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Continuous extraction units are constructed having a plurality of extraction chambers containing extractable material. Without disruption of total fluid flow in the unit: an extraction chamber completely depleted of extract can be evacuated of solvent and replaced with an extraction chamber containing fresh extractable material. The extract is continuously separated from the solvent in an expansion chamber where it is continuously or periodically removed from the unit. All solvent can be retained within the unit. One or more compressors can be used to circulate the fluid through the extraction chambers, the expansion chamber, and a condenser, where the expansion chamber and the condenser can be coupled as a heat exchanger.

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(54) Title: CONTINUOUS EXTRACTOR, CONCENTRATOR AND DRYER

(57) Abstract: Continuous extraction units are constructed having a plurality of extraction chambers containing extractable material. Without disruption of total fluid flow in the unit: an extraction chamber completely depleted of extract can be evacuated of solvent and replaced with an extraction chamber containing fresh extractable material. The extract is continuously separated from the solvent in an expansion chamber where it is continuously or periodically removed from the unit. All solvent can be retained within the unit. One or more compressors can be used to circulate the fluid through the extraction chambers, the expansion chamber, and a condenser, where the expansion chamber and the condenser can be coupled as a heat exchanger.

CONTINUOUS EXTRACTOR, CONCENTRATOR AND DRYER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Application Serial No. 13/840,546, filed March 15, 2013, which claims the benefit of U.S. Provisional Patent Application Serial No. 61/736,211, filed December 12, 2012.

BACKGROUND OF THE INVENTION

The extraction process has been used for centuries for the isolation of desirable materials. The process involves the mixing of a solvent with extractable material, separation of the solution that is formed, and removal of the solvent from the solute, a desired material.

U.S. Patent 5,512,285, to Wilde, teaches a batch process for extraction of organic components from plant material. The process uses tetrafluoroethane as the extraction solvent. The process allows extraction of some desired components at near ambient temperatures, and is economical relative to super critical CO_2 extractions at high pressure. The system uses a tumbler to mix solvent and plant material in a sealed extractor, which is connected to an evaporator that is warmed in an immersion bath with a heater, the evaporator is connected to a compressor to effectively remove and retain the majority of the expensive solvent and return it to the extractor, if needed. The evaporator was the receiver for the extract, which, when the evaporator dropped in pressure to zero psig, the evaporator was opened and the extract drained from the evaporator. The evaporator is then connected to the compressor and heated to recover virtually all the solvent.

Hence, a flexible system permitting extraction that retains solvent nearly quantitatively, is cost effective, energy efficient, and can permit an effectively continuous operation is desirable.

BRIEF SUMMARY OF THE INVENTION

A continuous unit for the extraction of a desired product from plant or other extractable material is presented that allows the isolation of the product in a concentrated form, the recycling of the extraction solvent, and the drying of the extracted plant material while all are fully contained within the unit. The isolated extract is continuously removed from the unit. The unit employs a plurality of extraction chambers such that one extraction chamber is removed and replaced without halting the extraction process in other extraction chambers.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a schematic drawing of a continuous extraction system particularly suited for extraction solvents that are liquids at STP and employs a vacuum separation chamber, according to an embodiment of the invention.

Figure 2 shows a schematic drawing of a continuous extraction system particularly suited for extraction solvents that are gases at STP and employs pressures in excess of ambient atmospheric pressure, according to an embodiment of the invention.

Figure 3 shows a cross-section of a heat exchanger that combines the separation chamber and the condenser of the continuous extraction system, according to an embodiment of the invention.

Figure 4 shows a cross-section of a heat exchanger that combines the separation chamber and the condenser of the continuous extraction system, according to an embodiment of the invention.

Figure 5 shows a cross-section of a heat exchanger combined with a compressor where the crankcase of the compressor is included as a first portion of the separation chamber of the heat exchanger of the continuous extraction system, according to an embodiment of the invention.

Figure 6 shows a cross-section of a) an extraction chamber where the extraction solvent flows from the bottom to the top of the exchanger, b) an extraction chamber where the extraction solvent flows from the center to the periphery of the extraction chamber, c) an extraction chamber where the extraction solvent flows from the periphery to the center of the extraction chamber, and d) an external view of an extraction chamber with a jacket for heating or cooling of the contents of the extraction chamber for use in a continuous extraction system, according to an embodiment of the invention.

Figure 7 shows a schematic drawing of a continuous extraction system, according to an embodiment of the invention.

Figure 8 shows a schematic drawing of a continuous extraction system, according to an embodiment of the invention.

Figure 9 shows a cross-section of a) a heat exchanger that inserts a single tubular condenser within a tubular separation chamber and b) a heat exchanger that inserts a multiplicity of tubes that comprises the separation chamber within a tubular condenser for use in the continuous extraction system, according to embodiments of the invention.

Figure 10 shows a cross-section of an extraction chamber where the extraction solvent flows from the top through an entrance distribution plate having small orifices over the extractable material and the extract solution drains from the bottom through an exit distribution plate that has large orifices for washing of the extractable material without immersion for use in a continuous extraction system, according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the invention are directed to a continuous immersion extraction system. The extraction system consists of a unit comprising a plurality of extraction chambers that are individually addressed. The extractable material can be plant material or any other extractable material that, generally, can be handled as a solid. Sludge or liquid can be adapted for use in the continuous immersion extraction system. Throughout this disclosure, the extractable material is referenced to as plant material, but it is to be understood that other extractable material can be employed, including but not limited to animal matter, soil, and other mineral matter. The extraction system employs a separation chamber, which is an expansion chamber, where a solvent from a solution is vaporized, with the formation of an aerosol comprising one or more solutes that consolidates into an extract. The extraction chambers are independently: in a state of having plant material being extracted by a solvent, wherein the desired extract is a solute of a solution that is formed; in a state of being washed of residual solute and solution residing in the vicinity of the extracted material; in a state of removal of residual solvent, such that the extracted (spent) plant material can be prepared for removal from the unit; or in a state of being removed from the unit and replaced with an equivalent extraction chamber containing fresh plant material for extraction. The extraction system retains nearly all solvent within the system without losses of almost any solvent to the environment. The extraction system allows the continuous removal of the extract from the system. The extraction process is carried out in a manner where energy consumption is minimized, spent plant material is easily and safely disposed of as waste or employed as a useful by-product, and all other material is recycled solvent or the desired extract. The system can be constructed to couple heat absorbing and heat releasing portions of the system as a heat exchanger, which minimizes energy consumption.

In an embodiment of the invention, as illustrated, but not limited by, Figure 1, a plurality of equivalent extraction chambers **111**, **112**, **113**, and **114** contain plant material, where all but one of the extraction chambers **112**, **113**, and **114** experiences flow of an extraction solvent. The remaining extraction chamber **111** is in a state of being prepared for exchange or being exchanged with an equivalent extraction chamber containing fresh plant material. The extraction solvent is retained within the system and the desired extract is continually removed from the system as a neat or highly concentrated form. In embodiments of the invention, the extract solution flows through at least one nozzle **130** into a low-pressure separation chamber **140** where the extraction solvent is separated as a volatile from the solute comprising the desired extract. At least one filter resides at the exit of each extraction chamber **111**, **112**, **113**, and **114** and/or the conduit **129** connecting the extraction chamber to the nozzle **130** and separation chamber **140**, such that the plant material does not exit the extraction chambers **111**, **112**, **113**, and **114**, nor are fine particles introduced that can clog a nozzle **130**. The separation chamber **140** has a port **141** through which the extract, the solute of the extraction solution, is removed from the system in a continuous manner, optionally, by use of a pump **180**. Optionally, depending on the pressure and solvent volatility, the separation chamber and/or the piping preceding the nozzle **130** can include a means for heating.

The separation chamber **140** is maintained at a lower pressure than that of the extraction chambers and can be, but is not necessarily, under vacuum, as illustrated in Figure 1. The separation chamber **140** promotes solvent vaporization to separate the solvent from the extract as a neat solute or a highly concentrated solution. The extract flows under the influence of gravity and collects at port **141** where removal from the extractor system is carried out in a continuous manner using a pump **180** or where a reservoir **190** is filled by gravity induced flow without pump **180**. When a highly concentrated solution is removed, most, if not all, of the remaining solvent can be recovered and returned to the extraction system through an optional conduit **143** that is connected to: receiver **190**; a conduit between the pump **180** and the receiver **190**; and/or within a conduit **142** between the port **141** and the pump **180**.

The extraction solvent vaporized in the separation chamber is reverted to the condensed phase using a condenser **150** for reintroduction of the extraction solvent into the extraction chambers for further extraction of plant material. Fluid is transmitted through the system by a positive displacement pump **170.** The low pressure of the separation chamber **140** can be maintained by a vacuum pump connected at a port **210** to a chilled condenser **150** where the vaporized solvent is condensed before the inlet side of the positive displacement pump **170.** Optionally, a solvent reservoir **160** is situated between the condenser **150** and the pump **170** inlet.

In an embodiment of the invention, the system includes a multiplicity of extraction chambers **111**, **112**, **113**, and **114** that have valves or combinations of valves, **121**, **122**, **123**, and **124**, situated at the solution exit of the extraction chambers and valves or combinations of valves, **125**, **126**, **127**, and **128** at the opposite end of the chambers. As illustrated in Figure 1, for example, solvent from receiver **160** is pumped through conduit **161** and directed through valve **124** into extraction chamber **114**. Extraction chamber **114** contains plant material from which a large proportion of the extract solute has been removed, which results in a rapidly decreasing concentration of extract in the solution and ultimately solvent flowing from extraction chamber **114** through valve **128** into conduit **162**. Although Figure 1 shows fluid flow from the top to the bottom of extraction chamber **114**, it should be understood that the system is easily plumbed to cause that flow to be from the bottom to the top of extraction chamber **114.** From conduit **162**, the dilute solution or solvent, is directed into extraction chambers **112** and **113** through valves **126** and **127**, respectively. The flow rate in extraction chamber **114** is approximately double that experienced individually in extraction chambers **112** and **113**, as illustrated in Figure 1. The relative flow rate depends on the number of extraction chambers in the state illustrated for extraction chamber **114** versus the number of extraction chambers in the state illustrated for extraction chamber **113**, and generally, a system running at its highest efficiency will have significantly more in the state of extraction chamber **113.** Upon exit of the concentrated solution from extraction chambers **112** and **113** through valves **122** and **123**, respectively, flow is directed through conduit

129 to the nozzle **130** within the separation chamber **140**. While the fluid flow has been directed, as indicated, through extraction chambers **114**, **112**, and **113**, extraction chamber **111**, which contains completely extracted plant material, is in a state of being prepared for replacement with an equivalent extraction chamber. Figure 1 illustrates one manner in which this exchange preparation can be carried out by aligning valves **121**, as shown, and **125**, contrary to what is shown, to admit a gas, for example, nitrogen, to force the solvent into conduit **162**. When all solvent, except that wetting residual plant material, has been removed from extraction chamber **111**, valve **125**, as shown, is aligned to direct nitrogen and solvent vapor to conduit **151**, which directs the solvent vapors to condenser **150**, allowing the spent extracted material to be dried before removal from the unit. Valve **121** can be aligned as indicated or may be partially or completely shut off where the pressure drops in extraction chamber **111**, which also promotes drying of the spent plant material therein.

Upon removal of all, or nearly all, of the solvent from extraction chamber **111**, it is isolated from the system by closing valves **121** and **125**, and removed from the system. Subsequently, an equivalent freshly loaded recycled extraction chamber **111** is placed in the system and has its valves aligned as are the valves of extraction chambers **112** and **113**. Eventually, the more extract depleted extraction chamber, either **112** or **113,** has its valves, either **122** and **126** or **123** and **127**, aligned for fluid flow from solvent conduit **161** to **162**. Extraction chamber **114** is aligned using valves **124** and **128** to be in communication with gas line **201** in the manner that extraction chamber **111** was previously aligned before exchange. In this manner, as shown in Figure 1, at least one extraction chamber delivers solvent or a dilute solution to all but one of the other extraction chambers in the system and the remaining extraction chamber is being dried for replacement. Alternatively, conduit **161** can be directly connected to conduit **162**, not shown, and all extraction chambers not in a state of drying, can be in a state of extraction, as shown for extraction chambers **112** and **113**, in Figure 1. Conveniently and efficiently, at least one additional extraction chamber can be outside of the system being emptied of extracted material and reloaded with fresh extractable material for introduction into the system. Although four extraction chambers are illustrated in Figure 1, the system can employ 3, 5, 6, 7, 8, 9, 10 or more extraction chambers, where the majority are in the state shown for extraction chambers **112** and **113**, at least one can be in the state of extraction chamber **114**, and at least one is in the state of extraction chamber **111**.

In addition to those components illustrated in Figure 1, in embodiments of the invention, as desired, connectors, for example, quick release connectors, can be included within the system. Additionally, as desired, filters, heaters, chillers, heat exchangers, sampling ports, solvent input ports, level indicators, shutoff valves, isolation valves, flow meters, temperature gauges, and sensors for fluid analysis can be included in the system. In addition to the redundancy of extraction chambers, a redundancy of conduits, filters, liquid pumps, receivers, separation chambers, condensers, and vacuum pumps can be included in the system, as is readily appreciated by those skilled in the art. The system can be automated by interfacing fluid sensors, level indicators, valves, pumps, heaters, and chillers to a computer with programed or technician inputted parameters for control of the system. An extraction plant can employ a plurality of these systems, where, for example, a common solvent receiver, gas source, vacuum source, and product receiver may be shared, as desired, between the plurality of systems. It is envisioned that the extraction chambers are of a size that can be readily removed and replaced by one or more technicians, as needed, without or with the aid of equipment such as forklifts, jacks and/or other mechanical equipment, as can be appreciated by those skilled in the art. All conduits, filters, gauges, pumps, or other components can be plumbed to permit their emptying and evacuation for exchange without stopping the continuous extraction system. For example, a pair of filters can be plumbed in parallel with valves that permit isolating a clogged filter, draining the filter into the system, evacuating the filter, and replacing the filter while the system is processing extract. The temperature at which the solvent is introduced into the extraction chambers can be controlled by employing a heater, chiller, or other heat exchanger in the solvent reservoir or the conduits situated prior to flow into the extraction chambers. The extraction chambers can be jacketed and can have a heating or cooling fluid circulated through the jacket.

Solvents that can be used in a system as illustrated in Figure 1, include water, alcohols, hydrocarbons, ethers, fluorinated or other halogenated hydrocarbons, esters, amines, carboxylic acids, or any other solvents that are readily vaporized at temperatures of about 25 °C to about 250 °C at pressures from about 760 mm Hg to about 1 mm Hg. Solvents that can be used include, but are not limited to, acetaldehyde, diethyl ether, pentane, ethyl bromide, methylene chloride, carbon disulfide, cyclopentane, acetone, methyl acetate, chloroform, methanol, tetrahydrofuran, hexane, carbon tetrachloride, ethyl acetate, ethanol, benzene, cyclohexane, propanol, ethylene dichloride, heptane, dioxane, water, formic acid, toluene, butanol, octane, ethylene bromide, acetic acid, chlorobenzene, propionic acid, xylene, nonane, bromobenzene, turpentine, furfurol, butyric acid, dimethyl formamide, dimethyl acetamide, dimethyl sulfoxide, decane, phenol, aniline, propylene glycol, ethylene glycol, acetonitrile, pyridine, or any other solvent. Depending on the solvent employed, the unit can be constructed out of metal, glass, ceramic, or plastic. Depending on the use of the extract produced, the solvent should be carefully considered for the effect of any trace amounts of solvent in the extract to determine the appropriateness of the solvent's use. Mixtures of solvents may be employed, for example, a mixture of solvents with similar volatilities or in a composition where they form an azeotrope.

In another embodiment of the invention, the continuous extraction system is designed to employ solvents that are gases at typical room temperatures at one atmosphere, such as, but not limited to, fluorocarbons where all extraction and separation portion of the system is carried out at pressures above ambient atmospheric pressure. Alternatively, the pressures in the system can be below ambient for the low pressure vapor, where pressure controllers maintain the low pressure vapor and the high pressure vapor at sufficiently low pressures relative to the boiling point of the solvent and the temperature achieved by the compressive heating at those portions of the extraction system entering and exiting a compressor, such that a solvent having a relatively high boiling point can be employed as the solvent. As shown in Figure 2, liquid solvent under high pressure transports from a first, optional, receiver **100** via conduit **27** through valves **24** and **25** into extraction chambers **11** and **12** that contain plant material. Valves **21** and **22** are aligned to direct liquid solution to conduit **20** and to a second, optional, receiver **30**. Typically, although not shown, at least one filter is present at exits to all extraction chambers **11**, **12** and **13**, and/or in conduits **20** and/or **31**. Although, one or both of the receivers can be used to compensate for fluctuations in the volume of liquid contained in the extraction chambers, in principle, the system can function without a reservoir. High-pressure liquid solution from receiver **30** flows through thermal expansion valve **40** into a low-pressure expansion chamber **51** of heat exchanger **50**, where the solution disproportions into a solvent vapor and an aerosol of liquid extract upon the absorption of heat. The aerosol impinges on the internal surfaces of the expansion chamber **51** and drains to a collection port **54**, at a low portion of the expansion chamber **51**. The low-pressure solvent vapor travels through the low-pressure side of the heat exchanger through traps **52** and, optionally, **53**, which, although shown in Figure 2 with a serial geometry, a plurality of traps may be in parallel or may be baffles within the expansion chamber **51**. All trapped extract drains to the collection port **54** where it flows through valve **60** to extract receiver **70**. The low-pressure solvent vapor flows through conduit **81** to the inlet of compressor **80,** where the low-pressure solvent vapor is compressed to high-pressure solvent vapor. The high-pressure vapor flows through an optional oil trap **90,** when a compressor that employs oil is used. The oil used at the compressor **80** can be the extract to avoid contamination by a lubricant. The high-pressure vapor transports through conduit **82** into the high-pressure side of heat exchanger **50**, which is condenser **55**. Heat is released from the high-pressure vapor in the condenser **55** to the expansion chamber **51** resulting in the condensation of the high-pressure solvent vapor to liquid solvent in the condenser **55** of the heat exchanger **50**. The liquid solvent exits the condenser **55** where the liquid solvent flows through conduit **56** and to the solvent receiver **100**, from which the extraction chambers **11**, **12**, and **13** are filled with solvent.

The system is configured to employ a plurality of extraction chambers, illustrated with three extraction chambers **11**, **12**, and **13** in Figure 2, where at least one of the extraction chambers, illustrated with extraction chambers **11** and **12** in a state of extraction by the positioning of valves **21**, **22**, **24**, and **25** to transmit liquid solvent from receiver **100** through conduit **27** and into, and ultimately through, extraction chambers **11** and **12**. The remaining extraction chambers, illustrated in Figure 2 by the single extraction chamber **13**, have valves **23** and **26** aligned to vaporize to solvent and force the vapor solvent into the low pressure conduit **81**. After reducing the pressure in extraction chamber **13** to below the low pressure of the system via pump **110,** the extraction chamber **13** can be brought to atmospheric pressure or below by aligning valves **23** and **26** to vent to normal atmospheric or to vacuum in a manner that allows collection of the last residual solvent from the extracted plant material before removing extraction chamber **13**. Extraction chamber **13** is replaced with a recycle extraction chamber containing fresh plant material. Upon introducing the replacement extraction chamber

13, valves **23** and **26** are aligned to remove air via a vacuum source before opening replacement extraction chamber **13** into the system.

The extract from the traps **52** and **53** and expansion chamber **51** into the collection port **54** of the heat exchanger **50** is drained, or otherwise transported, to extract receiver **70** through valve **60**. When the extract in the receiver **70** contains solvent, valve **60** can be aligned to vent solvent vapor through pump **110** to the low-pressure conduit **81**. Subsequently, valve **60** can be aligned to remove final traces of solvent through conduit **61** to a vacuum source for collection.

In addition to those components illustrated in Figure 2, in embodiments of the invention, as desired, connectors, for example, quick release connectors can be included within the system. Additionally, as desired, filters, heaters, chillers, additional heat exchangers, sampling ports, solvent input ports, level indicators, shutoff valves, isolation valves, flow meters, and sensors for fluid analysis can be included in the system. In addition to the redundancy of extraction chambers, a redundancy of conduits, liquid pumps, receivers, separation chambers, condensers, and vacuum pumps can be included in the system, as is readily appreciated by those skilled in the art. The system can be automated by interfacing fluid sensors, level indicators, valves, pumps, heaters and chillers to a computer with programed or technician inputted parameters for control of the system. The extraction process can employ one or more systems, where, for example, a common solvent receiver, gas source, vacuum source, and product receiver may be shared, as desired, between a plurality of units. It is envisioned that the extraction chambers are of a size that can be readily removed and replaced by one or more technicians, as needed, without or with the aid of equipment such as forklifts, jacks and/or other mechanical equipment, as can be appreciated by those skilled in the art.

Solvents that can be used are freons, for example, but not limited to, trifluoromethane, difluoromethane, fluoromethane, pentafluoroethane, pentafluorodimethyl ether, 1,1,2,2-tetrafluoroethane, 1,1,1,2-tetrafluoroethane, *bis*(difluoromethyl)ether, 1,1,2-trifluoroethane, 1,1,1-trifluoroethane, methyl trifluoromethyl ether, 2,2,2-trifluoroethyl methyl ether, 1,2-difluoroethane, 1,1-difluoroethane, fluoroethane, 1,1,2,2,3,3,3-heptafluoropropane, trifluoromethyl 1,1,2,2-tetrafluoroethyl ether, 1,1,1,2,3,3,3-heptafluoropropane, trifluoromethyl 1,2,2,2-tetrafluoroethyl ether, 1,1,1,2,2,3-hexafluoropropane, 1,1,1,2,3,3-hexafluoropropane, 1,1,1,3,3,3-hexafluoropropane, 1,2,2,2-tetrafluoroethyl difluoromethyl ether, hexafluoropropane, 1,1,2,2,3-pentafluoropropane, pentafluoropropane, 1,1,2,3,3-pentafluoropropane, 1,1,1,2,3-pentafluoropropane, 1,1,1,3,3-pentafluoropropane, methyl pentafluoroethyl ether, difluoromethyl 2,2,2-trifluoroethyl ether, difluoromethyl 1,1,2-trifluoroethyl ether, 1,1,2,2-tetrafluoropropane, methyl 1,1,2,2-tetrafluoroethyl ether, trifluoropropane, difluoropropane, fluoropropane, 1,1,1,2,2,3,3,4,4-nonafluorobutane, 1,1,1,2,3,4,4,4-octafluorobutane, 1,1,1,2,2,3,3-heptafluorobutane, perfluoropropyl methyl ether, perfluoroisopropyl methyl ether, 1,1,1,3,3-pentafluorobutane, 1,1,3-trifluoropropane, 1,1,1,3,3-pentafluorobutane, 1,3-difluoropropane, 1,1-difluorobutane, 1,3-difluoro-2-methylpropane, 1,2-difluoro-2-methylpropane, 1,2-difluorobutane, 1,3-difluorobutane, 1,4-difluorobutane, 2,3-difluorobutane, 1,1,1-trifluoropentane, 1,1,1-trifluoro-3-methylbutane, 1,1-difluoropentane, 1,2-difluoropentane, 2,2-difluoropentane, 1,1,1-trifluorohexane, 3,3,4,4,5,5,6,6,6-nonafluoro-1-hexene, 1,1,3-trifluoropropane, 1,3-difluoropropane, 1,1,1,3,3-pentafluorobutane, 1,1-difluorobutane, 1,3-difluoro-2-methylpropane, 1,2-difluoro-2-methylpropane, 1,2-difluorobutane, 1,3-difluorobutane, 1,4-difluorobutane, 2,3-difluorobutane, 1,1,1-trifluoropentane, 1,1,1-trifluoro-3-methylbutane, 1,1-difluoropentane, 1,2-difluoropentane, 2,2-difluoropentane, 1,1,1-trifluorohexane, 3,3,4,4,5,5,6,6,6-nonafluoro-1-hexene, 1,1,2,2,3-pentafluoropropane, 1,1,1,3,3-pentafluoropropane, 1,1,3-trifluoropropane, 1,1,3-trifluoropropane, 1,3-difluoropropane, 2-(difluoromethyl)-1,1,1,2,3,3-hexafluoropropane, 1,1,2,2,3,3,4,4-octafluorobutane, 1,1,1,2,2,4-hexafluorobutane, 1,1,1,3,3-pentafluorobutane, 1,1-difluorobutane, 1,3-difluoro-2-methylpropane, 1,2-difluoro-2-methylpropane, 1,2-difluorobutane, 1,3-difluorobutane, 1,4-difluorobutane, 2,3-difluorobutane, 1,1,1,2,3,3,4,4-octafluoro-2-(trifluoromethyl)butane, 1,1,1,2,2,3,3,4,4,5,5-undecafluoropentane, 1,1,1,2,2,3,4,5,5,5-decafluoropentane, 1,1,1,2,2,3,3,5,5,5-decafluoropentane, 1,1,1,4,4,4-hexafluoro-2-(trifluoromethyl)butane, 1,1,1-trifluoropentane, 1,1,1-trifluoro-3-methylbutane, 1,1-difluoropentane, 1,2-difluoropentane, 2,2-difluoropentane, 1,1,1-trifluorohexane, 1, 1, 1, 2, 2, 3,3,4,4,5,5,6,6-tridecafluorohexane, 1,1,1,2,2,5,5,5-octafluoro-4-(trifluoromethyl)pentane, 1,1,2,2-tetrafluorocyclobutane, 3,3,4,4,5,5,6,6,6-nonafluoro-1-hexene, 1,1,1-trifluoroethane, pentafluoroethane, or any mixture thereof. In other embodiments of the invention, the solvent can be a non-freon, such as methyl ether, butane, propane, ammonia, or sulfur dioxide.

The compressor can be of any design and can be one that requires oil or is oil-free. If oil is employed in the compressor, the oil can be of any type, including, but not limited to, hydrocarbon, fluorocarbon or silicone oil.

The system can be used with pressures that are higher than normal air pressure, 14.7 psi. For example, the low-pressure side of the compressor may be 20 to 50 psi and the high-pressure side of the compressor may be 50 to 200 psi. Materials of construction for the extraction unit are those which may contain pressures in excess of the highest pressure of the system. For example, metal or metal alloys are useful materials of construction, although other materials may be used when they are capable of withstanding the high pressures of the system.

Although many different designs may be used, the cross-section of a heat exchanger **250** is shown in Figure 3. In this heat exchanger **250**, hot high pressure vapor enters the top of the heat exchanger **250** from conduit **282** and circulates through a coiled first portion of condenser **255** from the bottom of a trap **252** where the coils intimately contact the inside of a cylindrical heat sink **257**. Heat sink **257** transfers the heat from this coiled first portion of condenser **255** to the coiled expansion chamber **251** on the outside of cylindrical heat sink **257.** The thermal expansion valve **240** delivers an aerosol from the solution formed in extraction chambers to the lower-pressure coiled expansion chamber **251** where vaporization of the solvent occurs with the absorption of heat from the heat sink **257**. The heat sink **257** is heated by the hot and condensing high-pressure vapor, which, after rising through the first portion of condenser **255**, enters a second portion of the condenser **256**, where the high-pressure solvent vapor and/or liquid solvent flows over the coiled expansion chamber **251**. Any high-pressure solvent vapor completely condenses in this second portion of the condenser **256** and flows into the exit conduit **258**, as shown in Figure 3. Alternatively, as needed, cooled high-pressure solvent vapor from the second portion of the condenser **256** can lead to an additional third portion of the condenser, not shown, where additional cooling is provided to condense the solvent vapor into liquid solvent. The fluid extract drains to a collection port **254** and the solvent vapor rises through the trap **252** chamber around the first portion of condenser **255** exiting into the low pressure solvent vapor conduit **281** that ultimately leads to a compressor.

Another heat exchanger **350** that can be used, in a continuous extraction system according to an embodiment of the invention, is shown in Figure 4. In this heat exchanger **350**, hot high-pressure vapor enters the top of the first portion of coiled condenser **355** of the heat exchanger **350** from conduit **382**. The coiled condenser **355** spirals from the top of the heat exchanger **350** in intimate contact with a heat sink **357** and coiled expansion chamber **351**, where the condenser coils **355** and expansion coils **351** alternate as they proceed downward along heat sink **357**. The thermal expansion valve **340** delivers an extract solution into the low-pressure expansion coil **351** where vaporization of the solvent of the solution occurs upon the absorption of heat from the contacting coiled condenser **355** and the heat sink **357**. The high-pressure solvent vapor condenses in this coiled condenser **355** and flows into the exit conduit **358**, as shown in Figure 4. Any equilibrium high-pressure solvent vapor can enter an exterior coiled second portion of the condenser **356** where the solvent vapor is further cooled by the external environment or, as desired, by a second cooling source to assure condensing of the solvent vapor into liquid solvent. The fluid extract drains to a collection port **354** and the low pressure solvent vapor rises through the trap **352** chamber around the heat sink **357** exiting into the low pressure solvent vapor conduit **381** that ultimately leads to the compressor. To assure that extract is not entrained as an aerosol to the compressor, baffles **359** and **360** are constructed, but are not necessarily required, near the entrance and exit of the low-pressure vapor into trap **352**.

Another heat exchanger **810** that can be used, in a continuous extraction system according to an embodiment of the invention, is shown in Figure 9a. In this heat exchanger **810**, hot high-pressure vapor enters the top of the first portion of coiled condenser **855** of the heat exchanger **810** from conduit **382**. The coiled condenser **855** spirals from the top of the heat exchanger **810** within a coiled expansion chamber **851** such that there is a very large surface area for heat exchange between the condenser **855** and expansion chamber **851**. As shown in Figure 9a, the cross-sectional area of the inside of the condenser **855** is equal to the area of the vapor condensing portion of the expansion chamber **851**. The cross-sectional areas of the expansion chamber **851** and the condenser **855** can be of any size and ratio to optimize the heat exchange. Having a tube within a tube assures that as much of the heat as possible that is provided by the condensing vapor in the condenser **855** can be absorbed by the expanding gas of the engulfing expansion chamber **851.** Thermal expansion valve **840** delivers an extract solution into the low-pressure expansion chamber **851** where vaporization of the solvent of the solution occurs with the absorption of heat primarily by the engulfed condensing vapor within the coiled condenser **855**. The high-pressure solvent vapor condenses in this coiled condenser **855** and flows into the exit conduit **858**, as shown in Figure 9a. The fluid extract drains to a collection port **854** and the low pressure solvent vapor rises through the trap chamber **852** around the heat sink **857** exiting into the low pressure solvent vapor conduit **381** that ultimately leads to the compressor. To assure that extract is not entrained as an aerosol to the compressor; baffles **859** and **860** are constructed, but are not necessarily required, near the entrance and exit of the low-pressure vapor into trap **852.**

Alternatively to that illustrated in Figure 9a, the heat exchanger can be constructed with one or more tubes within a tube. The outer tube can be the condenser or the expansion chamber. Both of these alternatives constructions are illustrated in Figure 9b. As shown in Figure 9b, the coiled condenser **855** engulfs a plurality of tubes which comprise a partitioned expansion chamber **851**, which is illustrated with seven tubes. Again, as illustrated in Figure 9b, the combined cross-sectional area of the seven tubes comprising the expansion chamber **851** is equal to the area of the vapor condensing portion within the condenser **855.** Again, the dimensions of the tubes of the expansion chamber **851** and the condenser **855** need not be of the area proportions illustrated in Figure 9b. As shown in Figure 9b, the thermal expansion valve **840** delivers an extract solution into the low-pressure expansion chamber **851** at a distributer **845** where the fluid is distributed to the seven tubes, which can be formed using fittings, welding, adhering or any other means. Alternatively, not shown, the distribution can be carried out before a plurality of expansion valves that can individually address the plurality of tubes that comprise the expansion chamber. The geometry of the tubes of the expansion chamber **851** and the condenser **855** can be other than circular, for example, ovals, or any other shapes can be employed to increase the surface area of the tubes and the surface area between the condenser **855** and the ambient air and/or the heat sink **857**.

As shown in Figure 5, the compressor **480** can be combined with the heat exchanger **450**, which permits the cooling of the compressor **480** in addition to cooling the hot high-pressure solvent vapor. Although the illustrated compressor is a piston driven reciprocating compressor, many types of compressors can be used, including, but not limited to, rotary vane, diaphragm, scroll, and roots compressors. An oil-free compressor can be used or a compressor that requires a lubricant can be used. A conduit **420** delivers the extract solution from extraction chambers to the expansion valve **440** to the crankcase of the compressor, which constitutes a first portion of the expansion chamber **451**, where the extract separates from the low-pressure solvent vapor and the extract drains to the collection port **454** at the base of the compressor. As shown in Figure 5, the extract also functions as the lubricant for the crankshaft **486** of compressor **480**, where the cooling by the expanding solvent vapor in the expansion chamber **451** keeps the temperature below the thermal decomposition temperatures of the extract. The low-pressure vapor then enters a second portion of the expansion chamber **452**, where the fluid is in a conduit that contacts the condenser **482** of the heat exchanger **450** after the high-pressure solvent vapor exits the compressor **480** when forced through an exit check valve **484** upon the up-stroke of piston **485**. Although Figure 5 shows heat exchanger **450** as contacting straight conduits **452** and **482**, the heat exchange of this geometry is not required. As the warm high-pressure solvent vapor proceeds through the condenser **482**, it condenses and exits the heat exchanger **450** as a liquid solvent in an exit conduit **455**. Heat is exchanged to the cool low-pressure solvent vapor in the second portion of the expansion chamber **452** in heat exchanger **450** where it is drawn through the entrance conduit **481** though the entrance check valve **483** on the down-stroke of piston **485** of compressor **480**.

The extraction system, according to embodiments of the invention, is configured to employ a plurality of extraction chambers. Figure 6 illustrates some, but not all, possible extraction chamber designs that can be included into the extraction system. Figure 6a shows a simple cylindrical extraction chamber **500** where an inlet **501** feeds solvent through a filtering and fluid distributing screen **503**. The extract solution is formed as the fluid is carried through the plant material housed in the cylindrical extraction chamber **500** and exits through a second filtering screen, not shown, which is equivalent to screen **503**, at outlet **502**. As can be appreciated upon consideration of Figure 1, the fluid can be passed with a flow opposite of that illustrated in Figure 6a. The ends of extraction chamber **500** can be fixed by coupling a capping portion **505** to an end, shown with an optional flange **506**, to allow the removal of the caps **505** and the screens **503**. By exposing the entire central cylinder of the extraction chamber **500**, simple removal of the spent plant material is possible, leaving an empty open cylinder that can be refilled after fixing one of the caps **505** and screens **503**.

Figure 6b shows a second configuration of a extraction chamber **510**, where the solvent enters through the inlet **511** and enters a porous fluid distribution tube **513** closed by an impervious disc **517** at the end of tube **513** distal to inlet **511**, which forces the fluid flow radially through the plant material from the central fluid distribution tube **513**. The extract solution is forced through a filtering porous inner wall **514** of a jacket **516** where the extract solution is forced to consolidate at a consolidation volume **518** before exiting the extraction chamber **510** through outlet **512**. The ends of the extraction chamber **510** can employ caps **515** for ease of removing spent plant material and loading fresh plant material.

Figure 6c shows a third configuration of an extraction chamber **520**, where the solvent enters through an inlet **521**, entering a fluid distribution section **527** that diverts the solvent flow by a non-porous disc **526** to a jacket **524**. The solvent is forced through a porous distribution diffuser **523** on the interior of jacket **526** where the fluid flows through the plant material to a central porous filtration tube **525**, where the extract solution is directed through outlet **522** that resides on the same end of the extraction chamber **520** as inlet **521**. The ends of the extraction chamber **520** can employ caps **527** and **529** for ease of removing spent plant material and loading fresh plant material.

Figure 6d illustrates an extraction chamber **530**, which can have a fluid distribution jacket around an extraction chamber such as that shown in Figures 6a through 6c or any other design. The jacket permits the circulation of a heating or cooling fluid against the exterior of the extraction chamber **530**. The heating fluid can be the liquid solvent exiting the condenser of the heat exchanger. As shown in Figure 6d, fluid can be introduced to the jacket at an inlet **535**, fill the jacket, and exit an outlet **536** at the opposing end of the jacket. Optionally, the inlet can be at the base of a ramp **537** having an incline that makes a single revolution about the jacket to the inlet ending immediately above the opening from inlet **535** to promote a circuitous flow of the fluid that spirals up the jacket. The spiral flow can be further encouraged by a similar, optional, additional ramp **538** at the outlet **536** end of the jacket. Jackets or other heating or cooling sources, in reservoirs of the solvent or extract solution, or on conduits, for example, those leading into the extraction chamber or into expansion chambers, can augment providing a heating or cooling fluid on the jackets of the extraction chambers.

In an embodiment of the invention, a continuous extraction system can be used with nearly any solvent. As illustrated in Figure 7, the continuous extraction system comprises a multiplicity of jacketed extraction chambers **611**, **612**, **613**, and **614**. Fluid from solvent reservoir **663** is directed through jacket inlet valve **638** with jacket inlet valves **635**, **636**, and **637**, as well as jacket outlet valves **631**, **632**, and **633**, in closed positions to isolate jackets **641**, **642**, and **643**. The solvent exits jacket **644** through jacket outlet valve **634** into conduit **665** that delivers solvent to extraction chamber **611** through valve **621**. The plant material of extraction chamber **611** is nearly spent of the extract and, as shown, experiences twice the individual fluid flow rate of extraction chambers **612** and **613**. Although not necessary, this is advantageous for rapidly removing the last portions of extract on the plant material in extraction chamber **611**. The very dilute extract solution exits extraction chamber **611** exits through valve **625** into conduit **667** that feeds extraction chambers **612** and **613** through valves **626** and **627**. The concentrated extract solution from extraction chambers **612** and **613** flows through valves **622** and **623** into conduit **668** to an optional extract solution reservoir **620**. Extract solution reservoir **620** feeds concentrated extract solution through conduit **669** to the expansion valve **650** of expansion chamber **651** in a heat exchanger **656**, which suggests, but is not necessarily, the design shown in Figure 4 for the heat exchanger.

In the manner illustrated in Figure 4, the extract drains to the collection port **654** of the trap **651** of heat exchanger **656** and drains through extract valve **671** into extract receiver and concentrator **672**. Extract valve **671** is periodically opened, or is continuously open to a degree that a column of extract resides in the collection port **654** at the inlet of valve **671** throughout operation of the continuous extraction system. Low-pressure solvent vapor is in equilibrium with the extract in the extract receiver and concentrator **672**, which is connected via concentrator conduit **673** to concentrating and evacuating compressor **674**. On or more plates or baffles can be situated in extract receiver and concentrator **672** to spread wet extract over a larger surface area and increase the rate of solvent evaporation, and/or a stirrer or other mixer can be included in the extract receiver and concentrator **672**. Although not shown, a port with a valve permits the removal of extract from the extract receiver and concentrator **672**. The outlet of the concentrating and evacuating compressor extract receiver and concentrator **672** is connected to a check valve **675**, which forces low-pressure solvent vapor into trap **652** at the inlet **681** of compressor **680** only when the outlet pressure of the concentrating and evacuating compressor **674** exceeds the low-pressure solvent in the extraction chamber outlet **681**. This permits generation of a vacuum in the extract receiver and concentrator **672** to remove nearly all solvent from the extract. A vacuum of, for example, 20 Torr, for example, 10 Torr, for example, 5 Torr, for example, 1 Torr or less, can be achieved in the extract receiver and concentrator **672** to allow removal of the extract with almost no solvent therein.

The concentrating and evacuating compressor **674** is also connected through conduit **661** through valve **624** to extraction chamber **614**. Extraction chamber **614** contains completely spent plant material, which is dried by the vacuum created by extract receiver and concentrator **672**. The output high-pressure solvent vapor from compressor **680** is directed through conduit **682** to the condenser **655** portion of the heat exchanger **656** with an output of liquid solvent into conduit **662** to optional liquid solvent receiver **663** prior to introduction to the extraction chambers.

In an embodiment of the invention, by using a plurality of heat exchangers, and optionally a plurality of compressors, the continuous extraction can isolate a plurality of different extracts comprising different proportions of the extractable components from a given plant material with a single solvent or mixture of solvents based upon the degree of solubility of the different components and any effect of the partitioning of the various components into a solution higher or lower in the more readily extracted component. In this manner one product extract can predominately include the most soluble component or components, another product extracts extract can predominately include the least soluble component or components, and one or more additional extracts can include various proportions of these or be predominately of a component that has some intermediate solubility. In this manner, the different products result from a specific volume of solvent that has passed through an extraction chamber with that extraction solution directed to a desired heat exchanger followed by one or more subsequent volumes of solvent passed through the extraction chamber and directed to one or more other heat exchanges where the specific desired extract composition is to be isolated. As needed, the plurality of heat exchanges can be coupled with the means to selectively heat or cool the solvent and/or the extraction chambers for periods of time when during periods of extraction of a certain fraction of the components such as to enhance the selectivity of extraction during the passage of a particular amount of solvent to a particular heat exchanger. Such a continuous extraction system, according to an embodiment of the invention, is illustrated in Figure 8.

As illustrated in Figure 8, the continuous extraction system comprises a multiplicity of jacketed extraction chambers **711**, **712**, **713**, **714** and **715**. Fluid from solvent reservoir **763** is directed through an optional drying unit **766** where the fluid is passed through a desiccant or other means of drying, for example, freezing or osmotic means, prior to introduction to conduit **764** that directs the ambient temperature solvent to any one or more of a series of jacket inlet valves, **736**, **737**, **738**, **739**, and **740**. The drying unit **766** is constructed to have one portion in line with the fluid flow to conduit **764**, where the other portion having residual solvent removed into the low pressure vapor conduit **793** that is in communication with evacuating compressor **774**. Note that the three heat exchangers **756**, **756'**, and **756"** and all of their features have the same numbers with the number labeled to the feature only in one of the three heat exchangers in Figure 8. As illustrated, valve **736** is aligned to have the ambient temperature solvent enter jacket **741** of extraction chamber **711**, which is under the condition where the solvent exits through jacket outlet valve **731** through a conduit to valve **721** where it is directed into and through extraction chamber **711** having plant material that is, as desired, spent or nearly spent of the extract, where after flow through valve **726** into conduit **767**, as shown, extraction chamber **711** experiences three fold the individual fluid flow rate of extraction chambers **712**, **713**, and **714**. A nearly spent chamber may be advantageous when the least soluble component will subsequently partition and concentrate in other extraction chambers. In other configurations the transport of solvent from conduit **764** to conduit **767** through valve **794** is preferable. As illustrated in Figure 8, three compressors **780**, **780'** and **780"** are employed; however, there may be more than one heat exchanger feeding a single compressor; for example, all three heat exchangers could be plumbed to a single compressor.

Jacket inlet valves **736**, **737**, **738**, **739**, and **740** are configured to allow ambient temperature solvent to be selected for introduction into extraction chamber jackets **711**, **712**, **713**, **714**, and **715**, respectively; and independently, either the ambient temperature solvent from conduit **764**, forces the solvent through thermal expansion valve **786**, **787**, **788**, **789**, and **790** for evaporative cooling of the jackets, or hot high pressure vapor from conduit **791**. As illustrated, simultaneously, extraction chambers, **714**, **713**, and **712** are cooled, maintained at ambient, and heated, respectively, where early extract, middle extract, and late extract, respectively, can be optimized for isolation of three different extract products with three different compositions.

In this configuration, cool early extract is carried from extraction chamber **714** in early extract solution through exit valve **724** into return selection valve **719** where it is directed to early extraction solution conduit **770** to the thermal expansion valve **750"** of expansion chamber **751"** of heat exchanger **756"**. The early extract is collected in extract receiver and concentrator **772"**, which is connected via concentrator conduit 773" to concentrating and evacuating compressor **774"** where concentrator conduit 773" passes through condenser **777"** that is cooled by passing some solvent from conduit **762"** through thermal expansion valve **776"** with the cold low pressure vapor discharged into trap **781"** of heat exchanger **756"**.

In this configuration, ambient temperature middle extract is carried from extraction chamber **713** in middle extraction solution through exit valve **723** into return selection valve **718** where it is directed to middle extraction solution conduit **769** to the thermal expansion valve **750'** of expansion chamber **751'** of heat exchanger **756'**. The middle extract is collected in extract receiver and concentrator **772'**, which is connected via concentrator conduit 773' to concentrating and evacuating compressor **774'** where concentrator conduit **773'** passes through condenser **777'** that, optionally, is cooled by passing some solvent from conduit **762'** through thermal expansion valve **776'** with the cold low pressure vapor discharged into trap **781'** of heat exchanger **756'**.

In this configuration, heated late extract is carried from extraction chamber **712** in late extract solution through exit valve **722** into return selection valve **717** where it is directed to middle extraction solution conduit **768** to the thermal expansion valve **750** of expansion chamber **751** of heat exchanger **756**. The early extract is collected in extract receiver and concentrator **772**, which is connected via concentrator conduit 773 to concentrating and evacuating compressor **774** where concentrator conduit 773 passes through condenser **777** that is not cooled by passing some solvent from conduit **762** through thermal expansion valve **776** with the cold low pressure vapor discharged into trap **781** of heat exchanger **756**.

As shown in Figure 8, extraction chamber **715** is under evacuation of residual solvent, where outlet valve **725** is aligned to evacuating compressor **774**. Jacket inlet valve **740** can be aligned to receive hot high pressure vapor from conduit **791** and direct it through extraction chamber jacket **745** and through jacket outlet valve **735** into conduit **792** to expansion chamber **751** of heat exchanger **756**.

Although not illustrated, flow meters, flow controllers and sensors for temperatures, fluid density, spectral characteristics, viscosity, or other parameters can be included to determine the quantity of solvent that has passed through each of the plurality of extraction chambers and send an input signal to a microprocessor, which can then control valves to direct the flow of solvent an extract solution. Solvent can be directed to expansion valves in the extraction chamber jackets and to condensers. Hot high pressure vapor can be directed to the extraction chamber jackets or to heat exchangers of any design in various conduits. Additionally, as desired, the extraction chambers can include ultrasonic processors, stirrers, or other means of agitation. In an embodiment of the invention, the extraction chambers can be those where plant material is not immersed or submerged, as that suggested in Figure 6, but where the extraction chamber comprises at least one nozzle or fluid distribution plate to spray and wash the surface of the plant material where the extract solution is drained or otherwise removed from the extraction chamber in a manner that the extract solution does not pool in the extraction chamber. Figure 10 illustrates an extraction chamber **800** where the extraction solvent enters an inlet **801** situated at the top of the extraction chamber **800** feeds solvent through a filtering and fluid distributer **803** supported by flange **807**. The inlet distributer **803** has small orifices such that the solvent exits as a spray of droplets that washes the plant material to be extracted but does not immerse the material as the outlet distributer **804** has significantly large orifices to allow the extract solution to collect under the outlet distributer supporting flange **808** and pass from the extraction chamber **800** through an outlet **802**without filling the extraction chamber **800**. Both ends of extraction chamber **800** can be fixed by coupling a capping portion **805** to an end, shown with an optional flange **806**, to allow the removal of the caps **805** and distributers **803** and **804** for ease of exposing the entire central cylinder of the extraction chamber **800**, for simple removal of the spent plant material, leaving an empty open cylinder that can be refilled. Using such an extraction chamber, the plant material can have surface extract removed with little or no infusion of the solvent into the plant material, which can allow the removal of pesticides and other chemicals that may be sprayed onto the plants in the field.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

CLAIMS

We claim:

1. A continuous extraction unit, comprising:

a plurality of extraction chambers, wherein each of the extraction chambers comprises one or more first valves to direct a fluid flow, and wherein the extraction chamber contains extractable material for extraction of a solute by a solvent to form a solution when under a fluid flow;

at least one compressor;

at least one heat exchanger comprising at least one expansion chamber directly contacting at least one condenser, wherein the expansion chamber comprises at least one solution inlet comprising at least one expansion valve that allows a pressure drop that promotes vaporization of the solvent from the solution and aerosolization, coalescence, and consolidation of the solute as an extract in the form of a neat solute or a concentrated solution, wherein the solvent in a vaporized state is condensed to a liquid in the condenser, wherein heat from the condenser is absorbed by the expansion chamber, and wherein the compressor is positioned upstream with respect to the fluid flow through the condenser and the extraction chambers and the compressor is positioned downstream with respect to the fluid flow through the expansion chamber; and

at least one pump or at least one second valve for continuously or periodically removing the extract without disruption of the fluid flow, wherein the first valves to direct the fluid flow permit removing one of said plurality of extraction chambers when the extractable material has been depleted of the extract and replacing the extraction chamber that is removed with an equivalent of the extraction chamber containing fresh extractable material without disruption of fluid flow through at least one of the extraction chambers, and wherein the solvent is retained within the continuous extraction unit.

2. The continuous extraction unit of claim 1, further comprising an information processor interfaced with at least one actuator and/or at least one sensor.

3. The continuous extraction unit of claim 2, wherein: the information processor comprises a programmed computer; the sensors comprise, independently or in combination, one or more

flow meters, fluid density sensors, refractive index detectors, infra-red, visible or ultraviolet light detectors, and/or conductivity detectors; and the actuators comprise, independently or in combination, one or more valves, pumps, and/or alarms.

4. A method of extracting at least one soluble component from extractable material, comprising:

providing a continuous extraction unit according to claim 1 having a plurality of extraction chambers containing an extractable material comprising an extractable solute;

flowing a liquid fluid comprising a solvent through a first conduit into the plurality of extraction chambers, wherein a solution comprising the extractable solute is formed;

directing flow of the solutions comprising the extractable solute from the extraction chambers into a second conduit, wherein the solutions comprising the extractable solute directed from extraction chambers are combined into a combined solution comprising the extractable solute;

flowing the combined solution comprising the extractable solute from the second conduit into the at least one solution inlet into the at least one expansion chamber, wherein the expansion chamber is maintained at a lower pressure than the pressure in the second conduit, wherein the combined solution comprising the extractable solute is partitioned into a low pressure solvent vapor and an extract comprising the extractable solute and wherein the low pressure solvent vapor is drawn into an intake of a compressor;

removing the extract from the continuous extraction unit by at least one pump or valve continuously or periodically without disruption of the fluid flow within the continuous extraction unit;

compressing the low pressure solvent vapor to a hot high pressure vapor at the output of the compressor;

condensing the hot high pressure vapor to the liquid comprising a solvent in the condenser, wherein heat from the hot high pressure vapor and heat formed upon condensing is transferred directly to the expansion chamber;

directing the flow of the liquid fluid comprising a solvent to the first conduit;

preventing flow of the liquid fluid comprising a solvent from the first conduit into any one of the extraction chambers rendered depleted of extract;

removing the solvent in the extraction chamber rendered free of extractable solute to the second conduit, the first conduit, and/or other portion of the continuous extraction;

isolating and removing the extraction chamber rendered depleted of the extract from the continuous extraction unit;

connecting an equivalent extraction chamber containing extractable material comprising a solute by connection to the first conduit and the second conduit;

restoring the flow of the liquid fluid comprising a solvent from the first conduit into the equivalent extraction chamber containing extractable material comprising a solute, wherein the solution comprising the extractable solute is formed; and

redirecting flow of the solution comprising the extractable solute from the equivalent extraction chambers into the second conduit.

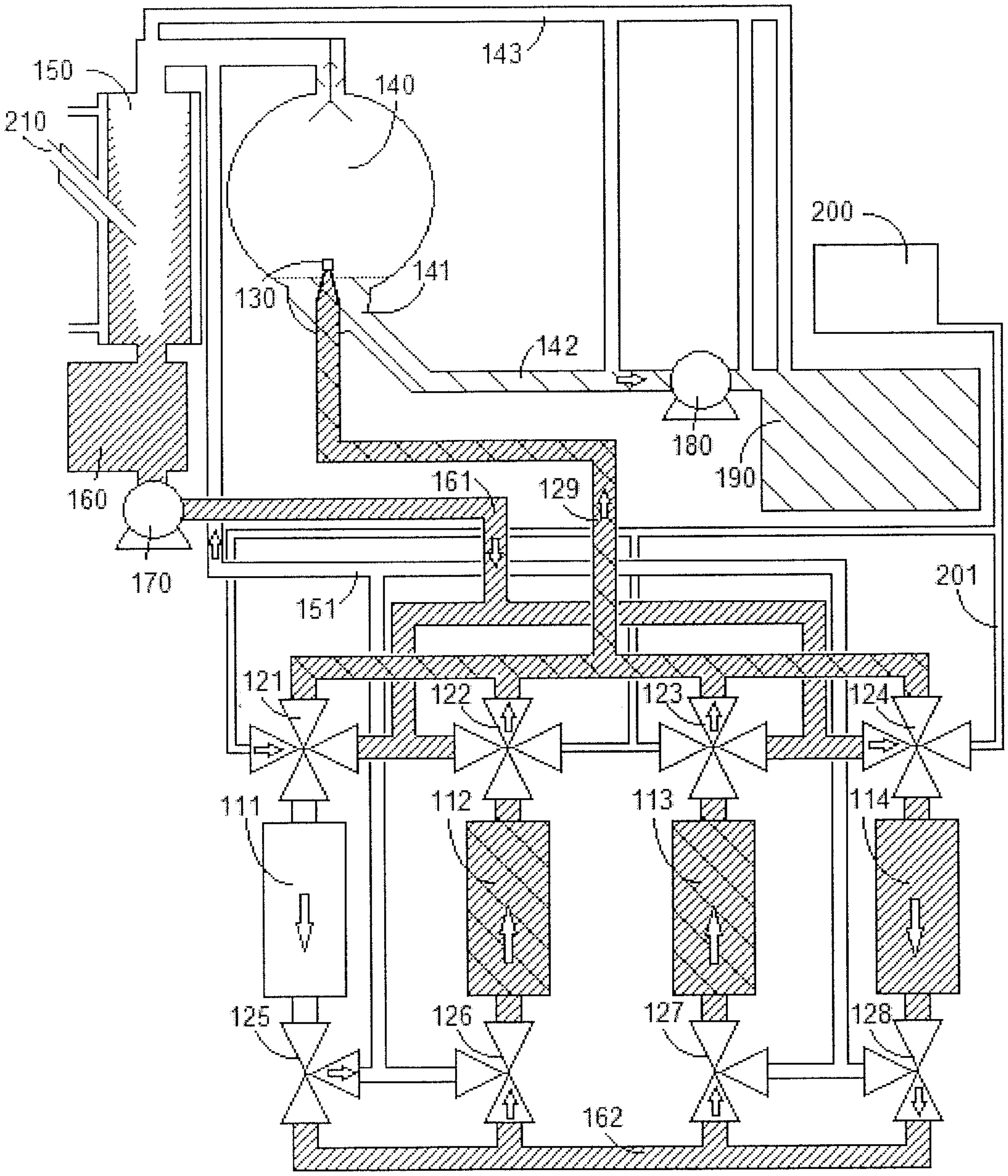
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Figure 1

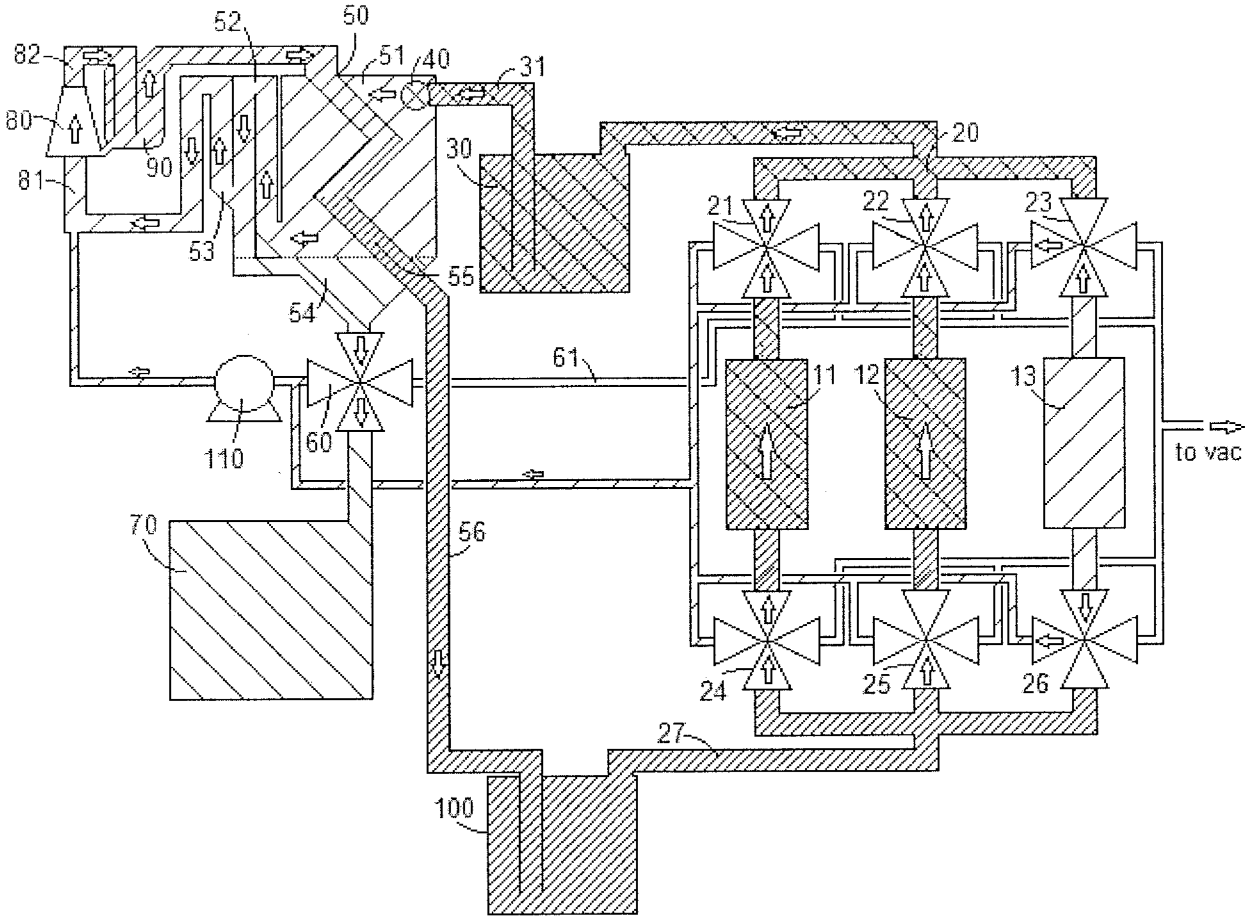
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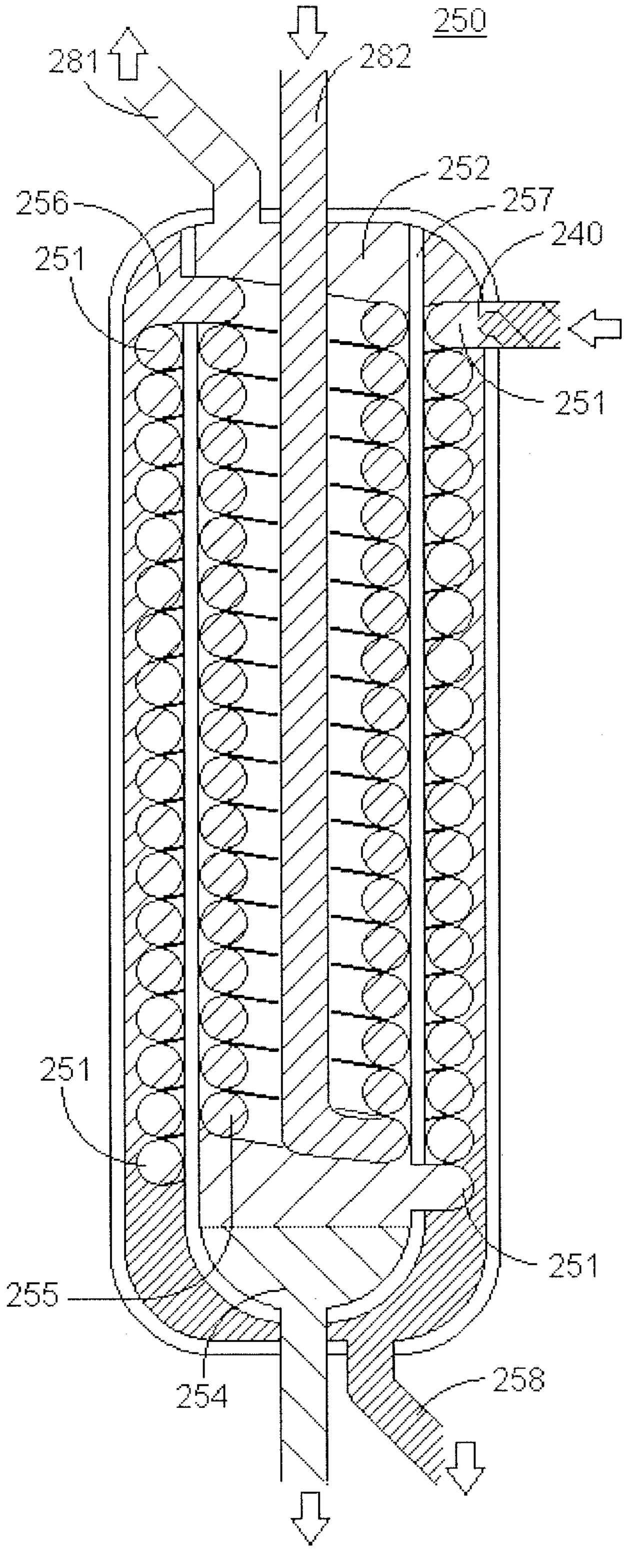
Figure 2



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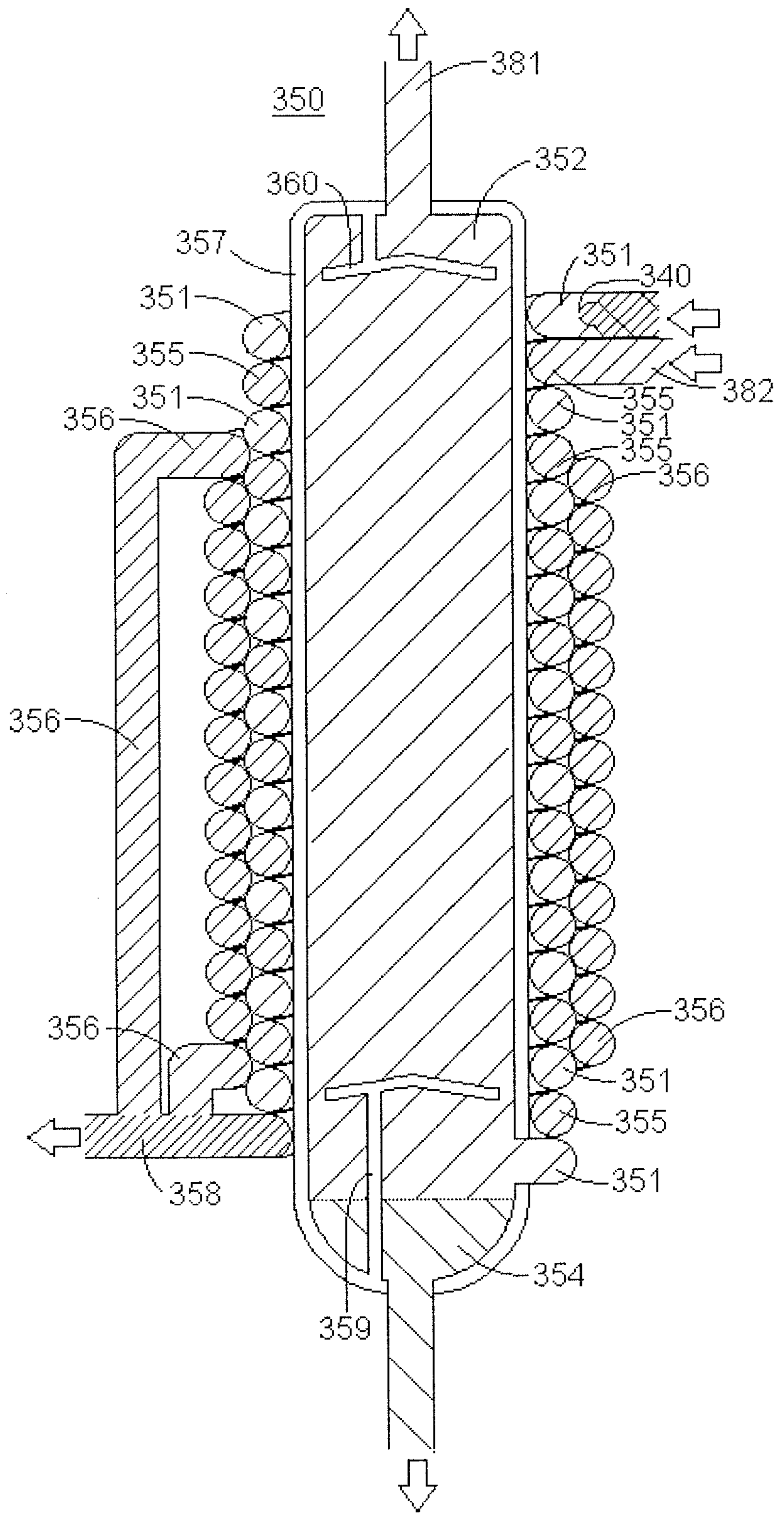

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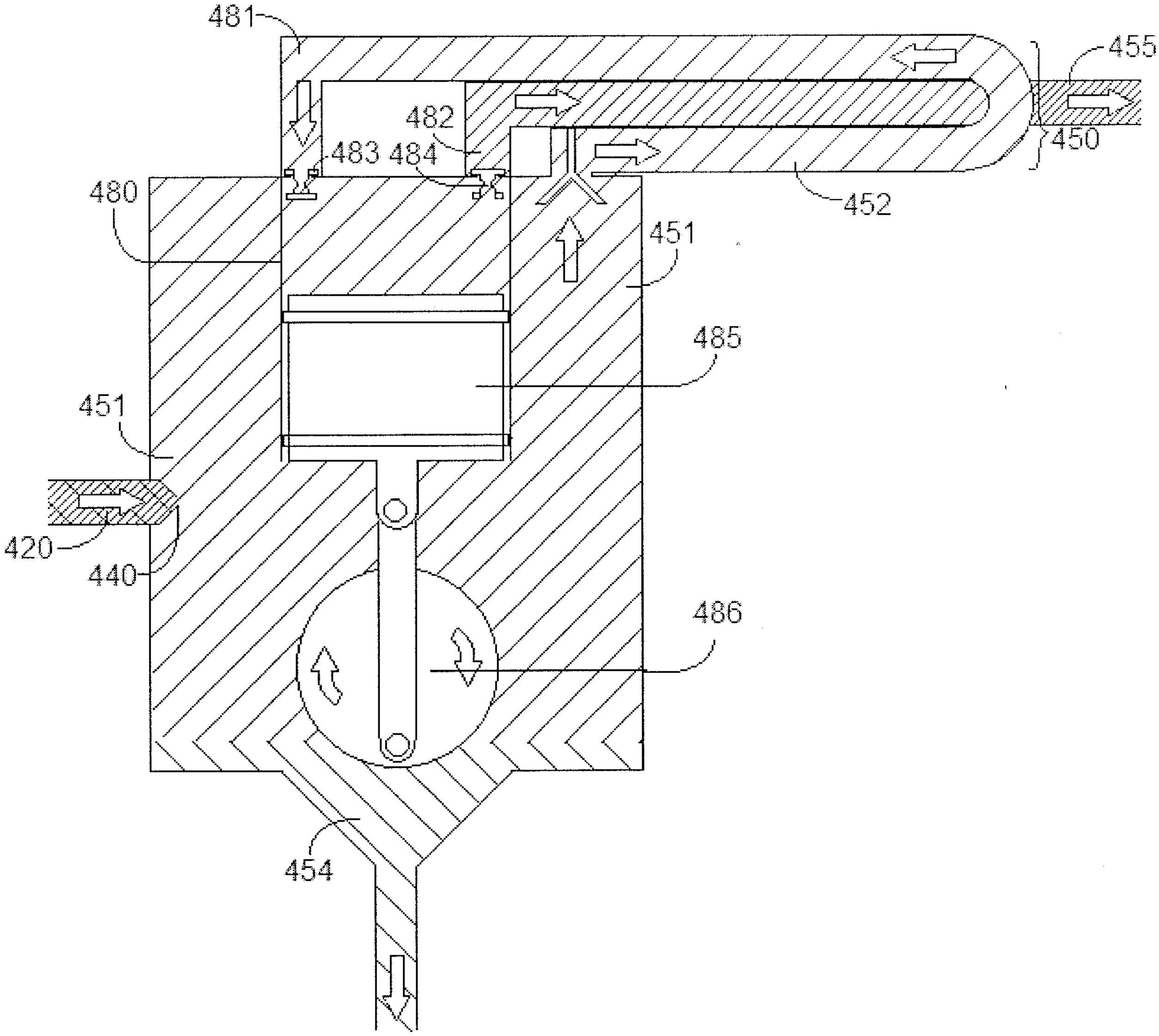

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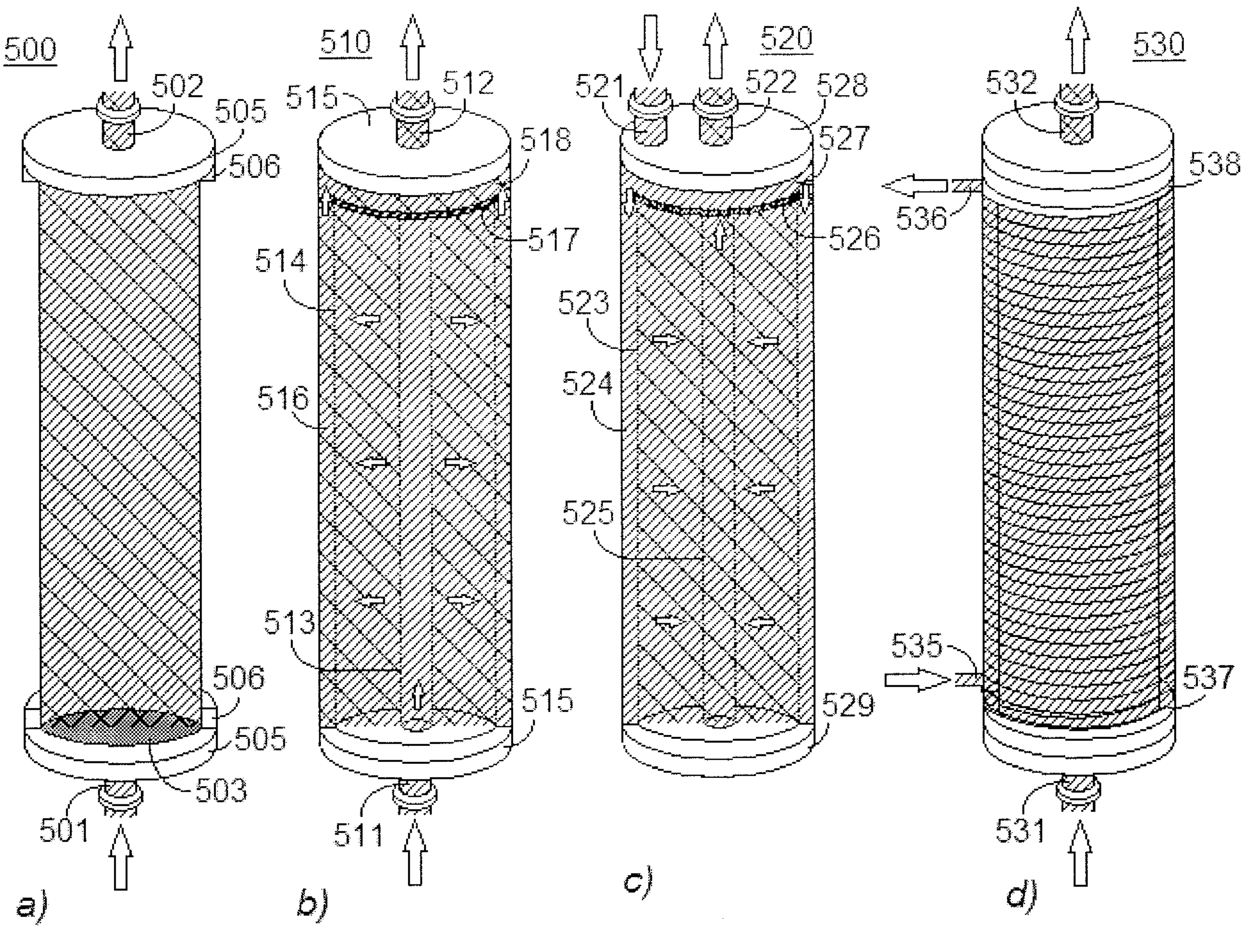
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Figure 6

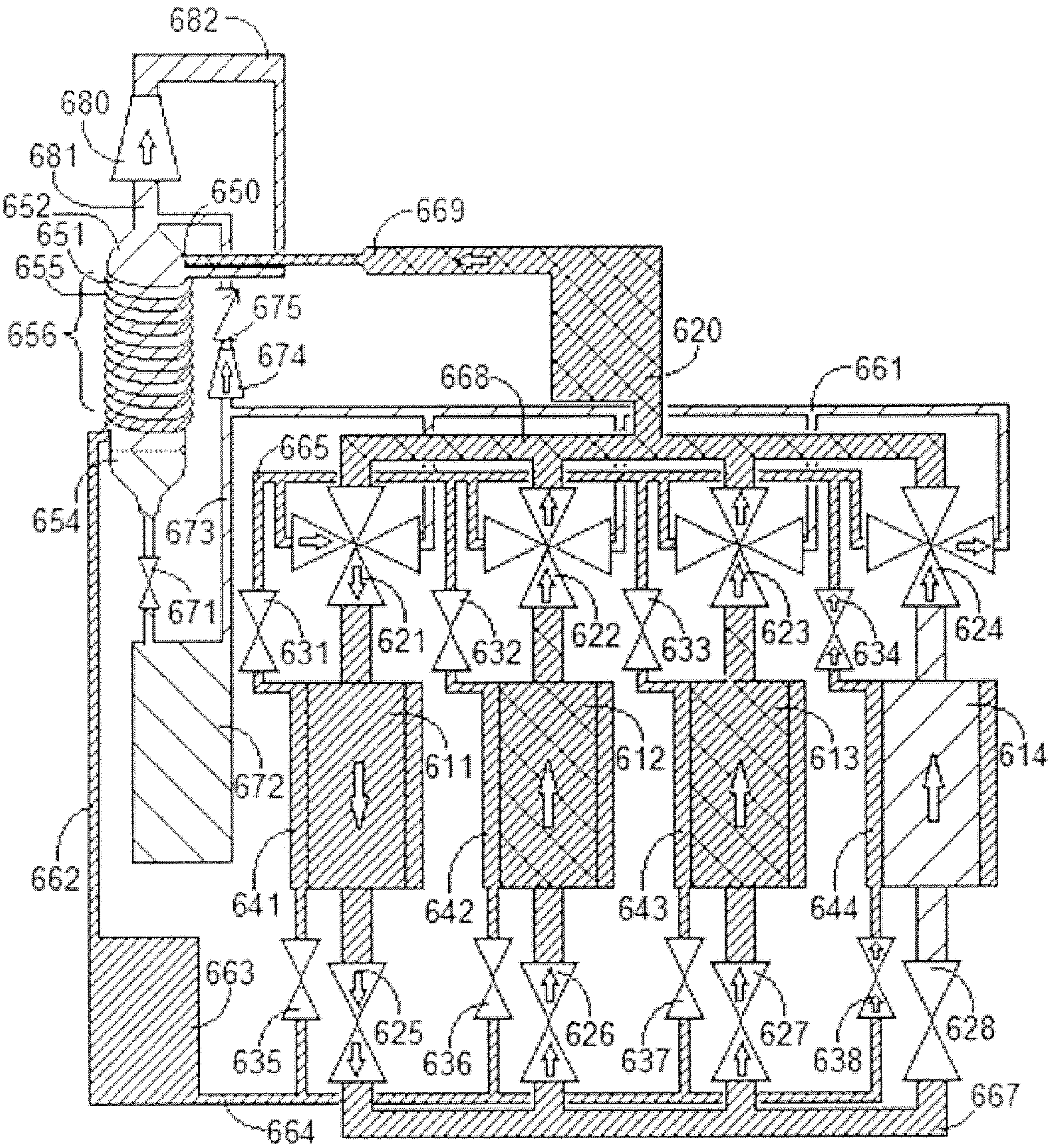
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Figure 7

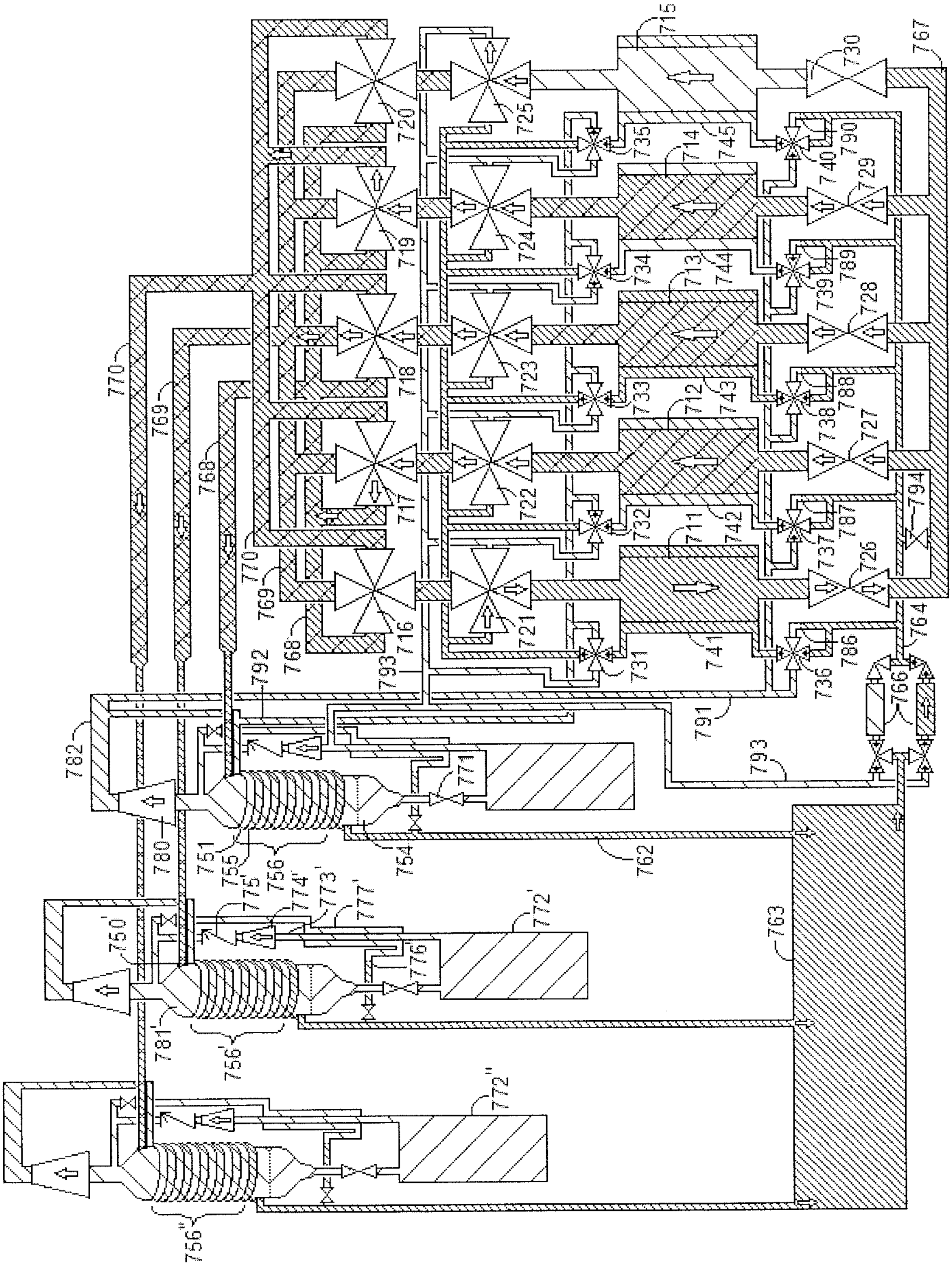
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Figure 8

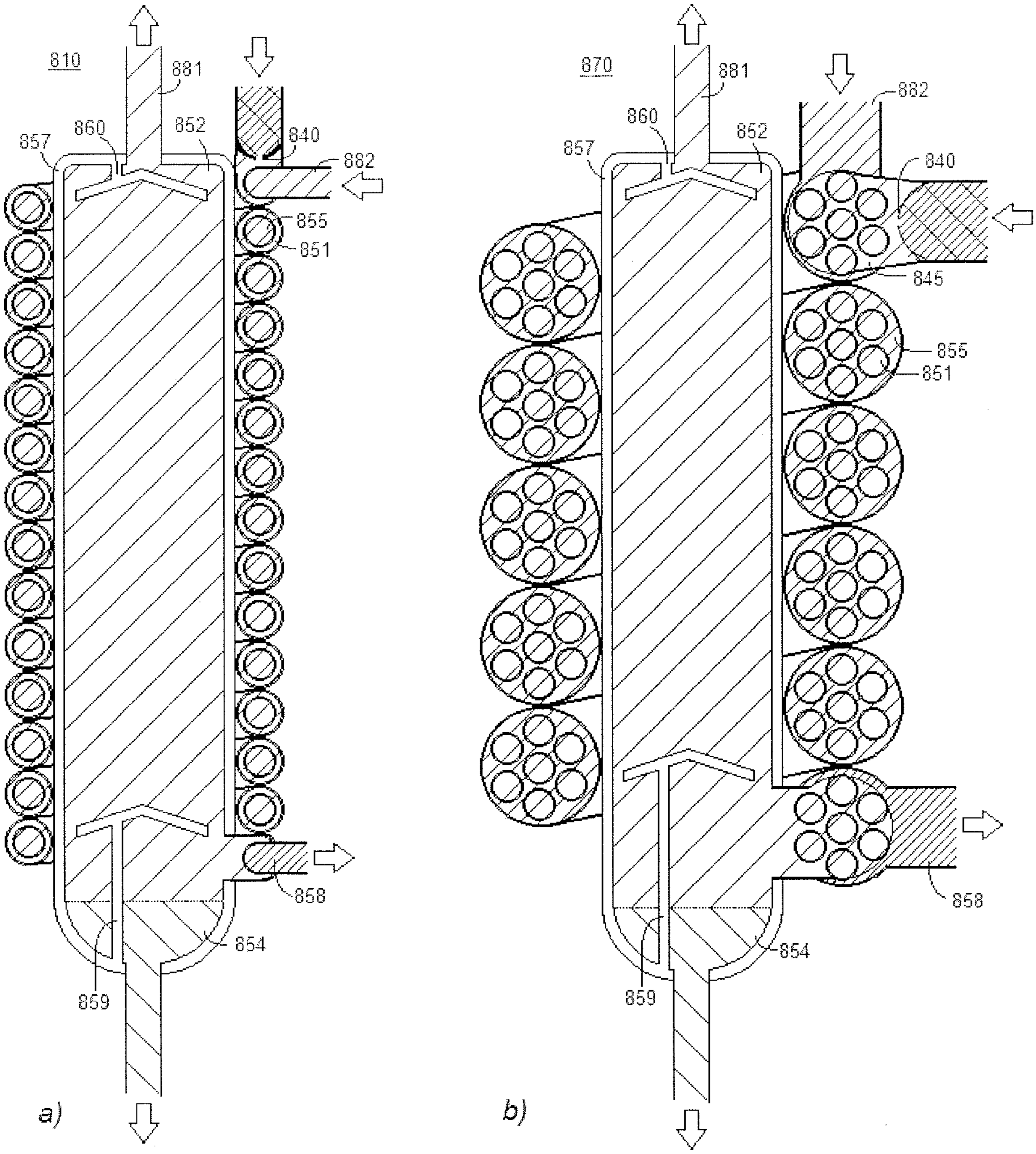
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Figure 9

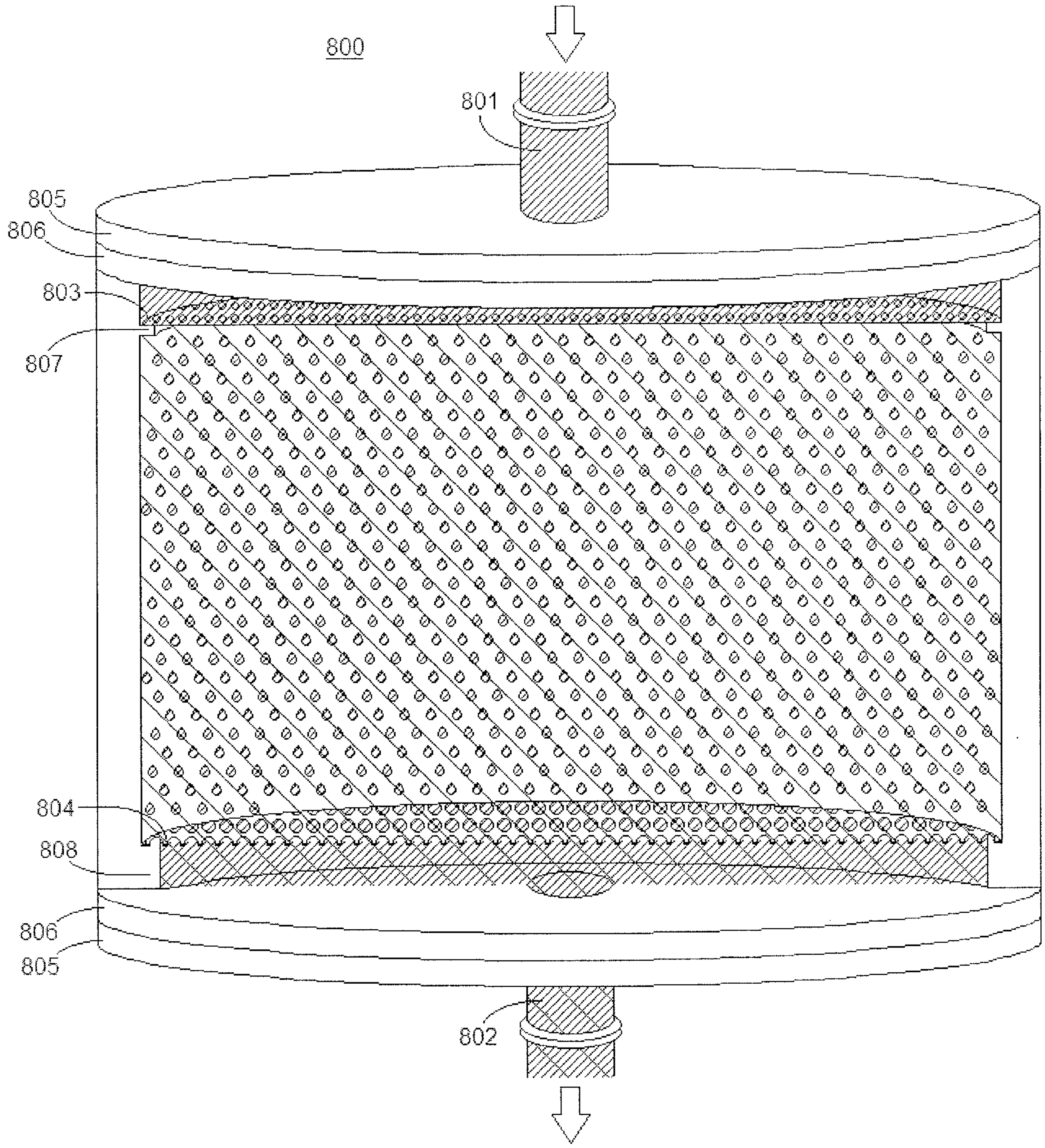

Figure 10