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FEEDSTOCK FEEDER SYSTEM

[0001] The present disclosure generally relates to systems and methods for feeding a solid feedstock into a pressurized system. More specifically, the present disclosure relates to a solid feedstock feeder system having a piston feeder and seal.

BACKGROUND OF THE DISCLOSURE

[0002] Currently, solid feedstock (e.g., solid biomass, municipal solid waste (MSW), coal, or any other suitable solid feedstock) is feed into a pressurized reactor by pressurizing a volume of the solid feedstock in, for example, a lock hopper system. While this approach is suitable for introducing the solid feedstock into the reactor, it requires a large vessel and consumes an undesirable amount of pressurized gas. In addition, existing lock hopper systems have a complex design. For example, the lock hopper system includes an atmospheric vessel, a sluice vessel, and a pressurized vessel along with several sets of valves. Moreover, because lock hopper systems pressurize the volume of the solid feedstock, a source of pressurized gas is required. It would be advantageous to use a solid feedstock feeding system that does not require the use of large amounts of pressurized gas and has a simpler design compared to existing lock hopper systems.

SUMMARY

[0003] In an embodiment, a piston includes a chamber and a barrel disposed in and that may translocate within the chamber. The barrel includes a terminal end having a seal, and the seal has an annular ring having a first wall and a second wall, the second wall is orthogonal to and extends from the first wall such that a first portion of the first wall protrudes away from the second wall in a first direction and a second portion of the first wall protrudes away from the second wall in a second direction that is substantially opposite to the first direction.

[0004] In another embodiment, a solid feedstock feeding system includes a piston feeder that may receive a solid feedstock and includes an inlet, an outlet, and at least one piston disposed between the inlet and the outlet. The at least one piston includes a chamber and a barrel disposed in and that may translocate within the chamber, the barrel includes a terminal end having a seal, and the seal has an annular ring having a first wall and a second wall, the second wall is orthogonal

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to and extends from the first wall such that a first portion of the first wall protrudes away from the second wall in a first direction and a second portion of the first wall protrudes away from the second wall in a second direction that is substantially opposite from the first direction.

[0005] In a further embodiment, a system includes a solid feedstock feeding system having a piston feeder that may receive a solid feedstock and including an inlet, an outlet, at least one piston disposed between the inlet and the outlet. The at least one piston includes a first chamber and a barrel disposed in and that may translocate within the first chamber, the barrel includes a terminal end having a seal, and the seal includes an annular ring having a first wall and a second wall positioned orthogonal to and extending from the first wall such that a first portion of the first wall protrudes away from the second wall in a first direction and a second portion of the first wall protrudes away from the second wall in a second direction that is substantially opposite from the first direction. The system also includes a reactor disposed downstream from and fluidly coupled to the solid feedstock feeding system. The reactor includes one or more inlets that may receive the solid feedstock and to generate a product stream.

[0006] Additional features and advantages of exemplary implementations of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by the practice of such exemplary implementations. The features and advantages of such implementations may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features will become more fully apparent from the following description and appended claims, or may be learned by the practice of such exemplary implementations as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Advantages of the disclosure may become apparent upon reading the following detailed description and upon reference to the drawings in which:

[0008] FIG. 1 is a block diagram of a system that includes a pressurized reactor and a solid feedstock feeding system fluidly coupled to the pressurized reactor and having a piston feeder and a dosing tank, in accordance with an embodiment of the present disclosure;

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[0009] FIG. 2 is a diagram of the solid feedstock feeding system of FIG. 1, whereby the piston feeder includes various pistons, in accordance with an embodiment of the present disclosure;

[0010] FIG. 3 is a diagram of a piston feeder that may be used in the solid feedstock system of FIG. 2, whereby the piston feeder includes a piston in a slanted configuration, in accordance with an embodiment of the present disclosure;

[0011] FIG. 4 is a perspective view of the components that make up a terminal end of a piston associated with the piston feeder of FIGS. 2 and 3, in accordance with an embodiment of the present disclosure;

[0012] FIG. 5 is a perspective view of the components of the terminal end of a piston associated with the piston feeder of FIGS. 2 and 3, in accordance with an embodiment of the present disclosure;

[0013] FIG. 6 is a perspective view of a terminal end of a piston associated with the piston feeder of FIGS. 2 and 3, in accordance with an embodiment of the present disclosure;

[0014] FIG. 7 is a cross-sectional view of the terminal end of the piston in FIG. 6 along line 7-7, in accordance with an embodiment of the present disclosure;

[0015] FIG. 8 is an exploded cross-sectional view of a portion of the terminal end of the piston in FIG. 7, in accordance with an embodiment of the present disclosure;

[0016] FIG. 9 is a cross-sectional view of the terminal end of a piston within a chamber of the piston feeder of FIGS. 2 and 3, in accordance with an embodiment of the present disclosure;

[0017] FIG. 10 is a cross-sectional view of the terminal end of the piston within a chamber of the piston feeder of FIGS. 2 and 3, whereby the terminal end includes a spring, in accordance with an embodiment of the present disclosure;

[0018] FIG. 11 is a cross-sectional view of the terminal end of the piston within a chamber of the piston feeder of FIGS. 2 and 3, whereby the terminal end includes a pressure assisted seat, in accordance with an embodiment of the present disclosure;

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[0019] FIG. 12 is a cross-sectional view of the dosing tank of the solid feedstock feeding system of FIG. 2, whereby the dosing tank includes agitators and solid transport devices to move the solid feedstock, in accordance with an embodiment of the present disclosure;

[0020] FIG. 13 is flow diagram of a method for using the piston feeder of FIGS. 2 and 3 to provide a solid feedstock to the dosing tank, in accordance with an embodiment of the present disclosure;

[0021] FIG. 14 is a cross-sectional view of the piston feeder of FIG. 2, whereby a first chamber and a second chamber are in fluid communication and isolated from an outlet of the piston feeder, in accordance with an embodiment of the present disclosure;

[0022] FIG. 15 is a cross-section view of the piston feeder of FIG. 2, whereby the solid feedstock has been fed to the second chamber and the outlet is isolated from the second chamber, in accordance with an embodiment of the present disclosure;

[0023] FIG. 16 is a cross-sectional view of the piston feeder of FIG. 2, whereby the second chamber having the solid feedstock is isolated from a first chamber and the outlet, in accordance with an embodiment of the present disclosure;

[0024] FIG. 17 is a cross-sectional view of the piston feeder of FIG. 2, whereby the second chamber having the solid feedstock is in fluid communication with the outlet and isolated from the first chamber, in accordance with an embodiment of the present disclosure; and

[0025] FIG. 18 is a cross-sectional view of the piston feeder of FIG. 2, whereby a feed chamber is aligned with an inlet, and the second chamber and the outlet are isolated from the first chamber and the feed chamber, in accordance with an embodiment of the present disclosure; and

[0026] FIG. 19 is plot of the number of cycles as a function of leak flow for the piston feeder, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0027] One or more specific embodiments of the present disclosure will be described below. These described embodiments are examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, not all features

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of an actual implementation may be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions will be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0028] When introducing elements of various embodiments of the present disclosure, the articles “a,” “an,” and “the” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to “one embodiment” or “an embodiment” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0029] The terms “approximately,” “about,” and “substantially” as used herein represent an amount close to the stated amount that still performs a desired function or achieves a desired result. For example, the terms “approximately,” “about,” and “substantially” may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of a stated amount.

[0030] As discussed in further detail below, the disclosed embodiments include a piston feeder system that may be used to provide solid feedstock (e.g., biomass) to a pressurized reactor. Certain existing pressurized systems use a lock hopper to provide solid feedstock (e.g., biomass) to a pressurized reactor. Lock hoppers generally require the use of multiple vessels for storing, transferring, and discharging/blowing the solid feedstock into the pressurized reactor. One problem with existing lock hoppers is that, when the solid biomass falls into each vessel, the solid biomass is compacted. For example, certain lock hopper configurations have a storage tank that supplies the solid feedstock to a transfer vessel (e.g., sluice vessel) that is pressurized after having received the solid feedstock from the storage tank, which is at ambient pressure. As the solid

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feedstock falls from the storage tank into the transfer vessel, the solid feedstock may become compacted. Compacting of the solid feedstock in the transfer vessel results in lumps or clusters of solid feedstock, which impact the operation of the reactor and the efficiency as well as the reliability of the process that uses the pressurized reactor. For example, a lump or cluster of solid feedstock has substantially less surface area than the total surface area of the solid feedstock parts forming the lump or cluster; which may hinder the process efficiency. In addition, feedstock lumps or clusters will make the feeding operation unreliable due to bridging and blocking of the feed flow path by the lumps or clusters. Reactor operation is impacted as a result of the unstable and unreliable feeding as well as forming of solid tar lumps within the adjacent feeding system to the reactor (e.g., when using solid biomass to generate biofuels). Therefore, it is desirable to develop a solid feedstock feeding system that may provide industrial-scale volumes of solid feedstock to an industrial pressurized reactor in a manner that does result in compaction of the feedstock.

[0031] Moreover, the lock hopper feeding systems used in industrial-scale applications are based on batch-wise transportation of volumes of solid feedstock through the lock hopper vessels to the reactors, thereby the vessels used in the lock hopper feeding systems are generally large (e.g., typically holding volumes in the order of 50 – 80 cubic meters (m³)). As such, the amount of pressurized gas (e.g., approximately 5000 kilogram/hour (kg/hr)) used to transfer the required volume of the solid feedstock into the reactor may be undesirable. For example, the amount of pressurized gas required may impact the efficiency of the process due, in part, to the amount of energy used to pressurize the gas. Accordingly, it would be advantageous to develop a solid feedstock feeding system that does not require or uses a small amount of pressurized gas, and has a smaller/compact configuration that mitigates compaction of the solid feedstock compared to existing lock hopper feeding systems. It has been recognized that a piston feeder may be used to feed solid feedstock into a pressurized reactor at an industrial scale while mitigating the undesirable compacting, vessel size, and pressurized gas quantity associated with lock hopper feeding systems. Piston feeders generally use o-rings to seal and maintain pressure within its chambers (i.e. cylinders). However, over time, forces exerted on the o-rings from the reciprocating motion of the piston may result in creep and eventually damage to the o-ring such that the seal and the desired pressure within a respective chamber of the piston feeder is not maintained. Therefore, it may be advantageous to provide a piston feeder and seal that mitigate the problems associated

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with existing feedstock feeding systems. Disclosed herein is a piston feeder system having an improved seal for delivering a solid feedstock to an industrial reactor in a manner that maintains a desired pressure in respective chambers and does not rely on pressurized gas nor results in compaction of the solid feedstock.

[0032] With the foregoing in mind, **FIG. 1** is a block diagram of an embodiment of a system **10** that may include the disclosed piston feeder for providing a solid feedstock (e.g., biomass and/or waste plastics/oils) to a reactor (e.g., a pressurized reactor). In the illustrated embodiment, the system **10** includes a solid feedstock feeding system **12** and a reactor **14** positioned downstream from and fluidly coupled to the solid feedstock feeding system **12**. The reactor **14** may be used to react a solid feedstock **18** with other components under pressure to generate a desired product **16** (e.g., a biofuel). For example, in operation, the pressure within the reactor **14** may be between approximately 0.1 megapascal (MPa) to approximately 5 MPa (approximately 1-50 bar). However, in other embodiments, the reactor **14** may be at a pressure greater than 5 MPa (50 bar). The reactor **14** may be any suitable reactor. By way of non-limiting example, the reactor **14** may be a fluidized bed reactor, fixed bed reactor, bubbling bed reactor, entrained flow reactor, or any other suitable reactor. In certain embodiments, the reactor **14** includes a catalyst. In other embodiments, the reactor **14** does not include a catalyst. While the illustrated embodiment has single reactor **14**, it should be appreciated that the system **10** may include additional reactors and other system components that facilitate generating the desired product **16** without departing from the scope of the present disclosure. For example, the system **10** may include 1, 2, 3, 4, 5, 6, or more reactors **14** arranged in series or in parallel. Additionally, the system **10** may include particulate removal systems (e.g., cyclones, filters, or any other suitable separator for solids removal), purifying systems (e.g., distillation units, scrubbers, and the like) disposed downstream and fluidly coupled to the reactor(s) **14**.

[0033] In operation, the solid feedstock **18** is introduced into the reactor **14** via a piston feeder **30** of the solid feedstock feeding system **12**. As described in further detail below, the piston feeder **30** does not require the use of a pressurized gas and various vessels as in existing lock hopper feeding systems. Moreover, the piston feeder **30** has chambers for receiving and transferring the solid feedstock **18** that are approximately 75% or more smaller compared to the

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vessels used in existing lock hopper feeding systems. For example, the piston feeder **30** may have chambers that have a volume that is between approximately 75% and 99% less than a volume of the vessels in existing lock hopper systems. The solid feedstock feeding system **12** also includes a dosing tank **32** downstream from and fluidly coupled to the piston feeder **30** and the reactor **14**. The configuration of the piston feeder **30** and the dosing tank **32** mitigate compacting of the solid feedstock **18** in the solid feedstock feeding system **12**. In embodiments, in which the system **10** includes multiple reactors **14**, the dosing tank **32** is fluidly coupled to and provides the solid feedstock **18** to each of the reactors **14**, as discussed in further detail below with reference to **FIG. 12**. In one embodiment, the dosing tank **32** is positioned upstream of the piston feeder. In other embodiments, the system **10** does not include the dosing tank **32**. As such, the piston feeder **30** feeds the solid feedstock **18** directing into the reactor **14** rather than into the dosing tank **32**.

[0034] The solid feedstock **18** used in the disclosed process may include a residual waste feedstock and/or a biomass feedstock containing lignin, lignocellulosic, cellulosic, hemicellulosic material, or any combination thereof. Suitable lignocellulose-containing biomass includes woody biomass and agricultural and forestry products and residues (whole harvest energy crops, round wood, forest slash, bamboo, sawdust, bagasse, sugarcane tops and trash, cotton stalks, corn stover, corn cobs, castor stalks, Jatropha whole harvest, Jatropha trimmings, de-oiled cakes of palm, castor and Jatropha, coconut shells, residues derived from edible nut, rice husk, rice straw production and mixtures thereof), animal waste and municipal solid wastes containing lignocellulosic material. The municipal solid waste (MSW) may include any combination of lignocellulosic material (yard trimmings, pressure-treated wood such as fence posts, plywood), discarded paper and cardboard and waste plastics, along with refractories such as glass, metal. Prior to use in the process disclosed herein, municipal solid waste may be optionally converted into pellet or briquette form. The pellets or briquettes are commonly referred to as Refuse Derived Fuel in the industry. Certain feedstocks (such as algae and lemna) may also contain protein and lipids in addition to lignocellulose. Residual waste feedstocks are those having mainly waste plastics. In certain embodiments, the solid feedstock **19** may be different ranks of coal, peat or any other suitable solid feedstock that may be fed to a pressurized reactor.

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[0035] The solid feedstock **18** may be provided to the reactor **14** in the form of loose particles having a majority of particles preferably less than about 3.5 millimeters (mm) in size or in the form of a solid/liquid slurry. However, as appreciated by those skilled in the art, the solid feedstock **18** may be pre-treated or otherwise processed in a manner such that larger particle sizes may be accommodated. In an embodiment of the present disclosure, a double-screw system having a slow screw for metering the solid feedstock **18** followed by a fast screw to push the solid feedstock **18** into the reactor without causing thermo-chemical reaction in the screw housing is used for dosing. An inert gas or hydrogen flow is maintained over the fast screw to further reduce the residence time of the solid feedstock **18** in the fast screw housing. As should be appreciated, dosing of the solid feedstock **18** into the reactor **14** may be achieved by other suitable means such as, but not limited to, a rotary valve.

Solid Feedstock System

[0036] As discussed above, the solid feedstock system **12** provides the solid feedstock **18** to the reactor **14** in a manner that does not require a pressurized gas and large volume vessels compared to lock hopper feeding systems, and does not result in compaction of the solid feedstock **18**. **FIG. 2** illustrates an arrangement of the piston feeder **30** and the dosing tank **32** of the solid feedstock system **12**, in accordance with an embodiment of the present disclosure. The solid feedstock system **12** may have an axial axis or direction **96**, a radial axis or direction **98** away from axis **96**, and a circumferential axis or direction **100** around the axis **96**. The piston feeder **30** includes multiple pistons arranged in a manner that allow the solid feedstock **18** to move through the piston feeder **30** and into the dosing tank **32** while maintaining a desired pressure within each chamber of the piston feeder **30**. For example, in the illustrated embodiment, the piston feeder **30** includes a first piston **102**, a second piston **104**, a third piston **106**, and a fourth piston **108**. The piston feeder **30** also includes a first chamber **110**, a second chamber **112**, and a conduit **114** extending between and fluidly coupling the chambers **110**, **112**. Each piston **102**, **104**, **106**, **108** includes a respective barrel **116**, **117**, **118**, and **119**. The barrel **116**, **117**, **118**, **119** translocates within a respective chamber to facilitated movement of the solid feedstock **18** through the piston feeder **30** and into the dosing tank **32**, as discussed in further detail below.

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[0037] In addition, the piston feeder **30** includes an inlet **120** positioned adjacent to and extending in the axial direction **96** away from the first piston **102** and the first chamber **110**, a feed chamber **122** disposed within the first chamber **110** and fluidly coupled to the inlet **120**, and an outlet **124** positioned adjacent to and extending axially **96** away from the fourth piston **108** and the second chamber **112**. However, the inlet **120** and the outlet **124** may be arranged in any other suitable manner than allows a flow of the solid feedstock **18** into and out of the piston feeder **30**.

[0038] At least a portion of the barrel **116** of the first piston **102** is disposed within the first chamber **110** and moves (e.g., translocates) along a length of the first chamber **110**, for example, in the radial direction **98** to move the solid feedstock **18** from the first chamber **110** and into the conduit **114**. Similar to the first piston **102**, at least a portion of the barrel **117** of the second piston **104** is disposed within the second chamber **112** and moves (e.g., translocates) along a length of the second chamber **112** to move the solid feedstock **18** from the second chamber **112** and into the dosing tank **32**. In the illustrated embodiment, a portion of the conduit **114** is slanted relative to the axial axis **96**. However, in certain embodiment, the conduit **114** may be parallel to the axial axis **96**.

[0039] In the illustrated embodiment, the first piston **102** and the second piston **104** radially extend along the radial axis **98** and are positioned parallel to one another. The third piston **106** and the fourth piston **108** extend axially along the axial axis **96** and are parallel to one another and orthogonal to the pistons **102**, **104**. However, in other embodiments, the pistons **102**, **104** are not positioned parallel to one another. For example, **FIG. 3** illustrates an embodiment of the piston feeder **30** in which the piston **104** is oriented at an acute angle α relative to a centerline axis **126** of the piston **108** and orthogonal to a centerline axis **128** of the piston **106**. Consequently, the second chamber **112** of the piston feeder **30** is also oriented at the acute angle α relative to the centerline axis **126** of the piston **108**. By arranging the piston **104** and the second chamber **112** in this way, the solid feedstock may move along the second chamber **112** easily due, in part, to gravitational forces and eroding of an interior surface of the second chamber **112** may be mitigated. For example, the solid feedstock may be abrasive and scratch, or otherwise erode, the interior surface of the second chamber **112** as the barrel **117** of the piston **104** pushes the solid feedstock toward the fourth piston **108** and into the dosing tank **32**. Such movement of the solid feedstock

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may, overtime, wear away the interior surface of the second chamber **112**. In addition, the solid feedstock may lodge between the interior surface of the second chamber **112** and the outer surface of the barrel **117**. As such, the barrel **117** may be unable to properly move within the second chamber **112** and transfer the solid feedstock into the dosing tank **32**. The slanted, or angled, configuration of the second piston **104** and the second chamber **112** may mitigate wear of the piston feeder surfaces (e.g., the interior surface of the second chamber **112** and the outer surface of the piston **106**) and lodging of the solid feedstock between the interior surface of the second chamber **112** and the outer surface of the piston **104**.

[0040] Returning to **FIG. 2**, the outlet **124** couples (e.g., connects) the piston feeder **30** to the dosing tank **32** such that the solid feedstock **18** may be transferred from the second chamber **112** to the dosing tank **32**. In operation, the first chamber **110** and the conduit **114** are maintained at ambient pressure (e.g., approximately 0.1 MPa (1 bara)) and the second chamber **112** and the dosing tank **32** are pressurized according to the pressure within the reactor **14**. For example, the second chamber **112** and the dosing tank **32** may be at a pressure of between approximately 0.1 megapascal (MPa) to approximately 5 MPa (approximately 1-50 bara). As discussed in further detail below, the third piston **106** may be used to maintain the different pressures within the chambers **110**, **112** and mitigate flow back of the solid feedstock **18** from the dosing tank **32** back into the piston feeder **30** due to pressure differentials between, for example, a feedstock storage tank and the dosing tank **32**.

[0041] The piston feeder **30** includes various valves and seals that facilitate a flow of the solid feedstock **18** through the chambers **110**, **112** and the conduit **114**, and mitigate flow back of the solid feedstock **18** from the dosing tanks **32** and/or reactor **14** back into the piston feeder **30**. For example, the piston feeder **30** includes a seal **130** and **132** at an end of the barrels **116**, **117**, respectively. The piston feeder **30** also includes pressure seals **134** and **136** at an end of the barrels **118**, **119**, respectively. In operation, the pressure seal **136** provides a seal between the dosing tank **32** and the second chamber **112** such that when the second chamber **112** receives the solid feedstock **18** from the first chamber **110**, which is at atmospheric pressure (e.g., 0.1 MPa (1 bara)), the solid feedstock **18** in the dosing tank **32**, which is at a higher pressure than the chamber **110**, **112** (e.g., at a pressure of between 0.6 MPa (6 bara) and 5 MPa (50 bara)), does not flow back into

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the piston feeder **30**. Similarly, the pressure seal **134** provides a seal between the chambers **110**, **112** such that when the second chamber **112** is pressurized to equal the pressure within the dosing tank **32**, the solid feedstock **18** does not flow back into the first chamber **110** and the conduit **114**, which are at atmospheric pressure. Once the second chamber **112** is isolated from the first chamber **110**, conduit **114**, and dosing tank **32**, the second chamber **112** may be filled with H₂ and pressurized to the pressure within the dosing tank **32** and the reactor **14**. For example, the piston feeder **30** may have a purge valve **140** and a bypass valve **142** that allow the second chamber **112** to be filled with the H₂ and pressurized the chamber **112**. During pressurization of the second chamber **112**, the valves **140**, **142** are open to allow the air within the chamber **112** to be displaced by the H₂. After some time, the purge valve **140** is closed and the bypass valve **142** remains open such that the chamber **112**, that is filled with H₂, may be pressurized to the desired pressure. Once the second chamber **112** is at the desired pressure, the bypass valve **140** is closed and the third piston **108** moves in the axial direction **96** away from the outlet **24** to release the seal and allow fluid communication between the second chamber **112** and the outlet **124**.

[0042] As discussed above, certain existing piston feeders use an o-ring to provide a seal and maintain pressure in a respective chamber. However, the force exerted on the o-ring by the continuous motion of the piston results in creep of the o-ring and, over time, damage. As such, the o-ring may be unable to seal and maintain the desired pressure within the respective chamber. Therefore, the pressure seal **134**, **136** disclosed herein is configured in a such a way to mitigate damage resulting from the forces exerted by the piston **106**, **108**. For example, **FIGS. 4** and **5** are perspective views of an end portion **150** of the piston **106**, **108** having the disclosed pressure seal **134**, **136**. In addition to the pressure seal **134**, **136**, the end portion **150** includes a top plate **152**, a bottom plate **154**, a middle plate **156**, and an insert **160**. The pressure seal **134**, **136** has an annular ring **162** that is positioned between the plates **152**, **156**. The end portion also includes an o-ring **164** between the bottom plate **154** and the insert **160**. The plates **152**, **154**, **156**, the insert **160**, the pressure seal **134**, **136**, and the o-ring **164** are held together by bolts **168**, thereby forming the end portion **150**, as shown in **FIG. 6**.

[0043] **FIG. 7** is a cross-sectional view of the end portion **150** along line 7-7. As shown in the illustrated embodiment, the annular ring **162** of the pressure seal **134**, **136** has recesses **172**

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and protrusions **174** such that the annular ring **162** has a T-shaped cross-section. For example, the annular ring **162** has a first wall **175** extending between a first side **176a** and a second side **176b** of the annular ring **162**, the second side **176b** being substantially opposite (e.g., 180 degrees) from the first side **176a**. The annular ring **162** also has a second wall **177** extending from and orthogonal to the first wall **175**. The second wall **177** forms part of the first side **176a** and the second side **176b**. A portion of the first wall **175** extends (or protrudes out) from a surface of the first side **176a** to form the protrusion **174a** and recess **172a**, and another portion of the first wall **175** extends (or protrudes out) from a surface of the second side **176b** to form the protrusion **174b** and recess **172b**, thereby giving the annular ring **162** the T-shaped cross-sectional geometry. In certain embodiments, a flat ring may be disposed between the protrusion **174a** and an inner surface of the plate **152** such that the terminal end of the protrusion **174a** is not against and abuts the inner surface of the plate **152**. In the illustrated embodiment, the protrusions **174** have a rectangular or square geometry. However, the protrusions **174** may have any other suitable geometry such as trapezoidal, triangular, polygonal, and combinations thereof. For example, in certain embodiments, protrusion **174a** may have one cross-sectional geometry and the other protrusion **174b** may have another cross-sectional geometry that is different from the cross-sectional geometry of the protrusion **174a**.

[0044] As discussed in further detail below, the T-shape of the annular ring **162** facilitates coupling of the pressure seal **134**, **136** to the end portion **150** and mitigates damage that may be caused by the forces exerted on the seal **134**, **136** by the plates **152**, **154** during operation of the piston feeder **30**. For example, during operation, the second wall **177** of the seal **134**, **136** expands in a linear direction **179** toward an inner surface of a respective piston chamber housing the barrels of the piston **106**, **108** (e.g., the barrels **118**, **119**), thereby creating the seal. In addition to creating the seal, the liner movement (i.e., expansion) of the second wall **177** cleans the sealing surface during movement of the piston **106**, **108** by removing feedstock that may be lodged between the barrel of the piston **106**, **108** and the inner surface of the piston chamber. When the seal **134**, **136** is deactivated, the second wall **177** retracts and returns to its original shape. Unlike o-ring shaped seals, the first wall **175** (e.g., the T-bar) forces the second wall **177** back to its original shape as the first wall **175** is held in place by the plates **152**, **156** and is unable to move. As such, the first wall **175** pulls the second wall **177** back to its original shape and mitigates wear on the seal **134**,

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136 that may be caused by frictional forces exerted by the inner surface of the piston chamber onto the second wall **177**. The T-shape of the annular ring **162** blocks, or otherwise mitigates, the pressure seal **134, 136** from creeping and allows it to maintain its original diameter. Additionally, narrow tolerances of the T-shape mitigate extrusion of portions of the seal **134, 136** as it is compressed during operation, which would change its shape and available material resulting in loss of sealing effectiveness. The annular ring **162** may be formed from an elastic incompressible material such that the annular ring may expand and contract to return to its original shape after application and removal of forces exerted by the plates **152, 154, 156**. By way of non-limiting example, the thermoplastic material may be selected from polyurethane materials and the like. As used herein, the term “elastic incompressible material” denotes a material that maintains its density (i.e., it is incompressible) but not necessarily its shape (i.e., the material deforms) when a force is applied, and returns to its original shape when the force is removed. To facilitate discussion of the pressure seal **134, 136**, reference will be made to **FIG. 8**, which is an exploded view of a section of the end portion **150**. As shown in the illustrated embodiment, the T-shape cross-sectional geometry of the annular ring **162** facilitates retaining the pressure seal **134, 136** in the end portion **150**. For example, the plates **152, 156** each have a lip **178, 180**, respectively, that form a rim around an outer circumference of the plates **152, 156**. The plates **152, 156** also have a recessed wall **184, 186** (e.g., annular recesses wall) sized and shaped to receive the protrusions **174a, 174b**, respectively, of the pressure seal **134, 136**. When assembled, the pressure seal **134, 136** does not about a top plate outer surface **190** and a middle plate outer surface **192**. For example, as shown in the illustrated embodiment, there is a gap **188a** between a first seal outer surface **194a** and the top plate outer surface **190**, and a gap **188b** between a second seal outer surface **194b** and the middle plate outer surface **192**. The gap **188** extends circumferentially around the end portion **150** when the seal is not activated. Additionally, a terminal end **191** of the second wall **177** is positioned entirely within the lips **178, 180** such that the terminal end **191** does not protrude away from or is flush with the outer surfaces of the end portion **150**. That is, the terminal end **191** is nested within the plates **152, 156**. This seal configuration keeps the seal **134, 136** from rubbing against an inner surface of the respective piston feeder chamber the piston during movement of the piston, thereby mitigating creep and damage to the seal during operation. Additionally, it allows for the second wall **177** to expand and create the seal when pressure is applied by the plates **152,**

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156 as described in further detail below with reference to **FIG. 9**. Unlike the surfaces **194** of the second wall **177**, portion **198a**, **198b** of seal outer surface **197a**, **197b** of the sides **176a**, **176b** abuts a top plate surface **200** and middle plate surface **204**, respectively. That is, there is no gap between the outer surface **197** of the pressure seal **134**, **136** and the respective plate surfaces **220**, **204**. In addition, the middle plate **156** includes an interior wall **208** adjacent to the recessed wall **186** and extending from the middle plate surface **204**. An outer portion **210** of the first wall **175** abuts an outer surface **214** of the interior wall **208**.

[0045] A second gap **218** between a top plate inner surface **220** and a terminal end **224** of the interior wall **208** allows for the top plate **152** to exert a force **226** on the pressure seal **134**, **136** when the piston (e.g., the piston **106**, **108**) translocates to isolate the chamber (e.g., the second chamber **112**) and/or the outlet (e.g., the outlet **124**) such that a pressure differential between the dosing tank (e.g., the dosing tank **32**) and piston chambers at atmospheric pressure (e.g., the first chamber **110**) does not result in flow back of the solid feedstock (e.g., the solid feedstock **18**) from the dosing tank back into the piston feeder (e.g., the piston feeder **30**). For example, as the piston **106**, **108** moves in a direction towards the outlet **124** the bottom plate **154** abuts against a terminal end of the chamber it is in causing the bottom plate **154** and the middle plate **156** to move in a direction opposite to the direction the piston **106**, **108** is moving. Consequently, the gap **218** is decreased causing the top plate **152** to exert the force **226** on the pressure seal **134**, **136**. The bottom plate **154** also exerts a force counter to the force **226**, which pushes against the pressure seal **134**, **136**, thereby causing a portion of the annular ring **162** to compress and pushing it towards an inner wall of the chamber, as explained in further detail below. The compression of the annular ring **162** creates a seal within the chamber and blocks fluid communication between a space of the piston feeder or chamber adjacent to (or above) the top plate **152** and a space of the piston feeder or chamber adjacent to (or below) the bottom plate **154**.

[0046] For example, **FIG. 9** is cross-sectional view of a portion of the piston feeder **30** having the pressure seal **134**, **136** of the present disclosure in an activated configuration. In the illustrated embodiment, the end portion **150** of the piston **106**, **108** is positioned within a chamber **230** of the piston feeder **30** such that the bottom plate **154** abuts against a portion of an inner chamber wall **232**. The bottom plate **154** has a beveled terminal end **234** having a slanted wall

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236 that forms an angle θ of between approximately 30° and 50° . A portion **240** of the beveled terminal end **234** contacts the inner chamber wall **232** such that the inner chamber wall **232** exerts a force **246** against the bottom plate **152**. Consequently, the gap **218** decreases, thereby exerting the force **226** and a counter force **250** onto the pressure seal **134**, **136** causing the annular ring **162** compress and the second wall **177** to expand, thereby closing the gap **188** and pushing the terminal end **191** out toward an inner surface **252** of the chamber **230** to provide the seal. The T-shape configuration of the annular ring **162**, in combination with the beveled terminal end **234** of the bottom plate **154**, mitigate damage to the annular ring **162** that may be caused by creep, as discussed above.

[0047] **FIG. 10** illustrates an alternative embodiment of the end portion **150** of the piston **106**, **108** in which the end portion includes a spring and an o-ring between the plates **152**, **154**. For example, in the illustrated embodiment, an end portion **254** includes a spring **256** within a void **258** that forms between the plates **152**, **156** of the end portion **254**. Unlike the end portion **150**, the end portion **254** does not include a separate middle plate (e.g., the middle plate **156**). Rather, the bottom plate **154** of the end portion **254** is combined with the middle plate (e.g. the middle plate **156**) such that the bottom plate **154** and the middle plate form a single unitary structure. In the illustrated embodiment, coupled to the bottom plate **154** is a volume dispenser **255** having a concave configuration. The volume dispenser **255** facilitates movement of the solid feedstock through the piston feeder, the dosing tank, and/or the reactor.

[0048] As discussed above, the seal **134**, **136** expands when activated, forcing the second wall **177** toward the inner surface of the piston chamber (e.g., the inner surface **252**) to create the seal. When the seal **134**, **136** is deactivated (e.g., when the seal is broken), the second wall **177** is pulled toward the first wall **175** and the seal **134**, **136** returns to its original shape. The spring **256** facilitates pulling the second wall **177** toward the first wall **175** after the forces **226**, **250** are released by overcoming the friction forces exerted on the second wall **177** by the surface **190**, **192** of the plates **152**, **156**, respectively. In addition to facilitating retraction of the second wall **177** when the seal **134**, **136** is deactivated, the spring **256** mitigates wear of the terminal end **191** resulting from friction forces exerted by the inner surface of the piston chamber against the terminal end **191** when the second wall **177** does not retract to its original shape once deactivated.

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For example, once the seal **134, 136** is deactivated, the piston **106, 108** moves in a direction away from an end of the chamber (e.g., in a direction that is substantially the same as the counter force **250**). If the second wall **177** of the seal **134, 136** does not retract to its original shape, the terminal end **191** may rub against the inner surface of the chamber. This rubbing (i.e., friction) may wear the seal **134, 136** over time causing leakage and feedstock to get trapped between the piston and the inner surface of the chamber. The spring **256** may be any spring suitable for overcoming the friction forces of the seal **134, 136**. The spring **256** has an annular configuration and may be made from materials such as, but not limited to, steel, metal alloys, or the like. The end portion **254** may have any number of springs **256**. For example, the end portion **254** may have 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more springs **256**.

[0049] In addition to the spring **256**, the end portion **254** includes a backup ring **258** between the recessed wall **184** and the outer surface **197a** of the pressure seal **134, 136**. The backup ring **258** mitigates extrusion of the first wall **175**, for example, when there is a gap between the recessed wall **258** and the outer surface **197a** of the seal **134, 136**. The backup ring **258** may be made of any suitable material with sufficient durability and elastomeric properties to withstand the forces **226, 250** and block extrusion of the first wall **175** during operation of the piston feeder. By way of non-limiting example, the backup ring **258** may be a nylon ring or the like.

[0050] FIG. 11 illustrates another embodiment of the end portion **150** of the piston **106, 108** in which the end portion includes a pressure assisted seat **253**. The pressure-assisted seat **253** works by balancing of process pressure **255** (e.g., the pressure below the end portion **150**) against seat pressure **257** (e.g., the pressure inside of the piston for de-activating the seal function). The seat pressure **257** is maintained higher than the process pressure **255**. For example, the seat pressure **257** is maintained at between approximately 0.5% and 25% higher than the process pressure **255**. By way of non-limiting example, the seat pressure **257** may be between approximately 1 and 15 bar higher than the reactor pressure, and the process pressure **255** may be between approximately 1 and 10 bar higher than reactor pressure. In this way, it is ensured that the pressure on the seal **134, 136** may be released when the piston (e.g., the piston **106, 108**) is retracted independently of the operating pressure. An advantageous aspect of this design is that having a higher seat pressure **257** compared to the process pressure **255** secures the retraction of

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the seal **134**, **136** when removing pressure from the pressure-assisted seat **253** when the piston moves away from the outlet (e.g., the outlet **124**) of the piston feeder or of the chamber in which the piston is housed. Additionally, bearings may be positioned adjacent to seal **134**, **136** (e.g., adjacent to and abutting the first wall **175** of the T-shaped annular ring **162**) to control the concentricity of the pressure-assisted seat **253**. The bearings ensure that the seat can move axially without damaging surfaces of the end portion **150** and the piston chamber. The bearings **259** may be made from a material having a hardness that is different from a hardness of the pressure-assisted seat **253**. By way of non-limiting example, the bearings may be bronze or any other material that is softer than the material of the pressure-assisted seat **253**. A central part **263** sets the precompression of the seal **134**, **136** when no pressure is set on a metal-metal seat **265**. The central part **263** of the end portion **150** of the piston is pressurized by an external source of inert gas through a pipe in the piston. By maintaining a higher pressure in the piston than in the process it is ensured that all leaks will be from the inside and out and thereby avoiding dust or foreign matters from entering the moving parts of the seat construction. For example, the higher pressure in the metal-metal seat **265** compared to the process pressure ensures that dust does not accumulate and, in case there is a leak due to a damaged O-ring, gas will not flow into the equipment which may otherwise cause damage and impact performance.

[0051] As discussed above, the disclosed piston feeder (e.g., the piston feeder **30**) provides solid feedstock (e.g., the solid feedstock **18**) to the dosing tank **32**. The dosing tank **32** may include additional features such as agitators and screw conveyors that keep the solid feedstock **18** in motion, mitigate compaction, and facilitate dosing the solid feedstock **18** into the reactor **14**. **FIG. 12** is a cross-sectional view of an embodiment of the dosing tank **32**. The dosing tank **32** includes the body **260**, inlets **262**, and outlet **264**. While in the illustrated embodiment, the dosing tank **32** has a single outlet **264**, the dosing tank **32** may have multiple outlets. The body **260** defines a housing **270** (e.g., vessel) of the dosing tank **32** that contains a desired volume of feedstock (e.g., the solid feedstock **18**). For example, the housing **270** may contain a volume of solid feedstock that is between approximately 10 m³ to 130 m³. As such, dimensions of the housing **270** may be between approximately 2 m (meters) diameter x 4 m length and 4 m diameter x 10 m length. However, as should be appreciated, the housing **270** may be any size suitable for containing the desired amount of solid feedstock. The housing **270** has a longitudinal axis **272** that extends from

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a first end 276 to a second end 278 of the dosing tank 32. In embodiments having multiple outlets 264, one or more outlets 264 are positioned at the first end 276 and one or more outlets 264 are positioned on the second end 278. The outlets 264 may feed the solid feedstock (e.g., the solid feedstock 18) into the reactor (e.g., the reactor 14) symmetrically (e.g., each outlet feeding the solid feedstock into the reactor simultaneously) or in series (e.g., one outlet feeds the solid feedstock into the reactor followed by the other outlet feeding the feedstock into the reactor). Each outlet 264 may dose the same or different amounts of the solid feedstock into the reactor. In certain embodiments, each outlet 264 may be fluidly coupled to separate reactors such that one dosing tank 32 may feed the solid feedstock into multiple reactors.

[0052] As shown in FIG. 12, along the longitudinal axis 272 are multiple agitators 274 that move the solid feedstock entering the housing 270 toward a center 280. The agitators 274 include a shaft 282 having a plurality of blades 284 that maintain movement of the solid feedstock 18 within the dosing tank 32. In operation, the agitators 274a and 274c move in a first direction along the longitudinal axis 272 such that the respective blades 284 move a first portion of the solid feedstock 18 toward the center 282, and the agitators 274b and 274d move in a second direction opposite the first direction along the longitudinal axis 272 such that the respective blades 284 move a second portion of the solid feedstock 18 toward the center 280.

[0053] The housing 270 also includes one or more troughs 286 into which the solid feedstock enters through an opening 288 at the center 280 of the housing 270. The troughs 286 extend along the longitudinal axis 272 from the first end 276 to the second end 278 and terminate at the respective outlet 264. In embodiments having multiple troughs 286, the troughs 286 are adjacent to one another and separated by a partition such that the solid feedstock in one trough 286 is separated from the solid feedstock in an adjacent trough 286. Each trough 286 includes a solid feed transport device 290 that moves and doses the solid feedstock in the trough 286 to the reactor (e.g., the reactor 14). By way of non-limiting example, the solid feed transport device 290 is a screw conveyor type, pneumatic transport system, or any other suitable solid feed transport device. The dosing tank 32 may include one or more control device 292 that control and facilitate movement of the agitator 274 and the solid feed transport device 290. The agitators 274 and the solid feed transport device 290 operate independently from one another. Therefore, the agitator

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274 and the solid feedstock transport device **290** each have their own control device **292**. However, in certain embodiment, the agitator **274** and the solid feedstock transport device **290** are independently operated using the same control device **292**. As should be appreciated, the dosing tank **32** may be used in combination with the disclosed piston feeder. It may be positioned upstream or downstream of the piston feeder. In certain embodiments, the dosing tank **32** may be integral with the piston feeder. In other embodiments, the dosing tank **32** is a standalone unit that is separate from and removably coupled to the piston feeder. By having the dosing tank **32** as a standalone unit, it may be retrofit into existing reactor system and allows flexibility in adjusting the solid feedstock feeding system configuration (e.g., move the dosing tank from a downstream position to an upstream position relative to the piston feeder, remove the dosing tank from a solid feedstock feeding system already in place, or add the dosing tank to a solid feedstock feeding system already in place).

[0054] Present embodiments also include a method of feeding a solid feedstock (e.g., the solid feedstock **18**) to a reactor (e.g., the reactor **14**). For example, **FIG. 13** is a flow diagram of a method **300** that may be used to feed the solid feedstock into the reactor using the disclosed piston feeder (e.g., the piston feeder **30**), while also avoiding flow back of the solid feedstock from the dosing tank (e.g., the dosing tank **32**) back into the piston feeder. To facilitate discussion of the acts of the method **300**, reference will be made to **FIG. 14-18**. The method **300** includes providing the solid feedstock to a first chamber of the piston feeder at ambient pressure (block **304**).

[0055] For example, with reference to **FIG. 14**, the piston feeder **30** receives the solid feedstock **18** from a solid feedstock storage tank through the inlet **120**. As shown in the illustrated embodiment, the inlet **120** is fluidly coupled to the feed chamber **122**. The feed chamber **122** is aligned with the inlet **120** and receives the solid feedstock **18** from the solid feedstock storage tank disposed upstream of the piston feeder **30**. In the illustrated embodiment, the fourth piston **108** is positioned such that the chambers **110**, **112**, **122** and the conduit **114** are isolated from the outlet **124** and the dosing tank (e.g., the dosing tank **32**) to avoid flow back of the solid feedstock **18** that may be in the dosing tank. For example, as discussed above the dosing tank is at a pressure of between approximately 0.6 MPa (6 bara) and 5 MPa (50 bara), which is the pressure within the

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reactor (e.g., the reactor **14**). In contrast, the pressure within the chambers **110**, **112**, **122** and the conduit **114** is at ambient (e.g., approximately 0.1 MPa (1 bara)). The pressure differential between the piston feeder **30** and the dosing tank may cause flow back of the solid feedstock **18** back into the piston feeder **30** if an exit **206** of the second chamber **112** is not blocked and isolated from the outlet **124**. Therefore, while in this position, the end portion **150** of the fourth piston **108** abuts the inner chamber wall **232** of the chamber **230b**, thereby exerting a force on the pressure seal **136** causing it to compress, which forces it out against an inner surface of the chamber **230b**. In this way, the pressure seal **136** provides a seal and isolates the outlet **124** from the chambers **110**, **112**, **122** and the conduit **114** to maintain the pressuring at the outlet **124** substantially the same as the pressure within the dosing tank.

[0056] Returning to **FIG. 13**, the method **300** also includes transferring the solid feedstock from the feed chamber into the second chamber (block **310**). For example, as shown in **FIG. 15** the first piston **102** moves towards a terminus **312** of the first chamber **110** to align the feed chamber **122** with an opening **316** of the conduit **114**. Once the feed chamber **122** is aligned with the opening **316**, the solid feedstock **18** flows through the conduit **114** and into the second chamber **112**. The fourth piston **108** remains in place to continue isolating the outlet **124** and blocking fluid communication between the chambers **110**, **112**, **122** and the conduit **114** and the dosing tank, thereby mitigating flow back of the solid feedstock **18** already in the dosing tank.

[0057] Once again returning to **FIG. 13**, following transfer of the solid feedstock to the second chamber in accordance with the acts of block **310**, the method **300** includes pressurizing the second chamber (block **318**). For example, the third piston **106** moves toward the second chamber **112**, thereby blocking fluid communication between the chambers **110**, **122** and the conduit **114** and the second chamber **112**, as shown in **FIG. 16**. The second chamber **112** is isolated from the conduit **114** (and anything upstream of the conduit **114**) and the outlet **124** of the piston feeder **30**. Similar to the fourth piston **108**, the end portion **150b** of the third piston **106** abuts an inner wall **320** of a chamber inlet **324** associated with the second chamber **112**, thereby exerting a force on the pressure seal **134** causing it to compress, which forces it out against an inner surface of a second conduit **326** that houses the barrel **118** of the third piston **106**. The fourth piston **108** remains in position blocking fluid communication between the second chamber **112**

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and the outlet **124**. In this way, the pressure seal **134** provides a seal and isolates the second chamber **112** from the conduit **114** and upstream of the conduit **114**, and the pressure seal **136** seals and isolates the second chamber **112** from the outlet **124** to allow the second chamber **112** to be pressurized to a pressure that is substantially the same as the pressure within the dosing tank.

[0058] For example, a pressure of the second chamber **112** is at ambient. Therefore, the second chamber **112** is pressurized according to block **312** of the method **300** such that the pressure within the second chamber **112** is approximately equal to the pressure within the dosing tank. Pressurizing the second chamber **112** before feeding the solid feedstock **18** into the dosing tank mitigates flow back of the solid feedstock **18** within the dosing tank that may be caused due to the pressure differential between the second chamber **112** and the dosing tank. As discussed above, the second chamber **112** includes the bypass valve **140** through which H₂ gas may be injected into the second chamber **112**. The purge valve **142** is opened such that the air within the second chamber **112** may be displaced by the H₂ gas. Once the air within the second chamber **112** is displaced, the purge valve **142** is closed and the H₂ gas continues to fill the second chamber **112** until the desired pressure is reached. For example, the dosing tank may be at a pressure of between approximately 0.6 MPa (6 bara) and 5 MPa (5 bara). Accordingly, the second chamber **112** is pressurized to a pressure of 0.6 MPa (6 bara) and 5 MPa (5 bara).

[0059] Returning to **FIG. 13**, the method includes feeding the solid feedstock to a dosing tank (block **330**). To feed the solid feedstock **18** into the dosing tank (e.g., the dosing tank **32**), the fourth piston **108** moves away from the outlet **124** while the third piston **106** remains in place to maintain the second chamber **112** isolated from the first chambers **110**, **122** and the conduit **114**, as shown in **FIG. 17**. Movement of the fourth piston **108** in the direction **332** releases the force (e.g., the forces **226**, **250**) from the pressure seal **136**, which opens and allows fluid communication between the second chamber **112** and the dosing tank via the outlet **124**. The barrel **117** of the second piston **104** moves within the second chamber **112** in a direction **334** toward outlet **124** to move the solid feedstock **18** into the dosing tank. As should be noted, the pistons **104**, **108** may move simultaneously or in series. For example, in one embodiment, the third piston **106** moves in the direction **334** as the fourth piston **108** moves in the direction **332**. In other embodiments, the fourth piston **108** moves in the direction **332** first to allow fluid communication between the second

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chamber **112** and the outlet **124**, followed by movement of the second piston **104** in the direction **334** to feed the solid feedstock **18** into the dosing tank.

[0060] Once the solid feedstock **18** is fed to the dosing tank, the piston feeder **30** may receive another batch of the solid feedstock **18**. For example, returning to **FIG. 13**, the method **300** includes aligning the feed chamber with the inlet of the piston feeder (block **340**). The step may be done after or during the acts of block **330**. In certain embodiments, the acts of block **340** may be done simultaneously with the acts of block **318**. During alignment of the feed chamber **122** and the inlet **124**, the first piston **102** moves in a direction **342** away from the terminus **312** of the first chamber **110** and toward the inlet **124** (see **FIG. 18**). The pistons **104**, **106**, **108** remain in place to keep the first chamber **110** and the conduit **114** isolated from the second chamber **112**, the outlet **124**, and the dosing tank. In this way, flow back of the solid feedstock **18** in the dosing tank may be mitigated.

[0061] Following alignment of the feed chamber **122** with the inlet **124**, the solid feedstock **18** is provided to the feed chamber **122** in accordance with the acts of block **304**. The method **300** may be repeated for each batch of solid feedstock that is fed to the dosing tank. Before, during, or after each batch of solid feedstock **18** is provided to the feed chamber **122**, the second piston **104** may move away from the fourth piston **108** and the outlet **124** in a direction substantially opposite from the direction **334** and the fourth piston **108** may move toward the outlet **124** in a direction substantially opposite from the direction **332**. The third piston **106** remains in place such that the second chamber **112** remains isolated from the first chamber **110** and the conduit **114**. The configuration of the pistons **106** and **108** block fluid communication between the second chamber **112** and the first chamber **110** and the outlet **124**, respectively. While in this configuration, the purge valve **142** may be opened to release the H₂ and depressurized the second chamber **112**. Once depressurized, the third piston **106** may move away from the second chamber **112** in a direction **346** to allow fluid communication between the first chamber **110** and the second chamber **112** (see **FIG. 18**). As should be noted, based on the arrangement of the pistons **106** and **108**, the directions **332**, **346** may be the same or different.

[0062] A piston having the seal and end portion configuration disclosed herein was tested for leakage. The leakage test was performed by pressurizing the piston and maintaining the

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pressure over a period of time. A reduction in pressure was measured during that time period, and the leakage rate was determined from the rate of pressure decrease. For example, the piston was pressurized to 41.5 bar. After 45 seconds, the pressure was measured every second for 300 seconds. A slope of a linear regression of the measured pressure was determined and the leak flow was calculated from the slope. The leakage test provides a good indication as to whether the piston maintains a seal for a desired number of cycles. The experimental setup included a piston having an end portion similar to that shown **FIG. 10** and disposed in a housing. The piston was moved in cycles, each cycle including a downward movement (e.g., toward a sealing area adjacent to an outlet/terminal end of the housing) to activate the seal (e.g., cause the seal to linearly expand) and an upward movement (e.g., away from the sealing area and toward a housing opening opposite to the terminal end) to deactivate the seal (e.g., cause the seal to linearly retract). A pressure vessel pressurized with inert gas (e.g., nitrogen (N₂) or helium (He)) was positioned below the piston to measure the sealing ability of the seal. A pressure of the pressure vessel was observed for a period of time to estimate a leak rate of the inert gas and changes to the leak rate during the test. **FIG. 19** is a plot **350** of number of cycles **352** as a function of leak flow **354** in normal liters/hour (NL/h) of a piston having the spring loaded end portion and seal disclosed herein (e.g., as shown in **FIG. 10**). As shown in the illustrated embodiment, the end portion and seal configuration disclosed herein maintained the seal for over 500,000 cycles without degradation and/or wear of the seal. The leakage flow was maintained between approximately 1NL/h and approximately 6 NL/h, which is within specifications, and remained fairly steady throughout the 500,000 cycles. Conventional o-ring type seals that do not have the T-bar configuration of the seal disclosed herein begin to degrade/wear after approximately 20 cycles. In contrast the seal disclosed herein may go through 500,000 cycles or more without any observable degradation/wear and changes in leak rate.

[0063] As discussed above, the solid feedstock system disclosed herein may be used to provide a solid feedstock (e.g., biomass) to a reactor (e.g., a hydroprocessing reactor) in a manner that does not require large vessels and pressurized gas compared to lock hopper feeding systems used in commercial applications. The disclosed system and methods may also mitigate compaction of the solid feedstock that may affect the overall efficiency of hydroprocessing techniques and cost. The disclosed system and method use a unique configuration of pistons that transfer the feed through different chambers and into a dosing tank. Certain pistons of the piston

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feeder provide a seal that isolates chambers to facilitate pressurizing and mitigate flow back of the solid feedstock back into the piston feeder. The disclosed seal is designed in such a manner that mitigates damage caused by creep that may result in undesirable leakage and flow back of the solid feedstock from the dosing tank to the piston feeder. Additionally, the terminal end of the pistons having the disclosed seal have a beveled terminus such that the force applied by the terminus of the piston to the seal minimizes damage to the seal overtime.

[0064] The present disclosure may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the disclosure is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

CLAIMS

We claim:

1. A piston, comprising
a chamber; and
a barrel disposed in and configured to translocate within the chamber, wherein the barrel comprises a terminal end having a seal, and wherein the seal comprises an annular ring having a first wall and a second wall, wherein the second wall is orthogonal to and extends from the first wall such that a first portion of the first wall protrudes away from the second wall in a first direction and a second portion of the first wall protrudes away from the second wall in a second direction that is substantially opposite to the first direction.
2. The piston of claim 1, wherein the terminal end comprises a first plate, a second plate, and a third plate, wherein the third plate forms a terminus of the terminal end, and wherein the seal is disposed between the first plate and the second plate, and wherein the terminal end is configured to apply one or more forces on the seal to push at least a portion of the seal toward an inner surface of the chamber .
3. The piston of claim 2, wherein the first plate comprises a first surface, a first recessed wall, and first lip adjacent to the first recessed wall, the first recessed wall is circumferentially around the first surface and the first lip is around a circumference of the first plate, and wherein the second plate comprises a second surface, a second recessed wall, a second lip, and an interior wall extending from the second surface and positioned parallel to the second lip, the second lip is around a circumference of the second plate and the second recessed wall is disposed between the second lip and the interior wall and is circumferentially around the second surface.
4. The piston of claim 3, wherein the first portion of the first wall of the seal is disposed within the first recessed wall, the second portion of the first wall of the seal is disposed within the second recessed wall, the first wall abuts the interior wall, and the second wall of the seal is disposed between the first lip and the second lip.

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5. The piston of claim 2, wherein the third plate has a beveled end having an angle of between approximately 35° and 50°.
6. The piston of claim 1, wherein the seal is an elastic incompressible material.
7. The piston of claim 1, wherein a cross-sectional geometry of the seal is T-shaped.
8. A solid feedstock feeding system, comprising:
 - a piston feeder configured to receive a solid feedstock and comprising an inlet, an outlet, and at least one piston disposed between the inlet and the outlet, wherein the at least one piston comprises:
 - a chamber; and
 - a barrel disposed in and configured to translocate within the chamber, wherein the barrel comprises a terminal end having a seal, and wherein the seal comprises an annular ring having a first wall and a second wall, wherein the second wall is orthogonal to and extends from the first wall such that a first portion of the first wall protrudes away from the second wall in a first direction and a second portion of the first wall protrudes away from the second wall in a second direction that is substantially opposite from the first direction.
9. The solid feedstock feeding system of claim 8, wherein the terminal end comprises a first plate, a second plate, and a third plate, wherein the third plate forms the terminus of the terminal end, wherein the seal is disposed between the first plate and the second plate, and wherein the terminal end is configured to apply one or more forces on the seal to push at least a portion of the seal toward an inner surface of the chamber .
10. The solid feedstock feeding system of claim 9, wherein the first plate comprises a first surface, a first recessed wall, and a lip adjacent to the first recessed wall, the first recessed wall is circumferentially around the first surface and the first lip is around a circumference of the first plate, and wherein the second plate comprises a second surface, a second recessed wall, a second

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lip, and an interior wall extending from the second surface and positioned parallel to the second lip, the second recessed wall is disposed between the second lip and the interior wall and is circumferentially around the second surface.

11. The solid feedstock feeding system of claim 10, wherein the first portion of the first wall of the seal is disposed within the first recessed wall, the second portion of the first wall of the seal is disposed within the second recessed wall, the first wall abuts the interior wall, and the second wall is disposed between the first lip of the first plate and the second lip of the second plate.

12. The solid feedstock feeding system of claim 9, wherein the third plate has a beveled end, and wherein an angle of the bevel is between approximately 35° and 50°.

13. The solid feedstock system of claim 9, wherein the seal is a thermoplastic material.

14. The solid feedstock system of claim 9, wherein a cross-sectional geometry of the seal is T-shaped.

15. The solid feedstock system of claim 9, comprising a second piston disposed upstream from the at least one piston, wherein the second piston comprises a second chamber and a second barrel disposed and configured to translocate within the second chamber, wherein the second barrel comprises a second terminal end having a top plate, a middle plate, a bottom plate, and a second seal disposed between the top plate and the middle plate, and wherein the second seal has a cross-sectional geometry that is T-shaped.

16. The solid feedstock feeding system of claim 9, comprising a dosing tank disposed downstream from and fluidly coupled to the piston feeder, wherein the dosing tank comprises a housing having one or more inlets, and one or more outlets, wherein at least one inlet of the one or more inlets is fluidly coupled to the outlet of the piston feeder and configured to receive the solid feedstock from the piston feeder and to provide the solid feedstock to a pressurized reactor,

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wherein the at least one piston is positioned adjacent to the one or more inlets of the dosing tank and is configured to isolate a portion of the piston feeder from the dosing tank.

17. A system, comprising:

a solid feedstock feeding system comprising a piston feeder configured to receive a solid feedstock and comprising an inlet, an outlet, at least one piston disposed between the inlet and the outlet, wherein the at least one piston comprises:

a first chamber; and

a barrel disposed in and configured to translocate within the first chamber, wherein the barrel comprises a terminal end having a seal, and wherein the seal comprises an annular ring having a first wall and a second wall positioned orthogonal to and extending from the first wall such that a first portion of the first wall protrudes away from the second wall in a first direction and a second portion of the first wall protrudes away from the second wall in a second direction that is substantially opposite from the first direction;

and

a reactor disposed downstream from and fluidly coupled to the solid feedstock feeding system, wherein the reactor comprises one or more inlets configured to receive the solid feedstock and to generate a product stream.

18. The system of claim 17, wherein the terminal end comprises a first plate, a second plate, and a third plate, wherein the third plate comprises a beveled end and forms a terminus of the terminal end, wherein the seal is disposed between the first plate and the second plate, and wherein the terminal end is configured to apply one or more forces on the seal to push at least a portion of the seal toward an inner surface of the first chamber .

19. The system of claim 17, wherein the seal is a thermoplastic material, and wherein a cross-sectional geometry of the seal is T-shaped.

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20. The system of claim 17, wherein the at least one piston is disposed adjacent to the outlet of the piston feeder and configured to isolate the outlet and the reactor from one or more second chambers of the piston feeder disposed upstream of the first chamber.

21. The system of claim 17, comprising a dosing tank disposed downstream from the piston feeder and upstream from the reactor, wherein the dosing tank comprises a housing having one or more inlets fluidly coupled to the outlet of the piston feeder, and one or more outlets fluidly coupled to the one or more inlets of the reactor.