

ULTRASONIC CLEANING IN FLEXIBLE CONTAINER

BACKGROUND

[0001] Unless otherwise indicated herein, the approaches described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

[0002] The washing of garments or other textiles generally involves the separation of undesirable matter from the fabric, such as dirt and stains, and the subsequent disposal of such matter. In general, the washing process is accomplished by using water, a detergent or surfactant, and some source of mechanical agitation (e.g., an impeller or rotating drum) that together cause the undesirable matter to separate from the textile. The undesirable matter is then isolated from the textile by the detergent and removed by the water, typically through one or more rinse cycles.

[0003] While current textile-cleaning processes are generally effective, the resources employed in such cleaning processes (water, chemicals, and energy) represent a significant environmental burden. Moreover, the amount of time and effort required by such processes is a significant inconvenience to individual consumers.

SUMMARY

[0004] In accordance with at least some embodiments of the present disclosure, an apparatus to clean garments or other textiles with ultrasonic energy includes a non-rigid container, an array of ultrasonic energy emitters, an air connection, and a water connection. The non-rigid container has a first inner surface and a second inner surface that forms a cleaning cavity in a planar region between the first inner surface and the second inner surface. The array of ultrasonic energy emitters are disposed proximate the first inner surface and configured to direct ultrasonic energy into the cleaning cavity. The air connection is fluidly coupled to the cleaning cavity and the water connection is fluidly coupled to the cleaning cavity. The non-rigid container

is configured so that the first inner surface and the second inner surface are displaced toward each other when negative pressure is present in the cleaning cavity.

[0005] In accordance with at least some embodiments of the present disclosure, a method to clean with ultrasonic energy comprises introducing a cleaning solution into a planar cleaning cavity formed between a first inner surface and a second inner surface of a non-rigid container, directing ultrasonic energy into the cleaning cavity from an array of ultrasonic energy emitters disposed on the first inner surface, and removing the cleaning solution from the cleaning cavity by creating a negative pressure in the cleaning cavity relative to atmospheric pressure, so that the first inner surface and the second inner surface are displaced toward each other.

[0006] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. These drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope. The disclosure will be described with additional specificity and detail through use of the accompanying drawings.

FIG. 1 is a schematic diagram illustrating an ultrasonic cleaning system, according to one or more embodiments of the present disclosure;

FIGS. 2A and 2B are schematic diagrams of a non-rigid container, configured according to one or more embodiments of the disclosure;

FIGS. 3A and 3B are schematic diagrams of a non-rigid container, configured according to one or more embodiments of the disclosure;

FIG. 4 is a schematic illustration of a microcapsule that may be employed in various embodiments of the present disclosure;

FIGS. 5A, 5B, 5C, 5D, and 5E are schematic diagrams illustrating the ultrasonic cleaning system of FIG. 1 in various phases of operation, according to one or more embodiments of the present disclosure; and

FIG. 6 sets forth a flowchart summarizing an example method to clean with ultrasonic energy, in accordance with at least some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0008] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. The aspects of the disclosure, as generally described herein, and illustrated in the Figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

[0009] As noted above, conventional cleaning processes for garments and other textiles require significant time and resources. For example, the batch nature of the laundry process in the developed world is particularly wasteful of human effort and space. Dirty clothes must be collected, sorted by color and/or fabric type, moved to the washer, moved to the dryer, resorted, then organized in a closet or wardrobe. Each step requires dedicated time, space (for a hamper, washer, dryer, and closet), and attention that could be used more enjoyably or productively. According to embodiments described herein, an ultrasonic cleaning system enables in-place washing of garments or other textiles in a closet or other storage space. Thus, such an ultrasonic cleaning system obviates the need for the space dedicated for laundering equipment, such as a washing machine and drier. Furthermore, because the herein described ultrasonic cleaning system can process an individual garment, or a small number of similar

garments, in the same location in which they are stored, ultrasonic cleaning system 100 saves the time and space usually allocated to sorting clean and dirty laundry.

[0010] FIG. 1 is a schematic diagram illustrating an ultrasonic cleaning system 100, according to one or more embodiments of the present disclosure. Ultrasonic cleaning system 100 is configured to clean, dry, and store a single garment or a plurality of smaller garments. Ultrasonic cleaning system 100 may include a non-rigid container 110 coupled to an air pump 120 and a liquid pump 130, a cleaning mixture subsystem 140, a controller 150, and an ultrasonic generator 160. Ultrasonic cleaning system 100 may further include a sink connection 101, an air-heating module 102, a liquid-heating module 103, a line sensor 104, an air valve 105, and a liquid valve 106, coupled together as shown.

[0011] Non-rigid container 110 is configured to contain and subsequently store a single garment or a plurality of smaller garments during a cleaning and drying process. Non-rigid container 110 includes a plurality of ultrasonic emitters 112 disposed proximate an inner surface of the non-rigid container. Non-rigid container 110 is coupled to air pump 120 and air-heating module 102 via valve 105, and is coupled to liquid pump 130, liquid-heating module 102, and sink connection 101 via liquid valve 106, while ultrasonic emitters 112 are each coupled to ultrasonic generator 160. One embodiment of non-rigid container 110 is illustrated in greater detail in FIGS. 2A and 2B.

[0012] FIGS. 2A and 2B are schematic diagrams of non-rigid container 110, configured according to one or more embodiments of the disclosure. FIG. 2A is a front view of non-rigid container 110 and FIG. 2B is an edge view of non-rigid container 110. In the embodiment illustrated in FIG. 2, non-rigid container 110 is formed from a front membrane 201 and a rear membrane 202, which are joined together at edges 203 to form an air-tight and liquid-tight seal. Alternatively, non-rigid container 110 may be formed from a single membrane, or a plurality of membranes, having a total thickness of between about 0.5 mm and about 5.0 mm. In either case, non-rigid container 110 generally includes two or more inner surfaces, for example an inner surface 201A of front membrane 201 and an inner surface 202A of rear membrane 202 that may be substantially planar and parallel with each other. Consequently, when negative pressure is present in non-rigid container 110, for example when suction is applied via air pump

120 or liquid pump 130 (shown in FIG. 1), inner surface 201A and inner surface 202A are urged together, and can be used to wring liquid from garments disposed within on-rigid container 110. It is noted that such a wringing process can be significantly quieter and more effective at removing liquid from a garment than a conventional spinning process, and does not employ a complicated, bulky, and motorized system with many potential points of failure.

[0013] Non-rigid container 110 also includes a resealable opening 204 that, when closed and sealed as shown, is configured to form an air-tight and liquid-tight seal. Thus, when resealable opening 204 is closed and sealed, non-rigid container 110 encloses a cleaning cavity 210 that is a substantially planar region between inner surface 201A of front membrane 201 and inner surface 202A of rear membrane 202.

[0014] Cleaning cavity 210 is configured to retain fluids and the positive pressurization caused by the introduction of air, water, cleaning fluid, or any other fluid into cleaning cavity 210. For example, resealable opening 204 is configured to retain hydrostatic pressure in cleaning cavity 210 that results when cleaning cavity 210 is filled with a liquid. In addition, resealable opening 204 is configured to retain the positive pressure that results when air pump 120 forces air into cleaning cavity 210, for example during a drying operation. In some embodiments, resealable opening 204 may include an interlocking or zip-lock type seal to effect such pressure retention. For example, a zip body may be disposed on a surface of front membrane 201 that extends from the surface and is configured for insertion into and retention by an engaging cavity that is disposed on an opposing surface of back membrane 202. Alternatively or additionally, resealable opening 204 may be configured with a water-tight folding band, or any other technically feasible reusable sealing mechanism capable of leak-free retention of positive pressure in cleaning cavity 210.

[0015] Front membrane 201 and rear membrane 202 are configured to be sufficiently flexible such that negative pressure present in cleaning cavity 210, such as pressure that is less than atmospheric pressure outside cleaning cavity 210, causes front membrane 201 and rear membrane 202 to be displaced toward each other. Furthermore, in some embodiments, front membrane 201 and rear membrane 202 are configured to be sufficiently flexible such that, when no garments are present in cleaning cavity 210, negative pressure present in cleaning cavity

210 causes an inner surface of front membrane 201 to be displaced toward and to contact an inner surface of rear membrane 202. In addition, front membrane 201 and rear membrane 202 generally include an air-tight and liquid-tight material. Thus, in some embodiments, front membrane 201 and rear membrane 202 may include a polymeric sheet or membrane, where the polymer is any suitable natural or synthetic polymer. Alternatively or additionally, front membrane 201 and rear membrane 202 may include one or more silicone-containing layers. For example, front membrane 201 and rear membrane 202 may include a heterogeneous membrane structure, such as a polyurethane coated fabric that is woven from any suitable fiber. Alternatively or additionally, front membrane 201 and rear membrane 202 may include a homogeneous membrane, such as a neoprene or other rubber sheet. Furthermore, front membrane 201 and rear membrane 202 may include any other technically feasible material that is air-tight, liquid-tight, and of the above-described flexibility.

[0016] As shown, non-rigid container 110 may further include a garment hanger 211, ultrasonic emitters 112, a horizontal support 212, a water connection 213, and one or more air connections 214. In the embodiment illustrated in FIGS. 2A and 2B, horizontal support 212, water connection 213, and air connections 214 are coupled to a central system 190 that may be configured to similarly couple to a plurality of additional non-rigid containers (not shown). In such embodiments, central system 190 may include one or more centrally located systems of ultrasonic cleaning system 100 shown in FIG. 1, such as air pump 120, liquid pump 130, cleaning mixture system 140, controller 150, ultrasonic generator 160, and/or sink connection 101. For clarity, air valve 105, liquid valve 106, and the individual power connections to each of ultrasonic emitters 112 are not shown in FIGS 2A and 2B.

[0017] Garment hanger 211 may be configured to hang a single garment, such as a shirt or pants, or a plurality of smaller garments, such as socks, underwear, and the like, within cleaning cavity 210. In the embodiment illustrated in FIG. 2, garment hanger 211 is depicted with the form factor of a conventional clothing hanger, but in other embodiments, garment hanger 211 may have any other suitable configuration. In some embodiments, garment hanger 211 may be a replaceable component of non-rigid container 110, and can be switched out depending on what particular garment or garments are to be stored and washed in non-rigid container 110.

[0018] Ultrasonic emitters 112 may be any technically feasible devices capable of delivering ultrasonic energy into cleaning cavity 210 at a suitable energy density. For example, in one embodiment, each ultrasonic emitter 112 includes a sonicator, such as a piezoelectric transducer, that transforms high-voltage, high-frequency electrical energy received from ultrasonic generator 160 to mechanical vibrations. The mechanical vibrations are generated as a result of the characteristics of an internal piezoelectric crystal or crystals in the sonicator. In some embodiments, each ultrasonic emitter 112 may further include an apparatus to enhance distribution of ultrasonic energy emitted by the sonicator, such as an acoustic lens or any other technically feasible device. For example, without an acoustic lens, a sonicator typically produces a narrow channel of acoustic energy, whereas with a suitably configured acoustic lens, a sonicator can more uniformly distribute ultrasonic energy into cleaning cavity 210.

[0019] The size, number, and spacing between ultrasonic emitters 112 may be selected based on multiple factors, including a thickness 207 of cleaning cavity 210 when garments are contained therein, a target maximum output power of each ultrasonic emitter 112, and a target resonant frequency of each ultrasonic emitter 112, among others. For example, in one embodiment, ultrasonic emitters 112 may be configured to have a resonant frequency of 1 MHz, to be arranged with a spacing of between 5 cm and 20 cm, and to generate a total of about 400 W of power at 1 MHz, or to individually generate an average power density in cleaning cavity 210 of about 0.05 W/cm². Alternatively, ultrasonic emitters 112 may be configured to have a resonant frequency that is greater than or less than 1 MHz, for example between about 20 kHz and about 20 MHz. In addition, ultrasonic emitters 112 may be configured to generate a total power that is greater than or less than 400 W, for example between about 100 W and about 2000 W. It is noted that for spacings of more than about 20 cm, sonicators capable of directing sufficient ultrasonic energy into all portions of cleaning cavity 210 may be impractically bulky. Conversely, for spacings less than about 4 or 5 cm, the number of sonicators to be included in non-rigid container 110 may be impractically large.

[0020] Furthermore, in some embodiments, ultrasonic emitters 112 may not have a single uniform configuration. Thus, in some embodiments, a portion of ultrasonic emitters 112 may have one configuration, while a remainder portion may have a different configuration. For

example, ultrasonic emitters 112 that are disposed proximate a portion of cleaning cavity 210 that may be thicker than other portions of cleaning cavity 210 may be configured to better penetrate cleaning cavity 210. For instance, such ultrasonic emitters 112 may be configured to generate a higher power density of ultrasonic energy at the resonant frequency, and/or to direct such ultrasonic energy into cleaning cavity 210 in a more concentrated channel than other ultrasonic emitters 112 included in non-rigid container 110.

[0021] In some embodiments, ultrasonic emitters 112 are disposed proximate inner surface 201A of front membrane 201, and are oriented to direct ultrasonic energy into cleaning cavity 210. Ultrasonic emitters 112 may be disposed directly on inner surface 201A, within front membrane 201, or on an outer surface of front membrane 201. In the latter case, ultrasonic energy generated by an ultrasonic emitter 112 may be directed through front membrane 201 or through an opening in front membrane 201. Alternatively or additionally, some or all of ultrasonic emitters 112 may be disposed proximate inner surface 202A of rear membrane 202, where ultrasonic emitters so disposed are oriented toward front membrane 201, i.e., in the opposite direction that ultrasonic emitters 112 disposed proximate inner surface 201A are oriented. Alternatively, a portion of ultrasonic emitters 112 may be disposed proximate inner surface 202A and a portion may be disposed proximate inner surface 201A.

[0022] In some embodiments, ultrasonic emitters 112 are arranged in an array that facilitates uniform distribution of ultrasonic energy in cleaning cavity 112. Thus, in some embodiments, such an array distributes ultrasonic emitters 112 across a planar portion of front membrane 201 that is substantially parallel to a primary axis 210A of cleaning cavity 210. Any suitable array or grid-pattern may be employed that facilitates uniform distribution of ultrasonic energy in cleaning cavity 112. In some embodiments, ultrasonic emitters 112 are disposed proximate inner surface 201A in a first array and proximate inner surface 202A in a second array. One such embodiment is illustrated in FIGS. 3A and 3B.

[0023] FIGS. 3A and 3B are schematic diagrams of non-rigid container 110, configured according to one or more embodiments of the disclosure. FIG. 3A is a front view of non-rigid container 110 and FIG. 3B is an edge view of non-rigid container 110. As shown, a first array 301 of ultrasonic emitters 112 are disposed proximate inner surface 201A and a second array

302 of ultrasonic emitters 112 are disposed proximate inner surface 202A. As shown, in some embodiments, first array 301 and second array 302 may be configured so that ultrasonic emitters 112 included in first array 301 are offset from ultrasonic emitters 112 included in second array 302. In such embodiments, uniform distribution of ultrasonic energy in cleaning cavity 210 may be enhanced by such an offset between the positions of ultrasonic emitters 112 included in first array 301 and ultrasonic emitters 112 included in second array 301.

[0024] Returning to FIGS. 2A and 2B, horizontal support 212 is coupled to central system 190, or any other suitable structural element. In addition, horizontal support 212 is configured to support front membrane 201 and rear membrane 202 so that, despite being flexible materials, front membrane 201 and rear membrane 202 are arranged so that inner surface 201A and inner surface 202A are substantially planar surfaces that are substantially parallel to each other. Hence, a garment suspended from garment hanger 211 is allowed to hang freely and maintain an original shape, and is not compressed, wrinkled, or otherwise misshapen by front membrane 201 and rear membrane 202.

[0025] Liquid connection 213 is fluidly coupled to non-rigid container 110, and is configured for introduction of water and/or cleaning solution into cleaning cavity 210, for example via liquid pump 130 and liquid valve 106 (both shown in FIG. 1). In some embodiments, liquid connection 213 is also configured for removal of water and/or cleaning solution from cleaning cavity 210. In the embodiment illustrated in FIGS 2A and 2B, liquid connection 213 is disposed on a bottom edge or surface of non-rigid container 110, thereby facilitating removal of liquid, via gravity drain, suction generated by liquid pump 130, and/or positive pressure generated by air pump 120. In the embodiment illustrated in FIGS. 2A and 2B, liquid pump 130 is disposed in central system 190, and therefore liquid connection 213 is coupled to central system 190. In other embodiments, liquid connection 213 may be coupled to sink connection 101 without a connection to central system 190, for example when gravity draining of liquids is employed for removal of liquid from non-rigid container 110. In some embodiments, multiple liquid connections 213 may be coupled to non-rigid container 110, on a bottom edge or surface of non-rigid container 110, and/or at other locations.

[0026] Air connections 214 are fluidly coupled to non-rigid container 110, and are configured for introduction and removal of heated and/or unheated air into cleaning cavity 210, for example via air pump 120 and air valve 105 (both shown in FIG. 1). In the embodiment illustrated in FIGS. 2A and 2B, air connections 214 are disposed at or proximate a top edge or surface of non-rigid container 110, thereby facilitating removal of air via suction generated by air pump 120. In the embodiment illustrated in FIGS. 2A and 2B, air pump 120 is disposed in central system 190, and therefore air connection 214 is coupled to central system 190. In other embodiments, air connection 214 may be coupled to a dedicated air pump 120 that is not part of central system 190, for example when ultrasonic cleaning system 100 does not include central system 190.

[0027] Returning to FIG. 1, in addition to non-rigid container 110, ultrasonic cleaning system 100 further includes air pump 120, liquid pump 130, cleaning mixture subsystem 140, controller 150, ultrasonic generator 160, sink connection 101, air-heating module 102, liquid-heating module 103, and/or line sensor 104. In some embodiments, one or more of the above components of ultrasonic cleaning system 100 (e.g., air pump 120, liquid pump 130, cleaning mixture subsystem 140, controller 150, ultrasonic generator 160, sink connection 101, air-heating module 102, or liquid-heating module 103) are disposed in central system 190, and may be configured to support a plurality of non-rigid containers 110. Alternatively, ultrasonic cleaning system 100 may include a different instance of one or more of these components for each non-rigid container 110 included in ultrasonic cleaning system 100. For example, in one embodiment, ultrasonic cleaning system 100 may include a plurality of non-rigid containers 110 and a single air pump 120 and a single liquid pump 130 that are each disposed in central system 190 and fluidly coupled to each of the non-rigid containers 110. By contrast, in this embodiment, ultrasonic cleaning system 100 may also include a separate instance of controller 150 and ultrasonic generator 160 for each of the plurality of non-rigid containers 110, so that, in such an embodiment, a dedicated controller 150 and ultrasonic generator 160 are associated with each non-rigid container 100.

[0028] Air pump 120 may be any technically feasible air pump configured to pressurize non-rigid container 110 and to remove air from non-rigid container 110. Thus, in some embodiments, air pump 120 is a single air pump that can apply positive or negative pressure to

non-rigid container 110 via air valve 105 and air connection 214, which is shown in FIGS. 2A and 2B. For example, ultrasonic cleaning system 100 may include additional air lines and valves that enable the input and the output of air pump 120 to be selectively coupled to non-rigid container 110, so that air pump 120 can be employed to introduce air into or remove air from non-rigid container 110. In other embodiments, air pump 120 may include multiple air pumps, one for introducing air into non-rigid container 110 and another for removing air from non-rigid container 110.

[0029] Liquid pump 130 may be any technically feasible liquid pump configured to introduce water and/or cleaning fluid into non-rigid container 110 and to remove water and/or cleaning fluid from non-rigid container 110. In some embodiments, liquid pump 130 is a single liquid pump that can add liquids to or remove liquids from non-rigid container 110 via liquid valve 106. For example, in such embodiments, liquid pump 130 may include additional liquid lines and valves that enable the input and the output of liquid pump 130 to be selectively coupled to non-rigid container 110. In other embodiments, liquid pump 130 may include multiple pumps, one for introducing liquid into non-rigid container 110 and another for removing liquid from non-rigid container 110.

[0030] Cleaning mixture subsystem 140 is a subsystem of ultrasonic cleaning system 100 that selectively provides water or cleaning solution to non-rigid container 110. The cleaning solution may be a suitable mixture of water and detergent, or a suitable mixture of water, detergent, and microcapsules that include a gas precursor as a core material. Thus, in the embodiment illustrated in Figure 2, cleaning mixture subsystem 140 may include a detergent module 141 for selectively dispensing the detergent, a microcapsule suspension module 142 for selectively dispensing a microcapsule suspension, and a fresh water module 143 for selectively dispensing fresh water. In some embodiments, cleaning mixture subsystem 140 may be configured to selectively vary the relative quantities of detergent, microcapsule suspension, and fresh water based on how soiled and/or delicate the garment being washed is.

[0031] Detergent module 141, microcapsule suspension module 142, and fresh water module 143 may each include a separate controller for respectively dispensing appropriate quantities of detergent, microcapsule suspension, and fresh water. Alternatively, detergent module 141,

microcapsule suspension module 142, and fresh water module 143 may be controlled by a central controller (not shown) included in cleaning mixture subsystem 140, or may each be controlled directly by controller 150 (described below).

[0032] The detergent dispensed by detergent module 141 may be any suitable cleaning agent. The microcapsule suspension dispensed by microcapsule suspension module 142 includes microcapsules configured to expand, resonate, and burst when an external energy is applied thereto, thereby contributing to the removal of dirt and/or stains from the fabric of a garment or other textile disposed in non-rigid container 110. FIG. 4 illustrates one embodiment of such a microcapsule.

[0033] FIG. 4 is a schematic illustration of a microcapsule 400 that may be employed in various embodiments of the present disclosure. Microcapsule 400 may include a shell 410 and a core material 420 that is encapsulated in shell 410. In some embodiments, microcapsule 400 may be a liposome or vesicle. In some embodiments, shell 410 may include a surfactant and core material 420 may include one or more gas precursors. Alternatively or additionally, in some embodiments, shell 410 may include a protein or a polymer. Furthermore, in some embodiments, a mixture of different gas precursors may be included in core material 420. The diameter 411 of microcapsule 400 may be selected to facilitate penetration of microcapsules 400 into the structure of the fabric of a garment or other textile being cleaned in non-rigid container 110. In some embodiments, diameter 411 may be between several micrometers (or smaller) and several hundred micrometers.

[0034] Microcapsules 400 may be fabricated using various known methods. An example of a method of fabricating microcapsules 400 is disclosed in International Publication No. WO2005/004781, which refers to U.S. Pat. No. 6,551,576. Specifically, an aqueous suspension or powder (e.g., a bubble coating agent), preferably comprising lipids or albumin, is placed in a vial or container. A gas phase is then introduced above the aqueous suspension or powder phase in a remaining portion of the vial or container, i.e., in the headspace. The vial is then shaken for a predetermined period of time, thereby resulting in the formation of liposomes that entrap the gas.

[0035] Shell 410 may be formed from, for example, a phospholipid. In some embodiments, the phospholipid used to form shell 410 may be in the form of a monolayer or bilayer. Furthermore, in some embodiments, the monolayer or bilayer phospholipid may be used to form a series of concentric monolayers or bilayers. In other embodiments, shell 410 may be formed from at least one of albumin, gelatin, and/or alginic acid.

[0036] Core material 420 (i.e., the gas precursor) may be a compound that, at a selected activation or transition temperature, changes phase from a liquid or solid to a gas. According to embodiments of the present disclosure, ultrasonic energy generated by ultrasonic emitters 112 may be used to obtain the activation or transition temperature. Thus, materials of core material 420 may be selected that vaporize above a particular activation or transition temperature that can be achieved by ultrasonic emitters in some or all regions of cleaning cavity 210. In the present disclosure, the gas precursor may comprise a saturated or unsaturated C3-6 hydrocarbon, which may include a fluorine atom. For example, perfluorocarbons may be used for the gas precursor. The perfluorocarbons may include, for example, perfluorobutane, perfluorocyclobutane, perfluoromethane, perfluoroethane, perfluoropropane, perfluoropentane, and perfluorohexane. It should be understood that the gas precursors are not limited to the foregoing, and may include any suitable material capable of undergoing a phase transition to the gas phase when subjected to an appropriate temperature via ultrasonic emitters 112. Thus, a wide variety of materials may be employed as gas precursors in core material 420 in the present disclosure.

[0037] Returning to FIG. 1, controller 150 may be any technically feasible hardware unit capable of processing data and/or executing software applications to control various components of ultrasonic cleaning system 100 as described herein, including, without limitation, non-rigid container 110, air pump 120, liquid pump 130 cleaning mixture subsystem 140, ultrasonic generator 160, air valve 105, and/or liquid valve 106. As such, controller 150 may include, without limitation, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), any other type of processing unit, or a combination of different processing units. Controller 150 may further include computer-readable

media, for example one or more memories such as a nonvolatile memory (NVM), e.g., flash memory or read only memory (ROM), and a random access memory (RAM).

[0038] In some embodiments, controller 150 may be dedicated to control garment washing processes in a single non-rigid container 110. In other embodiments, controller 150 may be configured to control garment washing processes in multiple non-rigid containers 110, such as when a plurality of non-rigid containers 110 are coupled to central system 190.

[0039] Ultrasonic generator 160 is configured to provide the electrical energy for powering the ultrasonic transducers included in ultrasonic emitters 112. Thus, ultrasonic generator 160 transforms AC line power to high-frequency electrical energy, and provides this high-frequency electrical energy to ultrasonic emitters 112 as high voltage pulses of energy at a target frequency. The target frequency is typically at or near a resonant frequency of ultrasonic emitters 112, for example between about 20 kHz and about 20 MHz. Typically, the amplitude of electrical energy supplied to ultrasonic emitters 112 by ultrasonic generator 160 is controlled by controller 150 or some other equivalent control system. Ultrasonic emitters 112 are each connected to ultrasonic generator 160 by one or more high-voltage cables (not shown). In some embodiments, the amplitude of ultrasonic energy emitted by ultrasonic emitters 112 may be controlled by ultrasonic generator 160 and/or controller 150 based on how soiled and/or delicate a garment being washed is.

[0040] In some embodiments, ultrasonic generator 160 is configured to cause ultrasonic emitters 112 to selectively direct ultrasonic energy of multiple different energy densities into the cleaning cavity. Thus, in such embodiments, ultrasonic generator 160 may selectively provide different amplitudes of high-frequency energy to ultrasonic emitters 112, one for each different energy density. For example, a first such energy density may be employed for a mixing operation, where the first energy density is insufficient to cause microcapsules that are disposed in cleaning cavity 210 to burst, and is also insufficient to cause cavitation to occur in cleaning cavity 210. A second such energy density may be employed for causing microcapsules that are disposed in cleaning cavity 210 to burst. A third such energy density may be employed for causing cavitation to occur in cleaning cavity 210.

[0041] Ultrasonic generator 160 may include any feature or combination of features typically included in ultrasonic generators, such as varying the ultrasonic frequency generated by ultrasonic emitters 112 over a variable or fixed bandwidth to maximize transducer utilization and help provide uniform ultrasonic intensity throughout cleaning cavity 210, automatic frequency control based on impedance feedback from ultrasonic emitters 112 to facilitate improved transducer efficiency, multiple frequency generation capability, and the like.

[0042] Sink connection 101 may be any technically feasible connection to a waste drain, sink or sewer system. In some embodiments, sink connection may include one or more valves, additional plumbing, and/or a pump to facilitate the flow of liquids removed from non-rigid container 110 to such a waste drain, sink, or sewer system. Air-heating module 102 may be any technically feasible air-heating apparatus configured to heat air being pumped into non-rigid container 110, such as a heating coil or heat exchanger. Liquid-heating module 103 may be any technically feasible liquid-heating apparatus configured to heat water, cleaning agent, or other liquids being pumped into non-rigid container 110, such as a heating coil or heat exchanger. Line sensor 104 may be any sensor configured to detect the present of liquid at the top of non-rigid container 110 or at a particular max fill line.

[0043] FIGS. 5A, 5B, 5C, 5D, and 5E are schematic diagrams illustrating ultrasonic cleaning system 100 in various phases of operation, according to one or more embodiments of the present disclosure. To wash a garment or other item, the garment or item (not shown) is sealed inside non-rigid container 110. For example a garment or other textile may be hung on garment hanger 211, and then resealable opening 204 is closed. In some embodiments, air pump 120 may apply pressure to non-rigid container 110 to confirm that resealable opening 204 is sealed tight. Liquid pump 130 then injects a cleaning solution, such as a mixture of water and cleaning agent (detergent and/or microcapsule suspension), into non-rigid container 110 while air pump 120 removes air from non-rigid container 110, as shown in FIG. 5A. To reduce or minimize the amount of cleaning agent and water used in the washing process, ultrasonic cleaning system 100 may include a feedback loop in which liquid pump 130 introduces the cleaning agent mixture at a sufficiently slow rate, and stops when the liquid level has reached line sensor 104 at or near the top of non-rigid container 110.

[0044] In some embodiments, after cleaning solution is introduced into cleaning cavity 210, ultrasonic cleaning system 100 may perform a mixing operation in cleaning cavity 210. In some embodiments, air pump 120 may alternately introduce air into and remove air from non-rigid container 110, thereby raising and lowering the liquid level in non-rigid container 110 to facilitate mixing. Alternatively or additionally, in some embodiments, as part of the mixing operation, ultrasonic emitters 112 may emit lower energy ultrasonic waves to facilitate the penetration of microcapsules included in the cleaning agent into the fabric of the garment being washed. For example, controller 150, ultrasonic generator 160, and ultrasonic emitters 112 may be configured to direct ultrasonic energy of an energy density into cleaning cavity 210 that is insufficient to cause microcapsules present in non-rigid container 110 to burst, or to cause cavitation in the cleaning agent present in non-rigid container 110.

[0045] As shown in FIG. 5B, after cleaning solution is introduced into cleaning cavity 210 and any mixing process has been performed, an ultrasonic cleaning system 100 performs an ultrasonic cleaning operation. In some embodiments, ultrasonic emitters 112 may emit a higher-power ultrasonic wave that is directed into cleaning cavity 210 to facilitate cleaning of the garment in cleaning cavity 210. Thus, the ultrasonic energy emitted by ultrasonic emitters 112 during the ultrasonic cleaning operation generally has a higher energy level and/or greater energy density than the ultrasonic energy directed into cleaning cavity 210 as part of the above-described mixing operation. In some embodiments, the ultrasonic energy emitted by ultrasonic emitters 112 during the ultrasonic cleaning operation has an energy level or energy density sufficient to cause microcapsules included in the cleaning solution to burst, thereby contributing to the removal of dirt and/or stains from the fabric of a garment or other textile disposed in cleaning cavity 210. This portion of the operation proceeds much as described in US Patent 8,048,232. Alternatively or additionally, in some embodiments, the ultrasonic energy emitted by ultrasonic emitters 112 during the ultrasonic cleaning operation has an energy level or energy density sufficient to cause cavitation to occur in some or all regions of cleaning cavity 210, thereby contributing to the removal of dirt and/or stains from the fabric of a garment or other textile disposed in cleaning cavity 210. The duration of the cleaning process may be a function of multiple factors, including, without limitation, how soiled the garment was prior to washing,

how delicate the garment is, the energy level of ultrasonic energy employed during the cleaning process, and the concentration of microcapsules in the cleaning solution.

[0046] As shown in FIG. 5C, after completion of the above-described cleaning operation, the cleaning solution is then drained, either through passive gravitational draining or through active draining via liquid pump 130. Active draining advantageously removes more liquid from non-rigid container 110, thereby reducing the water used in subsequent rinse cycles. In some embodiments, liquid pump 130 may generate negative pressure in non-rigid cavity 110 relative to atmospheric pressure outside of non-rigid container 110. In such embodiments, the negative pressure generated inside non-rigid container 110 may be sufficiently great that inner surfaces of non-rigid container 110 (such as front membrane 201 and rear membrane 202 in FIGS. 2A and 2B) are displaced toward each other. Consequently, cleaning agent retained by the garment via wicking can be wrung from the garment with no additional mechanical actuator in non-rigid container 110.

[0047] As shown in FIG. 5D, a rinse operation is performed by injecting fresh water into non-rigid container 110 via liquid pump 130. In some embodiments, a mixing operation that includes sonication and/or raising and lowering of the water level, as described above, may be employed in conjunction with the rinse operation illustrated in FIG. 5D. Furthermore, the rinse operation may include multiple cycles of fresh water being introduced and drained.

[0048] As shown in FIG. 5E, ultrasonic cleaning system 100 may perform a drying operation in non-rigid container 110 after rinsing of the garment contained therein is complete. Thus, in some embodiments, air pump 120 circulates air through non-rigid container 110 to dry the garment contained therein. In some embodiments, air-heating module 103 heats the air introduced into non-rigid container 110 to speed this process. In some embodiments, the air connection through which the drying air exits non-rigid container 110 may include a valve, damper, or other orifice configured to provide back-pressure during the drying operation, thereby facilitating partial inflation of non-rigid container 110 during the drying operation. In some embodiments, non-rigid container 110 may include one or more directional vanes that are configured to deploy during the drying operation (for example when non-rigid container inflates). In such embodiments, the directional vanes can direct the motion of the drying air to effect more

efficient drying of the garment contained in non-rigid container 110. In addition, in some embodiments, non-rigid container 110 may include one or more support members disposed within that are configured to maintain a particular shape of a garment when the garment is disposed within the cleaning cavity, such as a collar, cuff, or sleeve shaper.

[0049] In embodiments in which ultrasonic cleaning system 100 includes multiple non-rigid containers 110, controller 150 is generally configured to manage the various above-described cycles for each of the multiple non-rigid containers 110. Thus, a user can hang up and seal an individual garment in a non-rigid container 110 after use. Then, when the user subsequently wants to use that garment, the cleaned garment is simply removed from non-rigid container 110. Unlike the batch nature of conventional laundry washing processes, no time or space is dedicated to sorting certain laundry types together prior to washing and re-sorting the laundry after washing.

[0050] FIG. 6 sets forth a flowchart summarizing an example method 600 to clean with ultrasonic energy, in accordance with at least some embodiments of the present disclosure. Method 600 may include one or more operations, functions or actions as illustrated by one or more of blocks 601 — 605. Although the blocks are illustrated in a sequential order, these blocks may also be performed in parallel, and/or in a different order than those described herein. Also, the various blocks may be combined into fewer blocks, divided into additional blocks, and/or eliminated based upon the desired implementation. Additional blocks representing other operations, functions or actions may also be provided. Although method 600 is described in conjunction with ultrasonic cleaning device 100 of FIG. 1, any apparatus configured to perform method 600 is within the scope of this disclosure.

[0051] Method 600 may begin in block 601 “introduce cleaning solution.” Block 601 may be followed by block 602 “perform mixing operation,” block 602 may be followed by block 603 “direct ultrasonic energy into cleaning cavity,” block 603 may be followed by block 604 “remove cleaning solution,” and block 604 may be followed by block 605 “force heated air into cleaning cavity.”

[0052] In block 601, ultrasonic cleaning system 100 introduces cleaning solution into non-rigid container 110, via liquid pump 130 and liquid valve 106. The cleaning solution generally includes a combination of water and cleaning agent, where the latter may include detergent, microcapsule suspension, or a combination of both. In some embodiments, the cleaning solution may be heated by liquid-heating module 103.

[0053] In optional block 602, ultrasonic cleaning system 100 performs a mixing operation. As described above in conjunction with FIG. 5A, the mixing operation may include lower-energy sonication, raising and lowering of the cleaning solution level in non-rigid container 110 via introduction and removal of air with air pump 120, or a combination of both. In such embodiments, the ultrasonic energy directed into cleaning cavity 210 typically has an energy density that is insufficient to cause microcapsules that are disposed in cleaning cavity 210 to burst. Furthermore, in such embodiments, the ultrasonic energy directed into cleaning cavity 210 may have an energy density that is insufficient to cause cavitation to take place.

[0054] In block 603, ultrasonic cleaning system 100 directs ultrasonic energy into cleaning cavity 210. In some embodiments, cleaning cavity 210 is a planar region between two inner surfaces of non-rigid container 110, and ultrasonic emitters 112 are arranged in an array that is substantially parallel to primary axis 210A of cleaning cavity 210. In such embodiments, ultrasonic energy emitted by ultrasonic emitters 112 can readily penetrate cleaning cavity 210 and any garment or other items disposed therein at a relatively low energy level or energy density. Consequently, damage to the fabric of garments disposed in cleaning cavity 210 can be avoided, since highly concentrated ultrasonic energy is not needed to penetrate cleaning cavity 210.

[0055] In some embodiments, ultrasonic emitters 112 may emit ultrasonic energy that has an energy density in some or all portions of cleaning cavity 210 sufficient to cause microcapsules in cleaning cavity 210 to burst. Furthermore, in some embodiments, ultrasonic emitters 112 may emit ultrasonic energy that has an energy density in some or all portions of cleaning cavity 210 sufficient to cause cavitation to occur.

[0056] In block 604, ultrasonic cleaning system 100 removes cleaning solution from non-rigid container 110. In some embodiments, cleaning solution is removed from cleaning cavity 210 passively, such as draining via gravity out of non-rigid container 110. In some embodiments, cleaning solution is removed from cleaning cavity 210 actively, such as via liquid pump 130. In some embodiments, cleaning solution absorbed in a garment or other textile being washed is removed in block 604 by the creation of a negative pressure in cleaning cavity 210 (relative to atmospheric pressure outside non-rigid container 110), so that inner surfaces of non-rigid container 110 are displaced toward each other. For example, in embodiments in which non-rigid container 110 includes inner surface 201A and inner surface 202A, inner surface 201A and inner surface 202A are urged together due to the negative pressure created in cleaning cavity 210 by liquid pump 130 and/or air pump 120, thereby wringing additional cleaning solution from the garment or textile being washed. In some embodiments, one or more rinse and drain operations, described above in conjunction with FIGS. 5C and 5D, may be included in block 604 to facilitate additional removal of cleaning solution from cleaning cavity 210.

[0057] In block 605, ultrasonic cleaning system 100 forces heated air into cleaning cavity 210 to dry the garment or other textile disposed in cleaning cavity 210. In some embodiments, after completing of block 605, heated or unheated air may be periodically directed into non-rigid container 110 to prevent staleness of the garment.

[0058] In sum, embodiments of the present disclosure provide systems and methods to clean clothing and other textiles with ultrasonic energy in a time- and space-efficient manner. By using a fully flexible, sealed container combined with a feedback system, the amount of water, microcapsule mixture, and detergent employed for cleaning an item of clothing may be reduced to an amount necessary to saturate the item. This is not the case with any existing laundry systems. In addition, the combination of a reasonably powerful pump and a flexible, sealed container can be much more effective at removing liquid from fabric compared to a spin cycle. Specifically, water is saved since much fewer rinse cycles are used, and each rinse cycle uses less water than a conventional rinse cycle. Energy is saved, since less water needs to be removed from the item through evaporation. Further, the complexity of the system is reduced, since there are very few moving parts, thereby lowering cost and improving reliability. Also

significant, by enabling single-item cleaning in the storage location of the item, the human effort and attention necessary to clean clothing is significantly reduced, since a user may simply hang a used item in a container and later remove the cleaned item when the item is to be worn again. Further, the release of cleaning chemicals into the environment may be reduced or substantially eliminated.

[0059] In some examples, a cleaning apparatus comprises a container having a first inner surface and a second inner surface that forms a cleaning cavity in a region between the first inner surface and the second inner surface, an arrangement (such as a regular array) of ultrasonic energy emitters disposed proximate the first inner surface and configured to direct ultrasonic energy into the cleaning cavity, an air connection fluidly coupled to the cleaning cavity, and a water connection fluidly coupled to the cleaning cavity. In some examples, the container is configured so that the first inner surface and the second inner surface are displaced toward each other when negative pressure is present in the cleaning cavity. In some examples, the container is non-rigid, and may in some examples have the general form of a flexible pouch. In some examples, the cleaning cavity may include a planar region (e.g. a generally planar region) between the first inner surface and a second inner surface. A cleaning apparatus may comprise a first flexible membrane, for example comprising a polymer sheet having a first inner surface, and a second flexible membrane having second inner surface. In some examples, the first and/or second membranes (e.g. inner surfaces) may comprise an ultrasonic energy emitter support surface, which may be rigid, semi-rigid, or flexible, and which may be configured to support one or more ultrasonic energy emitters. In some examples, ultrasonic energy emitters may be supported on outer surfaces. In some examples, a cleaning cavity may be defined by a pair of flexible membranes having opposed inner surfaces. In some examples, a cleaning cavity may be defined (at least in part) by a flexible sheet (such as a first membrane) and a semi-rigid or rigid member, where the sheet and member may have opposed inner surfaces. In some examples, a cleaning cavity may be located between a pair of rigid or semi-rigid members, such as generally planar members, the members being flexibly interconnected so that the members are urged towards one another on introduction of a negative pressure in the cleaning cavity, or may be compressed by an external force. A negative pressure may be a pressure less than the pressure present exterior to the container. In some examples, the container may be defined at

least in part by one or more flexible membranes. A flexible membrane may comprise a flexible polymer sheet. A container may further comprise reinforcing elements such as polymer bands, fibers (such as textile fibers, other polymer fibers, carbon fibers, and the like), wire, and the like, which may in some examples be incorporated into a membrane. In some examples, a thickness of a polymer sheet may be in the range 0.1 mm – 5 mm, for example 0.5 mm – 3 mm.

[0060] In some examples, a method to clean with ultrasonic energy comprises introducing a cleaning solution into a cleaning cavity formed between a first inner surface and a second inner surface of a container, and directing ultrasonic energy into the cleaning cavity from an array of ultrasonic energy emitters disposed on (or proximate to) the first inner surface. A method may further comprise removing the cleaning solution from the cleaning cavity by creating a negative pressure in the cleaning cavity relative to atmospheric pressure, so that the first inner surface and the second inner surface are displaced toward each other. In some examples, the cleaning solution may be removed by physical compression of the cleaning cavity. In some examples, a cleaning cavity may be generally planar. In some examples, a cleaning cavity may be defined by a first flexible sheet and a second semi-rigid or rigid sheet.

[0061] In some examples, the method may be a method of cleaning items, such as items comprising fabric, such as clothes. In some examples, the method may be a method of cleaning an item comprising silk.

[0062] There is little distinction left between hardware and software implementations of embodiments of systems; the use of hardware or software is generally (but not always, in that in certain contexts the choice between hardware and software can become significant) a design choice representing cost vs. efficiency tradeoffs. There are various vehicles by which processes and/or systems and/or other technologies described herein can be effected (e.g., hardware, software, and/or firmware), and that the preferred vehicle will vary with the context in which the processes and/or systems and/or other technologies are deployed. For example, if an implementer determines that speed and accuracy are paramount, the implementer may opt for a mainly hardware and/or firmware vehicle; if flexibility is paramount, the implementer may opt for a mainly software implementation; or, yet again alternatively, the implementer may opt for some combination of hardware, software, and/or firmware.

[0063] The foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In one embodiment, several portions of the subject matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), or other integrated formats. However, those skilled in the art will recognize that some aspects of the embodiments disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and/or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as a program product in a variety of forms, and that an illustrative embodiment of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include, but are not limited to, the following: a recordable type medium such as a floppy disk, a hard disk drive, a Compact Disc (CD), a Digital Video Disk (DVD), a digital tape, a computer memory, etc.; and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link, etc.).

[0064] Those skilled in the art will recognize that it is common within the art to describe devices and/or processes in the fashion set forth herein, and thereafter use engineering practices to integrate such described devices and/or processes into data processing systems. That is, at least a portion of the devices and/or processes described herein can be integrated into a data processing system via a reasonable amount of experimentation. Those having skill in the art

will recognize that a typical data processing system generally includes one or more of a system unit housing, a video display device, a memory such as volatile and non-volatile memory, processors such as microprocessors and digital signal processors, computational entities such as operating systems, drivers, graphical user interfaces, and applications programs, one or more interaction devices, such as a touch pad or screen, and/or control systems including feedback loops and control motors (e.g., feedback for sensing position and/or velocity; control motors for moving and/or adjusting components and/or quantities). A typical data processing system may be implemented utilizing any suitable commercially available components, such as those typically found in data computing/communication and/or network computing/communication systems.

[0065] The herein described subject matter sometimes illustrates different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being "operably couplable", to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

[0066] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0067] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean *at least* the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means *at least* two recitations, or *two or more* recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of

including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B."

[0068] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

I Claim:

1. A cleaning apparatus, comprising:
a non-rigid container having a first inner surface and a second inner surface that forms a cleaning cavity in a planar region between the first inner surface and the second inner surface;
an array of ultrasonic energy emitters disposed proximate the first inner surface and configured to direct ultrasonic energy into the cleaning cavity;
an air connection fluidly coupled to the cleaning cavity; and
a water connection fluidly coupled to the cleaning cavity,
wherein the non-rigid container is configured so that the first inner surface and the second inner surface are displaced toward each other when negative pressure is present in the cleaning cavity.
2. The cleaning apparatus of claim 1, wherein the array is disposed on a planar portion of the first inner surface, the planar portion being substantially parallel to a primary axis of the planar region.
3. The cleaning apparatus of claim 2, wherein the ultrasonic energy emitters in the array are arranged to direct ultrasonic energy toward the second inner surface through the planar region.
4. The cleaning apparatus of claim 2, wherein the second inner surface comprises a planar portion that is substantially parallel to the planar portion of the first inner surface.
5. The cleaning apparatus of claim 1, wherein the ultrasonic energy emitters are configured to selectively direct ultrasonic energy of multiple energy densities into the cleaning cavity.
6. The cleaning apparatus of claim 5, wherein one of the multiple energy densities is insufficient to cause microcapsules that are disposed in the cleaning cavity and include a gas precursor as a core material to burst.

7. The cleaning apparatus of claim 5, wherein one of the multiple energy densities is sufficient to cause microcapsules that are disposed in the cleaning cavity and include a gas precursor as a core material to burst, but is insufficient to cause cavitation in a solution disposed in the cleaning cavity.
8. The cleaning apparatus of claim 5, wherein one of the multiple energy densities is sufficient to cause cavitation in a solution disposed in the cleaning cavity.
9. The cleaning apparatus of claim 1, wherein the air connection is configured for introduction of air into the cleaning cavity and for removal of air from the cleaning cavity.
10. The cleaning apparatus of claim 1, further comprising a support member disposed within the cleaning cavity and configured to maintain a particular shape of a garment when the garment is disposed within the cleaning cavity.
11. A method to clean with ultrasonic energy, the method comprising:
 - introducing a cleaning solution into a planar cleaning cavity formed between a first inner surface and a second inner surface of a non-rigid container;
 - directing ultrasonic energy into the cleaning cavity from an array of ultrasonic energy emitters disposed on the first inner surface; and
 - removing the cleaning solution from the cleaning cavity by creating a negative pressure in the cleaning cavity relative to atmospheric pressure, so that the first inner surface and the second inner surface are displaced toward each other.
12. The method of claim 11, further comprising, after introducing the cleaning solution into the cleaning cavity, performing a mixing operation in the cleaning cavity.
13. The method of claim 12, wherein performing the mixing operation comprises adding air to the cleaning cavity to lower a level of the cleaning solution in the cleaning cavity.
14. The method of claim 12, wherein the cleaning solution includes microcapsules that include a gas precursor as a core material and can be caused to burst via the application of

ultrasonic energy of a first energy level, and wherein performing the mixing operation comprises directing ultrasonic energy into the cleaning cavity having an energy level insufficient to cause the microcapsules to burst.

15. The method of claim 14, wherein directing ultrasonic energy into the cleaning cavity comprises directing ultrasonic energy into the cleaning cavity from an array of ultrasonic energy emitters disposed on the first inner surface.

16. The method of claim 11, wherein creating the negative pressure in the cleaning cavity comprises removing air from the cleaning cavity.

17. The method of claim 11, wherein the cleaning solution includes microcapsules that include a gas precursor as a core material and can be caused to burst via the application of ultrasonic energy of a first energy level.

18. The method of claim 17, further comprising directing ultrasonic energy of at least the first energy level into the cleaning cavity from the array.

19. The method of claim 11, wherein the ultrasonic energy from the array of ultrasonic energy emitters has an energy level sufficient to cause cavitation in the cleaning solution.

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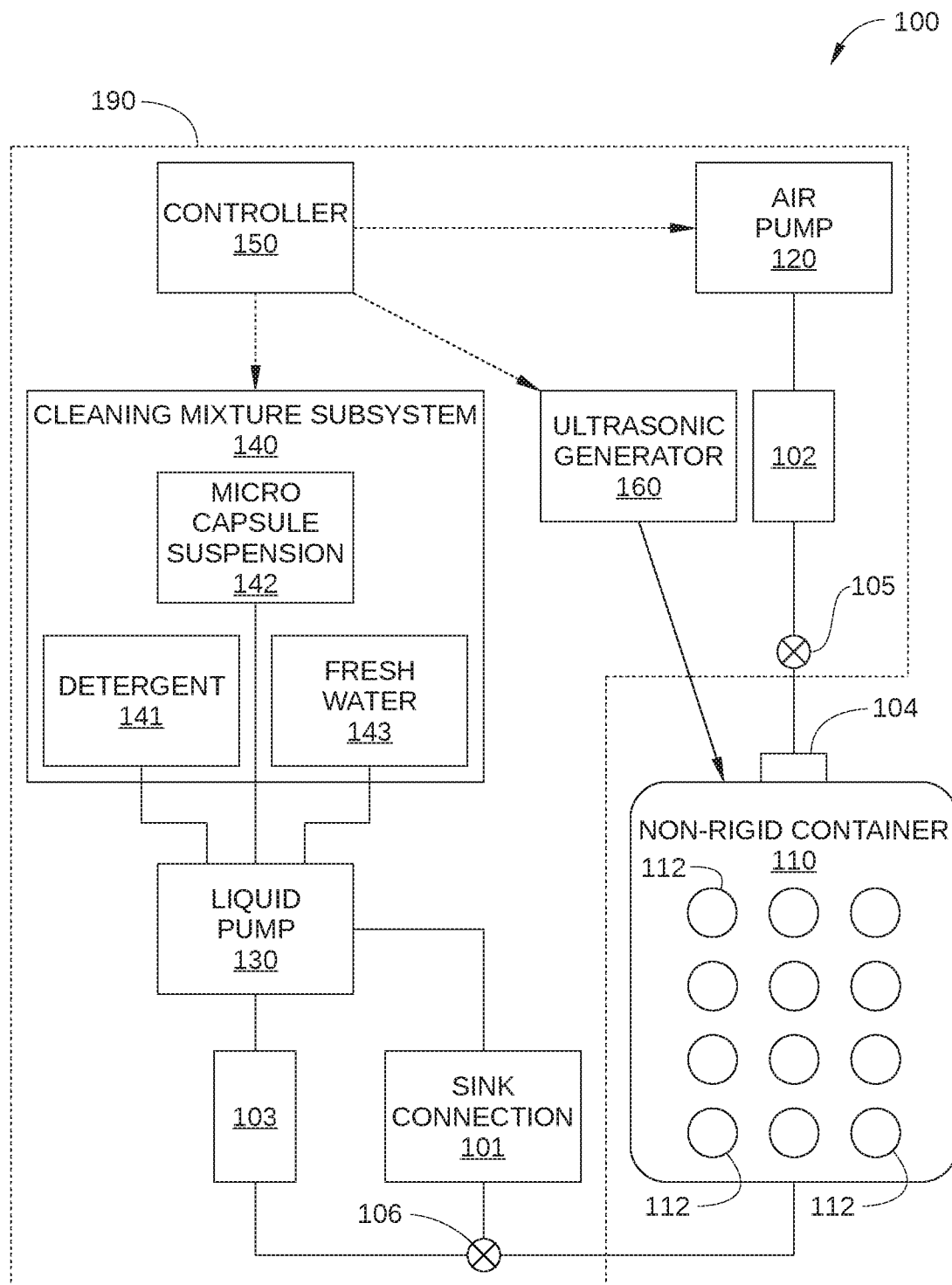


FIG. 1

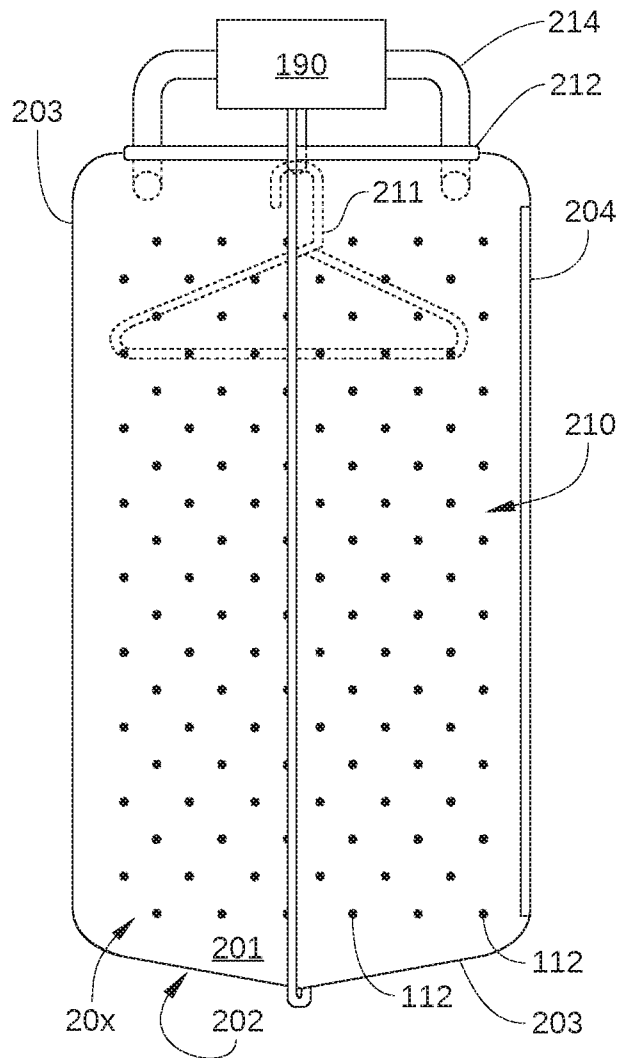


FIG. 2A

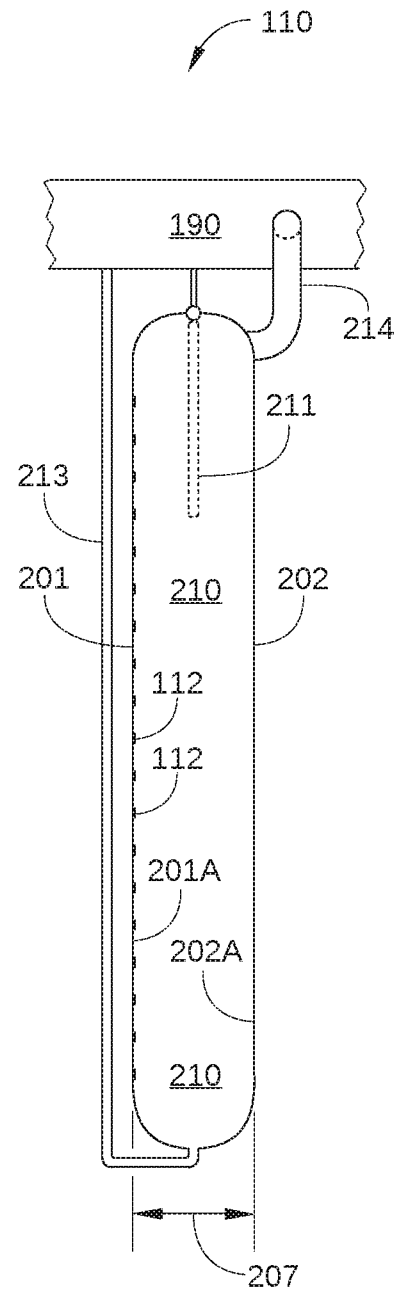


FIG. 2B

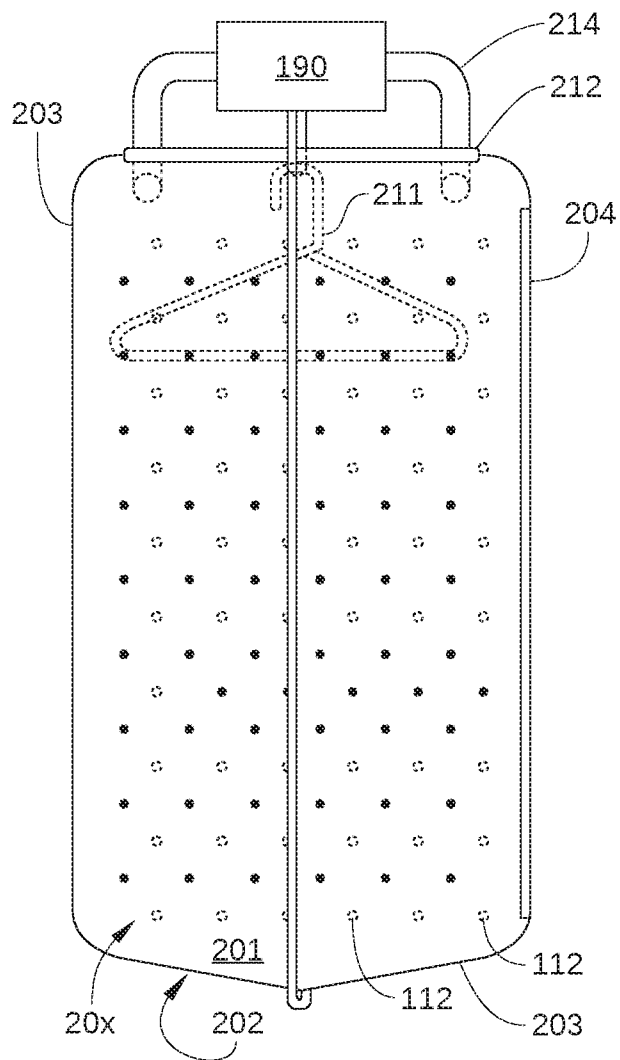


FIG. 3A

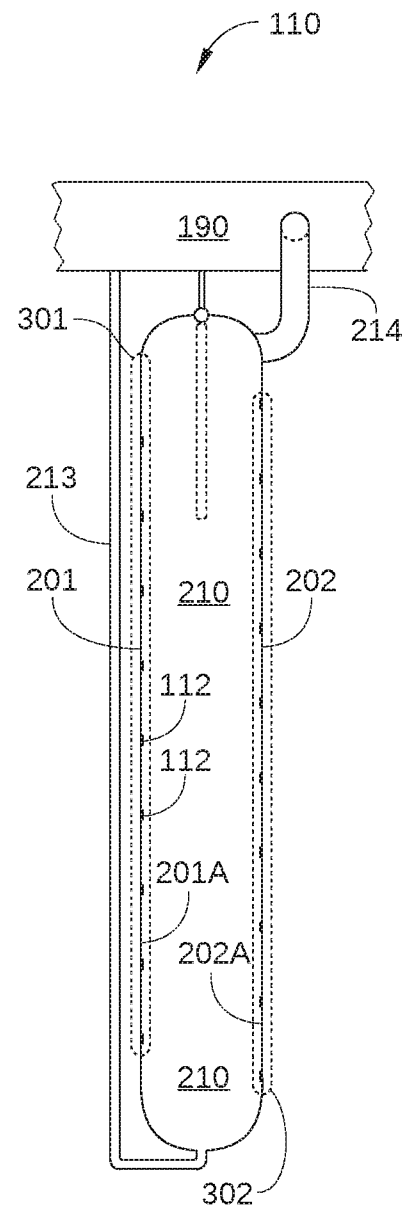


FIG. 3B

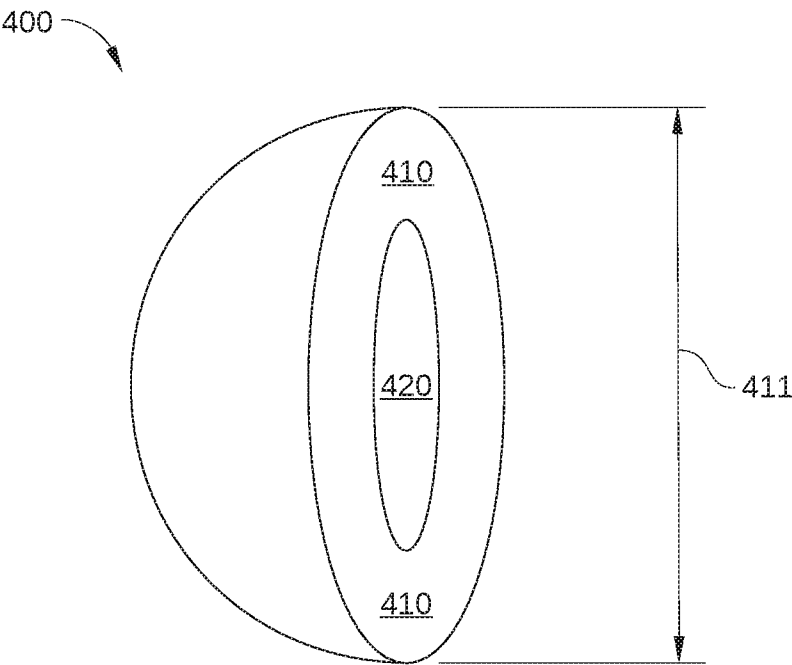


FIG. 4

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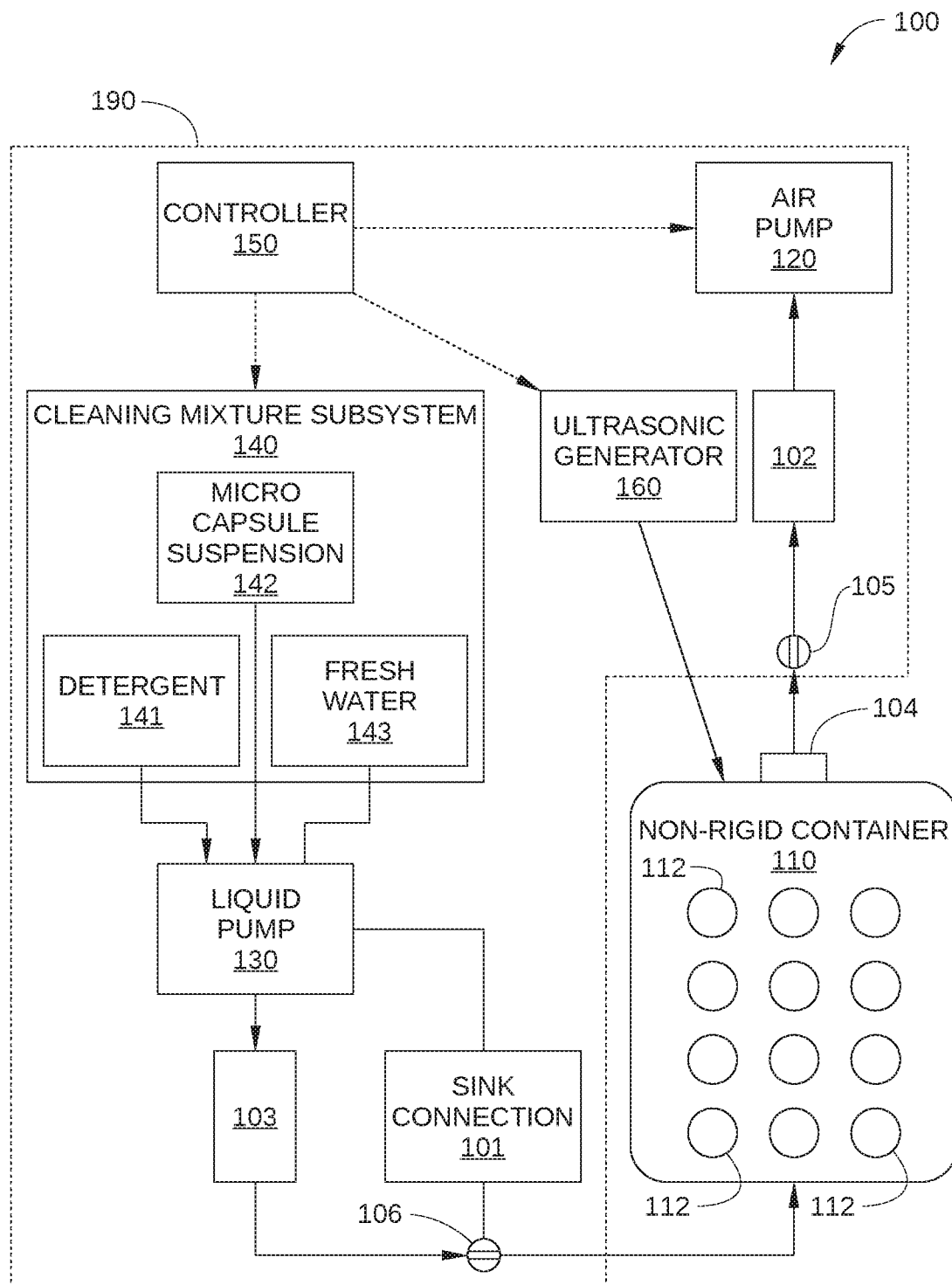


FIG. 5A

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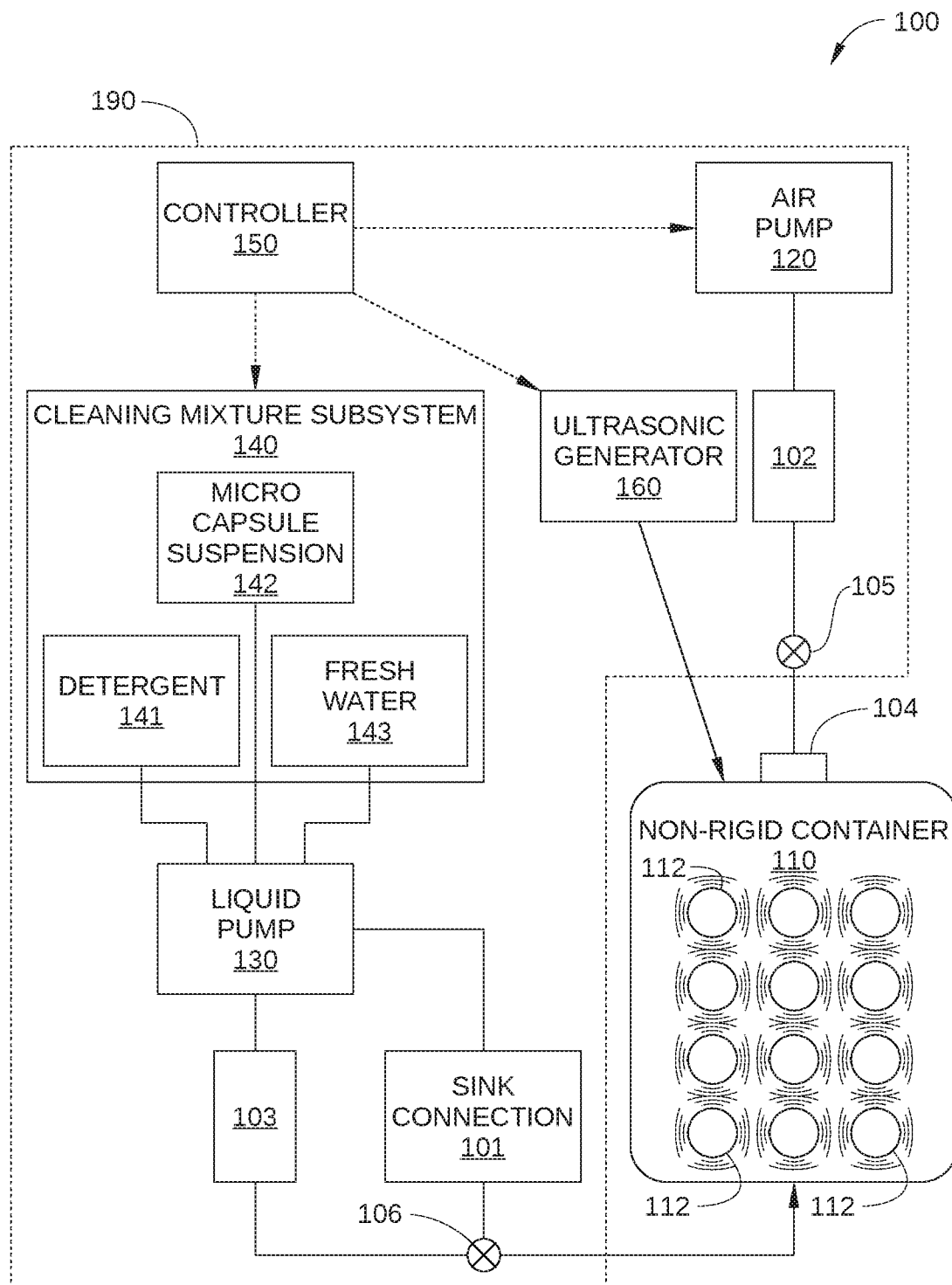


FIG. 5B

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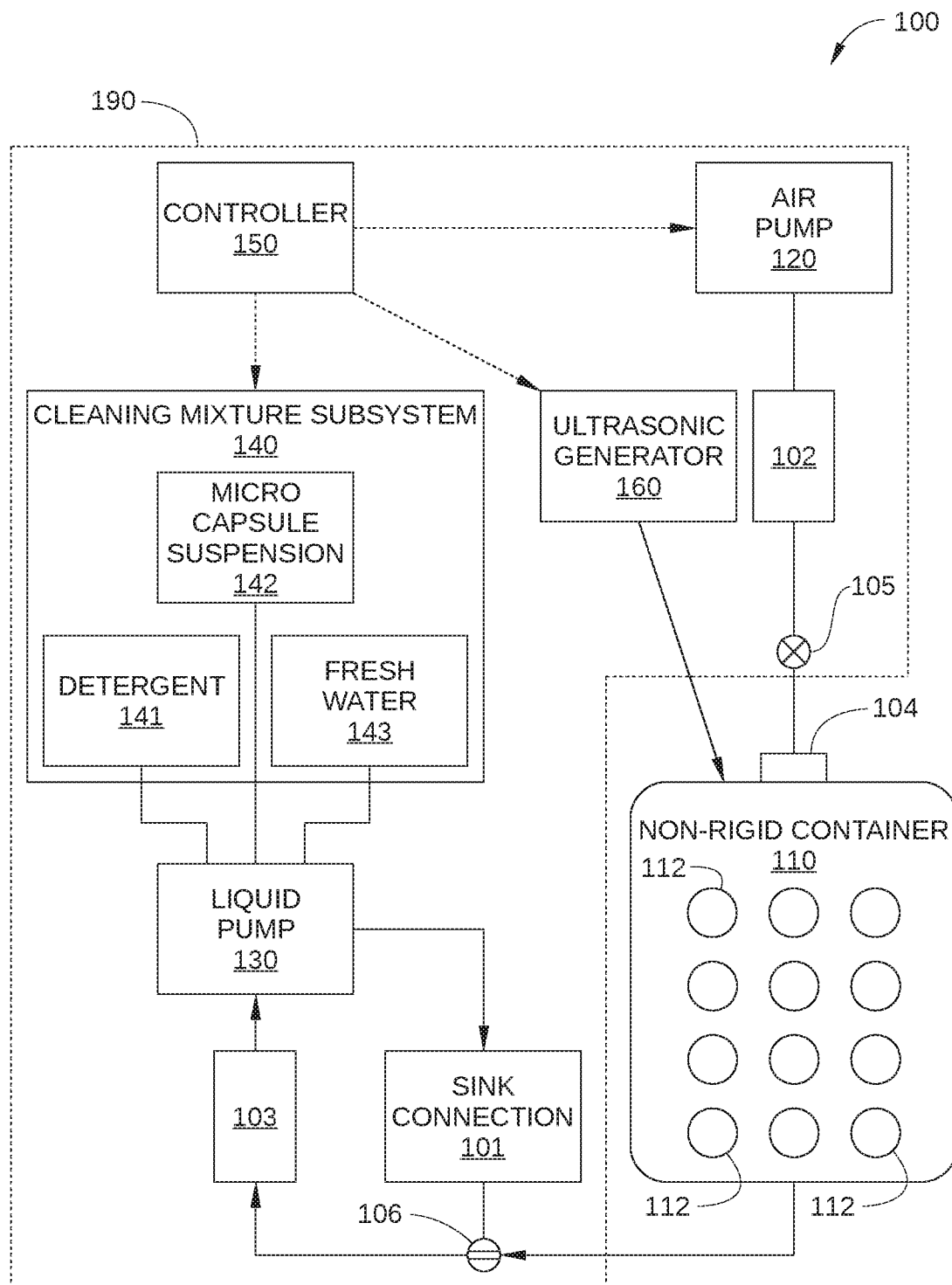


FIG. 5C

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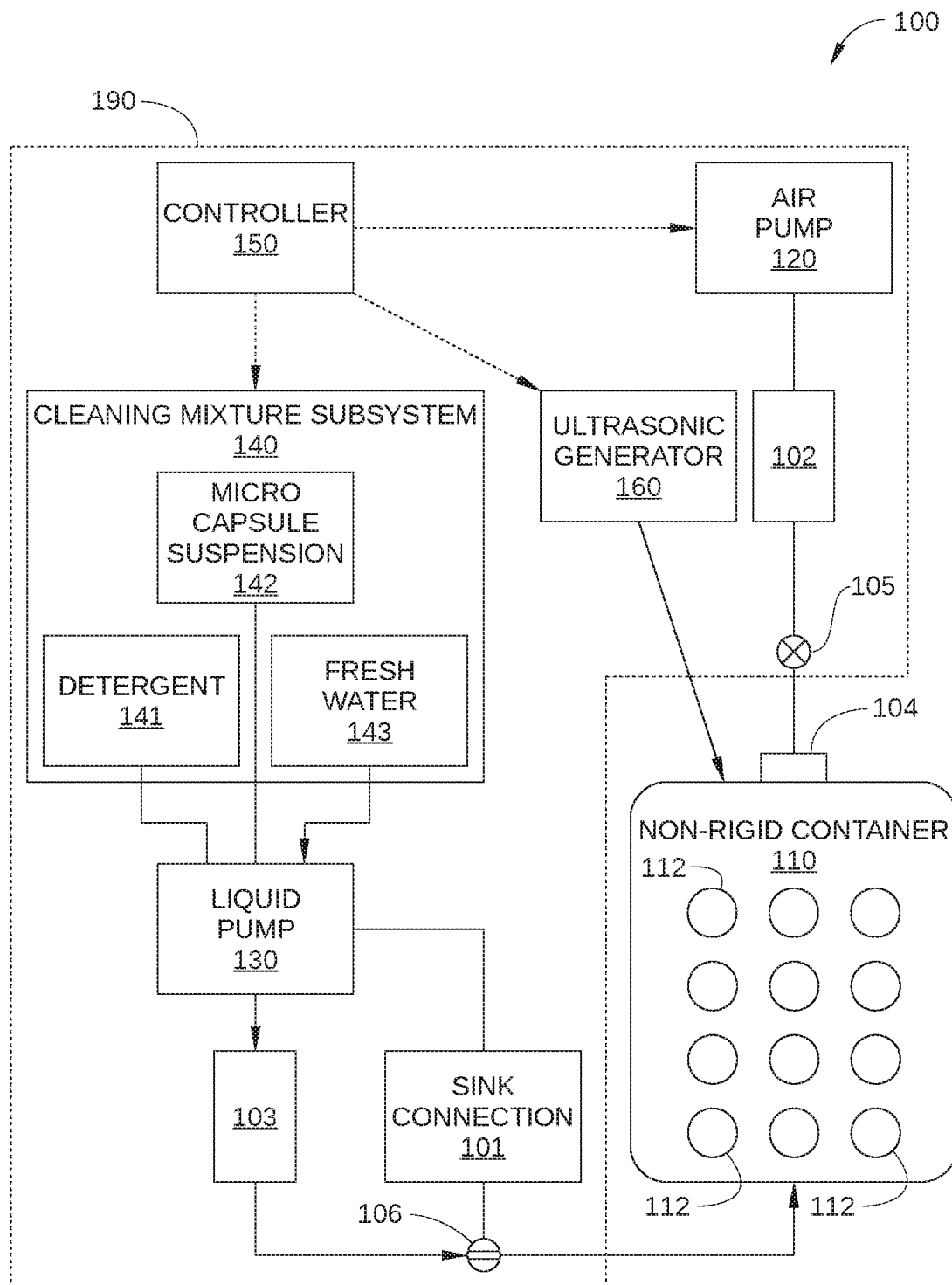


FIG. 5D

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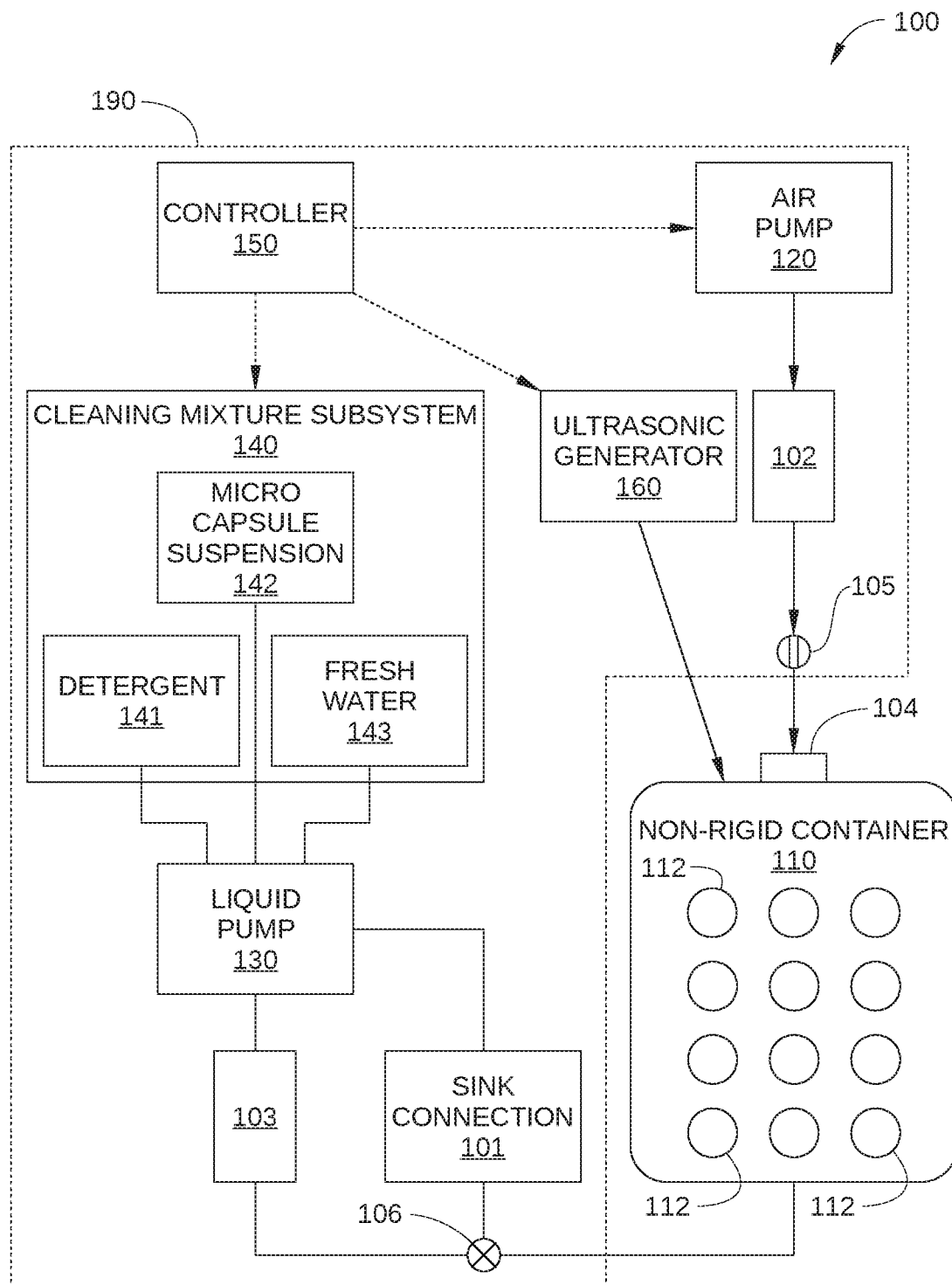


FIG. 5E

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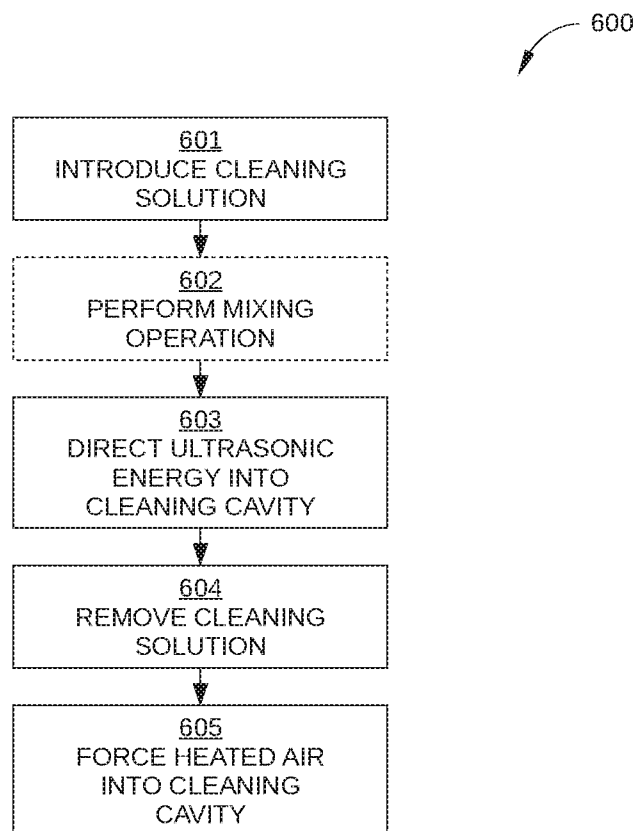


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/025806

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B08B 3/12; B05B 17/06; B08B 3/10; D06F 58/10; D06F 58/14; D06F 73/00; D06F 73/02(2017.01)
 CPC - B08B 3/12; B05B 17/06; B05B 17/0607; B08B 3/10; B08B 3/123; B08B 3/126; D06F 58/10; D06F 58/14; D06F 73/00; D06F 73/02; F26B 5/02; F26B 25/06 (2017.05)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

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

USPC - 34/202; 34/218; 34/219; 34/222; 34/223; 34/224; 34/225; 34/622; 68/5C; 223/51; 223/70 (keyword delimited)

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/0205513 A1 (MAGNUSSON) 15 August 2013 (15.08.2013) entire document	1-19
Y	US 8,048,232 B1 (KUSUURA) 01 November 2011 (01.11.2011) entire document	1-19
Y	US 2010/0282785 A1 (ROSELLE et al) 11 November 2010 (11.11.2010) entire document	10
Y	US 6,219,871 B1 (FREDERICK et al) 24 April 2001 (24.04.2001) entire document	13
A	US 4,193,818 A (YOUNG et al) 18 March 1980 (18.03.1980) entire document	1-19
A	US 2002/0053607 A1 (GAALOUL et al) 09 May 2002 (09.05.2002) entire document	1-19
A	US 2006/0191424 A1 (MCLOUGHLIN et al) 31 August 2006 (31.08.2006) entire document	1-19

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

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

03 June 2017

Date of mailing of the international search report

15 JUN 2017

Name and mailing address of the ISA/US

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

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