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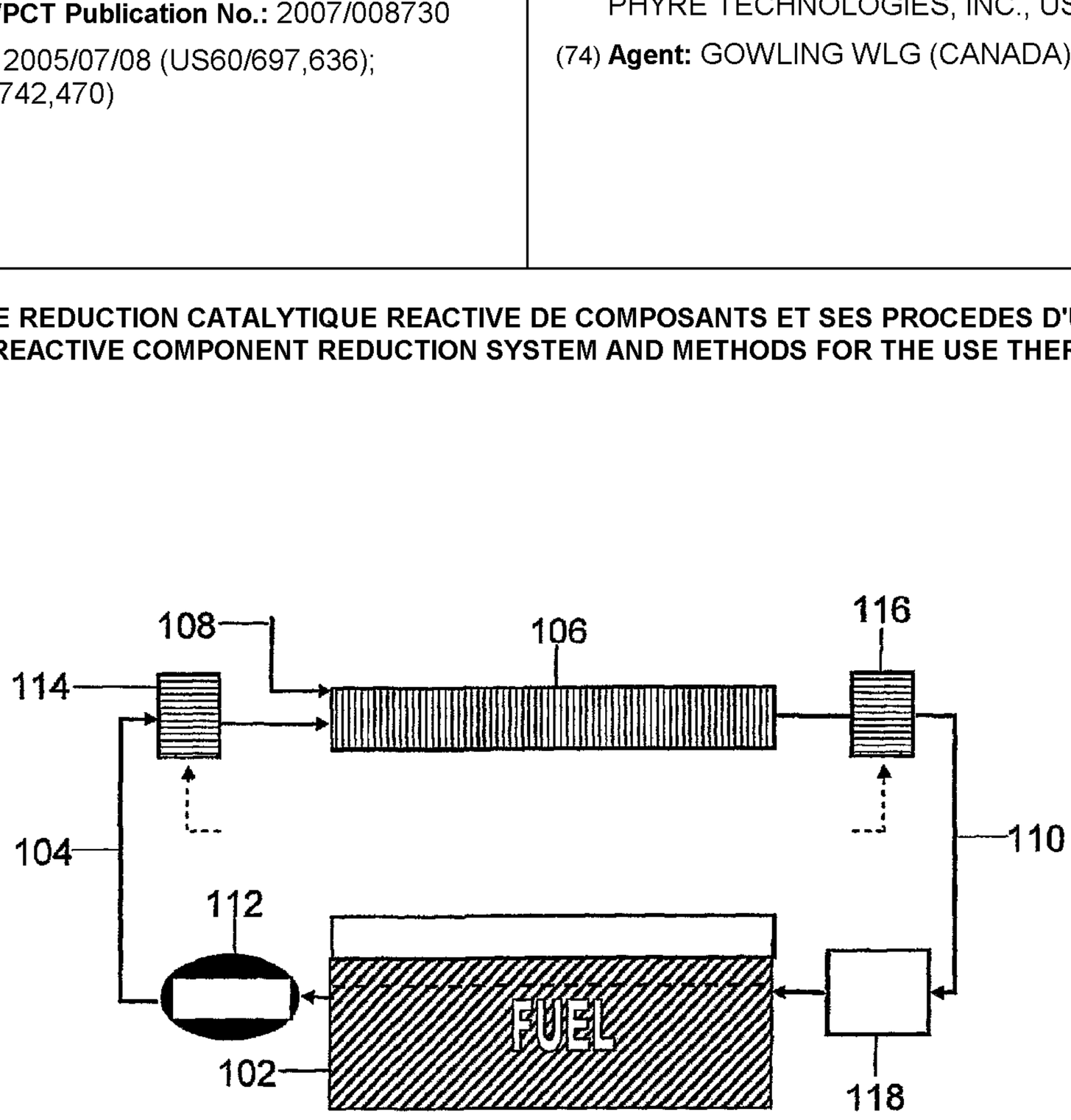
(54) **Titre : SYSTEME DE REDUCTION CATALYTIQUE REACTIVE DE COMPOSANTS ET SES PROCEDES D'UTILISATION**
(54) **Title: CATALYTIC REACTIVE COMPONENT REDUCTION SYSTEM AND METHODS FOR THE USE THEREOF**



(57) **Abrégé/Abstract:**
In accordance with the present invention, there are provided simplified systems and methods for catalytically deactivating, removing, or reducing the levels of reactive component(s) from the vapor phase of fuel storage tanks. The simple apparatus described herein can be utilized to replace complex OBIGGS systems on the market. Simply stated, in one embodiment of the invention, the vapor phase from the fuel tank is passed over a catalytic bed operated at appropriate temperatures to allow the reaction between free oxygen and the fuel vapor by oxidation of the fuel vapor, thus deactivating reactive component(s) in the gas phase.

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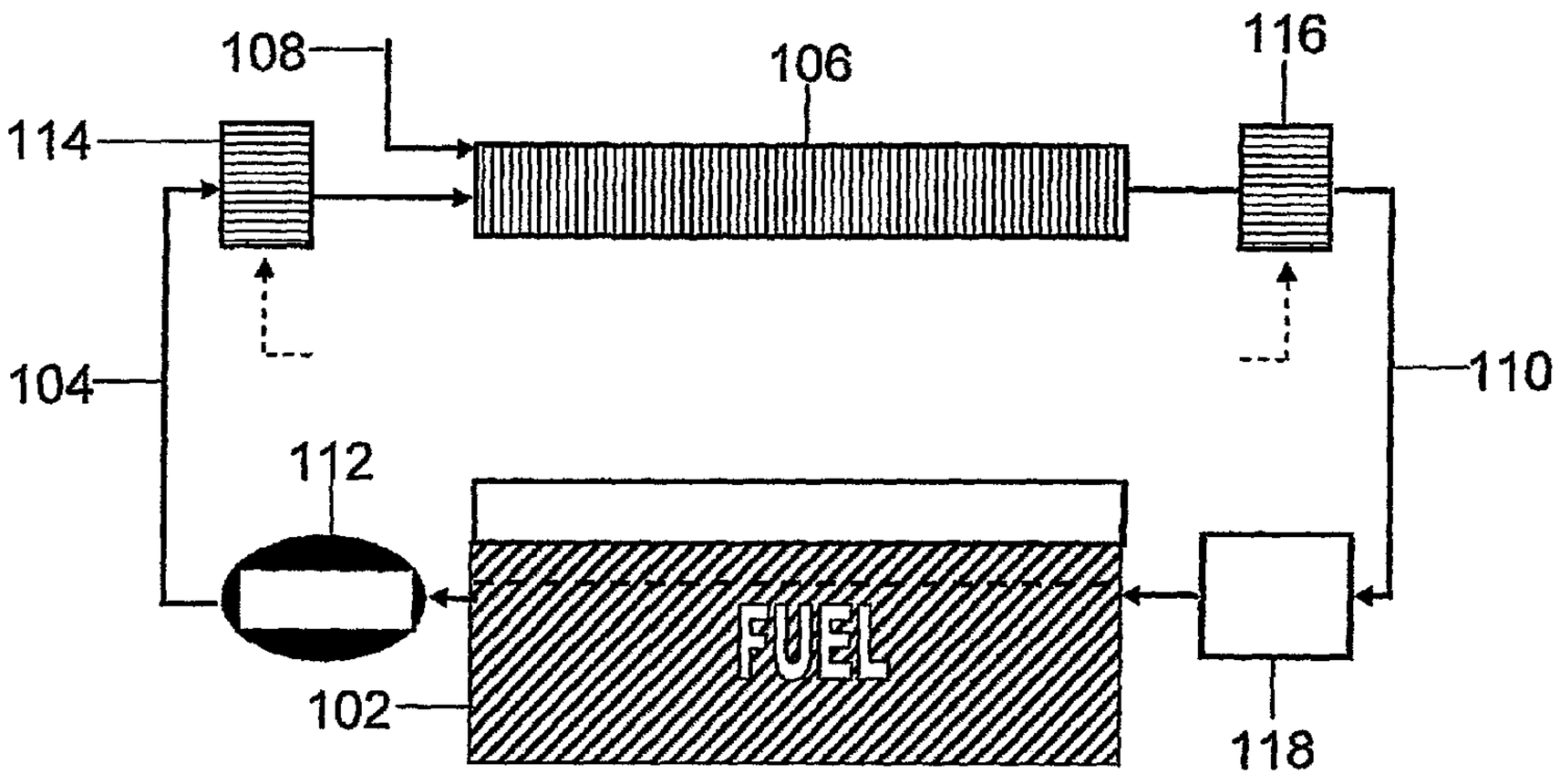
(54) Title: CATALYTIC REACTIVE COMPONENT REDUCTION SYSTEM AND METHODS



(57) Abstract: In accordance with the present invention, there are provided simplified systems and methods for catalytically deactivating, removing, or reducing the levels of reactive component(s) from the vapor phase of fuel storage tanks. The simple apparatus described herein can be utilized to replace complex OBIGGS systems on the market. Simply stated, in one embodiment of the invention, the vapor phase from the fuel tank is passed over a catalytic bed operated at appropriate temperatures to allow the reaction between free oxygen and the fuel vapor by oxidation of the fuel vapor, thus deactivating reactive component(s) in the gas phase.

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CATALYTIC REACTIVE COMPONENT REDUCTION SYSTEM AND METHODS FOR THE USE THEREOF

FIELD OF THE INVENTION

[0001] The present invention relates to the field of on board reactive component removal systems, and reaction systems and methods for the removal of reactive components from the vapor phase of fuel storage vessels. In a particular aspect, the invention relates to systems and methods for the catalytic removal of reactive components from the vapor phase of fuel storage vessels, specifically oxygen and/or fuel , thereby reducing the potential for fire and explosion in such vessels.

BACKGROUND OF THE INVENTION

[0002] In order to avoid the potential fire and explosion hazard in fuel tanks (e.g., aircraft fuel tanks, ships carrying flammable fluids as cargo, and the like), it is necessary to reduce the concentration of reactive components (e.g., oxygen and/or fuel vapors) in the gas phase that is in contact with liquid fuel. Many different approaches have been taken in efforts to address this problem. One such approach, for example, involves taking the bleed air from an aircraft engine, passing it through a membrane based gas separator to remove a sufficient amount of the oxygen so as to reduce the oxygen concentration below 10%. This reduced oxygen content gas is then used as an inert gas blanket in the fuel tank.

[0003] Another method employed in the art involves use of a pressure swing adsorption system to separate the oxygen from air to generate oxygen depleted inert gas.

[0004] These, as well as other systems described in the prior art require elaborate setup and add significantly to the cost of operation based on the provision of an on board inert gas generator system (OBIGGS). Accordingly, there is a need for improved systems and methods for removing reactive components (e.g., oxygen and/or fuel vapors), or reducing the levels thereof, from the vapor phase of fuel storage vessels.

SUMMARY OF THE INVENTION

[0005] In accordance with the present invention, there are provided simplified systems and methods for catalytically reducing the concentration of one or more reactive component(s) in the vapor phase of fuel storage tanks. The simple apparatus described herein can be utilized to replace complex OBIGGS systems on the market. Simply stated, in one embodiment of the invention, the vapor phase from the fuel tank is passed over a catalytic bed operated at appropriate temperatures to allow the reaction between free oxygen and the fuel vapor by oxidation of the fuel vapor, thus deactivating reactive components in the gas phase. In addition, circulation and treatment of vapors as contemplated herein minimizes the venting of fuel-containing vapors to the atmosphere.

[0006] In another embodiment of the present invention, there are provided systems for deactivating, reducing the concentration of, or removing one or more reactive components (e.g., oxygen and/or fuel vapors) from the vapor phase of a fuel storage tank. Invention systems include a reaction zone having an inlet and outlet, wherein the reaction zone provides conditions suitable to deactivate the reactive components. Optionally, inventive systems include the ability to remove heat and or water from the vapor phase.

[0007] In yet another embodiment of the present invention, there are provided fuel storage systems for use in a vessel (e.g., an aircraft, a ship carrying flammable fluids as cargo, and the like), such fuel storage systems being capable of maintaining the concentration levels of one or more reactive components in the vapor phase of the fuel storage tank at sufficiently low levels so as to dramatically reduce the risk of fire and explosion therefrom. Moreover, circulation and treatment of vapors as contemplated herein minimizes the venting of fuel-containing vapors to the atmosphere.

[0008] In still another embodiment of the present invention, there are provided methods for deactivating, reducing the concentration of, or removing one or more reactive components from the vapor phase of a fuel storage tank. Invention methods comprise passing at least a portion of the vapor phase from the fuel storage tank through a reaction zone which serves to deactivate the reactive components before the vapor phase is returned to the fuel storage tank.

Optionally, inventive methods include the ability to remove heat and/or water from the vapor phase.

BRIEF DESCRIPTION OF THE FIGURES

[0009] Figure 1 is a schematic illustration of one embodiment of a reactive component reduction system according to the invention.

[0010] Figure 2 is a schematic illustration of another embodiment of a reactive component reduction system according to the invention.

[0011] Figure 3 is a schematic illustration of yet another embodiment of a reactive component reduction system according to the invention.

[0012] Figure 4 illustrates the performance of an inventive catalytic reactive component removal system. At relatively low temperatures, a standard noble metal catalyst is capable of reducing the oxygen level from a starting level of 0.6% to less than 5 ppm.

[0013] Figure 5 is a schematic illustration of another embodiment of a reactive component reduction system according to the invention.

[0014] Figure 6 is an illustration of one embodiment of a catalyst containing reaction zone with heat exchanging capacity according to the invention.

[0015] Figure 7 is an illustration of one embodiment of a catalyst containing tube for the reduction of reactive component(s) according to the present invention.

[0016] Figure 8 is an illustration of a catalyst tube having a gradient density according to the present invention.

[0017] Figures 9A and 9B illustrate two embodiments of a catalyst tube having internal fins suitable for coating with catalyst.

[0018] Figure 10 collectively illustrates three embodiments of a catalyst tube contemplated for use in the practice of the present invention. Figure 10A is a view of an embodiment of a

catalyst tube having external fins. Figure 10B is a view of an embodiment of a catalyst tube having an internal cone which may be coated with catalyst. Figure 10C is a view of an embodiment of a catalyst tube having both external fins and an internal cone which may be coated with catalyst.

[0019] Figure 11 is a view of an embodiment of a reactive component reduction system according to the present invention.

[0020] Figure 12 is a view of another embodiment of a reactive component reduction system according to the present invention.

[0021] Figure 13 is a view of an embodiment of a reactive component reduction system featuring evaporative cooling according to the present invention.

[0022] Figure 14 is a view of an embodiment of a rotary water removal system contemplated for use in the practice of the present invention.

[0023] Figure 15 is a view of an embodiment of a catalyst tube contemplated for use in the practice of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0024] In accordance with the present invention, there are provided systems for reducing the concentration of one or more reactive component(s) from the vapor phase of a fuel storage tank (e.g., by deactivation of the reactive component(s) therein), wherein said fuel storage tank is provided with an outlet for removal of vapor therefrom and an inlet for return of vapor thereto. Invention systems comprise:

a reaction zone, wherein said reaction zone provides conditions suitable to deactivate said one or more reactive component(s) when contacted therewith,

an inlet to said reaction zone in fluid communication with the vapor space of said fuel storage tank via the outlet of the fuel storage tank, and

an outlet from said reaction zone in fluid communication with the vapor space of said fuel storage tank via the inlet of the fuel storage tank.

[0025] As readily recognized by those of skill in the art, there are a variety of reactive components which one may desirably wish to remove (or reduce the concentration of) when in contact with fuel (such as jet fuel). One reactive component contemplated for treatment in accordance with the present invention is oxygen. Another reactive component contemplated for treatment in accordance with the present invention may also include fuel vapor, as well as a variety of additives and/or impurities commonly associated therewith. A particular advantage of the present invention relates to the fact that circulation and treatment of vapors as contemplated herein minimizes the venting of fuel-containing vapors to the atmosphere, thereby reducing the environmental impact caused by the handling of such materials.

[0026] Invention systems optionally comprise an inlet/outlet which enables equilibration of pressure within the vessel depending on whether the vessel is exposed to sub- or super-atmospheric conditions. For example, it may be desirable to provide a source of make-up gas to equilibrate pressure within the system upon exposure to sub-atmospheric conditions. Alternatively, upon exposure to super-atmospheric conditions, it may be desirable to allow venting of the vessel to reduce the pressure therein. For example, upon ascent or descent of an aircraft, pressures within the aircraft, including fuel storage vessels therein, may vary significantly. In the case of descent, for example, it may be desirable to supplement the gas content of the vessel. Conversely, upon ascent of an aircraft, it may be desirable to relieve excess pressure on the fuel storage vessel. Optionally, make-up gas (or vented vapors) will be subjected to the invention method for deactivating one or more reactive component(s) therein (e.g., by reducing the concentration thereof) so as to reduce the safety hazards associated with the introduction of outside air into the system, or the venting of vapors to the atmosphere.

[0027] Invention systems may optionally be configured as closed loop systems. As employed herein, the term "closed loop" refers to the fact that the vapor having been treated to deactivate the reactive components therein is returned to the fuel storage vessel, rather than being vented. It is to be understood, however, that invention closed loop systems still

contemplate the presence of one or more inlets/outlets for such purposes as equilibration of pressure therein, removal of water vapor or other components therefrom, and the like. The reaction zone contemplated for use in the practice of the present invention can be configured in a variety of ways, e.g., the reaction zone may comprise a vessel containing catalyst, wherein said catalyst is reactive with said one or more reactive component(s) when contacted therewith under suitable conditions. In some embodiments, the vessel has an inlet end and an outlet end, and catalyst content can vary throughout the vessel. In certain other embodiments the catalyst content can increase from the inlet end to the outlet end of the vessel.

[0028] As employed herein, "deactivate" refers to the conversion of reactive components such as oxygen, fuel vapor, and the like, into substantially non-reactive species, i.e., species that are substantially inert under the conditions to which they are exposed. Preferably, deactivated species are non-flammable.

[0029] Catalysts contemplated for use in the practice of the present invention include optionally supported metal catalysts, such as, for example, noble metals (e.g., platinum, palladium, gold, silver, and the like), precious metals, transition metals, metal oxides, rare earth oxides, nitrides, carbides, enzymes, and the like, as well as mixtures of any two or more thereof. "Catalytic" refers to facilitating a reaction or interaction involving one or more reactants. Catalytic materials may include noble metals, transition metals, metal oxides (e.g., transition metal oxides such as RuOx, LaMnOx and peravskites), and the like, as well as various combinations thereof.

[0030] Catalytic materials contemplated for use herein may optionally be supported on a variety of materials, such as for example, metallic supports, activated carbon, carbon black, and the like, as well as mixtures thereof. Inorganic oxides may also be employed as support materials, either alone or in combination, e.g., silica, alumina, silica-alumina, magnesia, titania, zirconia, montmorillonite, and the like, or combinations thereof, for example, silica-chromium, silica-titania, and the like.

[0031] When catalytic treatment of reactive components is employed, a wide variety of suitable conditions for contacting said catalyst with said one or more reactive component(s)

are contemplated. Exemplary conditions comprise contacting the vapor phase materials with catalyst at a temperature in the range of about 25°C up to about 1200°C. Presently preferred temperatures contemplated for use herein range from about 50°C up to about 400°C. Even more preferred are temperatures ranging from about 100°C up to about 350°C.

[0032] To facilitate control of the above-described catalytic process, the invention system can optionally further comprise a temperature modulator. Optionally, the temperature modulator can be a heat exchanger, which may include a heat exchange medium. The heat exchange medium can optionally include a liquid or external air. Optionally, heat exchange can be accomplished by evaporative cooling. The heat exchanger can be positioned in a variety of locations within the invention system, e.g. the heat exchanger can be associated with the catalyst containing vessel; or the heat exchanger can be positioned upstream or downstream from the catalyst containing vessel; or the heat exchanger may be integrated with the catalyst vessel.

[0033] When the temperature modulator is positioned upstream of the catalyst containing vessel, it is preferably used to pre-heat either the fuel vapor, air, or a mixture thereof. When the temperature modulator is positioned downstream of the catalyst containing vessel, it is preferably used to reduce the temperature of the vapor exiting the catalyst containing vessel. When the temperature modulator is associated with the catalyst containing vessel, it can be used to heat or cool the reaction vessel, as necessary, to provide conditions suitable for catalyzing reaction of oxygen with fuel vapor, thereby deactivating reactive components (e.g., oxygen and/or fuel vapor) in the fuel vapor and air mixture.

[0034] Alternative methods for treating reactive components in accordance with the present invention include employing a reaction zone which comprises a source of microwave energy sufficient to deactivate said one or more reactive component(s) when contacted therewith.

[0035] As yet another alternative method for treating reactive components in accordance with the present invention, a reaction zone can be employed which comprises a source of plasma energy sufficient to deactivate said one or more reactive component(s) when contacted therewith.

[0036] Optionally, invention systems may further comprise a flame arrestor between the fuel storage tank and the reaction zone so as to prevent any possibility of combustion to communicate back to the fuel storage tank. Alternatively, the reaction zone can be designed so as to prevent any flame formation.

[0037] Additional optional features which may be included in invention systems include one or more oxygen sensors, which may be positioned upstream and/or downstream from the reaction zone so as to monitor the oxygen levels in the inlet and/or outlet gas of the fuel storage tank. Additionally, a feedback loop could be provided so as to adjust the contacting conditions within the reaction zone as a function of the oxygen levels detected before and/or after the reaction zone.

[0038] As used herein, the term "upstream" refers to an element in a flow scheme which is located prior to or before a reference point or reference element. As used herein, the term "downstream" refers to an element in a flow scheme which is located after a reference point or reference element.

[0039] In certain embodiments of the invention, the system may also include a fluid purification module adapted to remove water from the treated air. For example, the fluid purification module may include a condenser to reduce the temperature of the treated vapor below the dew point, thereby facilitating removal of any excess water. In a particular embodiment, the fluid purification module may include a pressure swing adsorption module. In other embodiments, the purification module may include membranes. A recirculation line may be provided to transfer the fluid from the fluid purification module to the inlet to the reaction zone. The fluid purification module may be located upstream or downstream from the reaction zone. In other embodiments, water may be removed by a moisture trap.

[0040] As used herein, "purification" and "purifying" refer to the removal from a fluid of one or more components. The removal may be partial, complete or to a desired level and may include removal of only some or all components.

[0041] In one embodiment, the system may also include a recirculation line adapted to transfer the fluid from the separator to the inlet of the reaction zone.

[0042] In one embodiment, the system may also include a vapor trap adapted to separate vaporized liquid mixed with the fluid from the separator.

[0043] In accordance with a further aspect of the present invention, there are provided systems for introducing reactive component-depleted vapor into a fuel storage vessel as fuel is withdrawn therefrom. Invention systems comprise:

a reaction zone having an inlet and outlet,

a source of air, wherein the source of air is in fluid communication with the inlet of the reaction zone,

a source of fuel vapor, wherein the source of fuel vapor is in fluid communication with the inlet of said reaction zone, and

optionally a filter/condenser, wherein when the filter/condenser is present, the reaction zone is in fluid communication with the inlet of the filter/condenser, and the outlet of the filter/condenser is in fluid communication with the fuel storage vessel,

wherein said reaction zone operates under conditions suitable to remove or reduce the concentration of oxygen in the source of air when contacted therewith in the presence of fuel vapor, and is in fluid communication with the fuel storage vessel.

[0044] In accordance with a still further aspect of the present invention, there are provided systems for displacing fuel in, or vapor in the vapor space of, a fuel storage vessel with reactive component-depleted vapor (e.g., as fuel or fuel vapor from the vapor space thereof is withdrawn therefrom). Invention systems comprise:

a reaction zone having an inlet and outlet,

a source of air, wherein the source of air is in fluid communication with the inlet of the reaction zone,

a source of fuel vapor, wherein the source of fuel vapor is in fluid communication with the inlet of said reaction zone, and

optionally a filter/condenser, wherein when the filter/condenser is present, the reaction zone is in fluid communication with the inlet of the filter/condenser, and the outlet of the filter/condenser is in fluid communication with the fuel storage vessel,

wherein said reaction zone provides conditions suitable to remove or reduce the concentration of oxygen in the source of air when contacted therewith in the presence of fuel vapor, wherein the reaction zone is in fluid communication with the fuel storage vessel.

[0045] In accordance with yet another aspect of the present invention, there are provided fuel storage systems for use in aircraft. Invention fuel storage systems comprise:

a fuel storage tank having an outlet for removal of vapor therefrom, and an inlet for return of vapor thereto, and

a reaction zone having an inlet and outlet, wherein said reaction zone provides conditions suitable to deactivate one or more reactive component(s) in the vapor phase of said fuel storage tank when contacted therewith,

wherein the outlet of said fuel storage tank is in fluid communication with the inlet of the reaction zone, and the inlet of said fuel storage tank is in fluid communication with the outlet of said reaction zone.

[0046] In accordance with still another aspect of the present invention, there are provided systems for reducing the concentration of one or more reactive components from the vapor

phase of a fuel storage tank (e.g., by deactivation of the reactive component(s) therein), wherein said fuel storage tank comprises an outlet for removal of vapor therefrom and an inlet for return of vapor thereto. Invention systems comprise,

a catalyst zone, said catalyst zone comprising an optionally supported metal catalyst, said catalyst being capable of promoting reaction of one or more reactive component(s) when contacted therewith under suitable conditions,

an inlet to said system in fluid communication with the vapor space of said fuel storage tank via the outlet of the fuel storage tank, and

an outlet from said reaction zone in fluid communication with the vapor space of said fuel storage tank via the inlet of the fuel storage tank.

Embodiments of the invention can include a temperature modulator associated with the catalyst zone. In other embodiments, invention systems can include a trap for removing water from the vapor.

[0047] In accordance with still another aspect of the present invention, there are provided fuel storage systems for use in aircraft. Invention systems comprise:

a fuel storage tank having an outlet for removal of vapor therefrom, and an inlet for return of vapor thereto, and

a reaction zone having an inlet and outlet, wherein said reaction zone provides conditions suitable to deactivate one or more reactive component(s) in the vapor phase of said fuel storage tank when contacted therewith,

wherein the outlet of said fuel storage tank is in fluid communication with the inlet of the reaction zone, and the inlet of said fuel storage tank is in fluid communication with the outlet of said reaction zone.

[0048] In accordance with still another aspect of the present invention, there are provided methods for reducing the concentration of one or more reactive component(s) from the vapor

phase of a fuel storage tank (e.g., by deactivation of the reactive component(s) therein), wherein said fuel storage tank is provided with outlet for removal of vapor therefrom and inlet for return of vapor thereto. Invention methods comprise:

passing at least a portion of the vapor phase from the fuel storage tank through a reaction zone, wherein said reaction zone provides conditions suitable to deactivate said one or more reactive component(s) when contacted therewith, thereby producing a vapor phase having reduced concentration of reactive component(s) therein, and thereafter

returning the vapor phase having reduced concentration of reactive component(s) therein to said fuel storage tank.

[0049] In accordance with yet another aspect of the present invention, there are provided methods for displacing fuel in, or vapors in the vapor space of, a fuel storage vessel with reactive component-depleted vapor (e.g., as fuel or fuel vapor from the vapor space thereof is withdrawn therefrom). Invention methods comprise:

combining air with vaporized fuel,

passing the resulting combination through a reaction zone under conditions suitable to produce reactive component-depleted vapor,

optionally removing any water from the reactive component-depleted vapor to produce substantially water-free, reactive component-depleted vapor, and

introducing the resulting substantially water-free, reactive component-depleted vapor into said fuel storage vessel.

[0050] Additional methods contemplated herein for displacing fuel in, or vapors in the vapor space of, a fuel storage vessel with reactive component-depleted vapor (e.g., as fuel or fuel vapor from the vapor space thereof is withdrawn therefrom) comprise:

contacting a combination of air and vaporized fuel in a reaction zone under conditions suitable to produce reactive component-depleted air,

optionally removing any water from the reactive component-depleted air to produce substantially water-free, reactive component-depleted air,

introducing the resulting substantially water-free, reactive component-depleted air into said fuel storage vessel.

[0051] Additional methods contemplated herein for displacing fuel in, or vapors in the vapor space of, a fuel storage vessel with reactive component-depleted vapor comprise introducing treated vapor into said fuel storage vessel as fuel or fuel vapor from the vapor space thereof is withdrawn therefrom,

wherein said treated vapor is prepared by passing a combination of air and vaporized fuel through a reaction zone under conditions suitable to produce reactive component-depleted air, and

optionally removing any water from the reactive component-depleted air.

[0052] Figure 1 is a schematic illustration of one embodiment of the present invention. Reactive component reduction system **100** is supplied with a mixture of air (containing nitrogen and oxygen) and fuel vapor from fuel vessel **102**. The air/fuel vapor mixture is supplied via line **104** to catalyst bed **106** which is maintained at conditions sufficient to reduce the oxygen content of the air and fuel vapor mixture. Optionally, air may be supplied to (or removed from) catalyst bed **106** (as needed) via line **108** to allow for equalization of the pressure in the fuel vessel. The air and fuel vapor mixture can then be supplied from catalyst bed **106** via line **110** to fuel vessel **102**.

[0053] Figure 2 is a schematic illustration of another embodiment of the invention reactive component reduction system shown in Figure 1. Pump **112** is provided to facilitate supplying the air and fuel vapor mixture from fuel vessel **102** to catalyst bed **106**. Optional porous plug flame arrestors **114** and **116** can be provided upstream and downstream of catalyst bed **106**, respectively, to prevent flames or sparks from the catalyst bed from spreading or contacting

fuel vessel **102**. Water filter **118** can be provided downstream from catalyst bed **106** and flame arrestor **116** can be provided to remove water present in the air and fuel vapor mixture of reduced reactive component content before the mixture is recirculated to fuel vessel **102**.

[0054] Figure 3 is a schematic representation of another embodiment of the present invention, wherein source of air **202** and source of fuel vapor **206** are supplied to line **210** via lines **204** and **208**, respectively, where they are combined to form a fuel vapor/air mixture and supplied to catalyst bed **212**. Alternatively, the air **202** and fuel vapor **206** can be supplied directly to catalyst bed **212** where they are combined. The fuel vapor/air mixture is subjected to the action of a catalyst such that the catalyst reduces the reactive component content of the fuel vapor/air mixture. Any of a number of different catalysts can be employed in the practice of the present invention, e.g., a presently preferred catalyst employed is a standard noble metal catalyst. The fuel vapor/air mixture, having a reduced reactive component content, exits catalyst bed **212** via line **214**, may optionally be passed through filter/condenser **216** to remove any water formed during the catalytic treatment, and thereafter introduced into fuel storage vessel **218** as fuel is withdrawn therefrom.

[0055] Figure 4 shows the performance of a catalyst under low oxygen concentration. A mixture of air and fuel vapor was passed over pellets of a standard noble metal catalyst packed in a ½ inch by 7 inch stainless steel tube at varying temperatures, and the oxygen content of the effluent gases therefrom was determined. The graph shows the concentration of oxygen in the catalyst tube effluent as a function of increasing temperature. As shown in Figure 4, oxygen content in the catalyst tube effluent declines rapidly as the temperature is increased to approximately 290°F (143°C), wherein an oxygen content of approximately 650 ppm was measured. As temperature is further increased from 290°F (143°C) to 400°F (204°C), the oxygen content in the effluent gradually decreases to less than 5 ppm. This example clearly demonstrates the ability of operating such a reactive component reduction system.

[0056] Figure 5 shows one embodiment of an invention reactive component removal system which includes a temperature modulator and a catalyst zone. Reactive component removal system **300** is supplied with vapor from a fuel tank (which may include oxygen

dissolved therein) via inlet **302**. Inlet **302** can include blower **304**, which may facilitate the movement of the vapor through reactive component removal system **300**. Inlet **302** may also include sample port **306** for sampling the content of the inlet gas, and may also include reverse flow valve **308**. Vapor entering the system via inlet **302** is supplied to temperature modulator **310**, which may include, for example, a shell and tube design heat exchanger. The heat exchange medium can be external air or gas, or can be a liquid. Optionally, purified vapor from the reactive component removal system may be used as the heat exchange medium. The system may also include heater **312** upstream from catalyst bed **314**. Catalyst bed **314** may be configured in a variety of ways, e.g. a fluidized bed, or may include catalyst supported on fins or cones.

[0057] Temperature modulator **310**, which may be a heat exchanger, may also include means for removal or water from a vapor stream, and may include water drain **322** and automatic moisture drain valves **320**. Vapor of reduced reactive component content exits the system via outlet **328**, which can include oxygen sensor **324** and reverse flow valve **330**.

[0058] **R**eactive component removal system **300** may be sized appropriately based upon the volume of vapor to be treated and the desired rate of removal of reactive component from the vapor. Similarly, heat exchanger **310** may vary in size based on a variety of parameters, including the heat exchange medium employed and the temperature gradient.

[0059] In one example of the invention reactive component removal system, a unit designed to have a flow rate of at least 50 CFM (cu. ft./min.) is provided. Preferably, the system provides a flow rate of at least 150 CFM (cu. ft./min.). In one example of the invention reactive component removal system, the dimensions of the unit are approximately 12 in. X 12 in. X 40 in. In one such system, the catalyst bed can be a round tube at least 5 in. diameter and 4.5 in. in length.

[0060] Figure 6 illustrates one embodiment of the invention systems which includes a temperature modulator. Catalyst containing reaction zone **400** is supplied with reactive component containing vapor **402** via inlet **404**. Reaction zone **400** includes catalyst coated tubes **406** positioned vertically in the reaction zone. Preferably, tubes **406** are removable to

facilitate catalyst replacement. Reaction zone **400** can include fins or passages **408** to facilitate passage of a heat exchange medium for heating or cooling of the reaction zone. As shown in the Figure, a heat exchange medium (either a gas, such as air, or a liquid, such as water) can enter the reaction zone via top **410** of reaction zone **400**, flowing across the fins or passages **408** of the reaction zone, and exit bottom **412**. Vapor of a reduced reactive component content exits reaction zone **400** via outlet **414**.

[0061] Figure 7 illustrates one embodiment of a catalyst tube for the reduction of reactive component(s) according to the present invention. Tube **500** includes a catalyst coated cone **502**, positioned such that tip **504** of the cone is upstream from the base of cone **506**. Flow of gas stream **501** through the tube is generally shown by the arrows. Such an arrangement, wherein a cone is positioned within the tube, facilitates maximum interaction between the catalyst and the vapor, allows for a greater concentration of catalyst downstream, and allows for control of the flow of the fuel vapor and air mixture from which reactive component is being extracted. Vapor having reduced reactive component content **507** flows past cone **506**.

[0062] Figure 8 illustrates an embodiment of a catalyst tube/heat exchanger for the reduction of reactive component(s) in a fuel vapor. Catalyst tube/heat exchanger system **600** can include tube **602**, which can be packed with catalyst particles **604** (shown in the Figure as open circles). Optionally, inert non-catalytic solid particulates (not shown) may also be present in the tube. The tube may include screens positioned at entrance **606** and exit **608** of the catalytic zone for retention of the catalyst and non-catalyst particles. In the embodiment shown in the Figure, catalyst density in the tube can be higher downstream than upstream. Non-catalytic solid particles may be spent catalyst, support materials without catalyst, glass beads, or the like. The gradient catalyst distribution facilitates even distribution of heat loads and results in a gradual reduction of reactive component concentration from the feed vapor. The tube design can incorporate fins or ridges **610** to provide maximum surface area to function as a heat exchanger.

[0063] Figure 9 collectively illustrates two embodiments of a catalyst tube/heat exchange system (shown as **700a** and **700b** in Figures 9A and 9B, respectively) for the removal of reactive component(s) from a fuel vapor, and optionally air, stream. Flow of the fuel vapor

mixture is indicated by the arrows wherein the vapor stream to be treated enters the tube at an upstream position and exits at a downstream position. The interior of catalyst tubes **700a** and **700b** includes catalyst coated fins **704a** and **704b**. The tubes may be configured to have a gradient catalyst density, as shown in tube **700a**, wherein the length of catalyst coated fins **704a** increases as the vapor stream progressed downstream in the tube. In another embodiment, the tube may be configured to have a uniform catalyst density, as shown in tube **700b**, wherein the length of catalyst coated fins **704b** is uniform throughout the length of the catalyst tube. As shown, the tubes can include heat exchange fins, as shown on the exterior of tubes **706a** and **706b**. The greater the surface area exposed in a heat exchanger system, the greater facilitation of heat transfer. Catalyst coated fins **704a** and **704b** may vary in width to facilitate maximum contacting of the fuel vapor with the catalyst.

[0064] Figure 10 collectively illustrates three catalyst tube/heat exchanger designs. As shown in Figure 10A, a catalyst tube is provided for the removal of reactive component(s) from a feed stream of fuel vapor and air. Tube **800a** includes wall **802a** and interior section **804a**. Optionally, interior **804a** can include screens (not shown) to retain catalyst particles in a defined space and volume. Tube **800a** includes fins **806a** on the outside surface of the tube to facilitate heat transfer with the catalyst tube.

[0065] As shown in Figure 10B, a catalyst tube with no heat exchanger fins is provided. The tube includes wall **802b**, interior section **804b**, wherein the interior section can include catalyst coated cone **808b**. Preferably, the catalyst coated cone **808b** has tip **810b** and base **812b**, and preferably the tip of cone **810b** is positioned upstream from the base of catalyst cone **812b**.

[0066] As shown in Figure 10C, a catalyst tube with catalyst coated cone **808c** and heat exchange fins **806c** is provided. The tube includes wall section **802c** and interior section **804c** provided within the wall of the tube. Interior **804c** includes catalyst coated cone **808c**, wherein the cone preferably has tip **810c** and base **812c**, wherein the tip of the cone **810c** is preferably positioned upstream from base **812c** of catalyst coated cone **808c**. Fins **806c** extend from the exterior of the tube wall, and facilitate heat transfer.

[0067] Figure 11 shows an embodiment of the invention reactive component removal system. Fuel vapor **902** is supplied to reactive component removal system **900a** via line **904** which may optionally include a control valve **906**. Fresh or recycled air **908** can be supplied via inlet **910**. Air inlet **910** may optionally include heater **912**, which may include fins **914** on the interior of the heater, to preheat the air feed stream. Fuel vapor **902** and preheated air **908** combine in reaction zone **918** where the mixture contacts catalyst coated heat exchanger fins **920**. Catalyst coated fins **920** are positioned in the interior of catalytic zone **918**, while fins **922** are located on the exterior of catalytic zone **918**. Catalyst fins **920** can be of various widths and can be positioned within the catalytic zone to facilitate maximum contact between the reactive component containing vapor and the catalyst coated fins. As shown in the Figure, the catalyst zone may be configured to have a gradient catalyst density, or optionally, may have a uniform catalyst density. Fuel vapor/air of reduced reactive component content exits the system via outlet **924**.

[0068] Figure 12 shows another embodiment of an invention reactive component removal system. Fuel vapor **1002** is supplied to reactive component removal system **1000** via line **1004** which may optionally include valve **1006**. Air **1008**, which may be freshly supplied air or recycled air, is supplied to inlet **1010** of reactive component removal system **1000**. The air passes through preheat zone **1011**, which can include heat exchanger **1012** and fins **1014** or other means of increasing the surface area the air comes in contact with. The preheated air and fuel vapor enter reaction zone **1030** which can include a catalyst source. As shown in the Figure, the catalyst containing source may be a wire mesh or honeycomb structure **1032**. The fuel vapor/air mixture of reduced reactive component content exits reactive component removal system **1000** via outlet **1034**.

[0069] Figure 13 illustrates one embodiment of an inerting system which employs evaporative cooling to facilitate the removal of moisture from a feed stream comprising the vapor phase from a fuel cell (not shown). Fuel vapor **1102** is supplied to inlet **1104** of inerting system **1100** where it optionally combines with second gas source **1106** supplied via line inlet **1108**, such as for example, air. The vapor is passed through heater **1110**, which can be a heat exchanger, and is then passed into reaction zone **1112**, which can include a catalyst system and a heating or cooling system as desired. The vapor exiting the reaction zone via

reaction zone outlet **1114** passes through condenser section **1116**, which can be contacted on the exterior of the piping with a liquid, such as for example, water. Water removed from the treated vapor in the condenser section can be collected at the bottom of the tubes, and may be removed from condenser section **1116** via any one of a plurality of valves **1118** located at a low point of condenser section **1116**. Liquid removed from the treated vapor via drain valves **1118** can be circulated within the evaporative cooling system via pump **1124** and used as needed. Inerting system **1100** can also include moisture filter system **1120** and can optionally include other desired filtering system(s) **1122**, such as for example, a system configured for the removal of oxygen, hydrocarbons, or any other undesired component remaining in the treated vapor stream. The evaporative cooling system can recirculate water removed from the vapor via line **1126** to holes **1128**, thereby allowing the water to contact condenser section **1116** of the reactive component removal system, thereby further facilitating removal of water from the vapor.

[0070] Figure 14 illustrates one embodiment of a system for the removal of heat and moisture from a vapor stream. Fuel vapor feed stream **1202**, and optionally air, is supplied to inlet **1204** of removal system **1200**. Inlet **1204** may optionally include pre-heater **1206**. The optionally preheated stream is supplied to catalytic zone **1208**, which may include a catalyst material positioned to facilitate maximum contact between the vapor and the catalyst. Treated vapor of a reduced reactive component content exits catalytic zone **1208** via outlet line **1210** and enters rotary inline device **1212**. The rotary inline device may be used to facilitate either water removal, heat removal or both from the exiting vapor stream. Device **1212** rotates either clockwise or counter-clockwise about the axis defined by outlet **1210**. Vapor exits inline device **1212** via line **1214**.

[0071] Figure 15 illustrates one method for the control of cooling within an reactive component removal system. Vapor enters the cooling device **1300** via line **1302**. Preferably, vapor stream **1302** is cooled by expansion cooling, wherein the diameter of the inlet tubing is smaller than the diameter of the outlet tubing. The greater volume leads lower pressure, and subsequently a lower temperature. The expansive heating unit can include screen **1306** which can further facilitate a reduction in pressure upon exiting device **1300**.

[0072] While the exemplary embodiments illustrated in the Figures and described above are presently preferred, it should be understood that these embodiments are offered by way of example only. Other embodiments may include, for example, different techniques for performing the same operations. The invention is not limited to a particular embodiment, but extends to various modifications, combinations, and permutations. The scope of the claims should not be limited by the preferred embodiments or the examples but should be given the broadest interpretation consistent with the description as a whole.

What is claimed is:

1. A system for reducing the concentration of one or more reactive component(s) from the vapor phase of a fuel storage tank, wherein said fuel storage tank is provided with an outlet for removal of vapor therefrom and an inlet for return of vapor thereto, said system comprising:

a reaction zone, wherein said reaction zone provides conditions suitable to deactivate said one or more reactive component(s) when contacted therewith,

an inlet to said reaction zone in fluid communication with the vapor space of said fuel storage tank via the outlet of the fuel storage tank, and

an outlet from said reaction zone in fluid communication with the vapor space of said fuel storage tank via the inlet of the fuel storage tank.

2. The system of claim 1 wherein said system is a closed loop system.

3. The system of claim 1 further comprising inlet/outlet for equilibrating pressure within the system upon exposure to sub- or super-atmospheric conditions.

4. The system of claim 3, which said inlet/outlet comprises a source of make-up gas to equilibrate pressure within the system upon exposure to sub-atmospheric conditions.

5. The system of claim 3 wherein said inlet/outlet comprises a vent to equilibrate pressure within the system upon exposure to super-atmospheric conditions.

6. The system of claim 1 wherein said reactive component(s) is oxygen.

7. The system of claim 1 wherein said vapor phase further comprises fuel vapor.

8. The system of claim 1 wherein said reaction zone comprises a vessel containing catalyst, wherein said catalyst is reactive with said one or more reactive component(s) when contacted therewith under suitable conditions.

9. The system of claim 8 wherein the vessel has an inlet end and an outlet end, and the catalyst content varies from the inlet end to the outlet end.

10. The system of claim 9 wherein the catalyst content increases from the inlet end to the outlet end.

11. The system of claim 8 wherein said catalyst is a metal catalyst.

12. The system of claim 11 wherein said metal catalyst is a supported metal catalyst.

13. The system of claim 11 or 12 wherein said metal catalyst is a noble metal, precious metal, transition metal oxide, rare earth oxide, or mixtures of any two or more thereof.

14. The system of claim 8 wherein said suitable conditions for contacting said catalyst with said one or more reactive component(s) comprise a temperature in the range of about 25°C up to about 1200°C.

15. The system of claim 8 wherein the reaction zone is associated with a temperature modulator.

16. The system of claim 15 wherein said temperature modulator is a heat exchanger.

17. The system of claim 16 wherein the heat exchanger is integrated with the catalyst containing vessel.

18. The system of claim 16 wherein said heat exchanger comprises a heat exchange medium.

19. The system of claim 16 wherein the heat exchange medium is external air or a liquid.

20. The system of claim 16 wherein said heat exchanger is a heat pump.

21. The system of claim 15 wherein said temperature modulator is an evaporative cooler.

22. The system of claim 1 wherein said reaction zone comprises a source of microwave energy to deactivate said one or more reactive component(s) when contacted therewith.

23. The system of claim 1 wherein said reaction zone comprises a source of plasma energy to deactivate said one or more reactive component(s) when contacted therewith.

24. The system of claim 1 further comprising a flame arrestor positioned on the inlet or outlet of the fuel storage tank.

25. The system of claim 1 further comprising a flame arrestor positioned on the inlet and outlet of the fuel storage tank.

26. The system of claim 1 further comprising an oxygen sensor before or after the reaction zone.

27. The system of claim 1 further comprising an oxygen sensor before and after the reaction zone.

28. The system of claim 1 further comprising a trap downstream from the reaction zone for the removal of water from the vapor.

29. The system of claim 15 further comprising a trap downstream from the reaction zone for the removal of water from the vapor.

30. A system for introducing reactive component-depleted air into a fuel storage vessel as fuel is withdrawn therefrom, said system comprising:

a reaction zone having an inlet and outlet,

a source of air, wherein the source of air is in fluid communication with the inlet of the reaction zone, and

a source of fuel vapor, wherein the source of fuel vapor is in fluid communication with the inlet of said reaction zone,

wherein said reaction zone operates under conditions suitable to remove or reduce the concentration of reactive component in the source of air when contacted therewith in the presence of fuel vapor, and is in fluid communication with the fuel storage vessel.

31. The system of claim 30, further comprising a filter/condenser, the reaction zone being in fluid communication with the inlet of the filter/condenser, and the outlet of the filter/condenser being in fluid communication with the fuel storage vessel.

32. A system for displacing fuel in, or vapor in the vapor space of, a fuel storage vessel with reactive component-depleted air, said system comprising:

a reaction zone having an inlet and outlet,

a source of air, wherein the source of air is in fluid communication with the inlet of the reaction zone, and

a source of fuel vapor, wherein the source of fuel vapor is in fluid communication with the inlet of said reaction zone,

wherein said reaction zone provides conditions suitable to remove or reduce the concentration of reactive component(s) in the source of air when contacted therewith in the presence of fuel vapor, wherein the reaction zone is in fluid communication with the fuel storage vessel.

33. The system of claim 32, further comprising a filter/condenser, the reaction zone being in fluid communication with the inlet of the filter/condenser, and the outlet of the filter/condenser being in fluid communication with the fuel storage vessel.

34. A system for reducing the concentration of one or more reactive components from the vapor phase of a fuel storage tank, wherein said fuel storage tank comprises an outlet for removal of vapor therefrom and an inlet for return of vapor thereto, said system comprising,

a catalyst zone, said catalyst zone comprising a metal catalyst,

said catalyst being reactive with one or more reactive component(s) when contacted therewith under suitable conditions,

an inlet to said system in fluid communication with the vapor space of said fuel storage tank via the outlet of the fuel storage tank, and

an outlet from said reaction zone in fluid communication with the vapor space of said fuel storage tank via the inlet of the fuel storage tank.

35. The system of claim 34, wherein the catalyst zone comprises a supported metal catalyst.

36. The system of claim 34 or 35 further comprising a temperature modulator associated with the catalyst zone.

37. The system of claim 34 or 35 further comprising a trap for removing water from the vapor.

37. A fuel storage system for use in aircraft, said system comprising:

a fuel storage tank having an outlet for removal of vapor therefrom, and an inlet for return of vapor thereto, and

a reaction zone having an inlet and outlet, wherein said reaction zone provides conditions suitable to deactivate one or more reactive component(s) in the vapor phase of said fuel storage tank when contacted therewith,

wherein the outlet of said fuel storage tank is in fluid communication with the inlet of the reaction zone, and the inlet of said fuel storage tank is in fluid communication with the outlet of said reaction zone.

38. The system of claim 37 wherein said reaction zone further comprises a vessel containing catalyst, wherein said catalyst is capable of promoting deactivation of said one or more reactive component(s) when contacted therewith under suitable conditions.

39. The system of claim 38 further comprising a temperature modulator.

40. The system of claim 39 wherein the temperature modulator is associated with the catalyst containing vessel.

41. A method for reducing the concentration of one or more reactive component(s) from the vapor phase of a fuel storage tank, wherein said fuel storage tank comprises an outlet for removal of vapor therefrom and inlet for return of vapor thereto, said method comprising:

passing at least a portion of the vapor phase from the fuel storage tank through a reaction zone, wherein said reaction zone provides conditions suitable to deactivate said one or more

reactive component(s) when contacted therewith, thereby producing a vapor phase having reduced concentration of reactive component(s) therein, and thereafter

returning the vapor phase having reduced concentration of reactive component(s) therein to said fuel storage tank.

42. The method of claim 41 wherein said reaction zone comprises a catalyst containing vessel.

43. The method of claim 41 further comprising contacting said vapor phase from the fuel storage tank with a temperature modulator upstream of the reaction zone.

44. A method for displacing fuel in, or vapor in the vapor space of, a fuel storage vessel with reactive component-depleted air as fuel is withdrawn therefrom, said method comprising:

(1) combining air with vaporized fuel,

(2) passing the resulting combination through a reaction zone under conditions suitable to produce reactive component-depleted air, and

(3) introducing the resulting substantially water-free, reactive component-depleted air into said fuel storage vessel as fuel is withdrawn therefrom.

45. The method of claim 44, further comprising the step of removing any water from the reactive component-depleted air of step (2) to produce substantially water-free, reactive component-depleted air.

FIGURE 1

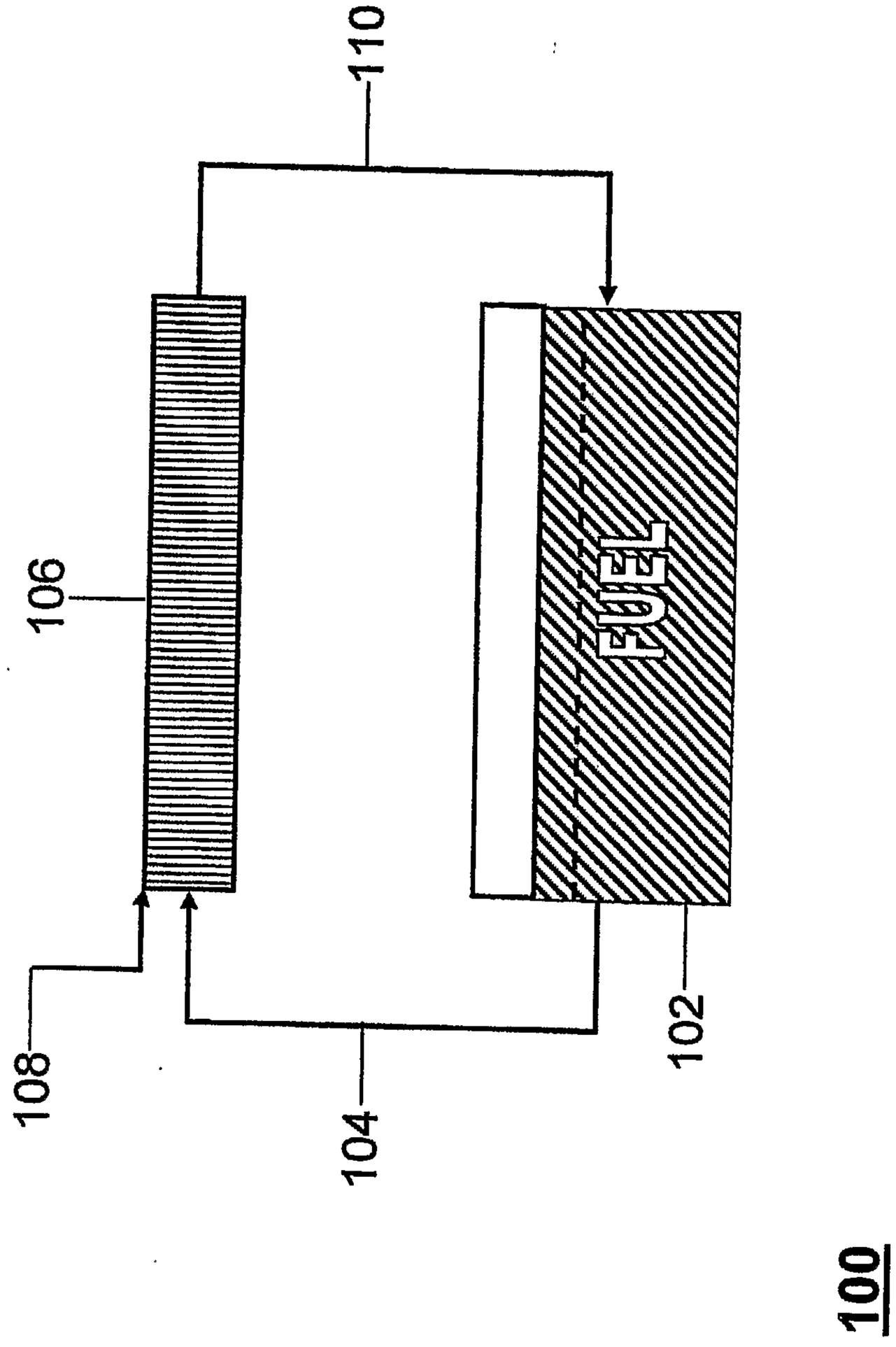


FIGURE 2

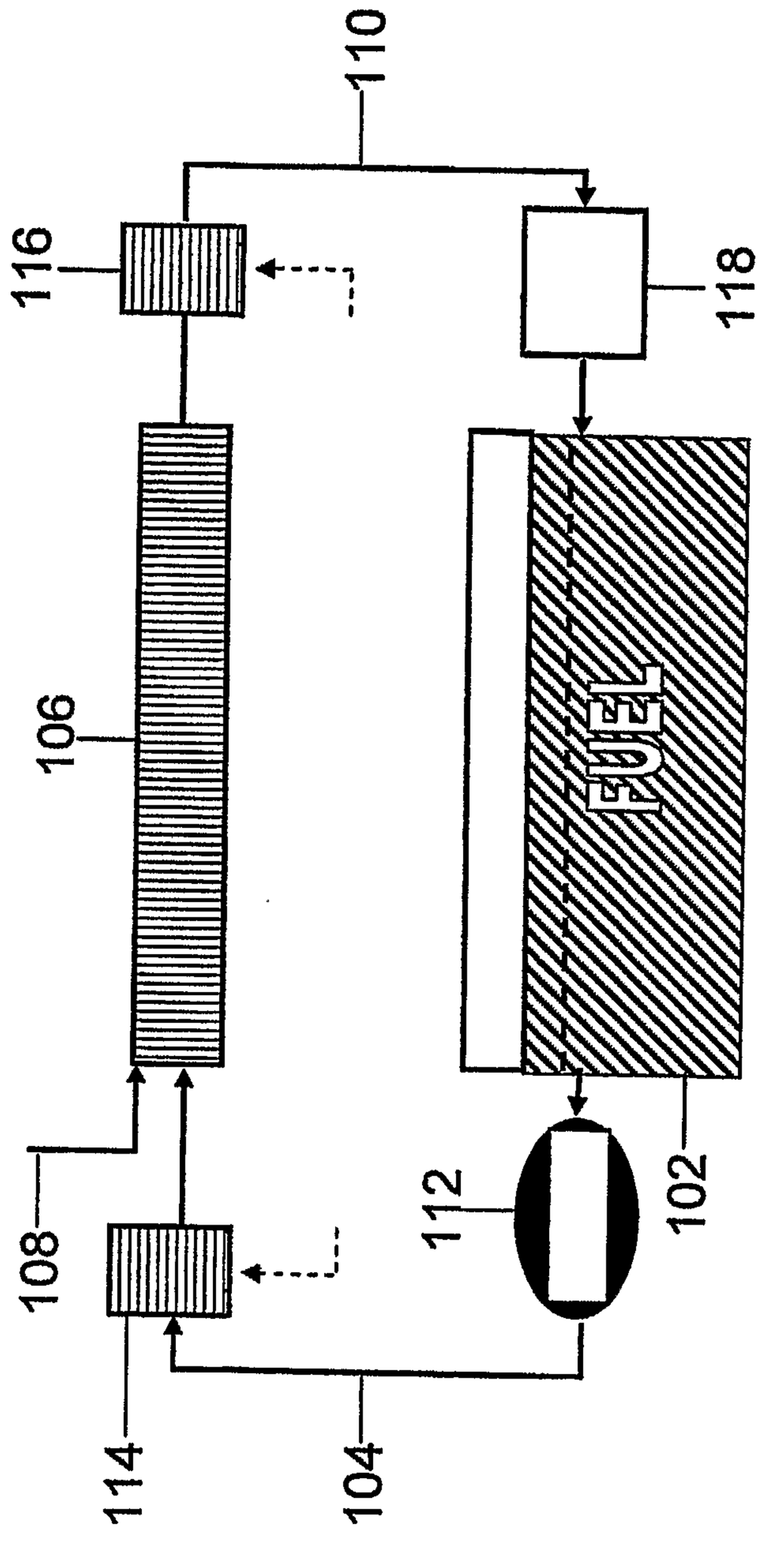


FIGURE 3

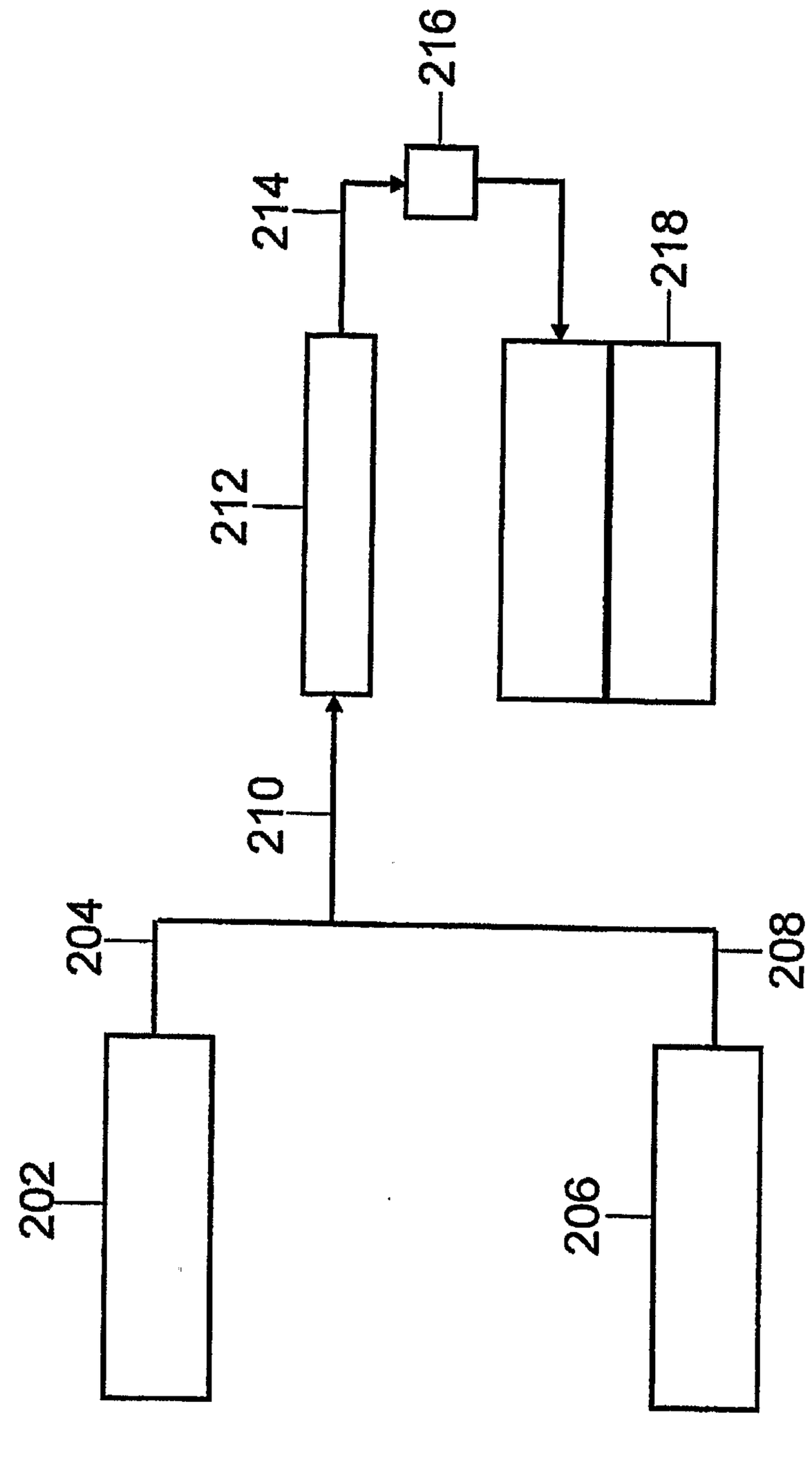


FIGURE 4

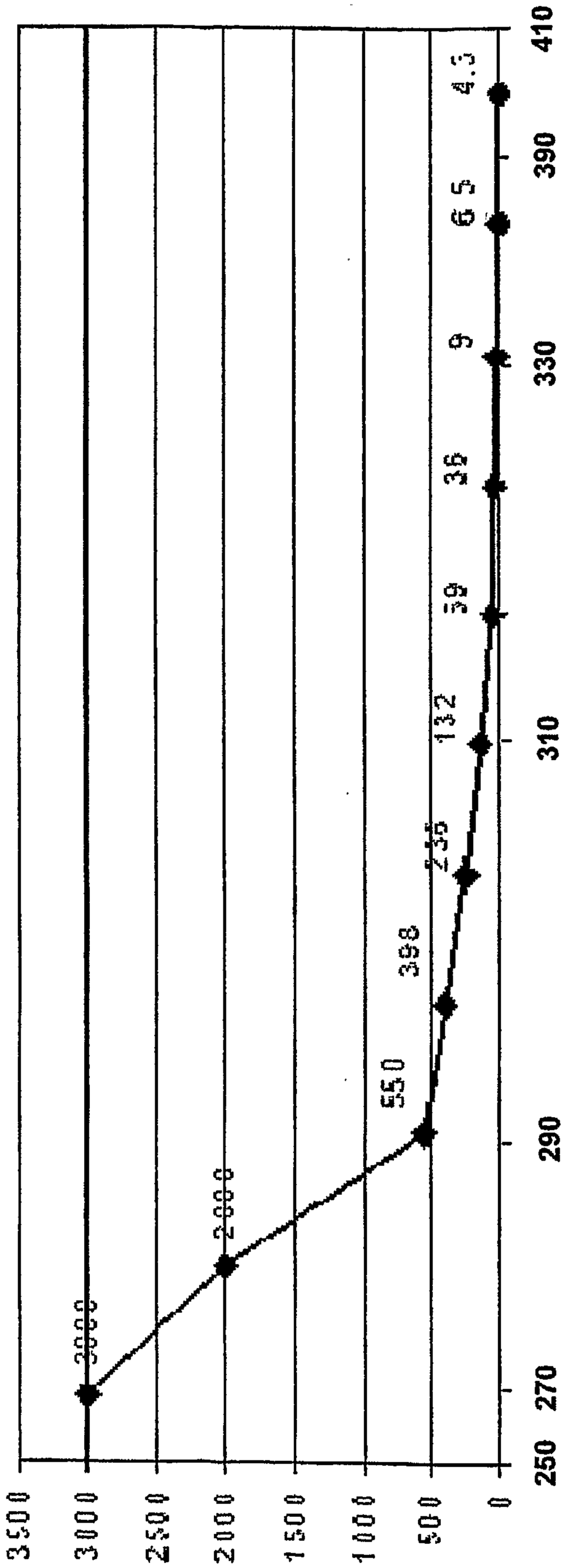

Oxygen Output (ppm)
Temperature °F
3500
3000
2500
2000
1500
1000
500
0
250
270
290
310
330
350
370
390
410
132
39
35
9
65
235
398
550
2000
3000

FIGURE 5

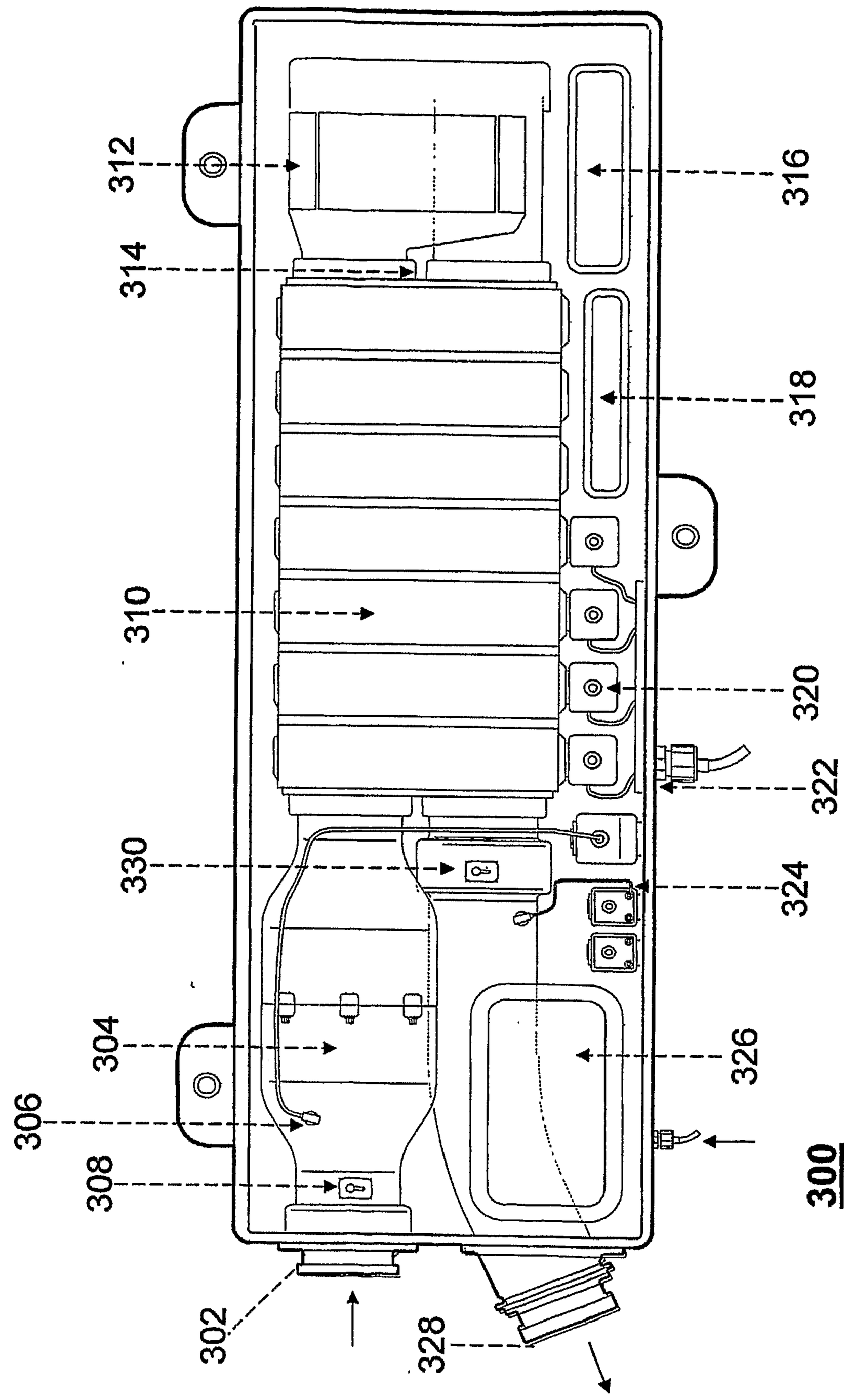


FIGURE 6

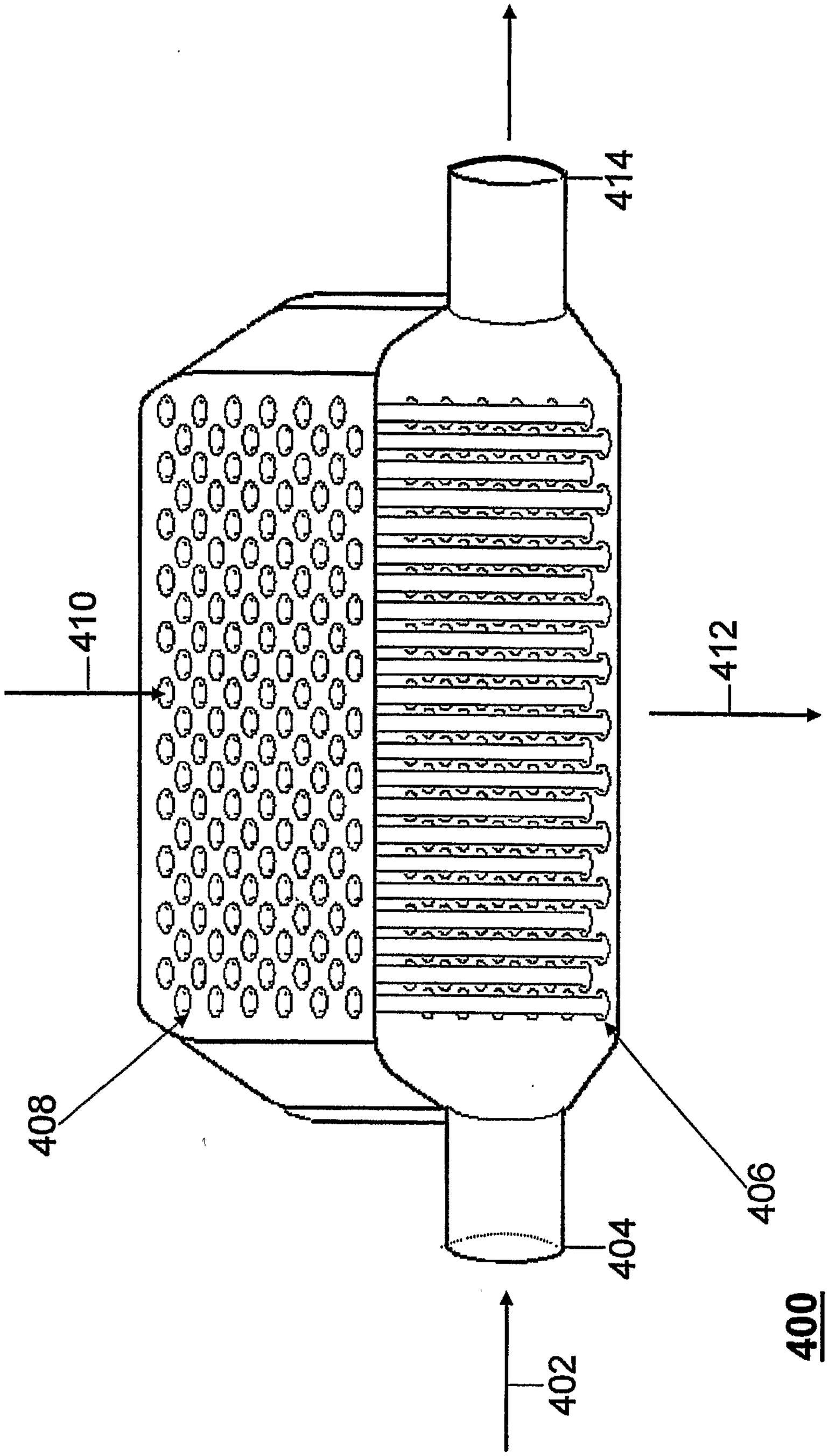


FIGURE 7

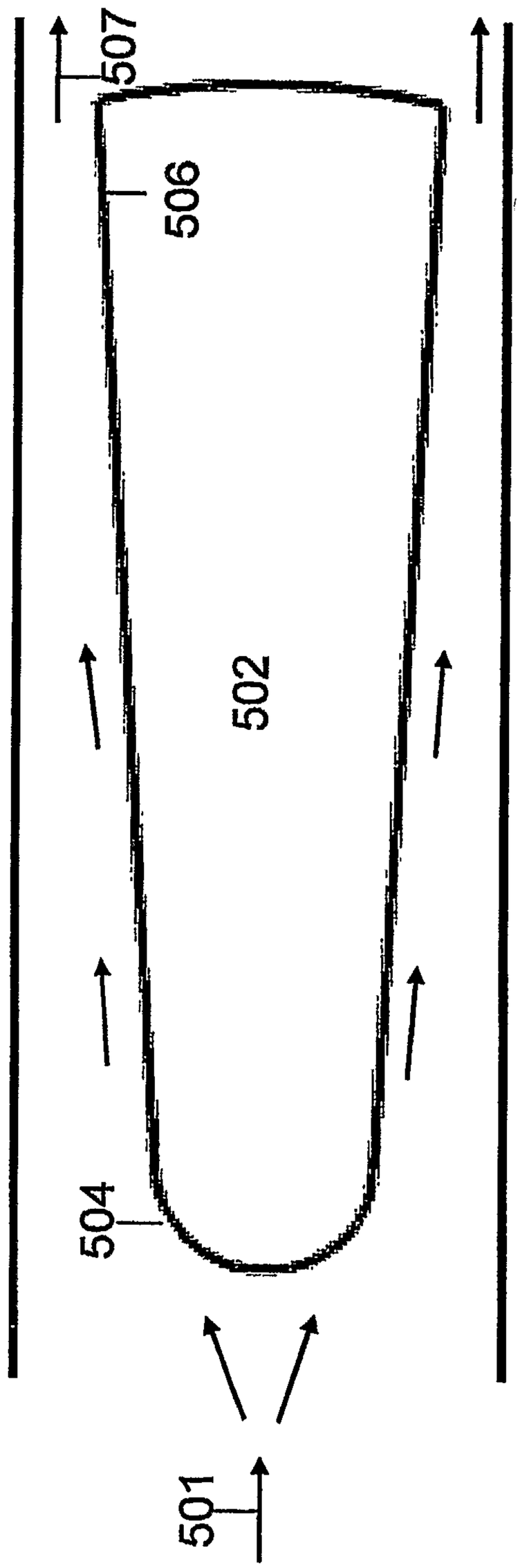


FIGURE 8

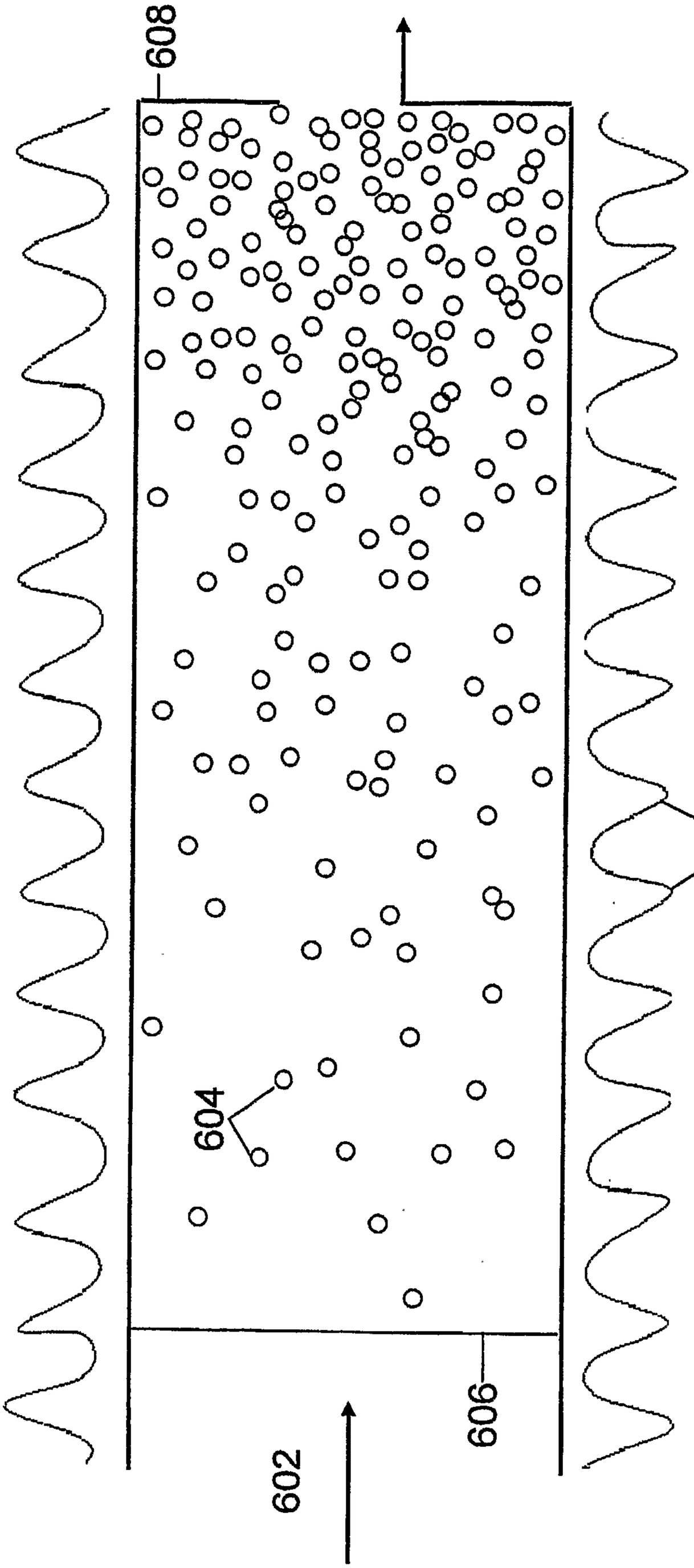
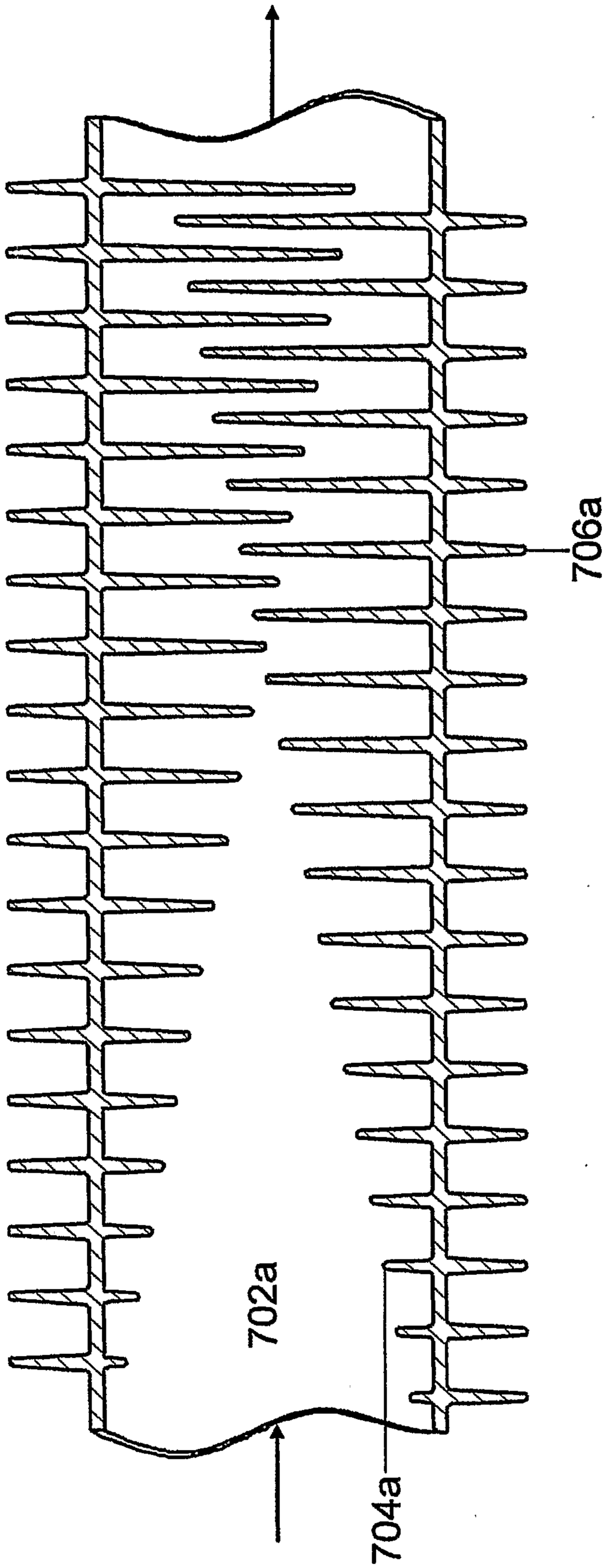


FIGURE 9A



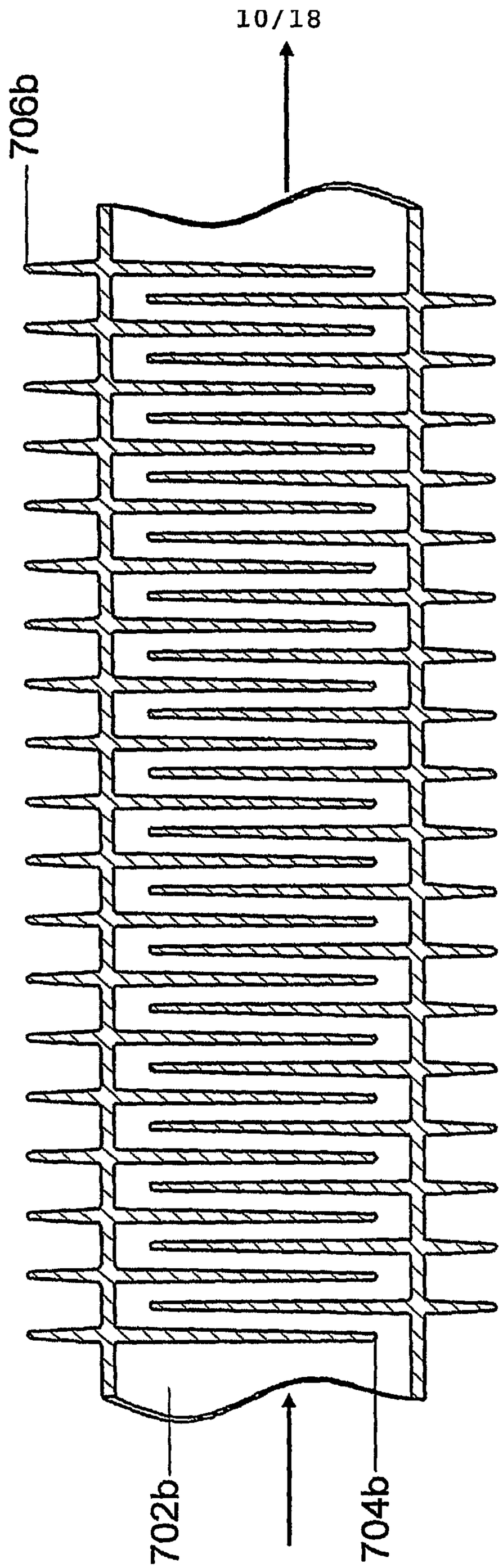


FIGURE 9B

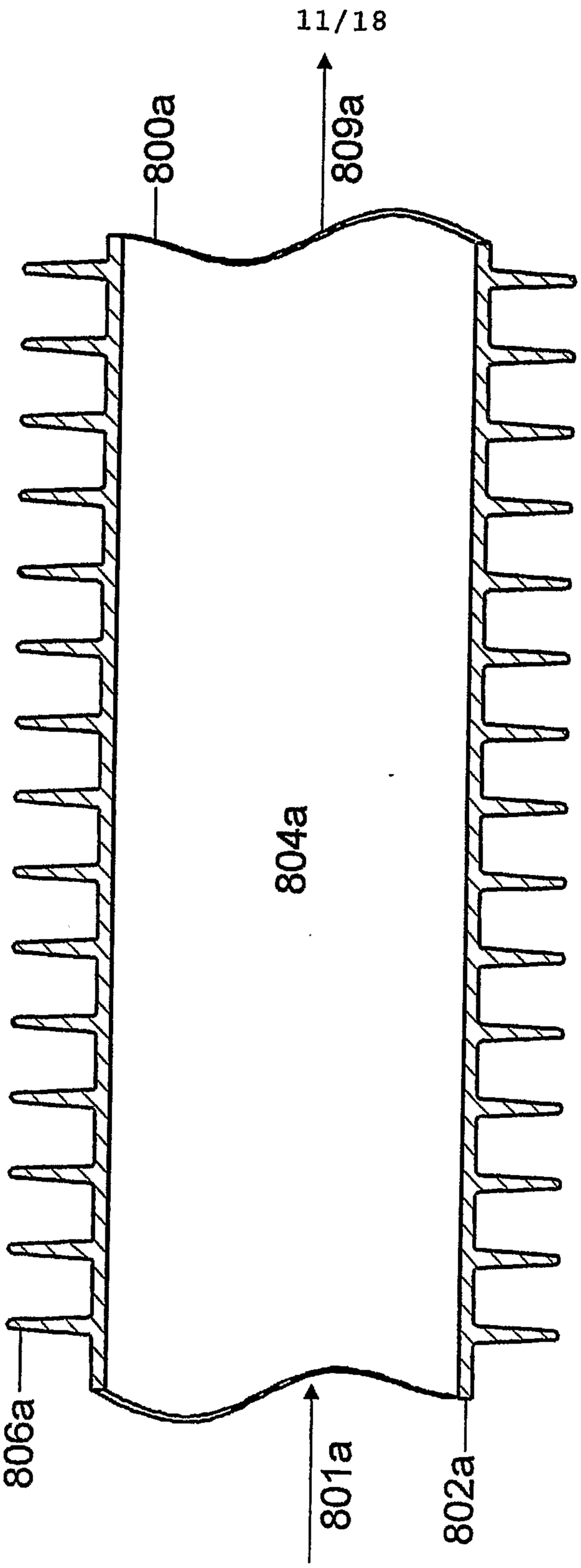


FIGURE 10A

800a

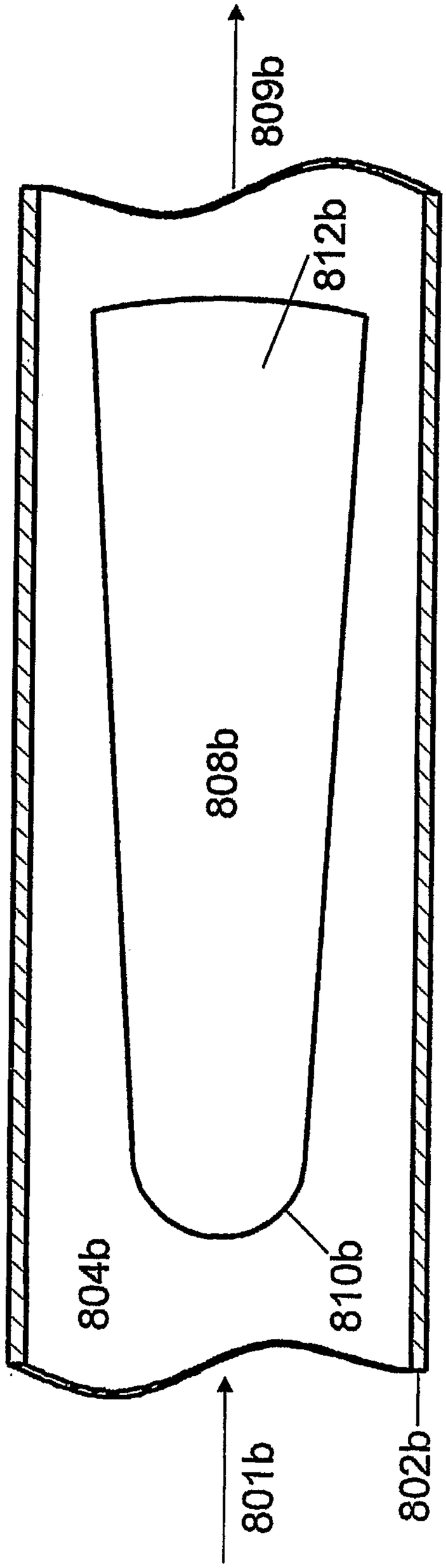


FIGURE 10B

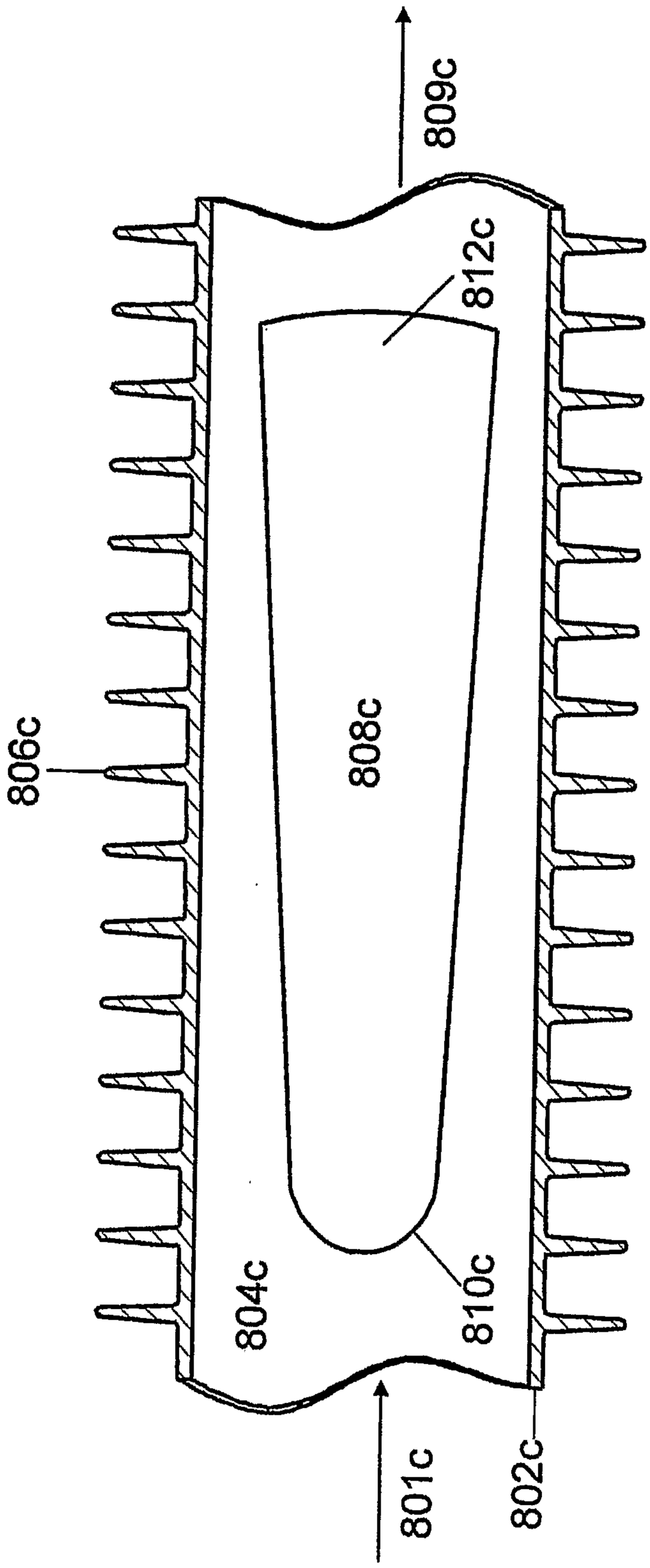


FIGURE 10C

FIGURE 11

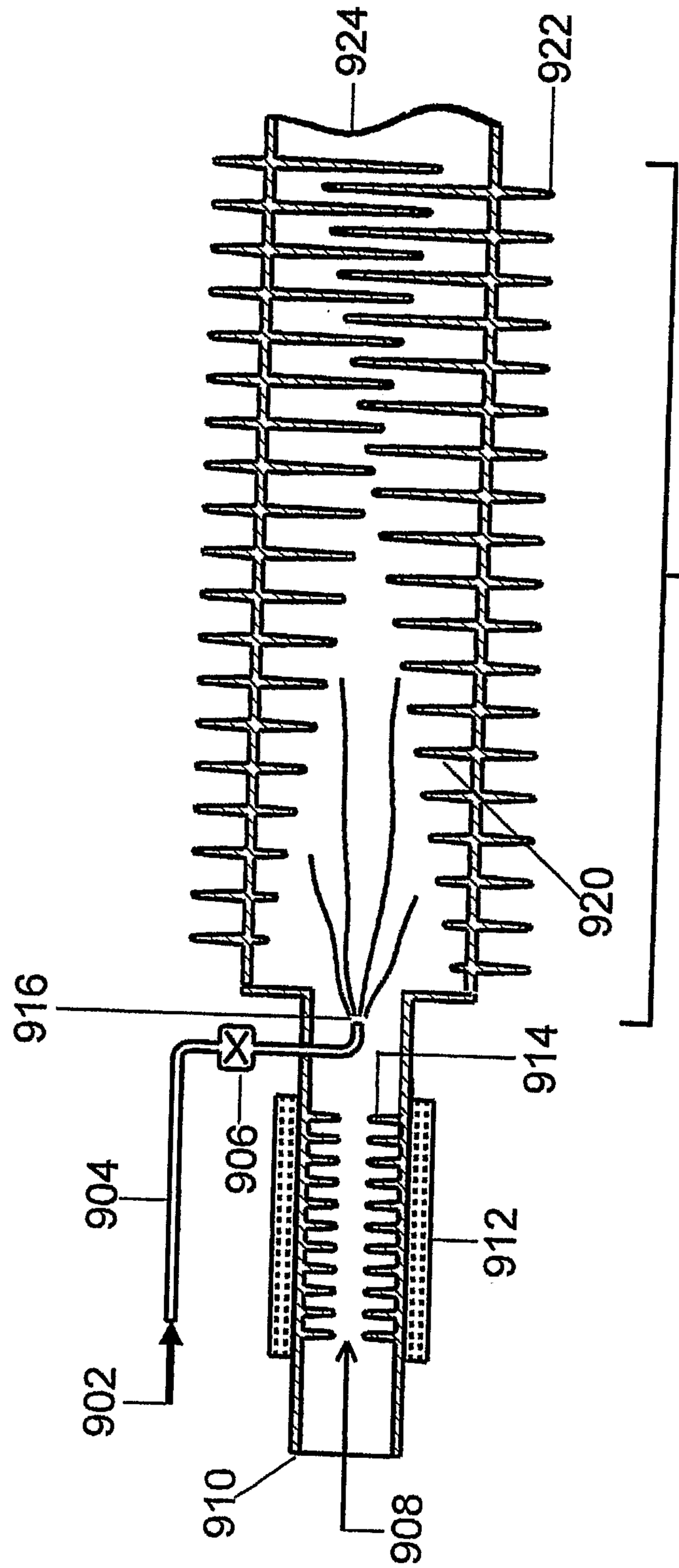
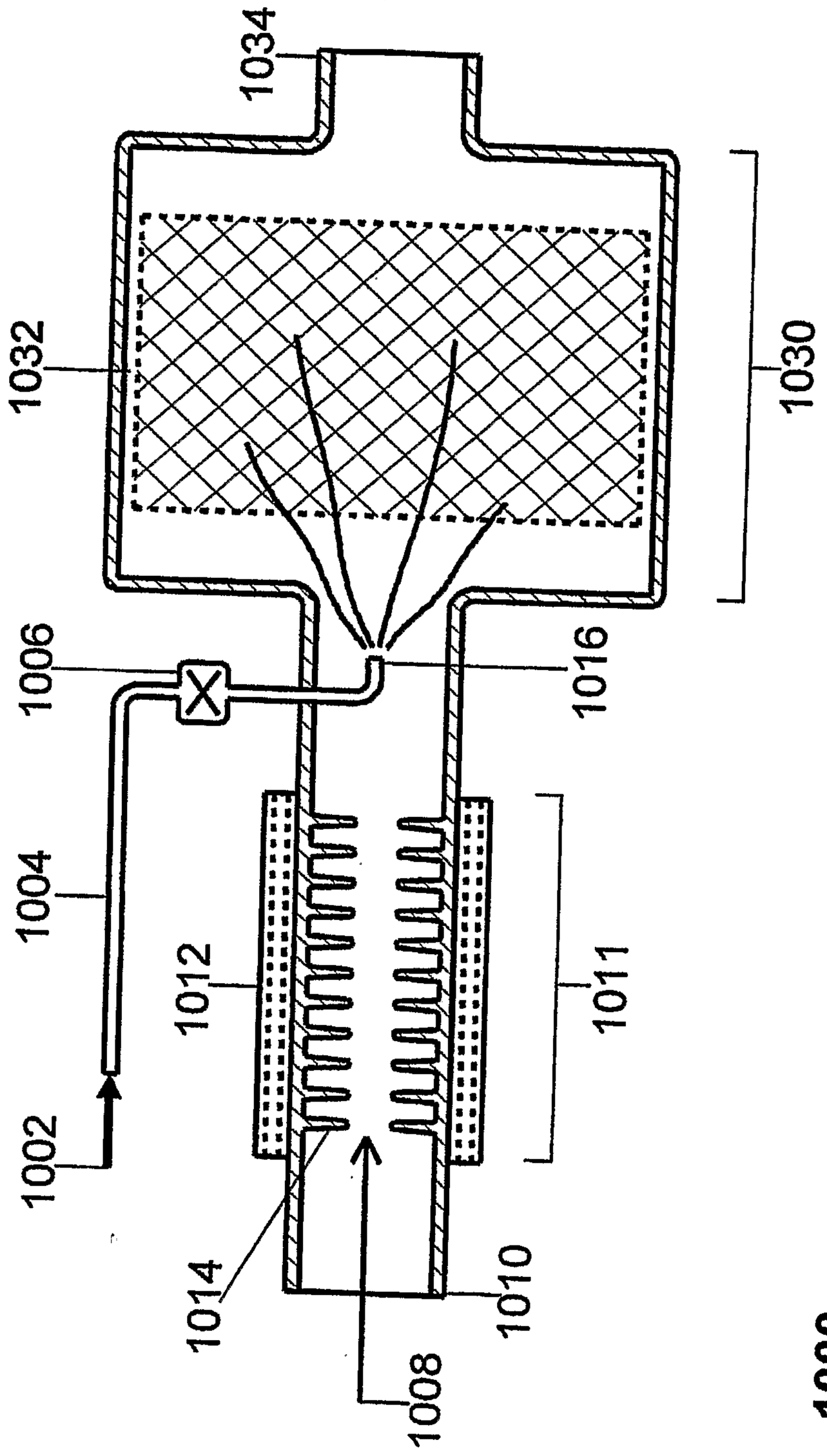


FIGURE 12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1032
1030
1006
1016
1004
1012
1011
1002
1014
1010
1008
1000

FIGURE 13

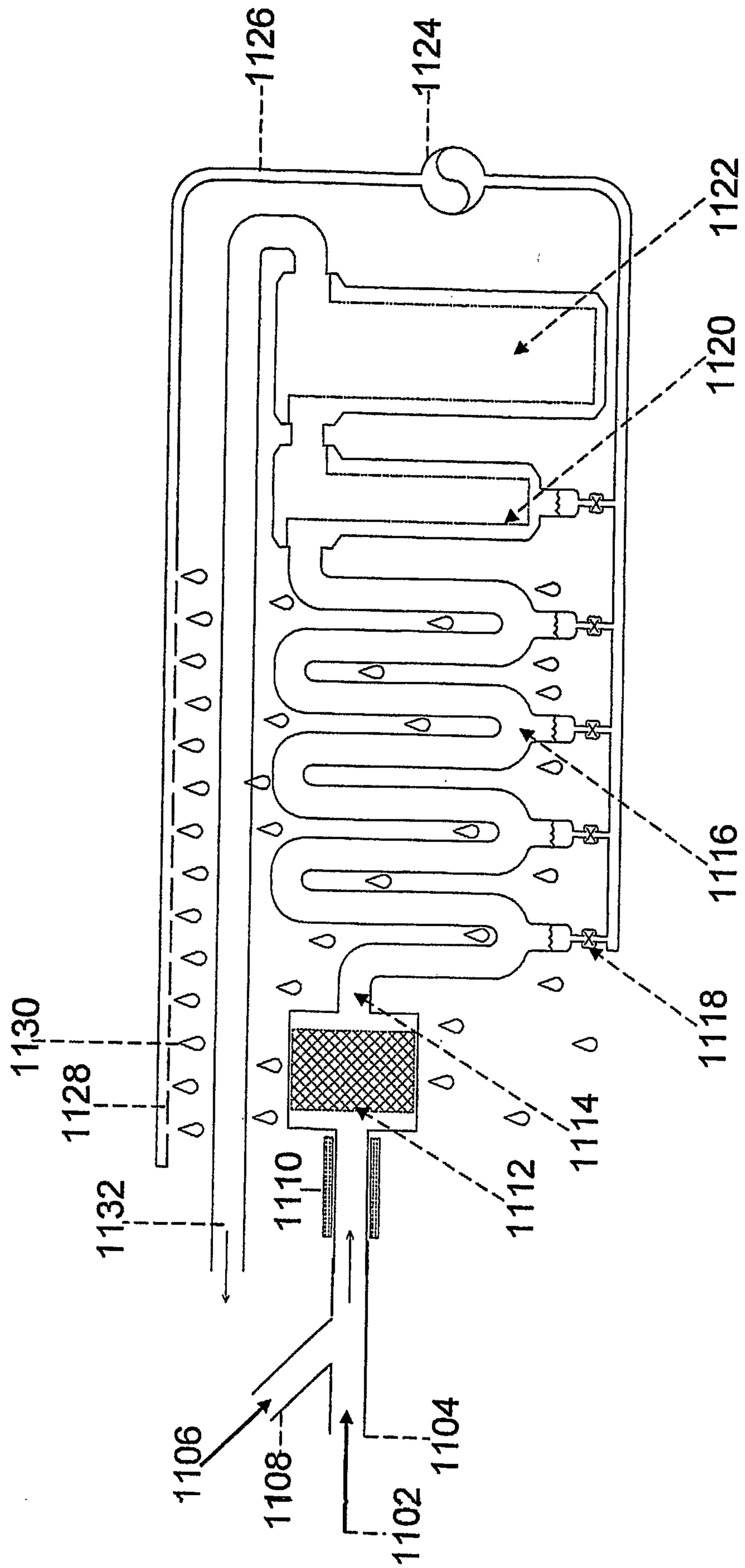

1126
1124
1122
1120
1116
1118
1114
1112
1110
1132
1130
1128
1106
1108
1102
1104
1100

FIGURE 14

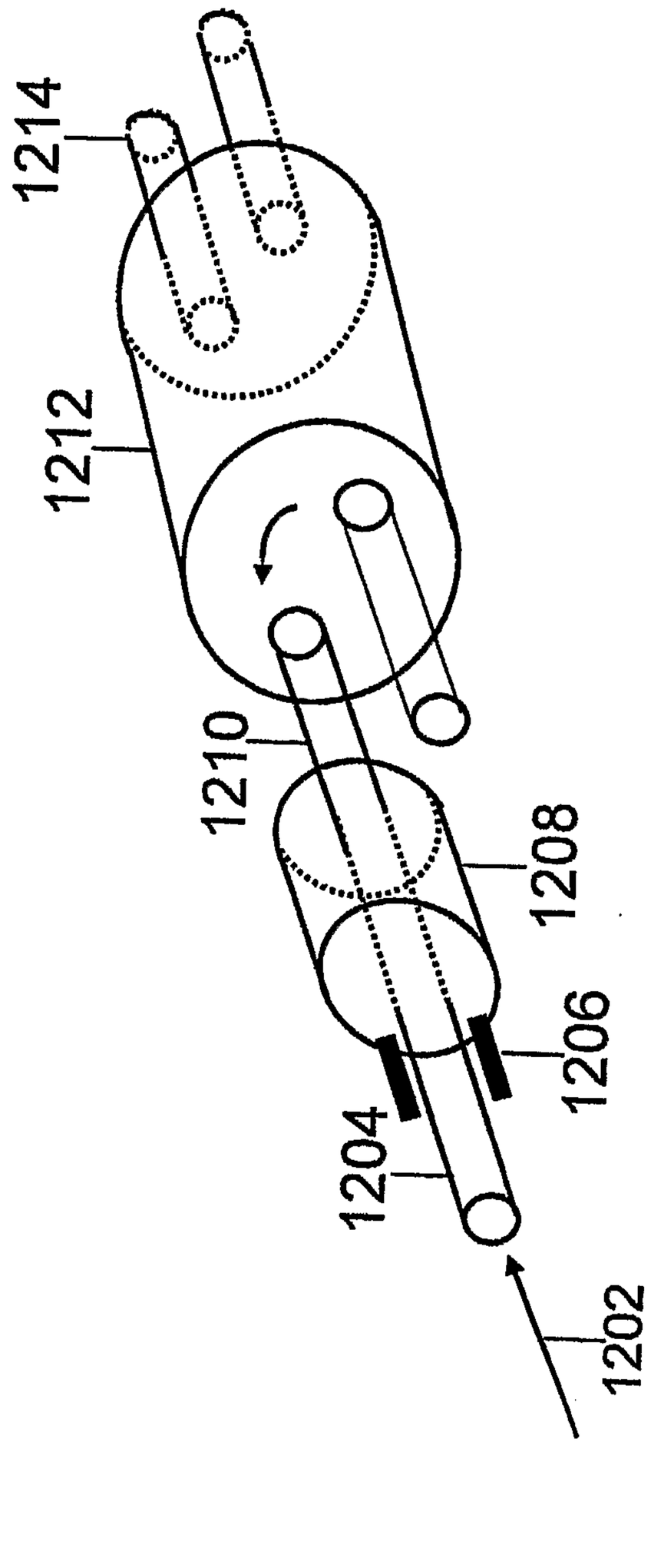
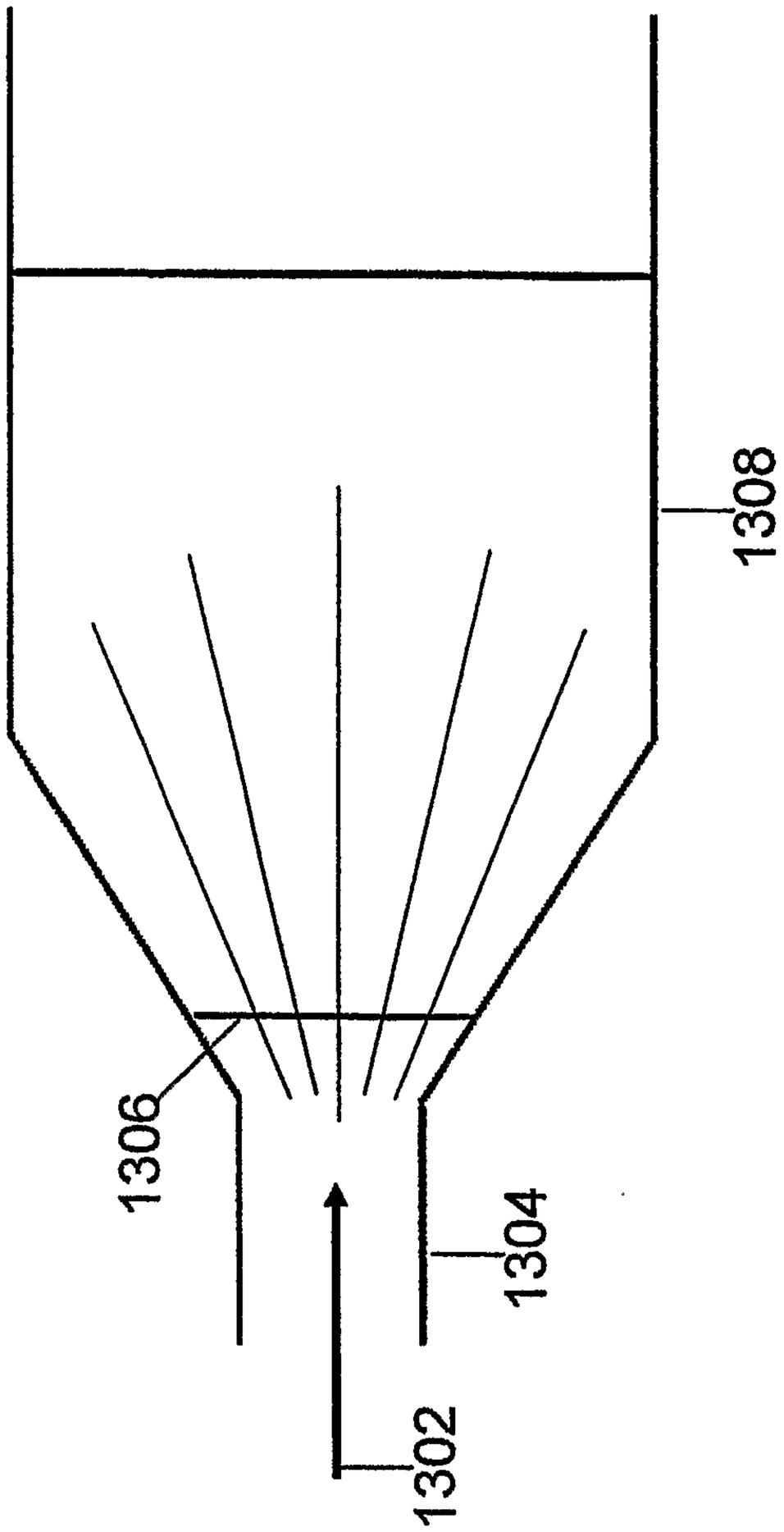
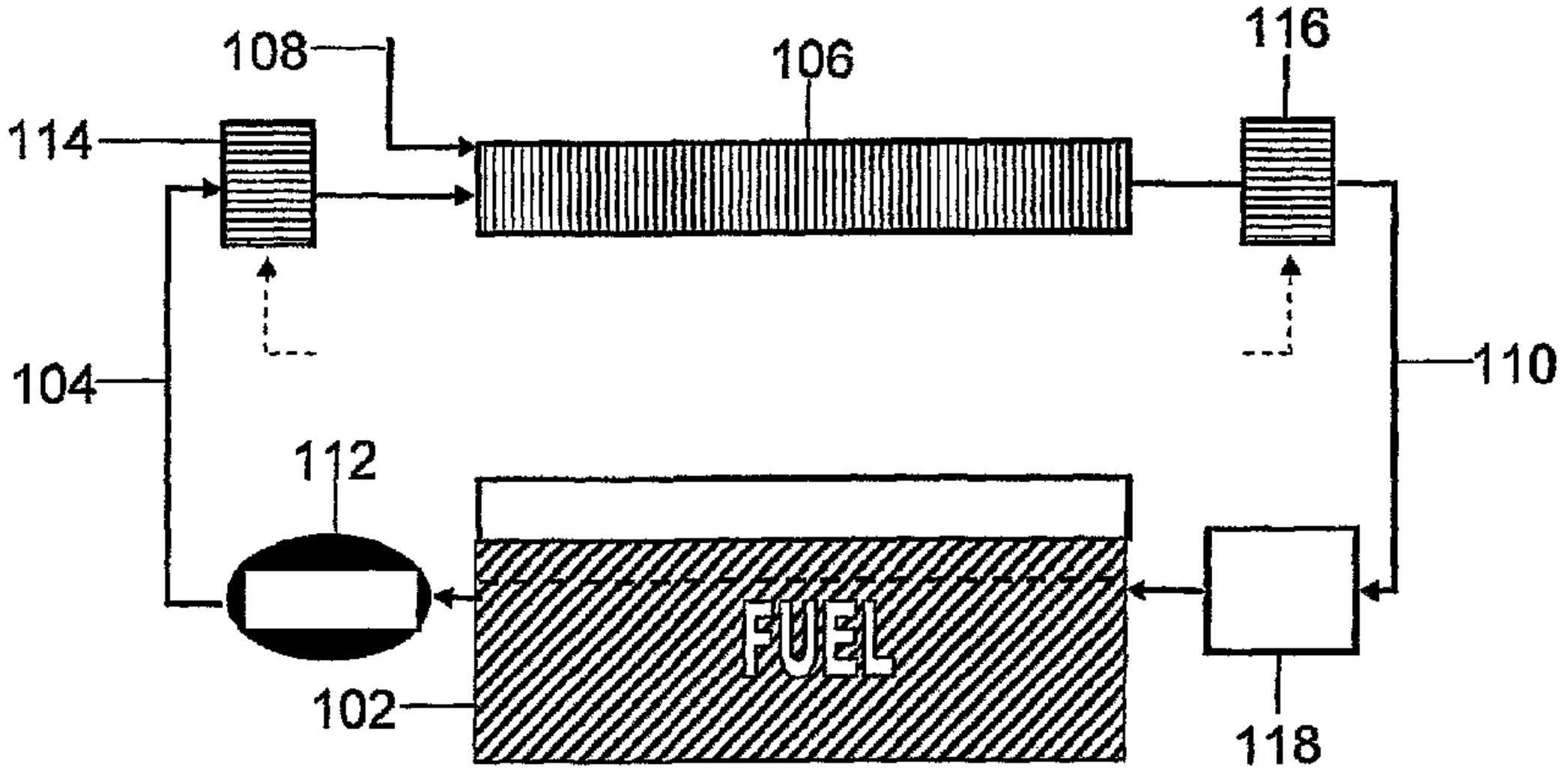


FIGURE 15





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