

STERILE DISPOSABLE PRIME TUBE**CROSS-REFERENCE TO RELATED APPLICATION**

[0001] This application claims priority to United States Provisional Patent Application No. 63/505,593, filed 01 June 2023, the disclosure of which is incorporated by reference herein in its entirety.

BACKGROUND OF THE DISCLOSURE**Field of the Disclosure**

[0002] The present disclosure relates generally to prime or purge tubes, such as prime or purge tubes for priming a fluid path set with fluid and/or purging of air from the fluid path set prior to performance of an injection protocol. More specifically, the present disclosure relates to prime or purge tubes for use in priming and/or purging of air from the fluid path set used in a fluid injector system for injecting a contrast media for a contrast enhanced imaging procedure prior to performance of the contrast enhanced imaging procedure.

Description of Related Art

[0003] Powered fluid injector systems are widely used in medical imaging procedures such as angiography, computed tomography (CT), and nuclear magnetic resonance (NMR)/magnetic resonance imaging (MRI). Such injector systems provide precision and accuracy of fluid delivery beyond that which is achievable with a manual syringe. Furthermore, powered fluid injector systems offer many safety features to prevent harm to the patient during an injection procedure.

[0004] Air may be present in syringes or reservoirs of a fluid injector system as packaged from the manufacturer. Additionally, air may accumulate in syringes or reservoirs during automatic or manual filling of syringes or reservoirs from one or more bulk fluid sources. Furthermore, air may be present in an unused fluid path set that is connected to the syringe or reservoir. Any air present in the syringe/reservoir and fluid path set must be purged and the fluid path set must be filled with fluid prior to performance of an injection procedure to avoid injection of air into the vasculature of a patient.

[0005] For example, after the syringe/reservoir is filled with fluid, a tubing set may be connected to the discharge outlet of the syringe/reservoir, and the fluid injector system may be actuated to prime the system by delivering fluid into the tubing set and ejecting the air from the distal end of the tubing set, until the syringe/reservoir and the tubing set are filled only with fluid. In certain cases, liquid fluid may flow out of the distal end as an indication that all the air have been purged from the system. While this technique may be effective in purging air

from the tubing set and the syringe/reservoir, dispensing fluid from the end of the tubing set may cause contamination or fouling of system components and may lead to spills in the injection suite that may be a safety hazard and must be cleaned. Furthermore, in some cases it might not be clear to the technologist when the syringe/reservoir and the tubing set have been completely primed and substantially all of the air removed from the system.

[0006] Therefore, new prime or purge tube configurations that retain the priming fluids and are configured for automated visualization to ensure complete priming of the fluid injector system before an injection procedure are needed.

SUMMARY OF THE DISCLOSURE

[0007] In view of the foregoing, there exists a need for devices, systems, and methods for improved priming of syringes and fluid injector systems. Examples of the present disclosure are directed to a prime or purge tube for use with a fluid injector. In some examples, provided is a prime tube for use with a fluid injector. The prime tube may include a patient tube connector having a proximal end and a distal end, and a prime cap having a proximal end and a distal end. The prime cap may have a sensing region configured for sensing a fluid within a second internal chamber defined in the prime cap. The prime tube further may include a connection interface for removably connecting the distal end of the patient tube connector to the proximal end of the prime cap. The connection interface may include a first connector at the proximal end of the prime cap, and a second connector at the distal end of the patient tube connector. The first connector may include a releasable locking mechanism connected to a sidewall of the prime cap. The second connector may include an engagement feature configured to engage at least a portion of the releasable locking mechanism. Disengagement of the engagement feature from the releasable locking mechanism permits removal of the patient tube connector from the prime cap.

[0008] In some examples, provided is a fluid injector system that may have at least one fluid container, at least one drive member configured for delivering a fluid from the fluid container to a fluid path set, and a prime tube connected to the fluid path set. The prime tube may have a patient tube connector and a prime cap. The prime cap may have a sensing region configured for sensing a fluid within a second internal chamber defined in the prime cap. A sensing arrangement may be provided for sensing at least one characteristic of the prime tube. The sensing arrangement may include at least one sensor configured to at least one of: sense a presence of the prime tube in a prime tube housing of the fluid injector system and sense at least one property of a fluid in the prime cap. A controller may be configured to control

operation of the at least one drive member based on a detection status of the sensing arrangement.

[0009] In some examples, provided is a sensing arrangement for a fluid injector system for sensing at least one characteristic of a prime tube having a patient tube connector and a prime cap. The sensing arrangement may include at least one sensor configured to at least one of: sense a presence of the prime cap in a prime tube housing of the fluid injector system; and sense a at least one property of a fluid in the prime cap.

[0010] In some examples, provided is a prime cap for priming a fluid path. The prime cap may include a hollow body having a proximal end configured for connecting with a patient tube connector and a distal end configured to be at least partially inserted into a priming container; and a cover enclosing the distal end of the hollow body. The cover may be configured to enclose the distal end and may be configured to open when a pressure differential across the cover exceeds a predetermined threshold.

[0011] In some examples, provided is a method of priming a patient line with a fluid using a fluid injector system, wherein the patient line is connected to a prime tube having a patient tube connector and a prime cap. The method may include detecting a presence of the prime tube in a prime tube housing of the fluid injector system using a prime tube sensor of the fluid injector system. Upon detecting the presence of the prime tube in the prime tube housing, the method may include actuating a drive member of the fluid injection system to deliver fluid to the prime tube during a priming operation. The method further may include detecting at least one property of the fluid within an internal chamber of the prime cap using a priming status sensor of the fluid injector system. Upon detecting the at least one property of the fluid within the internal chamber of the prime cap, the method may include providing an indication that the patient line is primed with the fluid.

[0012] Non-limiting illustrative examples of examples of the present disclosure will now be described in the following numbered clauses.

[0013] Clause 1: A prime tube for use with a fluid injector, the prime tube comprising: a patient tube connector having a proximal end and a distal end; a prime cap having a proximal end and a distal end, wherein the prime cap has a sensing region configured for sensing a fluid within a second internal chamber defined in the prime cap; and a connection interface for removably connecting the distal end of the patient tube connector to the proximal end of the prime cap, the connection interface comprising: a first connector at the proximal end of the prime cap; and a second connector at the distal end of the patient tube connector; wherein the first connector comprises a releasable locking mechanism connected to a sidewall of the prime

cap, wherein the second connector comprises an engagement feature configured to engage at least a portion of the releasable locking mechanism, and wherein disengagement of the engagement feature from the releasable locking mechanism permits removal of the patient tube connector from the prime cap.

[0014] Clause 2: The prime tube according to clause 1, wherein the releasable locking mechanism is a removable strip or a deformable or tearable ring connected to the sidewall of the prime cap by a frangible edge that extends around at least a portion of an outer perimeter of the prime cap.

[0015] Clause 3: The prime tube according to clause 2, wherein the frangible edge is configured to break upon rotation of the patient tube connector relative to the prime cap.

[0016] Clause 4: The prime tube according to any of clauses 1 to 3, wherein the patient tube connector comprises a first sidewall defining a first internal chamber between the proximal end and the distal end of the patient tube connector, and wherein the first sidewall is configured to allow sensing of a fluid content of the first internal chamber.

[0017] Clause 5: The prime tube according to clause 4, wherein the prime cap comprises a second sidewall defining the second internal chamber between the proximal end and the distal end of the prime cap, and wherein the second sidewall comprises the sensing region configured to allow sensing of a fluid content of the second internal chamber.

[0018] Clause 6: The prime tube according to clause 5, wherein second sidewall, at least in the sensing region, is configured to permit transmittance of electromagnetic energy or ultrasonic energy therethrough.

[0019] Clause 7: The prime tube according to clause 5, wherein second sidewall, at least in the sensing region, is transparent or translucent.

[0020] Clause 8: The prime tube according to clause 5, wherein second sidewall, at least in the sensing region, comprises a textured surface configured to deflect or scatter the electromagnetic energy.

[0021] Clause 9: The prime tube according to clause 5, wherein second sidewall, at least in the sensing region, has a circular or polygonal cross-sectional shape.

[0022] Clause 10: The prime tube according to clause 5, wherein the first internal chamber is in fluid communication with the second internal chamber.

[0023] Clause 11: The prime tube according to any of clauses 1 to 10, wherein the distal end of the prime cap comprises a cover.

[0024] Clause 12: The prime tube according to clause 11, wherein a tortuous path is defined between the cover and the second internal chamber of the prime cap to permit passage of air from the second internal chamber of the prime cap.

[0025] Clause 13: The prime tube according to any of clauses 1 to 12, wherein the distal end of the patient tube connector comprises a male or a female luer connector, and wherein the male or the female luer connector is at least partially surrounded by a skirt having the second connector thereon.

[0026] Clause 14: The prime tube according to any of clauses 1 to 13, further comprising at least one gripping element protruding radially outward from a sidewall of at least one of the prime cap and the patient tube connector.

[0027] Clause 15: The prime tube according to any of clauses 1 to 14, further comprising at least one alignment tab protruding radially outward from a sidewall of the prime cap.

[0028] Clause 16: A fluid injector system comprising: at least one fluid container; at least one drive member configured for delivering a fluid from the fluid container to a fluid path set; a prime tube connected to the fluid path set, the prime tube having a patient tube connector and a prime cap, wherein the prime cap has a sensing region configured for sensing a fluid within a second internal chamber defined in the prime cap; a sensing arrangement for sensing at least one characteristic of the prime tube, the sensing arrangement comprising at least one sensor configured to at least one of: sense a presence of the prime tube in a prime tube housing of the fluid injector system and sense at least one property of a fluid in the prime cap; and a controller configured to control operation of the at least one drive member based on a detection status of the sensing arrangement.

[0029] Clause 17: The fluid injector system according to clause 16, wherein the at least one property of the fluid is at least one of fluid type, a transition between air and liquid, and a concentration of contrast.

[0030] Clause 18: The fluid injector system according to clause 16 or 17, wherein the at least one sensor is a through-beam sensor configured to measure intensity of infrared radiation passing through the prime cap.

[0031] Clause 19: The fluid injector system according to any of clauses 16 to 18, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.

[0032] Clause 20: The fluid injector system according to any of clauses 16 to 19, wherein the at least one sensor comprises an optical emitter and at least one optical receiver.

[0033] Clause 21: The fluid injector system according to any of clauses 16 to 20, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.

[0034] Clause 22: The fluid injector system according to any of clauses 16 to 21, wherein the at least one sensor comprises an ultrasonic emitter on a first side of the prime cap and an ultrasonic receiver on a second side of the prime cap.

[0035] Clause 23: The fluid injector system according to any of clauses 16 to 22, wherein the at least one sensor comprises an ultrasonic emitter and an ultrasonic receiver on a same side of the prime cap.

[0036] Clause 24: The fluid injector system according to any of clauses 16 to 23, wherein the at least one sensor comprises a capacitive plate configured to contact at least a portion of the prime cap and measure a change in capacitance of the prime cap due to the at least one property of the fluid in the prime cap.

[0037] Clause 25: The fluid injector system according to any of clauses 16 to 24, wherein the at least one sensor comprises a piezoelectric transducer configured to contact at least a portion of the prime cap and detect a change in vibratory characteristics of the prime cap due to the the at least one property of the fluid in the prime cap.

[0038] Clause 26: The fluid injector system according to any of clauses 16 to 25, wherein the at least one sensor comprises a transducer configured to contact at least a portion of the prime cap and detect a change in outer diameter of the prime cap due to the at least one property of the fluid in the prime cap.

[0039] Clause 27: A sensing arrangement for a fluid injector system for sensing at least one characteristic of a prime tube having a patient tube connector and a prime cap, the sensing arrangement comprising: at least one sensor configured to at least one of: sense a presence of the prime cap in a prime tube housing of the fluid injector system; and sense a at least one property of a fluid in the prime cap.

[0040] Clause 28: The sensing arrangement according to clause 27, wherein the at least one sensor is a through-beam sensor configured to measure intensity of infrared radiation passing through the prime cap.

[0041] Clause 29: The sensing arrangement according to clause 27 or 28, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.

[0042] Clause 30: The sensing arrangement according to any of clauses 27 to 29, wherein the at least one sensor comprises an optical emitter and at least one optical receiver.

[0043] Clause 31: The sensing arrangement according to any of clauses 27 to 30, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.

[0044] Clause 32: The sensing arrangement according to any of clauses 27 to 31, wherein the at least one sensor comprises an ultrasonic emitter on a first side of the prime cap and an ultrasonic receiver on a second side of the prime cap.

[0045] Clause 33: The sensing arrangement according to any of clauses 27 to 32 wherein the at least one sensor comprises an ultrasonic emitter and an ultrasonic receiver on a same side of the prime cap.

[0046] Clause 34: The sensing arrangement according to any of clauses 27 to 33, wherein the at least one sensor comprises a capacitive plate configured to contact at least a portion of the prime cap and measure a change in capacitance of the prime cap due to the at least one property of the fluid in the prime cap.

[0047] Clause 35: The sensing arrangement according to any of clauses 27 to 34, wherein the at least one sensor comprises a piezoelectric transducer configured to contact at least a portion of the prime cap and detect a change in vibratory characteristics of the prime cap due to the at least one property of the fluid in the prime cap.

[0048] Clause 36: The sensing arrangement according to any of clauses 27 to 35, wherein the at least one sensor comprises a transducer configured to contact at least a portion of the prime cap and detect a change in outer diameter of the prime cap due to the at least one property of the fluid in the prime cap.

[0049] Clause 37: A prime cap for priming a fluid path, the prime cap comprising: a hollow body having a proximal end configured for connecting with a patient tube connector and a distal end configured to be at least partially inserted into a priming container; and a cover enclosing the distal end of the hollow body, wherein the cover is configured to enclose the distal end, and wherein the cover is configured to open when a pressure differential across the cover exceeds a predetermined threshold.

[0050] Clause 38: The prime cap of according to clause 37, wherein the cover comprises an opening that is normally closed and is openable when the pressure differential across the cover exceeds the predetermined threshold.

[0051] Clause 39: The prime cap of according to clause 37, wherein the cover comprises a membrane that is configured to burst when the pressure differential across the cover exceeds the predetermined threshold.

[0052] Clause 40: The prime cap of according to clause 37, wherein the cover comprises a cap movable relative to the distal end of the prime cap, and wherein the cap has a piercing element configured to pierce the membrane when the cap is moved toward the proximal end of the prime cap.

[0053] Clause 41: The prime cap of according to clause 37, wherein the cover comprises a cover having a first portion connected to the distal end and a second portion connected to the distal end, and wherein the first position is configured to separate from the distal end when the pressure differential across the cover exceeds the predetermined threshold.

[0054] Clause 42: The prime cap of according to clause 37, wherein the cover comprises a one-way valve.

[0055] Clause 43: The prime cap of according to clause 37, wherein the cover comprises a duck bill valve.

[0056] Clause 44: The prime cap according to clause 37, wherein the cover comprises a seal having a pinched portion formed by sealingly connecting opposing sides of a sidewall of the seal.

[0057] Clause 45: A method of priming a patient line with a fluid using a fluid injector system, wherein the patient line is connected to a prime tube having a patient tube connector and a prime cap, the method comprising: detecting a presence of the prime tube in a prime tube housing of the fluid injector system using a prime tube sensor of the fluid injector system; upon detecting the presence of the prime tube in the prime tube housing, actuating a drive member of the fluid injection system to deliver fluid to the prime tube during a priming operation; detecting at least one property of the fluid within an internal chamber of the prime cap using a priming status sensor of the fluid injector system; and upon detecting the at least one property of the fluid within the internal chamber of the prime cap, providing an indication that the patient line is primed with the fluid.

[0058] Clause 46: The method according to clause 45, further comprising removing the patient tube connector from the prime cap and connecting the patient tube connector to a patient tube.

[0059] Clause 47: The method according to clause 45 or 46, further comprising actuating the drive member of the fluid injection system to deliver the fluid in accordance with a predetermined injection protocol.

[0060] Clause 48: The method according to any of clauses 45 to 47, wherein detecting the presence of the prime tube in the prime tube housing comprises detecting a presence of an alignment tab within an opening of the prime tube housing.

[0061] Clause 49: The method according to any of clauses 45 to 48, wherein actuating a drive member of the fluid injection system to deliver fluid to the prime tube during a priming operation comprises detecting air within the internal chamber of the prime cap and continuing to actuate the drive member until substantially all of the air exits the prime cap through a cover at the distal end of the prime cap.

[0062] Clause 50: The method according to clause 49, wherein a tortuous path is defined between the cover and an inner surface of the prime cap to permit passage of the air from the internal chamber of the prime cap.

[0063] Further details and advantages of the various examples described in detail herein will become clear upon reviewing the following detailed description of the various examples in conjunction with the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064] **FIG. 1** is a partial perspective view of a fluid injector system according to an example of the present disclosure;

[0065] **FIG. 2A** is a schematic view of a fluid injector system in accordance with an example of the present disclosure;

[0066] **FIG. 2B** is a partial schematic view of the fluid injector system of **FIG. 2A**, shown with a prime tube attached to each syringe (various components of **FIG. 2A** are not shown in **FIG. 2B** for clarity);

[0067] **FIG. 3A** is a perspective view of a prime tube and prime cap according to an example of the present disclosure;

[0068] **FIG. 3B** is a perspective cross-sectional view of the prime tube and prime cap shown in **FIG. 3A**;

[0069] **FIG. 3C** is a side view of the prime tube and prime cap shown in **FIG. 3A**;

[0070] **FIG. 3D** is a side cross-sectional view of the prime tube and prime cap shown in **FIG. 3C**;

[0071] **FIG. 3E** is a detailed view of a connection interface between a prime tube and a prime cap in accordance with an example of the present disclosure;

[0072] **FIG. 3F** is a cross-sectional view of the connection interface between the prime tube and the prime cap shown in **FIG. 3E**;

[0073] **FIG. 3G** is a detailed view of a connection interface between a prime tube and a prime cap in accordance with an example of the present disclosure;

[0074] **FIG. 3H** is a cross-sectional view of the connection interface between the prime tube and the prime cap shown in **FIG. 3G**;

- [0075] FIG. 3I is a detailed view of a distal end of the prime tube shown in FIG. 3D;
- [0076] FIG. 4A is a perspective view of a prime tube and prime cap prior to insertion into a prime tube housing of a fluid injector;
- [0077] FIG. 4B is a perspective cross-sectional view of the prime tube and prime cap shown in FIG. 4A;
- [0078] FIG. 4C is a side cross-sectional view of the prime tube and prime cap shown in FIG. 4A;
- [0079] FIG. 5A is a perspective view of a prime tube and prime cap inserted into a prime tube housing of a fluid injector;
- [0080] FIG. 5B is a cross-sectional view of prime tube and prime cap shown in FIG. 5A;
- [0081] FIG. 5C is a side cross-sectional view of the prime tube and prime cap shown in FIG. 5A;
- [0082] FIG. 6A is a perspective view of a prime tube removed from a prime cap and a prime tube housing of a fluid injector;
- [0083] FIG. 6B is a cross-sectional view of prime tube and prime cap shown in FIG. 6A;
- [0084] FIG. 7A is a perspective view of a prime cap removed from a prime tube housing of a fluid injector;
- [0085] FIG. 7B is a cross-sectional view of the prime cap shown in FIG. 7A;
- [0086] FIG. 8A is a perspective view of a prime tube and a prime cap with a sensing arrangement for sensing a presence of the prime cap on the prime tube and for sensing at least one property of a fluid in the prime cap;
- [0087] FIG. 8B is a cross-sectional perspective view of the prime tube and the prime cap with the sensing arrangement shown in FIG. 8A;
- [0088] FIG. 8C is a perspective view of a prime tube and prime cap inserted into a prime tube housing of a fluid injector that is in fluid communication with a waste container in accordance with an example of the present disclosure;
- [0089] FIG. 8D is a cross-sectional view of prime tube and prime cap shown in FIG. 8C;
- [0090] FIG. 8E is a perspective view of a prime tube and prime cap having an integrated waste container in accordance with an example of the present disclosure;
- [0091] FIG. 8F is a cross-sectional view of the prime tube and prime cap shown in FIG. 8E;
- [0092] FIG. 9A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [0093] FIG. 9B shows graphs of sensor/detector outputs for various conditions of the sensing arrangement shown in FIG. 9A;

- [0094] FIG. 10A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [0095] FIG. 10B shows changes in sensing and detector output for various conditions of the sensing arrangement shown in FIG. 10A;
- [0096] FIG. 11A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [0097] FIG. 11B shows graphs of changes in sensing and detector output for various conditions of the sensing arrangement shown in FIG. 11A;
- [0098] FIG. 12 is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [0099] FIG. 13A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [00100] FIG. 13B shows graphs of sensor/detector outputs for various conditions of the sensing arrangement shown in FIG. 13A;
- [00101] FIG. 14A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [00102] FIG. 14B shows graphs of sensor/detector outputs for various conditions of the sensing arrangement shown in FIG. 14A;
- [00103] FIG. 15A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [00104] FIG. 15B shows graphs of sensor/detector outputs for various conditions of the sensing arrangement shown in FIG. 15A;
- [00105] FIG. 16A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [00106] FIG. 16B shows a graphical plot of sensor/detector outputs for various conditions of the sensing arrangement shown in FIG. 16A;
- [00107] FIG. 17A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure;
- [00108] FIG. 17B shows graphs of sensor/detector outputs for various conditions of the sensing arrangement shown in FIG. 17A;
- [00109] FIG. 18A is a schematic illustration of a sensing arrangement for sensing a presence of fluid in the prime cap in accordance with an example of the present disclosure, with the sensing arrangement shown in a first state;

- [00110] FIG. 18B is a schematic illustration of the sensing arrangement shown in FIG. 18A, with the sensing arrangement shown in a second state;
- [00111] FIG. 19A is a perspective view of a prime cap and a prime reservoir according to an example of the present disclosure;
- [00112] FIG. 19B is a perspective cross-sectional view of the prime cap and prime reservoir shown in FIG. 19A;
- [00113] FIG. 19C is a detailed side cross-sectional view of a membrane at a distal end of the prime cap shown in FIG. 19B;
- [00114] FIG. 20A is a perspective cross-sectional view of a prime cap and a prime reservoir according to an example of the present disclosure with a membrane at a distal end of the prime cap shown in a closed configuration;
- [00115] FIG. 20B is a detailed side cross-sectional view of a membrane shown in FIG. 20A;
- [00116] FIG. 21A is a perspective cross-sectional view of the prime cap and prime reservoir of FIG. 20A with the membrane at the distal end of the prime cap shown in an open configuration;
- [00117] FIG. 21B is a detailed side cross-sectional view of a membrane shown in FIG. 21A;
- [00118] FIG. 22A is a perspective cross-sectional view of a prime cap and a prime reservoir according to an example of the present disclosure with a membrane at a distal end of the prime cap shown in a closed configuration;
- [00119] FIG. 22B is a detailed side cross-sectional view of a membrane shown in FIG. 22A;
- [00120] FIG. 23A is a perspective cross-sectional view of the prime cap and prime reservoir of FIG. 23A with the membrane at the distal end of the prime cap shown in an open configuration;
- [00121] FIG. 23B is a detailed side cross-sectional view of a membrane shown in FIG. 23A;
- [00122] FIG. 24A is a top perspective view of a prime cap according to an example of the present disclosure;
- [00123] FIG. 24B is a bottom perspective view of the prime cap shown in FIG. 24A;
- [00124] FIG. 25A is a perspective cross-sectional view of a prime cap shown in FIG. 24A;
- [00125] FIG. 25B is a perspective cross-sectional view of the prime cap shown in FIG. 25A shown installed on a prime cap;
- [00126] FIG. 25C is a detailed side cross-sectional view of a membrane and a cover at a distal end of the prime cap shown in FIG. 25A, with the cover shown in a first position;
- [00127] FIG. 25D is a detailed side cross-sectional view of a membrane and a cover at a distal end of the prime cap shown in FIG. 25A, with the cover shown in a second position;

[00128] **FIG. 26A** is a perspective cross-sectional view of a prime cap and a prime reservoir according to an example of the present disclosure;

[00129] **FIG. 26B** is a detailed side cross-sectional view of a membrane at a distal end of the prime cap shown in **FIG. 26A** prior to being pierced by a piercing member of the prime reservoir;

[00130] **FIG. 26C** is a detailed side cross-sectional view of the membrane at the distal end of the prime cap shown in **FIG. 26B** after being pierced by the piercing member of the prime reservoir;

[00131] **FIG. 27A** is a side view of a prime cap and a prime reservoir according to an example of the present disclosure;

[00132] **FIG. 27B** is a side cross-sectional view of the prime cap and prime reservoir of **FIG. 27A** taken along line A-A;

[00133] **FIG. 28A** is a side view of a prime cap and a prime reservoir according to an example of the present disclosure;

[00134] **FIG. 28B** is a side cross-sectional view of the prime cap and prime reservoir of **FIG. 28A** taken along line B-B;

[00135] **FIG. 29A** is a side view of a prime cap and a prime reservoir according to an example of the present disclosure; and

[00136] **FIG. 29B** is a side cross-sectional view of the prime cap and prime reservoir of **FIG. 29A** taken along line C-C.

DETAILED DESCRIPTION

[00137] For purposes of the description hereinafter, the terms “upper”, “lower”, “right”, “left”, “vertical”, “horizontal”, “top”, “bottom”, “lateral”, “longitudinal”, and derivatives thereof shall relate to the disclosure as it is oriented in the drawing figures. Spatial or directional terms, such as “left”, “right”, “inner”, “outer”, “above”, “below”, and the like, are not to be considered as limiting as the disclosure can assume various alternative orientations. As used herein, the singular form of “a”, “an”, and “the” include plural referents unless the context clearly dictates otherwise. All numbers used in the specification and claims are to be understood as being modified in all instances by the term “about”. The terms “approximately”, “about”, and “substantially” mean a range of plus or minus ten percent of the stated value.

[00138] As used herein, the term “at least one of” is synonymous with “one or more of”. For example, the phrase “at least one of A, B, and C” means any one of A, B, and C, or any combination of any two or more of A, B, and C. For example, “at least one of A, B, and C” includes one or more of A alone; or one or more of B alone; or one or more of C alone; or one

or more of A and one or more of B; or one or more of A and one or more of C; or one or more of B and one or more of C; or one or more of all of A, B, and C. Similarly, as used herein, the term “at least two of” is synonymous with “two or more of”. For example, the phrase “at least two of D, E, and F” means any combination of any two or more of D, E, and F. For example, “at least two of D, E, and F” includes one or more of D and one or more of E; or one or more of D and one or more of F; or one or more of E and one or more of F; or one or more of all of D, E, and F.

[00139] It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification, are simply exemplary examples of the disclosure. Hence, specific dimensions and other physical characteristics related to the examples disclosed herein are not to be considered as limiting.

[00140] When used in relation to a component of a fluid delivery system, such as a fluid reservoir, a syringe, a fluid line, prime cap, or a prime tube, the term “distal” refers to a portion of said component nearest to a patient. When used in relation to a component of a fluid delivery system, such as a fluid reservoir, a syringe, a fluid line, prime cap, or a prime tube, the term “proximal” refers to a portion of said component nearest to the injector (i.e., the portion of said component farthest from the patient). When used in relation to a component of a fluid delivery system, such as a fluid reservoir, a syringe, a fluid line, or a prime tube, the term “upstream” refers to a direction away from the patient. For example, if a first component is referred to as being “upstream” of a second component, the first component is located farther away from the patient than the second component. When used in relation to a component of a fluid delivery system, such as a fluid reservoir, a syringe, a fluid line, or a prime tube, the term “downstream” refers to a direction towards the patient. For example, if a first component is referred to as being “downstream” of a second component, the first component is located nearer to the patient than the second component.

[00141] The terms “first”, “second”, and the like are not intended to refer to any particular order or chronology, but refer to different conditions, properties, or elements. The term “at least” is synonymous with “greater than or equal to”. The term “not greater than” is synonymous with “less than or equal to”.

[00142] All documents referred to herein are “incorporated by reference” in their entirety.

[00143] It is to be understood that the disclosure may assume alternative variations and step sequences, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification, are simply exemplary aspects of the disclosure. Hence, specific

dimensions and other physical characteristics related to the examples disclosed herein are not to be considered as limiting.

[00144] While the devices, systems, and methods described herein are generally discussed in the context of a computed tomography (CT) injection system, injection systems configured for other pressurized injection protocols, such as angiography (CV), ultrasound, positron emission tomography (PET), and magnetic resonance imaging (MRI) may also incorporate the various examples of the prime or purge tubes described herein. Further, while many of the examples or prime or purge tubes described herein are detailed in reference to a syringe or syringe-based fluid injector, it should be understood that other powered injection systems, such as those including pumps such as a peristaltic pump, can be primed using various examples of the prime or purge tubes described herein. Thus, the presently described prime cap arrangements are not limited to syringe passed fluid injection systems.

[00145] Referring to the drawings in which like reference characters refer to like parts throughout the several views thereof, the present disclosure is generally directed to a prime or purge tube (hereinafter referred to as “prime tube”) for fluid injector systems. The prime tube is located at a distal end of a fluid line that is fluidly connected to fluid reservoir, such as a syringe or bulk fluid container, and fluid delivery mechanism, such as a syringe actuator (piston) or pumping system (e.g., a peristaltic pump) of a fluid injector and is configured to provide indication that the fluid is line is filled with liquid rather than air prior to initiation of a fluid injection procedure.

[00146] Referring to **FIG. 1**, an example of a fluid injector system **2000** is partially illustrated showing features of the main housing of fluid injector system **2000**. The fluid injector system **2000** is configured for injection of one or more medical fluids through a fluid path into a patient. The fluid injector system **2000** may include at least one graphical user interface (GUI) **11** through which an operator can input injection parameters for, view the progress of, and/or control the status of an injection procedure. The GUI **11** may be in operative communication with a controller **900** (see **FIGS. 2A-2B**) which sends and receives commands between and receives input from the GUI **11** and fluid injector system **2000**.

[00147] The fluid injector system **2000** may have a prime tube housing **400** having a prime tube slot **402** or other feature configured to interact with any of the various embodiments of the prime tube **300** described herein. The prime tube slot **402** or feature may be shaped to receive at least a portion of a prime tube **300** during a priming operation. The prime tube slot **402** or feature may be configured to place the prime tube **300** in fluid communication with a waste

container **404** configured to receiving priming fluid delivered from the prime tube **300** during a priming operation. With reference to **FIGS. 8C-8D**, waste container **404** may be sized to receive fluid from multiple priming procedures conducted over a length of time, such as one or more injection procedures or hospital shifts or injection procedure conducted over 24 hours or any other appropriate length of time. In this manner, a plurality of priming procedures may be conducted to collect fluid in waste container **404** without having to replace the waste container.

[00148] Details and examples of suitable non-limiting fluid injector systems and features, including syringes, pressure jackets and pressure jacket retention mechanisms, tubing, shut-off valves, controllers, and air detectors, are described in U.S. Provisional Application Serial No. 63/578,287, U.S. Patent Nos. 5,383,858; 7,553,294; 7,666,169; 8,945,051; 9,173,995; 10,022,493; 10,507,319, and 10,549,084, and International PCT Application Nos. PCT/US2013/061275; PCT/US2018/034613; PCT/US2019/028139; PCT/US2020/049885; PCT/US2021/035273; PCT/US2021/019507; PCT/US2021/029963; PCT/US2021/018523; PCT/US2021/037623; PCT/US2021/037574; PCT/US2021/045298; PCT/US2022/017812; PCT/US2022/017900; PCT/US2023/020171; PCT/US2023/025159 and PCT/US2023/035311 which disclosures are hereby incorporated by reference in their entireties.

[00149] Referring to **FIG. 2A**, a schematic diagram of the fluid injector system **2000** in accordance with one example is illustrated. The fluid injector system **2000** has a first fluid path **210A** for a medical fluid, such as an imaging contrast media for an injection procedure, and a second fluid path **210B** for a flushing fluid, such as saline or Ringer's lactate. The fluid paths **210A**, **210B** may be connected to respective outlets **16A**, **16B**, e.g., nozzles, of syringes **10A**, **10B** filled with medical fluid **F**, such as contrast or a flushing agent. As used herein, medical fluid **F** is a liquid. The dual syringe fluid injector system **2000** may include an injector housing **12** having two syringe ports **15** configured to engage the syringes **10A**, **10B**. In some examples, the syringes **10A**, **10B** may be retained within corresponding pressure jackets, for example, to prevent pressure-induced swelling of the syringes **10A**, **10B**.

[00150] The dual syringe fluid injector system **2000** may further include bulk fluid containers **19A** and **19B** for filling and refilling the respective syringes **10A**, **10B** with imaging contrast media and flushing fluid, respectively. The bulk fluid containers **19A** and **19B** may be in selective fluid communication with the syringes **10A**, **10B** via respective bulk fluid paths **216A** and **216B** and bulk fluid valves **215A** and **215B**.

[00151] The fluid injector system **2000** includes one or more pistons **13A**, **13B** respectively associated with each of syringes **10A**, **10B**. Each of pistons **13A**, **13B** is configured to reciprocally drive a respective plunger **14A**, **14B** within a barrel of their respective syringe.

[00152] The controller **900** is operatively associated with the injector system **2000**, for example, to actuate the pistons **13A**, **13B** to reciprocatively move the plungers **14A**, **14B** within the syringes **10A**, **10B** and thereby execute, control, and halt an injection procedure. In a corresponding peristaltic pump system, the controller **900** would be configured to operate the rotors of the corresponding peristaltic pump. In particular, the controller **900** may include at least one processor programmed or configured to actuate the pistons **13A**, **13B** and various other components of the injector system **2000**, such as one or more valves **215A**, **215B**, to take in and deliver medical fluids according to a programmed protocol (e.g., initiating a priming a patient tubing set and/or delivering a set volume of contrast media and saline at a specified flow rate over a specified time) for an injection procedure. The controller **900** may include computer readable media, such as memory, on which one or more injection protocols may be stored for execution by the at least one processor.

[00153] The controller **900** may be programmed or configured to execute a filling operation during which the piston **13A**, **13B** associated with each syringe **10A**, **10B** is withdrawn toward a proximal end of the syringe **10A**, **10B** to draw injection fluid **F** (e.g., imaging contrast media and flushing fluid) into the syringe **10A**, **10B** from the bulk fluid containers **19A**, **19B**. During such a filling operation, controller **900** may be programmed or configured to selectively actuate bulk fluid valves **215A** and **215B** to establish fluid communication between the respective syringes **10A**, **10B** and the bulk fluid containers **19A**, **19B** via bulk fluid paths **216A** and **216B** to control filling of syringes **10A**, **10B** with the appropriate injection of medical fluid **F**.

[00154] The controller **900** may be further programmed or configured to execute a priming/purging operation, either automatically according to a work flow or after receiving a prompt from a user, to remove any air from the syringes **10A**, **10B** and the fluid paths **210A**, **210B** upon completion of the filling operation. Specific details of the priming/purging operation will be described herein in connection with the various examples of the purge tubes **300** discussed herein.

[00155] After the filling operation and priming operation, the controller **900** may be further programmed or configured to execute a fluid delivery operation during which the piston **13A**, **13B** associated with one or both of syringes **10A**, **10B** is moved toward a distal end of the syringe to inject the medical fluid **F** into the first fluid path **210A** and the second fluid path **210B**, respectively. The controller **900** may be programmed or configured to selectively actuate

the bulk fluid valves **215A** and **215B** to establish fluid communication between the syringes **10A**, **10B** and the patient, via the fluid paths **210A**, **210B**. The first fluid path **210A** and the second fluid path **210B** ultimately merge into a patient fluid line **210C**, for example with turbulent mixing using a mixing connector according to International PCT Application No. PCT/US2021/019507, in fluid communication with the vasculature of the patient.

[00156] Referring now to **FIG. 2B**, the fluid injector system **2000** is shown with a prime tube **300** in fluid communication with each of the syringes **10A**, **10B**, whereas **FIG. 1** shows the fluid injector system **2000** with a single prime tube **300** connected to patient fluid line **210C**. In either example, the fluid injector system **2000** may have the prime tube housing **400** with at least one prime tube slot **402**, with each prime tube slot **402** configured to receive a single prime tube **300**, as discussed herein with reference to **FIG. 1**. The prime tube **300** may be fluidly connected to the syringes **10A**, **10B** after a filling operation in which the syringes **10A**, **10B** are filled from the bulk fluid containers **19A** and **19B** and prior to an injection procedure. In other embodiments, the fluid injector system **2000** may include a manifold assembly, for example as described in International PCT Application No. PCT/US2022/017812, which allows for filling of syringes **10A**, **10B** from bulk fluid containers **19A**, **19B** and delivery of fluid from syringes **10A**, **10B** with the prime tube according to the various embodiments attached to the fluid path **210C** during a filling or priming operation. Other examples may be directed towards priming of at least a portion of the fluid paths **210A**, **210B** in preparation for a fluid injection procedure. For example, in one example, the prime tube **300** may be attached to a distal end of the fluid paths **210A**, **210B** (as shown in **FIG. 2A**), such as a multi-use portion. In other examples, the prime tube **300** may be attached to a distal end of a newly installed single patient tubing set (attached to the distal end of the multi-use tube set) to ensure priming of the single patient tubing set **210C** prior to attaching to a patient catheter. The fluid paths **210A**, **210B** may be disconnected from the syringes **10A**, **10B** to allow for connection of the prime tubes **300**. With the prime tubes **300** fluidly connected to the syringes **10A**, **10B**, the fluid injector system **2000** may be actuated to prime/purge the syringes **10A**, **10B** of any air by extending the pistons **13A**, **13B** distally to eject air from the syringes **10A**, **10B** into the associated prime tubes **300** via the fluid paths **210A**, **210B** and/or **210C**.

[00157] In some examples, the controller **900** may be programmed or configured to automatically extend each of the pistons **13A**, **13B** a predetermined distance, corresponding to a predetermined fluid volume, to eject the predetermined air/fluid volume from each syringe **10A**, **10B** into the associated prime tubes **300** when the programmed injection protocol requires the priming operation, for example after filling of the syringes **10A**, **10B** from bulk fluid

containers **19A**, **19B** and before disconnection of the single patient tubing set **210C** from the prim tube **300** and connection of the single patient tubing set **210C** to the patient catheter. The predetermined air/fluid volume may be selected to ensure that all (or substantially all) of the air in the syringes **10A**, **10B** is ejected into the prime tubes **300**. For example, the predetermined air/fluid volume may be selected based on empirical data of the maximum volume of air within syringes after a fill operation. The predetermined air/fluid volume may include a factor of safety to ensure that even an abnormally high amount of air will be fully ejected from the syringe during the priming/purging operation. As the predetermined air/fluid volume is typically larger than the actual volume of air present in the syringes **10A**, **10B**, some amount of the medical fluid **F** will be ejected into the prime tubes **300** along with the volume of air. Alternatively, according to various embodiments described herein, the prime tube **300** and associated patient tube connector **302** and prime cap **304** may be configured with a sensing feature, as described herein, that allows for monitoring of the priming operation and detecting air and liquid fluid in the prime cap **300** to determine when substantially all of the air has been ejected from the prime tube **300**.

[00158] With reference to **FIGS. 3A-3D**, the prime tube **300** is shown separate from the rest of the fluid injector system **2000**. The prime tube **300** generally includes a patient tube connector **302** and a prime cap **304**. The patient tube connector **302** and the prime cap **304** are removably connected together, as discussed herein. As shown in **FIG. 3B**, the patient tube connector **302** includes a sidewall **310** having a proximal end **312** and a distal end **314** and defining an internal chamber **316**, for example a lumen passing through patient tube connector **302** from the proximal end **312** to the distal end **314** and providing fluid communication therethrough. The proximal end **312** of the sidewall **310** is open and may include a first connector **320** configured to connecting to a distal end of one of the fluid paths **210A**, **210B**, and /or **210C** (shown in **FIGS. 2A-2B**). In some examples, the first connector **320** may be integrally formed with the distal end of one of the fluid paths **210A**, **210B**, and/or **210C**.

[00159] With reference to **FIGS. 3B** and **3D**, the distal end **314** of the patient tube connector **302** is open and has a second connector **321** configured for removably connecting to the prime cap **304**. The second connector **321** may include one or more engaging lugs **322** having a profile complementary to at least a portion of a first connector **338** at a proximal end **322** of prime cap **304** to retain the prime cap **304**. The distal end **314** of the patient tube connector **302** further may be configured to connect to a fluid path element for delivering fluid to a patient when the prime cap **304** is removed from the patient tube connector **302**. In some examples, distal end **314** of the patient tube connector **302** may have a male or a female luer connector **318**. At least

one gripping element **325** may protrude radially outward from the sidewall **310** of the patient tube connector **302** to provide a gripping surface to facilitate disconnection of the patient tube connector **302** from the prime cap **304** and/or connection of the patient tube connector **302** with the fluid path element. In some examples, a pair of opposing gripping elements **325** may be provided to provide a gripping surface for the user in order to enable an easier twisting movement of patient tube connector **302** when disconnecting from prime cap **304** or connecting with the patient catheter.

[00160] The prime cap **304** includes a sidewall **330** having a proximal end **332** and a distal end **334** and defining an internal chamber **336**. The proximal end **332** of the sidewall **330** may include a first connector **338** configured to connecting to the distal end of the patient tube connector **302**, for example in the form of a lumen passing through prime cap **304** from the proximal end **332** to the distal end **334** and providing fluid communication therethrough. The distal end **334** of the prime cap **304** may be at least partially closed with a cover **340**. For example, cover **340** may include a tortuous pathway, valve, or other pathway to allow gas to flow therethrough but substantially prevent a liquid fluid from flowing therethrough. In some embodiments, the cover **340** may be configured to permit passage of air therethrough to evacuate air from the internal chamber **336** before permitting liquid to exit the internal chamber **336**. In this manner, the internal chamber **336** can be fully filled with liquid, before any liquid can exit the internal chamber **336** via the cover **340**. The internal chamber **336** of the prime cap **304** is in fluid communication with the internal chamber **316** of the patient tube connector **302** when the prime cap **304** is connected to the patient tube connector **302**. At least one gripping element **350** or key element **351** may protrude radially outward from at least a portion of sidewall **330** of the prime cap **304** to provide a gripping surface to facilitate removal of patient tube connector **302** from prime cap **304** or providing a keyed connection between prime cap **304** and a complementary keyed insertion portion on prime tube housing **400** on fluid injector system **2000**.

[00161] In some examples, the internal chamber **316** of the patient tube connector **302** and the internal chamber **336** of the prime cap **304** may have a volume sufficient to hold the predetermined liquid fluid volume ejected from the associated syringe **10A**, **10B** during the syringe priming/purging operation. In some examples, the volume defined by the internal chambers **316**, **336** may range from 0.1 mL to 10 mL. In specific examples, the volume may be sufficient to account for cases when more than one prime sequence is required, for example, when air bubbles are still observed in the system or to accommodate two or more fluid injection operations. In certain examples, a prime operation may include two injection sequences, a first

forceful flow rate with low ejected volumes to remove the majority of air from system and then a second slower flow rate with larger flow volumes, optionally accompanied by tapping or vibrations – either manual by the user or by a vibration feature associated with the fluid injector system **2000**, to remove small air bubbles from the syringes or fluid path.

[00162] With reference to **FIG. 3A**, in certain embodiments, the prime cap **304** may have a gripping element **350** protruding radially outward from the sidewall **330**. The gripping element **350** may extend radially outward in a direction substantially perpendicular to a major longitudinal axis **L** of the prime cap **304**. In some examples, the gripping element **350** may be angled at an oblique angle relative to the longitudinal axis **L**. The gripping element **350** defines a gripping surface **352** configured for being grasped by a user when handling the prime cap **304**, such as during installation or removal of the prime cap **304** on the prime tube housing **400** on the fluid injector system **2000** (shown in **FIG. 1**). For example, the gripping surface **352** may be grasped between the user's thumb and index finger during installation or removal of the prime cap **304** in the prime tube slot **402** of the prime tube housing **400**, as described herein. The gripping surface **352** may have one or more protrusions **354** configured to prevent slippage of the prime cap **304** from the user's grip while handling the prime cap **304**.

[00163] The gripping element **350** may have a skirt **356** protruding in a proximal direction. The skirt **356** is configured to surround at least a portion of the proximal end **332** of the prime cap **304**. In some examples, the skirt **356** is radially spaced apart from the proximal end **332** of the prime cap **304** such that the distal end **314** of the prime tube connector **302** can be received in a space between the skirt **356** and the proximal end **332**. The skirt **356** may be circumferentially continuous or have one or more openings **358** extending therethrough. The skirt **356** may include a reversible connection feature, for example in the form of a threaded surface on an interior surface thereof for providing a reversible connection with a corresponding threaded surface on the prime tube connector **302**.

[00164] The prime cap **304** may have an alignment tab **360** protruding radially outward from the sidewall **330**. The alignment tab **360** may extend radially outward in a direction substantially perpendicular to the major longitudinal axis **L** of the prime cap **304**. In some examples, the alignment tab **360** may be angled at an oblique angle relative to the longitudinal axis **L**. In certain embodiments, the alignment tab **360** may be provided on an opposite side of the prime cap **304** to the gripping element alignment tab **360**, such that the alignment tab **360** and the gripping element **350** extend in substantially opposite directions from each other. The alignment tab **360** may have at least one alignment groove **362** or other alignment feature or key feature **351** that is configured to align the prime cap **302** relative to the prime tube slot **402**

or other corresponding alignment feature on the prime tube housing **400** on the fluid injector system **2000** (shown in **FIG. 1**) during installation of the prime cap **304**. In some examples, the alignment tab **360** may be tapered such that its width decreases in a direction radially outward from the sidewall **330** of the prime cap **304**. Alignment of the prime cap **304** relative to the prime tube slot **402** of the prime tube housing **400** assures proper orientation of the prime cap **304** relative to a sensing arrangement configured for sensing the presence of air and/or liquid within internal chamber **336** of the prime cap **304**, as discussed herein.

[00165] To perform a priming/purging operation to expel air from the syringe **10A**, **10B** (shown in **FIGS. 2A-2B**) and/or fluid paths **210A**, **210B**, and/or **210C**, the syringe **10A**, **10B** may be held in a substantially upright vertical position with the outlet **16A**, **16B** at the highest point, the syringe **10A**, **10B** may be primed, e.g., the plunger **13A**, **13B** moved in the distal direction to expel a portion of the contents of the syringe (i.e., air and small volume medical fluid **F**), to purge any air from the interior of the syringe **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C**. In the vertical position, a majority of the air in the syringe **10A**, **10B** rises to the distal end of the syringe adjacent the outlet **16A**, **16B** due to buoyancy of air in the medical fluid **F**. As the syringe **10A**, **10B** is primed, the air at the distal end of the syringe **10A**, **10B** is expelled through outlet **16A**, **16B** and travels through fluid paths **210A**, **210B**, and/or **210C** and enters the internal chambers **316**, **336** of patient tube connector **302** and prime cap **304**. Similarly, in certain embodiments the prime cap **304** may be oriented in a vertical position with the distal end pointing upwards to allow any air in prime cap **304** to rise toward the distal end due to buoyancy. During a priming operation, air may be dislodged from the various interior surfaces of the syringe and the surface of the plunger **14A**, **14B** and/or fluid paths **210A**, **210B**, and/or **210C** to ensure that all air is primed from the system. Examples of such methods for dislodging air bubbles (including microbubbles) from interior surfaces or plunger surface are described in International PCT Application No. PCT/US2019/028139, for example, by placing the syringe contents under an at least partial vacuum to coalesce the small air bubbles into larger bubbles and/or vibrating, knocking, or otherwise impacting the syringe, tubing, and/or piston/plunger assembly to dislodge the bubbles.

[00166] With reference to **FIG. 3I**, and with continued reference to **FIG. 3B**, the prime cap **304** may include a cover **340** associated with the distal end **334** of the sidewall **330**. In certain embodiments, at least a portion of the cover **340** may be configured to contact an inner surface **331** of the sidewall **330** such that a tortuous fluid path **341** is defined between the cover **340** and the inner surface **331** of the sidewall **330**. Alternatively, cover **340** may be formed from a material having at least one tortuous fluid path therethrough. In certain embodiments, the

tortuous fluid path **341** may be such that the cover **340** is permeable to air and liquid to allow passage of air and liquid through the internal chamber **336** of the prime cap **304** into, for example, the waste container **404** (shown in **FIG. 1**) during a priming operation. The tortuous fluid path **341** provides a restriction to outlet flow such that the internal chamber **336** may be filled with liquid prior to allowing the liquid to exit the internal chamber **336** through the cover **340**. This improves the detection capability of a sensing arrangement configured to detect a presence of liquid within the internal chamber **336** and reduces the amount of waste fluid exiting the prime cap **304**. For prime caps **304** where the diameter of the internal chamber **336** is larger than the diameter of the internal chamber **316** of the patient tube connector **302**, a restriction provided by the tortuous fluid path **341** improves the efficiency of fluid detection since it forces the internal chamber **336** of the prime cap **304** to fill with liquid instead of a air/liquid mixture. For prime caps **304** where the diameter of the internal chamber **336** is larger than the diameter of the internal chamber **316** of the patient tube connector **302**, the restriction provided by the tortuous fluid path **341** helps the liquid "cling" to the wall of the internal chamber **336** of the prime cap **304** due to surface tension effects. This alternate design could provide fluid detection even without the cover **340**.

[00167] In some examples, after the priming operation, the tortuous fluid path **341** may be configured to prevent further passage of liquid out of internal chamber **336** of prime cap **304**. In other embodiments, tortuous fluid path **341** may be such that cover **340** is permeable to air but substantially impermeable to liquid to allow passage of air but not liquid through cover **340** of the prime cap **304**.

[00168] In some examples, cover **340** also prevents contamination of the fluid within internal chamber **336** by preventing outside contaminants from entering internal chamber **336**. The tortuous fluid path **341** may be shaped to prevent direct entry of outside microbial contaminants into internal chamber **336** due to conditions outside the prime cap **304**, such as air currents. In this manner, cover **340** helps preserve a sterile fluid path from the syringe to patient tube connector **302**.

[00169] During the priming operation of the syringes **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** (shown in **FIGS. 2A-2B**), air ejected from the syringes **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** by pressurization of the syringe contents may flow out of the patient tube connector **302** and the prime cap **304** via the cover **340**. As liquid is introduced into the internal chamber **336** via the prime cap **304**, air that is within the internal chamber **336** is displaced from the internal chamber **336** to the outside (i.e., the waste container **404** or to the atmosphere) via the tortuous fluid path **341**. In certain embodiments, as air is

completely displaced from the internal chamber **336** such that liquid (e.g., contrast media or saline) fills the internal chamber **336**, as the liquid then begins to exit the prime cap **304** into, for example, the waste container **404**, to complete the priming operation. In some examples, such as shown in **FIGS. 8E-8F**, the waste container **404** may be integrated with the prime cap **304** and may be sized to receive a volume of liquid from a single priming operation or from multiple priming operations. Alternatively, waste container **404** may be separate from the prime cap **304** and may be sized to receive volumes of liquid from multiple priming operations. Once liquid reaches the cover **340** or starts exiting the prime cap **304** through cover **340**, further liquid delivery into the internal chamber **336** may be stopped. The cover **340** may be configured to prevent further loss of liquid from the internal chamber **336** when additional liquid is not delivered to the internal chamber **336** under pressure.

[00170] In some examples, the cover **340** may be permeable to air and substantially impermeable to liquids. For example, the cover **340** may be a porous material, such as a material having at least one tortuous path or aperture having a cross-sectional area sized to allow to allow passage of air and substantially prohibit passage of a medical fluid through the at least one aperture. As such, during a priming operation of the syringes **10A**, **10B**, and/or fluid paths **210A**, **210B**, and/or **210C**, air ejected from the syringes **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** by pressurization of the syringe contents may flow out of the patient tube connector **302** and the prime cap **304** via the cover **340**, while any medical fluid ejected from the syringe **10A**, **10B** is retained within the internal chamber **316** of the patient tube connector **302** and the internal chamber **336** of the prime cap **304**. In some examples, the cover **340** may be made from a hydrophobic medical grade plastic, such as those commercially available under the trade names Gore-tex® and Porex®, which generally allow passage of gas but not liquid therethrough. In some examples, the cover **340** may be a solid material defining one or more apertures having a sufficient cross-sectional area to allow the passage of air out of the prime tube **300**, but an insufficient cross-sectional area to allow the passage of the liquid. In some examples, the cover **340** may include an absorbent material, such as cotton or other fibrous material, to absorb and retain the liquid while allowing air to pass out of the prime tube **300**. In some examples, the cover **340** may be a solid member impermeable to all fluids, e.g., air and medical fluids, such that all fluids injected into the patient tube connector **302** and the prime cap **304** from syringe **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** are retained within internal chambers **316**, **336**.

[00171] In various examples, the internal chamber **336** of the prime cap **304** may be configured to promote or enhance fluid adherence to an inner surface of the internal chamber

336. In some examples, the internal chamber **336** of the prime cap **304** may have a portion having a reduced internal diameter configured to permit the fluid to cling to the internal surfaces of the internal chamber **336**. In some examples, the inner surface of the internal chamber **336** may have one or more spiral grooves configured to spin the fluid as the fluid flows into the internal chamber **336**, thereby enhancing the adherence of the fluid to the inner surface of the internal chamber **336**. In some examples, the internal chamber **336** of the prime cap **304** may have one or more protrusions protruding radially inward relative to the inner surface of the internal chamber **336**. For example, the one or more protrusions may be formed as one or more ribs arranged in an axial and/or a radial pattern and configured to divert the fluid toward the inner surface of the internal chamber **336**. In some examples, the inner surface of the internal chamber **336** may have one or more surface texturization features that roughen the inner surface to promote fluid adherence. In some examples, the internal chamber **336** of the prime cap **304** may be configured to accumulate fluid to a predetermined level, which level would be indicative of a complete purge of the internal chamber **316** of the patient tube connector **302**. In some examples, the prime cap **304** may be configured to be arranged at an oblique angle relative to a vertical orientation of fluid injector system **2000** when engaged with prime tube housing **400** such that fluid is forced to flow along at least an inclined portion of the inner surface of the internal chamber **336**. In further examples, the prime cap **304** may have one or more internal flow diverting features configured to divert a flow of the fluid toward the inner surface of the internal chamber **316**. For example, the one or more flow diverting features may be one or more baffles configured to deflect the fluid flow toward the inner surface of the internal chamber **316**. In further examples, the one or more flow diverting features may be a flow diverter in a middle of the internal chamber **316** that is configured to deflect the fluid flow toward the inner surface of the internal chamber **316**. In further examples, the internal chamber **336** of the prime cap **304** may have any combination of the features described herein to promote or enhance fluid adherence to an inner surface of the internal chamber **336**.

[00172] With reference to **FIGS. 3E-3F**, an embodiment of a connection interface between the distal end **314** of the patient tube connector **302** and the proximal end **332** of the prime cap **304** is shown in detail. As shown in **FIG. 3F**, the proximal end **332** of the prime cap **304** has the first connector **338** configured to connecting to the second connector **321** at the distal end **314** of the patient tube connector **302**. In some examples, the first connector **338** on the prime cap **304** may include a releasable locking mechanism, such as a removable strip **342** or other tamper resistant feature that is configured to engage the second connector **321** on the patient tube connector **302** that is configured as an engagement feature, such as a lip **323**. When the

removable strip **342** is engaged with the lip **323**, the prime cap **304** is connected to the patient tube connector **302** in such a manner that the prime cap **304** cannot be removed from the patient tube connector **302**. For example, a user may presume that a prime tube **300** may have been tampered with and may potentially have been previously used or potentially contaminated with microbial contamination if the removable strip **342** has been damaged or removed. The removable strip **342** is connected to the sidewall **330** of the prime cap **304** by a frangible edge **344** (shown in **FIG. 3E**) to allow for tearing or separation of the removable strip **342** from the sidewall **330** of the prime cap **304**. When the removable strip **342** is removed from the sidewall **330** of the prime cap **304** due to tearing or separation of the frangible edge **344**, the removable strip **342** can be removed from the lip **323**, which permits removal of the prime cap **304** from the patient tube connector **302**. Removal of the removable strip **342** may provide tactile feedback to the user that the patient tube connector **302** can be disconnected from the prime cap **304**. The removable strip **342** serves as a tamper-evident feature that maintains the sterility of the patient tube connector **302**. For example, a user may presume that a prime tube **300** may have been tampered with and may potentially have been previously used or potentially contaminated with microbial contamination if the removable strip **342** has been damaged or removed. Absence of the removable strip **342** serves as an indicator that prime cap **304** may have been removed from the patient tube connector **302**.

[00173] With reference to **FIGS. 3G-3H**, another embodiment of a connection interface between the distal end **314** of the patient tube connector **302** and the proximal end **332** of the prime cap **304** is shown in detail. The proximal end **332** of the prime cap **304** has the first connector **338** configured to connecting to the second connector **321** at the distal end **314** of the patient tube connector **302**. In some examples, the first connector **338** on the prime cap **304** may be a deformable ring **343** that is configured to engage the second connector **321** on the patient tube connector **302** that is configured as a lip **323**. The deformable ring **343** may be connected to a portion of the sidewall **330** of the prime cap **304** (shown in **FIG. 3D**) and is configured to deform from a first configuration, in which deformable ring **343** is substantially circular, and a second configuration, in which deformable ring **343** is substantially oval.

[00174] In various other examples, the connection interface between the distal end **314** of the patient tube connector **302** and the proximal end **332** of the prime cap **304** may be embodied as one or more tamper-evident connection interfaces described in International PCT Application No. PCT/US2023/020171.

[00175] When the deformable ring **343** is engaged with the lip **323** in the first configuration, the prime cap **304** is connected to the patient tube connector **302** in such a manner that the

prime cap **304** cannot be removed from the patient tube connector **302**. When the deformable ring **343** is moved to the second configuration, such as by squeezing the deformable ring **343**, the deformable ring **343** may be removed from the lip **323**, which permits removal of the prime cap **304** from the patient tube connector **302**. In the embodiment deformable ring **343** has been moved to the second configuration, the threads on patient tube connector **302** be unthreaded from the corresponding threads of prime cap **304** to disconnect the patient tube connector **302**. The deformable ring **343** serves as a tamper-evident feature that maintains the sterility of the patient tube connector **302**. Absence of the deformable ring **343** serves as an indicator that prime cap **304** may have been removed from the patient tube connector **302**.

[00176] With reference to **FIGS. 4A-4C**, an embodiment of the prime tube **300**, including the patient tube connector **302** and the prime cap **304** is configured for insertion into an embodiment of a prime tube slot **402** of a prime tube housing **400** on a fluid injector system **2000** (shown in **FIG. 1**). While **FIGS. 4A-4B** show the prime tube **300** and the prime tube housing **400** in a vertical orientation relative to the orientation of the drawing page, it should be noted that, in practice, the prime tube **300** could be arranged horizontally or any convenient orientation for ease of access and use. The prime tube slot **402** may be shaped to receive at least a portion of the prime cap **304** and retain the prime tube **300** during a set-up and/or a priming operation. The prime tube slot **402** has an opening **404** shaped to correspond to an outer shape of at least a portion of the prime cap **304**. In some examples, the opening **404** may be formed as an open slot having an upper portion **404a** and a lower portion **404b** that are spaced apart from each other to define the open slot that is configured to slidably receive at least a portion of the prime cap **304**. For example, the opening **404** may be shaped to slidably receive the alignment tab **360** of the prime cap **304**. An end surface **406** of the prime tube housing **400** may be configured to engage at least a portion of the prime cap **304**, such as an end surface **366** of the alignment tab **360**, to delimit an insertion length of the prime cap **304** into the opening **404**. For example, the end surface **406** of the prime tube housing **400** may engage the end surface **366** on the alignment tab **360** when the prime cap **304** is fully inserted into the opening **404**, such as shown in **FIGS. 5A-5C**. According to another embodiment, opening **404** of prime tube slot **402** may define a receiving space having a complementary shape to at least a portion of an outside surface of prime cap **304**, such that at least a portion of prime cap **304** may be inserted into the receiving space and indexed to interact with a sensing arrangement within the receiving space of prime tube housing **400**. According to another embodiment, opening **404** of prime tube slot **402** may define a receiving space including a reader capable of reading an indicia, such as a bar code, RFID, QR Code, or other identifying

indicia, on prime cap **304** to ensure that the prime cap **304** has not been previously used, is not counterfeit, and is the correct type for interacting and use with the fluid injector system **2000**.

[00177] After inserting prime tube **300** into opening **404** of prime tube slot **402** (FIGS. 5A-5C), the controller **900** of fluid injector system **2000** (shown in FIG. 1) may initiate a priming procedure. In certain embodiments, the controller **900** may automatically initiate the priming procedure once the prime tube **300** is recognized by the controller **900** as being correctly engaged with the prime tube housing **400**. In other embodiments, the controller **900** may initiate the priming procedure in response to a user input after the prime tube **300** is recognized by the controller **900** as being correctly engaged with the prime tube housing **400**. Once a priming procedure has been initiated, either manually or automatically by the fluid injector system **2000**, the medical fluid **F** from the syringes **10A**, **10B** is expelled through the outlet **16A**, **16B**, flows through and/or fluid paths **210A**, **210B**, and/or **210C**, and enters internal chambers **316**, **336** of the patient tube connector **302** and the prime cap **304**, respectively. As described herein, during a priming operation of syringes **10A**, **10B**, and/or fluid paths **210A**, **210B**, and/or **210C**, any air in the system is ejected from syringes **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** by pressurization of the syringe contents may flow out of the patient tube connector **302** and the prime cap **304** via the tortuous fluid path **341** of the cover **340**. When medical fluid **F** starts flowing from cover **340**, internal chamber **316** of patient tube connector **302** and internal chamber **336** of prime cap **304** are filled with medical fluid **F** and are void of any air. As described herein, a sensing arrangement within prime tube housing **400** may be configured to monitor prime cap **304** and determine which substantially all the air has been primed from the system and the system is ready to connect to the patient and initiate a fluid injection protocol.

[00178] Upon completion of the priming operation, the patient tube connector **302** may be removed from the prime cap **304** to allow for connection of the patient tube connector **302** to a fluid path element for delivering fluid to a patient. In some examples, the patient tube connector **302** may be removed from the prime cap **304** by breaking or fracturing a tamper resistant feature, such as at least a portion of the removable strip **342**, such as due to tearing or separation of the frangible edge **344**. Such breaking or fracturing of at least a portion of the removable strip **342** may occur when the patient tube connector **302** is rotated about its longitudinal axis relative to the prime cap **304**. For example, by rotating the patient tube connector **302** about its longitudinal axis in a direction of arrows **A** shown in FIG. 5A, at least a portion of the frangible edge **344** connecting the removable strip **342** to the prime cap **304** may be broken, thereby allowing removal of the patient tube connector **302** from the prime cap **304**. With reference to FIGS. 6A, 6B, when the patient tube connector **302** (tubing not shown) is removed from the

prime cap **304**, the prime cap **304** remains connected to the prime tube housing **400**. After removal of the patient tube connector **302**, the prime cap **304** can be removed from the prime tube housing **400** (**FIGS. 7A, 7B**), for example by sliding the prime cap **304** in a direction of arrow **C** to allow insertion of a new prime tube **300** into the prime tube housing **400**.

[00179] With reference to **FIGS. 8A-8B**, the fluid injector system **2000** (shown in **FIG. 1**) may include a sensing arrangement **500** for at least one of (A) detecting the presence of the prime cap **304**, for example after insertion of prime cap **304** into prime tube housing **400**; and (B) detecting at least one property of a fluid in the prime cap **304**. Non-limiting examples of properties of a fluid that may be sensed by sensing arrangement **500** may include one or more of, presence of the prime cap **304**, presence of air in the prime cap **304**, presence of liquid fluid in the prime cap **304**, volume of air within the prime cap **304**, volume of liquid fluid within the prime cap **304**, fluid type (saline vs. contrast) in the prime cap **304**, type (brand name, concentration) of the contrast in the prime cap **304**, correct or incorrect installation of the prime cap **304** into prime tube slot **402**, etc. Once the at least one property of the fluid within the prime cap **304** has been determined by sensing arrangement **500**, the sensing arrangement **500** may then communicate that at least one property to a user of the fluid injector system **2000**, through controller **900**. The sensing arrangement **500** may be integrated into the prime tube housing **400** on the fluid injector system **2000** such that the sensing arrangement **500** may (A) detect the presence of the prime cap **304** and (B) detect at least one property of a fluid in the prime cap **304** when the prime tube **300** is inserted into the prime tube housing **400**. In certain embodiments, the sensing arrangement **500** may include at least one first sensor **502** (hereinafter referred to as “prime cap sensor **502**”) configured for detecting the presence of the prime cap **304** and at least one second sensor **504** (hereinafter referred to as “priming status sensor **504**”) configured for detecting a presence of fluid in the prime cap **304**. The prime cap sensor **502** and the priming status sensor **504** may be in communication with the controller **900** (shown in **FIG. 1**). In other embodiments, the prime cap sensor **502** may also be combined into the at least one second sensor **504** such that the at least one second sensor **504** may also be able to detect the presence of the prime cap **304**. In some embodiments, the functions of the prime cap sensor **502** and the priming status sensor **504** may be performed by a single sensor.

[00180] In various embodiments, the prime cap sensor **502** may be an optical time-of-flight sensor that is configured for measuring distance from the sensor to at least one surface of the prime cap **304**. If the measured distance detected by the prime cap sensor **502** is within an expected range, the sensor **502** may provide an indication to controller **900** that the prime cap **304** is correctly inserted into the prime tube housing **400** and a priming operation may

commence. If the measured distance detected by the prime cap sensor **502** is outside the expected range, this provides an indication that prime cap **304** has not been correctly inserted into the prime tube **400** and the controller may direct a user that the prime cap **304** insertion must be corrected before a priming operation may be commenced. In other embodiments, the prime cap sensor **502** may be a through-beam sensor that is configured for measuring the intensity of an infrared radiation beam going through the sidewall **330** of the prime cap **304** for example by measuring an intensity of the electromagnetic radiation at a detector after it has passed through prime cap **304**.

[00181] In further examples, the prime cap sensor **502** may be an optical camera configured for acquiring image data of an area above the prime cap **304**. Image processing software may be used to analyze the image data and determine if the prime cap **304** is present in the prime tube housing **400**. Information regarding the presence of the prime cap **304** may be sent to the controller **900**, which then may control one or more functions of the fluid injector system **2000**. For example, the controller **900** may initiate a priming procedure if the prime cap sensor **502** detects that the prime cap **304** is present in the prime tube housing **400**. Similarly, the controller **900** may prevent initiation of a priming procedure if the prime cap sensor **502** detects that the prime cap **304** is absent from or incorrectly inserted into the prime tube housing **400**.

[00182] The priming status sensor **504** may be in communication with the controller **900** and may be configured to detect one or more of: the presence of the prime cap **304**, if the prime cap **304** contains air, if the prime cap **304** contains saline, if the prime cap **304** contains contrast, or other properties of a fluid within prime cap **304**. For example, priming status sensor **504** may determine a priming status, e.g., whether the syringes **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** have been primed to remove all air therefrom, based on observation and/or measurement of air and/or fluid in the prime cap **304**. In various examples, the priming status sensor **504** may include light emitter/sensors, optical sensors (e.g., cameras), strain gauges, microphones, ammeters, limit switches, pressure transducers, or any other variety of sensor capable of detecting a property of the system **2000** that can be used to determine the priming status. The controller **900** may be programmed or configured to permit performance of an injection procedure only after a successful prime of the syringe **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** has been detected, such as when the priming status sensor **504** detects a presence of saline or contrast in the internal chamber **336** of the prime cap **304**. The controller **900** may be programmed or configured to prevent performance of an injection procedure until a successful prime of the syringe **10A**, **10B** and/or fluid paths **210A**, **210B**, and/or **210C** has been detected, such as when the priming status sensor **504** detects a presence of air in the

internal chamber **336** of the prime cap **304**. In some embodiments, the priming status sensor **504** may be a pair of sensors, with a first sensor positioned to detect the priming status of the prime cap **304** and a second sensor (not shown) configured to detect a presence and/or measure a volume of liquid in the waste container **404** (shown in **FIG. 8C-8D**). Measurement values from the first and the second sensors can be compared to assure that the priming operation is performing as expected over a single priming sequence or over a series of priming operations. Further details of priming status sensor **504** will be discussed with reference to **FIGS. 9A-18B**.

[00183] With reference to **FIG. 9A**, the priming status sensor **504** is shown in accordance with another example. The priming status sensor **500** may include at least one emitter **506** configured to emit electromagnetic energy, for example electromagnetic energy have one or more specific wavelengths, and at least one receiver **508** configured to detect the emitted electromagnetic energy. Examples of methods and uses of detectors and receivers of specific wavelengths for determining fluid presence and types are described in International PCT Application Publication Nos. PCT/US2022/017812 and PCT/US2022/017900. In some examples, the at least one emitter **506** may be an LED or other suitable source configured for emitting electromagnetic energy in one or more of the visible spectrum, infrared spectrum, ultraviolet spectrums, or at specific wavelengths of light in any of these spectrums, and the at least one receiver **508** may be a phototransistor or similar detector configured for detecting the electromagnetic energy in one or more of the visible spectrum, infrared spectrum, ultraviolet spectrums or at specific wavelengths of light in any of these spectrums. The at least one emitter **506** and the at least one receiver **508** may be positioned substantially perpendicular relative to a longitudinal axis of the prime cap **304**. In some examples, the at least one emitter **506** may be positioned on opposite side of the sidewall **330** of the prime cap **304** as the at least one receiver **508** such that electromagnetic energy emitted by the at least one emitter **506** passes through the opposing sidewalls **330** of the prime cap **304** and the internal chamber **336** before being received by the at least one receiver **508**. The sidewall **330** may be configured to permit passage of the electromagnetic energy therethrough such that the energy emitted from the at least one emitter **506** can be detected by the at least one receiver **508** after passing through the sidewall **330**. The at least one receiver **508** is configured to detect the wavelength and/or intensity of the electromagnetic radiation, which is dependent based on whether the prime cap **304** is present between the at least one emitter **506** and the at least one receiver **508** and whether air or liquid (e.g., contrast or flushing agent) is present in internal chamber **336** of prime cap **304**. In some examples, the priming status sensor **504** may be configured for detecting a type of fluid that is within the prime cap **304** (e.g., contrast or flushing agent, or the specific contrast

from a plurality of different contrasts, or a concentration of contrast agent in the solution of contrast), see, International PCT Application Publication No. PCT/US2022/017900.

[00184] With reference to **FIG. 9B**, a graph depicting the output of the at least one emitter **506** and the at least one receiver (detector) **508** described herein with reference to **FIG. 9A** is shown. For a set intensity of the at least one emitter **506**, the intensity of the signal detected by the at least one receiver **508** decreases based on whether the prime cap **304** is present between the at least one emitter **506** and the at least one receiver **508** (i.e., the prime cap **304** is correctly inserted into the prime tube housing **400**), based on whether the internal chamber **336** of the prime cap **304** is filled with air due to absorption of some electromagnetic energy by the air, and based on whether the internal chamber **336** of the prime cap **304** is filled with liquid due to absorption of greater amounts of electromagnetic energy by the liquid. In some examples, the intensity of the signal detected by the at least one receiver **508** may be correlated to a type of liquid within the prime cap **304** (e.g., contrast vs. flushing solution, concentration of contrast, or different types of contrast) due to differences in absorption of the electromagnetic energy by the different liquids. The presence of the prime cap **304** and the fluid within the internal chamber **336** of the prime cap **304** significantly attenuates the intensity of the signal detected by the at least one receiver **508**. The signal detected by the at least one receiver **508** may be used in determining the priming status of the prime cap **304**.

[00185] With reference to **FIG. 10A**, in certain embodiments, the priming status sensor **504** may include at least one emitter **506** configured to emit electromagnetic energy and an array **510** of receivers **508** configured to detect electromagnetic energy. In some examples, the at least one emitter **506** may be an LED configured for emitting electromagnetic energy in the visible spectrum, infrared spectrum, or other region of the electromagnetic spectrum, as described herein, and the array **510** of receivers **508** may be phototransistors configured for detecting electromagnetic energy in the visible spectrum, or other region of the electromagnetic spectrum, as described herein. Similar to the example shown in **FIG. 9A**, the at least one emitter **506** may be positioned on opposite side of the sidewall **330** of the prime cap **304** such that electromagnetic energy emitted by the at least one emitter **506** passes through the opposing sidewalls **330** of the prime cap **304** and the internal chamber **336** before being received by the one of the receivers **508** in the array **510**. The at least one emitter **506** and the at least one receiver **508** may be positioned across from each other at a non-perpendicular angle relative to a longitudinal axis of the prime cap **304**. The sensor configuration may use the refraction of the electromagnetic radiation as it passes through the sensing region to determine the presence of prime cap **304** and type of fluid contained within the prime cap **304** as described herein.

[00186] With reference to **FIG. 10B**, electromagnetic energy emitted from the at least one emitter **506** will be deflected and refracted based on whether the prime cap **304** is present between the at least one emitter **506** and the at least one receiver **508** and based on whether the internal chamber **336** of the prime cap **304** is filled with air (i.e., “empty”) or filled with liquid. Such deflection/refraction may occur due to, for example, refraction of the beam of electromagnetic energy as it passes through different media (air, sidewall **330** of the prime cap **304**, and the specific type of liquid in the internal chamber **336** of prime cap **304**). The deflected beam of electromagnetic energy will then be received by a different single or multiple receivers **508a-508c** of the array **510**. The presence of the prime cap **304** and the fluid within the internal chamber **336** of the prime cap **304** deflects the beam of electromagnetic energy such that a different receiver **508a-508c** of the array **510** detects the beam. The signal detected by the at least one receiver **508a-508c** may be used in determining a priming status of prime cap **304**.

[00187] With reference to **FIG. 11A**, in certain embodiments, the priming status sensor **504** may include at least one emitter **506** configured to emit electromagnetic energy and at least one receiver **508** configured to detect electromagnetic energy, similar to the arrangement shown and described herein with reference to **FIGS. 9A-9B**. The at least one emitter **506** may be positioned on the opposite side of the sidewall **330** of the prime cap **304** relative to the at least one receiver **508** and substantially perpendicular relative to a longitudinal axis of the prime cap **304** such that electromagnetic energy emitted by the at least one emitter **506** passes through the opposing sidewalls **330** of the prime cap **304** and the internal chamber **336** before being received by the at least one receiver **508**. At least a portion of the internal or external sidewall **330** on the side of the prime cap **304** which the electromagnetic energy enters the prime cap **304** may have a textured surface **512** configured to scatter or deflect the beam of electromagnetic energy emitted from the at least one emitter **506** as the beam of electromagnetic energy passes through the sidewall **330**.

[00188] With reference to **FIG. 11B**, a graph depicting the output of the at least one emitter **506** and the at least one receiver (detector) **508** is shown. For a set intensity of the at least one emitter **506**, the intensity of the signal detected by the at least one receiver **508** may be highest when no prime cap **304** is present between the at least one emitter **506** and the at least one receiver **508** because there is not textured surface to scatter the electromagnetic energy. When an air filled prime cap **304** is between the at least one emitter **506** and the at least one receiver **508**, the textured surface **512** of the sidewall **330** may be configured to deflect the beam of electromagnetic energy, thereby reducing the intensity of the signal detected by the at least one receiver **508**. When the prime cap **304** filled with a liquid is between the at least one emitter

506 and the at least one receiver **508**, the intensity of the signal detected by the at least one receiver **508** may be higher compared to the intensity of the signal when air is present due to the fluid preventing the diffusion of the beam of electromagnetic energy. The signal detected by the at least one receiver **508** may be used in determining a priming status of prime cap **304**.

[00189] With reference to **FIG. 12**, in certain embodiments, the priming status sensor **504** may be an optical camera **514** configured to take image data of the prime cap **304**. In some examples, the optical camera **514** may be configured to detect the presence of a fluid marker **516** provided on the sidewall **330** of the prime cap **304**, for example by a molded imprint or a shaped adhesive sticker. At least a portion of the sidewall **330** may be transparent or translucent to permit the optical camera **514** to gather image data of the sidewall **330**. The fluid marker **516** is desirably oriented on the side of the sidewall **330** that is opposite to the optical camera **514**. In some examples, the shape of an image of the fluid marker **516** that is visible to the optical camera **514** may change depending on the presence or absence of fluid in the internal cavity **336** of the prime cap **304**. For example, the fluid marker **516** having an oval shape may appear to the optical camera **514** to have a circular shape if a liquid fluid is present due to changes in refraction of light due to the presence of the liquid in the prime cap **304**. Whereas the fluid marker **516** having an oval shape may appear to the optical camera **514** to have an oval shape if air is present due to little or no refraction of light due to the presence of the air in the prime cap **304**. If no oval or circle is observed by optical camera **514**, then prime cap **304** must not have been inserted into prime tube housing **400** and the controller **900** notified that the system is not ready for priming. Suitable examples of fluid refraction of oval fluid markers are described in U.S. Patent Nos. 4,452,251 and 5,254,101, the disclosures of which are incorporated by this reference. While an oval shape of fluid marker **516** is specifically disclosed herein, other shapes for fluid marker **516**, such as any regular or irregular geometric shape including letters, numbers, and images or trademarks are not precluded. Image data detected by optical camera **514** may be used in determining a priming status of prime cap **304**.

[00190] With reference to **FIG. 13A**, in certain embodiments, the priming status sensor **504** may include at least one emitter **506** configured to emit electromagnetic energy and at least one receiver **508** configured to detect electromagnetic energy, similar to what is described herein with reference to **FIGS. 9A-9B**. Rather than having a circular cross-sectional shape, the prime cap **304** according to certain embodiments may have at least one flattened surface running at least a portion of the longitudinal axis of a sidewall of the prime cap **304**, for example a six-sided cross-sectional shape with a plurality of angled flat portions **515**. The at least one emitter **506** and the at least one receiver **508** may be positioned substantially perpendicular relative to

each other and having the at least one flattened surface oriented such that the emitted signal and received signal pass through the at least one flattened surface that is substantially perpendicular to the path of the signal as it passes therethrough. In some examples, the at least one emitter **506** may be positioned such that electromagnetic energy emitted therefrom is at least partially directed toward one of the angled flat portions **515**, which is configured to deflect at least a portion of the incident electromagnetic energy toward the at least one receiver **508**. The receiver **508** is configured to detect the intensity of the electromagnetic radiation, which is dependent based on whether prime cap **304** is present between the at least one emitter **506** and the at least one receiver **508** and whether air or liquid is present in internal chamber **336** of prime cap **304**.

[00191] With reference to **FIG. 13B**, graphical representations depicting the output of the at least one emitter **506** and the at least one receiver (detector) **508** are shown. For a set intensity of the at least one emitter **506**, the intensity of the signal detected by the at least one receiver **508** increases based on whether prime cap **304** is present between the at least one emitter **506** and the at least one receiver **508**, wherein no signal is detected due to all of the electromagnetic energy being directed in a direction away from the at least one receiver **508**, and based on whether the internal chamber **336** of the prime cap **304** is filled with air or filled with a particular liquid. The presence of the liquid within internal chamber **336** of prime cap **304** significantly amplifies the intensity of the signal detected by the at least one receiver **508** due to the electromagnetic energy being reflected/deflected off the angled flat portion **515**. The signal detected by the at least one receiver **508** may be used in determining the priming status of prime cap **304**, i.e., whether prime cap **304** is filled with air or a particular liquid (saline or contrast) as described herein.

[00192] With reference to **FIG. 14A**, in certain embodiments, the priming status sensor **504** may include at least one ultrasonic emitter **520** configured to emit ultrasonic energy and at least one ultrasonic receiver **522** configured to detect ultrasonic energy. In some examples, the at least one ultrasonic emitter **520** may be positioned on opposite side of the sidewall **330** of the prime cap **304** and substantially perpendicular relative to a longitudinal axis of the prime cap **304** such that ultrasonic energy emitted by the at least one ultrasonic emitter **520** passes through the opposing sidewalls **330** of the prime cap **304** and the internal chamber **336** and its content before being received by the at least one ultrasonic receiver **522**. The at least one ultrasonic receiver **522** is configured to detect the intensity of the ultrasonic energy, which may be dependent on whether prime cap **304** is present between the at least one ultrasonic emitter **520**

and the at least one ultrasonic receiver **522** and whether air or liquid is present in internal chamber **336** of prime cap **304**.

[00193] With reference to **FIG. 14B**, graphical representations depicting the output of the at least one ultrasonic emitter **520** and the at least one ultrasonic receiver (detector) **522** are shown. For a set intensity of the at least one ultrasonic emitter **520**, the intensity of the signal detected by the at least one ultrasonic receiver **522** decreases based on whether prime cap **304** is present between the at least one ultrasonic emitter **520** and the at least one ultrasonic receiver **522**, based on whether the internal chamber **336** of the prime cap **304** is filled with air, or whether the internal chamber **336** of the prime cap **304** is filled with a particular liquid. The presence of the prime cap **304** and the liquid within the internal chamber **336** of the prime cap **304** significantly attenuates the intensity of the signal detected by the at least one ultrasonic receiver **522**. The signal detected by the at least one ultrasonic receiver **522** may be used in determining a priming status of prime cap **304**.

[00194] With reference to **FIGS. 15A-15B**, in certain embodiments, the at least one ultrasonic emitter **520** and the at least one ultrasonic receiver **522** may be positioned on the same side relative to the prime cap **304**, instead of on opposite sides as shown in **FIGS. 14A, 14B**. The ultrasonic energy emitted by the at least one ultrasonic emitter **520** may be reflected by the far sidewall **330** of the prime cap **304** and detected by the at least one ultrasonic receiver **522**. For a set intensity of the at least one ultrasonic emitter **520**, the intensity of the signal detected by the at least one ultrasonic receiver **522** depends based on whether the prime cap **304** is present and on whether the internal chamber **336** of the prime cap **304** is filled with air (“empty”) or filled with liquid. No signal is detected when there is no prime cap **304**. When an air filled prime cap **304** is placed next to the at least one ultrasonic emitter **520** and the at least one receiver **522**, the near sidewall **330** may be configured to deflect the beam of ultrasonic energy, thereby reducing the intensity of the signal detected by the at least one ultrasonic receiver **522**. When prime cap **304** filled with a particular liquid is placed between the at least one ultrasonic emitter **520** and the at least one ultrasonic receiver **522**, the intensity of the signal detected by the at least one ultrasonic receiver **522** may be higher compared to the intensity of the signal when air is present due to the ultrasonic energy being reflected off of far sidewall **330**. The signal detected by the at least one ultrasonic receiver **522** may be used in determining a priming status of prime cap **304**.

[00195] With reference to **FIG. 16A**, the priming status sensor **504** may include at least one capacitive plate **524** controlled by the controller **900** according to one embodiment. The at least one capacitive plate **524** may be positioned substantially parallel relative to a longitudinal axis

of prime cap 304. The at least one capacitive plate 524 is configured to measure a capacitance/charge level within a detection area 526, which is dependent based on whether prime cap 304 is present in detection area 526 and whether air or a liquid is present in internal chamber 336 of prime cap 304.

[00196] With reference to FIG. 16B, a graph depicting the output of the at least one capacitive plate 524 is shown. The intensity of the signal detected by the at least one capacitive plate 524 increases based on whether prime cap 304 is present in the detection area 526 and based on whether internal chamber 336 of prime cap 304 is filled with air or filled with liquid. The presence of the liquid within internal chamber 336 of prime cap 304 amplifies the intensity of the capacitance signal detected by the at least one capacitive plate 524. The signal detected by the at least one capacitive plate 524 may be used in determining a priming status of prime cap 304.

[00197] With reference to FIG. 17A, in certain embodiments, the priming status sensor 504 may include at least one piezo transducer 528 controlled by the controller 900. The at least one piezo transducer 528 may be positioned substantially perpendicular relative to the longitudinal axis of the prime cap 304. The at least one piezo transducer 528 is configured to induce vibrations 304 and measure the vibration response of prime cap 304 and the contents of prime cap 304, which is dependent based on whether prime cap 304 is present and whether air or a liquid is present in internal chamber 336 of prime cap 304.

[00198] With reference to FIG. 17B, graphical representations depicting the output of the at least one piezo transducer 528 are shown. Initially, the at least one piezo transducer 528 outputs a high-frequency vibration. In there is no prime cap 304 present, the at least one piezo transducer 528 does not receive any vibratory response. The characteristics of the vibratory signal detected by the at least one piezo transducer 528 changes based on whether the internal chamber 336 of the prime cap 304 is filled with air or filled with liquid. Amplitude and frequency of an air-filled prime cap 304 are higher than amplitude and frequency compared to a liquid filled prime cap 304 due to liquid damping the vibration. In certain embodiments, the type of liquid may impact the vibration response, for example due to a viscosity of the liquid. Thus, it may be possible to differentiate between low viscosity saline and high viscosity contrast. The signal detected by the at least one piezo transducer 528 may be used in determining a priming status of prime cap 304.

[00199] With reference to FIG. 18A, in certain embodiments, the priming status sensor 504 may include at least one spring-loaded pin or biasing sensor 530. The longitudinal axis of the at least one spring-loaded pin sensor 530 may be positioned substantially perpendicular relative

to the longitudinal axis of the prime cap **304**. A pin **532** of the at least one spring-loaded pin sensor **530** is configured to contact an outer surface of the sidewall **330** of the prime cap **304** and is configured to detect an outward deflection of the sidewall **330** of the prime cap **304** due to capacitance expansion of the sidewall **330** from the pressurized contents. As the internal chamber **336** is filled with a pressurized fluid F (i.e., liquid contrast or flushing agent), the pressure of the fluid F causes the sidewall **330** of the prime cap **304** to expand in a radially outward direction, thereby compressing the pin **532** of the at least one spring-loaded pin sensor **530**. In contrast, when the prime cap **304** is filled with pressurized air, the compressibility of air results in little or no expansion of sidewall **330** and thus, no compressing of pin **532**. Finally, the pin sensor **530** may be configured to have a first state where when prime cap **304** is not present, the pin sensor **530** has no compression and when the prime cap **304** is inserted, the sidewall **330** compresses the pin sensor **530** to a second state due to the diameter of prime cap **304**, indicating that prime cap **304** has been inserted into prime tube housing **400**. The internal chamber **336** may have an internal restriction **337** to increase the fluid pressure within internal chamber **336** when prime cap **304** is filled with fluid. The output of the at least one spring-loaded pin sensor **530** may be used in determining a priming status of prime cap **304**.

[00200] With reference to **FIG. 19A**, a prime cap **604** is shown in accordance with another example of the present disclosure. The prime cap **604** may be configured for connecting with any of the patient tube connectors **302** described herein with reference to **FIGS. 3A-18B**. Prime cap **604** may be configured to connect at its distal end with or be at least partially inserted into an interior of a priming reservoir **700**. For example, the distal end **634** of the prime cap **604** may be inserted into an opening **702** of priming reservoir **700** such that any liquid primed or purged from the prime cap **604** may enter an interior **704** (see, **FIG. 19B**) of priming reservoir **700**. In some examples, priming reservoir **700** may be provided as a separate component relative to the prime cap **604** or the fluid injector system **2000**. In other embodiments, priming reservoir **700** may be integrated with prime cap **604** and/or fluid injector system **2000**. For example, priming reservoir **700** may be connected, such as removably or non-removably connected, to the injector housing. Priming reservoir **700** is configured to receive a volume of liquid primed from prime cap **604** during a priming operation, as described herein.

[00201] With reference to **FIG. 19B**, the priming reservoir **700** has a hollow body **706** having a proximal end **708** and a distal end **710** with the interior **704** extending between the proximal and distal ends **708**, **710**. In some examples, the distal end **710** is closed while the proximal end **708** has the opening **702**. The interior **704** of the priming reservoir **700** may be sized to receive liquid delivered from the prime cap **604** during a plurality of priming

operations. In some examples, the priming reservoir **700** may be sized to receive a total amount of fluid that is discharged during priming operations for fluid injection protocols conducted during a predetermined period of time, such as a length of a hospital or radiologist shift, a 24-hour period, or the like. In specific examples, the volume priming reservoir **700** should be sufficient to account for cases when more than one prime sequence per patient is required, for example, when air bubbles are still observed in the system and a second priming operation must be performed. In certain examples, a prime operation may include two injection sequences, a first forceful flow rate with low ejected volumes of liquid to remove the majority of air from the system and then a second slower flow rate with larger flow volumes, optionally accompanied by tapping or vibrations, to remove small air bubbles, as described herein.

[00202] With continued reference to **FIG. 19B**, the prime cap **604** may include a sidewall **630** having a proximal end **632** and a distal end **634** and defining an internal chamber **636**. The proximal end **632** of the sidewall **630** may include a first connector **638** configured to connecting to the distal end of the patient tube connector **302** (shown in **FIGS. 3A-3B**). The internal chamber **636** of prime cap **604** is in fluid communication with internal chamber **316** of the patient tube connector **302** when prime cap **604** is connected to patient tube connector **602**. At least one gripping element **635** may protrude radially outward from sidewall **630** of prime cap **604** to provide a gripping surface to facilitate removal of prime cap **604** from patient tube connector **302**.

[00203] The distal end **634** of prime cap **604** is configured to be at least partially inserted through opening **702** at the proximal end **708** of priming reservoir **700**. In some examples, distal end **634** of prime cap **604** may be positioned such that it is not in physical contact with a sidewall of the hollow body **706** surrounding opening **702**. In other examples, the distal end **634** of prime cap **604** may be in direct physical contact with at least a portion of the hollow body **706** surrounding opening **702**. A locking mechanism may be provided for releasably connecting distal end **634** of prime cap **604** to proximal end **708** of the priming reservoir **700**.

[00204] With reference to **FIG. 19C**, and with continued reference to **FIG. 19B**, the distal end **634** of the prime cap **604** may include a cover **640**. The cover **640** may have a body **644** having an outer surface configured for contacting the inner surface **641** of the distal end **634** of the prime cap **604**. In some examples, the distal end **634** may be open such that the cover **640** is inserted into the open distal end **634**. The outer surface of the body **644** of the cover **640** may be engaged with the inner surface **641** of the distal end **634** via friction fit, adhesive, welding, or other mechanical fastening process. In some examples, a cap may be provided to prevent

distal movement of the cover **640** relative to the prime cap **604**. In some examples, the cover **640** may be made from a medical-grade elastomeric material.

[00205] With reference to **FIG. 19C**, cover **640** may have an opening **642** that is normally closed such that fluid can be retained within the internal chamber **636** of the prime cap **604**. The opening **642** may be provided in a portion of the body **644** of the cover **640** having a first thickness **T1** that is smaller than a second thickness **T2** of the remaining portion of the body **644**. The opening **642** is configured to be openable when a pressure differential between a first side of the opening **642** (e.g., the internal chamber **636** of the prime tube **604**) and a second side of the opening **642** (e.g., ambient environment within the interior **704** of the priming reservoir **700**) exceeds a predetermined threshold. For example, the opening **642** may be configured to transition from the normally closed configuration to an open configuration when the pressure-differential exceeds a predetermined threshold of 1-10 psi.

[00206] With continued reference to **FIG. 19B**, the opening **642** may be a slit **648** having a first portion **650** and a second portion **652**. The first and second portions **650**, **652** may contact each other to seal the opening **642** in the normally closed configuration of the opening **642**. When at sufficient pressure differential between first and second sides of the cover **640**, the first and second portions **650**, **652** are configured to at least partially separate from each other, such as by deflecting from each other in a direction of arrows **A**, thereby defining a fluid path for the fluid to exit the prime cap **604** and enter the priming reservoir **700** (shown in **FIG. 19B**).

[00207] With reference to **FIGS. 20A-21B**, the prime cap **604** is shown in accordance with additional examples of the present disclosure. The components of the prime cap **604** shown in **FIGS. 20A-21B** are substantially similar or identical to the components of the prime cap **604** described herein with reference to **FIGS. 19A-19C**. Accordingly, reference numerals in **FIGS. 20A-21B** are used to illustrate identical components of the corresponding reference numerals in **FIGS. 19A-19C**. As the previous discussion regarding the prime cap **604** generally shown in **FIGS. 19A-19C** is applicable to the prime cap **604** shown in **FIGS. 20A-21B**, only the relative differences between the prime cap **604** shown in **FIGS. 19A-19C** and the prime cap **604** shown in **FIGS. 20A-21B** are discussed hereinafter.

[00208] With reference to **FIGS. 20A-20B**, the cover **640** may have a membrane **654** extending across the distal end **634** of the prime cap **604**. In some examples, the membrane **654** may be connected to an insert **656** that is inserted into the distal end **634** of the prime cap **604**. For example, an outer surface of the insert **656** may be at least partially inserted into the distal end **634** and connected therewith, such as by adhesive, friction fit, welding, or other mechanical connection mechanism. In some examples, an inner surface of the insert **656** may be connected

to an outer surface of the distal end **634**. In further examples, the membrane **654** may be connected directly to the distal end **634** of the prime cap **604**.

[00209] The membrane **654** may be connected to the insert **656** and/or the distal end **634** of the prime cap **604** via an adhesive, welding, or being integrally molded therewith. As shown in **FIG. 20B**, the membrane **654** may have at least one perforation **658** that defines a weakened region. The membrane **654** is configured to break at the at least one perforation **658** when a pressure differential between a first side of the membrane **654** (e.g., the internal chamber **636** of the prime tube **604**) and a second side of the membrane **654** (e.g., ambient environment within the interior **704** of the priming reservoir **700**) exceeds a predetermined threshold. For example, the membrane **654** may be configured to burst or break, as shown in **FIGS. 21A-21B**, when the pressure-differential exceeds a predetermined threshold of 1-10 psi.

[00210] With reference to **FIGS. 22A-23B**, the prime cap **604** is shown in accordance with additional examples of the present disclosure. The components of the prime cap **604** shown in **FIGS. 22A-23B** are substantially similar or identical to the components of the prime cap **604** described herein with reference to **FIGS. 20A-21B**. Accordingly, reference numerals in **FIGS. 22A-23B** are used to illustrate identical components of the corresponding reference numerals in **FIGS. 20A-21B**. As the previous discussion regarding the prime cap **604** generally shown in **FIGS. 20A-21B** is applicable to the prime cap **604** shown in **FIGS. 22A-23B**, only the relative differences between the prime cap **604** shown in **FIGS. 20A-21B** and the prime cap **604** shown in **FIGS. 22A-23B** are discussed hereinafter.

[00211] With reference to **FIGS. 22-22B**, cover **640** may have a cover **660** extending across the distal end **634** of prime cap **604**. In some examples, cover **660** may be connected to the insert **656** that is inserted into the distal end **634** of prime cap **604**. Cover **660** may be connected to the insert **656** via an adhesive, welding, or being integrally molded therewith. In further examples, cover **660** may be connected directly to the distal end **634** of prime cap **604**.

[00212] As shown in **FIG. 22B**, a first portion **661a** of the cover **660** may be adhered or otherwise connected to the insert **656** in a manner that is less adhered or otherwise connected as a second portion **661b** of the cover **660**. In this manner, the first portion **661a** of the cover **660** may be configured to separate from the insert **656** and/or the distal end **634** of the prime cap **604** when a pressure differential between a first side of the cover **660** (e.g., the internal chamber **636** of the prime tube **604**) and a second side of the cover **660** (e.g., ambient environment within the interior **704** of the priming reservoir **700**) exceeds a predetermined threshold while the second portion **661b** of the cover **660** remains connected to the insert **656** and/or the distal end **634** of the prime cap **604**. For example, the first portion **661a** of the cover

660 may be configured to separate from the insert **656** and/or the distal end **634** of the prime cap **604**, as shown in **FIGS. 23A-23B**, when the pressure-differential exceeds a predetermined threshold of 1-10 psi. The second portion **661b** of cover **660** may remain connected to the insert **656** and/or the distal end **634** of prime cap **604**.

[00213] With reference to **FIGS. 24A-25D**, the prime cap **604** is shown in accordance with additional examples of the present disclosure. The components of the prime cap **604** shown in **FIGS. 24A-25D** are substantially similar or identical to the components of the prime cap **604** described herein with reference to **FIGS. 19A-19C**. Accordingly, reference numerals in **FIGS. 24A-25D** are used to illustrate identical components of the corresponding reference numerals in **FIGS. 19A-19C**. As the previous discussion regarding the prime cap **604** generally shown in **FIGS. 19A-19C** is applicable to the prime cap **604** shown in **FIGS. 24A-25D**, only the relative differences between the prime cap **604** shown in **FIGS. 19A-19C** and the prime cap **604** shown in **FIGS. 24A-25D** are discussed hereinafter. With reference to **FIGS. 24A-24B**, the distal end **634** of prime cap **604** may have a cap **662** that is movably connected to the distal end **634**. The cap **662** has a proximal end **664** connected to the distal end **634** of the prime cap **604** and a distal end **668** having at least one aperture **670**. The cap **662** may be movable between a first position (shown in **FIG. 25C**) and a second position (shown in **FIG. 25D**) in a direction of a longitudinal axis of the prime cap **604**. In some examples, the cap **662** may be movable from the first position to the second position due to contact with at least a portion of the priming reservoir **700**, such as a ledge **720** extending across the opening **702** (shown in **FIG. 25D**). As shown in **FIG. 25B**, the cap **662** may have a piercing element **672** protruding proximally from the distal end **668**. The piercing element **672** is configured to pierce through the membrane **654** extending across the distal end **634** of the prime cap **604**. For example, when the distal end **634** of the prime cap **604** is inserted into the opening **704** of the priming reservoir **700**, the distal end **668** of the cap **662** contacts the ledge **720**. Continued distal movement of prime cap **604** causes cap **662** to move proximally from the first position to the second position. Such movement causes piercing element **672** to pierce through membrane **654**, thereby permitting fluid to exit through a distal end **634** of prime cap **604** via at least one aperture **670** of cap **662**.

[00214] As shown in **FIGS. 25C-25D**, the cap **662** may have one or more protrusions **674** that protrude radially inward to form an inner surface of the sidewall of the cap **662**. In some examples, the one or more protrusions **674** may be configured to be received in one or more grooves **676** recessed radially inward into the sidewall of the distal end **634** of the prime cap **604**. The one or more protrusions **674** may be configured to be received within the one or more grooves **676** to secure the cap **662** on the distal end **634** of the prime cap **604**. In some examples,

the axial spacing between the one or more grooves **676** may correspond to a location of the cap **662** between the first and second positions. In this manner, the cap **662** can be locked in the first position prior to the membrane **654** being pierced by the piercing element **654**. Movement of the cap **662** in the proximal direction relative to the prime cap **604** causes the one or more protrusions **674** to be unlocked from a first groove **676** such that the cap **662** can be moved distally until the one or more protrusions **674** is locked in a second groove **676**. In some examples, the location of the one or more protrusions **674** and the one or more grooves **676** may be reversed, such that the o protrusions **674** are provided at the distal end **634** of prime cap **604** and the one or more grooves **676** are provided on the inner surface of cap **662**.

[00215] In some examples, such as shown in **FIGS. 26A-26C**, the piercing element **672** may be provided on the ledge **720** of the priming reservoir **700**. In this manner, when the distal end **634** of the prime cap **604** is inserted into the opening **704** of the priming reservoir **700**, the membrane **654** of the cap **662** contacts the piercing element **672**. Continued distal movement of the prime cap **604** causes the piercing element **672** to pierce through the membrane **654**, thereby permitting fluid to exit through the distal end **634** of the prime cap **604**.

[00216] With reference to **FIGS. 27A-29B**, the prime cap **604** is shown in accordance with additional examples of the present disclosure. The components of the prime cap **604** shown in **FIGS. 27A-29B** are substantially similar or identical to the components of the prime cap **604** described herein with reference to **FIGS. 19A-19C**. Accordingly, reference numerals in **FIGS. 27A-29B** are used to illustrate identical components of the corresponding reference numerals in **FIGS. 19A-19C**. As the previous discussion regarding the prime cap **604** generally shown in **FIGS. 19A-19C** is applicable to the prime cap **604** shown in **FIGS. 27A-29B**, only the relative differences between the prime cap **604** shown in **FIGS. 19A-19C** and the prime cap **604** shown in **FIGS. 27A-29B** are discussed hereinafter.

[00217] With reference to **FIG. 27B**, the distal end **634** of the prime cap **604** may include a valve assembly **680**. The valve assembly **680** has a housing **682** with a first portion **684** having an outer surface configured for contacting the inner surface **641** of the distal end **634** of the prime cap **604**. The housing **682** further has a second portion **686** that is connected to the first portion **684** such that an inner chamber **688** is defined therebetween. A valve member **690** is positioned within the inner chamber **688**. In some examples, the valve member **690** may be operable to permit one-way fluid flow, such as in a direction from the prime cap **604** and into the priming reservoir **700**. The valve member **690** may be normally closed and be openable when a pressure differential between a first side of the valve member **690** (e.g., the internal chamber **636** of the prime tube **604**) and a second side of the valve member **690** (e.g., ambient

environment within the interior 704 of the priming reservoir 700) exceeds a predetermined threshold. For example, the valve member 690 may be configured to transition from the normally closed configuration to an open configuration when the pressure-differential exceeds a predetermined threshold of 1-10 psi.

[00218] With reference to FIGS. 28A-28B, the distal end 634 of the prime cap 604 may include a duck bill valve 692. The duck bill valve 692 has a body 693 with an outer surface configured for contacting the inner surface 641 of the distal end 634 of the prime cap 604. The duck bill valve 692 further has a pair of lips 694 that are normally closed to prevent fluid flow through the duck bill valve 692. The duck bill valve 692 may be operable to permit one-way fluid flow, such as in a direction from the prime cap 604 and into the priming reservoir 700. The duck bill valve 692 may be normally closed and be openable when a pressure differential between a first side of the duck bill valve 692 (e.g., the internal chamber 636 of the prime tube 604) and a second side of the duck bill valve 692 (e.g., ambient environment within the interior 704 of the priming reservoir 700) exceeds a predetermined threshold. For example, the duck bill valve 692 may be configured to transition from the normally closed configuration to an open configuration when the pressure-differential exceeds a predetermined threshold of 0.1-5 psi. In the open configuration, the lips 694 are configured to separate from each other to define an opening for permitting fluid flow through the duck bill valve 692. In some examples, the duck bill valve 692 may be made from an elastomeric, medical grade material.

[00219] With reference to FIGS. 29A-29B, the distal end 634 of the prime cap 604 may include a seal 696 having a pinched portion 698. The seal 696 is inserted into the distal end 634 of the prime cap 604 such that an outer surface contacts the inner surface 641 of the distal end 634 of the prime cap 604. The pinched portion 698 is formed by sealingly connecting opposing sides of a sidewall 699 of the seal 696 to prevent fluid flow through the seal 696. For example, the opposing sides of the sidewall 699 may be connected by adhesive or heat sealing. The seal 696 may be normally closed and be openable when a pressure differential between a first side of the pinched portion 698 (e.g., the internal chamber 636 of the prime tube 604) and a second side of the pinched portion 698 (e.g., ambient environment within the interior 704 of the priming reservoir 700) exceeds a predetermined threshold. For example, the pinched portion 698 may be configured to transition from the normally closed configuration to an open configuration when the pressure-differential exceeds a predetermined threshold of 1-10 psi. In the open configuration, the opposing sides of the sidewall 699 at the pinched portion 698 are configured to separate from each other to define an opening for permitting fluid flow through seal 696. In some examples, seal 696 may be made from a plastic, medical grade material.

[00220] As described herein with reference to the prime cap 304, prime cap 604 described herein with reference to FIGS. 19A-29B may be configured for insertion into a prime tube slot 402 of a prime tube housing 400 on a fluid injector system 2000 (shown in FIG. 1). The prime tube slot 402 may be shaped to receive at least a portion of the prime cap 604 during a priming operation. Furthermore, prime cap 604 described herein with reference to FIGS. 19A-29B may be configured to be used with sensing arrangement 500 detecting a presence of fluid in prime cap 604. As described herein, sensing arrangement 500 may include at least one priming status sensor 504 configured for detecting a presence of fluid in prime cap 604.

[00221] While various examples of the present disclosure were provided in the foregoing description, those skilled in the art may make modifications and alterations to these examples without departing from the scope and spirit of the disclosure. For example, it is to be understood that features of various examples described herein may be adapted to other examples described herein. Accordingly, the foregoing description is intended to be illustrative rather than restrictive. The disclosure described hereinabove is defined by the appended claims, and all changes to the disclosure that fall within the meaning and the range of equivalency of the claims are to be embraced within their scope.

CLAIMS

WE CLAIM:

1. A prime tube for use with a fluid injector, the prime tube comprising:
 - a patient tube connector having a proximal end and a distal end;
 - a prime cap having a proximal end and a distal end, wherein the prime cap has a sensing region configured for sensing a fluid within a second internal chamber defined in the prime cap; and
 - a connection interface for removably connecting the distal end of the patient tube connector to the proximal end of the prime cap, the connection interface comprising:
 - a first connector at the proximal end of the prime cap; and
 - a second connector at the distal end of the patient tube connector;wherein the first connector comprises a releasable locking mechanism connected to a sidewall of the prime cap,
 - wherein the second connector comprises an engagement feature configured to engage at least a portion of the releasable locking mechanism, and
 - wherein disengagement of the engagement feature from the releasable locking mechanism permits removal of the patient tube connector from the prime cap.
2. The prime tube according to claim 1, wherein the releasable locking mechanism is a removable strip or a deformable or tearable ring connected to the sidewall of the prime cap by a frangible edge that extends around at least a portion of an outer perimeter of the prime cap.
3. The prime tube according to claim 2, wherein the frangible edge is configured to break upon rotation of the patient tube connector relative to the prime cap.
4. The prime tube according to any of claims 1 to 3, wherein the patient tube connector comprises a first sidewall defining a first internal chamber between the proximal end and the distal end of the patient tube connector, and wherein the first sidewall is configured to allow sensing of a fluid content of the first internal chamber.
5. The prime tube according to claim 4, wherein the prime cap comprises a second sidewall defining the second internal chamber between the proximal end and the distal end of

the prime cap, and wherein the second sidewall comprises the sensing region configured to allow sensing of a fluid content of the second internal chamber.

6. The prime tube according to claim 5, wherein second sidewall, at least in the sensing region, is configured to permit transmittance of electromagnetic energy or ultrasonic energy therethrough.

7. The prime tube according to claim 5, wherein second sidewall, at least in the sensing region, is transparent or translucent.

8. The prime tube according to claim 5, wherein second sidewall, at least in the sensing region, comprises a textured surface configured to deflect or scatter the electromagnetic energy.

9. The prime tube according to claim 5, wherein second sidewall, at least in the sensing region, has a circular or polygonal cross-sectional shape.

10. The prime tube according to claim 5, wherein the first internal chamber is in fluid communication with the second internal chamber.

11. The prime tube according to any of claims 1 to 10, wherein the distal end of the prime cap comprises a cover.

12. The prime tube according to claim 11, wherein a tortuous path is defined between the cover and the second internal chamber of the prime cap to permit passage of air from the second internal chamber of the prime cap.

13. The prime tube according to any of claims 1 to 12, wherein the distal end of the patient tube connector comprises a male or a female luer connector, and wherein the male or the female luer connector is at least partially surrounded by a skirt having the second connector thereon.

14. The prime tube according to any of claims 1 to 13, further comprising at least one gripping element protruding radially outward from a sidewall of at least one of the prime cap and the patient tube connector.

15. The prime tube according to any of claims 1 to 14, further comprising at least one alignment tab protruding radially outward from a sidewall of the prime cap.
16. A fluid injector system comprising:
at least one fluid container;
at least one drive member configured for delivering a fluid from the fluid container to a fluid path set;
a prime tube connected to the fluid path set, the prime tube having a patient tube connector and a prime cap, wherein the prime cap has a sensing region configured for sensing a fluid within a second internal chamber defined in the prime cap;
a sensing arrangement for sensing at least one characteristic of the prime tube, the sensing arrangement comprising at least one sensor configured to at least one of: sense a presence of the prime tube in a prime tube housing of the fluid injector system and sense at least one property of a fluid in the prime cap; and
a controller configured to control operation of the at least one drive member based on a detection status of the sensing arrangement.
17. The fluid injector system according to claim 16, wherein the at least one property of the fluid is at least one of fluid type, a transition between air and liquid, and a concentration of contrast.
18. The fluid injector system according to claim 16 or 17, wherein the at least one sensor is a through-beam sensor configured to measure intensity of infrared radiation passing through the prime cap.
19. The fluid injector system according to any of claims 16 to 18, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.
20. The fluid injector system according to any of claims 16 to 19, wherein the at least one sensor comprises an optical emitter and at least one optical receiver.
21. The fluid injector system according to any of claims 16 to 20, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.

22. The fluid injector system according to any of claims 16 to 21, wherein the at least one sensor comprises an ultrasonic emitter on a first side of the prime cap and an ultrasonic receiver on a second side of the prime cap.
23. The fluid injector system according to any of claims 16 to 22, wherein the at least one sensor comprises an ultrasonic emitter and an ultrasonic receiver on a same side of the prime cap.
24. The fluid injector system according to any of claims 16 to 23, wherein the at least one sensor comprises a capacitive plate configured to contact at least a portion of the prime cap and measure a change in capacitance of the prime cap due to the at least one property of the fluid in the prime cap.
25. The fluid injector system according to any of claims 16 to 24, wherein the at least one sensor comprises a piezoelectric transducer configured to contact at least a portion of the prime cap and detect a change in vibratory characteristics of the prime cap due to the the at least one property of the fluid in the prime cap.
26. The fluid injector system according to any of claims 16 to 25, wherein the at least one sensor comprises a transducer configured to contact at least a portion of the prime cap and detect a change in outer diameter of the prime cap due to the at least one property of the fluid in the prime cap.
27. A sensing arrangement for a fluid injector system for sensing at least one characteristic of a prime tube having a patient tube connector and a prime cap, the sensing arrangement comprising:
at least one sensor configured to at least one of:
sense a presence of the prime cap in a prime tube housing of the fluid injector system;
and
sense a at least one property of a fluid in the prime cap.
28. The sensing arrangement according to claim 27, wherein the at least one sensor is a through-beam sensor configured to measure intensity of infrared radiation passing through the prime cap.

29. The sensing arrangement according to claim 27 or 28, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.
30. The sensing arrangement according to any of claims 27 to 29, wherein the at least one sensor comprises an optical emitter and at least one optical receiver.
31. The sensing arrangement according to any of claims 27 to 30, wherein the at least one sensor comprises an optical camera configured to acquire image data of the prime cap.
32. The sensing arrangement according to any of claims 27 to 31, wherein the at least one sensor comprises an ultrasonic emitter on a first side of the prime cap and an ultrasonic receiver on a second side of the prime cap.
33. The sensing arrangement according to any of claims 27 to 32 wherein the at least one sensor comprises an ultrasonic emitter and an ultrasonic receiver on a same side of the prime cap.
34. The sensing arrangement according to any of claims 27 to 33, wherein the at least one sensor comprises a capacitive plate configured to contact at least a portion of the prime cap and measure a change in capacitance of the prime cap due to the at least one property of the fluid in the prime cap.
35. The sensing arrangement according to any of claims 27 to 34, wherein the at least one sensor comprises a piezoelectric transducer configured to contact at least a portion of the prime cap and detect a change in vibratory characteristics of the prime cap due to the at least one property of the fluid in the prime cap.
36. The sensing arrangement according to any of claims 27 to 35, wherein the at least one sensor comprises a transducer configured to contact at least a portion of the prime cap and detect a change in outer diameter of the prime cap due to the at least one property of the fluid in the prime cap.

37. A prime cap for priming a fluid path, the prime cap comprising:
a hollow body having a proximal end configured for connecting with a patient tube connector and a distal end configured to be at least partially inserted into a priming container;
and
a cover enclosing the distal end of the hollow body,
wherein the cover is configured to enclose the distal end, and
wherein the cover is configured to open when a pressure differential across the cover exceeds a predetermined threshold.
38. The prime cap of according to claim 37, wherein the cover comprises an opening that is normally closed and is openable when the pressure differential across the cover exceeds the predetermined threshold.
39. The prime cap of according to claim 37, wherein the cover comprises a membrane that is configured to burst when the pressure differential across the cover exceeds the predetermined threshold.
40. The prime cap of according to claim 37, wherein the cover comprises a cap movable relative to the distal end of the prime cap, and wherein the cap has a piercing element configured to pierce the membrane when the cap is moved toward the proximal end of the prime cap.
41. The prime cap of according to claim 37, wherein the cover comprises a cover having a first portion connected to the distal end and a second portion connected to the distal end, and wherein the first position is configured to separate from the distal end when the pressure differential across the cover exceeds the predetermined threshold.
42. The prime cap of according to claim 37, wherein the cover comprises a one-way valve.
43. The prime cap of according to claim 37, wherein the cover comprises a duck bill valve.
44. The prime cap according to claim 37, wherein the cover comprises a seal having a pinched portion formed by sealingly connecting opposing sides of a sidewall of the seal.

45. A method of priming a patient line with a fluid using a fluid injector system, wherein the patient line is connected to a prime tube having a patient tube connector and a prime cap, the method comprising:

detecting a presence of the prime tube in a prime tube housing of the fluid injector system using a prime tube sensor of the fluid injector system;

upon detecting the presence of the prime tube in the prime tube housing, actuating a drive member of the fluid injection system to deliver fluid to the prime tube during a priming operation;

detecting at least one property of the fluid within an internal chamber of the prime cap using a priming status sensor of the fluid injector system; and

upon detecting the at least one property of the fluid within the internal chamber of the prime cap, providing an indication that the patient line is primed with the fluid.

46. The method according to claim 45, further comprising removing the patient tube connector from the prime cap and connecting the patient tube connector to a patient tube.

47. The method according to claim 45 or 46, further comprising actuating the drive member of the fluid injection system to deliver the fluid in accordance with a predetermined injection protocol.

48. The method according to any of claims 45 to 47, wherein detecting the presence of the prime tube in the prime tube housing comprises detecting a presence of an alignment tab within an opening of the prime tube housing.

49. The method according to any of claims 45 to 48, wherein actuating a drive member of the fluid injection system to deliver fluid to the prime tube during a priming operation comprises detecting air within the internal chamber of the prime cap and continuing to actuate the drive member until substantially all of the air exits the prime cap through a cover at the distal end of the prime cap.

50. The method according to claim 49, wherein a tortuous path is defined between the cover and an inner surface of the prime cap to permit passage of the air from the internal chamber of the prime cap.