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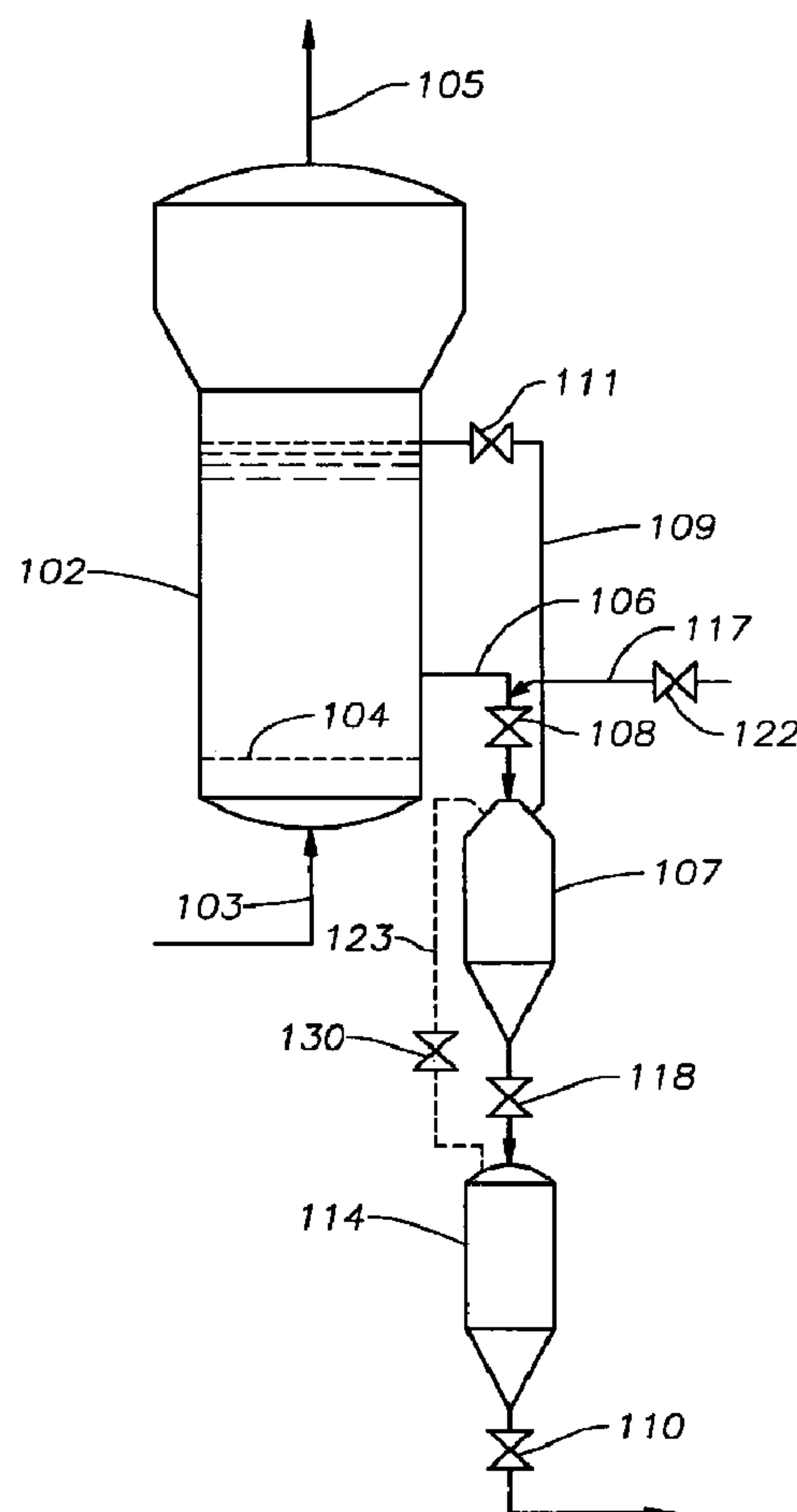
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(54) Titre : SYSTEMES DE DECHARGE ET PROCEDES QUI LES UTILISENT

(54) Title: DISCHARGE SYSTEMS AND METHODS OF USING THE SAME



(57) Abrégé/Abstract:

A discharge system for removing a solid/gas mixture from a fluidized bed pressure vessel is provided. The discharge system includes a fluidized bed pressure vessel, a settling vessel, a transfer vessel, discharge line, primary discharge valve, and primary exit



(57) **Abrégé(suite)/Abstract(continued):**

valve. Also included is a method to operate the discharge system. The method includes transferring a solid/gas mixture from a fluidized bed pressure vessel to a settling vessel, transferring the solids to a transfer vessel, and then emptying the transfer vessel.

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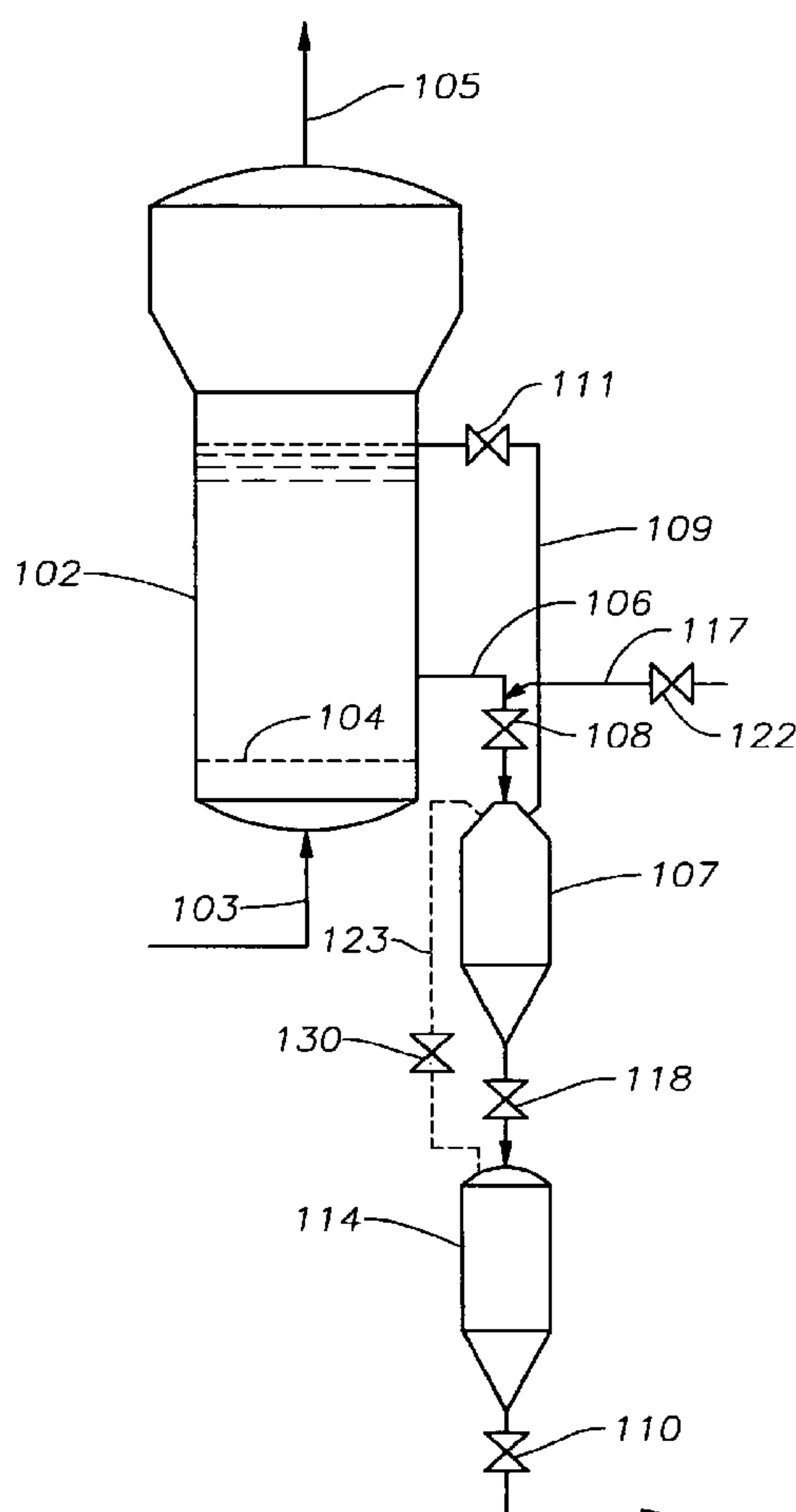
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[Continued on next page]

(54) Title: DISCHARGE SYSTEMS AND METHODS OF USING THE SAME



(57) Abstract: A discharge system for removing a solid/gas mixture from a fluidized bed pressure vessel is provided. The discharge system includes a fluidized bed pressure vessel, a settling vessel, a transfer vessel, discharge line, primary discharge valve, and primary exit valve. Also included is a method to operate the discharge system. The method includes transferring a solid/gas mixture from a fluidized bed pressure vessel to a settling vessel, transferring the solids to a transfer vessel, and then emptying the transfer vessel.

WO 2008/045172 A1

**WO 2008/045172 A1**

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## DISCHARGE SYSTEMS AND METHODS OF USING THE SAME

### CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit of Provisional Application Nos. 60/850,552, filed October 10, 2006, and 60/965,916, filed August 23, 2007, the disclosures of which are incorporated by reference in its entirety.

### FIELD OF THE INVENTION

**[0002]** This disclosure relates generally to a discharge system and method for removing matter such as, for example, a solid/gas mixture, from a pressure vessel with minimum gas loss. More specifically, this disclosure relates to a system and method for removing primarily solids from a fluidized bed pressure vessel with minimum gas removal.

### BACKGROUND

**[0003]** There are many systems and methods for discharging solids from a fluidized bed pressure vessel, gas phase fluidized bed pressure vessel, or gas phase fluidized bed polymerization vessel. However, the use of existing discharge systems and methods can result in higher loss of reactants from the discharge system than is desirable. Specifically, a significant amount of the gas or gas/liquid mixture may be lost because the void space within and around the particles is filled with a high-pressure gas mixture. The lost gas must then be either replaced, consuming additional raw materials, or recycled back into the system via compression, condensation with pumping, or a combination of these. In either scenario, raw materials are wasted and energy consumed.

**[0004]** One process that involves the discharge of a gas/solids mixture from a pressure vessel is the process for the manufacture of polyolefin resins, thereby involving the polymerization of olefin monomers in a fluidized bed

reactor. An example of a process for the manufacture of polyolefin resins is disclosed in, for example, U.S. Patent No. 4,003,712 ("the '712 patent"). As therein defined, a product is discharged from the reaction zone through a gas lock zone and the unreacted monomer that accompanies the resin is vented and recycled back to the reaction zone by compression. The product is then transferred to downstream equipment via a conventional dilute phase conveying system.

**[0005]** An alternative discharge system is described in, for example, U.S. Patent No. 4,621,952 ("the '952 patent"). The '952 patent describes a gas lock zone system involving multiple settling vessels operating in series. The '952 patent describes that the gas mixture lost from the process could be significantly reduced by using the gas displacing ability of solids using two or more vessels with pressure equalization between each. As described, a valve between a nozzle on the fluidized bed pressure vessel and settling vessel is opened, and solids along with pressurized gas enter settling vessel. A second connection between the top of the settling vessel to a slightly lower pressure section of the reactor provides a flow path for the gas while solids settle out to essentially fill settling vessel. Both valves are then closed, leaving the settling vessel full of the solid particles, but with interstitial spaces between the particles filled with the gas mixture, and the settling vessel at full reactor pressure. The settling vessels of the discharge systems described in the '952 patent typically comprise a hemispherical top head, a straight section and a conical bottom section. The second connection is typically in this hemispherical head.

**[0006]** After the settling tank is isolated from the fluidized bed pressure vessel, a valve is then opened and solids are transferred to a transfer tank. As the solids flow into the transfer tank, pressure equalization also occurs between transfer tank and settling vessel. Upon completion, the pressure in transfer tank and settling vessel are at a moderate level. However, the transfer tank still contains a substantial amount of gas in the interstitial spaces between particles. Some practitioners then open a crossie valve to allow the moderate



pressure gas to transfer to an empty transfer tank in another series of tanks. Once the pressure in the transfer tank is relatively low, the product is transferred to other vessels for additional processing with only a modest pressurized gas transfer therein. The gas retained in the settling vessel is transferred back into the fluidized bed pressure vessel during the next fill cycle.

**[0007]** Additionally, U.S. Patent Nos. 6,255,411 (“the ‘411 patent”) and 6,498,220 describe the crosstie concept mentioned above in detail and describe various improvements. The ‘411 patent also offers a faster cycle time.

**[0008]** Other background references include U.S. Patent No. 6,472,483, EP 0 250 169A2, and WO 2006/079774.

**[0009]** Accordingly, there exists a need for an improved method to remove matter, such as, primarily solids, from a fluidized bed pressure vessel with maximum volumetric fill of the settling tank, which results in greater efficiency in the processing of the matter, while addressing safety concerns of dealing with a pressurized reactor system.

## SUMMARY

**[0010]** The invention described herein provides a method and system for removing solids from a fluidized bed pressure vessel. In one class of embodiments, the discharge system comprises: a settling vessel comprising a conical top head; a discharge line fluidly connecting a fluidized bed pressure vessel to the settling vessel; a primary discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to the settling vessel; a transfer vessel in fluid communication with the settling vessel; a transfer valve between the settling vessel and the transfer vessel that controls a transfer flow from the settling vessel to the transfer vessel; and a primary exit valve that controls an exit flow of the fluid mixture from the transfer vessel.

**[0011]** In any of the embodiments described herein, the transfer vessel may comprise a conical top head.

**[0012]** In other embodiments, the invention may comprise a secondary discharge valve in series with the primary discharge valve, wherein the primary discharge valve and the secondary discharge valve are located between the fluidized bed pressure vessel and the settling vessel, and wherein both the primary discharge valve and the secondary discharge valve control the discharge flow to the settling vessel.

**[0013]** In still other embodiments, the invention may comprise at least two secondary discharge valves and at least two settling vessels, wherein each secondary discharge valve controls the flow to one settling vessel, and wherein one primary discharge valve is in fluid communication with the at least two secondary discharge valves and the at least two settling vessels, such that the one primary discharge valve, in combination with the at least two secondary discharge valves, controls the discharge flow to each of the at least two settling vessels.

**[0014]** In yet other embodiments, the invention may comprise a vent line fluidly connecting an upper portion of the fluidized bed pressure vessel and the settling vessel and a primary vent valve that controls a vent flow through the vent line.

**[0015]** In still other embodiments, the invention may comprise a secondary vent valve in series with the primary vent valve that controls a vent flow through the vent line in addition to the primary vent valve.

**[0016]** Other embodiments may comprise at least two secondary vent valves and at least two settling vessels, wherein each secondary vent valve controls the vent flow between the upper portion of the fluidized bed pressure vessel and one settling vessel, and wherein one primary vent valve is in fluid communication with the at least two secondary vent valves and the at least two settling vessels, such that the one primary vent valve, in combination with the at least two secondary vent valves, controls the vent flow between the upper



portion of the fluidized bed pressure vessel and each of the at least two settling vessels.

**[0017]** Any of the embodiments described herein may comprise a secondary exit valve, wherein both the primary exit valve and the secondary exit valve control the exit flow from the transfer vessel.

**[0018]** Any of the embodiments described herein may comprise a means to detect an abnormal condition in the discharge system, and a means to close the secondary exit valve upon detection of the abnormal condition.

**[0019]** In some embodiments, the means to detect an abnormal condition may comprise an automated control system and a means to detect pressure, flow, temperature, vessel stress, valve position, or actuator position.

**[0020]** In some embodiments, the means to close the secondary exit valve may comprise the automated control system and a signal to close the secondary exit valve.

**[0021]** In other embodiments, the secondary exit valve may be normally open.

**[0022]** In still other embodiments, the secondary exit valve may close within about 5 seconds, or within about 2.5 seconds of detection of the abnormal condition.

**[0023]** Any of the embodiments described herein, may comprise a solids monitoring device that detects when a settling vessel is full.

**[0024]** Any of the embodiments described herein, may comprise a dry-gas purge fed to the settling vessel.

**[0025]** Any of the embodiments described herein, may comprise a dry-gas purge fed to the transfer vessel.

**[0026]** Any of the embodiments described herein, may comprise a clean-gas purge fed to the discharge line.

- [0027]** Any of the embodiments described herein, may comprise a clean-gas purge fed to the vent line.
- [0028]** Another class of embodiments described herein relate to a method for removing solids from a fluidized bed pressure vessel. The method includes the steps of: providing a discharge system comprising a plurality of settling vessels and a plurality of transfer vessels, wherein at least one of the a plurality of settling vessels comprises a conical top head; filling a first settling vessel of the plurality of settling vessels with a mixture from a fluidized bed pressure vessel, wherein the mixture comprises a solid and a pressurized gas; equalizing the first settling vessel, wherein a first portion of pressurized gas is transferred from the first settling vessel to at least one of the plurality of settling vessels that is not the first settling vessel; transferring the solid and a second portion of pressurized gas from the first settling vessel to a first transfer vessel; re-equalizing the first settling vessel, wherein a return pressurized gas is transferred from at least one of the plurality of settling vessels that is not the first settling vessel to the first settling vessel; equalizing the first transfer vessel with a second transfer vessel, wherein a third portion of the pressurized gas is transferred from the first transfer vessel to at least one of the plurality of transfer vessels that is not the first transfer vessel; emptying the first transfer vessel; and re-equalizing the first transfer vessel, wherein a return transfer gas is transferred from at least one of the plurality of transfer vessels that is not the first transfer vessel to the first transfer vessel.
- [0029]** In any of the embodiments, at least one of the plurality of transfer vessels provided may comprise a conical top head.
- [0030]** Any of the embodiments described herein the method may provide a primary exit valve and a secondary exit valve, wherein the secondary exit valve may be closed automatically when an abnormal condition is detected.
- [0031]** Other embodiments of the method may comprise the steps of clean-gas purging a discharge line, clean-gas purging a vent line, dry-gas purging a settling vessel, or dry-gas purging a transfer vessel.



**[0032]** In other embodiments, the method may provide that a volume of discharged solid particles is at least about 100% of the actual volume of the settling vessel.

**[0033]** In yet other embodiments, the method may provide that a volume of discharged solid particles is about 90% or greater, or, in the alternative, about 95% or greater, of a valved-in volume of the first settling vessel.

**[0034]** In another class of embodiments, the invention provides a discharge system, the discharge system comprises: at least three settling vessels arranged in parallel; a discharge line fluidly connecting a fluidized bed pressure vessel to at least one of the at least three settling vessels; a primary discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to at least one of the at least three settling vessels; a vent line fluidly connecting an upper portion of the fluidized bed pressure vessel and at least one of the at least three settling vessels; a primary vent valve that controls a vent flow through the vent line; at least three crosstie lines fluidly connecting the at least three settling vessels; a crosstie valve that controls a crosstie flow through the at least three crosstie lines, wherein the crosstie valve is a multi-port valve; at least three transfer vessels in fluid communication with the at least three settling vessels; at least three transfer valves between the at least three settling vessels and the at least three transfer vessels that control a plurality of transfer flows from the at least three settling vessels to the at least three transfer vessels; a lower crosstie line fluidly connecting at least two of the at least three vessels; a lower crosstie valve that controls a lower crosstie flow through the lower crosstie line; and at least three primary exit valves that control a plurality of exit flows of the fluid mixture from the at least three transfer vessels.

**[0035]** In any of the embodiments, the multi-port crosstie valve may be a flow-controlling type valve. In any of the embodiments the multi-port crosstie valve may have a variable flow area depending on the degree of rotation of a stem of the crosstie valve.



**[0036]** In any of the embodiments, the multi-port crosstie valve may be a v-ball valve.

**[0037]** In some of the embodiments, the crosstie line may be absent a flow restricting device other than the crosstie valve.

**[0038]** In some embodiments, the discharge system may comprise at least three lower crosstie lines, and the lower crosstie valve is a multi-port valve that controls the lower crosstie flow through the at least three lower crosstie lines.

**[0039]** In any of the embodiments, the lower crosstie multi-port valve may be a flow-controlling type valve. In some embodiments, the lower crosstie multi-port valve may have a variable flow area depending on the degree of rotation of a stem of the crosstie valve.

**[0040]** In some embodiments, the lower crosstie multi-port valve may be a v-ball valve.

**[0041]** In some embodiments, the lower crosstie line may be absent a flow restricting device other than the lower crosstie valve.

**[0042]** Another class of embodiments described herein provides a discharge system comprising: a plurality of settling vessels arranged in parallel; a discharge line fluidly connecting a fluidized bed pressure vessel and at least two of the plurality of settling vessels; a primary discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to at least two of the plurality of settling vessels; a plurality of secondary discharge valves, wherein each of the plurality of secondary discharge valves controls the discharge flow to at least one of the plurality of settling vessels; a plurality of transfer vessels in fluid communication with the plurality of settling vessels; a plurality of transfer valves between the plurality of settling vessels and the plurality of transfer vessels that control plurality of transfer flows from the plurality of settling vessels to the plurality of transfer vessels; and a plurality of primary exit

valves that control a plurality of exit flows of the fluid mixture from the plurality of transfer vessels.

**[0043]** In any embodiment described herein, the discharge system may further comprise a vent line fluidly connecting an upper portion of the fluidized bed pressure vessel and the settling vessel, and a primary vent valve that controls a vent flow through the vent line.

**[0044]** Some embodiments may comprise a secondary vent valve in series with the primary vent valve that controls the vent flow through the vent line in addition to the primary vent valve.

**[0045]** Other embodiments may comprise at least two secondary vent valves and at least two settling vessels, wherein each secondary vent valve controls the vent flow between the upper portion of the fluidized bed pressure vessel and one settling vessel, and wherein one primary vent valve is in fluid communication with the at least two secondary vent valves and the at least two settling vessels, such that the one primary vent valve, in combination with the at least two secondary vent valves, controls the vent flow between the upper portion of the fluidized bed pressure vessel and each of the at least two settling vessels.

**[0046]** In another class of embodiments described herein, a discharge system comprises: a settling vessel; a discharge line fluidly connecting a fluidized bed pressure vessel and the settling vessel; a discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to the settling vessel; a transfer vessel that receives solid particles from the settling vessel; a transfer valve between the settling vessel and the transfer vessel that controls a transfer flow from the settling vessel to the transfer vessel; a primary exit valve that controls an exit flow of the fluid mixture from the transfer vessel; a secondary exit valve that controls the exit flow of the fluid mixture from the transfer vessel in addition to the primary exit valve; a means to detect an abnormal condition in the discharge



system; and a means to close the secondary exit valve upon detection of the abnormal condition.

**[0047]** In one embodiment, the means to detect an abnormal condition may comprise an automated control system and a means to detect pressure, flow, temperature, vessel stress, valve position, or actuator position.

**[0048]** In other embodiments, the means to close the secondary exit valve may comprise the automated control system and an automatic actuator connected to the secondary exit valve.

**[0049]** In still another embodiment, the secondary exit valve is normally open.

**[0050]** In other embodiments wherein the secondary exit valve is normally open, the secondary exit valve may close within about 5 seconds, or within about 2.5 seconds, of detection of the abnormal condition.

**[0051]** In yet another aspect of the invention, embodiments herein relate to a method for removing a solid from a fluidized bed pressure vessel comprising the steps of: providing a discharge system comprising a discharge line, settling vessel, discharge valve, transfer vessel, transfer valve, primary exit valve, and secondary exit valve; filling the settling vessel with a mixture from a fluidized bed pressure vessel, wherein the mixture comprises a solid and a pressurized gas; transferring the solid and a portion of pressurized gas from the settling vessel to the transfer vessel; emptying the transfer vessel to a receiving vessel; monitoring the discharge system for an abnormal condition with an automated control system; and closing the secondary exit valve automatically when the abnormal condition is detected.

**[0052]** In some embodiments, the filling step and the emptying step may occur at least partially concurrently.

**[0053]** In other embodiments, there may only be a single valve closed between the fluidized bed pressure vessel and the receiving vessel during some steps of the method.



**[0054]** In still other embodiments, the abnormal condition is detected and the secondary exit valve is closed within about 10 seconds, or within about 5 seconds, of the occurrence of the abnormal condition.

**[0055]** In some embodiments, the abnormal condition may be a high pressure, high flow, or incorrect valve position in the discharge system.

**[0056]** In another class of embodiments described herein, a discharge system comprises: a plurality of settling vessels arranged in parallel; a discharge line fluidly connecting a fluidized bed pressure vessel to at least one of the plurality of settling vessels; a primary discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to at least one of the plurality of settling vessels; a crosstie line fluidly connecting at least two of the plurality of settling vessels; a crosstie valve that controls a crosstie flow through the crosstie line, wherein the crosstie valve is a flow-controlling type valve; a plurality of transfer vessels in fluid communication with the plurality of settling vessels; a plurality of transfer valves between the plurality of settling vessels and the plurality of transfer vessels that control a transfer flow from the plurality of settling vessels to the plurality of transfer vessels; a lower crosstie line fluidly connecting at least two of the plurality of transfer vessels; a lower crosstie valve that controls a lower crosstie flow through the lower crosstie line; and a plurality of primary exit valves that control a plurality of exit flows of the fluid mixture from the plurality of transfer vessels.

**[0057]** In some of the embodiments described herein, the crosstie valve may have a variable flow area depending on the degree of rotation of a stem of the crosstie valve.

**[0058]** In some of the embodiments described herein, the crosstie valve may be an eccentric plug rotary valve, v-ball valve, or butterfly valve.

**[0059]** In some embodiments, the crosstie line may be absent a flow restricting device other than the crosstie valve.

**[0060]** In some of the embodiments described herein, the lower crosstie valve may be a flow-controlling type valve.

**[0061]** In some of the embodiments described herein, the lower crosstie valve may have a variable flow area depending on the degree of rotation of a stem of the crosstie valve.

**[0062]** In some of the embodiments described herein, the lower crosstie valve may be an eccentric plug rotary valve, v-ball valve, or butterfly valve.

**[0063]** In yet other embodiments, the lower crosstie line may be absent a flow restricting device other than the lower crosstie valve.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0064]** Figure 1 is a schematic drawing of a single train discharge system.

**[0065]** Figure 2 is a schematic drawing of settling vessels with elliptical and conical top heads.

**[0066]** Figure 3 contains two pages, labeled Fig. 3A and Fig. 3B, and is a schematic drawing of a multi-train discharge system.

**[0067]** Figure 4 contains two pages, labeled Fig. 4A and Fig. 4B, and is a schematic drawing of an alternative version of a multi-train discharge system.

**[0068]** Figure 5 is a block diagram of the steps of a method of removing a solid from a fluidized bed pressurize vessel.

#### DETAILED DESCRIPTION

**[0069]** Generally, embodiments disclosed herein relate to discharge systems for removing a solid/gas mixture from a pressurized vessel. More specifically, embodiments disclosed herein relate to discharge systems for removing flowable solid particles from a pressurized and fluidized vessel.



**[0070]** Referring initially to Figure 1, a schematic view of a fluidized bed pressure vessel and a discharge system in accordance with any of the embodiments of the present disclosure is shown. Generally, a granular solid is fluidized in the fluidized bed pressure vessel **102** by a flow of gas or gas/liquid mixture from an inlet **103**, through a gas distributor **104**, and exiting the fluidized bed pressure vessel **102** through outlet **105** for recycling. The fluidized bed pressure vessel **102** may be a reactor, a polymerization reactor, a vessel capable of holding a fluidized solid, or any pressure vessel from which a granular, powder, or particulate solid product may be removed.

**[0071]** Still referring to Figure 1 (see also Figures 3 and 4), in any embodiments of the invention described herein, a discharge system comprises a discharge line **106, 306a-d, 406ab,cd**, a settling vessel **107, 307a-d, 407a-d**, a primary discharge valve **108, 308a-d, 408ab,cd**, a transfer vessel **114, 314a-d, 414a-d**, a transfer valve **118, 318a-d, 418a-d**, and a primary exit valve **110, 310a-d, 410a-d**. Although this disclosure only discusses components necessary for functionality within the present disclosure, the discharge system, one of ordinary skill in the art will recognize that additional components not discussed herein including, for example, pressure monitoring equipment, additional release valves, fill sensors, safety regulators, or any other component beneficial in the removal of a solid from a fluidized bed pressure vessel may be optionally included. In addition, any embodiment herein may also comprise a vent line **109, 309a-d, 409a-d**, and a primary vent valve **111, 311a-d, 411ab,cd**, and/or a lower vent line **123, 323a-d, 423a-d**, and a lower vent valve **130, 330a-d, 430a-d**.

**[0072]** To remove solids from the fluidized bed pressure vessel **102, 302, 402**, a discharge line **106, 306a-d, 406ab,cd** fluidly connects the fluidized bed pressure vessel **102, 302, 402** to the settling vessel **107, 307a-d, 407a-d**. It may be desirable to minimize the length of the discharge line **106, 306a-d, 406ab,cd**. In any embodiments, the discharge line **106, 306a-d, 406ab,cd** may be self-draining. In other embodiments, the discharge line **106, 306a-d, 406ab,cd** may be swept clean with a clean-gas purge **117, 317a-d, 417ab,cd**.



The clean-gas purge **117, 317a-d, 417ab,cd** may be from a fresh monomer feed, inert feed, or may be recycle gas flow from the discharge of a recycle compressor (not shown), bottom head, or other higher pressure source. Some embodiments may also comprise a clean gas purge valve **122, 322a-d, 422ab,cd**.

**[0073]** The settling vessel **107, 307a-d, 407a-d** is filled with a discharge flow of a discharge fluid, preferably comprising a mixture of solids and gas. To control the discharge flow from the fluidized bed pressure vessel **102, 302, 403** to the settling vessel **107, 307a-d, 407a-d**, a primary discharge valve **108, 308a-d, 408ab,cd** is located along the discharge line **106, 306a-d, 406ab,cd**. As the primary discharge valve **108, 308a-d, 408ab,cd** is opened, the solid/gas mixture initially flows under pressure from fluidized bed pressure vessel **102, 302, 402** to the settling vessel **107, 307a-d, 407a-d**. As used herein, "control" of a flow refers to the ability to start and stop the flow or regulate the subject flow. A device may be the only device controlling a flow, or there may be a number of devices that "control" a subject flow. For example, where a primary and a secondary valve "control" a subject flow, either the primary or secondary valve may close, thus stopping the flow.

**[0074]** Still referring to Figure 1 (see also Figures 3), in any embodiment herein, a vent line **109, 309a-d, 409a-d** may fluidly connect the settling vessel **107, 307a-d, 407a-d** to a lower pressure region, for example an upper portion of the fluidized bed pressure vessel **102, 302, 402**. This vent line **109, 309a-d, 409a-d** allows a flow to continue through the discharge valve after the pressure equalizes. The gases that enter the settling vessel **107, 307a-d, 407a-d** travel up the vent line **109, 309a-d, 409a-d** to the upper portion of the fluidized bed pressure vessel **102, 302, 402** while the solids settle in the settling vessel **107, 307a-d, 407a-d**. This method maximizes the volume of solids that fill the settling vessel **107, 307a-d, 407a-d** and thus minimizes the amount of gas escaping the discharge system. A primary vent valve **111, 311a-d, 411ab,cd** may be located along vent line **109, 309a-d, 409a-d** to control a vent flow of gas in the vent line **109, 309a-d, 409a-d** between the

settling vessel 107, 307a-d, 407a-d and the fluidized bed pressure vessel 102, 302. The primary vent valve 111, 311a-d, 411ab,cd may be located in the vertical piping section so that it is self-draining. In some embodiments, the primary vent valve 111, 311a-d, 411ab,cd is located close to the settling vessel 107, 307a-d, 407a-d to reduce the valved-in volume of the settling vessel/piping combination. If the primary vent valve is located close to the settling vessel 107, 307a-d, 407a-d a vent purge (not shown) of clean gas may be used to prevent material settling in the vertical section of the vent line 109, 309a-d, 409a-d from the primary vent valve 111, 311a-d, 411ab,cd to the fluidized bed pressure vessel 102, 302, 402 when the primary vent valve 111, 311a-d, 411ab,cd is closed. In some embodiments, the primary vent valve 111, 311a-d, 411ab,cd may be located at the fluidized pressure vessel 102, 302, 402. In other embodiments, the primary vent valve 111, 311a-d, 411ab,cd may be located close to the fluidized pressure vessel 102, 302, 402 and a secondary vent valve 427a-d (not shown in Figures 1 and 3) may be located in the vent line 109, 309a-d, 409a-d close to the settling vessel 107, 307a-d, 407a-d. In any of these embodiments, a vent line purge and vent line purge valve as described above may be desirable. This arrangement can decrease the valved-in volume, and may or may not require purging of the vent line 109, 309a-d, 409a-d.

[0075] Still referring to Figure 1 (see also Figures 3-4), when the primary discharge valve 108, 308a-d, 408ab,cd is open, a solid gas mixture flows from the fluidized bed pressure vessel 102, 302, 402 to the settling vessel 107, 307a-d, 407a-d. Optionally, the primary vent valve 111, 311a-d, 411ab,cd is opened, allowing the gas or a gas/liquid mixture to flow back to a lower pressure region, for example, in the upper portion of the fluidized bed pressure vessel 102, 302, 402. In a fluidized bed system, the pressure differential between the bottom and top of the fluidized bed results in a flow path between a lower portion of the fluidized bed pressure vessel 102, 302, 402 to the settling vessel 107, 307a-d, 407a-d, and then up to the upper portion of the fluidized bed pressure vessel 102, 302, 402, where the pressure is lower.



When the settling vessel 107, 307a-d, 407a-d is full, the primary discharge valve 108, 308a-d, 408ab,cd and primary vent valve 111, 311a-d, 411ab,cd may be closed. The settling vessel 107, 307a-d, 407a-d may be deemed filled as determined by any number of variables including, for example, a preset time, level measurement, pressure condition, change in solids concentration in the vent line 109, 309a-d, 409a-d, or any other means provided.

[0076] After the settling vessel 107, 307a-d, 407a-d fills, the solids and a portion of the gas are transferred to a transfer vessel 114, 314a-d, 414a-d located below the settling vessel 107, 307a-d, 407a-d by opening the transfer valve 118, 318a-d, 418a-d. The solid flows initially by pressure, then by gravity from the settling vessel 107, 307a-d, 407a-d to the transfer vessel 114, 314a-d, 414a-d. The transfer vessel 114, 314a-d, 414a-d may be the same and slightly larger volume than the settling vessel to make sure there is room for all of the solids in the settling vessel 107, 307a-d, 407a-d. Because solids may agglomerate, it is preferred that no solids remain in the settling vessel 107, 307a-d, 407a-d or in the transfer valve 118, 318a-d, 418a-d. To assist with efficient transfer of solids, in any embodiment, a lower vent line 123, 323a-d, 423a-d may be provided that fluidly connects the upper portion of the transfer vessel 114, 314a-d, 414a-d to the settling vessel 107, 307a-d, 407a-d. This line allows gasses in the transfer vessel 114, 314a-d, 414a-d to flow back up into the settling vessel 107, 307a-d, 407a-d while the solids flow down through the transfer valve 118, 318a-d, 418a-d.

[0077] After the solids are transferred into the transfer vessel 114, 314a-d, 414a-d, they can be transferred to downstream vessels for processing. Thus, any embodiment described herein may comprise a primary exit valve 110, 310a-d, 410a-d that controls the flow of solid and gas exiting the transfer vessel 114, 314a-d, 414a-d. The primary exit valve 110, 310a-d, 410a-d may be located, for example, directly on the outlet of the transfer vessel 114, 314a-d, 414a-d.

[0078] In any of the embodiments disclosed herein, the valves referenced are automatically actuated valves. The valves may be full port, quick acting



valves such as ball, cylinder, cam, or gate valve designed for reliable, high-cycle operation. The valves may be metal seated, and/or trunnion supported ball valves. In some embodiments, the primary discharge valve **108, 308a-d, 408ab,cd** and /or the primary vent valve **111, 311a-d, 411ab,cd** are designed to minimize the space between the sealing element and the interior of the fluidized bed pressurized vessel **102, 302, 402**. The automatically actuated valves are typically controlled by an automated control system, such as a sequence logic control system or similar system.

**[0079]** In any embodiment described herein, the discharge system may be absent a filter element to filter fluids exiting the settling vessel **107, 307a-d, 407a-d** via significant process streams. Significant process streams are process streams exiting the settling vessel **107, 307a-d, 407a-d**, for example, through the vent line **109, 309a-d, 409a-d**, or crosstie lines (discussed below). Filter elements, as used herein, refers to filter elements located in the substantial process streams designed to preclude the carryover of most of the solid particles out of the settling vessel **107, 307a-d, 407a-d** when the gas exits the vessel. Filter elements, as used herein, does not refer to elements used to exclude particles from non-significant streams, for example, pressure taps or analyzer taps fluidly connecting an instrument to a vessel. Filter elements, for example sintered metal filters, are typically used in some prior art systems, such as those described in U.S. Patent No. 4,003,712.

**[0080]** Still referring to Figure 1, in any embodiment described herein, a blow-off line (not shown), for example, connected vent line **109, 309a-d, 409a-d**, may be provided to a flare or other system to maintain pressure stability in the discharge system. This blow-off line may be beneficial to bleed-off some of the pressure from the discharge system before the primary exit valve **110, 310a-d, 410a-d** is opened. In certain embodiments, gas may be transferred from the settling vessel **107, 307a-d, 407a-d** to, for example, a gas recovery system (not shown), such that the pressure of discharge system is maintained according to the requirements of a given operation.

**[0081]** One class of embodiments provides a discharge system for removing solids from a fluidized bed pressure vessel comprising: a settling vessel **107, 307a-d, 407a-d** comprising a conical top head; a discharge line **106, 306a-d, 406ab,cd** fluidly connecting a fluidized bed pressure vessel **102, 302, 402** to the settling vessel **107, 307a-d, 407a-d**; a primary discharge valve **108, 308a-d, 408ab,cd** that controls a discharge flow of a fluid mixture from the fluidized pressure vessel **102, 302, 402** through the discharge line **106, 306a-d, 406ab,cd** to the settling vessel **107, 307a-d, 407a-d**; a transfer vessel **114, 314a-d, 414a-d** in fluid communication with the settling vessel **107, 307a-d, 407a-d**; a transfer valve **118, 318a-d, 418a-d** between the settling vessel **107, 307a-d, 407a-d** and the transfer vessel **114, 314a-d, 414a-d** that controls a transfer flow from the settling vessel **107, 307a-d, 407a-d** to the transfer vessel **114, 314a-d, 414a-d**; and a primary exit valve **110, 310a-d, 410a-d** that controls an exit flow of the fluid mixture from the transfer vessel **114, 314a-d, 414a-d**.

**[0082]** Referring now to Figure 2, a cross-section drawing of a settling vessel with an elliptical top head **201** and a settling vessel with a conical top head **202** is shown. Specifically, a settling vessel with an elliptical top head **201** is shown being filled from a discharge line **206** through a discharge line valve **208**. As a solid product fills the settling vessel, theoretically, areas of unfilled space **209** are created by the angle of repose of the material in the elliptical head. During vessel filling, the unfilled space **209** results in a greater volume of residual gas in the vessel, resulting in greater gas loss when the vessel is emptied. Without being bound to theory, it is believed that the volume of the unfilled space **209** in the elliptical head is less than that represented by the angle of repose of the material due to the presence of a significant amount of turbulence during filling. However, it is theorized that some portions of this theoretical void space do not fill with solids during the filling process. To reduce the unfilled volume inside the settling vessel, a conical top head may be used in accordance with any of the embodiments described herein. As illustrated, during vessel filling, the settling vessel with



the conical top head **202** reduces the volume of residual gas or gas/liquid mixture in the settling vessel because the contours of the conical top head may more closely approximate the fill pattern of the solid product. Less gas volume in the settling vessel means less gas may be lost during vessel emptying. Thus, in any of the embodiments described herein, it may be beneficial to provide a settling vessel **202** conical top head to decrease the storage of residual gas and gas/liquid.

**[0083]** In any other embodiments described herein, the transfer vessel **214** may comprise a conical top head as described above for the settling vessel **201**. The same rationale described above for the settling vessel **201** applies to the transfer vessel **214**.

**[0084]** Still referring to Figure 2, in any embodiment described herein, the discharge system may further comprise a solids monitoring device **203a,b**. The solids monitoring device **203a,b**, may be any device known to one of ordinary skill in the art that detects the presence of a solid in a pressurized vessel. For example, the solids monitoring device **203a,b**, may be a nuclear level detection device, tuning fork device, static probe, pressure monitor, acoustic emissions device, or entrainment device. The solids monitoring device **203a,b** may be an upper solids monitoring device **203a** located near the top of the settling vessel **201, 202**, in the vent line **205**, or any other suitable location to measure when the tank is full. Alternately, the solids measuring device may be a lower solids monitoring device **203b** located near the bottom of the settling vessel **201, 202**, or any other suitable location that allows the lower solids monitoring device **203b** to detect when the settling vessel **201, 202** empties completely. Addition of a solids monitoring device **203a,b** may allow the discharge system to detect the fill rate in a settling vessel, and adjusting the time of filling, depressurizing, repressurizing, or transferring solids out of the settling vessel such that the efficiency of the process is increased. One of ordinary skill in the art will realize that any number of fill devices may be used in a given discharge system, and may be placed in multiple locations.



**[0085]** Furthermore, the current invention may further comprise a solids monitoring device **210a,b** as described above connected to a transfer vessel **214**. The solids monitoring device may be an upper transfer tank solids monitoring device **210a** located near the top of the transfer vessel or any other suitable location to measure when the tank is full. Alternately, the solids measuring device may be a lower transfer tank solids monitoring device **210b** located near the bottom of the transfer vessel, in the conveying line **204**, or any other suitable location that allows the solids monitoring device to detect when the transfer vessel empties completely.

**[0086]** Referring now to Figure 3 (see also Figure 4), multiple trains of discharge vessels may be utilized to practice the current invention. For example, Figure 3 shows four settling vessels **307a-d**, **407a-d**, and four transfer vessels **314a-d**, **414a-d**. However, it should be realized that other discharge systems may include only one or any other number of settling vessels **307a-d**, **407a-d** and transfer vessels **314a-d**, **414a-d** capable of configuration in accordance with the present disclosure. In some embodiments, the addition of more settling vessels **307a-d**, **407a-d** and transfer vessels **314a-d**, **414a-d** may increase the capacity or efficiency of gas retention. When providing a plurality of settling vessels **307a-d**, **407a-d** and transfer vessels **314a-d**, **414a-d**, the settling vessels **307a-d**, **407a-d** may be arranged in parallel, thus solid material flows from the fluidized bed pressure vessel **302**, **402** to any one of the settling vessels **307a-d**, **407a-d** and then to the respective transfer vessel **314a-d**, **414a-d**. As used herein, arranged in parallel refers to an arrangement of settling vessels such that each settling vessel takes a mixture containing a solid material from the fluidized bed pressure vessel and passes the solid material on to downstream equipment without a substantial amount of the solid material received by one settling vessel having to flow through other settling vessels. In one preferred embodiment, each settling vessel/transfer vessel set may be operated independently of the other settling vessel/transfer vessel set.

**[0087]** Still referring to Figure 3 (see also Figure 4), in any embodiment described herein, the discharge system may comprise a secondary discharge valve **316a-d, 416a-d** in series with the primary discharge valve **308a-d, 408ab,cd**, wherein the primary discharge valve **308a-d, 408ab,cd** and the secondary discharge valve **316a-d, 416a-d** are located between the fluidized bed pressure vessel **302, 402** and the settling vessel **307a-d, 407a-d**, and wherein both the primary discharge valve **308a-d, 408ab,cd** and the secondary discharge valve **316a-d, 416a-d** control the discharge flow to the settling vessel **307a-d, 407a-d**. Adding the secondary discharge valve **316a-d, 416a-d** close to the settling vessel **307a-d, 407a-d** improves the discharge system efficiency, by reducing closed-valve volume. Furthermore, the secondary discharge valve **316a-d, 416a-d** enables providing a clean-gas purge **317a-d, 417ab,cd** of the discharge line **306a-d, 406ab,cd** after the settling vessel **307a-d, 407a-d** has been filled. In these embodiments, the secondary discharge valve **316a-d, 416a-d** may be closed and primary discharge valve **308a-d, 408ab,cd** may be opened to provide a clean-gas purge and sweep the solids from the discharge line **306a-d, 406ab,cd**. The clean-gas purge **317a-d, 417ab,cd** may have a clean-gas purge valve **322a-d, 422ab,cd** to control the flow of clean-gas. In all embodiments disclosed herein, the primary discharge valve **308a-d, 408ab,cd**, the secondary discharge valve **316a-d, 416a-d** and any other valves referenced are automatically controlled and actuated valves.

**[0088]** In any embodiment described herein, the discharge system may also comprise a secondary exit valve **319a-d, 419a-d** in series with the primary exit valve **310a-d, 410a-d**, wherein the primary exit valve **310a-d, 410a-d** and the secondary exit valve **319a-d, 419a-d** are located downstream of the transfer vessel **314a-d, 414a-d**, and wherein both the primary exit valve **310a-d, 410a-d** and the secondary exit valve **319a-d, 419a-d** control the exit flow to the transfer vessel **314a-d, 414a-d**. Adding the secondary exit valve **319a-d, 419a-d** provides an improvement in safety by providing an additional valve that can be closed between the high pressure source of the fluidized bed pressure vessel **302, 402** and a downstream receiving vessel (not shown).



Adding the additional automatic valve allows a discharge vessel train to fill the settling vessel while concurrently emptying the transfer vessel. This shortens the cycle time, which allows more drops, and thus a higher discharge system capacity for a given size system.

**[0089]** Providing the secondary exit valve **319a-d, 419a-d** fills a long felt need to shorten discharge system cycle times. In prior art systems comprising only one automatic secondary exit valve, the transfer vessel **314a-d, 414a-d** had to be emptied and the primary exit valve **310a-d, 410a-d** confirmed closed before the settling vessel **307a-d, 407a-d** was filled. This was to make sure that at least two valves (for example, the transfer valve **318a-d, 418a-d** and primary exit valve **310a-d, 410a-d**, or the primary discharge valve **308a-d, 408ab,cd** and transfer valve **318a-d, 418a-d**) were closed to protect low pressure downstream vessels from high pressure gases potentially blowing through to the downstream vessel from the fluidized bed pressure vessel **302, 402** in the event that one valve failed open (from a valve or actuator failure, for example due to a stem failure). Dual tank product discharge systems (containing a settling vessel and a transfer vessel as disclosed in the '952 patent discussed above) have been operating since about 1981. There has been a long-felt need in the industry to decrease the cycle time of product discharge systems while retaining the safety protection provided by the dual closed valve method. Providing the secondary exit valve **319a-d, 419a-d** provides the desired safety protection while decreasing the total cycle time of the system.

**[0090]** Still referring to Figure 3, in any of the embodiments described herein, a dry-gas purge **320a-d** (not shown in Figure 4) may be fed to the settling vessel **307a-d**. The dry-gas purge **320a-d** may have a dry-gas purge valve **321a-d** to control the flow of dry-gas. In some applications a fluidized bed polymerization reactor may be operated with a liquid phase present. This could be from injecting liquid feeds or recycle into the reactor or condensed mode operation where the gas composition and inlet temperature allows for condensation of heavier hydrocarbons. It is known in the art that when

removing solid particles from a fluidized bed pressure vessel **302** operating in condensing or super-condensing mode, the solid particles may be saturated with liquid, and/or liquid may enter the settling tank when the filling step is executed. To facilitate the displacement of any liquids present, the dry-gas purge **320a-d** may be fed into the settling vessel **307a-d** during any suitable step in the process, and preferably during the filling step, more preferably during the filling step after the discharge valve **308a-d** has closed, but before the primary vent valve **311a-d** is closed. The dry-gas purge **320a-d** may be added at a rate that does not cause fluidization in the discharge tank. In some embodiments of the invention, the dry-gas purge **320a-d** is fed into the lower section of the settling vessel **307a-d**. The dry gas purge **320a-d** may be a gas compatible with the process, as some of this gas will be recycled up into the fluidized bed pressure vessel. In some embodiments, the dry-gas purge **320a-d** may be cycle gas taken from a point in the fluidized bed process where liquids are not present, such as the outlet of the fluidized bed pressure vessel **302**. In one embodiment, the dry gas is taken downstream of the compressor, which is circulating material through the fluidized bed pressure vessel, but before a cycle gas cooler where condensation may occur. In some embodiments, the dry-gas purge **320a-d** may be an inert to the process, such as nitrogen in a polymerization process.

[0091] In any of the embodiment herein, a dry-gas purge as described above may be fed to a lower portion of a transfer vessel **314a-d**. To facilitate the displacement of any liquids present, the dry-gas purge (not shown) may be fed into the transfer vessel **314a-d** during any suitable step in the process, and preferably while the solids are transferring from the settling vessel **307a-d** to the transfer vessel **314a-d** or during an equalizing step.

[0092] Still referring to Figure 3 (see also Figure 4), any of the embodiments herein may comprise a crosstie line **312ab,bc,cd,ac,bd,ad, 412a-d** that fluidly connects at least two of the settling vessels **307a-d, 407a-d** together. In some embodiments, a plurality of crosstie lines **312ab,bc,cd,ac,bd,ad, 412a-d** fluidly connects a plurality of settling vessels



**307a-d, 407a-d** together. The crosstie lines **312ab,bc,cd,ac,bd,ad, 412a-d** allow the flow of gas between settling vessels **307a-d, 407a-d**. The crosstie valve **313ab,bc,cd,ac,bd,ad, 413ab,cd** controls a crosstie flow of fluid, typically a reactor gas mixture, through the crosstie line **312ab,bc,cd,ac,bd,ad, 412a-d**. As illustrated, the crosstie lines **312ab,bc,cd,ac,bd,ad, 412a-d** extend from the vent lines **309a-d, 409a-d**; however, one of ordinary skill in the art will recognize that the crosstie lines **312ab,bc,cd,ac,bd,ad, 412a-d** may be independent of the vent line **309a-d, 409a-d**, so long as gas may flow between each of the plurality of settling vessels **307a-d, 407a-d**. In one preferred embodiment, the crosstie lines are self-draining. In some preferred embodiments, the crosstie flow rate is restricted so that the solid material in the settling vessel **307a-d, 407a-d** is not fluidized, which can result in excessive solid particle carryover. This restriction may be done with an orifice, converging/diverging flow nozzle, or by the use of a crosstie valve **313ab,bc,cd,ac,bd,ad, 412a-d** that is a flow-controlling type. Flow-controlling-type crosstie valves may, for example, have a flow area that varies as valve stem rotates to opens the valve. In some embodiments, the flow-controlling-type valves may, for example, be an eccentric plug rotary valve, V-ball valve, butterfly valve, or other valve designed to gradually increase the open area and regulate the flow rate as the valve is opened. By using a flow-controlling-type crosstie valve, the initial flow through the crosstie line can be restricted when the crosstie valve is first opened, which is when the pressure difference between vessels is highest. This pressure differential drops over time. As the flow-controlling-type valve continues to open, the flow area of the valve increases, allowing a high flow rate to be maintained as the pressure differential drops. In prior art systems, fixed flow restriction devices were used, which resulted in the crosstie flow dropping dramatically as the pressure difference between vessels dropped.

**[0093]** In any embodiment herein, a lower crosstie may also be provided to improve the gas efficiency of the system. After the solids are transferred to the transfer vessel **314a-d, 414a-d**, portions of the gases are removed from the

interstitial voids and any free space above the solids in the transfer vessel **314a-d, 414a-d** by equalizing the full transfer vessel **314a-d, 414a-d** with an empty transfer vessel(s) **314a-d, 414a-d**. A lower crosstie line **326ab,bc,cd,ac,bd,ad, 434a-d** fluidly connects at least two transfer vessels **314a-d, 414a-d** to allow the flow of gases between the vessels. A lower crosstie valve **328ab,bc,cd,ac,bd,ad, 428ab,cd** controls the flow between transfer vessels **314a-d, 414a-d**. For instance, a lower crosstie line **326ab** fluidly connects a first transfer vessel **314a** to a second transfer vessel **314b**, and a first lower crosstie valve **328ab** controls the flow of gas between the two vessels. In any of the embodiments, the lower crosstie valve **328ab,bc,cd,ac,bd,ad, 428ab,cd** may also be a flow-controlling-type crosstie valve as described above.

[0094] Carryover of solid particles with the crosstie flow can result in solid particles, such as polymer particles, being left in the crosstie lines **312ab,bc,cd,ac,bd,ad, 412a-d**. Reactive solids left in the crosstie lines **312ab,bc,cd,ac,bd,ad, 412a-d** can continue to react, causing operating problems. In particular, polymer particles left in the lines can polymerize between discharge cycles and plug the crosstie line **312ab,bc,cd,ac,bd,ad, 412a-d**. However, it is theorized that if the discharge cycle time is fast, the risk of continued reaction resulting in agglomeration is low and the crossties may be designed for faster transfer with instantaneous fluidization of the material in the settling vessel **307a-d, 407a-d** and a resulting carryover to the receiving settling vessel.

[0095] Still referring to Figure 3 (see also Figure 4), solids are transferred out of the transfer vessel **314a-d, 414a-d** to a downstream receiving vessel (not shown) through the conveying line **315a-d, 415a-d**. Each transfer vessel **314a-d, 414a-d** may have its own conveying line **315a-d 415a-d** to downstream processing equipment. In any embodiment, any number of transfer vessels **314a-d, 414a-d** may share a common conveying line (not shown). In the later embodiment, each settling vessel has its own primary exit valve **310a-d, 410a-d**, which is opened during the transfer.



**[0096]** Still referring to Figure 3, while any granular solid transfer method may be used, one preferred method uses a conveying assist gas fed through a conveying assist gas line **324a-d** and controlled by a conveying assist valve **325a-d**. The conveying assist gas is preferably injected into the lower part of the settling vessel **307a-d**. The conveying assist gas is preferably an inert, a dry-gas purge, a recycled gas, nitrogen, or a byproduct gas from downstream operations, such as vent recovery.

**[0097]** Still referring to Figure 3 (see also Figure 4), one class of embodiments provides a discharge system comprising: a settling vessel **307a-d, 407a-d**; a discharge line **306a-d, 406ab,cd** fluidly connecting a fluidized bed pressure vessel to the settling vessel; a discharge valve **308a-d, 408ab,cd** that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to the settling vessel; a transfer vessel **314a-d, 414a-d** that receives solid particles from the settling vessel; a transfer valve **318a-d, 418a-d** between the settling vessel and the transfer vessel that controls a transfer flow from the settling vessel to the transfer vessel; a primary exit valve **310a-d, 410a-d** that controls an exit flow of the fluid mixture from the transfer vessel; a secondary exit valve **319a-d, 419a-d** that controls the exit flow of the fluid mixture from the transfer vessel in addition to the primary exit valve; a means to detect an abnormal condition in the discharge system; and a means to close the secondary exit valve upon detection of the abnormal condition.

**[0098]** An abnormal condition may be any condition that warrants the termination of flow from the transfer vessel to a downstream receiving vessel. An abnormal condition may be, for example, high pressure, high flow, high or low temperature, high vessel stress, incorrect valve position, or incorrect actuator position. In some embodiments, the secondary exit valve may be a normally open valve. In some embodiments, the secondary exit valve may close within about 5, or about 2.5 seconds of detecting an abnormal condition.

**[0099]** A means to detect an abnormal condition may be any means known to one of skill in the art for detecting the parameter selected for monitoring. A

means to detect an abnormal condition may comprise, for example, an automated control system and a device to detect the state of a process parameter. In some embodiments, the means to detect an abnormal condition may comprise, for example, an automated control system that receives a signal from a pressure detection device, a flow detection device, a temperature detection device, a vessel stress detection device, a valve position detection device, or a valve actuator position detection device.

[00100] A means to close the secondary exit **319a-d, 419a-d** valve upon detection of the abnormal condition may be any means known to one of skill in the art for analyzing a process to determine when an abnormal condition has occurred, and sending a signal to close an automated valve. In some embodiments, the means to close the secondary exit valve **319a-d, 419a-d** upon detection of the abnormal condition may include, for example, an automated control system that monitors a process parameter, for example, a pressure, flow, temperature, vessel stress, valve position, or valve actuator position, may determine when that process parameter is outside of the acceptable values, and provide a signal to the secondary exit valve **319a-d, 419a-d** to close. As previously discussed, all valves referenced herein are automatically actuated valves. Thus, as used herein, the secondary exit valve **319a-d, 419a-d** refers to the valve/actuator combination.

[00101] Referring now to Figure 4, in some embodiments, the connections between the fluidized bed pressure vessel **402** and the plurality of settling vessels **407a-d**, as well as the connections between the plurality of settling vessels **407a-d** may be reduced as compared to the embodiments shown in Figure 3. Specifically, at least two of the plurality of settling vessels **407a-d** may share a discharge line **406ab,cd** and one primary discharge valve **408ab,cd**. The grouping of the plurality of settling vessels **407a-d** into at least pairs decreases the amount of connections required to transfer solids from the fluidized bed pressure vessel **402**. Additionally, a secondary discharge valve **416a-d** may be added to control the flow of solids between the fluidized bed pressure vessel **402** and individual settling vessels **407a-d**. For example, some



embodiments may comprise at least two secondary discharge valves **416a-b** and at least two settling vessels **407a-b**, wherein each secondary discharge valve **407a-b** controls the flow to one of the settling vessels **407a-b**, and wherein one primary discharge valve **408ab,cd** is in fluid communication with the at least two secondary discharge valves **416a-d** and the at least two settling vessels **407a-d**, such that the one primary discharge valve **408ab,cd**, in combination with the at least two secondary discharge valves **416a-b**, controls the discharge flow to each of the at least two settling vessels **407a-d**. In short, at least two settling vessels **407a-d** are fluidly connected to the fluidized bed pressure vessel **402** through the one primary discharge valve **408ab,cd**.

[00102] Still referring to Figure 4, to reduce the number of connections necessary to transfer gas between the fluidized bed pressure vessel **402** and the settling vessels **407a-d**, some embodiments of the invention tie at least two vent lines **409a-d** together to route the process flow through a common vent line **426ab,cd** and one primary vent valve **411ab,cd**. In some embodiments there may be at least two secondary vent valves **427a-d** in series with one primary vent valve **411ab,cd**. Thus, for example, for fluid to flow between the fluidized pressure vessel **402** and the settling vessel **407a**, both the primary vent valve **411ab** and one secondary vent valve **427a** must be open, while the other secondary vent valve **427b** is closed. Thus, this embodiment of the invention comprises at least two secondary vent valves **427a-d** and at least two settling vessels **407a-d**, wherein each secondary vent valve **427a-d** controls the vent flow between the upper portion of the fluidized bed pressure vessel **402** and one settling vessel **407a-d**, and wherein one primary vent valve **411ab,cd** is in fluid communication with the at least two secondary vent valves **427a-d** and the at least two settling vessels **407a-d**, such that the one primary vent valve **411ab,cd**, in combination with the at least two secondary vent valves **427a-d**, controls the vent flow between the upper portion of the fluidized bed pressure vessel **402** and each of the at least two settling vessels **407a-d**. Some embodiments further comprise a vent-line purge **429ab,cd** and a vent line purge valve **424ab,cd** to sweep any solid particles in the common

vent line **426ab,cd** into the fluidized bed pressure vessel **402**. The vent line purge gas may be a fresh monomer feed, inert feed, or may be recycle gas flow from the discharge of a recycle compressor (not shown), bottom head, or other pressure source.

**[00103]** Still referring to Figure 4, to reduce the number of connections necessary to transfer gas between the settling vessels **407a-d**, in any embodiments herein, the discharge system **401** may comprise a crosstie valve **413ab,cd** that is a multi-port valve. The multi-port crosstie valve **413ab,cd** may control the flow between at least three settling vessels **407a-d**, allowing the transfer of gas there between. As illustrated in Figure 4, a first multi-port crosstie valve **413ab** may control flow between a first settling vessel **407a** and a second settling vessel **407b**, and may control the flow from the first settling vessel **407a** or the second settling vessel **407b** to a third settling vessel **407c** or a fourth settling vessel **407d** via connection to a second multi-port crosstie valve **413cd**. The multi-port valve **413ab,cd** may be configured to allow the transfer of gas between any of the settling vessels **407a-d**. While this embodiment illustrates a discharge system **401** with four settling vessels **407a-d** and two multi-port crosstie valves **413ab,cd**, it should be realized that the number of settling vessels and multi-port valves may vary as required by different discharge systems. For example, an alternate discharge system may be foreseen wherein four vessels are connected by one multi-port crosstie valve **413ab,cd**, or wherein any number of vessels are connected by any number of multi-port crosstie valves. Additionally, the number of ports on the multi-port crosstie valves **413ab,cd** may vary such that in certain embodiments, a single multi-port crosstie valve **413ab,cd** may accept vent lines from any number of settling vessels.

**[00104]** Still referring to Figure 4, to reduce the number of connections necessary to transfer gas between the transfer vessels **414a-d**, in any embodiment herein, the discharge system **401** may comprise a lower crosstie valve **428ab,cd** that is a multi-port valve. The lower multi-port crosstie valve **428ab,cd** can control the flow from at least three transfer vessels **414a-d**,



allowing the transfer of gas there between. As illustrated in Figure 4, a first lower multi-port crosstie valve **428ab** may control flow between a first transfer vessel **414a** and a second transfer vessel **414b**, and may control the flow from the first transfer vessel **414a** or the second transfer vessel **414b** to a third transfer vessel **414c** or a fourth transfer vessel **414d** via connection to a second lower multi-port crosstie valve **428cd**. The lower multi-port crosstie valves **428ab,cd** may be configured to allow the transfer of gas between any two of the transfer vessels **414a-d**. While this embodiment illustrates a discharge system **401** with four transfer vessels **414a-d** and two lower multi-port crosstie valves **428ab,cd**, it should be realized that the number of transfer vessels and lower multi-port crosstie valves **428ab,cd** may vary as required by different discharge systems.

[00105] Referring again to Figure 4, one class of embodiments comprises: at least three settling vessels **407a-d** arranged in parallel; a discharge line **406ab,cd** fluidly connecting a fluidized bed pressure vessel **402** to at least one of the at least three settling vessels **407a-d**; a primary discharge valve **408ab,cd** that controls a discharge flow of a fluid mixture from the fluidized pressure vessel **402** through the discharge line **406ab,cd** to at least one of the at least three settling vessels **407a-d**; a vent line **409a-d** fluidly connecting an upper portion of the fluidized bed pressure vessel **402** and at least one of the at least three settling vessels **407a-d**; a primary vent valve **411ab,cd** that controls a vent flow through the vent line **409a-d**; at least three crosstie lines **412a-d** fluidly connecting the at least three settling vessels **407a-d**; a crosstie valve **413ab,cd** that controls a crosstie flow through the at least three crosstie lines **412a-d**, wherein the crosstie valve **413ab,cd** is a multi-port valve; at least three transfer vessels **414a-d** in fluid communication with the at least three settling vessels **407a-d**; at least three transfer valves **418a-d** between the at least three settling vessels **407a-d** and the at least three transfer vessels **414a-d** control a plurality of transfer flows from the at least three settling vessels **407a-d** to the at least three transfer vessels **414a-d**; a lower crosstie line **434a-d** fluidly connecting at least two of the at least three vessels **407a-d**; a lower

crosstie valve **428ab,cd** that controls a lower crosstie flow through the lower crosstie line **434a-d**; and at least three primary exit valves **410a-d** that control a plurality of exit flows of the fluid mixture from the at least three transfer vessels **414a-d**.

**[00106]** In another embodiment, the discharge system comprises at least three lower crosstie lines **434a-d**, wherein a lower crosstie valve **428ab,cd** is a multi-port valve that controls the lower crosstie flow through the at least three lower crosstie lines **434a-d**.

**[00107]** Still referring again to Figure 4, in some embodiments, the discharge system may comprise at least four settling vessels **407a-d**; at least four crosstie lines **412a-d**; a first set of crosstie lines comprising a first of the at least four crosstie lines **412a-d** and a second of the at least four crosstie lines **412a-d**; a second set of crosstie lines comprising a third of the at least four crosstie lines **412a-d** and a fourth of the at least four crosstie lines **412a-d**; and at least two multi-port valves **413ab, 413cd**, wherein the at least two multi-port valves fluidly connect the first set of crosstie lines to the second set of crosstie lines.

**[00108]** Again referring to Figure 4, in another embodiment, the discharge system may comprise at least four transfer vessels **414a-d**; at least four lower crosstie lines **434a-d**; a first set of lower crosstie lines comprising a first of the at least four lower crosstie lines **434a-d** and a second of the at least four lower crosstie lines **434a-d**; a second set of lower crosstie lines comprising a third of the at least four lower crosstie lines **434a-d** and a fourth of the at least four lower crosstie lines **434a-d**; and at least two lower multi-port valves **428ab,cd**, wherein the at least two lower multi-port valves fluidly connect the first set of lower crosstie lines to the second set of lower crosstie lines.

**[00109]** Now referring to Figure 5, an order of operation for a discharge system in accordance with an embodiment of the present invention is shown. The discharge system may alternate sequentially between any one of seven steps. While the embodiment described below provides seven steps of operation, it should be realized that according to the requirements of a given



discharge system, some discharge systems will have less than seven steps of operation, while other discharge systems will have more than seven steps of operation.

**[00110]** Generally, Figure 5 describes the steps of operation that a single set of discharge vessels (for example a first settling vessel and a first transfer vessel) may undergo during one cycle. Specifically, a cycle comprises filling a settling vessel **510**, equalizing the settling vessel **520**, transferring solids to a transfer vessel **530**, re-equalizing the settling vessel **540**, equalizing the transfer vessel **550**, emptying the transfer vessel **560**, and re-equalizing the transfer vessel **570**. Clearly, some of the equalizing and re-equalizing steps may be skipped to decrease cycle time. For instance, the equalizing the settling vessel step **520** could be skipped, in which case there would be no re-equalizing the settling vessel step **540**.

**[00111]** Still referring to Figure 5, one class of embodiments provides a method for removing a solid from a fluidized bed pressure vessel comprising the steps of: providing a discharge system comprising a plurality of settling vessels and a plurality of transfer vessels, wherein at least one of the at least three settling vessels comprises a conical top head; filling a first settling vessel **510** of the plurality of settling vessels with a mixture from a fluidized bed pressure vessel, wherein the mixture comprises a solid and a pressurized gas; equalizing the first settling vessel **520**, wherein a first portion of pressurized gas is transferred from the first settling vessel to at least one of the plurality of settling vessels that is not the first settling vessel; transferring **530** the solid and a second portion of pressurized gas from the first settling vessel to a first transfer vessel; re-equalizing the first settling vessel **550**, wherein a return pressurized gas is transferred from at least one of the plurality of settling vessels that is not the first settling vessel to the first settling vessel; equalizing the first transfer vessel **540** with a second transfer vessel, wherein a third portion of the pressurized gas is transferred from the first transfer vessel to at least one of the plurality of transfer vessels that is not the first transfer vessel; emptying the first transfer vessel **560**; and re-equalizing the first transfer

vessel **570**, wherein a return transfer gas is transferred from at least one of the plurality of transfer vessels that is not the first transfer vessel to the first transfer vessel.

**[00112]** Referring to the steps of Figure 5 and the embodiments of Figure 3, the process will be described, for example purposes, wherein a first settling vessel **307a** and a first transfer vessel **314a** are stepping through the cycle. Initially, during the tank filling step **510**, primary discharge valve **308a** and primary vent valve **311a** may be opened, and a solid/gas mixture may flow into a first settling vessel **307a**, as described herein above. After the completion of the filling step **510**, the primary discharge valve **308a** and the primary vent valve **311a** are closed.

**[00113]** During the equalizing the settling vessel step **520**, a first portion of pressurized gas is transferred from the first settling vessel to at least one of the plurality of settling vessels that is not the first settling vessel. For example, a first crosstie valve **313ab** may be opened fluidly connecting the first settling vessel **307a** and a second settling vessel **307b**. Gas will flow from the higher pressure of the first settling vessel **307a** to the lower pressure of the second settling vessel **307b**. Upon depressurization of the first settling vessel, the second settling vessel **307b** may contain more gas because it is empty of solids, and the first settling vessel **307a** has a portion of its gas capacity displaced by the solids contained therein. After this first depressurization, the settling vessel **307a** may be further depressurized by equalizing with a third settling vessel **307c** by opening a second crosstie valve **313ac** connecting the first settling vessel **307a** and a third settling vessel **307c**. Gas will flow from the higher pressure of the first settling vessel **307a** to the lower pressure of the second settling vessel **307c**. This process may be repeated any number of times depending of the number of settling vessels contained in the discharge system. Thus, equalizing the settling vessel may comprise a plurality of depressurizing steps wherein the first settling vessel is fluidly connected to a plurality of settling vessels that are not the first settling vessel.



**[00114]** In certain embodiments, as the first settling vessel **307a** and the second settling vessel **307b** are being equalized, equalization may occur between a fourth settling vessel **307d** that is solid full and a third settling vessel **307c** that is empty.

**[00115]** Continuing the example sequence, during the transferring solids to the transfer vessel step **530**, which occurs after the equalizing the settling vessel step **520**, a first transfer valve **318a** opens to allow solids to drop from the first settling vessel **307a** to the first transfer vessel **314a**. A first lower vent valve **330a** also opens to allow gases to vent from the first transfer vessel **314a** back up into the first settling vessel **307a**. A second portion of the pressurized gas may be carried from the settling vessel **307a** into the first transfer vessel **314a** with the solids. After the transferring solids to the transfer vessel step **530** is complete, the first transfer valve **318a** and the first lower vent valve **330a** close and the cycle continues to the equalizing the transfer vessel step **540**, and the re-equalizing the settling vessel step **550**, which may occur at least partially concurrently.

**[00116]** During the equalizing the transfer vessel step **540**, a third portion of pressurized gas is transferred from the first transfer vessel **314a** to at least one of the plurality of transfer vessels that is not the first transfer vessel. For example, a first lower crosstie valve **328ab** may open connecting the first transfer vessel **314a** and a second transfer vessel **314b**. Gas will flow from the higher pressure of the first transfer vessel **314a** to the lower pressure of the second transfer vessel **314b**. After this first depressurization, the transfer vessel **314a** may be further depressurized by equalizing with a third transfer vessel **314c** by opening a second lower crosstie valve **328ac** connecting the first transfer vessel **314a** and a third transfer vessel **314c**. This process may be repeated any number of times depending of the number of transfer vessels contained in the discharge system. Thus, equalizing the transfer vessel may comprise a plurality of depressurizing steps wherein the first transfer vessel is fluidly connected to a plurality of transfer vessels that is not the first transfer vessel.

**[00117]** During the re-equalizing the settling vessel step **550**, the first settling vessel **307a** is re-pressurized from at least one of the plurality of settling vessels **307b-d** that is not the first settling vessel. For example, opening the crosstie valve **313ab** will allow a return pressurized gas to flow from the second settling vessel **307b**, which has been previously filled with solid particles and is at high pressure, into the first settling vessel **307a**. During the re-equalizing the settling vessel step **550**, the first settling vessel **307a** may be empty and the second settling vessel **307b** may be granular solid full and at a relatively high pressure. Thus, while the first settling vessel **307a** is in the re-equalizing the settling vessel step **550**, the second settling vessel **307b** may be in the equalizing the settling vessel step **520**. These re-pressuring steps may be repeated any number of times during the re-equalizing the settling vessel step **550** depending of the number of settling vessels contained in the discharge system. Thus, the re-equalizing the settling vessel step **550** may comprise a plurality of re-pressurizing steps wherein the first settling vessel is fluidly connected to a plurality of settling vessels that are not the first settling vessel.

**[00118]** As used in this application, “equalizing” or “re-equalizing” refers to the transfer of a portion of gas from one vessel to another. The pressure may be allowed to substantially equalize between the vessels, or the controlling valve (a crosstie valve **313ab,bc,cd,ac,bd,ad** or a lower crosstie valve **328ab,bc,cd,ac,bd,ad**) may close before the pressures equalize between the two vessels.

**[00119]** The emptying the transfer vessel step **560** occurs after the transferring solids to the transfer vessel step **530**, and may occur after the equalizing the transfer vessel step **540**. Continuing with the example, during the emptying the transfer vessel step **560**, a primary exit valve **310a** opens to allow the solids and any remaining gasses to be conveyed to a downstream vessel. If the system includes a secondary exit valve **319a**, it must also be open to allow the transfer. By the emptying step **560**, the pressure has been reduced to a level substantially lower than that in the fluidized bed pressure vessel **302**. Volatile



materials absorbed in the solids may have flashed as the pressure was reduced in each step. As such, the product of the flash may have been recovered to other vessels as transferred gas. Thus, the first transfer vessel **314a** may be emptied of solids with minimal removal of gas or liquid from the discharge system **301**.

**[00120]** Still referring to Figures 5 and 3, partially contemporaneous with the emptying step **560** of one set of discharge vessel, another set of discharge vessel may be filling. For example, the first settling vessel **307a** may be emptying while a third transfer vessel **314c** is filling.

**[00121]** During the emptying phase, the first transfer vessel **314a** is isolated from other vessels in the discharge system **301**. While emptying the first transfer vessel **314a**, the first primary discharge valve **308a** is closed, the first transfer valve **318a** is closed, all lower crosstie valves **328ab, bc, cd, ac, bd, ad** fluidly connecting the first transfer vessel **314a** to other transfer vessels **314b, c, d** may be closed, and primary exit valve **310a** is opened, allowing the solid/gas mixture may be discharged from the discharge system. As the solid/gas mixture exits discharge system, the solids may be transferred to a downstream vessel. It should be noted that while the first transfer vessel **314a** is emptying, the corresponding first settling vessel **307a** may be receiving gas from another settling vessel **307b, c, or d**.

**[00122]** Continuing with the example, after the first transfer vessel **314a** is emptied, the first transfer vessel **314a** is re-pressurized in the re-equalizing the transfer vessel step **570**. During this step, the first transfer vessel **314a** is re-pressurized from at least one of the plurality of transfer vessels that is not the first transfer vessel (**314 b-d**). For example, the first transfer vessel **314a** may undergo re-pressurization from the second transfer vessel **314b** by opening the first lower crosstie valve **328ab**. During the re-equalizing the transfer vessel step **570**, the first transfer vessel **314a** is empty and the second transfer vessel **314b** may be granular solid full and at a medium pressure. Thus, while the first transfer vessel **314a** is in the re-equalizing the settling vessel step **570**, the second transfer vessel **314b** may be in the equalizing the transfer vessel step

**540.** These re-pressuring steps may be repeated any number of times during the re-equalizing the transfer vessel step **570** depending of the number of transfer vessels contained in the discharge system. Thus, the re-equalizing the transfer vessel step **570** may comprise a plurality of re-pressurizing steps wherein the first transfer vessel is fluidly connected to a plurality of transfer vessels that are not the first transfer vessel.

**[00123]** In the embodiment described above, upon the completion of steps **510** through **570**, the process may repeat. Thus, the primary vent valve **311a** and primary discharge valve **308a** may then be opened and gas in the first settling vessel **307a** will be pushed back into the fluidized bed pressure vessel **302**.

**[00124]** Any number of settling vessels **307a-d** including discharge systems with two, three, four, or more settling vessels **307a-d** may be utilized in the current invention. Additionally, the steps of vessel filling, equalizing, emptying, and re-equalizing should be viewed as one illustrative method of practicing the disclosed discharge system. Alternate methods of practice, as would be obvious to one of ordinary skill in the art may be foreseen, wherein, for example, the order of operations are modified, additional operations are added, or the discharge system is otherwise expanded.

**[00125]** Now referring to the steps of Figure 5 and the embodiments of Figure 4, some embodiments may comprises more than two settling vessels **407a-d** and a multi-port crosstie valve **413ab,cd**. After the completion of filling step **510**, the first settling vessel **407a** enters into the equalizing the settling vessel step **520**. For example, during this step, the pressure in the first settling vessel **407a** may be equalized with a second settling vessel **407b** by aligning a first multi-port crosstie valve **413ab** to fluidly connect the first settling vessel **407a** and the second settling vessel **407b** (occurring after the filling step as illustrated in Figure 5). In certain embodiments, the pressure in settling vessel **407a** may be further equalized by aligning the first multi-port crosstie valve **413ab** to fluidly connect the first settling vessel **407a** and a third settling vessel **407c**, and/or a fourth settling vessel **407d**.



[00126] In an alternate embodiment of the above step, the first multi-port crosstie valve **413ab** may remain closed during the first depressurizing step, thereby isolating the first settling vessel **407a** and the second settling vessel **407b** from the rest of discharge system **401**. Subsequently, a first secondary vent valve **427a** and a second secondary vent valve **427b** may be opened to allow the flow of gas between the first settling vessel **407a** and the second settling vessel **407b**.

[00127] Still referring to Figure 5 and Figure 4, some embodiments may comprise more than two transfer vessels **414a-d** and a lower multi-port valve **428ab,cd**. In these embodiments, the equalizing the transfer vessel step **560** involves aligning a first lower multi-port crosstie valve **428ab** to fluidly connect the first transfer vessel **414a** and the second transfer vessel **414b**. In certain embodiments, the pressure in transfer vessel **414a** may be further lowered through equalization by aligning the first lower multi-port crosstie valve **428ab** to fluidly connect the first transfer vessel **414a** and a third transfer vessel **414c**, and/or a fourth transfer vessel **414d**.

[00128] Similarly, the first transfer vessel **414a** is re-pressurized in the re-equalizing the transfer vessel step **570** using the first lower multi-port crosstie valve **428ab** to fluidly connect the first transfer vessel **414a** and the second transfer vessel **414b**. In certain embodiments, the pressure in transfer vessel **414a** may be further raised through re-equalization by aligning the first lower multi-port crosstie valve **428ab** to fluidly connect the first transfer vessel **414a** and a third transfer vessel **414c** and/or a fourth transfer vessel **414d**.

[00129] Still referring to Figure 4, the valved-in volume not filled with a solid after the filling step may be minimized by providing a secondary discharge valve **416a-d** as described above and adding a step of clean-gas purging (not shown in Figure 5) the discharge piping. The step of clean-gas purging the discharge piping comprises the steps of: closing the primary discharge valve **408ab,cd**, and the primary vent valve **411ab,cd** after the filling step; pausing a short time to allow resin entrained in the vent line **409a-d** and the discharge line **406ab,cd** to settle back into the settling vessel **407a-d** after the filling

step; closing the secondary discharge valve **416a-d** and a secondary vent valve **427a-d** after the pausing step; and opening the primary discharge valve **408ab,cd**, the primary vent valve **411ab,cd**, a clean-gas purge valve **422ab,cd**, and a vent line purge valve **424ab,cd** after closing the secondary discharge valve **416a-d** to allow the purging gas to sweep the discharge line **406ab,cd** and the common vent line **426ab,cd** to clear of any residual solid particles from the lines. As used herein, pausing a short time means pausing a period of time from about 1 second to about 1 minute, more preferably from about 1 to about 15 seconds, and even more preferably from about 1 to about 5 seconds. These valves may be left open, or closed when the line purging is complete in order to minimize the use of the purging gas. In some embodiments, each settling vessel **407a-d** will have a vent line purge, and vent line purge valve, whereas in other embodiments, at least two settling vessels will have a single vent line purge **429ab,cd**, and vent line purge valve **424ab,cd**.

**[00130]** In other embodiments, the primary discharge valve **408ab,cd** closes at the end of the filling step, and the secondary discharge valve **416a-d** stays open until at least a portion of the solids have transferred to the transfer vessel **414a-d**. This allows any solids that may be trapped in the ball of the secondary discharge valve **416a-d** to drop into the settling vessel **407a-d** as solids transfer to the transfer vessel **414a-d**. In this embodiment, the secondary discharge valve **416a-d** closes a short period of time after the transfer to the transfer vessel **414a-d** begins.

**[00131]** In the above described embodiments of the present disclosure, upon the completion of the above steps **510** through **570**, the process may repeat. Additionally, the steps of vessel filling, depressurizing, emptying, and repressurizing should be viewed as an illustrative method of practicing the disclosed discharge system. Alternate methods of practice, as would be obvious to one of ordinary skill in the art may be foreseen, wherein, for example, the order of operations are modified, additional operations are added, or the discharge system is otherwise expanded.



**[00132]** As may be seen from the above described discharge system, each settling vessel in the discharge system may be in a different phase at any given time. The more overlap between the phases of operation, the faster the discharge valve cycle time. As such, in certain embodiments, it is foreseeable that each settling vessel may be in a phase of operation corresponding to a specific phase of operation of at least one of the other settling vessels in the discharge system.

**[00133]** It is desirable to prevent high pressure gas from passing from the fluidized bed pressure vessel to a receiving vessel, which is typically a lower pressure rated vessel located downstream of the transfer vessel. Thus, in any embodiment of the methods herein, there may be logic steps in place to assure that there is always at least two valves closed between the fluidized bed pressure vessel and a downstream vessel. As used herein, the receiving vessel may be any vessel that is downstream of any transfer vessel.

**[00134]** Referring to Figures 3 & 4, in any embodiments described herein, the discharge system may comprises a secondary exit valve **319a-d, 419a-d** and the method may comprise the step of closing the secondary exit valve **319a-d, 419a-d** automatically when an abnormal condition is detected. An abnormal condition may be any condition that warrants the termination of flow from the transfer vessel to a downstream receiving vessel. An abnormal condition may be, for example, high pressure, high flow, high or low temperature, high vessel stress, incorrect valve position, or incorrect actuator position. In some embodiments, the secondary exit valve **319a-d, 419a-d** may be a normally open valve. In some embodiments, the secondary exit valve **319a-d, 419a-d** may close within about 5, or about 2.5 seconds, of detecting an abnormal condition.

**[00135]** Thus, one class of embodiments provides a method for removing a solid from a fluidized bed pressure vessel comprising the steps of: providing a discharge system comprising a discharge line, settling vessel, discharge valve, transfer vessel, transfer valve, primary exit valve, and secondary exit valve; filling the settling vessel with a mixture from a fluidized bed pressure vessel,

wherein the mixture comprises a solid and a pressurized gas; transferring the solid and a portion of pressurized gas from the settling vessel to the transfer vessel; emptying the transfer vessel to a receiving vessel; monitoring the discharge system for an abnormal condition with an automated control system; and closing the secondary exit valve automatically when the abnormal condition is detected.

**[00136]** In some embodiments of this method, the filling step and the emptying step of a single train of discharge vessels occur at least partially concurrently. Referring to Figure 3, what is meant by a "single train of discharge vessels" is a settling vessel **307a-d** and the associated transfer vessel **314a-d** that receives solids from the settling vessel **307a-d**. For example, settling vessel **307a** and transfer vessel **314a** are a "single train of discharge vessels." One skilled in the art will recognize that this means that if the settling vessel **307a-d** and the transfer vessel **314a-d** of a single train of discharge vessels are filled and emptied at least partially concurrently, only one valve will be closed between the fluidized bed pressure vessel **302** and a receiving vessel (not shown) downstream of the transfer vessel **314a-d**. For example, if the first settling vessel **307a** is filling while the first transfer vessel **314a** is emptying, only the first transfer valve **318a** is closed between the fluidized bed pressure vessel **302** and the receiving vessel. Monitoring the discharge system for an abnormal condition with an automated control system and closing the secondary exit valve automatically when the abnormal condition is detected provides a secondary level of protection against blowing high pressure gas and solids from the fluidized bed pressure vessel **302** directly to the receiving vessel, which could result in overpressure or other harmful conditions in the receiving vessel.

**[00137]** In some embodiments, the abnormal condition is detected and the secondary exit valve **319a-d** is closed within about 10 seconds or about 5 seconds of the occurrence of the abnormal condition. In any of this class of embodiments, the abnormal condition may be, for example, a high pressure, high flow, or incorrect valve position in the discharge system.



**[00138]** One of ordinary skill in the art may realize that as the number of depressurizing and repressurizing steps for each tank increases, the efficiency of the discharge system may increase. By adding additional depressurizing and repressurizing steps, the potential for increased gas and gas/liquid recovery prior to emptying increases. As such, the discharge system may result in greater gas recovery and less raw material loss.

**[00139]** One of skill in the art will also recognize that discharge system gas efficiency is improved by minimizing the valved-in volume of the discharge system that is not filled with a solid after the filling step. As used herein, the valved-in volume of a vessel refers to the combined volume of the vessel and the associated piping fluidly connected to the vessel up to the first closed automatic valve.

**[00140]** Using the methods and devices described herein, a product discharge system that provides improved gas efficiency may be provided. In any embodiment of the invention, a volume of discharged solid particles may be at least 95%, 98%, or 100% of an actual volume of the settling vessel. In any embodiment, the volume of discharged solid particles may be greater than about 90%, 95% or about 100% of a valved-in volume.

**[00141]** While described relative to embodiments of the present disclosure described herein, one of ordinary skill in the art will realize that any discharge system or method in accordance with the present disclosure may be retrofitted into an existing discharge system for removing solids from a pressure vessel. For example, in one alternate embodiment, the discharge systems and methods disclosed herein may be applied to an existing discharge system by modifying the existing discharge system to include features, for example, multi-port valves, discussed above.

**[00142]** Further, in some embodiments greater solids removal capacity is desirable. Embodiments of the present discharge system may be run with more than one vessel at least partially concurrently filling while more than one vessel are at least partially concurrently discharging. In some embodiments,

the gas recovery efficiency may be reduced by decreasing the number of equalization steps for the advantage of increasing the solids removal rate.

**[00143]** Additional advantages may be realized by increasing the frequency of product drops from the settling vessels. Tank size may be varied to allow the optimal product drop intervals without risking loss of recyclable material. Further, smaller valves and piping may be used in discharge systems with more tanks, thereby decreasing initial discharge system installation costs, as well as costs for maintenance and replacement.

**[00144]** Furthermore, because of the additional pressure equalization steps, some embodiments of the current discharge system may provide a decrease in the loss of gas and gas/liquid mixture from the discharge system. In certain embodiments, the discharge system may be efficient enough so as to remove post discharge gas recovery/recycling systems used in current discharge systems.

#### EXAMPLES DERIVED FROM MODELING TECHNIQUES

**[00145]** It is to be understood that while the invention has been described in conjunction with the specific embodiments thereof, the foregoing description is intended to illustrate and not limit the scope of the invention. Other aspects, advantages and modifications will be apparent to those skilled in the art to which the invention pertains.

**[00146]** Therefore, the following examples are put forth so as to provide those skilled in the art with a complete disclosure and description of how to make and use the compounds of the invention, and are not intended to limit the scope of that which the inventors regard as their invention.

**[00147]** The following examples are derived from modeling techniques and although the work was actually achieved, the inventors are not presenting these examples in the past tense to comply with M.P.E.P. § 608.01(p) if so required.

**[00148]** An Improved Product Discharge System (IPDS) is simulated in the example below to demonstrate the potential effect of conical heads on the



capacity and gas efficiency of the system. In all examples herein, ideal gas laws apply. Examples 1 and 2 are based on operation with a Linear Low Density Polyethylene (LLDPE) of 0.918 gr/cc (918 kgs/m<sup>3</sup>) density granular resin with a 22 lbs/ft<sup>3</sup> (352 kgs/m<sup>3</sup>) settled bulk density and 15.4 lbs/ft<sup>3</sup> (247 kgs/m<sup>3</sup>) fluidized bulk density. In the LLDPE examples herein, a 62% void space in the settled material ((918 - 352)/918) and 73% void space in the fluidized resin is assumed. The solid density range for LLDPE is typically, for example, about 910 to 930 kgs/m<sup>3</sup> and the range for settled bulk density in a gas phase process is typically, for example, about 336 to 431 kgs/m<sup>3</sup>. Fluidized bulk density is typically, for example, between about 208 to 352 kgs/m<sup>3</sup> but can be lower if there is excessive dilution. From this it can be seen that in all cases there will be a substantial difference in the void volume between fluidized to settled to solid. However, the examples herein are representative of the ability of the invention to deliver value for all products.

**[00149]** Examples 3 and 4 are based on operation with a High Density Polyethylene (HDPE) of about 0.948 gr/cc (948 kgs/m<sup>3</sup>) density granular resin with a 29.5 lbs/ft<sup>3</sup> (412 kgs/m<sup>3</sup>) settled bulk density and 21 lbs/ft<sup>3</sup> (336 kgs/m<sup>3</sup>) fluidized bulk density. These Examples provide results applicable to HDPE, which may have a density range, for example, from about 0.930 to about 0.980 kgs/m<sup>3</sup>. The settled bulk density may range, for example, from about 352 to 486 kgs/m<sup>3</sup> while the fluidized bulk density may be between about 208 to 352 kgs/m<sup>3</sup>.

**[00150]** Simulations for all examples are based on two sets of discharge vessels, "trains," with settling vessels crosstied, and transfer vessels crosstied. Settling vessels are assumed to have a volume of 169.6 ft<sup>3</sup> (4.802 m<sup>3</sup>) and assumed to be equipped with 8-inch (.20 meter) inlets and 12-inch (.30 meter) outlets. The transfer vessels are assumed to be the same volume as the settling vessels, with 12-inch (.30 meter) inlets and 8-inch (.20 meter) outlets. Resin fill volumes are based on the ideal assumption that the volume of resin filling the vessel is controlled by a 35 degree angle of repose of the granular resin. Although granular resins settle at an angle that is less than the angle of repose,

this angle is used for comparative purposes to show the theoretical changes in system capacity and efficiency.

**[00151]** Simulations for LLDPE and HDPE are shown in Cases A-F. For Case A (the baseline case), the capacity is simulated for an IPDS with elliptical tops heads on both the settling vessels and transfer vessels assuming the steps of: filling; equalizing the transfer vessel with the other transfer vessels; transferring to the transfer vessel, equalizing the transfer vessel with the other transfer vessels and re-equalizing the settling vessel from the other settling vessels; emptying the transfer vessels; and re-equalizing the transfer vessel from the other transfer vessels. Capacity for Case B using the same cycle steps using conical heads and theoretical angle of repose for the fill capacity is then simulated. The theoretical effect on system capacity is shown in Tables 1 and 3 for LLDPE and HDPE, respectively. In Cases A and B, it is assumed that the IPDS uses a primary vent valve located at the top of the vent line mounted flush with the side of the fluidized pressure vessel. In Cases A and B, the total valved-in volume is calculated to be about 193.9 ft<sup>3</sup> (5.490 m<sup>3</sup>) based on settling vessels of 169.6 ft<sup>3</sup> (4.802 m<sup>3</sup>) and piping volumes of 24.3 ft<sup>3</sup> (.688 m<sup>3</sup>).

**[00152]** In Case C, results are simulated for an IPDS with conical heads, a lowered vent valve wherein the vent valve is located within 25 feet (7.6 meters) of the settling vessel. In this case, the same 169.6 ft<sup>3</sup> (4.80 m<sup>3</sup>) settling vessel volume is used, but the piping volume is reduced to 15.7 ft<sup>3</sup> (0.445 m<sup>3</sup>), making the total valved-in volume about 185.3 ft<sup>3</sup> (5.247 m<sup>3</sup>).

**[00153]** In Case D, results are simulated assuming an IPDS with conical head, a lowered vent valve wherein the vent valve is located within 25 feet (7.6 meters) of the settling vessel, and flow-controlling type crosstie valves. In this case, the valved-in volume is also assumed to be 185.3 ft<sup>3</sup> (5.247 m<sup>3</sup>) because adding the flow-controlling type crosstie valve will not affect the system volume.



**[00154]** In Case E, results are simulated assuming an IPDS with conical head, a lowered vent valve wherein the vent valve is located within 25 feet (7.6 meters) of the settling vessel, flow-controlling-type crosstie valves, and an automated secondary exit valve. Use of the automated secondary exit valve theoretically provides an increase in capacity by allowing the settling vessel in a train to fill concurrently while the transfer vessel in that train is being safely emptied. Thus, the time to fill the discharge vessel will not add to the total cycle time for the system.

**[00155]** In case F, results are simulated for an IPDS with conical heads, flow-controlling-type crosstie valves, an automated secondary exit valve, and two vent valves (primary and secondary) wherein the primary vent valve is located at or near the reactor nozzle and the secondary vent valve is located within 38.5 feet (11.7 meters) of the settling vessel.

#### Example 1

**[00156]** Example 1 shows the increase in capacity that can theoretically be obtained using the improvements of the current invention with LLDPE polyethylene production. As can be seen in Table 1, the conical heads of Case B allow for an increased capacity of about 8% due to removing more resin per drop than a system using elliptical heads.

Table 1

<b>LLDPE Product Discharge System Capacity</b>					
<b>Case</b>	<b>Drop Size</b>	<b>Cycle Time</b>	<b>Drops/hr</b>	<b>Maximum Rate</b>	<b>Capacity % of Case A</b>
	kgs/drop	sec		kgs/hr	
<b>A</b>	1,732	222	32.4	56,188	100
<b>B</b>	1,862	221	32.6	60,669	108
<b>C</b>	1,802	220	32.8	59,113	105
<b>D</b>	1,802	207	34.9	62,834	112
<b>E</b>	1,802	175	41.1	74,144	132
<b>F</b>	1,862	175	41.1	76,616	136

**[00157]** As shown in Table 1, the lowered vent valve of Case C results in a slightly smaller drop size than Case B, which results in a slightly lower capacity than when using a conical head alone.

**[00158]** The capacity improvement for Case D (adding the flow-controlling type crosstie valves) is demonstrated to be 112% of Case A versus the 105% for Case C with the same vent valve location. This advantage is gained because the equalization occurs faster as the flow rate of the equalization is maintained at a higher level. The equalization step for the settling vessel is completed in about 12 seconds for the flow-controlling type crosstie valve versus 22 seconds for the standard crosstie valve. The equalization time for the transfer vessel is estimated to be about 13 seconds for the flow-controlling type crosstie valve versus 19 seconds for the standard crosstie valve. This reduces the theoretical total cycle time of the IPDS from about 222 seconds for Case A to 207 seconds for Case D. As shown in Table 1, the shorter cycle time results in more drops per hour, and thus an hourly capacity of about 112% of that of Case A.

**[00159]** For Case E, the total cycle time can be reduced from about 222 seconds for Case A to about 175 seconds. As shown in Table 1, the



shorter cycle time results in more drops per hour, and thus an hourly capacity that is about 132% of that of Case A.

**[00160]** In Case F, the primary vent valve closes before the secondary vent valve, causing the fluidized resin contained in the vent line to settle into the settling vessel or attached piping and increase the drop size from the 1,802 kgs of Case E to 1,862 kgs. After the secondary vent valve is closed the valved-in volume is unchanged from Case E. As shown in Table 1, the larger drop size increases the hourly capacity of LLDPE to about 136% of that of Case A.

#### Example 2

**[00161]** The theoretical effect of conical heads on product discharge system efficiency for LLDPE polyethylene production can also be simulated using the assumptions described above. The effects of the various features of the invention on IPDS efficiency for LLDPE are shown in Table 2.

Table 2

<b>LLDPE Product Discharge System Efficiency</b>						
<b>Case</b>	<b>IPDS Efficiency</b>			<b>Gas Loss</b>		
	<b>Resin Fill Efficiency</b>	<b>Gas Volume % of Total System Volume</b>	<b>Gas Recovery % of Case A</b>	<b>Net Gas Loss / Drop</b>	<b>Net Gas Loss Rate</b>	<b>Gas Loss vs. Case A</b>
	<b>%</b>	<b>%</b>	<b>%</b>	<b>kgmole/drop</b>	<b>kgmole/kg PE</b>	<b>%</b>
<b>A</b>	89.5	65.6	100	0.30	0.00017	0.0
<b>B</b>	96.2	63.0	104	0.28	0.00015	-11.8
<b>C</b>	97.5	62.6	105	0.26	0.00015	-14.9
<b>D</b>	97.5	62.6	105	0.26	0.00015	-14.9
<b>E</b>	97.5	62.6	105	0.26	0.00015	-14.9
<b>F</b>	98.3	62.3	106	0.27	0.00014	-16.8

**[00162]** As shown in Table 2, the fill efficiency for Case B (conical heads) theoretically increases from 89.5% in Case A to 96.2%. As used herein, Resin Fill Efficiency is the volume of settled resin per drop divided by the valved-in volume (defined in the specification above). The Gas Volume is the volume of gas in the interstitial spaces between the resin particles and above the resin. Gas Recovery % is the amount of gas that is retained in the IPDS as compared to the base case of the IPDS with the elliptical heads. The Net Gas Loss is the amount of gas (per drop or per kg of resin) that travels with the granular resin to the downstream receiving vessel when the transfer tank is emptied. The Gas Loss vs. Case A reflects the theoretical amount of gas lost compared to the standard IPDS with elliptical heads of Case A. Thus, this Example shows that, theoretically, the Resin Fill Efficiency of the conical heads could be as much as 6.7% better than a system with the elliptical heads (a 7.5% improvement) and the gas losses could be about 17.6% less than a system with the elliptical heads.

**[00163]** Next, the improvements in efficiency that can theoretically be obtained using the lowered vent valve of Case C were determined. Lowering the vent valve to within 38.5 feet (11.7 meters) decreases the piping volume as discussed above, thus resulting in less unfilled volume and a corresponding increase in efficiency. As shown in Table 2, lowering the vent valve resulted in a Resin Fill Efficiency of 97.5% as opposed to a Resin Fill Efficiency of 96.2% over a system with conical heads alone. The gas losses theoretically improve to show a loss improvement of 20.4% versus 17.6% improvement for a system with conical heads alone.

**[00164]** Next, the improvements in efficiency that can theoretically be obtained using the two vent valves of Case F are simulated. Using the primary and secondary vent valves results in more resin being contained within the same valved-in volume. As shown in Table 2 this increases the percentage of filled space from 97.5% of Cases C-E to 98.3%. The gas losses are further reduced, in theory, showing a loss improvement of 22.3% versus 20.4% with the single lowered vent valve.



Example 3

**[00165]** Example 3 shows the increase in capacity that can theoretically be obtained using the improvements of the embodiments described herein with HDPE polyethylene production. The theoretical effect on system capacity is shown in Table 3 for each of the Cases A-E described above. As can be seen in Table 3, the conical heads of Case B theoretically result in an increased capacity of about 8% (108% of the base case) for HDPE due to removing more resin per drop than a system using elliptical heads.

Table 3

HDPE Product Discharge System Capacity					
Case	Drop Size	Cycle Time	Drops/hr	Maximum Rate	Capacity % of Case A
	kgs/drop	sec		kgs/hr	
<b>A</b>	2,327	225	32.1	74,628	100
<b>B</b>	2,501	223	32.3	80,746	108
<b>C</b>	2,419	221	32.6	78,808	106
<b>D</b>	2,419	209	34.5	83,533	112
<b>E</b>	2,419	177	40.7	98,398	132
<b>F</b>	2,501	177	40.7	101,731	136

**[00166]** As with the LLDPE Example, Case C results in a slightly smaller drop size for HDPE than Case B, which results in a slightly lower capacity than when using a conical head alone.

**[00167]** In Case D, the advantage of adding the flow-controlling type crosstie valves is simulated to be 112% of Case A versus the 106% for Case C. This advantage is gained because the equalization occurs faster as the flow rate of the equalization is maintained as a higher level. The equalization step for the settling vessel is assumed to be completed in about 14 seconds for the flow-controlling type crosstie valve versus 26 seconds for the current system with the standard crosstie valve. The equalization time for the transfer vessel is assumed to be about 13 seconds for the flow-controlling type crosstie valve

versus 17 seconds for the current design crosstie valve. This reduces the total cycle time of the IPDS from about 225 seconds for Case A to 209 seconds for Case D. As shown in Table 3, the shorter cycle time results in more drops per hour, and thus an hourly capacity of about 112% of that of Case A.

**[00168]** In Case E, the total cycle times for HDPE can theoretically be reduced from about 225 seconds for Case A to about 177 seconds for Case E. As shown in Table 3, the shorter cycle time results in more drops per hour, and thus an hourly capacity that is about 132% of that of Case A.

**[00169]** In Case F, the drop size theoretically increases from the 2,419 kgs of Case E to 2,501 kgs for HDPE. As shown in Table 3, the larger drop size increases the hourly capacity to about 136% of that of Case A.

#### Example 4

**[00170]** The effect of conical heads on product discharge system efficiency for HDPE polyethylene production can also be simulated using the assumptions described above. The theoretical effects of the various features of the invention on IPDS efficiency for HDPE are shown in Table 4.



Table 4

HDPE Product Discharge System Efficiency						
Case	IPDS Efficiency			Gas Loss		
	Resin Fill Efficiency	Gas Volume % of Total System Volume	Gas Recovery % of Case A	Net Gas Loss / Drop	Net Gas Loss Rate	Gas Loss vs. Case A
	%	%	%	kgmole/drop	kgmole/kg PE	%
A	89.7	55.3	100	0.195	0.000084	0.0
B	96.4	51.9	106	0.160	0.000064	-23.8
C	97.6	51.3	108	0.147	0.000061	-27.4
D	97.6	51.3	108	0.147	0.000061	-27.4
E	97.6	51.3	108	0.147	0.000061	-27.4
F	98.2	51.0	108	0.148	0.000059	-29.2

[00171] As shown in Table 4, the fill efficiency for HDPE theoretically increases from 89.7% in Case A using elliptical heads to 96.4% using the conical heads of Case B. This Example shows that theoretically the Resin Fill Efficiency of a system with conical heads could be as much as 6.7% better than a system with elliptical heads, resulting in the gas losses of about 23.8% less than a system with elliptical heads.

[00172] Next, the improvements in efficiency for HDPE that can theoretically be obtained using Case C (a lowered vent valve). Lowering the vent valve to within 38.5 feet (11.7 meters) decreases the piping volume as discussed above, thus resulting in less unfilled volume and a corresponding increase in efficiency. As shown in Table 4, lowering the vent valve theoretically results in a Resin Fill Efficiency of 97.6% as opposed to a Resin Fill Efficiency of 96.4% over a system with conical heads alone. The gas losses theoretically improve to show a loss improvement of 27.4% versus 23.8% improvement for a system with conical heads alone.

**[00173]** Next, the improvements in efficiency that can theoretically be obtained using the two vent valves of Case F are simulated. As shown in Table 4, Case F theoretically increases the percentage of filled space from 97.6% of Cases C-E to 98.2%. The gas losses theoretically improve to show a loss improvement of 29.5% over the Case A.

**[00174]** The phrases, unless otherwise specified, "consists essentially of" and "consisting essentially of" do not exclude the presence of other steps, elements, or materials, whether or not, specifically mentioned in this specification, as long as such steps, elements, or materials, do not affect the basic and novel characteristics of the invention, additionally, they do not exclude impurities normally associated with the elements and materials used.

**[00175]** For the sake of brevity, only certain ranges are explicitly disclosed herein. However, ranges from any lower limit may be combined with any upper limit to recite a range not explicitly recited, as well as, ranges from any lower limit may be combined with any other lower limit to recite a range not explicitly recited, in the same way, ranges from any upper limit may be combined with any other upper limit to recite a range not explicitly recited. Additionally, within a range includes every point or individual value between its end points even though not explicitly recited. Thus, every point or individual value may serve as its own lower or upper limit combined with any other point or individual value or any other lower or upper limit, to recite a range not explicitly recited.

**[00176]** All priority documents are herein fully incorporated by reference for all jurisdictions in which such incorporation is permitted and to the extent such disclosure is consistent with the description of the present invention. Further, all documents and references cited herein, including testing procedures, publications, patents, journal articles, etc. are herein fully incorporated by reference for all jurisdictions in which such incorporation is



permitted and to the extent such disclosure is consistent with the description of the present invention.

**[00177]** While the invention has been described with respect to a number of embodiments and examples, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope and spirit of the invention as disclosed herein.

**CLAIMS**

What is claimed is:

1. A discharge system, the discharge system comprising:
  - (a) a settling vessel comprising a conical top head;
  - (b) a discharge line fluidly connecting a fluidized bed pressure vessel to the settling vessel;
  - (c) a primary discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to the settling vessel;
  - (d) a transfer vessel in fluid communication with the settling vessel;
  - (e) a transfer valve between the settling vessel and the transfer vessel that controls a transfer flow from the settling vessel to the transfer vessel; and
  - (f) a primary exit valve that controls an exit flow of the fluid mixture from the transfer vessel.
2. The discharge system of claim 1, wherein the transfer vessel comprises a conical top head.
3. The discharge system of any one of the preceding claims, comprising a secondary discharge valve in series with the primary discharge valve, wherein the primary discharge valve and the secondary discharge valve are located between the fluidized bed pressure vessel and the settling vessel, and wherein both the primary discharge valve and the secondary discharge valve control the discharge flow to the settling vessel.
4. The discharge system of claim 3, comprising at least two secondary discharge valves and at least two settling vessels, wherein each secondary discharge valve controls the flow to one settling vessel, and wherein one primary discharge valve is in fluid communication with the at least two secondary discharge valves and the at least two settling vessels, such that the one primary discharge valve, in combination with the at least two



secondary discharge valves, controls the discharge flow to each of the at least two settling vessels.

5. The discharge system of any one of the preceding claims, comprising:
  - (a) a vent line fluidly connecting an upper portion of the fluidized bed pressure vessel and the settling vessel; and
  - (b) a primary vent valve that controls a vent flow through the vent line.
6. The discharge system of claim 5, comprising a secondary vent valve in series with the primary vent valve that controls the vent flow through the vent line in addition to the primary vent valve.
7. The discharge system of claim 6, comprising at least two secondary vent valves and at least two settling vessels, wherein each secondary vent valve controls the vent flow between the upper portion of the fluidized bed pressure vessel and one settling vessel, and wherein one primary vent valve is in fluid communication with the at least two secondary vent valves and the at least two settling vessels, such that the one primary vent valve, in combination with the at least two secondary vent valves, controls the vent flow between the upper portion of the fluidized bed pressure vessel and each of the at least two settling vessels.
8. The discharge system of any one of the preceding claims, comprising a secondary exit valve, wherein both the primary exit valve and the secondary exit valve control the exit flow from the transfer vessel.
9. The discharge system of claim 8, comprising:
  - (a) a means to detect an abnormal condition in the discharge system; and
  - (b) a means to close the secondary exit valve upon detection of the abnormal condition.
10. The discharge system of claim 9, wherein the means to detect an abnormal condition comprises an automated control system and a means to detect pressure, flow, temperature, vessel stress, valve position, or actuator position.

11. The discharge system of any one of the claims 9-10, wherein the means to close the secondary exit valve comprises the automated control system and a signal to close the secondary exit valve.
12. The discharge system of any one of the claims 8-11, wherein the secondary exit valve is normally open.
13. The discharge system of any one of the claims 8-12, wherein the secondary exit valve closes within about 5 seconds or within about 2.5 seconds of detection of the abnormal condition.
14. The discharge system of any one of the preceding claims, comprising a solids monitoring device that detects when a settling vessel is full.
15. The discharge system of any one of the preceding claims, comprising a dry-gas purge fed to the settling vessel or the transfer vessel.
16. The discharge system of any one of the preceding claims, comprising a clean-gas purge fed to the discharge line.
17. A method for removing a solid from a fluidized bed pressure vessel, the method comprising the steps of:
  - (a) providing a discharge system comprising a plurality of settling vessels and a plurality of transfer vessels, wherein at least one of the plurality of settling vessels comprises a conical top head;
  - (b) filling a first settling vessel of the plurality of settling vessels with a mixture from a fluidized bed pressure vessel, wherein the mixture comprises a solid and a pressurized gas;
  - (c) equalizing the first settling vessel, wherein a first portion of pressurized gas is transferred from the first settling vessel to at least one of the plurality of settling vessels that is not the first settling vessel;
  - (d) transferring the solid and a second portion of pressurized gas from the first settling vessel to a first transfer vessel;



- (e) re-equalizing the first settling vessel, wherein a return pressurized gas is transferred from at least one of the plurality of settling vessels that is not the first settling vessel to the first settling vessel;
  - (f) equalizing the first transfer vessel with a second transfer vessel, wherein a third portion of the pressurized gas is transferred from the first transfer vessel to at least one of the plurality of transfer vessels that is not the first transfer vessel;
  - (g) emptying the first transfer vessel; and
  - (h) re-equalizing the first transfer vessel, wherein a return transfer gas is transferred from at least one of the plurality of transfer vessels that is not the first transfer vessel to the first transfer vessel.
18. The method of claim 17, wherein at least one of the plurality of transfer vessels comprises a conical top head.
19. The method of any one of the claims 17-18, wherein the discharge system provided comprises a primary exit valve and a secondary exit valve, and wherein the secondary exit valve is closed automatically when an abnormal condition is detected.
20. The method of any one of the claims 17-19, comprising the step of clean-gas purging a discharge line or a vent line.
21. The method of any one of the claims 17-20, comprising the step of dry-gas purging at least one of the plurality of settling vessels or at least one of the plurality of transfer vessels.
22. The method of any one of the claims 17-21, wherein a volume of discharged solid particles is at least 100% of an actual volume of the settling vessel.
23. The method of any one of the claims 17-22, wherein a volume of discharged solid particles is greater than about 90% of greater than about 95% of a valved-in volume of the first settling vessel.
24. A discharge system, the discharge system comprising:

- (a) at least three settling vessels arranged in parallel;
  - (b) a discharge line fluidly connecting a fluidized bed pressure vessel to at least one of the at least three settling vessels;
  - (c) a primary discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to at least one of the at least three settling vessels;
  - (d) a vent line fluidly connecting an upper portion of the fluidized bed pressure vessel and at least one of the at least three settling vessels;
  - (e) a primary vent valve that controls a vent flow through the vent line;
  - (f) at least three crosstie lines fluidly connecting the at least three settling vessels;
  - (g) a crosstie valve that controls a crosstie flow through the at least three crosstie lines, wherein the crosstie valve is a multi-port valve;
  - (h) at least three transfer vessels in fluid communication with the at least three settling vessels;
  - (i) at least three transfer valves between the at least three settling vessels and the at least three transfer vessels that control a plurality of transfer flows from the at least three settling vessels to the at least three transfer vessels;
  - (j) a lower crosstie line fluidly connecting at least two of the at least three vessels;
  - (k) a lower crosstie valve that controls a lower crosstie flow through the lower crosstie line; and
  - (l) at least three primary exit valves that control a plurality of exit flows of the fluid mixture from the at least three transfer vessels.
25. The discharge system of claim 24, wherein the crosstie valve or the lower crosstie valves is a flow-controlling type valve.



26. The discharge system of any one of the claims 24-25, wherein the crosstie valve or lower crosstie valve has a variable flow area depending on the degree of rotation of a stem of the crosstie valve.
27. The discharge system of any one of the claims 24-26, wherein the crosstie valve or lower crosstie valve is a v-ball valve.
28. The discharge system of any one of the claims 24-27, wherein the crosstie line or lower crosstie line is absent a flow restricting device other than the crosstie valve.
29. A discharge system, the discharge system comprising:
  - (a) a plurality of settling vessels arranged in parallel;
  - (b) a discharge line fluidly connecting a fluidized bed pressure vessel to at least two of the plurality of settling vessels;
  - (c) a primary discharge valve, wherein one primary discharge valve controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to at least two of the plurality of settling vessels;
  - (d) a plurality of secondary discharge valves, wherein each of the plurality of secondary discharge valves controls the discharge flow to at least one of the plurality of settling vessels;
  - (e) a plurality of transfer vessels in fluid communication with the plurality of settling vessels;
  - (f) a plurality of transfer valves between the plurality of settling vessels and the plurality of transfer vessels that control a plurality of transfer flows from the plurality of settling vessels to the plurality of transfer vessels; and
  - (g) a plurality of primary exit valves that control a plurality of exit flows of the fluid mixture from the plurality of transfer vessels.
30. The discharge system of claim 29, comprising:

- (a) a vent line fluidly connecting an upper portion of the fluidized bed pressure vessel and the settling vessel; and
  - (b) a primary vent valve that controls a vent flow through the vent line.
31. The discharge system of claim 30, comprising a secondary vent valve in series with the primary vent valve that controls the vent flow through the vent line in addition to the primary vent valve.
32. The discharge system of claim 31, comprising at least two secondary vent valves and at least two settling vessels, wherein each secondary vent valve controls the vent flow between the upper portion of the fluidized bed pressure vessel and one settling vessel, and wherein one primary vent valve is in fluid communication with the at least two secondary vent valves and the at least two settling vessels, such that the one primary vent valve, in combination with the at least two secondary vent valves, controls the vent flow between the upper portion of the fluidized bed pressure vessel and each of the at least two settling vessels.
33. The discharge system of any one of the claims 29-32, comprising a dry-gas purge fed to the settling vessel or the transfer vessel.
34. The discharge system of any one of the claims 29-33, comprising a clean-gas purge fed to the discharge line.
35. The discharge system of any one of the claims 30-34, comprising a clean-gas purge fed to the vent line.



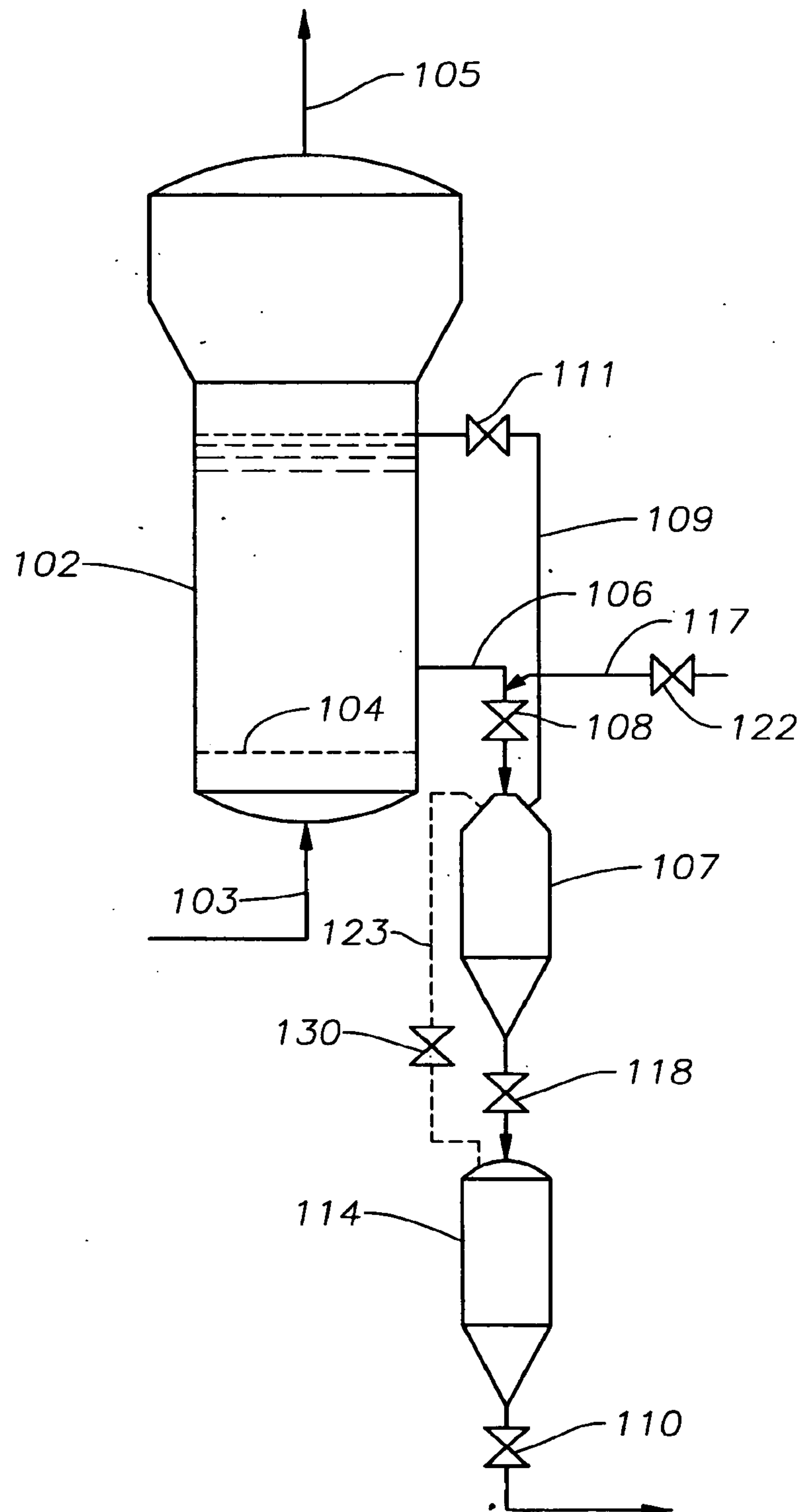
36. A discharge system, the discharge system comprising:
- (a) secondary a settling vessel;
  - (b) a discharge line fluidly connecting a fluidized bed pressure vessel to the settling vessel;
  - (c) a discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to the settling vessel;
  - (d) a transfer vessel that receives solid particles from the settling vessel;
  - (e) a transfer valve between the settling vessel and the transfer vessel that controls a transfer flow from the settling vessel to the transfer vessel;
  - (f) a primary exit valve that controls an exit flow of the fluid mixture from the transfer vessel;
  - (g) a secondary exit valve that controls the exit flow of the fluid mixture from the transfer vessel in addition to the primary exit valve;
  - (h) a means to detect an abnormal condition in the discharge system; and
  - (i) a means to close the exit valve upon detection of the abnormal condition.
37. The discharge system of claim 36, wherein the means to detect an abnormal condition comprises an automated control system and a means to detect pressure, flow, temperature, vessel stress, valve position, or actuator position.
38. The discharge system of any one of the claims 36-37, wherein the means to close the secondary exit valve comprises the automated control system and a signal to close the secondary exit valve.
39. The discharge system of any one of the claims 36-38, wherein the secondary exit valve is normally open.
40. The discharge system of any one of the claims 36-39, wherein the secondary exit valve closes within about 5 seconds or about 2.5 seconds of detection of the abnormal condition.

41. A method for removing a solid from a fluidized bed pressure vessel, the method comprising the steps of:
- (a) providing a discharge system comprising a discharge line, settling vessel, discharge valve, transfer vessel, transfer valve, primary exit valve, and secondary exit valve;
  - (b) filling the settling vessel with a mixture from a fluidized bed pressure vessel, wherein the mixture comprises a solid and a pressurized gas;
  - (c) transferring the solid and a portion of pressurized gas from the settling vessel to the transfer vessel;
  - (d) emptying the transfer vessel to a receiving vessel;
  - (e) monitoring the discharge system for an abnormal condition with an automated control system; and
  - (f) closing the secondary exit valve automatically when the abnormal condition is detected.
42. The method of claim 41, wherein the filling step and the emptying step of a single train of discharge vessels occur at least partially concurrently.
43. The method of any one of the claims 41-42, wherein there is only a single valve closed between the fluidized bed pressure vessel and the receiving vessel during some portions of steps (a)-(d).
44. The method of any one of the claims 41-43, wherein the abnormal condition is detected and the secondary exit valve is closed within 10 seconds or about 5 seconds of the occurrence of the abnormal condition.
45. The method of any one of the claims 41-44, wherein the abnormal condition is a high pressure, high flow, or incorrect valve position in the discharge system.
46. A discharge system, the discharge system comprising:
- (a) a plurality of settling vessels arranged in parallel;
  - (b) a discharge line fluidly connecting a fluidized bed pressure vessel to at least one of the plurality of settling vessels;



- (c) a primary discharge valve that controls a discharge flow of a fluid mixture from the fluidized pressure vessel through the discharge line to at least one of the plurality of settling vessels;
  - (d) a crosstie line fluidly connecting at least two of the plurality of settling vessels;
  - (e) a crosstie valve that controls a crosstie flow through the crosstie line, wherein the crosstie valve is a flow-controlling type valve;
  - (f) a plurality of transfer vessels in fluid communication with the plurality of settling vessels;
  - (g) a plurality of transfer valves between the plurality of settling vessels and the plurality of transfer vessels that control a transfer flow from the plurality of settling vessels to the plurality of transfer vessels;
  - (h) a lower crosstie line fluidly connecting at least two of the plurality of transfer vessels;
  - (i) a lower crosstie valve that controls a lower crosstie flow through the lower crosstie line; and
  - (j) a plurality of primary exit valves that control a plurality of exit flows of the fluid mixture from the plurality of transfer vessels.
47. The discharge system of claim 46, wherein the lower crosstie valve is a flow-controlling type valve.
48. The discharge system of any one of the claims 46-47, wherein the crosstie valve or the lower crosstie valve has a variable flow area depending on the degree of rotation of a stem of the crosstie valve.
49. The discharge system of any one of the claims 46-48, wherein the crosstie valve or the lower crosstie valve is an eccentric plug rotary valve, v-ball valve, or butterfly valve.
50. The discharge system of any one of the claims 46-49, wherein the crosstie line or the lower crosstie line is absent a flow restricting device other than the crosstie valve.

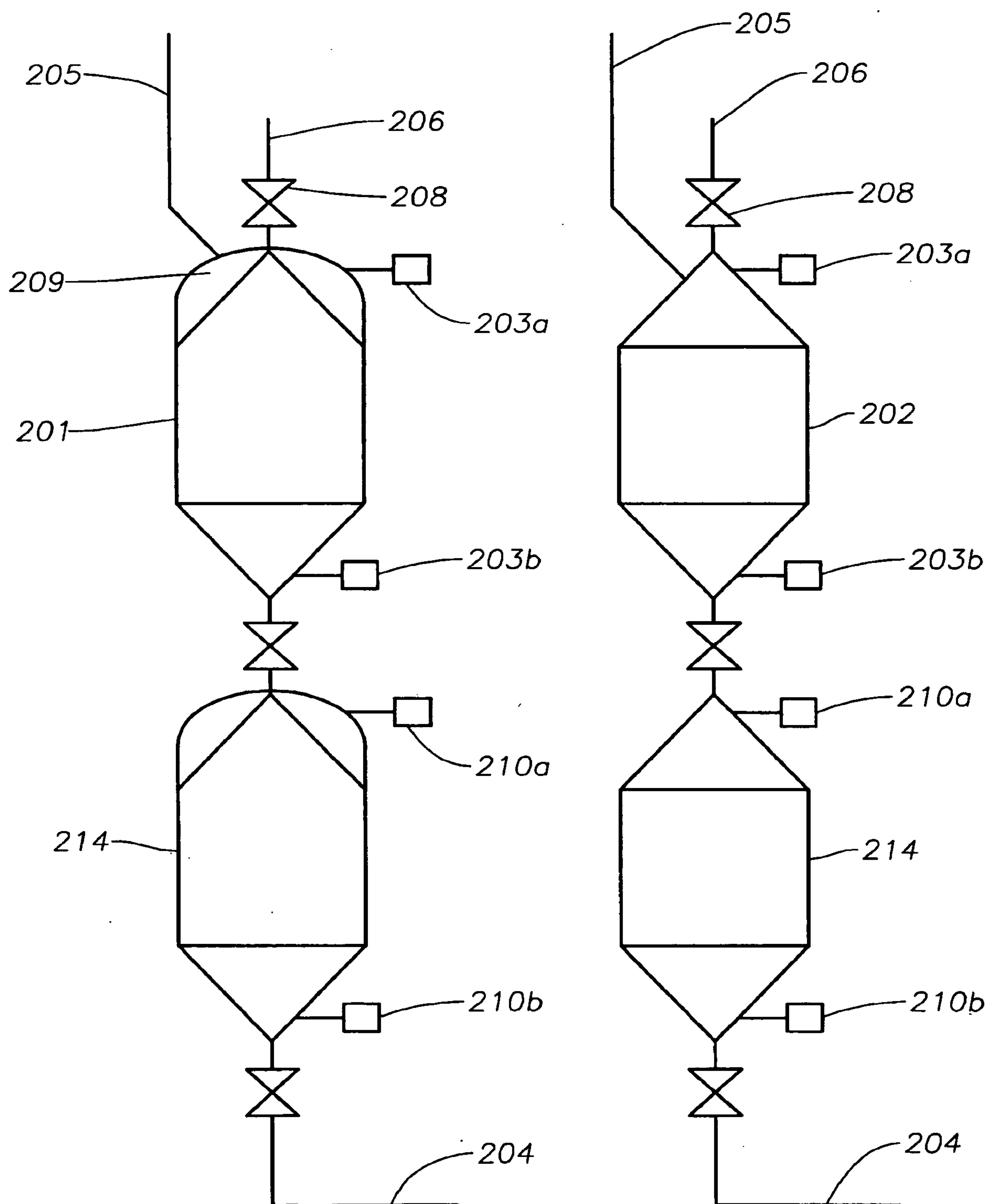
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**Fig. 1**



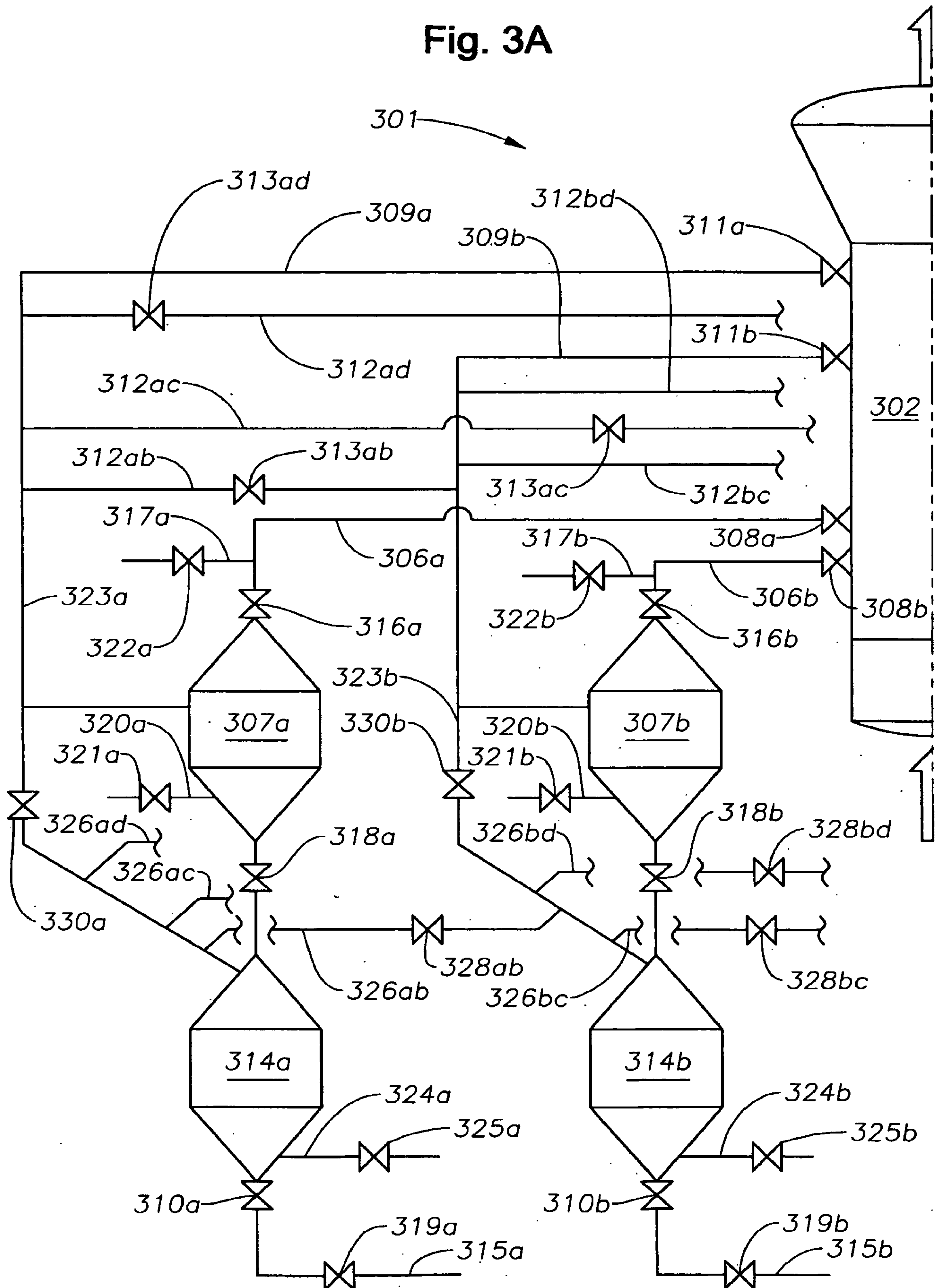
2/7

Fig. 2



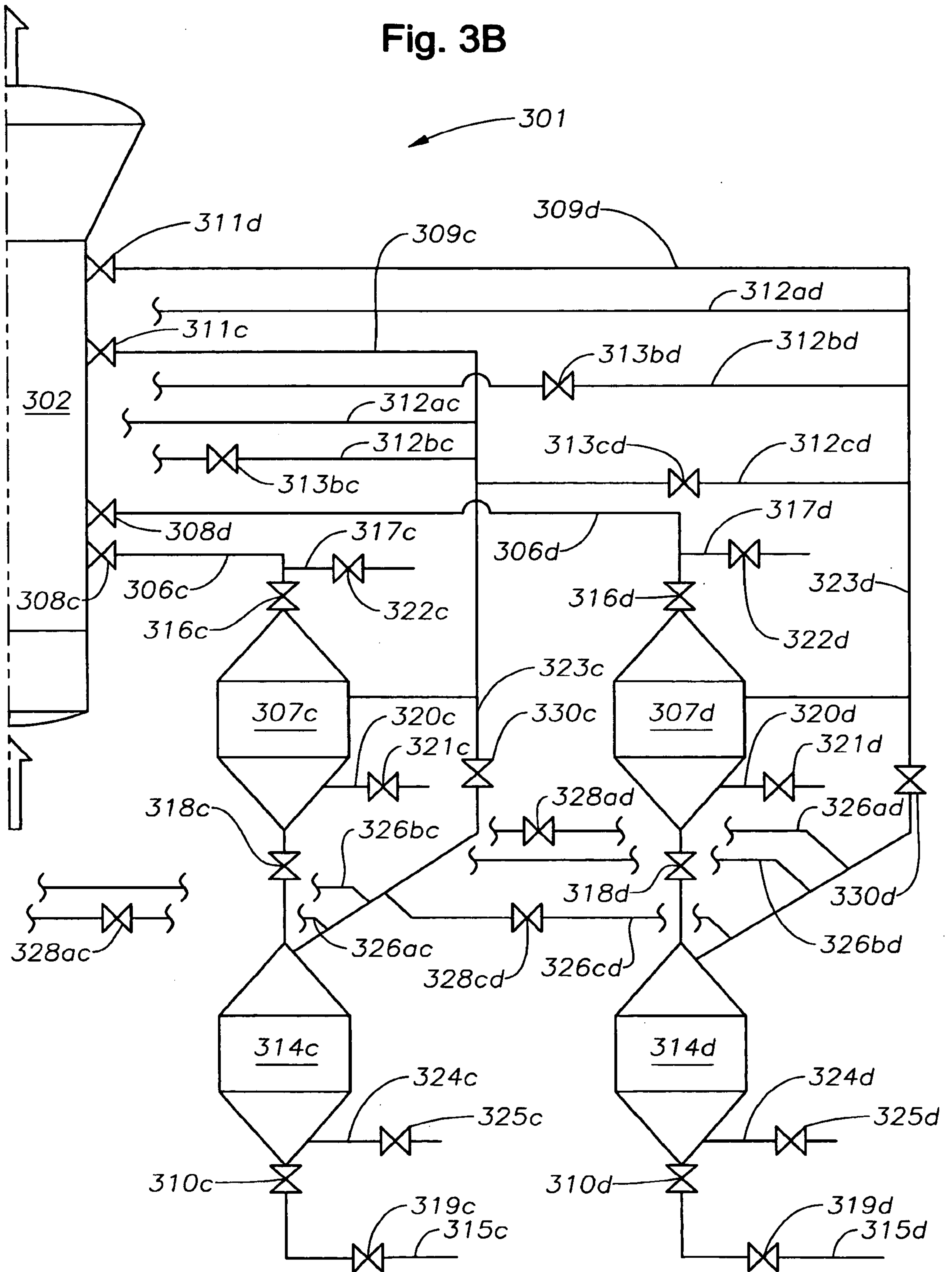
3/7.

Fig. 3A



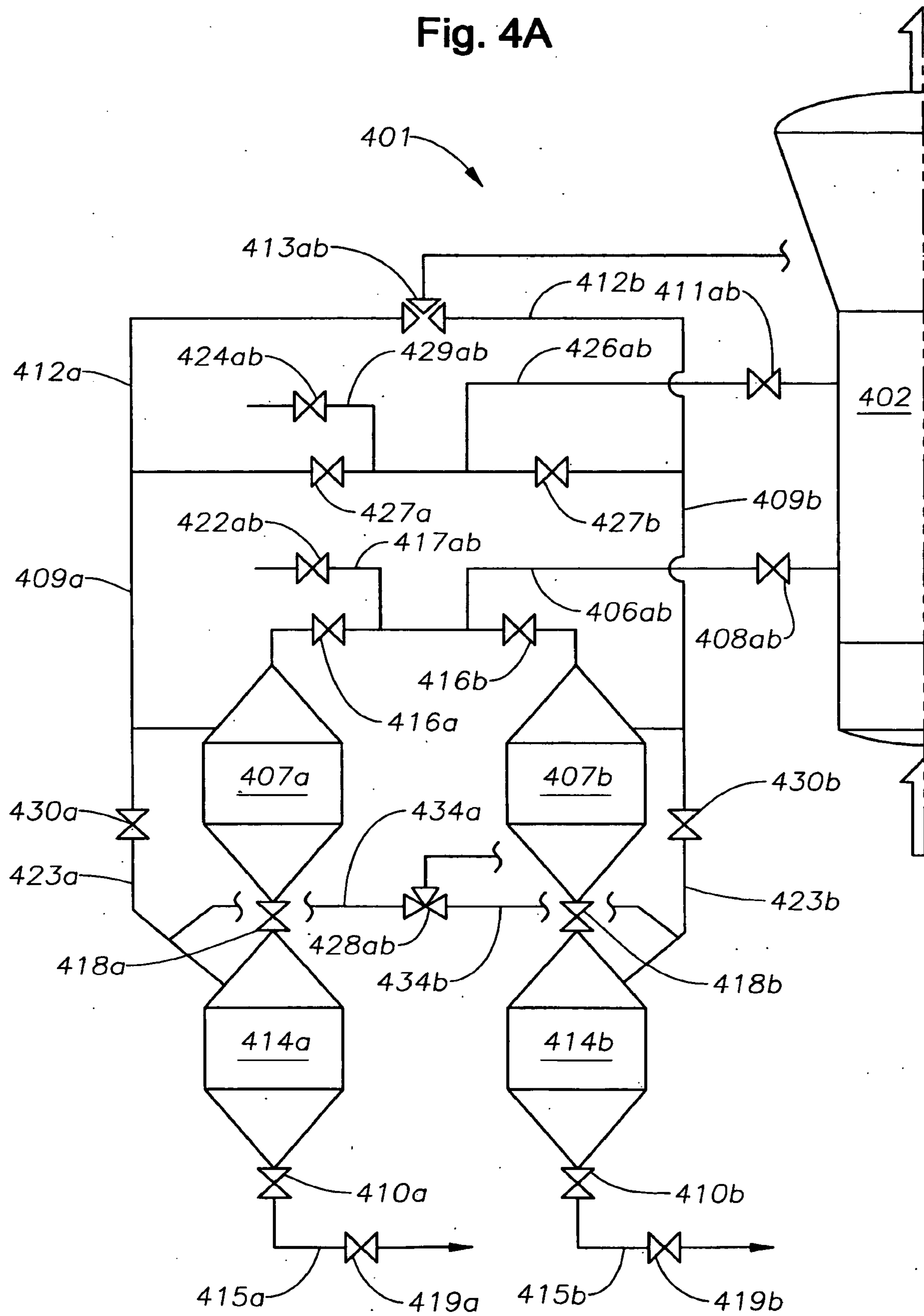


4/7

**Fig. 3B**

5/7

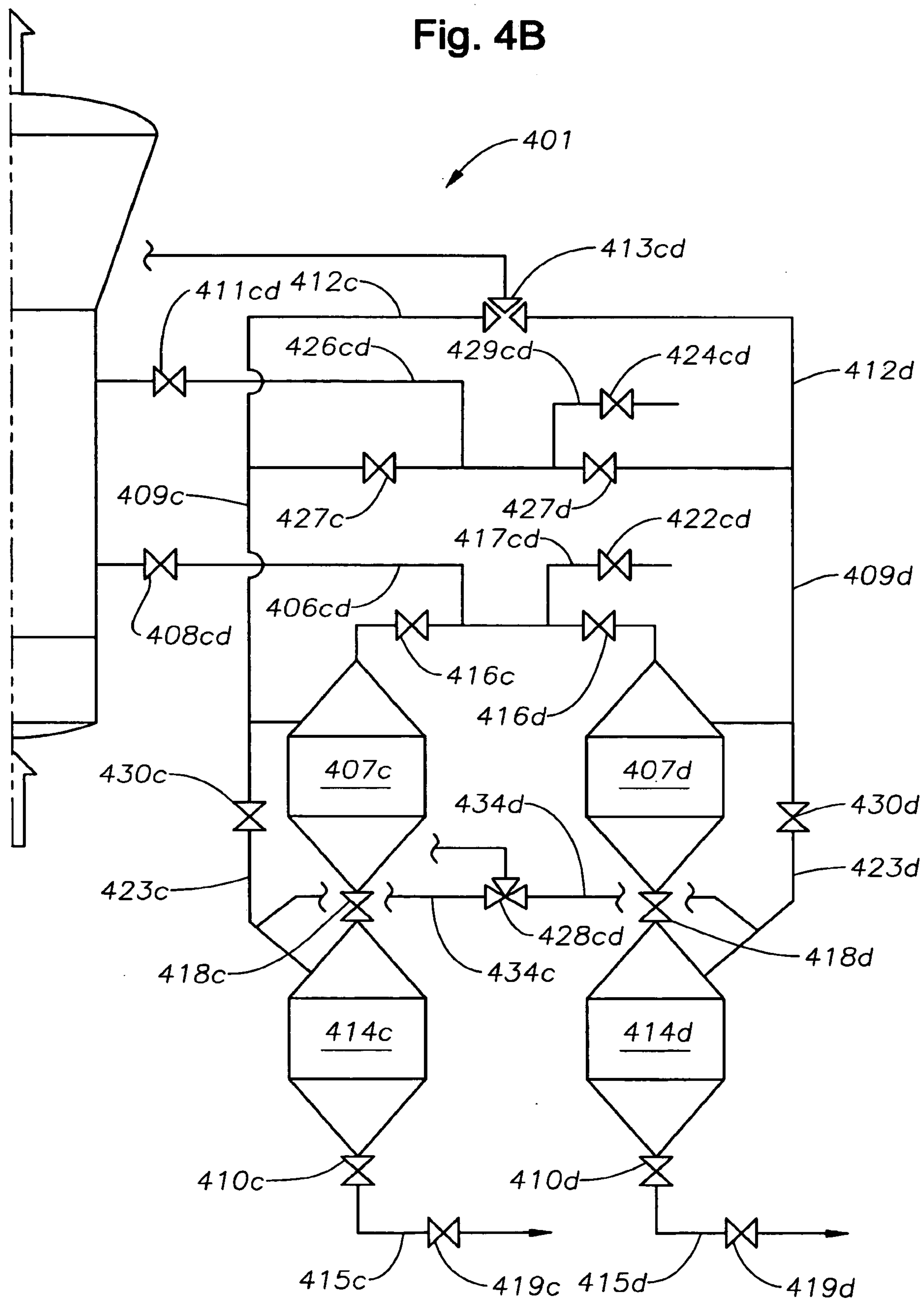
Fig. 4A





6/7

Fig. 4B



7/7

**Fig. 5**