may be triggered in response to detecting when the level of the water **192** has reached a predetermined water volume. The trigger preferably indicates that a water volume is ready to be evacuated. When evacuated, a water volume preferably exits the fuel water separator **154**, crosses the water line valve **172**, and enters into the water filter **156**. In many illustrative embodiments, the water volume may be related to the predetermined water volume by a safety factor. For example, the predetermined water volume may be 50 mL and the water volume to be evacuated may be 40 mL.

[00123] The water filter **156** includes an inlet **196** and an outlet **198**. The water filter **156** is preferably designed to evacuate the first or oldest water volume out of the outlet **198**

when a new water volume enters the inlet **196**. For example, when the water filter **196** is first installed, there are no water volumes in the water filter **196**, and upon a first evacuation, a first water volume preferably equal to the predetermined water volume enters the water filter **156**. Then, additional evacuations raise the water level in the filter **156**, preferably in increments of the predetermined water volume. As schematically shown, the inlet **196** is positioned adjacent the bottom of the water filter **156** and the outlet **198** is positioned adjacent the top, or at the opposite end, of the water filter **156**. Preferably, only purified, clean water exits, or evacuates, from the outlet **198**.

[00124] In many embodiments, the water filter **156** includes one or more hydrocarbon absorbers. The hydrocarbon absorbers preferably include the hydrocarbon absorber material described in the hydrocarbon-in-water purification systems **10, 100**. The water filter **156** may include one or more types of hydrocarbon absorber materials. Stages may be defined by the water filter **156** according to the type of material. In at least one embodiment, two hydrocarbon absorber materials are utilized, such as a high capacity material and a polishing material, which respectively define a high capacity stage and a polishing stage.

[00125] Models may be generated that predict the behavior of hydrocarbon removal as water advances through the water filter **156**, for example, by considering the total volume of the water filter **156** as a plurality of discrete purification beds **300** (for example, bins, stages, or zones). Water volumes can "enter" and "exit" a purification bed **300**. Such models may presume that, as a new water volume enters the water filter **156**, existing water volumes in the water filter **156** are displaced upward and that each water volume does not substantially mix with other water volumes as they advance through the water filter **156**.

[00126] In many illustrative embodiments, each purification bed **300** preferably is defined to have a void volume equal to the predetermined water volume. For example, the total volume of the purification bed **300** may be about 75 mL with a void volume of about 40 mL and about 35 mL for absorbing material. In other words, water may be estimated by the

model as advancing through the water filter **156** in discrete volumes in single file; each discrete volume residing in a discrete purification bed **300**; and each new water volume displacing the existing water volumes upward by one purification bed **300**.

[00127] Although any number of purification beds **300** may be defined, in the illustrated embodiment, the water filter **156** includes eight purification beds **301, 302, 303, 304, 305, 306, 307, 308** arranged from a first purification bed **301** to a final purification bed **308**. Each purification bed **300** may be defined as upstream or downstream from another purification bed **300** along the water line **166**.

[00128] The purification beds **300** may include a particular absorption material or a particular absorption stage. Furthermore, each purification bed **300** may correspond with a particular absorber, absorber material, or absorption stage. For example, in at least some embodiments, the last purification bed **308** corresponds to a polishing absorption stage including one polishing absorber made of a polishing material. Also, in at least one embodiment, the purification beds **301** to **307** correspond to one high capacity absorption stage having one high capacity absorber made of a high capacity material.

[00129] Each purification bed **300** may be considered to have a corresponding or associated bed loading state representing the ability of the purification bed **300** to absorb hydrocarbons from water, for example. For example, the bed loading state may increment if a water volume is fully or partially cleaned in the purification bed **300**. Once a purification bed **300** absorbs enough hydrocarbons, the purification bed **300** may be considered to have reached the end of its useful life, which may be defined by the adsorption isotherm model. Accordingly, a bed loading threshold for a purification bed **300** may be determined in response to the adsorption isotherm model. The bed loading state may be set to “threshold reached” or “ineffective” to indicate that the purification bed **300** can no longer effectively absorb hydrocarbons from unclean water. Conversely, a bed loading

state of "threshold not reached" or "effective" may indicate that the purification bed **300** can continue to absorb hydrocarbons and impact the purification of unclean water.

[00130] The bed loading threshold may be different for each purification bed **300** according to the adsorption isotherm model. In one example, the material, size, shape, and other characteristics of a hydrocarbon absorber may impact its capacity to absorb hydrocarbons over its useful service life, and the bed loading threshold may be adjusted accordingly. For example, a high capacity purification bed may have a bed loading threshold of 100, whereas a polishing purification bed may have a bed loading threshold of 10.

[00131] Furthermore, the position of the purification bed **300** in the water filter **156** may impact the bed loading threshold. The bed loading states are set based on modeling the multi-batch process using an adsorption isotherm model. In at least one embodiment, the bed loading threshold of the purification beds **300** may decrease in a downstream direction, recognizing that upstream purification beds **300** will absorb more hydrocarbons earlier in the useful life of the water filter **156**. For example, the bed loading thresholds may be set at 100 for the first purification bed **301**, 95 for the second purification bed **302**, 85 for the third purification bed **303**, and so on, 10 for the final purification bed **308** (for example, the final purification bed can clean 10 unclean water volumes before reaching the bed loading threshold).

[00132] Each water volume within each purification bed **300** may also be considered to have an associated purification state representing the how much the water volume has been purified. In many embodiments, new water volumes entering the water filter **156** are considered to be unclean water. Accordingly, the purification state of new water volumes are initialized or set to "unclean." However, once a water volume has resided in one or more effective purification beds **300** for the residence time threshold, the water may be considered to be clean water. Accordingly, the purification state may be set to "clean" to indicate that the water volume includes "clean water," which may be evacuated from the

water filter **156**. Conversely, as long as the water volume is considered to include "unclean water," the purification state may remain as "unclean."

[00133] The purification beds **300** may be arranged in any suitable manner in the water filter **156** to facilitate a FIFO process. In many embodiments, the first purification bed **301** is defined as downstream of the inlet **196** and upstream of all other purification beds **302** to **308**. For example, water entering into the water filter **156** may enter into the first purification bed **301** before any other purification bed.

[00134] In various embodiments, the last purification bed **308** is defined as upstream of the outlet **198** and downstream of all other purification beds **301** to **307**. For example, water exiting the water filter **156** may leave from the final purification bed **308** instead of any other purification bed.

[00135] In the illustrated embodiment, when the water **192** is introduced into the water filter **156**, the water passes through the first purification bed **301**, then the second purification bed **302**, then the third purification bed **303**, and so on until the water passes through the final purification bed **308** and exits the water filter through outlet **198**.

[00136] In at least one embodiment, the purification beds **300** are arranged linearly along an axis defined along the height of the water filter **156**. For example, the purification beds **300** may be defined as "stacked" along the height of the water filter **156**. The shapes and sizes of the purification beds **300** may also be defined in any other suitable manner, including a concentric or nested manner, similar the absorber material **36**, **46** shown in **FIG. 3**.

[00137] **FIG. 7** is a schematic diagram view of the illustrative controller **162**. As illustrated, the controller **162** is coupled to the WIF sensor **174** and the temperature sensor **176** to receive sensor data. The sensor data may indicate that a new water volume is ready to evacuate from a water collection reservoir, for example. A sensor data receiver **400** may

determine one or more parameters in response to the sensor data, such as the water in fuel parameter **404** and the water temperature parameter **422**.

[00138] The controller **162** is also shown coupled to the fuel line valve **170** and the fuel pump **158** to control water evacuation. In many illustrative embodiments, the controller **162** is operable to determine, to provide, and to store one or more parameters related to water evacuation management and control. As used herein, determining data may also include receiving data into the controller **162**.

[00139] In at least some embodiments, the controller **162** includes a water filter manager **401** configured to determine various parameters, thresholds, and states to manage the evacuation of water. In various embodiments, the water filter manager **401** also includes a purification bed tracker or a water volume tracker to facilitate management of water evacuation. For example, a purification bed tracker may maintain and update a bed loading state **416** for each purification bed based on its associated kinetic model. In another example, a water volume tracker may maintain and update a purification state **410** for each water volume based on the associated kinetic model of a current purification bed. The type of tracker may be selected, for example, based on resources available in the processing or memory of the controller **162**.

[00140] Further, in various embodiments, the controller **162** includes an evacuation operator **403** configured to provide one or more commands or states, such as alarm commands **408**, fault states **420**, and water evacuation command **420**. For example, a fault state **420** may be provided to an ECU external to the controller **162**. Commands and states may be represented by signals.

[00141] In at least one embodiment, the controller **162** is configured to determine an engine key parameter **402** indicating whether the engine key is turned to an "on" or "off" position. The controller **162** is also preferably configured to determine a water in fuel parameter

404 indicating whether a WIF sensor **174** is trigger or not triggered by the presence of a predetermined volume of water.

[00142] As illustrated, controller **162** is further configured to maintain a timer **406**, which may track one or more periods of time that have elapsed. A different timer **406** may be maintained for each period of time being tracked. In some embodiments, a timer **406** may track a period of time that has elapsed since the WIF sensor has been triggered. In various embodiments, a timer **406** may track a residence time for a water volume, which may be defined as the period of time that the water volume has spent in one or more effective purification beds. A timer **406** may be updated in any suitable time increments, on the order of seconds, minutes, or hours, for example.

[00143] Still further, the illustrated controller **162** is configured to provide one or more alarm commands **408** in response to the expiration of the timer **406**. The alarm commands **408** may warn an engine operator or take action to preserve the ability of the engine system to evacuate sufficiently purify water.

[00144] In various embodiments, the controller **162** is configured to determine one or more purification states **410** of one or more water volumes in response to one or more residence times **412** and one or more residence time thresholds **414**. For example, a purification state **410** may be set to unclean until a residence time **412** meets or exceeds a residence time threshold **414** for the water volume. The purification state **410** may then be set to clean.

[00145] In further embodiments, the controller **162** is configured to determine one or more bed loading states **416** and one or more bed loading thresholds **418** for one or more purification beds. The controller **162** may compare the bed loading states **416** to associated bed loading thresholds **418**. Once one or more bed loading states **416** reach

associated bed loading thresholds **418**, a fault state **420** may be updated to indicate an expired filter.

[00146] In many embodiments, the controller **162** is configured to determine a water temperature parameter **422** indicating the water temperature at the temperature sensor **176**. The controller **162** may also determine a low temperature threshold **424** for comparison with the water temperature parameter **422**. In response to the water temperature parameter **422** dropping below the low temperature threshold **424**, the controller **162** may update a fault state **420** to indicate a low temperature.

[00147] In at least some illustrative embodiments, the controller **162** may determine a water evacuation command **426** in response to the engine key parameter **402** indicating an "off" position, the water in fuel parameter **404** indicating a triggered WIF sensor, the fault state **420** not indicating a lower temperature (or other faults), and a purification state **410** associated with the next dischargeable water volume in the water filter being clean. In various illustrative embodiments, evacuation operator **403** provides the evacuation command **426** preferably to close the fuel line valve **170** and to reverse the fuel pump **158**.

[00148] Processes that may be implemented on the controller **162** are described herein in more detail with respect to **FIGS. 8, 9, 10, and 11**.

[00149] **FIG. 8** is a schematic diagram view of an illustrative process **202** for checking water evacuation conditions. The process **202** begins with determining that a new water volume is ready to evacuate in step **501**. Then, in step **502**, whether a water temperature is below a low temperature threshold is determined. If the water temperature is below the low temperature threshold, the process **202** bypasses the step of introducing a new water volume (for example, evacuating a water volume) and continues on to step **503**.

[00150] In step **503**, a fault state is updated in response to one or more conditions, such as a low temperature, an excess of water, and an expired filter. Each of the conditions may indicate that the new water volume cannot be evacuated, and thus an attempted evacuation has failed.

[00151] However, if in step **502**, the water temperature is not below the low temperature threshold, the process **202** may continue onto step **504**.

[00152] In many embodiments, the process **202** may be used with a water filter that contains one or more water volumes and a plurality of purification beds arranged from a first purification bed to the final purification bed such that the first purification bed receives new water introduced into the water filter from a water collection reservoir and the final purification bed discharges water from the water filter. The one or more water volumes preferably reside in the plurality of purification beds.

[00153] According to step **504**, the purification state of the water volume in the final purification bed, which would be discharged if a new water volume were introduced into the water filter, is determined. The purification state may be determined in response to tracking the residence time of the next dischargeable water volume in at least one of the purification beds.

[00154] In continuing onto step **505**, whether the dischargeable water volume in the final purification bed in the water filter is clean or not clean is determined, for example, in response to the purification state determined in step **504**. If the dischargeable water volume is clean, the process **202** may continue onto step **506** to evacuate water from the water collection reservoir to introduce a new water volume into the first purification bed of the water filter. On the other hand, if the dischargeable water volume is not clean, the process continues onto step **507** to determine whether one or more purification beds have reached associated bed loading thresholds.

[00155] According to step **506**, a new water volume is introduced into the first purification bed in response to determining that the dischargeable water volume is clean. The new water volume, once introduced, moves each of the one or more water volumes in the water filter such that the dischargeable water volume leaves the final purification bed and a next dischargeable water volume of the one or more water volumes enters the final purification bed.

[00156] On the other hand, in step **507**, whether the bed loading state associated with at least one of the purification beds exceeds an associated bed loading threshold is determined. The bed loading state may be determined in response to tracking the residence time of water in the at least one purification bed, for example.

[00157] In various embodiments, a filter may be determined to be expired in response to determining that one or more purification beds have bed loading states that exceed their associated bed loading thresholds. If the remaining effective purification beds in the water filter have insufficient capacity to clean one water volume, the water filter may be incapable of cleaning another water volume. The water filter may then be deemed expired. In one example, the filter may be considered expired if the final purification bed has reached its associated bed loading threshold. In another example, the filter may be considered expired if some or all of the purification beds have reached their associated bed loading thresholds.

[00158] Continuing on from step **507**, faults other than lower temperature, excess water, or expired filter may be checked for in step **508**, such as excessive restrictions or a valve failure during evacuation. Then, in step **503**, the fault states are updated and may be made available on a controller, for example, for diagnosis.

[00159] After either step **506** or **503**, the process **202** is then finished at step **509**. In this manner, water volumes that enter the water filter may be evaluated to facilitate only clean water being evacuated from the water filter.

[00160] **FIG. 9** is a schematic diagram view showing an illustrative process **600** for tracking a purification state (PS) and a bed loading state (LS) in a purification bed tracker, as water volumes advance through an illustrative water filter. In many embodiments, each purification bed in the water filter may be associated with a different purification bed tracker and, at any given time, a different water volume.

[00161] In the illustrated embodiment, the purification bed tracker keeps track of various water volumes Y that advance through purification bed X. For example, the process **600** may begin with a water evacuation in step **601**, which can be initiated by a water evacuation command form an illustrative controller. This may cause a previous water volume Y-1 to exit purification bed X in a downstream direction and cause a water volume Y to enter purification bed X from an upstream direction in step **602**.

[00162] In many illustrative embodiments, the purification bed tracker maintains parameters, such as a current residence time of a current water volume Y residing in the associated purification bed X, a current purification state of the current water volume Y, and a bed loading state of the associated purification bed X. The parameters may be stored in a data structure, such as a table, which may be updated by the process **600**.

[00163] The process **600** may track the purification state of the water volume Y from 1 to 0 with PS=1 representing an unclean state and PS=0 representing a clean state. In at least some illustrative embodiments, the purification state is tracked as a Boolean value as only 0 or 1. According to process **600** a water volume is preferably considered to be clean only when the water volume has resided in one or more effective purification beds for a total residence time equal to a full residence time threshold. For example, when an unclean

water volume (PS=1) resides in a first effective purification bed for half of the residence time threshold and resides in a second effective purification bed for another half of the residence time threshold, the purification state may be considered to be clean (PS=0) upon evacuation from the second effective purification bed.

[00164] The tracking process **600** may overestimate the loading of the purification bed X to preferably maintain a margin of safety in preventing unclean water from reaching the environment. The process **600** may track the bed loading state in integers, for example, integers ranging from LS=0 (no bed loading) to LS=100 (ineffective if the bed loading threshold is 100). Accordingly, the bed loading state is effective for LS=0 through LS=99. The bed loading state may be incremented (+1), for example, with each increment representing the absorption of the hydrocarbons of one full water volume into the purification bed X. However, if a water volume Y exits the purification bed X before the residence time threshold is reached, the bed loading state of the purification bed X is still incremented (LS=LS+1) even though the full amount of hydrocarbons from the water volume Y may not have been absorbed into the purification bed X. The bed loading state is also incremented (LS=LS+1) when the water volume Y exits the purification bed X after a full residence time threshold. Thus, the bed loading state of the purification bed X may be overestimated.

[00165] In many illustrative embodiments, upon the new water volume entering the water filter, a current purification state may be updated for purification bed X from the purification state of the upstream purification bed X-1 in step **603**. Further, the current purification state of the purification bed tracker associated with the first purification bed (X=1) may be updated to unclean (PS=1) in step **604** indicating that the new water volume has a full amount of hydrocarbons.

[00166] In step **605**, whether the current water volume Y is clean or not is determined in step **605**. For example, if the purification state is clean (PS=0), then the water volume is

determined to include clean water. If the water volume is not clean, whether the current bed loading threshold of purification bed X has been reached (has become ineffective) is determined in step **607**.

[00167] If the current bed loading state has reached a bed loading threshold, a fault state may be updated to indicate that the purification bed X has reached the bed loading threshold (is ineffective) in step **608**. The purification state and the residence time are preferably not updated, because as long as the water volume Y remains in the ineffective purification bed X, the water volume Y will not be further purified. However, if the current bed loading state has not reached the bed loading threshold (is effective), the current residence time of the current water volume Y is updated in step **609** (for example, is incremented by one hour).

[00168] After step **609**, whether the current residence time is equal to or greater than a residence time threshold in purification bed X is determined in step **610**. If the current residence time is meets or exceeds the residence time threshold, the current purification state may be updated to clean in step **611**. Furthermore, the current bed loading state may be incremented in step **613** to indicate that the hydrocarbons in one water volume have been absorbed into purification bed X.

[00169] However, if the current residence time is less than the residence time threshold, whether another water volume is ready to evacuate is determined in step **612**. If the next evacuation is not ready, whether the water volume is clean is checked in a loop back to step **605**.

[00170] However, if the next evacuation is ready, the water volume Y may be evacuated. Further, the current bed loading state may be incremented (LS=LS+1) in step **613** to overestimate the amount of hydrocarbons that have been absorbed into the purification bed X. Furthermore, the current water volume Y may be evacuated from the purification bed X

before the residence time threshold has been reached, and the water volume Y is still considered unclean (PS=0).

[00171] After any of steps **605**, **608**, or **613**, the process is then finished at step **614**. The process **600** may be repeated, however, each time a new volume of water is evacuated. In this manner, each water volume in the water filter may be tracked for purity based on residence time and each purification bed may be tracked until the end of its useful service life based on water volumes cleaned.

[00172] **FIG. 10** is a schematic diagram view showing an illustrative process **700** for tracking a purification state and a bed loading state in a water volume tracker as water volumes advance through an illustrative water filter. In many embodiments, water volume in the water filter may be associated with a different water volume tracker and, at any given time, a different purification bed. More specifically, a new water volume tracker may be created each time a new water volume enters the water filter.

[00173] In the illustrated embodiment, the water volume tracker keeps track of a water volume Y as it advances through various purification beds X. For example, process **700** may begin with a water evacuation in step **701**. This may cause the water volume Y to exit a previous purification bed X-1 in a downstream direction and to enter a current purification bed X in step **702**.

[00174] In many illustrative embodiments, the water volume tracker maintains parameters, such as a current residence time of the associated water volume Y, a current purification state of the associated water volume Y, a current purification bed X in which the associated water volume resides, and a current bed loading state of the current purification bed X. The parameters may be stored in a data structure, such as a table, which may be updated by the process **700**.

[00175] The process **700** may track the purification state of the water volume Y in a range between 0 and 1, for example, in increments of tenths (0.1) with PS=0 representing a clean state and PS=1 representing an unclean state. According to process **700** a water volume is preferably considered to be clean only when the water volume has resided in one or more effective purification beds for a total residence time equal to a full residence time threshold.

[00176] In particular, the process **700** may maintain a data structure (for example, table) representing the kinetic profile of one or more purification beds. Each table may associate a series of residence time thresholds (indexed by T_R), representing the time a water volume Y spends in an effective purification bed, with a series of purification states (PS), representing the normalized concentration of hydrocarbons estimated to be remaining in the water volume (for example, water volume purity). Each kinetic profile may be determined based on associated kinetic parameters for each purification bed. In one illustrative example, a table representing the kinetic profile may associate:

[00177] 0 hour residence time threshold (T_R=0) and 100% hydrocarbons remaining (PS=1);

[00178] 1 hour residence time threshold (T_R=1) and 20% hydrocarbons remaining (PS=0.2);

[00179] 3 hours residence time threshold (T_R=2) and 10% hydrocarbons remaining (PS=0.1); and

[00180] 6 hours residence time threshold (T_R=3) and 0% hydrocarbons remaining (PS=0).

[00181] In various embodiments, the difference between residence time thresholds and the purification states may define various purification changes over time. In one example, the rate of hydrocarbon absorption may be higher between hours 0 and 1 (for example, 80% hydrocarbon removed per hour) than between hours 1 and 3 (for example, 5% hydrocarbon removal per hour). In other words, each subsequent purification changes over time may be less than an immediately preceding purification change over time in

some embodiments. Purification changes over time may depend on kinetic or adsorption isotherm parameters, such as the temperature and the type of absorber material in the purification bed. Different tables may be used to represent different sets of kinetic and adsorption isotherm parameters for one or more purification beds.

[00182] In many illustrative embodiments, the purification state for water volume Y (PS) may be updated whenever the total residence time reaches a residence time threshold (T_R). Even when a water volume Y is evacuated before a next residence time threshold is reached, the water shot tracker may continue to update a residence time in a timer, for example, to keep track of the total residence time in the next effective purification bed X+1.

[00183] The process **700** may track the bed loading state for purification bed X from LS=0 (no bed loading) to LS=100 (ineffective if the bed loading threshold is 100) in tenths (0.1) instead of whole integers. Because the amount of hydrocarbons removed from the water volume Y is tracked in tenths (0.1), the difference between purification states may be used to increment the bed loading. For example, once a total residence time of the water volume Y reaches 1 hour, the current purification state may be reduced from PS=1 to PS=0.2 and the bed loading state for purification bed X may be increased by the difference (LS=LS+0.8).

[00184] The process **700** may overestimate the bed loading states, for example, by incrementing the bed loading state if a water volume Y is evacuated before the next loading threshold is reached. For example, a water volume tracker for the water volume Y that enters purification bed X at 0 hours and leaves after only 30 minutes may increment the current bed loading state as if the water volume Y resided in the purification bed X until the next residence time threshold at 1 hour (LS=LS+0.8). In this manner, the process **700** may provide a margin of safety in preventing the evacuation of unclean water from the water filter.

[00185] In many illustrative embodiments, upon a new water volume entering the water filter, the current purification bed for water volume Y may be updated from X-1 to X in step **703**. Further, a water volume tracker may be created and associated with the new water volume having a current purification bed associated with the first purification bed (X=1) and the purification state being not clean (PS=1) in step **704**.

[00186] In step **705**, whether the current water volume Y is clean is determined. For example, if the purification state is clean (PS=0), then the water volume is determined to include clean water. If the water volume is not clean, whether the current bed loading threshold of purification bed X has been reached (has become ineffective) is determined in step **707**.

[00187] If the current bed loading state has reached a bed loading threshold, a fault state may be updated to indicate that the purification bed X has reached a bed loading threshold (is ineffective) in step **708**. The purification state and the residence time are preferably not updated, because as long as water volume Y remains in the ineffective purification bed X, the water volume Y will not be further purified. However, if the current bed loading state has not reached the bed loading threshold (is effective), the current residence time of water volume Y is updated in step **709** (for example, is incremented by one hour).

[00188] After step **709**, whether another water volume is ready to evacuate is determined in step **710**. If the next evacuation is ready, the water volume Y may be evacuated. Further, the current bed loading state may be incremented ($LS=LS+PS(T_R)-PS(T_R+1)$) in optional step **711** to overestimate the amount of hydrocarbons that have been absorbed into the purification bed X. Still further, the water volume Y may enter purification bed X+1 and whether the bed loading limit of purification bed X+1 has been reached is determined in a loop back to step **707** (not illustrated), and the purification bed X+1 may be considered the current purification bed X in subsequent steps of the process **700**.

[00189] However, if the next evacuation is not ready, whether the current residence time is equal to or greater than the next residence time threshold (T_R+1) is determined in step **712**. If the current residence time meets or exceeds the residence time threshold, the current purification state may be updated to a next purification state (PS=PS(T_R+1)) associated with the next residence time threshold (T_R+1) in step **713**.

[00190] Further, the bed loading state (LS) for purification bed X may be incremented accordingly in step **714** (LS=LS+PS(T_R)-PS(T_R+1)). For example, the bed loading state (LS) may be incremented by the difference between the purification state of the current residence time threshold (PS(T_R)) and the purification state of the next residence time threshold (PS(T_R+1)). After step **714**, whether the water volume Y is clean is determined in a loop back to step **705**.

[00191] After any of step **705**, **708**, the process is then finished at step **715**. The process **700** may be repeated, however, each time a new volume of water is evacuated. In this manner, each water volume in the water filter may be tracked for purity based on residence time and each purification bed may be tracked until the end of its useful service life based on water volumes cleaned.

[00192] Some of the advantages of the disclosed systems and constructions are further illustrated by the following example. The particular materials, amounts and dimensions recited in this example, as well as other conditions and details, should not be construed to unduly limit the present disclosure.

EXAMPLES

[00193] Determination of Saturation and Polishing Capacities

[00194] The Freundlich Isotherm constants, $\mathbf{K_f}$ and **1/n**, are fitting constants that indicate the extent of interaction between the adsorbate and adsorbent. In this example the filter is designed to remove diesel hydrocarbons from water. In a typical experiment the adsorbent properties of various materials were determined as follows. Various masses of each material (50mg – 500mg) were challenged with 20 mL of a B5 diesel fuel-in-water dispersion (typically 1000 – 2500 ppm hydrocarbon content). The samples were equilibrated overnight and the equilibrium hydrocarbon concentration for each sample was determined using GC-MS (Gas Chromatography – Mass Spectrometry) relative to an n-hexadecane (C16) standard. The data was worked up using a linearized form of the empirical Freundlich isotherm expression:

$$\log_{10} q = \log_{10} \frac{x}{m} = \log_{10} K_f + \frac{1}{n} \log_{10} c_e$$

[00195] where **q** is the adsorbent loading in mg of hydrocarbons/g adsorbent (**x/m**), $\mathbf{c_e}$ is the equilibrium hydrocarbon concentration in the water, and $\mathbf{K_f}$ and **1/n** are the isotherm parameters that are material dependent and temperature dependent. In a multi-component adsorbate, such as diesel fuel, the isotherm parameters tended to be dependent on the initial fuel-in-water dispersion concentration. Isotherms constants and capacity values for a variety of materials are presented in **Table 1** (materials challenged with 2500ppm B5 diesel fuel-in-water dispersion) and **Table 2** (materials challenged with 1000ppm B5 diesel fuel-in-water dispersion).

[00196] **Table 1:** Freundlich Isotherm Constants for Materials Challenged with 2500 ppm B5 Diesel Fuel-in-Water dispersion

	Freundlich Isotherm Constants		**Material Capacity (mg hydrocarbon / gram material)**	
Material	Log K_f	1/n	Polishing, q_t (c_e = 2 ppm)	Saturation, q_{sat} (c_e = 2500ppm)
Norit GCN 1240	1.29	0.43	26.4	568
Silcarbon K48	0.00	0.86	1.8	854
Norit ROW 0.8 Supra	1.69	0.45	67	1613
Obermeier TyP Aqua S816	1.36	0.43	31	661
Chemviron Carbosrb 28FB	1.99	0.30	119	981
Calgon Filtersorb F300	1.88	0.31	94	853
Calgon Filtersorb F400	1.55	0.46	49	1356

[00197] **Table 2:** Freundlich Isotherm Constants for Materials Challenged with 1000 ppm B5 Diesel Fuel-in-Water dispersion

	Freundlich Isotherm Constants		**Material Capacity (mg hydrocarbon / gram material)**	
Material	Log K_f	1/n	Polishing, q_t (c_e = 2 ppm)	Saturation, q_{sat} (c_e = 1000ppm)
Chemviron Carbsorb 28FB	1.54	0.40	45.7	561
Polyurethane foam (Restek; Catalog #22957)	−2.69	2.08	0.0[a]	3686

[a] The polyurethane foam cannot purify water down to 2ppm, according to the Freundlich Isotherm parameters.

[00198] Norit GCN 1240 is commercially available from Cabot Corporation (Boston, MA).

[00199] Silcarbon K48 is commercially available from Silcarbon Aktivkohle GmbH (Kirchhundem, Germany).

[00200] Norit ROW 0.8 Supra is commercially available from Cabot Corporation (Boston, MA).

[00201] Obermeier TyP Aqua S816 is commercially available from Kurt Obermeier GmbH & Co. (Bad Berleburg, Germany).

[00202] Chemviron Carbosrb 28FB is commercially available from Chemviron Carbon (Feluy, Belgium).

[00203] Calgon Filtersorb F300 is commercially available from Calgon Carbon Corporation (Moon Township, PA).

[00204] Calgon Filtersorb F400 is commercially available from Calgon Carbon Corporation (Moon Township, PA).

[00205] **EXAMPLE A**

[00206] The adsorbent properties of a high capacity carbon (Silcarbon K48) and a polishing carbon (Norit GCN 1240) were determined by running an isotherm experiment as described previously. Isotherm parameters for a 2500 ppm B5 diesel fuel-in-water dispersion challenge are presented in Table 1. The target cleanliness for this example is 2ppm.

[00207] As observed, the Silcarbon K48 carbon has a higher saturation capacity, whereas the Norit GCN 1240 carbon has a higher loading capacity when targeting an outlet hydrocarbon concentration of 2 ppm. Therefore, a hydrocarbon in water purification

system including Silcarbon K48 high capacity stage followed by a Norit GCN 1240 polishing stage will have a longer lifetime than an equal mass system including only Norit GCN 1240 polishing carbon.

[00208] By breaking the absorbent bed into two stages, where the first uses a high capacity material and the second stage uses a polishing material, we can increase the lifetime of a water purification filter. Calculated results verify this increase in lifetime when the bed is challenged sequentially with 50mL water samples that have an initial hydrocarbon concentration of 2500ppm. In this model the water and carbon are allowed to equilibrate completely according to the Freundlich Isotherm expression before being transferred to the next filter stage or by leaving the element. The Freundlich isotherm parameters for the high capacity material and polishing material are based off of isotherm experiments using diesel fuel-in-water dispersion challenge (Table 1). This model was used in all examples. In this example both materials were activated carbons.

[00209] A filter containing 357g of Norit GCN 1240 will purify 68L of water before breaking through the target concentration of 2ppm. By breaking the filter into two stages of Silcarbon K48 (high capacity) and Norit GCN1240 (polishing) the optimal lifetime in the multi-batch model is 60% by weight high capacity carbon, and 40% by weight polishing carbon. In this ratio the will purify 82L before breakthrough at 2ppm. This is a 21% increase in hydrocarbon absorber filter lifetime.

[00210] EXAMPLE B

[00211] A filter containing 357g of Chemviron Carbsorb 28FB will purify 112L of water before breaking through the target concentration of 2ppm. By breaking the filter into two equal mass stages of Norit ROW 0.8 Supra (high capacity carbon) and Carbsorb 28FB (polishing carbon), the lifespan of the filter is increased to 148L of water. Further improving the system finds that the optimal life in the multi-batch model is 90% by

weight high capacity carbon, and 10% by weight polishing carbon. These ratios may differ for different specific adsorbents. In this ratio the filter will purify 167L before breakthrough at 2ppm. This is a 49% increase in hydrocarbon absorber filter lifetime.

[00212] EXAMPLE C

[00213] In another example of high capacity materials, a typical polishing carbon was compared to a polyurethane foam (Restek; Catalog #22957). The polyurethane and polishing carbon were challenged with 1000 ppm hydrocarbons (B5) in water dispersion to determine the Freundlich Isotherm parameters Log K and 1/n (Table 2). From these values the loading at saturation and at a target cleanliness (polishing) are computed. Here the target cleanliness is 2 ppm hydrocarbons in water. From experimental data, the Restek polyurethane cannot purify the water down to the intended cleanliness alone (q_t = 0 mg hydrocarbons/g material). In contrast, the typical polishing carbon has a capacity of q_t = 45.7 mg hydrocarbon/gram of carbon at the 2 ppm target cleanliness.

[00214] The Restek polyurethane has a significantly higher saturation capacity than the polishing carbon (Restek polyurethane: q_{sat} = 3686 mg hydrocarbons/g material; polishing carbon: q_{sat} = 561 mg hydrocarbons/g material). Thus a two-stage filter having a high-capacity polymer stage followed by a polishing carbon has a longer expected lifetime than a filter of carbon alone.

[00215] For example, in a multi-batch application (challenge water = 1000 ppm hydrocarbons in water) a calculated lifetime of a 250g polishing carbon element is 112L of before breaking through the target concentration of 2ppm. A filter element designed using 50g of Restek polyurethane followed by 200g of polishing carbon has a calculated lifetime to 132L before breakthrough. This is an 18% increase in hydrocarbon absorber filter lifetime.

[00216] The order of the absorbent stages is important to increase the overall lifetime of the hydrocarbon in water purification system. If the stages in the previous example are reversed (200g polishing carbon followed by 50g of Restek polyurethane) the lifetime of the system is decreased to 80L before breakthrough. This is a 29% decrease in hydrocarbon absorber filter lifetime.

[00217] **EXAMPLE D**

[00218] A multi-batch application filter has a high capacity stage of 120g of Calgon Filtersorb F400 carbon followed by a polishing stage of 60g of Chemviron Carbsorb 28FB. The filter is challenged with sequential 40mL volumes of 2500ppm hydrocarbon (B5 diesel fuel)-in-water dispersions. The filter will purify 64L of water before breaking through at 2 ppm hydrocarbon content. This is an increase in lifetime of 28% over an equivalent mass filter containing only polishing material (50L lifetime).

[00219] The increase in lifetime occurs over a range of water purification targets. If the maximum hydrocarbon concentration allowed to leave the bed is 20 ppm the high capacity/polishing filter described above will purify 69L of water before breakthrough. This is an increase in lifetime of 28% over an equivalent mass filter containing only polishing material (54L lifetime).

[00220] Alternatively, if the filter includes a high capacity stage of 120g of Norit ROW 0.8 Supra carbon followed by a polishing stage of 60g of Chemviron Carbsorb 28FB the filter will purify 70L of water before breaking through at 2ppm hydrocarbon content. This is an increase in lifetime of 40% over an equivalent mass filter containing only polishing material (50L lifetime).

[00221] **EXAMPLE E**

[00222] A multi-batch application filter has a high capacity stage of 70g of Norit Row 0.8 Supra carbon followed by a polishing stage of 70g of Chemviron Carbsorb 28FB carbon. The filter is challenged with sequential 50mL volumes of 1000ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 80L of water before breaking through at 5 ppm hydrocarbon content. This is an increase in lifetime of 36% over an equivalent mass filter containing only polishing material (59L lifetime)

[00223] **EXAMPLE F**

[00224] A multi-batch application filter has a high capacity stage of 140g of Silcarbon K48 carbon followed by a polishing stage of 140g of Obermeier TyP Aqua S816. The filter is challenged with sequential 50mL volumes of 2500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 64L of water before breaking through at 2 ppm hydrocarbon content. This is an increase in lifetime of 8% over an equivalent mass filter containing only polishing material (59L lifetime).

[00225] **EXAMPLE G**

[00226] A multi-batch application filter has a high capacity stage of 30g of polyurethane foam (Restek; Catalog #22957) followed by a polishing stage of 60g of Obermeier TyP Aqua S816. The filter is challenged with sequential 40mL volumes of 2500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 18L of water before breaking through at 2 ppm hydrocarbon content. This is an increase in lifetime of 50% over an equivalent mass filter containing only polishing material (12L lifetime).

[00227] **EXAMPLE H**

[00228] A filter design that starts with a high capacity material can have the lifetime increased by replacing the downstream portion of the filter with a polishing material. For example, a filter is designed to purify sequential 10mL volumes of 1000ppm hydrocarbon (B5 diesel

fuel)-in-water dispersion. A filter including 37.5g of high capacity material (Norit ROW 0.8 Supra) will purify 26L of water before breaking through at 5 ppm hydrocarbon content. Changing the design to include 30g of high capacity carbon material followed by 7.5 g of polishing material (Calgon Filtersorb F300) increased the lifetime to 29L of water purification. This is an increase in lifetime of 12%.

[00229] EXAMPLE I

[00230] A multi-batch application filter has a high capacity stage of 150g of polyurethane foam (Restek; Catalog #22957) followed by a polishing stage of 150g of Norit ROW 0.8 Supra carbon. The filter is challenged with sequential 100mL volumes of 2500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 131L of water before breaking through at 10 ppm hydrocarbon content. This is an increase in lifetime of 24% over an equivalent mass filter containing only polishing material (106L lifetime).

[00231] EXAMPLE J

[00232] A multi-batch application filter has a high capacity stage of 2.25kg of Norit ROW 0.8 Supra carbon followed by a polishing stage of 3.75kg Chemviron Carbsorb 28FB carbon. The filter is challenged with sequential 1L volumes of 1500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 3260L of water before breaking through at 1 ppm hydrocarbon content. This is an increase in lifetime of 31% over an equivalent mass filter containing only polishing material (2490L lifetime).

[00233] EXAMPLE K

[00234] The filter from Example J can be further enhanced by using multiple high capacity materials in series. The high capacity stage in the filter above is changed to contain 750g of polyurethane foam (Restek; Catalog #22957) followed by 1.5kg of Norit Row 0.8 Supra carbon; the polishing stage is unchanged. The filter is challenged with sequential

1L volumes of 1500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 4137L of water before breaking through at 1 ppm hydrocarbon content. This is an increase in lifetime of 66% over an equivalent mass filter containing only polishing material (2490L lifetime). If the high capacity stage is only polyurethane foam the lifetime is decreased to 3760L.

[00235] EXAMPLE L

[00236] A multi-batch application filter has a high capacity stage of 70g of Calgon Filtersorb F400 carbon followed by a polishing stage of 70g of Chemviron Carbsorb 28FB carbon. The filter is challenged with sequential 50mL volumes of 500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 106L of water before breaking through at 10 ppm hydrocarbon content. This is an increase in lifetime of 8% over an equivalent mass filter containing only polishing material (98L lifetime).

[00237] EXAMPLE M

[00238] The high capacity stage in Example L was replaced with 70g of Norit ROW 0.8 Supra carbon; the polishing stage is unchanged. The filter is challenged with sequential 50mL volumes of 500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 120L of water before breaking through at 10 ppm hydrocarbon content. This is an increase in lifetime of 22% over an equivalent mass filter containing only polishing material (98L lifetime).

[00239] EXAMPLE N

[00240] The high capacity stage in Example M was increased to 105g. The polishing stage was decreased to 35g. The filter is challenged with sequential 50mL volumes of 500ppm hydrocarbon (B5 diesel fuel)-in-water dispersion. The filter will purify 101L of water

before breaking through at 500 ppb hydrocarbon content. This is an increase in lifetime of 42% over an equivalent mass filter containing only polishing material (74L lifetime).

[00241] Thus, embodiments of HYDROCARBON-IN-WATER PURIFICATION SYSTEM are disclosed. One skilled in the art will appreciate that the purification systems described herein can be practiced with embodiments other than those disclosed. The disclosed embodiments are presented for purposes of illustration and not limitation.

CLAIMS:

1. A hydrocarbon-in-water purification system, comprising:

a high capacity hydrocarbon absorber stage comprising a high capacity hydrocarbon absorber material and an inlet configured to receive a hydrocarbon-in-water dispersion from a fuel system; and

a polishing hydrocarbon absorber stage in liquid communication and downstream of the high capacity hydrocarbon absorber stage, the polishing hydrocarbon absorber stage comprising polishing activated carbon;

the high capacity hydrocarbon absorber material has a greater saturation capacity than the polishing activated carbon and the polishing activated carbon having a greater polishing capacity than the high capacity hydrocarbon absorber material.

2. The system according to claim 1 wherein, the high capacity hydrocarbon absorber stage and the polishing hydrocarbon absorber stage are contained within a filter housing.

3. The system according to any of the preceding claims, wherein the high capacity hydrocarbon absorber material comprises activated carbon.

4. The system according to any of the preceding claims, wherein the high capacity hydrocarbon absorber material comprises polyethylene, polyurethane, polyester, and combinations thereof.

5. The system according to claim 4 wherein the high capacity hydrocarbon absorbing material comprises polyethylene, polyurethane, polyester and defines a non-woven fabric layer or a foam element.

6. The system according to any of the preceding claims wherein the high capacity hydrocarbon absorber material has a first weight and the polishing activated carbon has a second weight and the first and second weight equal a total absorber weight, and the first weight is in a range from 10% to 90% of the total weight or from 25 to 75% of the total weight.

7. The system according to claim 6 wherein the total absorber weight absorbs at least 10% or at least 20% or at least 30% more hydrocarbon than only polishing activated carbon having a weight equal to the total absorber weight.

8. The system according to any of the preceding claims wherein the high capacity hydrocarbon absorber stage defines a first volume and the polishing hydrocarbon absorber stage defines a second volume and the first volume and the second volume are contained within a filter housing, and a porous dividing element separates the first volume from the second volume.

9. An engine fuel and water separation system comprising:

a fuel and water separator system fluidly connected to an engine fuel line and having a water drain outlet; and

a hydrocarbon-in-water purification system, according to any of the preceding claims, in fluid communication with the water drain outlet.

10. The engine fuel system according to claim 9, wherein the engine fuel line contains diesel fuel.

11. The engine fuel system according to claims 9 or 10, wherein the fuel and water separator system comprises a fuel filter water separator fluidly connected between the fuel line and the hydrocarbon-in-water purification system, the fuel filter water separator removing particulates from the hydrocarbon fuel and forming a hydrocarbon-in-water dispersion that passes into the hydrocarbon-in-water purification system.

12. The engine fuel system according to claim 11, wherein the hydrocarbon-in-water dispersion has a hydrocarbon content of at least 500 ppm and the hydrocarbon-in-water purification system has a clean water outlet downstream of the polishing hydrocarbon absorber stage and the clean water outlet discharges clean water having a hydrocarbon content of 2 ppm or less.

13. A method comprising:

forming a hydrocarbon-in-water dispersion from a fuel system;

passing the hydrocarbon-in-water dispersion through a high capacity hydrocarbon absorber stage comprising a high capacity hydrocarbon absorber material and removing at least a portion of hydrocarbon from the dispersion to form a permeate that is substantially water; and

passing the permeate through a polishing hydrocarbon absorber stage comprising polishing activated carbon to adsorb hydrocarbon and form a polished water stream;

the high capacity hydrocarbon absorber material has a greater saturation capacity than the polishing activated carbon and the polishing activated carbon having a greater polishing capacity than the high capacity hydrocarbon absorber material.

14. The method according to claim 13 wherein the hydrocarbon-in-water dispersion comprises at least 100 ppm or at least 500 ppm or at least 1,000 ppm hydrocarbon and the polished water stream comprises less than 5 ppm hydrocarbon or less than 2 ppm hydrocarbon, or less than 1 ppm hydrocarbon.

15. The method according to any of claims 13 to 14 wherein the hydrocarbon is diesel fuel.

16. The method according to any of claims 13 to 15 wherein the hydrocarbon-in-water dispersion is provided by a fuel filter water separator.

17. The method according to any of claims 13 to 16 further comprising contacting the hydrocarbon-in-water dispersion with a high capacity hydrocarbon absorbing material being a polymeric material.

18. The method according to any of claims 13 to 17 further comprising contacting the hydrocarbon-in-water dispersion with a high capacity hydrocarbon absorbing material being a non-woven fabric layer or a foam element.

19. A method comprising:

determining whether a purification state of a dischargeable water volume in a final purification bed in a water filter is clean or not clean, wherein the water filter contains one or more water volumes and a plurality of purification beds arranged from a first purification bed to the final purification bed such that the first purification bed receives new water introduced into the water filter from a water collection reservoir and the final purification bed discharges water from the water filter, wherein the one or more water volumes reside in the plurality of purification beds;

introducing a new water volume into the first purification bed in response to determining that the purification state of the dischargeable water volume is clean, wherein introducing the new water volume moves each of the one or more water volumes in the water filter such that the dischargeable water volume leaves the final purification bed and a next dischargeable water volume of the one or more water volumes enters the final purification bed;

tracking a purification state associated with the next dischargeable water volume in response to a residence time of the next dischargeable water volume in at least one of the purification beds; and

tracking a bed loading state associated with the at least one of the purification beds in response to the residence time.

20. The method according to claim 19 further comprising:

determining whether a water temperature is below a low temperature threshold prior to determining whether the purification state of the dischargeable water volume is clean; and

bypassing the step of introducing the new water volume in response to determining that the water temperature is below the low temperature threshold.

21. The method according to claim 19 or 20 further comprising:

determining whether the bed loading state associated with the at least one of the purification beds exceeds a bed loading threshold associated with the at least one purification bed in response to the step of introducing the new water volume; and

updating a fault state to filter expired in response to determining that one or more of the plurality of purification beds have bed loading states exceeding the associated bed loading thresholds.

22. The method according to claim 21 further comprising:

updating the fault state in response to at least one of the following conditions: a low temperature, an excess restriction, a valve failure, an excess of water, and an expired filter.

23. The method according to any of claims 19 to 22 further comprising determining that the new water volume is ready to evacuate from the water collection reservoir and into the water filter.

24. The method according to any of claims 19 to 23 further comprising:

updating a purification bed tracker defining an associated purification bed corresponding to one of the plurality of purification beds in response to

introducing the new water volume, wherein the purification bed tracker maintains a current residence time of a current water volume residing in the associated purification bed, a current purification state of the current water volume, and a current bed loading state of the associated purification bed, wherein each of the plurality of purification beds is associated with a different purification bed tracker and a different water volume, wherein the current purification state of the purification bed tracker associated with the first purification bed is updated to unclean.

25. The method according to claim 24 wherein updating the purification bed tracker for associated purification beds other than the first purification bed comprises:

determining another current purification state corresponding to the current purification state of the purification bed tracker from which the current water volume previously resided prior to the introducing the new water volume; and

setting the current purification state of the purification bed tracker to the another current purification state.

26. The method according to any of claims 24 to 25 further comprising:

determining whether the current purification state of the current water volume is clean or not clean; and

determining whether the current bed loading state of the associated purification bed has reached an associated bed loading threshold or not in response to determining that the current purification state of the current water volume is not clean.

27. The method according to claim 26 further comprising updating the current residence time in response to determining that the current bed loading state has not reached the associated bed loading threshold.

28. The method according to claim 27 further comprising:

determining whether the current residence time is equal to or greater than a residence time threshold; and

updating the current purification state to clean in response to determining that the current residence time is equal to or greater than the residence time threshold.

29. The method according to claim 28 further comprising incrementing the current bed loading state of the current purification bed to indicate cleaning of the current water volume by the associated purification bed in response to determining that the current residence time is equal to or greater than the residence time threshold.

30. The method according to claim 28 further comprising incrementing the current bed loading state of the current purification bed in response to determining that another new water volume is ready to evacuate from the water collection reservoir before the current residence time is equal to or greater than the residence time threshold.

31. The method according to claim 28 further comprising:

updating the current residence time in response to determining that the current residence time is less than the residence time threshold and that another new water volume is not ready to evacuate.

32. The method according to any of claims 19 to 23 further comprising:

updating a water volume tracker defining an associated water volume corresponding to one of the water volumes in response to introducing the new water volume, wherein the water volume tracker maintains a current residence time of the associated water volume, a current purification state of the associated water volume, a current purification bed in which the associated water volume resides, and a current bed loading state of the current purification bed, wherein each of the one or more water volumes is associated with a different water volume tracker and a different purification bed; and

creating a water volume tracker associated with the new water volume.

33. The method according to claim 32 further comprising:

determining whether the current purification state of the associated water volume is clean or not clean; and

determining whether the current bed loading state of the current purification bed has reached an associated bed loading threshold or not in response to determining that the current purification state of the associated water volume is not clean.

34. The method according to claim 33 further comprising updating the current residence time in response to determining that the current bed loading state has not reached the associated bed loading threshold.

35. The method according to any of claims 33 to 35 further comprising:

determining whether the current residence time is equal to or greater than a next residence time threshold; and

updating the current purification state to a next purification state associated with the next residence time threshold defining a first purification change over time in response to determining that the current residence time is equal to or greater than the next residence time threshold.

36. The method according to claim 35 further comprising:

determining whether a subsequent current residence time is equal to or greater than a subsequent next residence time threshold in response to updating the current purification state to the next purification state; and

updating the current purification state to a subsequent next purification state associated with the subsequent next residence time threshold and defining a second purification change over time in response to determining that the subsequent current residence time is equal to or greater than the subsequent next residence time threshold, wherein the second purification change over time is less than the first purification change over time.

37. The method according to claim 35 further comprising updating the current bed loading state of the current purification bed by a next bed loading increment associated with the next residence time threshold to indicate cleaning of a water volume by the current purification bed in response to determining that the current residence time is equal to or greater than the next residence time threshold.

38. The method according to claim 37 wherein the next bed loading increment is equal to the first purification change over time.

39. The method according to claim 35 further comprising determining whether the current purification state of the associated water volume is clean or not clean in response to updating the current purification state.

40. A controller configured to carry out steps according to any of claims 19 to 39 comprising:

a sensor data receiver configured to receive at least a signal indicating that the new water volume is ready to evacuate from a water collection reservoir;

a timer configured to provide at least a residence time of a water volume of the one or more water volumes in the plurality of purification beds in the water filter;

a water filter manager including at least one tracker selected from a purification bed tracker and a water volume tracker, the water filter manager configured to determine whether to evacuate the new water volume in response to the signal indicating that the new water volume is ready to evacuate, the residence time of the water volume, and the at least one tracker; and

an evacuation operator configured to provide at least a signal to evacuate the new water volume from the water collection reservoir in response to the water filter manager determining to evacuate the new water volume.

41. A system comprising the controller according to claim 40 and configured to carry out steps according to any of claims 19 to 39 further comprising:

a fuel source to provide fuel to an engine;

a fuel water separator in fluid communication with the fuel source to separate water from the fuel before the fuel is provided to the engine, the fuel water separator comprising a water collection reservoir and a water-in-fuel sensor;

a water filter in fluid communication with the fuel water separator to receive the water separated from the fuel in response to the water being evacuated from the fuel water separator;

a fuel pump in fluid communication with the water filter to receive the signal to evacuate the new water volume from the fuel water separator and to provide pressure to evacuate the water from the fuel water separator such that the water enters the water filter; and

a temperature sensor to provide a signal indicating a water temperature,

wherein the controller is configured to receive the signal indicating that the new water volume is ready to evacuate in response to the water-in-fuel sensor and to receive the signal indicating the water temperature.

42. A method comprising:

introducing a new water volume into a first purification bed of a water filter, wherein the water filter contains one or more water volumes and a plurality of purification beds arranged from the first purification bed to a final purification bed such that the first purification bed receives new water introduced into the water filter from a water collection reservoir and the final purification bed discharges water from the water filter, wherein the one or more water volumes reside in the plurality of purification beds; and

updating a purification bed tracker defining an associated purification bed corresponding to one of the plurality of purification beds, wherein the purification bed tracker maintains a current residence time of a current water volume residing in the associated purification bed, a current purification state of the current water volume, and a current bed loading state of the associated purification bed, wherein each of the plurality of purification beds is associated with a different purification bed tracker and a different water volume; and

updating the current purification state of the purification bed tracker associated with the first purification bed to unclean.

43. A method comprising:

introducing a new water volume into a first purification bed of a water filter, wherein the water filter contains one or more water volumes and a plurality of purification beds arranged from the first purification bed to a final purification bed such that the first purification bed receives new water introduced into the water filter from a water collection reservoir and the final purification bed discharges water from the water filter, wherein the one or more water volumes reside in the plurality of purification beds; and

updating a water volume tracker defining an associated water volume corresponding to one of the water volumes, wherein the water volume tracker maintains a current residence time of the associated water volume, a current purification state of the associated water volume, a current purification bed in which the associated water volume resides, and a current bed loading state of the current purification bed, wherein each of the one or more water volumes is

associated with a different water volume tracker and a different purification bed; and

creating a water volume tracker associated with the new water volume with the current purification state of the new water volume set to unclean.

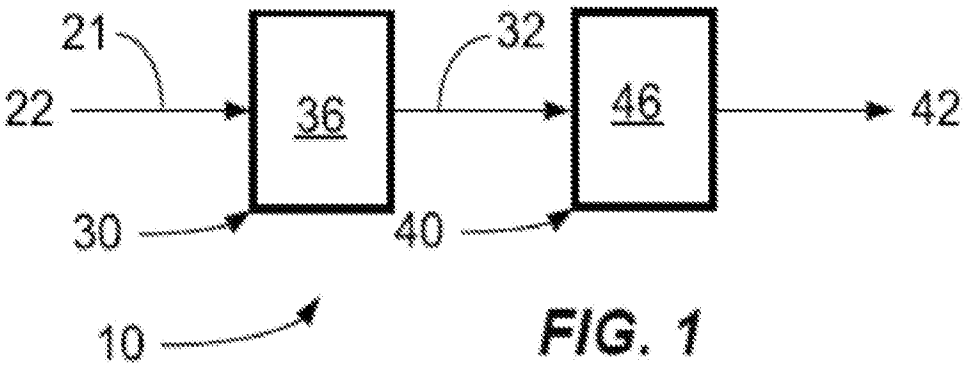

FIG. 1

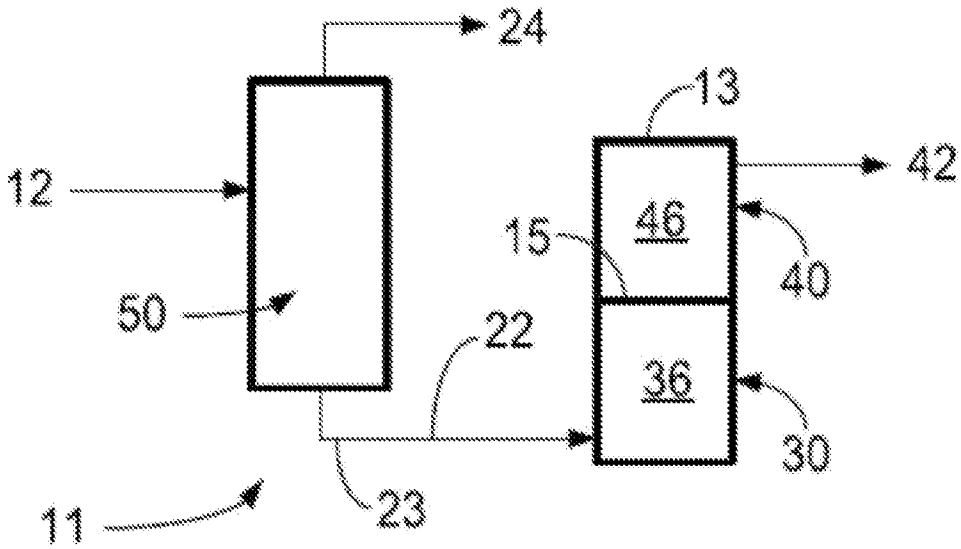

FIG. 2

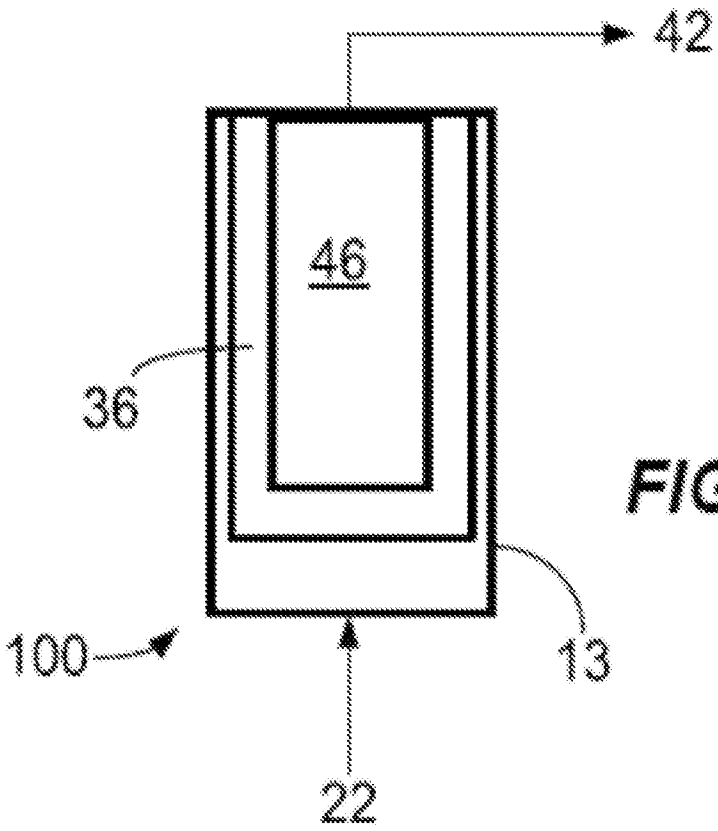

FIG. 3

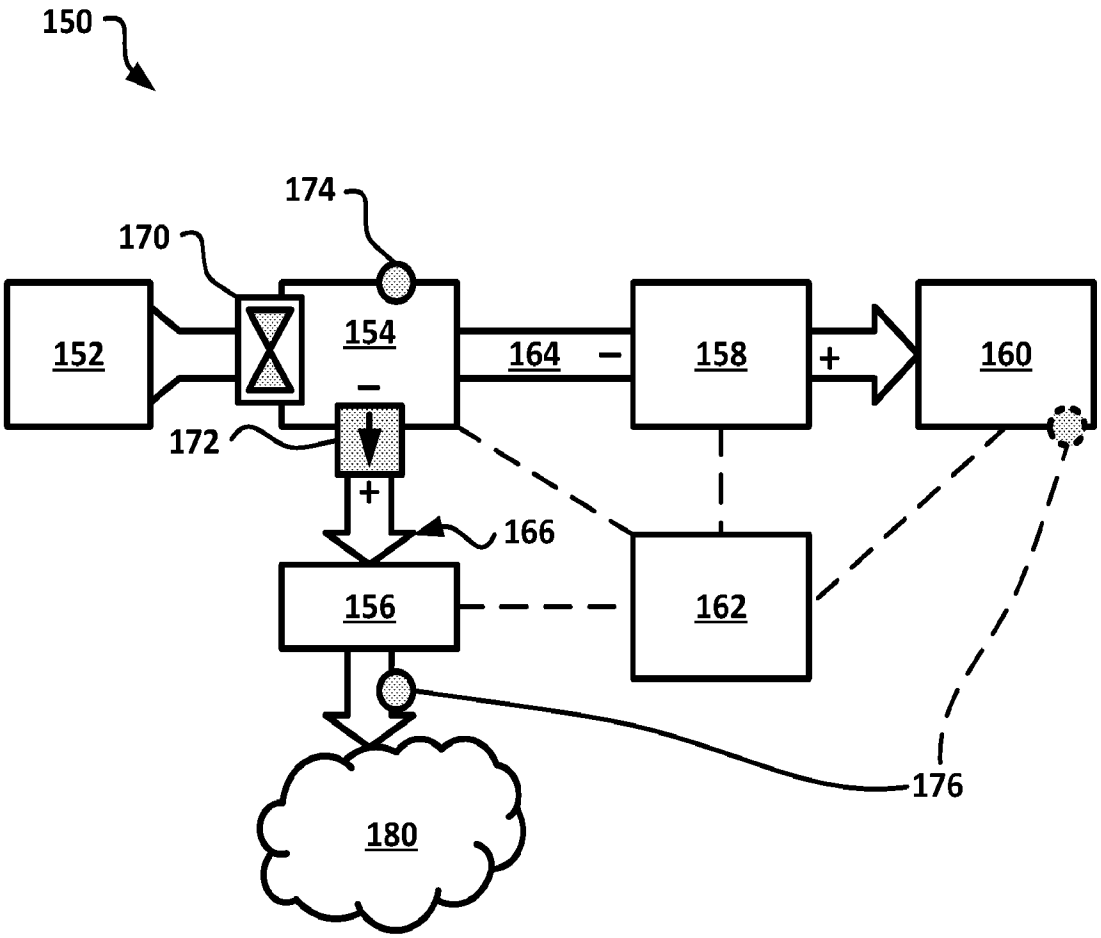

FIG. 4

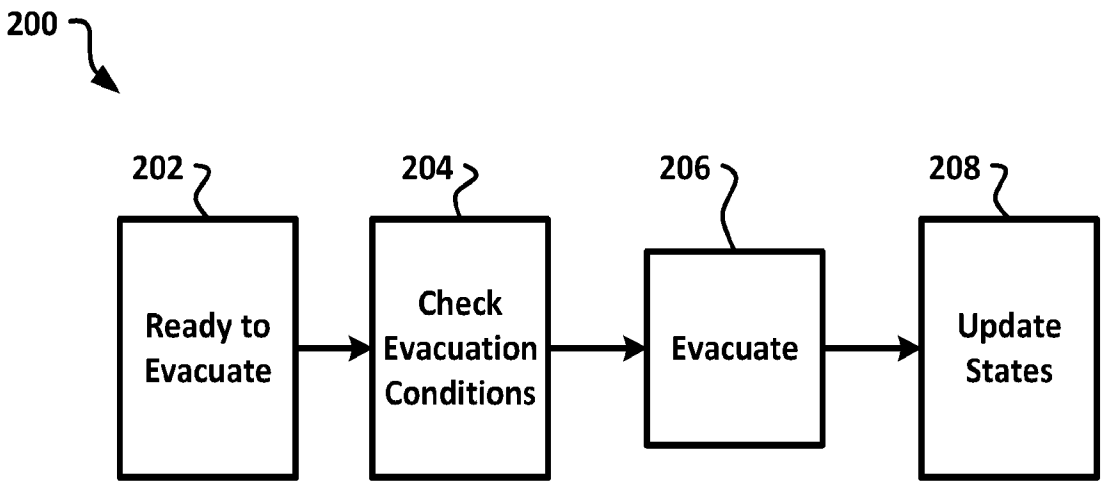
200
202
Ready to Evacuate
204
Check Evacuation Conditions
206
Evacuate
208
Update States

FIG. 5

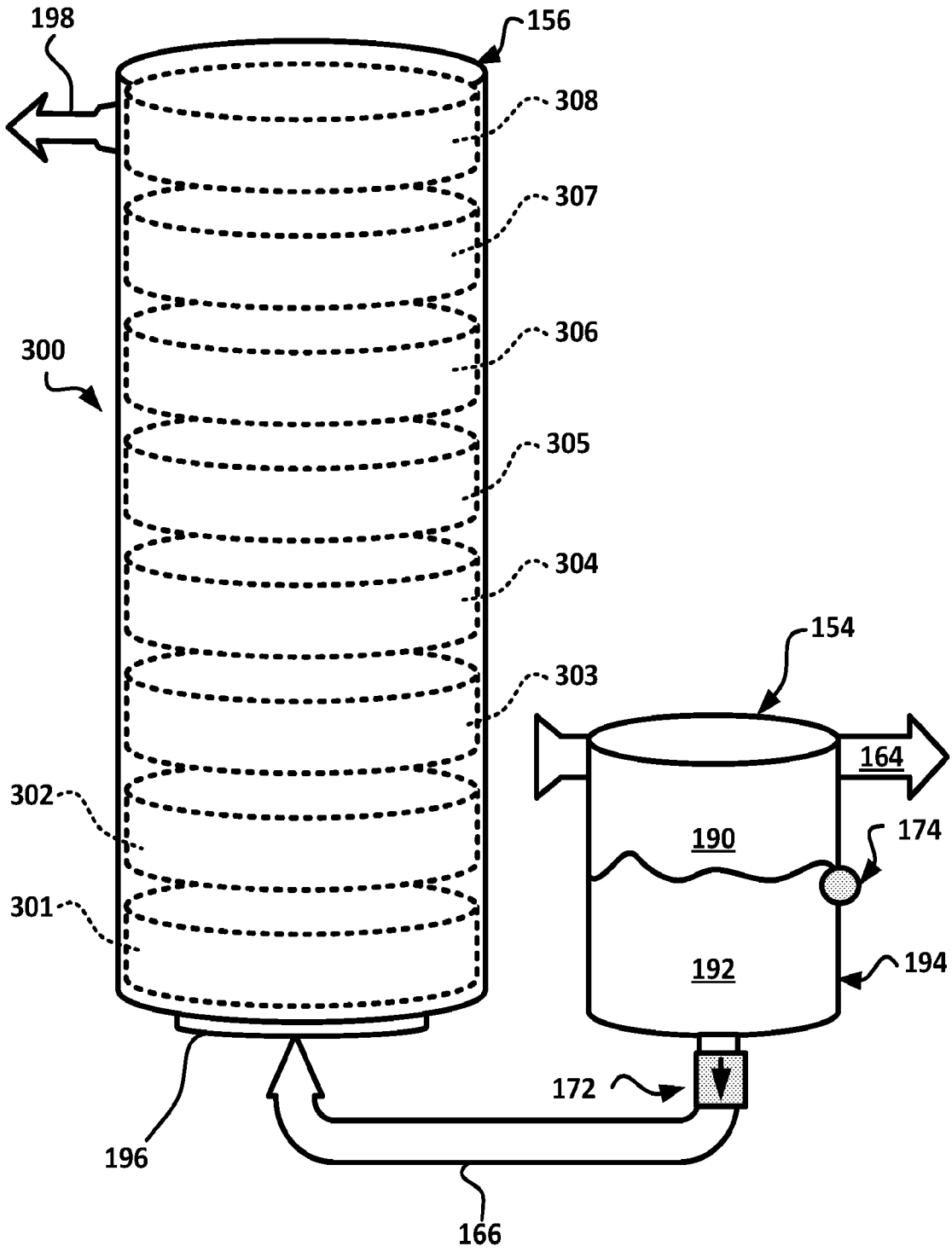
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FIG. 6

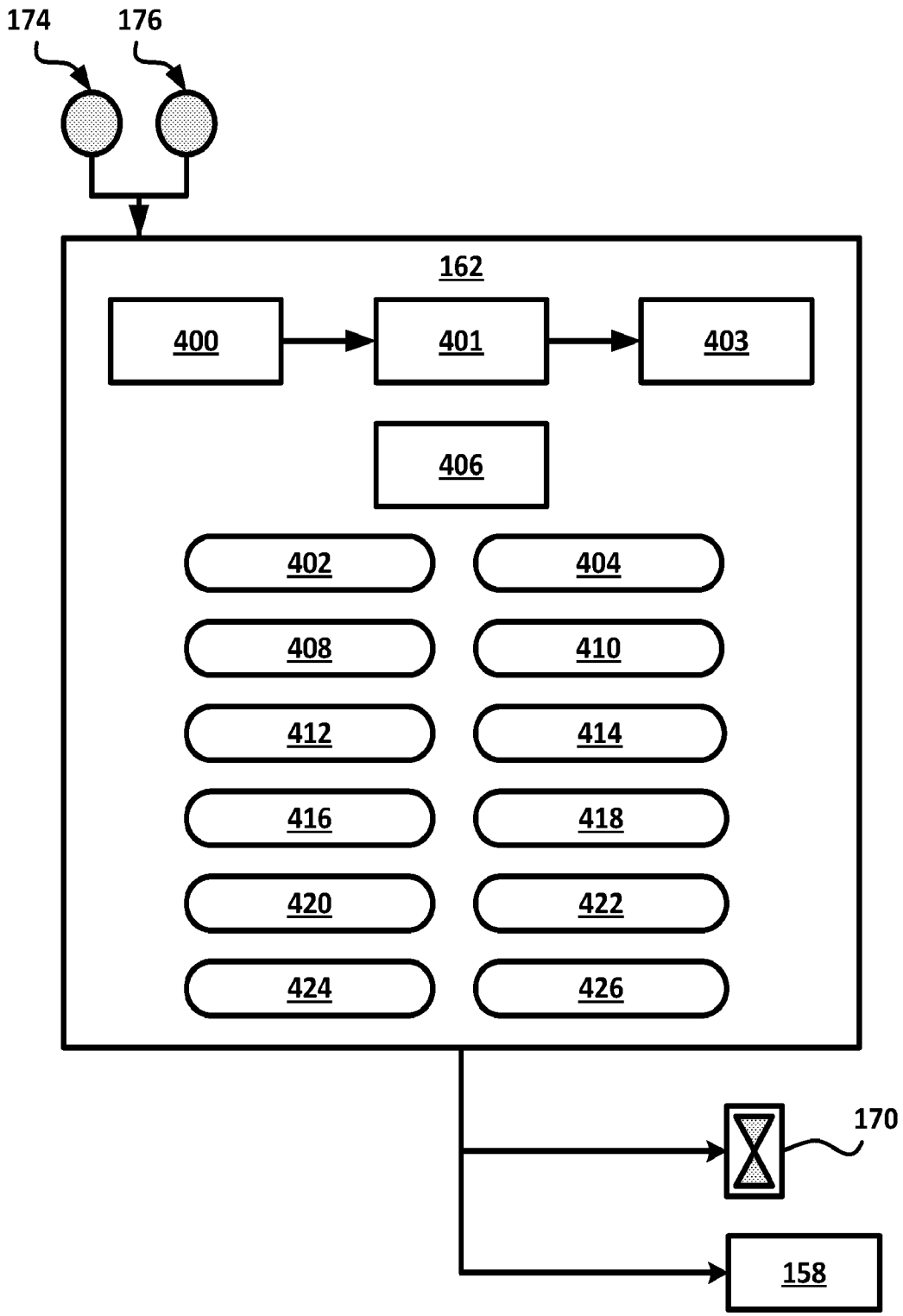
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FIG. 7

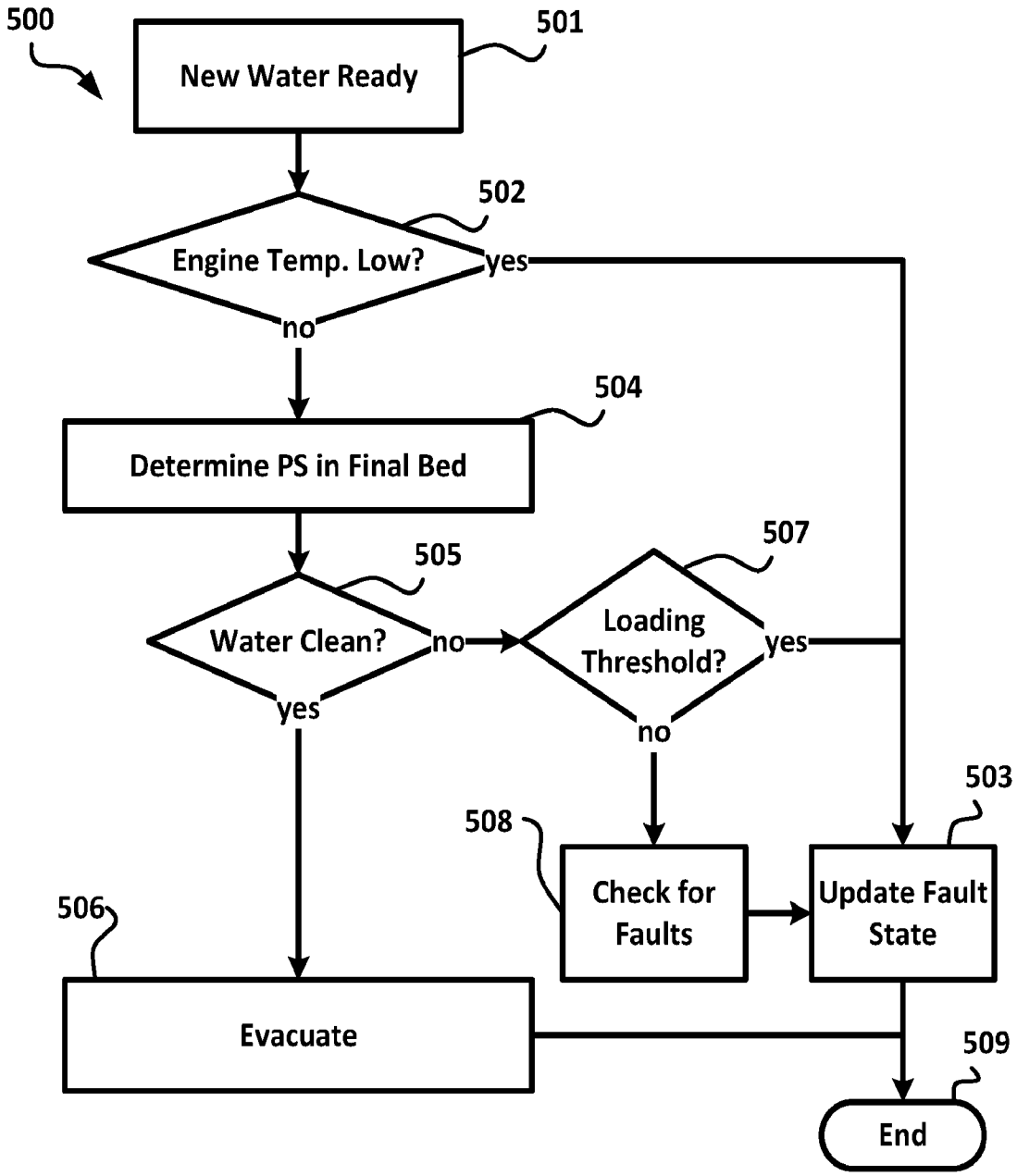
500
New Water Ready
501
502
Engine Temp. Low?
yes
no
504
Determine PS in Final Bed
505
Water Clean?
no
yes
507
Loading Threshold?
yes
no
503
508
Check for Faults
Update Fault State
506
Evacuate
509
End

FIG. 8

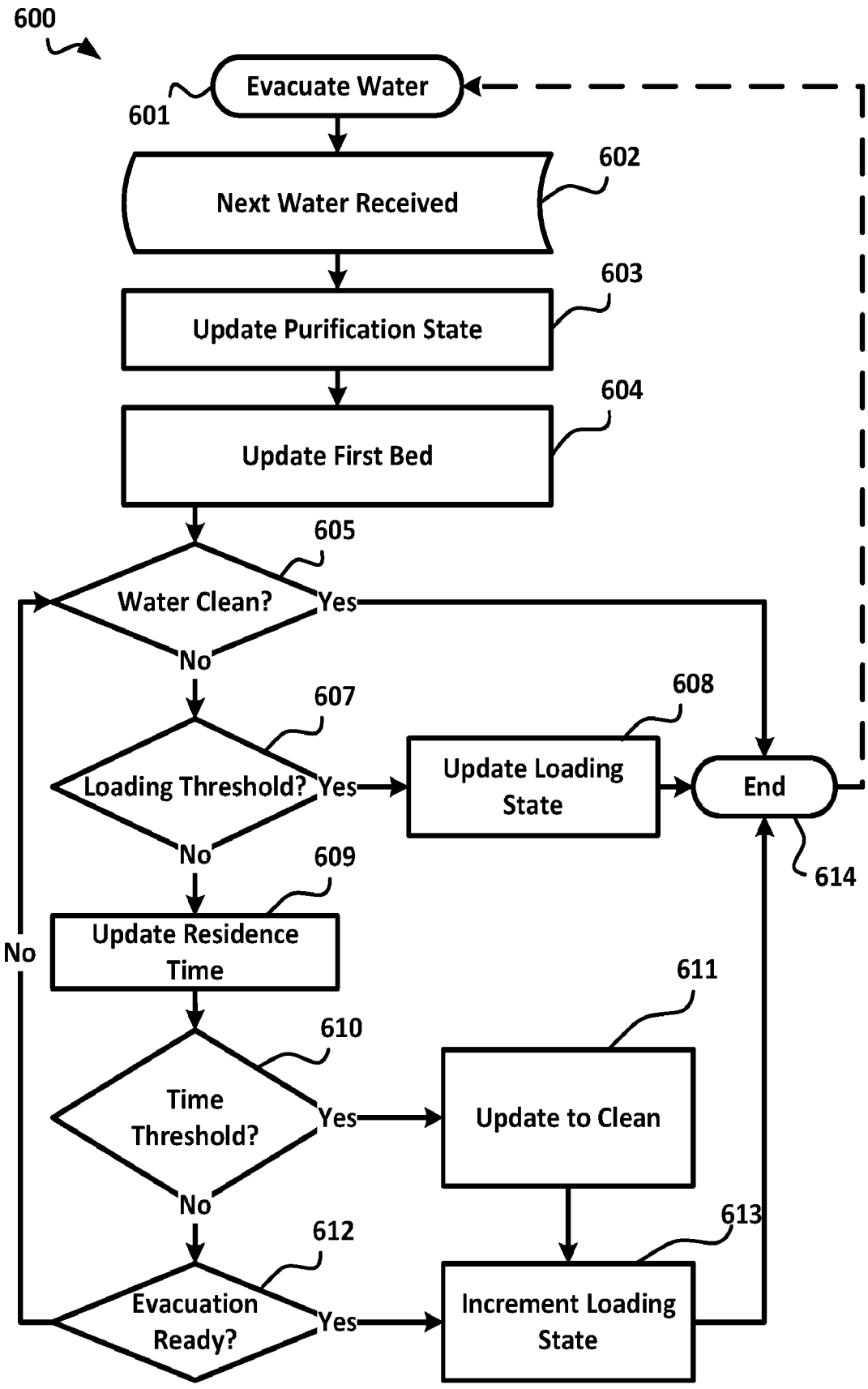
600
Evacuate Water
601
Next Water Received
602
Update Purification State
603
Update First Bed
604
Water Clean?
605
Yes
No
Loading Threshold?
607
Yes
No
Update Loading State
608
End
614
Update Residence Time
609
No
Time Threshold?
610
Yes
No
Update to Clean
611
Evacuation Ready?
612
Yes
Increment Loading State
613

FIG. 9

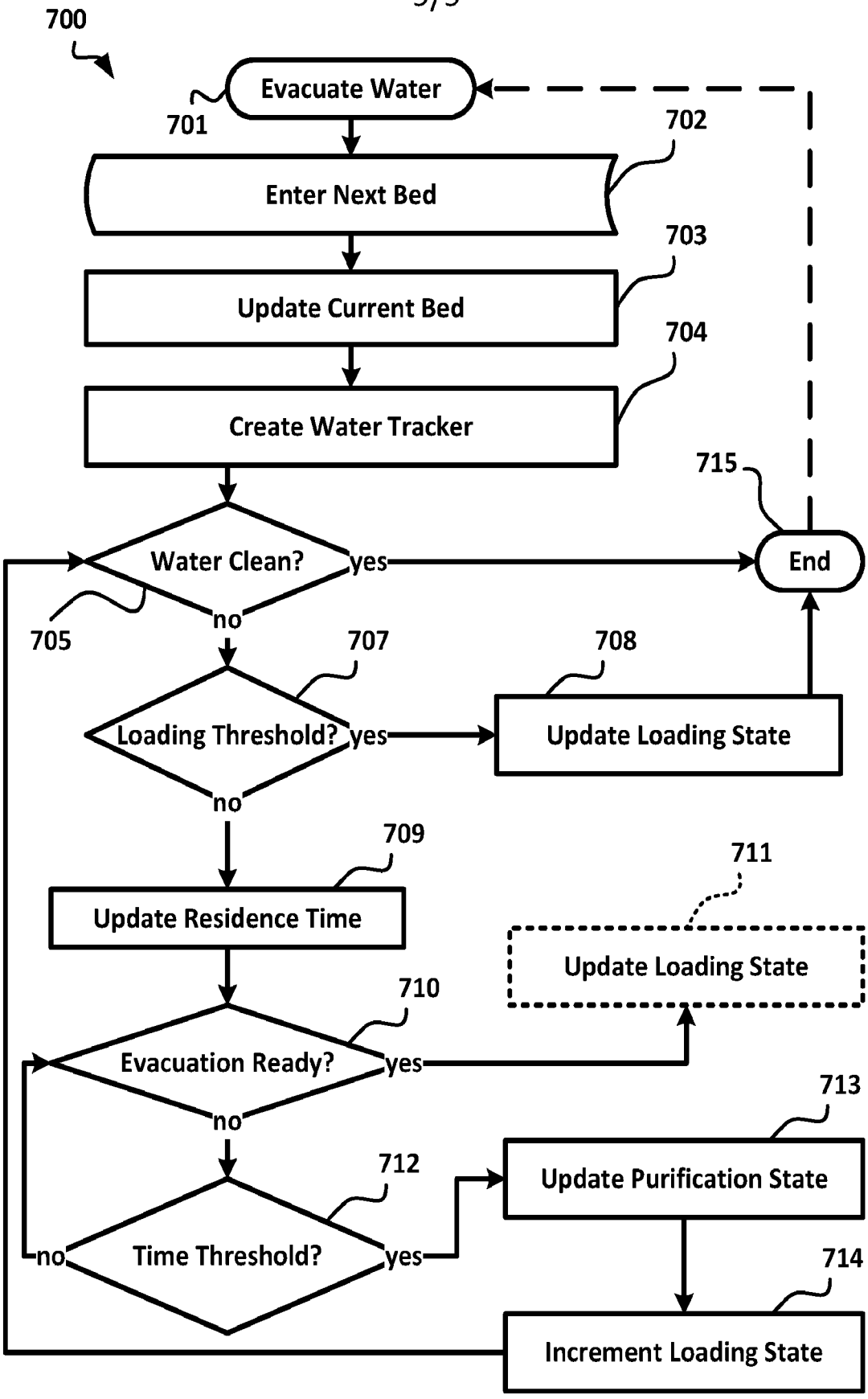
700
Evacuate Water
701
702
Enter Next Bed
703
Update Current Bed
704
Create Water Tracker
715
Water Clean?
yes
End
no
705
707
708
Loading Threshold?
yes
Update Loading State
no
709
711
Update Residence Time
Update Loading State
710
Evacuation Ready?
yes
713
no
712
Update Purification State
no
Time Threshold?
yes
714
Increment Loading State

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/22901

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B01D 15/00 (2016.01)
CPC - B01D 15/00; C02F 1/283; C02F 9/00
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) - B01D 15/00 (2016.01)
CPC - B01D 15/00; C02F 1/283; C02F 9/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC- Y10S210/924, Y10S210/05, Y10S210/925, C02F2103/06, C02F2201/008, B01D5/0036, B01D5/0045, B01D17/0202 and B01J20/22 (Search terms - See below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase and Google. Search terms: hydrocarbon, organic, oil, bitumen, water, "hydrocarbon-in-water", absorb, polish, purification and filter.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,027,653 A (Holland) 22 February 2000 (22.02.2000) Entire document, especially col 1, ln 61 to col 2, ln 6; col 5, ln 59-65; col 6,ln 48-50; col 11, ln 35-40 and col 13, ln 13-16	1-3 and 13-15
A	US 5,178,769 A (Simpson et al.) 12 January 1993 (12.01.1993). Entire document, especially col 1, ln 47-52; col 2, ln 9-14; col 3, ln 9-34 and col 5, ln 1-11	1-3 and 13-15
A	US 7,638,047 B1 (Jones) 29 December 2009 (29.12.2009) Entire document, especially col 3, ln 50 to col 4, ln 11 and col 5, ln 50-58	1-3 and 13-15
A	US 6,180,010 B1 (Alper) 30 January 2001 (30.06.2001) entire dcoument	1-3 and 13-15
A	US 5,462,785 A (Holland) 31 October 1995 (31.10.1995) entire dcoument	1-3 and 13-15

☐ Further documents are listed in the continuation of Box C. ☐

* 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
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 July 2016	05 AUG 2016
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/22901

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-12, 16-18 and 23-41
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: claims 1-3 and 13-15 directed to a hydrocarbon-in water purification system and the method comprising: forming a hydrocarbon -in-water dispersion from a fuel system

Group II: claims 19-22, directed to a method of determining whether a discharged water stream is clean or not clean and purifying water through one or more filter beds.

Group III: claims 42 and 43, directed to a method of purifying water using multiple water volumes and multiple purification bed and a purification tracker for facilitating the operation of the filter.

Continue on the first sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-3 and 13-15

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/22901

Continuation of Box III

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special technical features:

The special technical feature of Group I is a high capacity hydrocarbon absorber and a polishing hydrocarbon; the high capacity hydrocarbon material has a greater saturation capacity than the polishing activated carbon and the polishing activated carbon having a greater polishing activated carbon having a greater polishing capacity than the high capacity hydrocarbon absorber material, which is not required by groups II and III.

The special technical feature of Group II is determining whether a purification state of a dischargeable water is clean or not clean; introducing a new water volume into the first purification bed in response to determining that the purification state of the dischargeable water volume is clean, wherein introducing the new water volume moves each of the one or more water volumes in the water filter such that the dischargeable water volume leaves the final purification bed and a next dischargeable water volume of the one or more water volumes enters the final purification bed; determining that the purification state of the dischargeable water volume is clean, wherein introducing the new water volume moves each of the one or more water volumes in the water filter such that the dischargeable water volume leaves the final purification bed and a next dischargeable water volume of the one or more water volumes enters the final purification bed tracking a purification state associated with the next dischargeable water volume in response to a residence time of the next dischargeable water volume in at least one of the purification beds; and tracking a bed loading state associated with the at least one of the purification beds in response to the residence time, which is not required by groups I and III

The special technical feature of Group III is updating a purification bed tracker defining an associated purification bed corresponding to one of the plurality of purification beds, wherein the purification bed tracker maintains a current residence time of a current water volume residing in the associated purification bed, a current purification state of the current water volume, and a current bed loading state of the associated purification bed, wherein each of the plurality of purification beds is associated with a different purification bed tracker and a different water volume; and updating the current purification state of the purification bed tracker associated with the first purification bed to unclean; updating a water volume tracker defining an associated water volume corresponding to one of the water volumes, wherein the water volume tracker maintains a current residence time of the associated water volume, a current purification state of the associated water volume, a current purification bed in which the associated water volume resides, and a current bed loading state of the current purification bed, wherein each of the one or more water volumes is associated with a different water volume tracker and a different purification bed; and creating a water volume tracker associated with the new water volume with the current purification state of the new water volume set to unclean, which is not required by groups I and II

Common technical features:

Groups I-III share the technical feature of filtration or purification of water. However, this shared technical feature does not provide a contribution over the prior art because these shared technical features, of Groups I-II are anticipated by US 5,178,769 A to Simpson et al. (hereinafter 'Simpson'). Simpson teaches removing gaseous or liquid hydrocarbons from water. (col 1, ln 47-52 'The present invention provides a filter for removing gaseous and/or liquid hydrocarbon(s) from water and a process for removing gaseous and/or liquid hydrocarbon(s) from water which comprises passing the water containing the liquid hydrocarbon(s) through peat in fiber form, namely spaghnum peat').

Groups II and III share the technical feature of introducing a new water volume into the first purification bed. However, this shared technical feature does not provide a contribution over the prior art because these shared technical features, of Groups I-II are anticipated by Simpson. Simpson teaches introducing a new water volume into the first purification bed (col 2, ln 9-14 'The process in accordance with the present invention comprises passing the water which contains hydrocarbon(s) through a bed or beds of spaghnum peat in fiber form which has been dried initially to a moisture content of less than 5% by weight')

Groups I-III therefore, lack unity under PCT Rule 13.2, because they do not share a same or corresponding special technical feature providing a contribution over the prior art.