

MANUALLY-ACTUATED REDUCED PRESSURE TREATMENT SYSTEM HAVING REGULATED PRESSURE CAPABILITIES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/050,145, filed May 2, 2008, which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates generally to reduced pressure treatment systems and in particular to a manually-actuated reduced pressure treatment system having capabilities for providing a regulated pressure to a tissue site.

2. Description of Related Art

[0003] Clinical studies and practice have shown that providing a reduced pressure in proximity to a tissue site augments and accelerates the growth of new tissue at the tissue site. The applications of this phenomenon are numerous, but one particular application of reduced pressure has involved treating wounds. This treatment (frequently referred to in the medical community as “negative pressure wound therapy,” “reduced pressure therapy,” or “vacuum therapy”) provides a number of benefits, including migration of epithelial and subcutaneous tissues, improved blood flow, and micro-deformation of tissue at the wound site. Together these benefits result in increased development of granulation tissue and faster healing times. Typically, reduced pressure is applied to tissue through a porous pad or other manifold device. The porous pad contains cells or pores that are capable of distributing reduced pressure to the tissue and channeling fluids that are drawn from the tissue. The porous pad may be incorporated into a dressing having other components that facilitate treatment.

SUMMARY

[0004] The problems presented by existing reduced pressure systems are solved by the systems and methods of the illustrative embodiments described herein. In one illustrative embodiment, a manually-actuated reduced pressure pump includes a first barrel having a substantially cylindrical wall and a closed end. A piston is movably disposed within the first barrel and a charging chamber is defined between the closed end of the first barrel and the piston. A piston spring is operably associated with the piston to bias the piston in a direction that allows an increase in a volume of the charging chamber. A seal is disposed within the first barrel, and a regulated chamber is defined between the seal and the piston. A regulator passage provides fluid communication between the charging chamber and the regulated chamber. A second barrel is operably associated with the piston to move the piston toward a compressed position when the reduced pressure pump is being manually actuated by a user. A valve body is operably associated with the regulator passage to selectively allow or prevent fluid communication between the charging chamber and the regulated chamber.

[0005] In another embodiment, a reduced pressure treatment apparatus includes a piston chamber having a closed end and a piston disposed within the piston chamber that is movable between an extended position and a compressed position. A charging chamber is disposed between the piston and the closed end, the charging chamber having a first volume when the piston is in the compressed position and a second volume when the piston is in the extended position. The first volume is less than the second volume. A biasing member is provided to bias the piston toward the extended position. A valve member allows fluid to exit the charging chamber as the piston moves toward the compressed position and prevents fluid from entering the charging chamber as the piston moves toward the extended position. The reduced pressure treatment apparatus further includes a regulated chamber and a passage to allow fluid communication between the regulated chamber and the charging chamber. A regulator member is provided to regulate fluid communication through the passage between the charging chamber and the regulated chamber.

[0006] In another embodiment, a reduced pressure treatment apparatus includes a charging chamber that stores a first pressure less than an ambient pressure and a regulated chamber that stores a second pressure less than the ambient pressure. The first pressure is less than the second pressure. A conduit provides fluid communication between the regulated chamber and the charging chamber. A regulator member is operably associated with the conduit to prevent fluid communication through the conduit when the second pressure is less

than or equal to a desired therapy pressure and to allow fluid communication through the conduit when the second pressure exceeds the desired therapy pressure.

[0007] In still another embodiment, a reduced pressure treatment system includes a manifold adapted to be positioned at a tissue site and a regulated chamber in fluid communication with the tissue site to deliver a desired therapy pressure to the tissue site. A charging chamber is adapted to store a charging pressure that is less than the desired therapy pressure. A passage provides fluid communication between the regulated chamber and the charging chamber. A valve body is operably associated with the passage to substantially reduce fluid communication through the passage when a pressure in the regulated chamber is less than or equal to the desired therapy pressure and to allow fluid communication through the passage when the pressure in the regulated chamber exceeds the desired therapy pressure.

[0008] In yet another embodiment, a method of providing reduced pressure treatment to a tissue site includes storing a charging pressure within a charging chamber. A desired therapy pressure is delivered from a regulated chamber to the tissue site. When a pressure within the regulated chamber exceeds the desired therapy pressure, the pressure within the regulated chamber is reduced by allowing fluid communication between the charging chamber and the regulated chamber.

[0009] Other objects, features, and advantages of the illustrative embodiments will become apparent with reference to the drawings and detailed description that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 illustrates a perspective view of a reduced pressure treatment system according to an illustrative embodiment, the reduced pressure treatment system having a reduced pressure pump adapted to deliver a reduced pressure to a dressing positioned at a tissue site;

[0011] FIG. 2 depicts a cross-sectional front view of the dressing of FIG. 1 taken at 2-2;

[0012] FIG. 3 illustrates a schematic of a reduced pressure treatment apparatus according to an illustrative embodiment, the reduced pressure treatment apparatus having a charging chamber, a regulated chamber, and a regulator member, the regulator member being shown in an open position;

[0013] FIG. 4 depicts a schematic of the reduced pressure treatment apparatus of FIG. 3, the regulator member being shown in a closed position;

[0014] FIG. 5 illustrates a schematic of a piston-driven device for use with the reduced pressure treatment apparatus of FIG. 3 to charge the charging chamber with a reduced pressure, the piston-driven device having a piston shown in a compressed position;

[0015] FIG. 6 depicts a schematic of the piston-driven device of FIG. 5 with the piston shown in an extended position;

[0016] FIG. 7 illustrates a side perspective view of a reduced pressure treatment apparatus according to an illustrative embodiment;

[0017] FIG. 8 depicts a front view of the reduced pressure treatment apparatus of FIG. 7;

[0018] FIG. 9 illustrates an exploded side perspective view of the reduced pressure treatment apparatus of FIG. 7;

[0019] FIG. 10 depicts an exploded rear perspective view of the reduced pressure treatment apparatus of FIG. 7;

[0020] FIG. 11 illustrates a cross-sectional side view of the reduced pressure treatment apparatus of FIG. 8 taken at 11-11, the reduced pressure treatment apparatus shown in an extended position;

[0021] FIG. 12 depicts a top-rear perspective view of a piston of the reduced pressure treatment apparatus of FIG. 7;

[0022] FIG. 13 illustrates a bottom-rear perspective view of the piston of FIG. 12;

[0023] FIG. 14 depicts a top-rear perspective view of a seal of the reduced pressure treatment apparatus of FIG. 7;

[0024] FIG. 15 illustrates a bottom-rear perspective view of the seal of FIG. 14;

[0025] FIG. 16 depicts a top-rear perspective view of a second barrel of the reduced pressure treatment apparatus of FIG. 7;

[0026] FIG. 17 illustrates a bottom-rear perspective view of the second barrel of FIG. 16;

[0027] FIG. 18 depicts a cross-sectional side view of the reduced pressure treatment apparatus of FIG. 7, the reduced pressure treatment apparatus shown in a compressed position;

[0028] FIG. 19 illustrates an enlarged cross-sectional view of the reduced pressure treatment apparatus of FIG. 18, the reduced pressure treatment apparatus having a valve body shown in a closed position;

[0029] FIG. 20 depicts an enlarged cross-sectional view of the reduced pressure treatment apparatus of FIG. 19 with the valve body shown in an open position;

[0030] FIG. 20A depicts an enlarged cross-sectional view, similar to that of FIG. 20, of a reduced pressure treatment apparatus according to an illustrative embodiment;

[0031] FIG. 21 illustrates a perspective view of a reduced pressure treatment apparatus according to an illustrative embodiment;

[0032] FIG. 22 depicts a cross-sectional side view of the reduced pressure treatment apparatus of FIG. 21 taken at 22-22; and

[0033] FIG. 23 illustrates a graph of regulated chamber pressure vs. time for a reduced pressure treatment apparatus.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0034] In the following detailed description of several illustrative embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific preferred embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is understood that other embodiments may be utilized and that logical structural, mechanical, electrical, and chemical changes may be made without departing from the spirit or scope of the invention. To avoid detail not necessary to enable those skilled in the art to practice the embodiments described herein, the description may omit certain information known to those skilled in the art. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the illustrative embodiments are defined only by the appended claims.

[0035] The term “reduced pressure” as used herein generally refers to a pressure less than the ambient pressure at a tissue site that is being subjected to treatment. In most cases, this reduced pressure will be less than the atmospheric pressure at which the patient is located. Alternatively, the reduced pressure may be less than a hydrostatic pressure associated with tissue at the tissue site. Although the terms “vacuum” and “negative pressure” may be used to describe the pressure applied to the tissue site, the actual pressure reduction applied to the tissue site may be significantly less than the pressure reduction normally associated with a complete vacuum. Reduced pressure may initially generate fluid flow in the area of the tissue site. As the hydrostatic pressure around the tissue site approaches the desired reduced pressure, the flow may subside, and the reduced pressure is then maintained. Unless otherwise indicated, values of pressure stated herein are gauge pressures. Similarly, references to increases in reduced pressure typically refer to a decrease in absolute pressure, while decreases in reduced pressure typically refer to an increase in absolute pressure.

[0036] The term “tissue site” as used herein refers to a wound or defect located on or within any tissue, including but not limited to, bone tissue, adipose tissue, muscle tissue, neural tissue, dermal tissue, vascular tissue, connective tissue, cartilage, tendons, or ligaments. The term “tissue site” may further refer to areas of any tissue that are not necessarily wounded or defective, but are instead areas in which it is desired to add or promote the growth of additional tissue. For example, reduced pressure tissue treatment may be used in certain tissue areas to grow additional tissue that may be harvested and transplanted to another tissue location.

[0037] Reduced pressure treatment systems are often applied to large, highly exuding wounds present on patients undergoing acute or chronic care, as well as other severe wounds that are not readily susceptible to healing without application of reduced pressure. Low-severity wounds that are smaller in volume and produce less exudate have generally been treated using advanced dressings instead of reduced pressure treatment. Improvements in wound healing, however, may be obtained by using reduced pressure treatment, even with smaller and less severe wounds.

[0038] Currently, the use of reduced pressure treatment is not considered a viable or affordable option for low-severity wounds due to the manpower required to monitor and change system components, the requirement for trained medical personnel overseeing treatment, and the cost of treatment. For example, the complexity of current reduced pressure treatment systems limits the ability of a person with little or no specialized knowledge from administering such treatment to oneself or others. The size of current reduced pressure treatment systems also impairs the mobility of both the treatment system and the person to whom the treatment is being applied. For example, current reduced pressure treatment systems require the use of a separate canister that stores exudate or other liquid from the tissue site. Current reduced pressure treatment systems are also typically non-disposable after each treatment, and require electrical components or other powered devices in order to apply the reduced pressure used in treatment.

[0039] While reduced pressure treatment is usually provided in a hospital or monitored-care setting, a great number of situations exist where it may be advantageous to provide reduced pressure therapy to ambulatory and other patients outside of these traditional settings. A conventional reduced pressure system includes an electrically-powered reduced pressure pump that requires a patient to remain relatively still during treatment. A need exists for a portable pump that is small in size and is capable of being manually-actuated, and reactivated if necessary, by a patient receiving treatment.

[0040] Referring to FIGS. 1 and 2, a reduced pressure treatment system 100 according to an illustrative embodiment includes a reduced pressure dressing 104 positioned at a tissue site 108 of a patient. The reduced pressure dressing 104 is fluidly connected to a reduced pressure source 110 by a conduit 112. The conduit 112 may fluidly communicate with the reduced pressure dressing 104 through a tubing adapter 116. In the embodiment illustrated in FIG. 1, the reduced pressure source 110 is a manually-actuated pump such as the regulated pressure pumps described herein. In another implementation, the reduced pressure

source 110 may include pressure regulation capabilities but may initially be charged or re-charged to a selected reduced pressure by a reduced pressure or vacuum pump that is driven by an electric motor. In still another embodiment, the reduced pressure source 110 may be charged to the selected reduced pressure by a wall suction port such as are available in hospitals and other medical facilities.

[0041] The reduced pressure source 110 may be housed within or used in conjunction with a reduced pressure treatment unit (not shown), which may also contain sensors, processing units, alarm indicators, memory, databases, software, display units, and user interfaces that further facilitate the application of reduced pressure treatment to the tissue site 108. In one example, a sensor or switch (not shown) may be disposed at or near the reduced pressure source 110 to determine a source pressure generated by the reduced pressure source 110. The sensor may communicate with a processing unit that monitors and controls the reduced pressure that is delivered by the reduced pressure source 110. Delivery of reduced pressure to the reduced pressure dressing 104 and tissue site 108 encourages new tissue growth by maintaining drainage of exudate from the tissue site, increasing blood flow to tissues surrounding the tissue site, and creating microstrain at the tissue site.

[0042] The reduced pressure dressing 104 includes a distribution manifold 120 adapted to be positioned at the tissue site 108, and a seal layer 122 to seal the reduced pressure dressing 104 around the tissue site 108. A cover 124, or drape, is positioned over the distribution manifold 120 and the seal layer to maintain reduced pressure beneath the cover 124 at the tissue site. The cover 124 may extend beyond a perimeter of the tissue site and may include an adhesive or bonding agent on the cover 124 to secure the cover to tissue adjacent the tissue site. In one embodiment, the adhesive disposed on cover 124 may be used in lieu of the seal layer 122, however, the seal layer 122 may be used in conjunction with the adhesive of the cover 124 to improve sealing of the cover 124 at the tissue site 108. In another embodiment, the seal layer 122 may be used in lieu of adhesive disposed on cover 124.

[0043] The distribution manifold 120 of the reduced pressure dressing 104 is adapted to contact the tissue site 108. The distribution manifold 120 may be partially or fully in contact with the tissue site 108 being treated by the reduced pressure dressing 104. When the tissue site 108 is a wound, the distribution manifold 120 may partially or fully fill the wound.

[0044] The distribution manifold 120 may be any size, shape, or thickness depending on a variety of factors, such as the type of treatment being implemented or the nature and size of the tissue site 108. For example, the size and shape of the distribution manifold 120 may be

customized by a user to cover a particular portion of the tissue site 108, or to fill or partially fill the tissue site 108. Although the distribution manifold 120 illustrated in FIG. 3 has a square shape, the distribution manifold 120 may be shaped as a circle, oval, polygon, an irregular shape, or any other shape.

[0045] In one illustrative embodiment, the distribution manifold 120 is a foam material that distributes reduced pressure to the tissue site 108 when the distribution manifold 120 is in contact with or near the tissue site 108. The foam material may be either hydrophobic or hydrophilic. In one non-limiting example, the distribution manifold 120 is an open-cell, reticulated polyurethane foam such as GranuFoam® dressing available from Kinetic Concepts, Inc. of San Antonio, Texas.

[0046] In the example in which the distribution manifold 120 is made from a hydrophilic material, the distribution manifold 120 also functions to wick fluid away from the tissue site 108, while continuing to provide reduced pressure to the tissue site 108 as a manifold. The wicking properties of the distribution manifold 120 draw fluid away from the tissue site 108 by capillary flow or other wicking mechanisms. An example of a hydrophilic foam is a polyvinyl alcohol, open-cell foam such as V.A.C. WhiteFoam® dressing available from Kinetic Concepts, Inc. of San Antonio, Texas. Other hydrophilic foams may include those made from polyether. Other foams that may exhibit hydrophilic characteristics include hydrophobic foams that have been treated or coated to provide hydrophilicity.

[0047] The distribution manifold 120 may further promote granulation at the tissue site 108 when a reduced pressure is applied through the reduced pressure dressing 104. For example, any or all of the surfaces of the distribution manifold 120 may have an uneven, coarse, or jagged profile that causes microstrains and stresses at the tissue site 108 when reduced pressure is applied through the distribution manifold 120. These microstrains and stresses have been shown to increase new tissue growth.

[0048] In one embodiment, the distribution manifold 120 may be constructed from bioresorbable materials that do not have to be removed from a patient's body following use of the reduced pressure dressing 104. Suitable bioresorbable materials may include, without limitation, a polymeric blend of polylactic acid (PLA) and polyglycolic acid (PGA). The polymeric blend may also include without limitation polycarbonates, polyfumarates, and caprolactones. The distribution manifold 120 may further serve as a scaffold for new cell-growth, or a scaffold material may be used in conjunction with the distribution manifold 120 to promote cell-growth. A scaffold is a substance or structure used to enhance or promote the

growth of cells or formation of tissue, such as a three-dimensional porous structure that provides a template for cell growth. Illustrative examples of scaffold materials include calcium phosphate, collagen, PLA/PGA, coral hydroxy apatites, carbonates, or processed allograft materials.

[0049] Referring to FIGS. 3 and 4, a reduced pressure treatment apparatus 150, or reduced pressure pump, or reduced pressure source, is schematically illustrated and includes a charging chamber 154 fluidly connected by a passage 156, or conduit, to a regulated chamber 158. A regulator member 162 is operably associated with the passage 156 to selectively allow or prevent fluid communication between the charging chamber 154 and the regulated chamber 158. In the embodiment illustrated in FIGS. 3 and 4, the regulator member 162 includes a piston 164 that is disposed within the regulated chamber 158. The regulator member 162 further includes a regulator spring 166 to bias the piston 164 toward an open position as illustrated in FIG. 3. In the open position, the piston 164 allows fluid communication through the passage 156. In a closed position (shown in FIG. 4), the piston 164 prevents or at least substantially reduces fluid communication through the passage 156.

[0050] As previously noted, the charging chamber 154 is fluidly connected to the regulated chamber 158 by passage 156. The charging chamber 154 may include an inlet 170 for introduction of a reduced pressure to the charging chamber 154, or as explained below, the charging chamber 154 may be operably associated with a piston-driven or other device to charge the charging chamber 154 with the reduced pressure. The charging chamber 154 is well suited to receive the reduced pressure from a device that is manually-actuated, or alternatively that is powered by electrical or other means.

[0051] The regulated chamber 158 is fluidly connected by a conduit 172 to a dressing 174. In one embodiment, the conduit 172 and dressing 174 may be similar to conduit 112 and dressing 104. When reduced pressure treatment is applied to the dressing 174 and a tissue site, it is desired to deliver a reduced pressure to dressing 174 that is about equal to a desired therapy pressure. To accomplish this, the charging chamber 154 stores a first pressure that is less than an ambient pressure. The regulated chamber 158 stores a second pressure that is also less than the ambient pressure. The first pressure stored in the charging chamber 154 is less than the second pressure stored in the regulated chamber 158.

[0052] When the second pressure is less than or equal to the desired therapy pressure, a counteracting force on the piston is able to overcome a biasing force exerted by the regulator spring 166 on the piston 164. The counteracting force on the piston is a result of a

pressure differential across opposite sides of the piston 164. On a first side 176 of the piston 164, the ambient pressure (e.g. atmospheric pressure) surrounding the reduced pressure treatment apparatus 150 acts on the piston 164. On a second side 178 of the piston 164, the second pressure within the regulated chamber 158 acts on the piston. Since the second pressure is less than the ambient pressure, the counteracting force acts on the first side 176 of the piston 164 against the biasing force of the regulator spring 166. When the second pressure in the regulated chamber 158 is less than or equal to the desired therapy pressure, the piston 164 moves to and remains in the closed position.

[0053] If the second pressure in the regulated chamber 158 rises above (i.e. exceeds) the desired therapy pressure, possibly due to fluid leaks at the dressing 174 or within the reduced pressure treatment apparatus 150, the piston 164 is biased back to the open position by the regulator spring 166. In the open position, fluid communication is allowed between the charging chamber 154 and the regulated chamber 158. Since the first pressure in the charging chamber 154 is less than the second pressure in the regulated chamber 158, the second pressure in the regulated chamber 158 drops until the desired therapy pressure is reached, at which point the piston 164 again moves to the closed position.

[0054] In one embodiment, the first pressure stored in the charging chamber 154 is about -150 mm Hg, and the desired therapy pressure is about -125 mm Hg.

[0055] Referring to FIGS. 5 and 6, a piston-driven device 180 is provided for charging a charging chamber 182 similar to charging chamber 154. The piston-driven device 180 includes a piston 184 disposed within the charging chamber 182. This piston 184 is capable of reciprocal movement between a compressed position (see FIG. 5) and an extended position (see FIG. 6). A piston spring 188 or other biasing member is operably associated within the piston 184 to bias the piston 184 toward the extended position.

[0056] To charge the charging chamber 182, the piston 184 is moved to the compressed position. A seal 190 or other valve member allows fluid within the charging chamber 182 to exit the charging chamber 182 as a volume of the charging chamber 182 decreases. After moving the piston 184 to the compressed position, the piston spring 188 attempts to return the piston 184 to the extended position. As the volume of the charging chamber 182 increases, the seal 190 prevents fluid from entering the charging chamber 182 past the seal 190, which results in a pressure drop within the charging chamber 182. After the piston 184 has moved completely to the extended position, the piston 184 may be moved again to the compressed position to recharge the charging chamber 182 with a reduced pressure.

[0057] The piston-driven device 180 may be manually-actuated by a user compressing the piston 184. Alternatively, the piston 184 may be actuated by an electrical, hydraulic, or pneumatic actuator. For all of the charging chambers described herein, it should be noted that reduced pressure may be supplied to the charging chamber by manual or electrically powered means.

[0058] Referring to FIGS. 7 and 8, a reduced pressure treatment apparatus, or reduced pressure source 211 according to an illustrative embodiment is a manually-actuated pump having a first, or outer barrel 215 and a second, or inner barrel 219. The first barrel 215 includes a passage 223 (see FIG. 9) having a closed end and an open end. The passage 223 may be defined by a substantially cylindrical wall. The passage 223 slidably receives the second barrel 219 through the open end of the first barrel 215, and the second barrel 219 is movable between an extended position and a compressed position. While the first and second barrels are illustrated as having substantially cylindrical shapes, the shapes of the barrels could be any other shape that permits operation of the device.

[0059] In the extended position, the reduced pressure source 211 is discharged and does not actively deliver or supply a reduced pressure. In the compressed position, the reduced pressure source 211 is primed or charged, and the reduced pressure source 211 is capable of delivering a reduced pressure. An outlet port 227 is provided on the second barrel 219 and is adapted for fluid communication with a delivery tube or other conduit, which may be similar to delivery tube 135, such that reduced pressure generated by the reduced pressure source 211 may be delivered to the tissue site.

[0060] Referring to FIGS. 9-11, the reduced pressure source 211 further includes a barrel ring 229, a piston 231, and a seal 235. The barrel ring 229 is positioned at the open end of the first barrel 215 to circumscribe the second barrel 219. The barrel ring 229 eliminates large gaps between the first barrel 215 and the second barrel 219 at the open end of the first barrel 215. When the reduced pressure source 211 is assembled, the piston 231 and seal 235 are slidably received within the passage 223 of the first barrel 215. Both the piston 231 and the seal 235 are positioned in the passage 223 between the second barrel 219 and the closed end of the first barrel 215, the seal 235 being positioned between the second barrel 219 and the piston 231.

[0061] Referring more specifically to FIG. 11, the first barrel 215 includes a protrusion 239 extending from the closed end of the first barrel 215 into the passage 223. A piston spring 243 or other biasing member is positioned within the passage 223 and is received

at one end of the piston spring 243 by the protrusion 239. The protrusion 239 reduces lateral movement of the piston spring 243 within the passage 223. An opposite end of the piston spring 243 is received against the piston 231. The piston spring 243 biases the piston 231, the seal 235, and the second barrel 219 toward the extended position.

[0062] Referring again to FIGS. 9-11, but also to FIGS. 12 and 13, the piston 231 includes an outer wall 247 and an inner wall 251 joined by an outer floor 253. An annulus 255 is defined between the outer wall 247 and the inner wall 251, and a plurality of radial supports 259 are positioned between the outer wall 247 and the inner wall 251 in the annulus 255. The radial supports 259 provide additional rigidity to the piston 231, yet the presence of the annulus 255 as well as the sizes and spacing of the radial supports 259 within the annulus 255 reduces the weight of the piston 231 as compared to a single-wall piston that includes no annulus. However, it should be apparent that either piston design would be suitable for the reduced pressure source described herein.

[0063] A plurality of guides 263 is disposed on the piston 231, and in one embodiment, one of the guides 263 is disposed on each radial support 259. As described in more detail herein, the guides 263 serve to align the piston 231 relative to the seal 235 and the second barrel 219. The guides 263 further serve to secure the piston 231 to the second barrel 219 by means of a friction fit.

[0064] The piston 231 further includes an inner bowl 267 that is defined by the inner wall 251 and an inner floor 271. In one embodiment, the inner floor 271 may be two-tiered or multi-tiered as illustrated in FIG. 11, but the inner floor 271 may instead be single-tiered and/or substantially planar. The inner floor 271 may be positioned such that a recess 273 is defined beneath the inner floor 271 to receive an end of the piston spring 243 (see FIGS. 11 and 13). A regulator passage 275 passes through the inner floor 271. A valve seat 279 may be positioned in the inner bowl 267 near the regulator passage 275 such that fluid communication through the regulator passage 275 may be selectively controlled by selective engagement of the valve seat 279 with a valve body (described in more detail with reference to FIG. 15).

[0065] A well 283 is positioned in the annulus 255 of the piston 231, and a channel 287 is fluidly connected between the well 283 and the inner bowl 267. The channel 287 allows fluid communication between the well 283 and the inner bowl 267.

[0066] Referring still to FIGS. 9-11, but also to FIGS. 14 and 15, the seal 235 includes a central portion 291 that is circumscribed by a skirt portion 295. A plurality of guidance apertures 299 are disposed in the central portion 291 to receive the guides 263 of the

piston 231 when the reduced pressure source 211 is assembled. A communication aperture 301 is similarly disposed in the central portion 291, and in one embodiment, the communication aperture 301 is radially spaced an equal distance from a center of the seal as the guidance apertures 299. The communication aperture 301 permits fluid communication through the central portion 291 of the seal 235 and with the well 283 of the piston 231 upon assembly.

[0067] The skirt portion 295 of the seal 235 extends axially and radially outward from the central portion 291. As illustrated in FIG. 11, the radially-outward-extending skirt portion 295 engages an inner surface 305 of the first barrel 215 to permit unidirectional fluid communication past the seal 235. In other words, the skirt portion 295 of the seal 235 allows fluid to flow past the skirt portion 295 when the fluid flow is directed from the side of the seal 235 on which the piston 231 is disposed toward the opposite side of the seal 235. The skirt portion 295, however, substantially prevents fluid flow in the opposite direction. While the skirt portion of the seal effectively controls fluid communication past the skirt portion 295, a valve member such as, for example, a check valve or other valve could instead be used to perform this function.

[0068] As illustrated in more detail in FIGS. 11 and 15, a valve body 303 is positioned on the central portion 291 of the seal 235. Although valve bodies of many types, shapes and sizes may be used, the valve body 303 may be cone-shaped with an apex 309 that is adapted to sealingly engage the valve seat 279 of the piston 231. While the valve body 303 is illustrated as being an integral part of the seal 235, the valve body 303 may alternatively be a separate component from the seal 235 that is provided to engage the valve seat 279.

[0069] In one embodiment, both the seal 235 and the valve body 303 are made from an elastomeric material, which could include without limitation a medical grade silicone. While many different materials may be used to construct, form, or otherwise create the seal 235 and valve body 303, it is preferred that a flexible material be used to improve the sealing properties of the skirt portion 295 with the inner surface 305 and the valve body 303 with the valve seat 279.

[0070] Referring more specifically to FIG. 11, a regulator spring 307 is provided to bias the valve body 303 away from the piston 231 and the valve seat 279. One end of the regulator spring 307 may be positioned concentrically around the valve seat 279 within the inner bowl 267 of the piston 231, while another end of the regulator spring 307 may be positioned around the valve body 303. The biasing force provided by the regulator spring 307

urges the valve body 303 toward an open position in which fluid communication is permitted through the regulator passage 275. In one embodiment, when the spring 307 biases the valve body 303 toward the open position, only the central portion 291 of the seal 235 moves upward due to the flexibility of the seal (see FIG. 20). In another embodiment, the biasing force of the spring 307 may move the entire seal 235 toward the open position as illustrated in FIG. 20A.

[0071] Referring again to FIGS. 9-11, but also to FIGS. 16 and 17, the second barrel 219 includes a first housing portion 311 and a second housing portion 315. The first housing portion 311 includes an outer shell 319 having an aperture 323 disposed near an open end of the first housing portion 311. A floor 327 is integrally formed with or otherwise connected to the outer shell 319 on an end of the first housing portion 311 opposite the open end. A passage 331 may be centrally disposed in the floor 327. A boss 333 is integrated with or connected to the first housing portion 311. The boss 333 includes the outlet port 227, which is physically aligned with the aperture 323 to allow a delivery tube to be fluidly connected to the outlet port 227. In one embodiment, the boss 323 is a ninety degree fluid fitting that permits the outlet port 227 to fluidly communicate with a conduit 335 positioned within the first housing portion 311. The conduit 335 may be a rigid conduit that is formed from the same or similar material to that of the outer shell, or in one alternative embodiment, the conduit 335 may be flexible.

[0072] Referring more specifically to FIG. 17, a plurality of guidance apertures 337 are disposed in the floor 327 of the first housing portion 311. When the reduced pressure source 211 is assembled, the guidance apertures 337 receive the guides 263 of the piston 231 to ensure that the second barrel 219 remains aligned with the piston 231. A friction fit between the guides 263 and guidance apertures 337 assist in securing the relative positions of the piston 231 and the second barrel 219. It should be readily apparent, however, that the piston 231 and the second barrel 219 may be secured by alternative means. A communication aperture 338 is also disposed in the floor 327 to allow fluid communication with the conduit 335 through the floor 327.

[0073] The second housing portion 315 may include an end cap 339 integrally or otherwise connected to a guide 343. Together, the end cap 339 and guide 343 slidably engage the outer shell 319 of the first housing portion 311 to create a substantially closed second barrel 219 (with the exception of various apertures and passages). While the second barrel 219 may be constructed from fewer components, the existence of the first housing portion 311 and the second housing portion 315 allows easier access within the second barrel

219 and also allows easier assembly of the reduced pressure source 211. Additional advantages regarding the sliding engagement of the first housing portion 311 and the second housing portion 315 are explained in more detail below.

[0074] A shaft 347 extends from the end cap 339 and includes an engagement end 349 opposite the end cap 339. When the second barrel 219 is assembled, the shaft may be substantially coaxial to a longitudinal axis of the second barrel 219 and extend through the passage 331 in the floor 327 of the first housing portion 311. A spring 351 is positioned within the second barrel 219 such that one end of the spring 351 bears upon the floor 327 of the first housing portion 311 and another end of the spring 351 bears upon the shaft 347 or another portion of the second housing portion 315. The spring 351 biases the shaft 347 and other portions of the second housing portion 315 toward a disengaged position (see position of shaft 347 in FIG. 11) in which the engagement end 349 of the shaft 347 does not bear upon the seal 235 or valve body 303. The sliding relationship and engagement between the first and second housing portions 311, 315 allows a user to exert a force on the second housing portion (against the biasing force of the spring 351) to move the second housing portion 315 to an engaged position. In the engaged position, the engagement end 345 of the shaft 347 bears upon the seal 235 above the valve body 303 (see FIG. 18), which forces the valve body 303 against the valve seat 279, thereby preventing fluid communication through the regulator passage 275.

[0075] When the reduced pressure source 211 is assembled, as illustrated in FIG. 11, a charging chamber 355 is defined within the first barrel 215 beneath the piston 231. A regulated chamber 359 is defined within the inner bowl 267 of the piston 231 beneath the seal 235. The regulator passage 275 allows selective fluid communication between the charging chamber 355 and the regulated chamber 359 depending on the position of the valve body 303. The regulated chamber 359 fluidly communicates with the well 283 of the piston 231 through the channel 287. The well 283 is aligned with the communication aperture 301 of the seal 235 and the communication aperture 338 of the first housing portion 311, which allows fluid communication between the well 283 and the conduit 335 and outlet port 227 of the second barrel 219.

[0076] While the regulator passage 275 is illustrated as being disposed within the piston 231, the regulator passage 275 could instead be routed through the wall of the first barrel 215. The regulator passage 275 could be any conduit that is suitable for allowing fluid communication between the chambers.

[0077] In operation, the reduced pressure source 211 is capable of being used with other components of a reduced pressure treatment system similar to those of reduced pressure treatment system 100 (see FIG. 1). The outlet port 227 of the reduced pressure source 211 is adapted to be connected to a delivery tube or other conduit that is fluidly connected to a tissue site. Although a fluid canister could be integrated into the reduced pressure source 211, in one embodiment, the reduced pressure source 211 is not intended to collect wound exudates or other fluids within any internal chamber. In one embodiment, the reduced pressure source 211 may either be used with low-exudating wounds, or an alternative collection system such as an external canister or absorptive dressing may be used to collect fluids.

[0078] Referring to FIGS. 11 and 18, the extended position (see FIG. 11) and the compressed position (see FIG. 18) of the reduced pressure source 211 are illustrated. In the extended position, the reduced pressure source 211 is not “charged” and is thus not capable of delivering reduced pressure to the outlet port 227. To prime the reduced pressure source 211, the second barrel 219 is manually compressed into the first barrel 215 by a user such that the reduced pressure source 211 is placed in the compressed position. The force exerted by the user on the second barrel 219 must be greater than the biasing force provided by the piston spring 243. As the second barrel 219 compresses within the first barrel 215 and moves toward the closed end of the first barrel 215, the force being exerted on the second barrel 219 by the user is also transmitted to the seal 235 and piston 231. The movement of the second barrel 219, the seal 235, and the piston 231 into the compressed position decreases the volume of the charging chamber 355. As the volume of the charging chamber 355 decreases, the pressure in the charging chamber 355 increases, but air and other gases within the charging chamber 355 are allowed to escape past the skirt portion 295 of the seal 235 due to the increased pressure within the charging chamber 355.

[0079] When the user releases the compressive force exerted upon the second barrel 219, the biasing force exerted by the piston spring 243 on the piston 231 moves the piston 231, the seal 235, and the second barrel 219 toward the extended position. As this movement occurs, the volume of the charging chamber 355 increases. Since the skirt portion 295 of the seal 235 allows only unidirectional flow, air and other gases are not permitted to enter the charging chamber 355 past the skirt portion 295. A resulting drop in pressure (i.e., a generation of reduced pressure) occurs within the charging chamber 355 as the volume increases. The amount of reduced pressure generated within the charging chamber 355 is dependent on the spring constant of the piston spring 243 and the integrity of the seal 235. In

one embodiment, it is desired to generate a reduced pressure that is greater (i.e., a lower absolute pressure) than the amount of reduced pressure to be supplied to the tissue site. For example, if it is desired to provide 125 mmHg of reduced pressure to the tissue site, it may be desirable to have the charging chamber 355 charged to 150 mmHg of reduced pressure.

[0080] The regulated chamber 359 is used to generate the desired therapy pressure that is delivered to the outlet port 227 and the tissue site. When the reduced pressure within the charging chamber 355 is greater than the reduced pressure within the regulated chamber 359 and when the reduced pressure in the regulated chamber 359 is less than the desired therapy pressure, the upward force on the seal 235 (exerted by the increased absolute pressure in the regulated chamber 359 and the biasing force of the regulator spring 307, both against the atmosphere pressure exerted downward on the seal 235) moves the valve body 303 into the open position (see FIG. 20), thereby allowing fluid communication between the charging chamber 355 and the regulated chamber 359. The charging chamber 355 continues to charge the regulated chamber 359 with reduced pressure (i.e., the absolute pressure in the regulated chamber 359 continues to drop) until the reduced pressure in the regulated chamber 359, balanced against the atmospheric pressure above the seal 235, is sufficient to counteract the biasing force of the regulator spring 307 and move the valve body into the closed position (see FIG. 19). When the regulated chamber 359 is charged with the desired therapy pressure, this pressure may be delivered to the outlet port as detailed previously.

[0081] When the reduced pressure source 211 is initially connected to a delivery tube and tissue site for treatment, it will likely be necessary to compress the second barrel 219 within the first barrel 215 multiple times. As each compression stroke is completed, the reduced pressure generated within the charging chamber 355 will pull air and any other gases from the delivery tube and the tissue site until the pressure within the tube and at the tissue site begins to approach the desired therapy pressure.

[0082] As the reduced pressure source 211 is being primed by one or more compressions, it is important that air and other positively-pressurized gases being pushed out of the charging chamber 355 are pushed past the skirt portion 295 of the seal 235 and not into the regulated chamber 359. Positively pressurized gas flow to the regulated chamber 359 may transfer to the delivery tube and the tissue site, which would counteract the reduced pressure that is then being applied to the tissue site. To prevent positively pressurized gas from entering the regulated chamber 359, the shaft 347 is provided to engage the seal 235 and valve body 303. As the second barrel 219 is compressed within the first barrel 215, the second

housing portion 315 moves relative to the first housing portion 311 so that the shaft 347 exerts a force on the valve body 303 that holds the valve body 303 in the closed position. Since the shaft 347 remains engaged during the entire compression, or charging stroke of the reduced pressure source 211, the air within the charging chamber 355 is vented past the seal 235 and not into the regulated chamber 359.

[0083] While the reduced pressure source 211, including the first barrel 215, the second barrel 219, the piston 231, and the seal 235, have been described herein as being cylindrical, it will be readily apparent that all of these components may be any size or shape. Additionally, the relative positions of the valve seat 279 and the valve body 303 may be reversed such that the valve body 303 is positioned below the valve seat 279.

[0084] Referring to FIGS. 21 and 22, a reduced pressure treatment system 511 includes a reduced pressure treatment apparatus 513 for delivering a reduced pressure to a dressing 515 positioned at a tissue site 517. The reduced pressure treatment apparatus includes a first flexible bladder 521 and a second flexible bladder 523. The flexible bladders 521, 523 are preferably made from an elastomeric material such as, for example, a silicone polymer, rubber, or another elastomeric material. The first flexible bladder 521 includes a compressible chamber 527 in which is disposed a biasing member 529. The second flexible bladder 523 includes a charging chamber 535 in which is disposed a biasing member 537. The biasing members 529, 537 may be any device that provides a biasing force to resist collapse of the chambers 527, 535. In one embodiment, the biasing members 529, 537 may be a porous foam that allows flow of fluid within or through the chambers 527, 535, but resists collapse when the chambers are exposed to a pressure less than an ambient pressure surrounding the reduced pressure treatment apparatus 513.

[0085] The first flexible bladder 521 includes a one-way valve 541 to allow expulsion of air from the compressible chamber 527 when the first flexible bladder 521 is compressed by a user. As the biasing member 529 in the compressible chamber 527 attempts to move the first flexible bladder 521 back to an extended position, the one-way valve 541 prevents or substantially reduces fluid from entering the compressible chamber 527 through the one-way valve 541. Instead, fluid enters the compressible chamber 527 through a one-way valve 551 positioned between the first flexible bladder 521 and the second flexible bladder 523. This fluid is pulled from the charging chamber 535 into the compressible chamber 527 to create a reduced pressure within the charging chamber 535. The first flexible bladder 521 may be compressed and allowed to expand several times to create the desired amount of reduced

pressure in the charging chamber 535. In one embodiment, the biasing member 537 in the charging chamber 535 is a porous foam that is more resistant to collapse than the biasing member 529 disposed in the compressible chamber 527. This configuration allows the charging chamber 535 to resist collapse such that a greater reduced pressure may be stored in the charging chamber 535.

[0086] The charging chamber 535 is positioned in fluid communication with the dressing 515 to deliver a reduced pressure to the tissue site 517. A regulator member 561 is positioned between the charging chamber 535 and the tissue site 517 to regulate pressure delivered by the charging chamber 535 to the tissue site 517. The regulator member 561 may be similar to other regulators described herein, or may be any other type of regulator or device capable of regulating pressure. In one embodiment, it is desired that a pressure within the charging chamber 535 be less than the ambient pressure and less than a desired therapy pressure that is to be delivered to the tissue site 517. The regulator member 561 ensures that pressure delivered to the tissue site 517 does not drop below the desired therapy pressure. If the pressure supplied to the tissue 517 begins to exceed the desired therapy pressure (i.e. more reduced pressure is needed), the regulator opens to allow fluid communication between the charging chamber 535 and the tissue site 517.

[0087] In the embodiment illustrated in FIGS. 21 and 22, the reduced pressure treatment apparatus has been described as having a charging chamber similar in some respects to other embodiments described herein. While a well-defined regulated chamber has not been described in this particular embodiment, a regulated chamber exists either within the dressing 515 at which regulated pressure is maintained, or within a fluid conduit fluidly connecting the regulator member 561 to the dressing 515.

[0088] Referring to FIG. 23, a graph is provided that illustrates the changes in pressure over time within a regulated chamber such as the regulated chambers described herein. The ability of a charging chamber to recharge the regulated chamber allows the pressure within the regulated chamber to vary little from the desired therapy pressure during operation of the reduced pressure source.

[0089] It should be apparent from the foregoing that an invention having significant advantages has been provided. While the invention is shown in only a few of its forms, it is not just limited but is susceptible to various changes and modifications without departing from the spirit thereof.

CLAIMS

We claim:

1. A manually-actuated reduced pressure pump comprising:
 - a first barrel having a substantially cylindrical wall and a closed end;
 - a piston movably disposed within the first barrel, a charging chamber being defined between the closed end of the first barrel and the piston;
 - a piston spring operably associated with the piston to bias the piston in a direction that allows an increase in a volume of the charging chamber;
 - a seal disposed within the first barrel, a regulated chamber being defined between the seal and the piston;
 - a regulator passage providing fluid communication between the charging chamber and the regulated chamber;
 - a second barrel operably associated with the piston to move the piston toward a compressed position when the reduced pressure pump is being manually actuated by a user; and
 - a valve body operably associated with the regulator passage to selectively allow or prevent fluid communication between the charging chamber and the regulated chamber.
2. The manually-actuated reduced pressure pump of claim 1 further comprising:
 - a regulator spring operably associated with the valve body to bias the valve body toward an open position.
3. The manually-actuated reduced pressure pump of claim 1, wherein the valve body is disposed on a central portion of the seal.
4. The manually-actuated reduced pressure pump of claim 1, wherein the seal is an elastomeric material.

5. The manually-actuated reduced pressure pump of claim 1 further comprising:
 - a regulator spring operably associated with the valve body to exert a biasing force on the valve body toward an open position, the valve body in the open position allowing fluid communication through the regulator passage;
 - wherein the biasing force on the valve body is counteracted by a pressure within the regulated chamber;
 - wherein the valve body is positioned in a closed position when the pressure within the regulated chamber is less than or equal to a desired therapy pressure; and
 - wherein the valve body is positioned in the open position when the pressure within the regulated chamber is greater than the desired therapy pressure.
6. The manually-actuated reduced pressure pump of claim 1, wherein:
 - the charging chamber stores a first pressure;
 - the regulated chamber stores a second pressure;
 - the first pressure is less than the second pressure; and
 - the first pressure and the second pressure are less than an ambient pressure.
7. The manually-actuated reduced pressure pump of claim 6, wherein:
 - the first pressure is about -150 mm Hg; and
 - the second pressure is about -125 mm Hg.
8. The manually-actuated reduced pressure pump of claim 1, wherein the regulator passage passes through the piston.
9. The manually-actuated reduced pressure pump of claim 1 further comprising:
 - a regulator spring operably associated with the valve body to exert a biasing force on the valve body toward an open position, the valve body in the open position allowing fluid communication through the regulator passage;
 - wherein the charging chamber stores a first pressure that is less than an ambient pressure;
 - wherein the regulated chamber stores a second pressure that is less than the ambient pressure, the first pressure being less than the second pressure;

wherein the biasing force on the valve body is counteracted by the second pressure within the regulated chamber;
wherein the valve body is positioned in a closed position when the second pressure is less than or equal to a desired therapy pressure; and
wherein the valve body is positioned in the open position when the second pressure is greater than the desired therapy pressure.

10. A reduced pressure treatment apparatus comprising:

a piston chamber having a closed end;
a piston disposed within the piston chamber and being movable between an extended position and a compressed position;
a charging chamber disposed between the piston and the closed end, the charging chamber having a first volume when the piston is in the compressed position and a second volume when the piston is in the extended position, the first volume being less than the second volume;
a biasing member to bias the piston toward the extended position;
a valve member allowing fluid to exit the charging chamber as the piston moves toward the compressed position and preventing fluid from entering the charging chamber as the piston moves toward the extended position;
a regulated chamber;
a passage to allow fluid communication between the regulated chamber and the charging chamber;
a regulator member to regulate fluid communication through the passage between the charging chamber and the regulated chamber.

11. The apparatus of claim 10, wherein:

the regulator member closes the passage to prevent fluid communication through the passage when the pressure in the regulated chamber is less than or equal to a desired therapy pressure; and
the regulator member opens the passage to allow fluid communication through the passage when the pressure in the regulated chamber is greater than the desired therapy pressure.

12. The apparatus of claim 10, wherein the valve member is a seal that allows unidirectional fluid flow into the charging chamber.
13. The apparatus of claim 10, wherein the regulator member further comprises:
 - a valve seat disposed adjacent the passage; and
 - a valve body capable of engaging the valve seat to substantially reduce fluid communication through the passage.
14. The apparatus of claim 10, wherein:
 - the charging chamber stores a first pressure;
 - the regulated chamber stores a second pressure;
 - the first pressure is less than the second pressure; and
 - the first pressure and the second pressure are less than an ambient pressure.
15. The apparatus of claim 14 wherein:
 - the first pressure is about -150 mm Hg; and
 - the second pressure is about -125 mm Hg.
16. The apparatus of claim 10 wherein:
 - the charging chamber stores a first pressure that is less than an ambient pressure;
 - the regulated chamber stores a second pressure that is less than the ambient pressure, the first pressure being less than the second pressure;
 - the regulator member closes the passage to prevent fluid communication through the passage when the second pressure in the regulated chamber is less than or equal to a desired therapy pressure; and
 - the regulator member opens the passage to allow fluid communication through the passage when the second pressure is greater than the desired therapy pressure.

17. The apparatus of claim 10, wherein the biasing member is a piston spring.
18. A reduced pressure treatment apparatus comprising:
 - a charging chamber storing a first pressure less than an ambient pressure;
 - a regulated chamber storing a second pressure less than the ambient pressure, the first pressure being less than the second pressure;
 - a conduit providing fluid communication between the regulated chamber and the charging chamber;
 - a regulator member operably associated with the conduit to prevent fluid communication through the conduit when the second pressure is less than or equal to a desired therapy pressure and to allow fluid communication through the conduit when the second pressure exceeds the desired therapy pressure.
19. The apparatus of claim 18 further comprising an electric pump to deliver a reduced pressure to the charging chamber.
20. The apparatus of claim 18 further comprising a manually-actuated pump to deliver a reduced pressure to the charging chamber.
21. The apparatus of claim 18, wherein the regulator member further comprises:
 - a valve seat disposed adjacent the conduit; and
 - a valve body capable of engaging the valve seat to substantially reduce fluid communication through the conduit.
22. The apparatus of claim 21 further comprising:
 - a spring operably associated with the valve body to urge the valve body toward an open position which allows fluid communication through the conduit.
23. The apparatus of claim 18, wherein:
 - the first pressure is about -150 mm Hg; and
 - the second pressure is about -125 mm Hg.

24. A reduced pressure treatment system comprising:
- a manifold adapted to be positioned at a tissue site;
 - a regulated chamber in fluid communication with the tissue site to deliver a desired therapy pressure to the tissue site;
 - a charging chamber adapted to store a charging pressure that is less than the desired therapy pressure;
 - a passage providing fluid communication between the regulated chamber and the charging chamber; and
 - a valve body operably associated with the passage to substantially reduce fluid communication through the passage when a pressure in the regulated chamber is less than or equal to the desired therapy pressure and to allow fluid communication through the passage when the pressure in the regulated chamber exceeds the desired therapy pressure.
25. The system of claim 24, wherein:
- the desired therapy pressure is about -125 mm Hg; and
 - the charging pressure is about -150 mm Hg.
26. The system of claim 24 further comprising an electric pump to deliver the charging pressure to the charging chamber.
27. The system of claim 24 further comprising a manually-actuated pump to deliver the charging pressure to the charging chamber.
28. The system of claim 24, wherein the valve body is configured to engage a valve seat adjacent the passage to substantially reduce fluid communication through the passage.
29. The system of claim 24 further comprising:
- a spring operably associated with the valve body to urge the valve body toward an open position, the valve body in the open position allowing fluid communication through the passage.

30. A method of providing reduced pressure treatment to a tissue site, the method comprising:
- storing a charging pressure within a charging chamber;
 - delivering a desired therapy pressure from a regulated chamber to the tissue site; and
 - when a pressure within the regulated chamber exceeds the desired therapy pressure, reducing the pressure within the regulated chamber by allowing fluid communication between the charging chamber and the regulated chamber.
31. The method of claim 9 further comprising:
- selectively blocking a conduit between the charging chamber and the regulated chamber to prevent fluid communication between the charging chamber and the regulated chamber.
32. The method of claim 9 further comprising:
- charging the charging chamber by manually reducing a volume of the charging chamber and then allowing the volume of the charging chamber to expand.