INTERACTIVE SEALING ARRANGEMENT PRESSURIZED FLUID STORAGE SYSTEM AND METHOD

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ABSTRACT

An interactive sealing arrangement includes a sealing member operatively disposed across a gap between a first wall and a second wall that is movable relative to the first wall and at least partially defines a storage chamber. A passage extends through the second wall and is in fluid communication with the sealing member such that a portion of an associated fluid at an elevated pressure within the storage chamber can interact with the sealing member and thereby urge at least a portion of the sealing member into abutting engagement with the first wall. A pressurized fluid storage system for containing a quantity of an associated fluid at an elevated pressure level that includes such an interactive sealing arrangement and a method of sealing are also included.
INTERACTIVE SEALING ARRANGEMENT PRESSURIZED FLUID STORAGE SYSTEM AND METHOD


BACKGROUND

[0002] The subject matter of the present disclosure broadly relates to the art of pressure vessels and, more particularly, to an interactive sealing arrangement for use in storing pressurized fluids as well as a pressurized fluid storage system and method that utilize the same.

[0003] Pressure vessels and sealing arrangements are generally well known and commonly used. With the continued interest in developing alternative energy sources, new applications and/or uses for pressure vessels may be developed for which known pressure vessels and/or sealing arrangements may be inadequate. In some cases, the capability of known pressure vessels to achieve desired levels of compression, such as for the storage of liquids and/or gases, for example, may be insufficient. In other cases, known sealing arrangements may be incapable of maintaining pressurized fluids at these desired levels of compression for sufficient periods of time.

[0004] Accordingly, it is believed desirable to develop sealing arrangements as well as pressurized fluid storage systems and methods that advance the art of pressure vessels and high pressure sealing arrangements.

[0005] It will be appreciated that the subject concepts may find particular application and/or use in connection with the compression and storage of liquids and/or gases associated with usage as in connection with energy sources. As such, substances such as hydrogen, natural gas and liquefied natural gas, for example, may be specifically referred to herein. Additionally, applications associated with the manufacture of energy sources as well as the storage of fuel on moveable vehicles (e.g., watercraft, aircraft and/or land vehicle) are also contemplated. However, it is to be distinctly understood that the subject concepts are broadly applicable in connection with a wide variety of applications and/or uses, and that any particular reference herein to specific applications and/or uses are merely exemplary and not intended to be limiting.

BRIEF SUMMARY

[0006] One example of a pressurized fluid storage system in accordance with the subject matter of the present disclosure for containing a quantity of an associated fluid at an elevated pressure level can include a pressure vessel including a vessel wall that at least partially defines a storage chamber for storing a quantity of the associated fluid. The vessel wall can include an opening providing access to said storage chamber. A moveable wall structure can be displaceably supported within the pressure vessel and can extend across the opening to at least partially retain a quantity of the associated fluid in the storage chamber. The moveable wall structure can include an outer peripheral wall disposed adjacent the vessel wall such that a gap is formed between the outer peripheral wall and the vessel wall. An end wall can be disposed toward the storage chamber. A groove can extend into the moveable wall structure from along the outer peripheral wall such that the groove is in fluid communication with the storage chamber through the gap. At least one passage can extend through at least a portion of the moveable wall structure and in fluid communication between the groove and the storage chamber. An interactive sealing arrangement can be operatively disposed between the pressure vessel and the moveable wall structure and can be capable of forming a substantially fluid-tight seal therebetween. The interactive sealing arrangement can include a first sealing member that is positioned between the moveable wall structure and the vessel wall and is disposed at least partially within the groove of the moveable wall structure. The first sealing member can include a first peripheral portion disposed toward the vessel wall and a second peripheral portion disposed along the groove in fluid communication with the at least one passage such that a portion of the associated fluid at an elevated pressure within the storage chamber can interact with the second peripheral portion of the first sealing member and thereby urge the first peripheral portion of the first sealing member into abutting engagement with the vessel wall of the pressure vessel.

[0007] One example of an interactive sealing arrangement in accordance with the subject matter of the present disclosure, which is suitable for use on an associated pressurized storage container having an associated container wall that at least partially defines an associated storage chamber for containing a quantity of an associated pressurized fluid, can include a first wall and a sealing member. The first wall can be moveable with respect to the associated container wall and at least partially defines the associated storage chamber together therewith. The first wall includes an outer peripheral surface that is disposed adjacent the associated container wall. An end surface is disposed toward the associated storage chamber. A groove extends into the first wall from along the outer peripheral surface. At least one passage extends through the first wall in fluid communication with the groove. The sealing member is at least partially disposed within the groove between the first wall and the associated container wall. At least a portion of the sealing member is in fluid communication with the associated pressurized fluid through the passage such that the associated pressurized fluid can interact with the sealing member and thereby urge at least a portion of the sealing member into abutting engagement with the associated container wall.

[0008] One example of a method of storing pressurized fluid in accordance with the subject matter of the present disclosure can include providing a first wall that includes a first wall surface at least partially defining a storage chamber having a volume. The method can also include providing a second wall that is displaceable relative to the first wall to vary the volume of the storage chamber. The second wall can include an outer side surface, a groove formed into the second wall along the outer side surface and a first passage extending through at least a portion of the second wall and in fluid communication with the groove. The outer side surface can be spaced inwardly from the first wall surface such that a gap is at least partially formed therebetween. The method can further include positioning a sealing member within the groove and between the first and second walls. The method can also include pressurizing a quantity of fluid within the storage chamber. The method can further include exposing a first
portion of the sealing member to the quantity of pressurized fluid through the gap. The method can also include exposing a second portion of the sealing member to the quantity of pressurized fluid through the first passage such that the quantity of pressurized fluid interacts with the sealing member and thereby urges the first portion of the sealing member into abutting engagement with the first wall surface of the first wall.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a cross-sectional side view of one example of a pressurized fluid storage system that includes a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure.

[0010] FIG. 2 is a cross-sectional side view of a portion of the pressurized gas storage system in FIG. 1 illustrating the moveable wall and the interactive sealing arrangement thereof in additional detail.

[0011] FIG. 3 is an exploded isometric view of the moveable wall and the interactive sealing arrangement in FIGS. 1 and 2.

[0012] FIGS. 4 and 5 are cross-sectional side views of another example of a pressurized fluid storage system that includes an alternate embodiment of a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure respectively shown in moveable and sealed conditions.

[0013] FIG. 6 is an enlarged cross-sectional side view of the portion of the interactive sealing arrangement identified in Detail 6 of FIG. 5.

[0014] FIGS. 7-9 are cross-sectional side views of yet another example of a pressurized fluid storage system that includes yet another alternate embodiment of a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure respectively shown being transferred from a movable condition to a sealed condition.

[0015] FIG. 10 is an enlarged cross-sectional side view of the portion of the interactive sealing arrangement identified in Detail 10 of FIG. 7.

[0016] FIG. 11 is a cross-sectional side view of still another example of a pressurized fluid storage system that includes still another alternate embodiment of a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure shown in a movable condition.

[0017] FIG. 12 is an enlarged cross-sectional side view of another example of a sealing element suitable for use in an interactive sealing arrangement in accordance with the subject matter of the present disclosure.

[0018] FIG. 13 is an enlarged cross-sectional side view of yet another example of a sealing element suitable for use in an interactive sealing arrangement in accordance with the subject matter of the present disclosure.

[0019] FIG. 14 is an enlarged cross-sectional side view of still another example of a sealing element suitable for use in an interactive sealing arrangement in accordance with the subject matter of the present disclosure.

[0020] FIG. 15 is a greatly enlarged portion of the sealing element in FIG. 14 taken along line 15-15 thereof.

[0021] FIG. 16 is an enlarged cross-sectional side view of a further example of a sealing element suitable for use in an interactive sealing arrangement in accordance with the subject matter of the present disclosure.

DETAILED DESCRIPTION

[0022] Turning to the drawings, which illustrate examples of the subject matter of the present disclosure and which are not intended to be in any way limiting, FIG. 1 illustrates a pressurized fluid storage system 100 that includes a pressure vessel, including at least one vessel wall, such as a container or storage structure 102, for example, a moveable wall, such as a piston 104, for example, that is at least partially received within the storage structure, and a sealing arrangement 106 that is operatively disposed therebetween. In a preferred embodiment, sealing arrangement 106 can take the form of an interactive sealing arrangement that utilizes the pressurized fluid (e.g., gas and/or liquid) stored within storage structure 102 to urge a sealing member or element of the sealing arrangement into abutting engagement with the storage structure and/or the moveable wall. It is anticipated that such an arrangement will act to increase the effectiveness of the seal (i.e., the barrier) formed by the sealing arrangement, particularly at elevated pressure levels. As one example, a sealing member or element of the sealing arrangement can be placed in fluid communication with the pressurized fluid (e.g., gas and/or liquid) stored within the storage structure, such as by way of one or more fluid passages extending through the moveable wall, for example. It will be appreciated, however, that the arrangements shown and described herein are merely examples of suitable arrangements and that any other designs, configurations and/or constructions in accordance with the subject matter of the present disclosure could alternately be used.

[0023] Storage structure 102 includes at least one wall that at least partially defines a storage chamber suitable for storing or otherwise containing a quantity of fluid at an elevated pressure level. In the example shown in FIGS. 1 and 2, storage structure 102 includes a first or side wall 108 and a second or end wall 110 that together define a storage chamber 112. If two or more walls are used, it will be appreciated that the same can be secured to one another in any manner capable of forming a substantially fluid-tight connection of suitable strength, such as through the use of a flowed-material joint JNT, for example.

[0024] The movable wall can be of any suitable type, kind, configuration and/or construction, and can formed from or otherwise include any suitable number of one or more wall portions, segments and/or other components. For example, the moveable wall could be formed from two or more axially aligned (e.g., stacked) wall sections (not shown) that are secured to one another using one or more fasteners (not shown) to thereby form the moveable wall. Further to the above example, a first or inner wall section (not shown) having a first cross-sectional dimension could be secured between two second or outer wall sections (not shown) that have a second, greater cross-sectional dimension. The inner and outer wall sections could be secured together using a fastener (not shown) and, in this manner, an annular groove for receiving a sealing element of the sealing arrangement could be provided. It will be appreciated, however, that any other suitable arrangement and/or construction could alternately be used.

[0025] In the arrangement illustrated in FIGS. 1 and 2, piston 104 can include an outer peripheral wall 114 that extends in a generally longitudinal direction between a first or
inner end wall 116 and a second or outer end wall 118 of the piston. The moveable wall can be actuated or otherwise displaced in any suitable manner and through the use of any suitable device and/or system. As one example, a piston rod 120 is shown as operatively engaging piston 104 and projecting longitudinally from outer end wall 118 thereof in a direction opposite storage chamber 112. Piston rod 120 can extend from a suitable actuator or actuating device, such as a hydraulic cylinder (not shown), for example, that is capable of displacing the piston relative to the vessel wall (e.g., toward and/or away from end wall 110 of storage structure 102).

[0026] It is contemplated that a sealing arrangement in accordance with the subject matter of the present disclosure will permit the storage of fluids (e.g., gases and/or liquids) at pressures that may exceed the capacity of presently available pumps or fluid pumping systems that may be used to transfer fluids into the storage chamber. In order to achieve the desired high pressure levels for storing fluids, pressurized gas storage system 100 is shown as optionally including a second storage structure section 122 that is operatively interconnected with a first storage structure section, such as storage structure 102, for example. Second storage structure 122 includes a first or side wall 124 that extends longitudinally between opposing ends 126 and 128 to at least partially define an extended portion 112A of storage chamber 112. Side wall 124 can be operatively interconnected with side wall 108 of storage structure 102 such that a substantially fluid-tight seal is formed therebetween, as is generally indicated by item number 130.

[0027] Additionally, side walls 108 and 124 are preferably cooperable with one another such that a substantially uniform and continuous inner surface 132 of the storage structure is provided, such as may extend circumferentially about a longitudinally-extending axis AX (FIG. 2), for example. Such an arrangement would permit piston 104 to be received within storage chambers 112 and 112A, and displaced along inner surface 132 to pressurize the quantity of fluid within the storage structure, such as is discussed hereinafter, for example. In one preferred arrangement, piston 104 can be approximately circular in cross-section and can be received within the storage chamber in closely fitted relation to inner surface 132 of the storage structure. In such case, inner surface 132 can, for example, be substantially cylindrical in shape.

[0028] In use, piston 104 can be positioned at a first or extended position, which is indicated by reference character A in FIG. 1, toward end 126 of second storage structure section 122. A pump 134 can be in fluid communication with storage chamber 112 (including storage chamber portion 112A), and can operate to supply a quantity of fluid into the storage chamber at a suitable pressure. One example of a suitable pressure may be the highest pressure level that is practical to achieve using pump 134, such as a pressure level within a range of approximately 300 psi to approximately 2000 psi, for example. Piston 104 can then be advanced through the use of a suitable actuator, such as may be operatively connected to piston rod 120, for example, along second storage structure section 122 to a second or compressed position within storage structure 102, as is indicated by reference character B in FIG. 1.

[0029] It will be recognized that the displacement of piston 104 from position A to position B will act to compress a gas or gas/liquid mixture within storage chamber 112, such as for storage or transportation, for example. It is expected that a compression ratio of approximately 10:1 or greater may be feasible using such a construction and that a sealing arrangement in accordance with the subject matter of the present disclosure will be capable of maintaining compressed gas (or a gas/liquid mixture) at the resulting high pressure level. For many applications, it is expected that it will be desirable to eliminate the force used to compress the gas once the desired degree of compression has been achieved. This can be accomplished by locking piston 104 in the second or compressed position (e.g., position B), such as by using deadlock devices 136, for example.

[0030] In some cases, it may be possible for the second storage structure section (e.g., section 122) to be used only for the period during which compression takes place. Accordingly, second storage structure section 122 can be removably attached to storage structure 102 such that the same can be removed after the compression action is completed. In one embodiment, storage structure 102, which could be used to contain the compressed gas, could be of a smaller size (e.g., shorter length). In such case, once the compression has been completed, second storage structure section 122 could be removed, which may allow for easier access and handling of the smaller portion (i.e., storage structure 102).

[0031] As illustrated in FIGS. 1 and 2, outer peripheral wall 114 is disposed in radially-inwardly spaced relation with respect to inner surface 132 of the storage structure. As such a clearance or gap 138 is provided between the piston and storage structure that permits the piston to be displaced relative thereto. It will be appreciated, however, that such a clearance or gap is not to scale and is shown as having an exaggerated dimension for purposes of ease of illustration. In a preferred embodiment, the actual separation will preferably be the least allowable with reasonable and practical machining processes, such as within a range of from about 0.0005 inches to about 0.050 inches, for example. It will be appreciated that a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure can include any arrangement and/or configuration of features and/or components that are suitable for bridging the gap (e.g., gap 138) between the storage structure and the moveable wall and thereby at least partially forming a substantially fluid-tight seal between the storage structure and the moveable wall. It will be further appreciated that any such features and/or components can be provided on or along any walls or surfaces of any one or more components of pressurized fluid storage system 100 and in any suitable manner.

[0032] As one example, sealing arrangement 106 is shown as being operatively disposed between piston 104 and storage structure 102 such that a substantially fluid-tight seal can be formed therebetween. Such a sealing arrangement can include any one or more sealing members or elements of any suitable shape, size, shape, configuration, construction and/or arrangement. For example, the one or more sealing members or elements could have a circular, oval, rectangular or other cross-sectional shape (e.g., quad-ring). Additionally, the one or more sealing members or elements can be formed from any suitable material or combination of materials. In some cases, a sealing member may be formed from a single material, such as flexible polymeric material (e.g., synthetic rubber and urethane), a rigid polymeric material (e.g., polyethylene, polypropylene and PTFE), a metal or any combination thereof. In other cases, a sealing member could be formed from one or more layers of materials, such as a closed-cell...
foam, for example. In one such arrangement, layers of different closed-cell foams could be formed in a nested or annularly stacked arrangement, for example. 

[0034] As a more specific example, sealing arrangement 106 is shown in FIGS. 1-3 as including a sealing member or element 140 that extends circumferentially about piston 104 adjacent inner surface 132 of side wall 108. The sealing element is shown as being of a circular or oval-shaped cross section, such as a conventional o-ring, for example. It will be appreciated, however, that any other cross-sectional shape or configuration could alternately be used. Additionally, sealing element 140 could be formed from a suitable elastomeric material, such as a synthetic rubber or urethane, for example. 

[0035] The one or more sealing elements of sealing arrangement 106 can be operatively interengaged with the moveable wall (e.g., piston 104) of the pressurized fluid storage system in any suitable manner. One example of a suitable construction is shown in FIGS. 1-3 in which piston 104 includes a groove 142 or other suitable feature that extends about the periphery of the piston (e.g., circumferentially about exterior surface of outer peripheral wall 114). It will be appreciated that the groove or other suitable feature can be of any suitable shape, form and/or configuration. In the exemplary arrangement shown in FIGS. 1-3, for example, groove 142 is shown as being of a rectangular-shaped cross section that includes a bottom wall 144 and opposing side walls 146 that are axially-spaced from one another at least partially defining the groove. 

[0036] In the exemplary arrangements shown and described herein, the one or more sealing elements (e.g., sealing member 140) are each at least partially received within a groove (e.g., groove 142) or other suitable feature on or along the moveable wall (e.g., piston 104). In this manner, the one or more sealing elements can be retained in position on piston 104 as the piston is displaced in an axial direction, as is represented by arrow A1 in FIG. 1. 

[0037] During movement toward and away from a compressed position (e.g., position B), it is normally desirable for a sealing arrangement, such as sealing arrangement 106, for example, to generate a reduced level of resistance to movement, such as may be due to friction generated by contact with the storage structure, for example. In some cases, it may be desirable for the sealing arrangement to generate little or no resistance to movement, as frictional movement is commonly associated with wear between the moving parts. In the compressed position, however, it is desirable for the one or more sealing elements (e.g., sealing member 140) that form sealing arrangement 106 to bridge the gap or distance between the moveable wall and the storage structure. Additionally, it is anticipated that some amount of fluid loss may occur during transfer of the moveable wall into a compressed position. It is expected, however, that such fluid loss should be minimal and within acceptable limits. Optionally, a suitable exhaust and/or fluid recapture system (not shown) could be included. 

[0038] One feature of a sealing arrangement in accordance with the subject matter of the present disclosure is the capability to increase sealing engagement as the moveable wall approaches the compressed position. While the distance the one or more sealing elements travel to bridge the gap between the moveable wall and the storage structure is expected to be small, the compressive forces that are expected to be generated by the one or more sealing elements, such as may be due to the same being in fluid communication with the elevated pressure level of the contained fluid, is expected to allow containment at pressures beyond those presently attainable. 

[0039] The actuation of the one or more sealing members from a first or moveable condition to a second or compressed condition can be achieved in any suitable manner. As one example, one or more fluid passages can be provided that extend through the moveable wall to permit fluid communication between the one or more sealing elements and the pressurized fluid contained in the storage chamber of the storage structure. The elevated pressure level of the fluid contained in the storage chamber acts to bias or otherwise urge at least a portion of the one or more sealing members into abutting engagement with a wall of the storage chamber to form a substantially fluid-tight seal between the moveable wall and the storage structure. 

[0040] It will be appreciated that the one or more fluid passages can take any suitable size, shape, form, configuration and/or arrangement. In the exemplary embodiment shown in FIGS. 1-3, piston 104 includes two passages 148 that extend through at least a portion of piston 104. In the exemplary arrangement shown, each passage includes a first opening 150 that is provided on piston 104 in an area that is exposed to the pressurized fluid contained within the storage structure, such as along end wall 116 of piston 104, for example. Each passage also shown as including a second opening 152 that is disposed adjacent one of the sealing elements (e.g., sealing element 140). In this manner, pressurized fluid from the storage chamber can be communicated to one or more of the one or more sealing elements for biasing or actuation thereof. 

[0041] In the exemplary arrangement shown in FIGS. 1-3, second openings 152 are positioned such that the pressurized fluid is communicated in or along groove 142, such as by providing second openings 152 along bottom wall 144, for example. It will be appreciated, however, that any other suitable arrangement could alternately be used. Additionally, it will be appreciated that passages 148, together with the openings thereof, can be of any suitable size, shape, quantity (e.g., a number within a range of from 1 to 50), configuration and/or arrangement. As one example, a minimal number of passages (e.g., from 1 to 10) are provided that extend through the piston from an area along end wall 116 that is disposed radially-inwardly from outer peripheral wall 114. One benefit of such an arrangement is that issues related to the structural integrity of the piston can be minimized or even eliminated. 

[0042] Another example of a pressurized fluid storage system 200 is shown in FIGS. 4-6 that includes an alternate embodiment of a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure. Storage system 200 includes a storage structure 202, such as has been described above with regard to storage structure 102, for example, as well as a moveable wall and an interactive sealing arrangement. In the exemplary embodiment shown in FIGS. 4-6, the moveable wall includes a first piston 204 and the interactive sealing arrangement is identified by item number 206. 

[0043] Storage structure 202 is shown as including a first or side wall 208 that at least partially defines a longitudinally-extending storage chamber 210 having a longitudinal axis AX. It will be appreciated that side wall 208 and storage chamber 210 can be of any suitable type, kind, construction and/or configuration, such as has been described above in
detail with regard to storage structure 102, for example. As such, a further description of storage structure 202 is not provided here.

[0044] First piston 204 and sealing arrangement 206 differ from piston 104 and sealing arrangement 106 in several respects. For example, first piston 204 is configured to permit selective actuation of sealing arrangement 206, whereas the actuation of sealing arrangement 106 is related directly to the pressure level of the fluid confined in the storage chamber. As another example, sealing arrangement 206 is shown as including a plurality of sealing elements that at least partially define at least one intermediate chamber between the storage chamber and the atmosphere external to the storage system. As a further example, sealing arrangement 206 is shown as including an optional migration-reducing substance disposed in the intermediate chamber, which substance may be used to reduce or otherwise minimize the migration of the pressurized fluid stored within the storage chamber beyond the sealing arrangement.

[0045] In the exemplary embodiment in FIGS. 4-6, first piston 204 is shown as including a first outer peripheral or side wall 212 that extends approximately longitudinally between a first inner end wall 214 and a first outer end wall 216. In a preferred arrangement, first outer peripheral wall 212 is cooperatively dimensioned with respect to side wall 208 such that a clearance or gap 218 is provided between the first piston and the side wall of the storage structure, which gap permits the first piston to be displaced relative to the storage structure. It will be appreciated that such a clearance or gap is not to scale and is shown as having an exaggerated dimension for purposes of clarity and ease of illustration. In a preferred embodiment, the actual separation will preferably be the least allowable with reasonable and practical machining and manufacturing processes, such as within a range of from about 0.0005 inches to about 0.050 inches, for example.

[0046] As discussed above, for example, first piston 204 can be actuated or otherwise displaced in any suitable manner and through the use of any suitable device and/or system. As one example, a first piston rod 220 projecting longitudinally from first outer end wall 216. Such a piston rod can, for example, extend from a suitable actuating device, such as a hydraulic cylinder (not shown), for example, that is capable of displacing the first piston with respect to the storage structure.

[0047] A sealing arrangement in accordance with the subject matter of the present disclosure, such as sealing arrangement 206, for example, can include any number of one or more sealing elements. In shown in the exemplary embodiment in FIGS. 4-6, sealing arrangement is shown as including a first sealing element or membrane 222 and a second sealing element or membrane 224 that is disposed in longitudinally spaced relation to the first sealing element such that an intermediate chamber 226 is at least partially defined therebetween. In the exemplary embodiment shown, intermediate chamber 226 is further defined by side walls 208 and first outer peripheral wall 212, and, in a preferred embodiment, extends circumferentially about first piston 204. As discussed above, it will be appreciated that sealing elements 222 and 224 can be of any suitable size, shape, type, kind, configuration, construction and/or arrangement; and can be formed from any suitable material or combination of materials.

[0048] As discussed above, a moveable wall and sealing arrangement in accordance with the subject matter of the present disclosure can be adapted to permit selective actuation of the sealing arrangement between a first or moveable condition and a second or sealed condition. In the first or moveable condition, the sealing arrangement provides minimized or at least reduced interaction with at least one of the moveable wall and the storage structure so that the moveable wall can be more easily displaced. Such a condition may also minimize or at least reduce wear on the sealing arrangement during displacement of the moveable wall. In the second or sealed condition, the sealing arrangement provides maximized or at least significantly increased interaction with at least one of the moveable wall and the storage structure. Actuation of the sealing arrangement into the second or sealed condition can, for example, be performed once the moveable wall has reached a predetermined position or once the desired compression of the fluid contained in the storage structure has been achieved.

[0049] It will be appreciated that the selective actuation of the sealing arrangement between a first or moveable condition and a second or sealed condition, as discussed above, can be provided in any suitable manner and using any suitable combination of components and/or features. In the exemplary arrangement shown in FIGS. 4-6, for example, first piston 204 includes a cavity side wall 228 and a cavity end wall 230 that at least partially define an actuation cavity 232 that extends into first piston 204 from along first inner end wall 214. A second piston 234 includes a second inner end wall 236, a second outer end wall 238 and a second outer peripheral or side wall 240 that extends longitudinally therebetween. Second piston 234 is at least partially received within actuation cavity 232 such that second outer peripheral wall 240 is disposed in facing relation to cavity side wall 228. In a preferred arrangement, the second outer peripheral wall is spaced radially-inwardly from the cavity side wall such that a clearance or gap 242 is at least partially defined therebetween.

[0050] As discussed above, second piston 234 is adapted for selective actuation between a first position, which is shown in FIG. 4, and a second position, which is shown in FIG. 5. It will be appreciated that the second piston can be displaced between the first and second positions in any suitable manner. In the exemplary arrangement shown in FIGS. 4 and 5, first piston rod 220 includes an actuation passage 244 that extends longitudinally therethrough and second piston 234 includes a second piston rod 246 that extends longitudinally from along second outer end wall 238. Second piston rod 246 is shown as extending through actuation passage 244 such that second piston 234 can be selectively displaced relative to first piston 204, such as, for example, through the use of a suitable actuation device (not shown) that is operatively connected to second piston rod 246.

[0051] In the first position of second piston 234, which is shown in FIG. 4, a substantially fluid-tight seal is formed across gap 242 that substantially fluidically-isolates actuation cavity 232 from storage chamber 210. In the second position of the second piston, which is shown in FIG. 5, a substantially fluid-tight seal is formed across gap 242 that substantially fluidically-isolates actuator passage 244 from storage chamber 210. It will be appreciated that such substantially fluid-tight seals can be formed in any suitable manner. In the exemplary arrangement shown in FIGS. 4 and 5, a third sealing element or member 248 is operatively disposed between the first and second pistons to form the substantially fluid-tight seal therebetween when second piston 234 is disposed in the first position. Additionally, a fourth sealing element or member 250 can be operatively disposed between the first and second pistons to form the substantially fluid-tight seal therebetween when second piston 234 is disposed in the second position.
seal therebetween when second piston 234 is disposed in the second position. It will be appreciated, however, that any other suitable arrangement could alternately be used. Additionally, it will be understood that first, second, third and/or fourth (if provided) sealing elements, which are respectively identified by item numbers 222, 224, 246 and 250, can be retained on or along the first or second piston in any suitable manner, such as through the use of grooves 252 that extend into first piston 204 and at least partially receive a sealing element. Grooves 252 can take any suitable shape, form and/or configuration, such as has been described above with regard to groove 142, for example.

As discussed above, one or more of the sealing members (e.g., one or more of first-fourth sealing elements 222, 224, 226 and/or 228) are capable of actuation from a first or moveable condition to a second or compressed condition and such actuation can be achieved in any suitable manner. As was previously described, one or more fluid passages can be provided that extend through the moveable wall to permit fluid communication between one or more of the sealing elements and the pressurized fluid contained in the storage chamber of the storage structure. It will be appreciated that the one or more fluid passages, together with the corresponding openings or end thereof, can be of any suitable size, shape, configuration and/or arrangement, and that any number of one or more occurrences of one or more of the fluid passages can be used.

In the exemplary arrangement shown in FIGS. 4-6, two groups that each include several fluid passages or fluid passage portions are provided in approximately diametrically opposed sections of first piston 204. With second piston 234 in the first position, as shown in FIG. 4, the fluid passages extending through first piston 204 are substantially fluidically-isolated from storage chamber 210. As second piston 234 is displaced toward the second position, which is shown in FIG. 5, a first passage or passage portion 254 is disposed in fluid communication with storage chamber 210. As such, pressurized fluid from the storage chamber is communicated to first passage portion 254. Second and third passages or passage portions 256 and 258 are in fluid communication between first passage portion and the corresponding grooves of first and second sealing elements 222 and 224, respectively. As described above, the increased pressure from the pressurized fluid contained in storage chamber 210 acts to urge or otherwise bias the first and second sealing elements into abutting engagement with side wall 208 of the storage structure to thereby generate a sealed condition. An optional fourth passage or passage portion 260 is shown extending between first passage portion 254 and the groove associated with optional fourth sealing element 250. Using the same principles of operation described above, an improved seal could be achieved between the first and second pistons while the second piston is in the second position shown in FIG. 5.

As an alternative to providing fourth sealing element 250 and fourth passage portion 260, a conventional seal (not shown) could be provided on or along actuator passage 244 between first piston rod 220 and second piston rod 246. As another alternative, which is also not shown in the drawings, second piston 234 could be entirely encased within the first piston, so that there is no opening to an external pressure area (i.e., a lower pressure atmosphere ATM). A suitable electromagnetic or other actuator could be used to displace second piston 234 between the first and second positions, for example.

In an arrangement in which fourth sealing element 250 and fourth passage portion 260 are provided, as described above, first piston 204 can optionally include a fifth passage or passage portion 262 that can be selectively placed in fluid communication with an external pressure area, such as a lower pressure atmosphere ATM, for example, to at least briefly decrease the pressure level within fourth passage portion 260 and thereby permit second piston 234 to be more easily displaced from the second position, which is shown in FIG. 5, to the first position, which is shown in FIG. 4. Additionally, such an arrangement and method of operation may assist in decreasing wear on or along fourth sealing element 250 and/or second outer peripheral wall 240 of second piston 234. It will be appreciated that such selective communication along fifth passage portion 262 can be achieved in any suitable manner, such as by communicating an actuation signal 264 to a suitable fluid control device, such as a valve assembly 266, for example.

As discussed above, another feature of a moveable wall and sealing arrangement in accordance with the subject matter of the present disclosure involves the use of an optional migration-reducing substance to minimize or at least reduce the migration of the pressurized fluid stored within the storage chamber beyond the sealing arrangement. It will be appreciated that such a substance can be provided in any suitable manner. For example, a quantity of migration-reducing substance 268 can be contained within a suitable dispensing device 270, as is illustrated in FIG. 4. It will be appreciated that such a dispensing device can be of any suitable type, kind, configuration and/or construction and, in the exemplary embodiment shown, is supported on side wall 208 of storage structure 202. Additionally, it will be recognized that first piston 204 is positioned along side wall 208 such that a dispensing nozzle (not numbered) of dispensing device 270 is in fluid communication with intermediate chamber 226. Upon achieving a substantially fluid-tight seal, such as is illustrated in FIG. 5, for example, a dispensing signal 272 (FIG. 4) can be communicated to dispensing device 270 such that migration-reducing substance 268 is transferred into intermediate chamber 226, as is shown in greater detail in FIG. 6.

It will be appreciated that any suitable substance or combination of substances can be used to form a quantity of migration-reducing substance, such as substance 268, for example. Additionally, it will be appreciated that the quantity of migration-reducing substance can take any suitable form, such as a gas, a liquid, a solid or any combination thereof. Furthermore, it will be appreciated that the quantity of migration-reducing substance can act to minimize or at least reduce the migration of pressurized fluid stored within the storage chamber through or otherwise outwardly beyond the sealing arrangement, such as sealing arrangement 206, for example, in any suitable manner or combination of manners.

As one example, the migration-reducing substance could act alter the portion of the pressurized fluid that is captured within intermediate chamber, such as by modifying the chemical structure of the pressurized fluid in a manner that would minimize penetration or tunneling through one or more of the sealing elements (e.g., sealing elements 222 and 224), for example. More specifically, a migration-reducing substance, such as unsaturated vegetable oil, for example, could be used to increase the atomic or molecular size of a gas, such as hydrogen, for example, that is contained in the storage chamber. As another example, other migration-reduc-
ing substances could be used, such as to substantially thicken or even solidify a pressurized fluid, for example.

[0059] As another example, the migration-reducing substance could act to decrease the magnitude of movement, for example, Brownian motion, within the pressurized fluid contained within the intermediate chamber to thereby reduce the movement or energy of the atoms or molecules of the pressurized fluid acting on the sealing elements and thereby decrease the migration, penetration, or tunneling of the atoms or molecules through the sealing elements. As one example, intermediate chamber 226 could be substantially filled with a quantity of mercury. It is expected that such a quantity of mercury would significantly retard the migration of a pressurized gas, such as natural gas, for example, through the sealing elements.

[0060] A further example of a pressurized fluid storage system 300 is shown in FIGS. 7-10 that includes an alternate embodiment of a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure. It will be appreciated that storage system 300 is substantially similar to pressurized fluid storage system 200 shown and described hereinbefore with respect to FIGS. 4-6. Pressurized fluid storage system 300 is shown as including storage structure 302, as has been described above with regard to storage structure 202, for example. Pressurized fluid storage system 300 is shown as including a moveable wall, such as a first piston 304, for example, which is shown as being substantially similar to first piston 204. Additionally, pressurized fluid storage system 300 is shown as including an interactive sealing arrangement 306, as has been described above with regard to sealing arrangement 206, for example.

[0061] Pressurized fluid storage system 300 differs from storage system 200 in that first piston 304 is adapted to dispense a migration-reducing substance, rather than utilizing a dispensing device provided on the storage structure, such as has been described above with regard to dispensing device 270 and side wall 208, for example. In view of the many similarities between storage structure 202 and 302, first pistons 204 and 304, and sealing arrangements 206 and 306, the structural and operational differences of storage system 300 will now be described with contrasting reference to storage system 200, where applicable.

[0062] First piston 304 includes a second piston 308 that is substantially similar to second piston 234. As was described above with regard to second piston 234, second piston 308 is selectively displaceable between a first position, which is shown in FIG. 7, and a second position, which is shown in FIG. 8. First piston 304 differs from first piston 204, however, in that second piston 308 is capable of displacement into a third position, which is shown in FIG. 9. As was described above, in the first position with regard to the displacement of second piston 234, second piston 308 substantially fluidically isolates each group of fluid passages 310 of first piston 304 from storage chamber 312 of storage structure 302, such as through the use of a sealing element or member 314, for example. In the second position, second piston 308 permits each group of fluid passages 310 to fluidically communicate with storage chamber 312 and thereby actuate or otherwise bias sealing elements 316-320, such as has been previously described.

[0063] It will be recognized, however, that sealing arrangement 306 includes an additional (i.e., a fifth) sealing element or member 322, in contrast to sealing arrangement 206, that sealingly engages second piston 308 in the second position. As mentioned above, fluid passages 310 are in fluid communication with the storage chamber when the second piston is in the second position. However, the inclusion of this additional sealing element substantially fluidically isolates one or more dispensing passages 324 that extend through first piston 304. The one or more dispensing passages extend in fluid communication between an actuation cavity 326 of first piston 304 and an intermediate chamber 328 that is at least partially defined between sealing elements 316 and 318. A quantity of a suitable migration-reducing substance (not shown), such as has been previously discussed, for example, can be contained within the one or more dispensing passages. Additionally, an optional substance-storage chamber 330 could be provided to increase the quantity of the migration-reducing substance that is available to be dispensed.

[0064] Upon movement of second piston 308 from the second position toward the third position, which is shown in FIG. 9, a first open end 332 of dispensing passages 324 is exposed or otherwise placed into fluid communication with the pressurized fluid contained in storage chamber 312, such as by way of a gap or opening 334 (FIG. 9) formed between second piston 308 and sealing element 322, for example. Exposure of the dispensing passages to the elevated pressure level of the fluid within the storage chamber can act to urge or otherwise dispense at least a portion of the migration-reducing substance from the dispensing passages and/or the substance-storage chamber, if provided. Optionally, a gate 336 or other suitable component could be disposed along second open end 338 of dispensing passages 324, as is shown in FIG. 10. Gate 336, if provided, can be secured on or along first piston 304 in any suitable manner. For example, the gate could be pivotally attached to the first piston and open in a radially-outward direction, such as if operating like a trap door, for example. As another example, gate 336 could extend circumferentially about first piston 304 and could be displaced in an axial direction to expose second open end 338, as is shown in FIG. 10, for example.

[0065] Still a further example of a pressurized fluid storage system 400 is shown in FIG. 11 that includes an alternate embodiment of a moveable wall and an interactive sealing arrangement in accordance with the subject matter of the present disclosure. Pressurized fluid storage system 400 includes a storage structure 402, such as has been described above with regard to storage structures 102, 202 and 302, for example. Pressurized fluid storage system 400 is shown as including a moveable wall, such as a first piston 404, for example, which is shown as being somewhat similar to first pistons 204 and 304, for example. Additionally, pressurized fluid storage system 400 is shown as including an interactive sealing arrangement 406, such as has been generally described above with regard to sealing arrangements 206 and 306, for example.

[0066] Storage structure 402 is shown as including a first or side wall 408 that at least partially defines a longitudinally-extending storage chamber 410 having a longitudinal axis AX. It will be appreciated that side wall 408 and storage chamber 410 can be of any suitable type, kind, construction and/or configuration, such as has been described above in detail with regard to storage structures 102, 202 and 302, for example. As such, a further description of storage structure 402 is not provided here.

[0067] First piston 404 is received within storage structure 402 and includes a second piston 412 that is telescopically
received within first piston 404, such as has been previously described. Second piston 412 is adapted for reciprocal displacement between a first position, which is shown in FIG. 11, and a second position, which is represented by dashed line 414 in FIG. 11. First piston 404 also includes at least one fluid passage 416 that extends in fluid communication between an actuation cavity 418 and at least a portion of an outer peripheral wall 420 of first piston 404, such as a bottom wall (not numbered) of groove 422, which can be optionally provided but extends circumferentially about the first piston, for example.

Sealing arrangement 406 can include any number of one or more sealing elements, such as has been discussed above with regard to sealing arrangements 106, 206 and 306, for example. In the exemplary embodiment shown in FIG. 11, sealing arrangement 406 includes a first sealing element or member 424 that is disposed along outer peripheral wall 420 of first piston 404, such as by being at least partially received within groove 422, for example. Sealing arrangement 406 also includes second and third sealing elements or members 426 and 428 that are disposed along an inner side wall (not numbered) that at least partially defines actuation cavity 418, such as, for example, within grooves 430 that can be optionally provided and can extend circumferentially about actuation cavity 418.

Second and third sealing elements 426 and 428 are disposed in spaced relation to one another and fluid passage 416 is in fluid communication with actuation cavity at a location between the second and third sealing elements. As such, in the first position, second piston 412 substantially fluidically isolates fluid passage 416 from the pressurized fluid contained in storage chamber 410 due to the substantially fluid-tight seal formed by second sealing element 426 between the first and second pistons. As the second piston is transferred to the second position, fluid passage 416 is placed in fluid communication with the pressurized fluid contained in storage chamber 410, which pressurized fluid acts to bias or otherwise urge first sealing element 424 in a radially-outward direction to at least partially form a substantially fluid-tight seal between first piston 404 and side wall 408 of the storage structure, such as has been described in detail hereinbefore. Third sealing element 428 can sealingly engage second piston 412 in the second position to form a substantially fluid-tight seal between the first and second pistons and thereby prevent or at least minimize the transfer pressurized fluid from the storage chamber to an external pressure area, such as a lower pressure atmosphere ATM, for example, when the first piston is in a sealed condition.

Sealing arrangement 406 also includes fourth and fifth sealing elements or members 432 and 434 that are disposed in axially-spaced relation to one another along outer peripheral wall 420 of first piston 404. Fourth and fifth sealing elements 432 and 434 are shown as being received in circumferentially-extending grooves, which can be optionally provided along first piston 404. As shown in FIG. 11, fourth sealing element 432 is disposed in axially-spaced relation to first sealing element 424 such that a first intermediate chamber 436 is at least partially defined therebetween. Fifth sealing element 434 is positioned opposite the first sealing arrangement such that a second intermediate chamber 438 is at least partially defined between the fourth and fifth sealing elements. The first and second intermediate chambers are also at least partially defined by outer peripheral wall 420 of the first piston and side wall 408 of the storage structure.

First piston 404 and sealing arrangement 406 differ from previously described piston and sealing arrangements in that an additional portion of sealing element 432 (e.g., a portion disposed toward the bottom wall of the groove in which the sealing element is received) is exposed to the pressurized fluid contained in first intermediate chamber 436, rather than being directly exposed to the pressurized fluid contained within the storage chamber. This additional portion includes a section or surface area in addition to the portion of sealing element 432 that at least partially defines intermediate chamber 436. Similarly, an additional portion of sealing element 434 (e.g., a portion disposed toward the bottom wall of the groove in which the sealing element is received) is exposed to the pressurized fluid contained in second intermediate chamber 438. In this manner, the differential pressure from storage chamber 410 to lower pressure atmosphere ATM could be stepped-down at intermediate pressure levels in each of the intermediate chambers. Accordingly, it is expected that the differential pressure acting on any one sealing element could be reduced through the use of one or more intermediate or step-down sealing arrangements in which a portion of a sealing element is fluidically interconnected with a corresponding intermediate chamber. Additionally, it will be appreciated that any suitable number of such one or more intermediate or step-down sealing arrangements can be used (e.g., from 1 to 20 intermediate arrangements spaced apart from one another).

It will be appreciated that such a step-down pressure differential can be achieved in any suitable manner using any suitable structural elements and/or features. In the exemplary embodiment shown in FIG. 11, for example, first piston 404 includes a first intermediate passage 440 that extends in fluid communication between first intermediate chamber 436 and fourth sealing element 432. Additionally, first piston 404 includes a second intermediate passage 442 that extends in fluid communication between second intermediate chamber 438 and fifth sealing element 434.

It will be recognized, however, that the step-down sealing arrangement described above will operate in a natural and largely uncontrolled manner. That is, as pressurized fluid from storage chamber 410 passes into first intermediate chamber 436 and the pressure level increases, fourth sealing element 432 will be increasingly urged into sealing engagement with side wall 408. Similarly, as pressurized fluid from first intermediate chamber 436 passes into second intermediate chamber 438, the pressure level within the second intermediate chamber would be expected to increase and thereby increasingly urge fifth sealing element 434 into greater sealing engagement with the side wall. Additionally, or in the alternative, localized deflection of a sealing element into and/or otherwise along a gap or clearance 444 (e.g., gap or clearance 138 and/or 218) between the moveable wall and the side wall of the storage structure may also contribute to any increased in pressure within the first and/or second intermediate chambers.

In some cases, the natural and largely uncontrolled operation of the above-described step-down sealing arrangement may be beneficial, such as due to the simplicity of operation and lack of use of additional components, for example. However, in other cases, it may be desirable to provide some level of control over the flow of pressurized fluid through one or more of the intermediate passages, such as, for example, to ensure that one or more of the sealing
elements are actuated in a predetermined sequence and/or at predetermined pressure levels.

[0075] As such, first piston 404 and/or sealing arrangement 406 can optionally include any suitable number of one or more fluid control devices that operate to permit and prohibit fluid flow along a corresponding one or more of the intermediate passages. For example, first piston 404 is shown in FIG. 11 as including first fluid control devices, which are schematically represented by boxes 446, that are disposed in fluid communication along first intermediate passages 440. Additionally, or in the alternative, second fluid control devices can, optionally, be provided in fluid communication along second intermediate passage 442. The second fluid control devices are schematically represented in FIG. 11 by boxes 448.

[0076] As indicated above, it will be appreciated that first and second fluid control devices 446 and 448 can be of any suitable type, kind, configuration and/or construction and that the same can be actuated or otherwise operated in any suitable manner and/or in connection with any additional devices, components and/or systems that may be suitable for use in connection with the operation thereof. As one example, the first and second fluid control devices could be valves that are selectively operable through the use of electrical solenoids (not shown) or pneumatic actuators (not shown). And, selective operation of the fluid control devices could be initiated or otherwise handled by a controller (not shown) in response to inputs, such as, for example, a time period from a counter or timer, a pressure level from a pressure transducer or pressure sensor, a temperature level from a thermocouple or temperature probe, and/or a position or orientation identified by a proximity sensor or encoder.

[0077] As another example, first and second fluid control devices 446 and 448 could include pressure actuated valves, such as one-way spring-biased check valves, for example, that are respectively disposed in fluid communication along first and second intermediate passages 440 and 442. In one case, the first and second fluid control devices could be substantially identical to one another, such that the valves open and close at approximately the same pressure level. In a preferred arrangement, however, first fluid control devices 446 are actuated at a pressure level that is substantially greater than the pressure level at which second fluid control devices 448 are actuated. It will be appreciated, however, that other arrangements could alternately be used.

[0078] With more specific reference to the foregoing example, a pressurized fluid storage system in accordance with the subject matter of the present disclosure is anticipated to be capable of containing fluids at pressures well in excess of 5,000 psi, such as pressure levels within a range of from 10,000 to 50,000 psi (or greater), for example. It is assumed for explanatory purposes that a quantity of fluid is being stored within storage chamber 410 at a pressure of approximately 30,000 psi. In such case and further to this example, the valves of first fluid control devices 446 could be configured in a normally-closed condition and configured to change to an open condition at a fluid pressure level of approximately 20,000 psi. With still further reference to this example, the valves of second fluid control devices 448 could be configured in a normally-closed condition and configured to change to an open condition at a fluid pressure level of approximately 10,000 psi. In such case, it will be recognized that first intermediate chamber 436 would be expected to equalize at a pressure level of approximately 20,000 psi and that second intermediate chamber 438 would be expected to equalize at a step-down pressure differential of approximately 10,000 psi will be generated across each of sealing elements 424, 432 and 434.

[0079] Generally, it is expected that, during use, a first reduced pressure level (P1) will be achieved in first intermediate chamber 436 and that the first reduced pressure level will be less than the pressure level (P0) of the pressurized fluid contained in storage chamber 410, such as, for example, once the interactive seal formed by first sealing element 424 has been achieved. The pressurized gas in the first intermediate chamber will, by way of first intermediate passage 440, urge fourth sealing element 432 into sealing engagement between the first piston and the side wall of the storage structure. In turn, it is expected that a second reduced pressure level (P2) will be reached in second intermediate chamber 438 and that the second reduced pressure level will be less than the first reduced pressure level in the first intermediate chamber, such as, for example, once the interactive seal formed by fourth sealing element 432 has been achieved. As a result, the differential pressure between the second reduced pressure level and lower pressure atmosphere ATM is expected to be significantly less than the differential pressure between the pressure level of the storage chamber and the lower pressure atmosphere. This is expected to result in a more robust and/or increasingly effective sealing arrangement.

[0080] As discussed above, a sealing arrangement in accordance with the subject matter of the present disclosure can include one or more sealing elements or members of any suitable size, shape, configuration, construction and/or arrangement. For example, the one or more sealing members or elements could have a circular, oval, rectangular or other cross-sectional shape (e.g., quad-ring). Additionally, the one or more sealing members or elements can be formed from any suitable material or combination of materials. It will be recognized that the sealing elements shown in FIGS. 1-11 have an oval or otherwise somewhat circular cross-sectional shape, such as may be found in a conventional O-ring, for example.

[0081] Another embodiment of a sealing element or member 500 is shown in FIG. 12 that could alternately be used as one or more of the sealing elements in a sealing arrangement in accordance with the subject matter of the present disclosure, such as has been described with regard to sealing arrangements 106, 206, 306 and 406, for example. Sealing element 500 is shown in FIG. 12 as being operatively disposed between piston 104 and side wall 108 of storage structure 102, as are shown in Detail 12 in FIG. 2. Additionally, sealing element 500 is shown in an actuated or radially-outwardly biased condition suitable for forming a substantially fluid-tight seal between the piston and the side wall of the storage structure. A dashed box 500’ having a substantially rectangular shape represents the sealing element in a condition suitable for movement of piston 104.

[0082] As the pressure of the fluid (e.g., liquid and/or gas) within storage chamber 110 increases, the pressure within passage 148 will also increase. This increased pressure will act on one portion of sealing element 500 (e.g., inner surface 502 thereof), as shown by arrows AR2, which thereby forces another portion of sealing element 500 (e.g., outer surface 504) outwardly and into abutting engagement with first wall 108 of container 102 such that a substantially fluid-tight seal can be formed therewith. In a preferred arrangement, membrane 120 will be cooperative with one or more of the features (e.g., bottom wall 144 and/or side walls 146) of groove 142.
such that a substantially fluid-tight seal is similarly provided or maintained between the sealing element and the piston.

A further embodiment of a sealing element or member 600 is shown in FIG. 13 that could alternately be used as one or more of the sealing elements in a sealing arrangement in accordance with the subject matter of the present disclosure, such as has been described with regard to sealing arrangements 106, 206, 306 and 406, for example. Sealing element 600 is shown in FIG. 13 as being operatively disposed between piston 104 and side wall 108 of storage structure 102, as are shown in Detail 12 in FIG. 2. Additionally, sealing element 600 is shown in an actuated or radially-outwardly biased condition suitable for forming a substantially fluid-tight seal between the piston and the side wall of the storage structure. An unbiased condition of the sealing element that would be suitable form movement of piston 104 is not shown.

Sealing element 600 is similar to sealing element 500 in overall shape. Sealing element 600 differs from sealing element 500, however, in that sealing element 600 includes an outer body 602 that is at least partially filled with a liquid 604. It is believed that localized deflection along an inner surface 606 in the area of openings 152 would generate displacement of liquid 604, which, in turn, would assist in forcing an outer surface 608 against first wall 108, as described above. Additionally, or in the alternative, a coating, layer or other surface treatment can optionally be applied along any one or more portions of the sealing member, such as to provide abrasion resistance, improved sealing, adhesion and/or strength/stiffness. For example, an optional coating 610 is shown as being disposed along inner surface 606.

Still another example of a sealing element of member 700 is shown in FIGS. 14-16 that could alternately be used as one or more of the sealing elements in a sealing arrangement in accordance with the subject matter of the present disclosure, such as has been described with regard to sealing arrangements 106, 206, 306 and 406, for example. Sealing element 700 is shown in FIGS. 14-16 as being operatively disposed between piston 104 and side wall 108 of storage structure 102, as are shown in Detail 12 in FIG. 2. Additionally, sealing element 700 is shown in an actuated or radially-outwardly biased condition suitable for forming a substantially fluid-tight seal between the piston and the side wall of the storage structure. An unbiased condition of the sealing element that would be suitable form movement of piston 104 is not shown.

Sealing element 700 is shown in FIGS. 14-16 as taking the form of a thin-walled membrane. It will be appreciated that such a thin-walled membrane can take any suitable shape or configuration. In the exemplary arrangement shown in FIGS. 14-16, sealing element 700 has a U-shaped cross section that includes an outside surface 702 and an inside surface 704 that at least partially defines a seal chamber 706. The U-shaped cross section of sealing element 700 also includes a first radially-extending side portion 708, a second radially-extending side portion 710 that is disposed in spaced relation to the first side portion, and an end portion 712 that extends in an approximately longitudinal direction therebetween.

Sealing element 700 is disposed along an outer peripheral wall (not numbered) of piston 104. In a preferred embodiment, as is shown in FIGS. 14 and 16, sealing element 700 is cooperatively received in groove 142 such that first side portion 708 is disposed adjacent one of the side walls (e.g., side walls 146) of groove 142 and second side portion 710 is disposed adjacent the other side wall of groove 142. As the pressure of the fluid (e.g., liquid and/or gas) within storage chamber 110 increases, the pressure within passage 148 will also increase. This increased pressure will act on one portion of sealing element 700 (e.g., inside surface 704), as shown by arrows AR2, which thereby forces end portion 712 outwardly and into abutting engagement with first wall 108 of storage structure 102 such that a substantially fluid-tight seal can be formed therewith, as has been described above in detail.

In a preferred arrangement, at least a portion of sealing element 700 can be secured on or along piston 104 in any suitable manner such that a substantially fluid-tight seal is formed between the sealing element and the piston. In the exemplary arrangement shown in FIGS. 14 and 16, first radially-extending side portion 708 is secured on or along side wall 146 of groove 142, such as through the use of a suitable adhesive or sealant 714, for example. Optionally, second radially-extending side portion 710 can be secured on or along side wall 146 of groove 142, such as through the use of a suitable adhesive or sealant 716. It will be appreciated that the suitability of a particular adhesive or sealant will vary from application-to-application depending upon factors such as chemical compatibility and the magnitude of forces involved.

Optionally, first radially-extending side portion 708 and/or second radially-extending side portion 710 can include one or more features suitable for operatively interengaging a corresponding one of the side walls (e.g., side walls 146) of groove 142. As one example, a plurality of annular projections 718 are shown in FIGS. 14 and 16 as projecting outwardly from first side portion 708 toward the corresponding side wall of groove 142. Additionally, the side wall of the groove, such as side wall 146, for example, can optionally include one or more features for receiving the projections, such as annular recesses 720 in FIGS. 14 and 16, for example. It will be appreciated, however, that any other suitable features or combination of features in any suitable arrangement and/or configuration could alternately be used.

Optionally, a sealing arrangement in accordance with the subject matter of the present disclosure, such as arrangements 106, 206, 306 and 406, for example, could include a suitable liquid disposed within one or more of the fluid passages thereof. Additionally, it will be appreciated that any suitable sealing element or members can be used in connection with such a sealing arrangement, such as sealing elements 140, 500, 600 and/or 700, for example. In such an arrangement, the liquid could be used where the transfer of pressure is desired to be achieved with a minimum displacement. Any suitable type of membrane or sealing arrangement could be used to retain the liquid within the one or more fluid passages.

In the exemplary configuration shown in FIG. 16, a second sealing element 722 is disposed along fluid passage 148. Second sealing element 722 acts to retain a quantity of liquid 724 in seal chamber 706 and the portion of fluid passage 148 that is in fluid communication with seal chamber 706. It will be appreciated that any suitable liquid, such as migration-reducing substance 268, for example, can be used.

As mentioned above, the thin-walled membrane that at least partially forms sealing element 700 can be formed in any suitable manner and from any suitable material or combination of materials. For example, an enlarged portion of sealing element 700 is shown in cross-section in FIG. 15 that
includes a first or structural portion 726 and a second or filler portion 728. Additionally, an optional third or inside coating portion 730 and/or an optional fourth or outside coating portion 732 could be provided on or along the sealing element. Again, it will be appreciated that the suitability of particular materials and/or wall thicknesses will vary from application-to-application depending upon factors such as chemical compatibility and the magnitude of forces involved.

[0094] As one example, structural portion 726 of the thin-walled membrane can be formed from a suitable filament or wire-like material, such as a natural fiber cloth, a polymeric screen or cloth, a metal (e.g., steel or copper) screen or mesh or any combination thereof, for example, to provide strength to the thin-walled membrane while maintaining sufficient flexibility to form a substantially fluid-tight seal, as has been previously described. Filler portion 728 can act to fill or cover any openings or gaps formed in the structural portion, such as the openings formed by a mesh or screen material, for example. As shown in FIG. 15, filler or barrier material 728 substantially encapsulates structural portion 726. Additionally, the filler or barrier material is preferably selected to be sufficiently flexible to form the substantially fluid-tight seal, as has been previously described, while at least partially providing a barrier to migration of the pressurized fluid contained in the storage structure. The optional third and/or fourth portions (e.g., portions 730 and/or 732) can be formed from any material or combination of materials, such as, for example, may be suitable for further reducing migration of the pressurized fluid or forming a beneficial interrelationship with a liquid or migration-reducing substance, such as liquid 724 and/or migration reducing substance 268, for example.

[0095] Examples of materials that may be suitable for use as a barrier material and/or a coating material are metals, such as gold, lead and/or tin, for example, as well as polymeric materials, such as PTFE, for example. One advantage of the use of metallic materials over polymeric materials is that many gases, such as could be stored using a pressurized fluid storage system utilizing sealing arrangement in accordance with the subject matter of the present disclosure, may penetrate and/or degrade polymeric materials more quickly than may occur with metallic materials. Another advantage of using a metal as a barrier and/or coating material is that metals, such as gold, lead and tin, for example, are capable of providing other physical characteristics and/or properties that may be desired, such as increased flexibility, for example. A further advantage that may be associated with the use of such metal materials is that the same can be made to or will otherwise readily adhere to one another without the use of adhesives, such as by forming an amalgam, for example. One benefit of adhering materials together in this manner is that the use of a separate adhesive can be avoided. And, it will be appreciated that such adhesives are often polymer-based and, thus, may be undesirablely affected by exposure to certain atoms, molecules and/or substances that might be contained within a pressurized fluid storage system in accordance with the subject matter of the present disclosure. Additionally, it will be appreciated that one or more layers of first, second, third and/or fourth portions 726-732 could optionally be used.

That is, a multi-layered construction that includes one or more first portions, one or more second portions, one or more third portions and/or one or more fourth portions, in any order, arrangement and/or configuration, could be used.

[0096] It will be recognized that numerous different features and/or components are presented in the embodiments shown and described herein, and that no one embodiment is specifically shown and described as including all such features and components. However, it is to be understood that the subject matter of the present disclosure is intended to encompass any and all combinations of the different features and components that are shown and described herein, and, without limitation, that any suitable arrangement of features and components, in any combination, can be used. Thus it is to be distinctly understood claims directed to any such combination of features and/or components, whether or not specifically embodied herein, are intended to find support in the present disclosure.

[0097] Thus, while the subject matter of the present disclosure has been described with reference to the foregoing embodiments and considerable emphasis has been placed herein on the structures and structural interrelationships between the component parts of the embodiments disclosed, it will be appreciated that other embodiments can be made and that many changes can be made in the embodiments illustrated and described without departing from the principles hereof. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. Accordingly, it is to be distinctly understood that the foregoing descriptive matter is to be interpreted merely as illustrative of the subject matter of the present disclosure and not as a limitation. As such, it is intended that the subject matter of the present disclosure be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims and any equivalents thereof.

1. A pressurized fluid storage system for containing a quantity of an associated fluid at an elevated pressure level, said system comprising: a pressure vessel including a vessel wall that at least partially defines a storage chamber for storing a quantity of the associated fluid, said vessel wall including an opening providing access to said storage chamber; a moveable wall structure displaceably supported within said pressure vessel and extending across said opening to at least partially retain a quantity of the associated fluid in said storage chamber, said moveable wall structure including: an outer peripheral wall disposed adjacent said vessel wall such that a gap is formed between said outer peripheral wall and said vessel wall; an end wall disposed toward said storage chamber; a groove extending into said moveable wall structure from along said outer peripheral wall such that said groove is in fluid communication with said storage chamber through said gap; and, at least one passage extending through at least a portion of said moveable wall structure and in fluid communication between said groove and said storage chamber; and, an interactive sealing arrangement operatively disposed between said pressure vessel and said moveable wall structure and capable of forming a substantially fluid-tight seal therebetween, said interactive sealing arrangement including: a first sealing member positioned between said moveable wall structure and said vessel wall and disposed at least partially within said groove of said moveable wall structure, said first sealing member including a first peripheral portion disposed toward said vessel wall and a second peripheral portion disposed along said groove in fluid communication with said at least one passage such that a portion of the associated fluid at an elevated pressure within said storage chamber can interact with said second peripheral portion of said first sealing member and thereby urge said first peripheral portion of said
first sealing member into abutting engagement with said vessel wall of said pressure vessel.

2. A system according to claim 1, wherein said at least one passage includes a first passage having a first end in fluid communication with said groove and an opposing second end in fluid communication with said storage chamber.

3. A system according to claim 2, wherein said sealing arrangement includes a piston supported on said moveable wall structure that is displaceable between a first position on said moveable wall structure in which said second end of said passage is substantially fluidically-isolated from said storage chamber and a second position on said moveable wall structure in which said second end of said passage is in fluid communication with said storage chamber.

4. A system according to claim 3, wherein said sealing arrangement includes a second sealing member supported on one of said moveable wall structure and said piston and operative to form a substantially fluid-tight seal between said moveable wall structure and said piston in at least said first position of said piston.

5. A system according to claim 4, wherein said second sealing member is supported on said moveable wall structure and said sealing arrangement includes a third sealing member supported on said moveable wall structure in spaced relation to said second sealing member such that said third sealing member forms a substantially fluid-tight seal between said moveable wall structure and said piston said second position of said piston.

6. A system according to claim 5, wherein said groove extending into said moveable wall structure is a first groove and said moveable wall structure includes a second groove extending thereinto adjacent said piston, said third sealing member includes a first peripheral portion disposed toward said piston and a second peripheral portion disposed along said second groove, said at least one passage is disposed in fluid communication between said first groove, said second groove and said storage chamber in said second position of said piston such that a portion of the associated fluid at an elevated pressure within said storage chamber can interact with said second peripheral portion of said first and third sealing members and thereby urge said first peripheral portion of said first sealing member into abutting engagement with said vessel wall of said pressure vessel and said first peripheral portion of said third sealing member into abutting engagement with said piston.

7. A system according to claim 6, wherein said at least one passage includes a first passage having a first portion with a first end in fluid communication with said first groove, a second portion with a second end in fluid communication with said second groove and a third portion with a third end in fluid communication with said storage chamber.

8. A system according to claim 7, wherein said first passage is one of a plurality of first passages disposed in circumferentially-spaced relation to one another about said moveable wall structure.

9. A system according to claim 7, wherein said third end of said third portion of said first passage is fluidically isolated from said storage chamber in said first position of said piston.

10. A system according to claim 6, wherein said moveable wall structure includes a third groove extending thereinto from along said outer peripheral wall and in spaced relation along said outer peripheral wall from said first groove, and said interactive sealing arrangement includes a fourth sealing member at least partially disposed within said third groove of said moveable wall structure such that a portion of said gap disposed between said first and fourth sealing members at least partially defines an intermediate chamber.

11. A system according to claim 10, wherein said at least one passage includes a first passage having a first portion with a first end in fluid communication with said first groove, a second portion with a second end in fluid communication with said second groove, a third portion with a third end in fluid communication with said storage chamber, and a fourth portion with a fourth end in fluid communication with said third groove.

12. A system according to claim 6, wherein said at least one passage includes a first passage having a first portion with a first end in fluid communication with said first groove, a second portion with a second end in fluid communication with said second groove and a third portion with a third end in fluid communication with said storage chamber, and said moveable wall structure includes an exhaust passage in fluid communication between said first passage and an associated external atmosphere.

13. A system according to claim 12, wherein said interactive sealing arrangement includes a valve in fluid communication across said exhaust passage, said valve being selectively operable to permit fluid flow through said exhaust passage.

14.-26. (canceled)

27. A system according to claim 1, wherein said at least one passage includes a first passage having a first portion with a first end in fluid communication with said first groove and a second portion with a second end in fluid communication said storage chamber, and a second passage in fluid communication between said intermediate chamber and said second groove.

28. A system according to claim 27, said first passage is one of a plurality of first passages disposed in circumferentially-spaced relation to one another about said moveable wall structure, and said second passage is one of a plurality of second passages disposed in circumferentially-spaced relation to one another about said moveable wall structure.

29. A system according to claim 27, wherein said second sealing member includes a first peripheral portion disposed toward said vessel wall and a second peripheral portion disposed along said second groove such that at least a portion of the associated fluid at an elevated pressure within said intermediate chamber can interact with said second peripheral portion of said second sealing member through said second passage and thereby urge said first peripheral portion of said second sealing member into abutting engagement with said vessel wall of said pressure vessel.

30. A system according to claim 27, wherein said interactive sealing arrangement includes a valve in fluid communication across said second passage, said valve being selectively operable to permit fluid flow through said second passage.

31. A system according to claim 27, wherein said intermediate chamber is a first intermediate chamber, said moveable wall structure includes a third groove extending thereinto from along said outer peripheral wall and in spaced relation.
along said outer peripheral wall from said second groove in a direction generally opposite said first groove, and said interactive sealing arrangement includes a third sealing member positioned between said moveable wall structure and said vessel wall and disposed at least partially within said third groove of said moveable wall structure such that a portion of said gap is disposed between said second and third sealing members at least partially defines a second intermediate chamber.

32. A system according to claim 31, wherein said at least one passage includes a third passage in fluid communication between said second intermediate chamber and said third groove.

33. A system according to claim 32, said third passage is one of a plurality of third passages disposed in circumferentially-spaced relation to one another about said moveable wall structure.

34. A system according to claim 32, wherein said valve is a first valve and said interactive sealing arrangement includes a second valve in fluid communication across said third passage, said second valve being selectively operable to permit fluid flow through said third passage.

35.-78. (canceled)