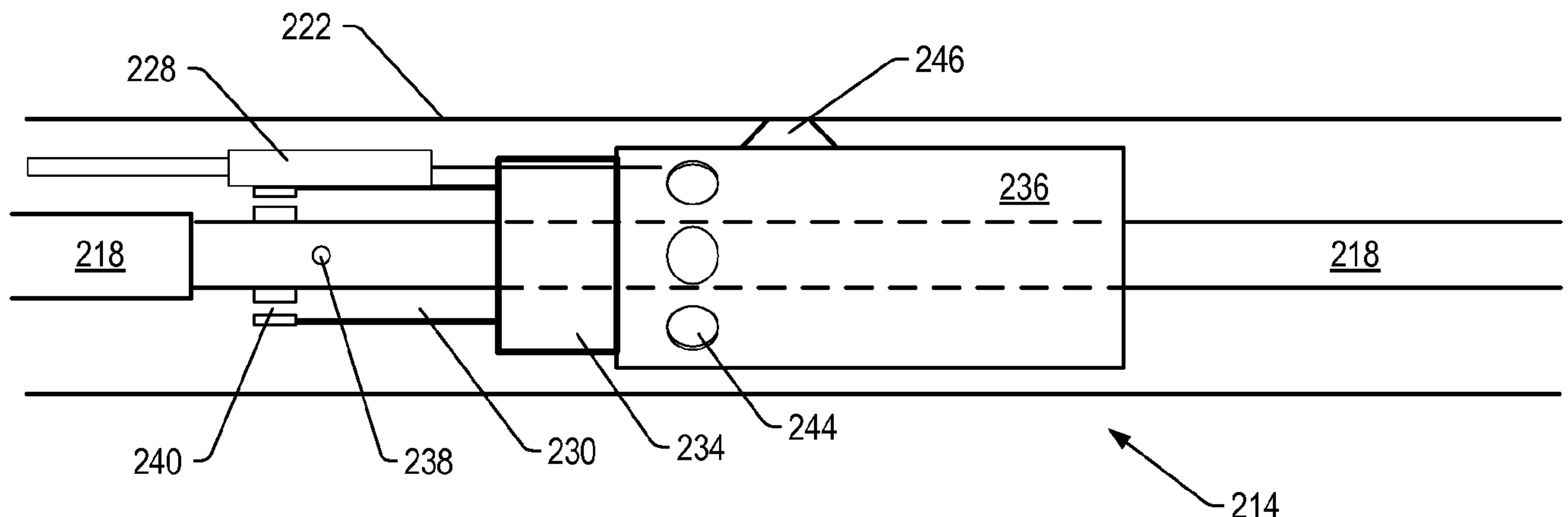




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(54) Title: IN SITU HEAT TREATMENT PROCESS UTILIZING OXIDIZERS TO HEAT A SUBSURFACE FORMATION



(57) **Abrégé/Abstract:**

Systems for heating a subsurface formation are described. The systems include a plurality of oxidizers positioned in a wellbore to form an oxidizer assembly. One or more of the oxidizers may include a shield with flame stabilizers. The flame stabilizers may stabilize the flame zone of the oxidizer by controlling fluid flow entering the shield and by controlling fluid flowing in the oxidizer. One or more of the oxidizers may be a catalytic oxidizer. Catalytic oxidizers may facilitate ignition of the oxidizers of the oxidizer assembly.

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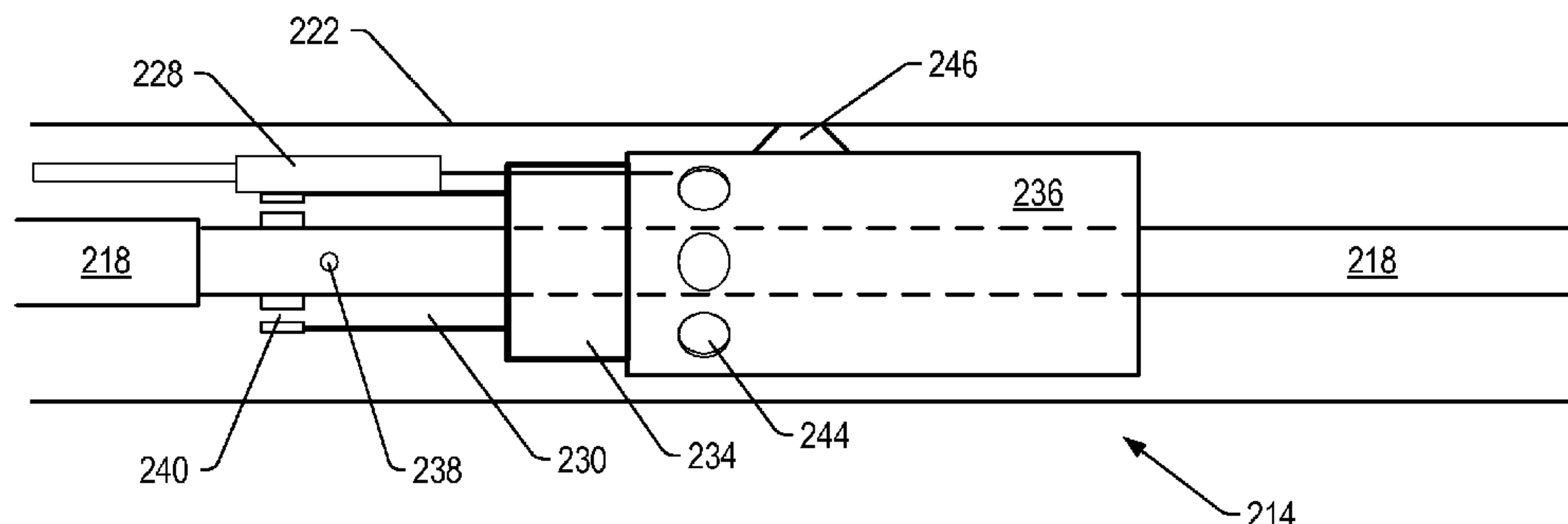
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(54) Title: IN SITU HEAT TREATMENT PROCESS UTILIZING OXIDIZERS TO HEAT A SUBSURFACE FORMATION



(57) Abstract: Systems for heating a subsurface formation are described. The systems include a plurality of oxidizers positioned in a wellbore to form an oxidizer assembly. One or more of the oxidizers may include a shield with flame stabilizers. The flame stabilizers may stabilize the flame zone of the oxidizer by controlling fluid flow entering the shield and by controlling fluid flowing in the oxidizer. One or more of the oxidizers may be a catalytic oxidizer. Catalytic oxidizers may facilitate ignition of the oxidizers of the oxidizer assembly.

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IN SITU HEAT TREATMENT PROCESS UTILIZING OXIDIZERS TO HEAT A SUBSURFACE FORMATION

BACKGROUND

5 1. Field of the Invention

[0001] The present invention relates generally to methods and systems for production of hydrocarbons, hydrogen, and/or other products from various subsurface formations such as hydrocarbon containing formations. In particular, certain embodiments relate to heating a selected portion or portions of the formation using oxidizers positioned in the formation
10 adjacent to the portion or portions of the formation to be heated.

2. Description of Related Art

[0002] Hydrocarbons obtained from subterranean formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available
15 hydrocarbon resources and concerns over declining overall quality of produced hydrocarbons have led to development of processes for more efficient recovery, processing and/or use of available hydrocarbon resources. In situ processes may be used to remove hydrocarbon materials from subterranean formations. Chemical and/or physical properties of hydrocarbon material in a subterranean formation may need to be changed to allow
20 hydrocarbon material to be more easily removed from the subterranean formation. The chemical and physical changes may include in situ reactions that produce removable fluids, composition changes, solubility changes, density changes, phase changes, and/or viscosity changes of the hydrocarbon material in the formation. A fluid may be, but is not limited to, a gas, a liquid, an emulsion, a slurry, and/or a stream of solid particles that has flow
25 characteristics similar to liquid flow.

[0003] Heaters may be placed in wellbores to heat a formation during an in situ process. Examples of in situ processes utilizing downhole heaters are illustrated in U.S. Patent Nos. 2,634,961 to Ljungstrom; 2,732,195 to Ljungstrom; 2,780,450 to Ljungstrom; 2,789,805 to Ljungstrom; 2,923,535 to Ljungstrom; and 4,886,118 to Van Meurs et al.

30 [0004] U.S. Patent No. 7,121,342 to Vinegar et al. describes oxidizer assemblies that may be used to heat subsurface formations. Oxidizers of the oxidizer assembly include an igniter, a mix chamber, a nozzle and a screen.

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[0005] The flow of fuel and/or oxidant to oxidizers may create an unstable flame in some oxidizers. Also, initiation of some oxidizers may be difficult. Thus, there is a need to improve downhole oxidizers to stabilize the flame zone produced by the oxidizers and facilitate initiation of one or more oxidizers in an oxidizer assembly.

5

SUMMARY

[0006] Embodiments described herein generally relate to systems, methods, and heaters for treating a subsurface formation. Embodiments described herein also generally relate to heaters that have novel components therein. Such heaters can be obtained by using the systems and methods described herein.

[0007] In some embodiments, a gas burner assembly for heating a subsurface formation includes an oxidant conduit; a fuel line positioned in the oxidant conduit; and a plurality of oxidizers coupled to the fuel conduit, wherein at least one of the oxidizers includes: a mix chamber for mixing fuel from the fuel conduit with a oxidizing fluid; an igniter; an ignition chamber; a shield, wherein the shield comprises a plurality of openings in communication with the oxidant conduit; and at least one flame stabilizer coupled to the shield.

[0008] In some embodiments, a gas burner assembly for heating a subsurface formation includes an oxidant conduit; a fuel conduit positioned in the oxidant conduit; and a plurality of oxidizers coupled to the fuel conduit, wherein at least one of the oxidizers includes: a mix chamber for mixing fuel from the fuel conduit with oxidizing fluid; an catalyst chamber configured to produce hot reaction products to ignite fuel and oxidizing fluid; an ignition chamber; and a shield, wherein the shield comprises a plurality of openings in communication with the oxidant conduit.

[0009] In some embodiments, a gas burner assembly for heating a subsurface formation includes an oxidant conduit; a fuel line positioned in the oxidant conduit; and a plurality of oxidizers coupled to the fuel conduit, wherein at least one of the oxidizers includes: a mix chamber for mixing fuel from the fuel conduit with oxidizing fluid; an igniter in the mix chamber configured to ignite fuel and oxidizing fluid to preheat fuel and oxidizing fluid; a catalyst chamber configured to react preheated fuel and oxidizing fluid from the mix chamber to produce hot reaction products to ignite fuel and oxidizing fluid; an ignition chamber; and a shield, wherein the shield comprises a plurality of openings in communication with the oxidant conduit.

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[0010] In further embodiments, additional features may be added to the specific embodiments described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

5 [0011] Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description and upon reference to the accompanying drawings in which:

[0012] FIG. 1 depicts an illustration of stages of heating a hydrocarbon containing formation.

10 [0013] FIG. 2 shows a schematic view of an embodiment of a portion of an in situ conversion system for treating a hydrocarbon containing formation.

[0014] FIG. 3 depicts a schematic representation of an embodiment of a downhole oxidizer assembly.

15 [0015] FIG. 4 depicts a perspective view of an embodiment of a portion of an oxidizer of a downhole oxidizer assembly.

[0016] FIG. 5 depicts a schematic representation of an oxidizer positioned in an oxidant line.

[0017] FIG. 6 depicts a cross-sectional representation of an embodiment of an oxidizer shield.

20 [0018] FIG. 7 depicts a cross-sectional representation of an embodiment of an oxidizer shield.

[0019] FIG. 8 depicts a cross-sectional representation of an embodiment of an oxidizer shield.

25 [0020] FIG. 9 depicts a cross-sectional representation of an embodiment of an oxidizer shield.

[0021] FIG. 10 depicts a cross-sectional representation of an embodiment of an oxidizer shield with multiple flame stabilizers.

[0022] FIG. 11 depicts a cross-sectional representation of an embodiment of an oxidizer shield.

30 [0023] FIG. 12 depicts a perspective representation of an embodiment of a portion of an oxidizer of a downhole oxidizer assembly with louvered openings in the shield.

[0024] FIG. 13 depicts a cross-sectional representation of a portion of a shield with a louvered opening.

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[0025] FIG. 14 depicts a cross-sectional representation of an embodiment of a catalytic burner.

[0026] FIG. 15 depicts a cross-sectional representation of an embodiment of a catalytic burner with an igniter.

5 [0027] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and may herein be described in detail. The drawings may not be to scale. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all
10 modifications, equivalents and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION

[0028] The following description generally relates to systems and methods for treating
15 hydrocarbons in the formations. Such formations may be treated to yield hydrocarbon products, hydrogen, and other products.

[0029] “Alternating current (AC)” refers to a time-varying current that reverses direction substantially sinusoidally. AC produces skin effect electricity flow in a ferromagnetic conductor.

20 [0030] “Curie temperature” is the temperature above which a ferromagnetic material loses all of its ferromagnetic properties. In addition to losing all of its ferromagnetic properties above the Curie temperature, the ferromagnetic material begins to lose its ferromagnetic properties when an increasing electrical current is passed through the ferromagnetic material.

25 [0031] A “formation” includes one or more hydrocarbon containing layers, one or more non-hydrocarbon layers, an overburden, and/or an underburden. The “overburden” and/or the “underburden” include one or more different types of impermeable materials. For example, overburden and/or underburden may include rock, shale, mudstone, or wet/tight carbonate. In some embodiments of in situ conversion processes, the overburden and/or
30 the underburden may include a hydrocarbon containing layer or hydrocarbon containing layers that are relatively impermeable and are not subjected to temperatures during in situ conversion processing that result in significant characteristic changes of the hydrocarbon containing layers of the overburden and/or the underburden. For example, the underburden

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may contain shale or mudstone, but the underburden is not allowed to heat to pyrolysis temperatures during the in situ conversion process. In some cases, the overburden and/or the underburden may be somewhat permeable.

[0032] “Formation fluids” refer to fluids present in a formation and may include
5 pyrolyzation fluid, synthesis gas, mobilized hydrocarbon, and water (steam). Formation fluids may include hydrocarbon fluids as well as non-hydrocarbon fluids. The term “mobilized fluid” refers to fluids in a hydrocarbon containing formation that are able to flow as a result of thermal treatment of the formation. “Produced fluids” refer to formation fluids removed from the formation.

10 [0033] A “heat source” is any system for providing heat to at least a portion of a formation substantially by conductive and/or radiative heat transfer. For example, a heat source may include electric heaters such as an insulated conductor, an elongated member, and/or a conductor disposed in a conduit. A heat source may also include systems that generate heat by burning a fuel external to or in a formation. The systems may be surface burners,
15 downhole gas burners, flameless distributed combustors, and natural distributed combustors. In some embodiments, heat provided to or generated in one or more heat sources may be supplied by other sources of energy. The other sources of energy may directly heat a formation, or the energy may be applied to a transfer medium that directly or indirectly heats the formation. It is to be understood that one or more heat sources that
20 are applying heat to a formation may use different sources of energy. Thus, for example, for a given formation some heat sources may supply heat from electric resistance heaters, some heat sources may provide heat from combustion, and some heat sources may provide heat from one or more other energy sources (for example, chemical reactions, solar energy, wind energy, biomass, or other sources of renewable energy). A chemical reaction may
25 include an exothermic reaction (for example, an oxidation reaction). A heat source may also include a heater that provides heat to a zone proximate and/or surrounding a heating location such as a heater well.

[0034] A “heater” is any system or heat source for generating heat in a well or a near wellbore region. Heaters may be, but are not limited to, electric heaters, burners,
30 combustors that react with material in or produced from a formation, and/or combinations thereof.

[0035] “Hydrocarbons” are generally defined as molecules formed primarily by carbon and hydrogen atoms. Hydrocarbons may also include other elements such as, but not limited

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to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur. Hydrocarbons may be, but are not limited to, kerogen, bitumen, pyrobitumen, oils, natural mineral waxes, and asphaltites. Hydrocarbons may be located in or adjacent to mineral matrices in the earth. Matrices may include, but are not limited to, sedimentary rock, sands, silicilytes, carbonates, diatomites, and other porous media. “Hydrocarbon fluids” are fluids that include hydrocarbons. Hydrocarbon fluids may include, entrain, or be entrained in non-hydrocarbon fluids such as hydrogen, nitrogen, carbon monoxide, carbon dioxide, hydrogen sulfide, water, and ammonia.

[0036] An “in situ conversion process” refers to a process of heating a hydrocarbon containing formation from heat sources to raise the temperature of at least a portion of the formation above a pyrolysis temperature so that pyrolyzation fluid is produced in the formation.

[0037] An “in situ heat treatment process” refers to a process of heating a hydrocarbon containing formation with heat sources to raise the temperature of at least a portion of the formation above a temperature that results in mobilized fluid, visbreaking, and/or pyrolysis of hydrocarbon containing material so that mobilized fluids, visbroken fluids, and/or pyrolyzation fluids are produced in the formation.

[0038] “Insulated conductor” refers to any elongated material that is able to conduct electricity and that is covered, in whole or in part, by an electrically insulating material (for example, magnesium oxide).

[0039] “Modulated direct current (DC)” refers to any substantially non-sinusoidal time-varying current that produces skin effect electricity flow in a ferromagnetic conductor.

[0040] “Orifices” refer to openings, such as openings in conduits, having a wide variety of sizes and cross-sectional shapes including, but not limited to, circles, ovals, squares, rectangles, triangles, slits, or other regular or irregular shapes.

[0041] “Pyrolysis” is the breaking of chemical bonds due to the application of heat. For example, pyrolysis may include transforming a compound into one or more other substances by heat alone. Heat may be transferred to a section of the formation to cause pyrolysis. In some formations, portions of the formation and/or other materials in the formation may promote pyrolysis through catalytic activity.

[0042] “Pyrolyzation fluids” or “pyrolysis products” refers to fluid produced substantially during pyrolysis of hydrocarbons. Fluid produced by pyrolysis reactions may mix with other fluids in a formation. The mixture would be considered pyrolyzation fluid or

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pyrolyzation product. As used herein, "pyrolysis zone" refers to a volume of a formation (for example, a relatively permeable formation such as a tar sands formation) that is reacted or reacting to form a pyrolyzation fluid.

[0043] "Superposition of heat" refers to providing heat from two or more heat sources to a selected section of a formation such that the temperature of the formation at least at one location between the heat sources is influenced by the heat sources.

[0044] "Synthesis gas" is a mixture including hydrogen and carbon monoxide. Additional components of synthesis gas may include water, carbon dioxide, nitrogen, methane, and other gases. Synthesis gas may be generated by a variety of processes and feedstocks.

10 Synthesis gas may be used for synthesizing a wide range of compounds.

[0045] "Temperature limited heater" generally refers to a heater that regulates heat output (for example, reduces heat output) above a specified temperature without the use of external controls such as temperature controllers, power regulators, rectifiers, or other devices. Temperature limited heaters may be AC (alternating current) or modulated (for example, "chopped") DC (direct current) powered electrical resistance heaters.

15

[0046] "Time-varying current" refers to electrical current that produces skin effect electricity flow in a ferromagnetic conductor and has a magnitude that varies with time. Time-varying current includes both alternating current (AC) and modulated direct current (DC).

20 [0047] The term "wellbore" refers to a hole in a formation made by drilling or insertion of a conduit into the formation. A wellbore may have a substantially circular cross section, or another cross-sectional shape. As used herein, the terms "well" and "opening," when referring to an opening in the formation may be used interchangeably with the term "wellbore." A "u-shaped wellbore" refers to a wellbore that extends from a first opening in the formation, through at least a portion of the formation, and out through a second opening in the formation. In this context, the wellbore may be only roughly in the shape of a "v" or "u", with the understanding that the "legs" of the "u" do not need to be parallel to each other, or perpendicular to the "bottom" of the "u" for the wellbore to be considered "u-shaped".

25

30 [0048] Hydrocarbons in formations may be treated in various ways to produce many different products. In certain embodiments, hydrocarbons in formations are treated in stages. FIG. 1 depicts an illustration of stages of heating the hydrocarbon containing formation. FIG. 1 also depicts an example of yield ("Y") in barrels of oil equivalent per

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ton (y axis) of formation fluids from the formation versus temperature (“T”) of the heated formation in degrees Celsius (x axis).

[0049] Desorption of methane and vaporization of water occurs during stage 1 heating.

Heating of the formation through stage 1 may be performed as quickly as possible. When

5 the hydrocarbon containing formation is initially heated, hydrocarbons in the formation desorb adsorbed methane. The desorbed methane may be produced from the formation. If the hydrocarbon containing formation is heated further, water in the hydrocarbon containing formation is vaporized. Water may occupy, in some hydrocarbon containing formations, between 10% and 50% of the pore volume in the formation. In other
10 formations, water occupies larger or smaller portions of the pore volume. Water typically is vaporized in a formation between 160 °C and 285 °C at pressures of 600 kPa absolute to 7000 kPa absolute. In some embodiments, the vaporized water produces wettability changes in the formation and/or increased formation pressure. The wettability changes and/or increased pressure may affect pyrolysis reactions or other reactions in the formation.

15 In certain embodiments, the vaporized water is produced from the formation. In other embodiments, the vaporized water is used for steam extraction and/or distillation in the formation or outside the formation. Removing the water from and increasing the pore volume in the formation increases the storage space for hydrocarbons in the pore volume.

[0050] In certain embodiments, after stage 1 heating, the formation is heated further, such
20 that a temperature in the formation reaches (at least) an initial pyrolyzation temperature (such as a temperature at the lower end of the temperature range shown as stage 2).

Hydrocarbons in the formation may be pyrolyzed throughout stage 2. A pyrolysis temperature range varies depending on the types of hydrocarbons in the formation. The pyrolysis temperature range may include temperatures between 250 °C and 900 °C. The
25 pyrolysis temperature range for producing desired products may extend through only a portion of the total pyrolysis temperature range. In some embodiments, the pyrolysis temperature range for producing desired products may include temperatures between 250 °C and 400 °C or temperatures between 270 °C and 350 °C. If a temperature of hydrocarbons in the formation is slowly raised through the temperature range from 250 °C
30 to 400 °C, production of pyrolysis products may be substantially complete when the temperature approaches 400 °C. Average temperature of the hydrocarbons may be raised at a rate of less than 5 °C per day, less than 2 °C per day, less than 1 °C per day, or less than 0.5 °C per day through the pyrolysis temperature range for producing desired

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products. Heating the hydrocarbon containing formation with a plurality of heat sources may establish thermal gradients around the heat sources that slowly raise the temperature of hydrocarbons in the formation through the pyrolysis temperature range.

[0051] The rate of temperature increase through the pyrolysis temperature range for
5 desired products may affect the quality and quantity of the formation fluids produced from the hydrocarbon containing formation. Raising the temperature slowly through the pyrolysis temperature range for desired products may inhibit mobilization of large chain molecules in the formation. Raising the temperature slowly through the pyrolysis temperature range for desired products may limit reactions between mobilized
10 hydrocarbons that produce undesired products. Slowly raising the temperature of the formation through the pyrolysis temperature range for desired products may allow for the production of high quality, high API gravity hydrocarbons from the formation. Slowly raising the temperature of the formation through the pyrolysis temperature range for desired products may allow for the removal of a large amount of the hydrocarbons present
15 in the formation as hydrocarbon product.

[0052] In some in situ conversion embodiments, a portion of the formation is heated to a desired temperature instead of slowly heating the temperature through a temperature range. In some embodiments, the desired temperature is 300 °C, 325 °C, or 350 °C. Other temperatures may be selected as the desired temperature. Superposition of heat from heat
20 sources allows the desired temperature to be relatively quickly and efficiently established in the formation. Energy input into the formation from the heat sources may be adjusted to maintain the temperature in the formation substantially at the desired temperature. The heated portion of the formation is maintained substantially at the desired temperature until pyrolysis declines such that production of desired formation fluids from the formation
25 becomes uneconomical. Parts of the formation that are subjected to pyrolysis may include regions brought into a pyrolysis temperature range by heat transfer from only one heat source.

[0053] In certain embodiments, formation fluids including pyrolyzation fluids are produced from the formation. As the temperature of the formation increases, the amount of
30 condensable hydrocarbons in the produced formation fluid may decrease. At high temperatures, the formation may produce mostly methane and/or hydrogen. If the hydrocarbon containing formation is heated throughout the entire pyrolysis range, the formation may produce only small amounts of hydrogen towards an upper limit of the

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pyrolysis range. After all of the available hydrogen is depleted, a minimal amount of fluid production from the formation will typically occur.

[0054] After pyrolysis of hydrocarbons, a large amount of carbon and some hydrogen may still be present in the formation. A significant portion of carbon remaining in the formation can be produced from the formation in the form of synthesis gas. Synthesis gas generation may take place during stage 3 heating depicted in FIG. 1. Stage 3 may include heating a hydrocarbon containing formation to a temperature sufficient to allow synthesis gas generation. For example, synthesis gas may be produced in a temperature range from about 400 °C to about 1200 °C, about 500 °C to about 1100 °C, or about 550 °C to about 1000 °C. The temperature of the heated portion of the formation when the synthesis gas generating fluid is introduced to the formation determines the composition of synthesis gas produced in the formation. The generated synthesis gas may be removed from the formation through a production well or production wells.

[0055] Total energy content of fluids produced from the hydrocarbon containing formation may stay relatively constant throughout pyrolysis and synthesis gas generation. During pyrolysis at relatively low formation temperatures, a significant portion of the produced fluid may be condensable hydrocarbons that have a high energy content. At higher pyrolysis temperatures, however, less of the formation fluid may include condensable hydrocarbons. More non-condensable formation fluids may be produced from the formation. Energy content per unit volume of the produced fluid may decline slightly during generation of predominantly non-condensable formation fluids. During synthesis gas generation, energy content per unit volume of produced synthesis gas declines significantly compared to energy content of pyrolyzation fluid. The volume of the produced synthesis gas, however, will in many instances increase substantially, thereby compensating for the decreased energy content.

[0056] FIG. 2 depicts a schematic view of an embodiment of a portion of the in situ heat treatment system for treating the hydrocarbon containing formation. The in situ heat treatment system may include barrier wells 200. Barrier wells are used to form a barrier around a treatment area. The barrier inhibits fluid flow into and/or out of the treatment area. Barrier wells include, but are not limited to, dewatering wells, vacuum wells, capture wells, injection wells, grout wells, freeze wells, or combinations thereof. In some embodiments, barrier wells 200 are dewatering wells. Dewatering wells may remove

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liquid water and/or inhibit liquid water from entering a portion of the formation to be heated, or to the formation being heated.

[0057] Freeze wells may be used to establish a low temperature zone around all or a portion of a treatment area. Refrigerant is circulated through freeze wells to form low temperature zones around each freeze well. The freeze wells are placed in the formation so that the low temperature zones overlap and form a low temperature zone around the treatment area. The low temperature zone established by freeze wells is maintained below the freezing temperature of aqueous fluid in the formation. Aqueous fluid entering the low temperature zone freezes and forms a frozen barrier.

[0058] In the embodiment depicted in FIG. 2, the barrier wells 200 are shown extending only along one side of heat sources 202, but the barrier wells typically encircle all heat sources 202 used, or to be used, to heat a treatment area of the formation.

[0059] Heat sources 202 are placed in at least a portion of the formation. Heat sources 202 may include heaters such as oxidizer assemblies, insulated conductors, conductor-in-conduit heaters, surface burners, flameless distributed combustors, and/or natural distributed combustors. Heat sources 202 may also include other types of heaters. Heat sources 202 provide heat to at least a portion of the formation to heat hydrocarbons in the formation. Energy may be supplied to heat sources 202 through supply lines 204. Supply lines 204 may be structurally different depending on the type of heat source or heat sources used to heat the formation. Supply lines 204 for heat sources may transmit electricity for electric heaters, may transport fuel for combustors, or may transport heat exchange fluid that is circulated in the formation. In some embodiments, electricity for an in situ heat treatment process may be provided by a nuclear power plant or nuclear power plants. The use of nuclear power may allow for reduction or elimination of carbon dioxide emissions from the in situ heat treatment process.

[0060] Production wells 206 are used to remove formation fluid from the formation. In some embodiments, production well 206 includes a heat source. The heat source in the production well may heat one or more portions of the formation at or near the production well. In some in situ heat treatment process embodiments, the amount of heat supplied to the formation from the production well per meter of the production well is less than the amount of heat applied to the formation from a heat source that heats the formation per meter of the heat source. Heat applied to the formation from the production well may increase formation permeability adjacent to the production well by vaporizing and

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removing liquid phase fluid adjacent to the production well and/or by increasing the permeability of the formation adjacent to the production well by formation of macro and/or micro fractures.

[0061] In some embodiments, the heat source in production well 206 allows for vapor
5 phase removal of formation fluids from the formation. Providing heating at or through the production well may: (1) inhibit condensation and/or refluxing of production fluid when such production fluid is moving in the production well proximate the overburden, (2) increase heat input into the formation, (3) increase production rate from the production well as compared to a production well without a heat source, (4) inhibit condensation of
10 high carbon number compounds (C_6 and above) in the production well, and/or (5) increase formation permeability at or proximate the production well.

[0062] Subsurface pressure in the formation may correspond to the fluid pressure generated in the formation. As temperatures in the heated portion of the formation increase, the pressure in the heated portion may increase as a result of increased fluid
15 generation and vaporization of water. Controlling rate of fluid removal from the formation may allow for control of pressure in the formation. Pressure in the formation may be determined at a number of different locations, such as near or at production wells, near or at heat sources, or at monitor wells.

[0063] In some hydrocarbon containing formations, production of hydrocarbons from the
20 formation is inhibited until at least some hydrocarbons in the formation have been pyrolyzed. Formation fluid may be produced from the formation when the formation fluid is of a selected quality. In some embodiments, the selected quality includes an API gravity of at least 20° , 30° , or 40° . Inhibiting production until at least some hydrocarbons are pyrolyzed may increase conversion of heavy hydrocarbons to light hydrocarbons.
25 Inhibiting initial production may minimize the production of heavy hydrocarbons from the formation. Production of substantial amounts of heavy hydrocarbons may require expensive equipment and/or reduce the life of production equipment.

[0064] After pyrolysis temperatures are reached and production from the formation is allowed, pressure in the formation may be varied to alter and/or control a composition of
30 formation fluid produced, to control a percentage of condensable fluid as compared to non-condensable fluid in the formation fluid, and/or to control an API gravity of formation fluid being produced. For example, decreasing pressure may result in production of a larger

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condensable fluid component. The condensable fluid component may contain a larger percentage of olefins.

[0065] In some in situ heat treatment process embodiments, pressure in the formation may be maintained high enough to promote production of formation fluid with an API gravity of greater than 20°. Maintaining increased pressure in the formation may inhibit formation subsidence during in situ heat treatment. Maintaining increased pressure may facilitate vapor phase production of fluids from the formation. Vapor phase production may allow for a reduction in size of collection conduits used to transport fluids produced from the formation. Maintaining increased pressure may reduce or eliminate the need to compress formation fluids at the surface to transport the fluids in collection conduits to treatment facilities.

[0066] Maintaining increased pressure in a heated portion of the formation may surprisingly allow for production of large quantities of hydrocarbons of increased quality and of relatively low molecular weight. Pressure may be maintained so that formation fluid produced has a minimal amount of compounds above a selected carbon number. The selected carbon number may be at most 25, at most 20, at most 12, or at most 8. Some high carbon number compounds may be entrained in vapor in the formation and may be removed from the formation with the vapor. Maintaining increased pressure in the formation may inhibit entrainment of high carbon number compounds and/or multi-ring hydrocarbon compounds in the vapor. High carbon number compounds and/or multi-ring hydrocarbon compounds may remain in a liquid phase in the formation for significant time periods. The significant time periods may provide sufficient time for the compounds to pyrolyze to form lower carbon number compounds.

[0067] Formation fluid produced from production wells 206 may be transported through collection piping 208 to treatment facilities 210. Formation fluids may also be produced from heat sources 202. For example, fluid may be produced from heat sources 202 to control pressure in the formation adjacent to the heat sources. Fluid produced from heat sources 202 may be transported through tubing or piping to collection piping 208 or the produced fluid may be transported through tubing or piping directly to treatment facilities 210. Treatment facilities 210 may include separation units, reaction units, upgrading units, fuel cells, turbines, storage vessels, and/or other systems and units for processing produced formation fluids. The treatment facilities may form transportation fuel from at least a

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portion of the hydrocarbons produced from the formation. In some embodiments, the transportation fuel may be jet fuel, such as JP-8.

[0068] FIG. 3 depicts a schematic of an embodiment of downhole oxidizer assembly 212 including oxidizers 214. In some embodiments, oxidizer assembly 212 may include
5 oxidizers 214 and flameless distributed combustors. Oxidizer assembly 212 may be lowered into an opening in a formation and positioned as desired. In some embodiments, a portion of the opening in the formation may be substantially parallel to the surface of the Earth. In some embodiments, the opening of the formation may be otherwise angled with respect to the surface of the Earth. In an embodiment, the opening may include a
10 significant vertical portion and a portion otherwise angled with respect to the surface of the Earth. In certain embodiments, the opening may be a branched opening. Oxidizer assemblies may branch from common fuel and/or oxidizer conduits in a central portion of the opening.

[0069] Fuel 216 may be supplied to oxidizers 214 through fuel conduit 218. In some
15 embodiments, the fuel for the oxidizers may be hydrogen or a high hydrogen content hydrocarbon mixture. Using hydrogen as the fuel has several advantages over hydrocarbon fuels. For example, hydrogen is easy to ignite, oxidizing hydrogen does not result in the generation of carbon dioxide or other undesired reaction products, and coking of the fuel line is eliminated.

[0070] In some embodiments, the fuel may be methane or natural gas. In some
20 embodiments, the fuel may be a mixture of hydrocarbons produced from an in situ heat treatment process. In certain embodiments, fuel used to initiate combustion may be enriched to decrease the temperature required for ignition. In some embodiments, hydrogen (H₂) or other hydrogen rich fluids may be used to enrich fuel initially supplied to
25 the oxidizers. After ignition of the oxidizers, enrichment of the fuel may be stopped. In some embodiments, a portion or portions of fuel conduit 218 may include a catalytic surface (for example, a catalytic outer surface) to decrease an ignition temperature of fuel 216.

[0071] Portions of the fuel conduit subjected to high temperatures, may include heat
30 shielding. The heat shielding may include an insulative underlayer and a thermally conductive overlayer. The overlayer may be a ceramic layer. The underlayer may be a low thermal conductivity ceramic sleeve or coating. The overlayer may be a high thermal

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conductivity coating. In some embodiments, the fuel line may be positioned in a conduit. A cooling flow may be circulated through the space between the fuel line and the conduit.

[0072] Oxidizing fluid 220 may be supplied to oxidizer assembly 212 through oxidizer conduit 222. In some embodiments, fuel conduit 218 and/or oxidizers 214 may be positioned concentrically, or substantially concentrically, in oxidizer conduit 222. In some embodiments, fuel conduit 218 and/or oxidizers 214 may be arranged other than concentrically with respect to oxidizer conduit 222. In certain branched opening embodiments, fuel conduit 218 and/or oxidizer conduit 222 may have a weld or coupling to allow placement of oxidizer assemblies 212 in branches of the opening.

[0073] An ignition source may be positioned in or proximate oxidizers 214 to initiate combustion. In some embodiments, an ignition source may heat the fuel and/or the oxidizing fluid supplied to a particular heater to a temperature sufficient to support ignition of the fuel. The fuel may be oxidized with the oxidizing fluid in oxidizers 214 to generate heat. Oxidation products may mix with oxidizing fluid downstream of the first oxidizer in oxidizer conduit 222. Exhaust gas 224 may include unreacted oxidizing fluid and unreacted fuel as well as oxidation products. In some embodiments, a portion of exhaust gas 224 from a first oxidizer, may be provided to oxidizers 214 downstream of the first oxidizer. In some embodiments, a portion of exhaust gas 224 may return to the surface through outer conduit 226. As the exhaust gas returns to the surface through outer conduit 226, heat from exhaust gas 224 may be transferred to the formation. Returning exhaust gas 224 through outer conduit 226 may provide substantially uniform heating along oxidizer assembly 212 due to heat from the exhaust gas integrating with the heat provided from individual oxidizers of the oxidizer assembly. In some embodiments, oxidizing fluid 220 may be introduced through outer conduit 226 and exhaust gas 224 may be returned through oxidizer conduit 222. In certain embodiments, heat integration may occur along an extended vertical portion of an opening.

[0074] In some embodiments, the oxidizer assembly may be a heat source used to heat water or steam. Steam produced by heat from the oxidizer assembly may be introduced into the formation. The oxidizer assembly may be placed in a conduit. The conduit may include critical flow orifices. The oxidizers may be started. Heat produced by the oxidizer assembly may be used to heat water introduced into the space between the oxidizer assembly and the conduit. Steam produced from the heat may pass through the critical flow orifices in the conduit into the formation.

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[0075] Oxidizing fluid supplied to an oxidizer assembly may include, but is not limited to, air, oxygen enriched air, and/or hydrogen peroxide. Depletion of oxygen in oxidizing fluid may occur toward a terminal end of an oxidizer assembly. In an embodiment, a flow of oxidizing fluid may be increased (for example, by using compression to provide excess oxidizing fluid) such that sufficient oxygen is present for operation of the terminal oxidizer. In some embodiments, oxidizing fluid may be enriched by increasing an oxygen content of the oxidizing fluid prior to introduction of the oxidizing fluid to the oxidizers. Oxidizing fluid may be enriched by methods including, but not limited to, adding oxygen to the oxidizing fluid, adding an additional oxidant such as hydrogen peroxide to the oxidizing fluid (for example, air) and/or flowing oxidizing fluid through a membrane that allows preferential diffusion of oxygen.

[0076] For oxidizers that use hydrocarbon fuel, steps may be taken to reduce coking of fuel in the fuel conduit after ignition of the oxidizers. For example, steam may be added to the fuel to inhibit coking in the fuel conduit. In some embodiments, the fuel may be methane that is mixed with steam in a molar ratio of up to 1:1. In some embodiments, coking may be inhibited by decreasing a residence time of fuel in the fuel conduit. In some embodiments, coking may be inhibited by insulating portions of the fuel conduit that pass through high temperature zones proximate oxidizers.

[0077] If steam is to be added to the fuel, the steam needs to be added at the right point. If steam is added to the fuel at the surface, the steam may condense in the fuel line on the way down to the first oxidizer. The resulting water may slug into the first oxidizer and flameout the oxidizer. In some embodiments, a separate water line is used to introduce water into the fuel line. In an embodiment, the water line is 1/4" tubing that transports softened water to the fuel line near the first oxidizer. When the oxidizers are first initialized, coking prevention may not be needed, so water is not sent through the water line. When the first oxidizer is hot, water may be sent through the water line to the fuel line. The water may be introduced into the fuel conduit at a location where the temperature is about 65 °C. The entrance nozzle, the heat from the first oxidizer and the velocity of the fuel in the fuel line may atomize or vaporize the water supplied to the fuel conduit.

[0078] During operation, there is enough flow through the oxidizer system to protect the fuel line from overheating and to minimize the flame temperature. The openings of the oxidizers are designed to allow a certain flowrate through the system that increases as the bypass flow increases. At lower bypass flows, the amount of gas is restricted and

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temperatures may become elevated. At the design bypass flow, the maximum temperatures are lower, which may result in no or low amounts of oxides of nitrogen and a low fuel line temperature.

[0079] In some embodiments, opening sizes in the oxidizers and the fuel line pressure
5 relative to the oxidant line pressure may be controlled to create a flammable mixture in each oxidizer. The composition of the fuel may be controlled to minimize flame temperatures. The composition of the fuel may be changed by adding diluent such as, but not limited to, steam and/or nitrogen. Opening sizes, fuel line pressure and fuel
10 composition allow the flame region of each oxidizer to remain hot, stable and protected from the bypass flow around the oxidizers so that the oxidizers burn out the fuel supplied to the individual oxidizers.

[0080] FIG. 4 depicts a perspective view of an embodiment of oxidizer 214 of the downhole heater assembly without an igniter. FIG. 5 depicts a schematic representation of oxidizer 214 with igniter 228 positioned in oxidant line 222. Oxidizer 214 may include
15 mix chamber 230, igniter holder 232, nozzle and flame holder 234, and heat shield 236. In some embodiments, the flame area in flame holder 234 and/or heat shield 236 may be at a temperature of about 1100 °C. The temperature adjacent to the oxidizer may be about 700 °C. Fuel conduit 218 may pass through oxidizer 214. Fuel conduit 218 may have one or more fuel openings 238 within mix chamber 230. Openings 240 allow oxidant to flow into
20 mix chamber 230. Opening 242 allows a portion of the igniter supported on igniter holder 232 to pass into oxidizer 214. Heat shield 236 may include openings 244. Openings 244 may provide additional oxidant to a flame in heat shield 236. Openings 244 may stabilize the flame in oxidizer 214 and moderate the temperature of the flame. The size and/or number of openings 244 may be varied depending on position of the oxidizer in the
25 oxidizer assembly to moderate the temperature and ensure fuel combustion. Spacers 246 may be positioned on heat shield 236 to keep oxidizer positioned in the oxidizer conduit.

[0081] In some embodiments, the igniters for the oxidizers include temperature limited heater elements. When the oxidizer is operating, the temperature of the oxidizer heats the igniter element above the Curie temperature of the igniter element so that skin effect
30 heating goes away and electricity flows through all or substantially all of the heater element. If the igniter element temperature is below the Curie temperature of the igniter element, the electricity flowing through the igniter element is confined to a certain depth so the effective resistance of the igniter element increases. The increase in effective

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resistance causes resistive heating that raises the temperature of the igniter element above the ignition temperature of the fuel and gas mixture for the oxidizer.

[0082] In some embodiments, catalytic igniters may be used. The catalytic igniters may have long operation life at high temperatures. Catalytic igniters may enable hot restarts
5 without having to shut down all flames in the remaining burners when one or more burners flame out. The amount of hydrogen can be varied in the fuel supply to the catalytic igniters so that fluid flow through the oxidizer system does not have to be lowered to hit ignition conditions for a particular oxidizer. Under certain operating conditions, one or more of the catalytic igniters could be supplied with fuel so that the igniter is hot to assist combustion
10 in case an oxidizer becomes weak or troublesome due to manufacturing or long term degradation of the oxidizer. Use of catalytic igniters may allow for relatively simple startups.

[0083] In some embodiments, flame stabilizers may be added to the oxidizers. The flame stabilizers may attach the flame to the shield. The high bypass flow around the oxidizer
15 cools the shield and protects the internals of the oxidizer from damage enabling long term operation. FIGS. 6-11 depict various embodiments of shields 236 with flame stabilizers 248. Flame stabilizer 248 depicted in FIG. 6 is a ring substantially perpendicular to shield 236. The ring shown in FIG. 7 is angled away from openings 244. The rings may amount to up to about 25% annular area blockage. The rings may establish a recirculation zone
20 near shield 236 and away from the fuel conduit passing through the center of the shield.

[0084] FIG. 8 depicts an embodiment of flame stabilizer 248 in shield 236. Flame stabilizer 248 is positioned at an angle over the openings. Flame stabilizer 248 may divert incoming fluid flow through openings 244 in an upstream direction. The diverted incoming fluid may set up a flow condition somewhat analogous to high swirl recirculation
25 (reverse flow). One or more stagnation zones may develop where a flame front is stable.

[0085] FIG. 9 depicts an embodiment of multiple flame stabilizers 248 in shield 236. Shield 236 may have two or more sets of openings 244 along an axial length of the shield. Rings may be positioned behind one or more of the sets of openings 244. In some embodiments, adjacent rings may cause too much gas flow interference. To inhibit gas
30 flow interference, 3 partial rings (each ring being about 1/6 the circumference) may be evenly spaced about the circumference instead of one complete ring. The next set of 3 partial rings along the axial length of heat shield may be staggered (for example, the partial rings may be rotated by 120° relative to the first set of 3 partial rings). FIG. 10 depicts a

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cross-sectional representation of shield 236 showing the last set of openings 244 and the last set of flame stabilizers 248. Shield 236 includes spacers 246. In other embodiments, fewer or more than 3 partial rings may be used (for example, two partial rings may be used for the first set of openings, and four partial rings may be used for the next set of

5 openings). Flame stabilizers 248 may be perpendicular to shield 236, angled towards openings 244, angled away from the openings (as depicted in FIG. 9) or positioned as combinations of perpendicular and angled orientations.

[0086] FIG. 11 depicts an embodiment wherein flame stabilizers 248 are deflector plates or baffles extending over all or portions of openings 244. The portions of flame stabilizers

10 248 positioned over the openings may be cylindrical sections with the concave portions facing openings 244. Flame stabilizers 248 may divert incoming fluid flow and allow the flame root area to develop around the deflectors. Some openings in the shield may not include flame stabilizers.

[0087] In some embodiments, deflectors may be positioned on the outer surface of the

15 shield near to openings in the shield. The deflectors may direct some of the gas flowing through the oxidant conduit through the openings in the shield.

[0088] In one embodiment, one or more of the oxidizers have flame stabilizers that utilize a louvered design to direct flow into the shield. FIG. 12 depicts oxidizer 214 with louvered openings 244 in shield 236. Louvered openings 244 are in communication with the

20 oxidant conduit. An extension on the inside wall of shield 236 directs gas flow into shield 236 in a direction opposite to the direction of flow in the oxidant conduit. FIG. 13 depicts a cross-sectional representation of a portion of shield 236 with louvered opening 244. Gas with oxidant entering shield 236 may be directed by extension 249 in a desired direction. Arrow 250 indicates the direction of gas flow from the oxidant conduit to the inside of

25 shield. Arrow 252 indicates the direction of gas flow in the oxidant conduit.

[0089] One or more of the oxidizers in an oxidizer assembly may be a catalytic burner. The catalytic burners may include a catalytic portion (for example, a catalyst chamber) followed by a homogenous portion (for example, an ignition chamber). Catalytic burners may be started late in an ignition sequence, and may ignite without igniters. Oxidant for

30 the catalytic burners may be sufficiently hot from upstream burners (for example, the oxidant may be at a temperature of about 370 °F (about 700 °C) if the fuel is primarily methane) so that a primary mixture would react over the catalyst in the catalyst portion and produce enough heat so that exiting products ignite a secondary mixture in the

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homogenous portion of the oxidizer. In some embodiments, the fuel may include enough hydrogen to allow the needed temperature of the oxidant to be lower. Catalysts used for this purpose may include palladium, platinum, platinum/iridium, platinum/rhodium, or mixtures thereof.

- 5 [0090] FIG. 14 depicts a cross-sectional representation of catalytic burner 254. Oxidizer may enter mix chamber 230 through openings 240. Fuel may enter mix chamber 230 from fuel conduit 218 through fuel openings 238'. Fuel and oxidizer may flow to catalyst chamber 256. Catalyst chamber 256 contains catalyst which reacts a mixture from mix chamber 230 to produce reaction products at a temperature that is sufficient to ignite fuel
- 10 and oxidant. In some embodiments, the catalyst includes palladium on a honeycomb ceramic support. The fuel and oxidant react in catalyst chamber 256 to form hot reaction products. The hot reaction products may be directed to the annular space between shield 236 and fuel conduit 218. Additional fuel enters the annular space through openings 238'' in fuel conduit 218. Additional oxidant enters the annular space through openings 244.
- 15 The hot reaction products generated by catalyst 256 may ignite fuel and oxidant in autoignition zone 258. Autoignition zone 258 may allow fuel and oxidant to form flame zone 260. In some embodiments, the catalytic burner includes flame stabilizers or other types of gas flow modifiers.

- [0091] In some embodiments a catalytic burner may include an igniter to simplify startup
- 20 procedures. FIG. 15 depicts catalytic burner 254 that includes igniter 228. Igniter 228 is positioned in mix chamber 230. Catalyst burner 254 includes catalyst chamber 256. Catalyst chamber contains a catalyst that reacts a mixture from mix chamber 230 to produce reaction products at a temperature that is sufficient to ignite fuel and oxidant. Oxidant enters mix chamber through openings 240A. Fuel enters the mix chamber from
- 25 fuel line through fuel openings 238A. The fuel input into mixture chamber 230 may be only a small fraction of the fuel input for catalytic burner 254. Igniter 228 raises the temperature of the fuel and oxidant to combustion temperatures in pre-heat zone 262. Flame stabilizer 248 may be positioned in mixing chamber 230. Heat from pre-heat zone 262 and/or combustion products may heat additional fuel that enters mixing chamber 230
- 30 through fuel openings 238B and additional oxidant that enters the mixing chamber through openings 240B. Openings 238B and openings 240B may be upstream of flame stabilizer 248. The additional fuel and oxidant are heated to a temperature sufficient to support reaction on catalyst 256.

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[0092] Heated fuel and oxidant from mixing chamber 230 pass to catalyst 256. The fuel and oxidant react on catalyst 256 to form hot reaction products. The hot reaction products may be directed to heat shield 236. Additional fuel enters heat shield 236 through openings 238C in fuel conduit 218. Additional oxidant enters heat shield 236 through openings 244. The hot reaction products generated by catalyst 256 may ignite fuel and oxidant in autoignition zone 258. Autoignition zone 258 may allow fuel and oxidant to form main combustion zone 260. In some embodiments, the catalytic burner includes flame stabilizers or other types of gas flow modifiers.

[0093] In some embodiments, all of the oxidizers in the oxidizer assembly are catalytic burners. In some embodiments, the first or the first several oxidizers in the oxidizer assembly are catalytic burners. The oxidant supplied to these burners may be at a lower temperature than subsequent burners. Using catalytic burners with igniters may stabilize the first performance of the first several oxidizers in the oxidizer assembly. Catalytic burners may be used in-line with other burners to reduce emissions by allowing lower flame temperatures while still having substantially complete combustion.

[0094] In some embodiments, a catalytic converter may be positioned at the end of the oxidizer assembly or in the exhaust gas return. The catalytic converter may remove unburned hydrocarbons and/or remaining NOx compounds or other pollutants. The catalytic converter may benefit from the relatively high temperature of the exhaust gas. In some embodiments, catalytic burners in series may be integrated with coupled catalytic converters to limit undesired emissions from the oxidizer assembly. In some embodiments, a selectively permeable material may be used to allow carbon dioxide or other fluids to be separated from the exhaust gas.

[0095] In some embodiments, a flameless distributed combustor may be the front and/or back burner. Having a flameless distributed combustor as the front burner may stabilize the front burner and provide heated oxidant to the next oxidizer. Having a flameless distributed combustor as the back burner may ensure that the exhaust is depleted in case one or more of the oxidizers flame out.

[0096] In some embodiments, the igniters may be removable or retractable from the flame after ignition. The igniter may be placed in a sheath or pulled back from the flame. Having the ability to remove or retract the igniters may extend the life of the igniters and provide for a more reliable system should one or more of the oxidizers need to be restarted.

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[0097] The spacing of the oxidizers in an oxidizer assembly may be varied. The spacing may be varied to accommodate rich and lean portions of the formation. In some embodiments, the heat duty of selected oxidizers may be increased by using ceramic parts inside the oxidizers. Increasing the heat duty may simplify the overall design and/or
5 permit a system with fewer burners.

[0098] In some embodiments, the fuel line may be located adjacent to the oxidizers. A separate line would need to be routed from the fuel line to each oxidizer. Air shields would be needed to shield and stabilize the flame due to the high gas flow requirements. Also, shielding may be needed to protect oxidizer components.

10 [0099] Further modifications and alternative embodiments of various aspects of the invention may be apparent to those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as
15 the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the
20 invention as described in the following claims. In addition, it is to be understood that features described herein independently may, in certain embodiments, be combined.

CLAIMS

1. A gas burner assembly for heating a subsurface formation, comprising:
 - an oxidant conduit;
 - 5 a fuel line positioned in the oxidant conduit; and
 - a plurality of oxidizers coupled to the fuel conduit, wherein at least one of the oxidizers includes:
 - a mix chamber for mixing fuel from the fuel conduit with a oxidizing fluid;
 - an igniter;
 - 10 an ignition chamber;
 - a shield, wherein the shield comprises a plurality of openings in communication with the oxidant conduit; and
 - at least one flame stabilizer coupled to the shield.
2. The assembly as claimed in claim 1, further comprising a water conduit coupled to the
- 15 fuel conduit, the water conduit configured to deliver water that inhibits coking of fuel to the fuel conduit before a first oxidizer in the gas burner assembly.
3. The assembly of claim 1, wherein a flame stabilizer comprises a ring.
4. The assembly of claim 1, wherein a flame stabilizer comprises a partial ring.
5. The assembly of claim 1, wherein a flame stabilizer comprises a ring that angles at least
- 20 partially over one or more of the openings.
6. The assembly of claim 1, wherein a flame stabilizer comprises a ring that angles away from one or more of the openings.
7. The assembly of claim 1, wherein a flame stabilizer comprises a rounded deflector.
8. The assembly of claim 1, wherein a flame stabilizer comprises a louvered opening in
- 25 the shield with an extension that directs gas entering the shield in a desired direction.
9. A gas burner assembly for heating a subsurface formation, comprising:
 - an oxidant conduit;
 - a fuel conduit positioned in the oxidant conduit; and
 - a plurality of oxidizers coupled to the fuel conduit, wherein at least one of the
 - 30 oxidizers includes:
 - a mix chamber for mixing fuel from the fuel conduit with oxidizing fluid;
 - an catalyst chamber configured to produce hot reaction products to ignite fuel and oxidizing fluid;

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an ignition chamber; and

a shield, wherein the shield comprises a plurality of openings in communication with the oxidant conduit.

10. The assembly as claimed in claim 9, further comprising a water conduit coupled to the fuel conduit, the water line configured to deliver water that inhibits coking of fuel to the fuel conduit before a first oxidizer in the gas burner assembly.

11. The assembly as claimed in claims 9 or 10, wherein a catalyst in the catalyst chamber comprises palladium on a ceramic support.

12. The assembly as claimed in claims 9-11, further comprising one or more rings coupled to an inside surface of the shield as a flame stabilizer.

13. The assembly as claimed in claims 9-11, further comprising a plurality of partial rings coupled to an inside surface of the shield as a flame stabilizer.

14. The assembly as claimed in claims 9-11, further comprising one or more rings coupled to an inside surface of the heat shield, wherein at least one ring is angled relative to the shield so that the ring extends towards one or more of the openings adjacent to the ring.

15. The assembly as claimed in claims 9-11, further comprising a plurality of rounded deflectors coupled to an inside surface of the shield downstream of one or more of the openings as flame stabilizers.

16. A gas burner assembly for heating a subsurface formation, comprising:

an oxidant conduit;

a fuel line positioned in the oxidant conduit; and

a plurality of oxidizers coupled to the fuel conduit, wherein at least one of the oxidizers includes:

a mix chamber for mixing fuel from the fuel conduit with oxidizing fluid;

an igniter in the mix chamber configured to ignite fuel and oxidizing fluid to preheat fuel and oxidizing fluid;

a catalyst chamber configured to react preheated fuel and oxidizing fluid from the mix chamber to produce hot reaction products to ignite fuel and oxidizing fluid;

an ignition chamber; and

a shield, wherein the shield comprises a plurality of openings in communication with the oxidant conduit.

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17. The assembly as claimed in claims 16, further comprising a water conduit coupled to the fuel conduit, the water line configured to deliver water that inhibits coking of fuel to the fuel conduit before a first oxidizer in the gas burner assembly.
18. The assembly as claimed in claims 16 or 17, wherein a catalyst in the catalyst chamber
5 comprises palladium on a ceramic support.
19. The assembly as claimed in claims 16-19, further comprising one or more rings coupled to an inside surface of the shield as a flame stabilizer.
20. The assembly as claimed in claims 16-19, further comprising a plurality of partial rings coupled to an inside surface of the shield as a flame stabilizer.
- 10 21. The assembly as claimed in claims 16-19, further comprising one or more rings coupled to an inside surface of the heat shield, wherein at least one ring is angled relative to the shield so that the ring extends towards one or more of the openings adjacent to the ring.

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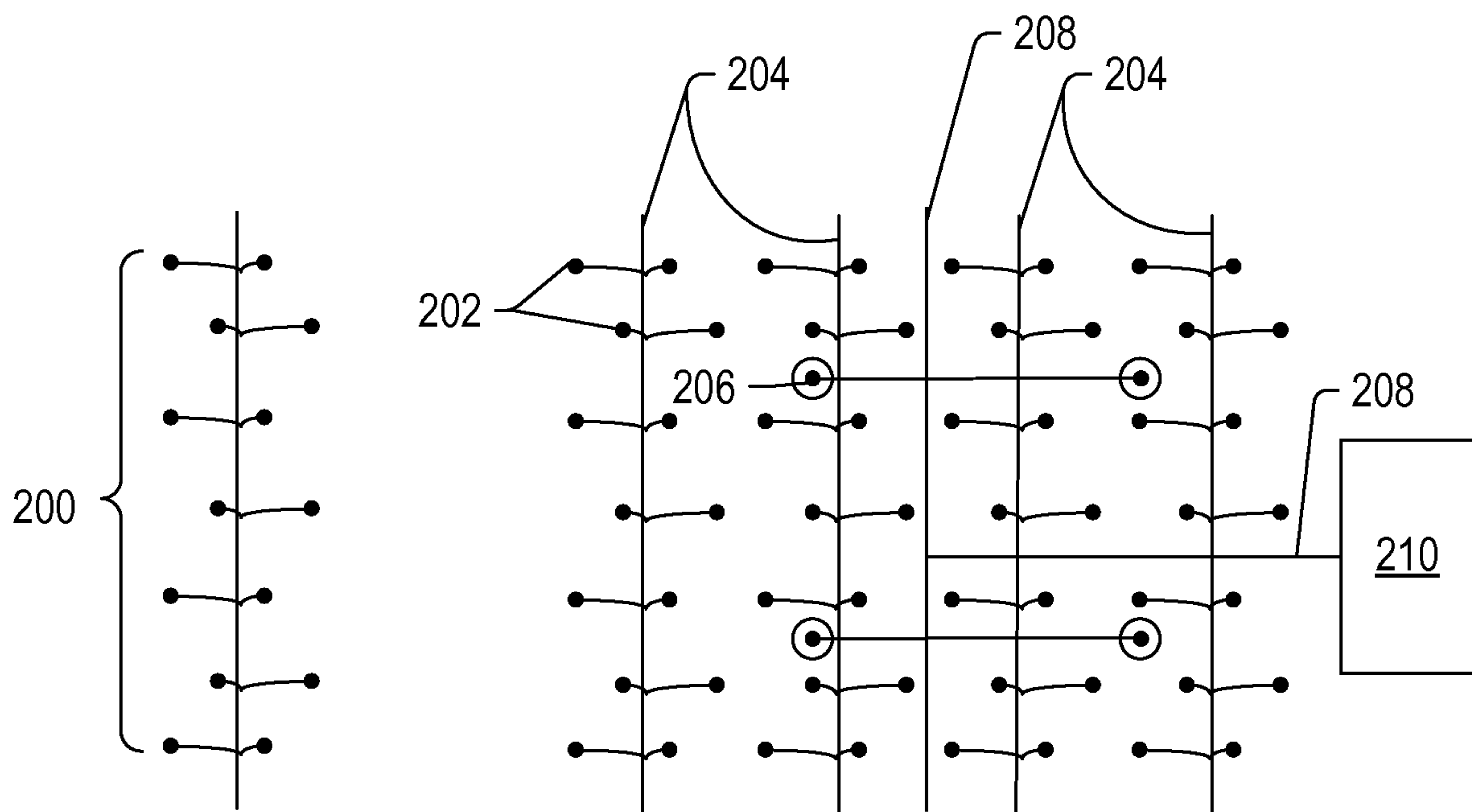
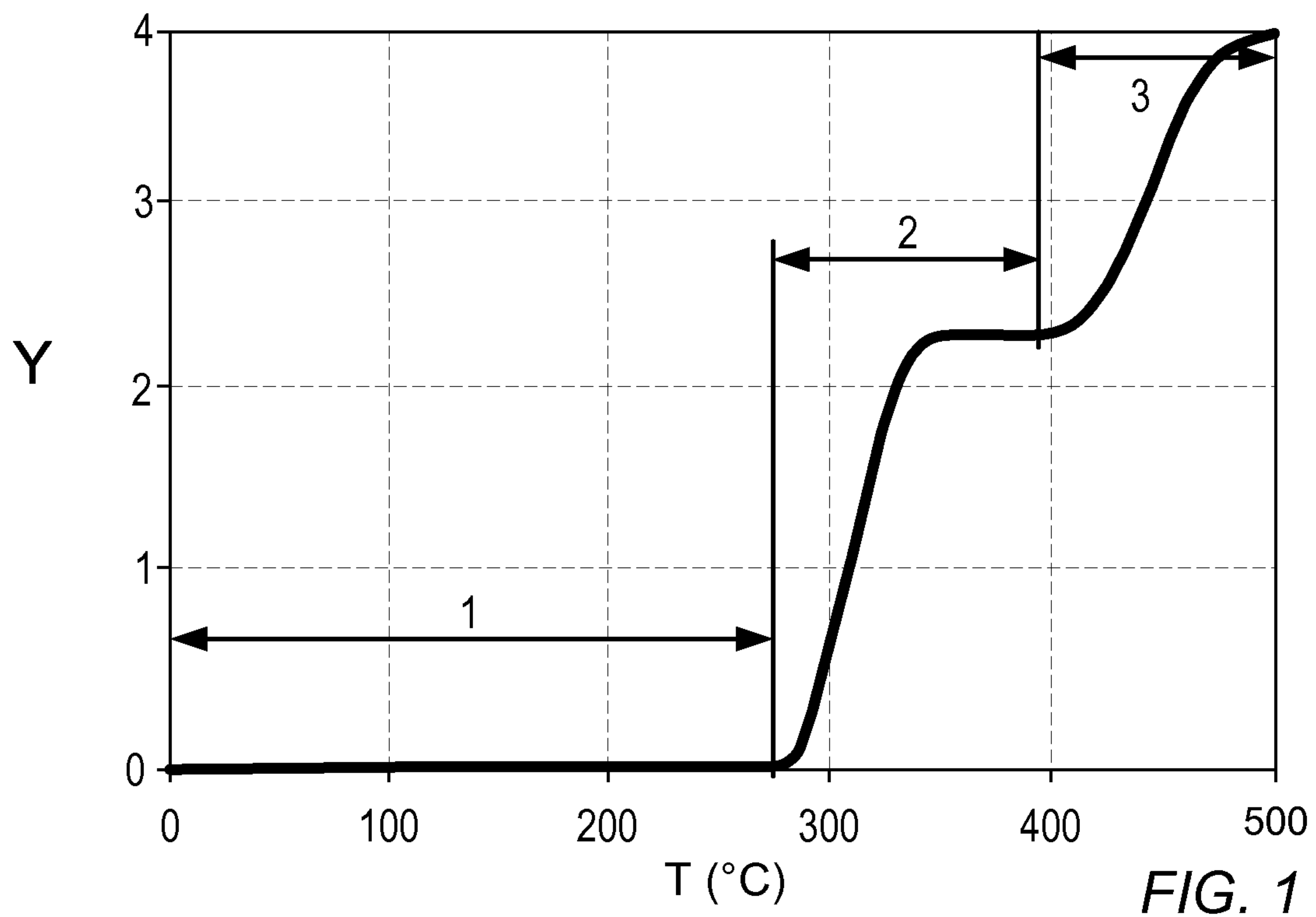
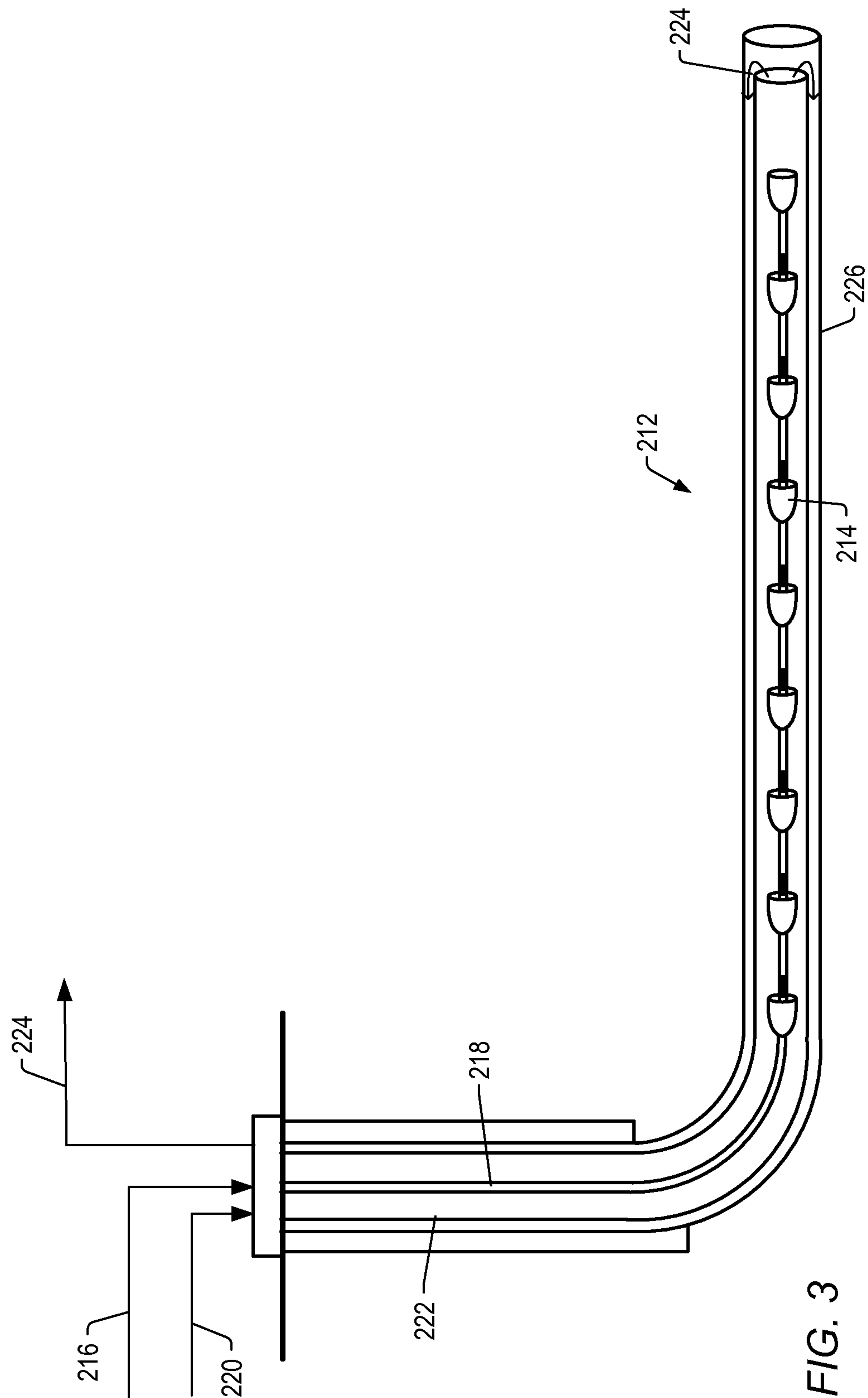


FIG. 2



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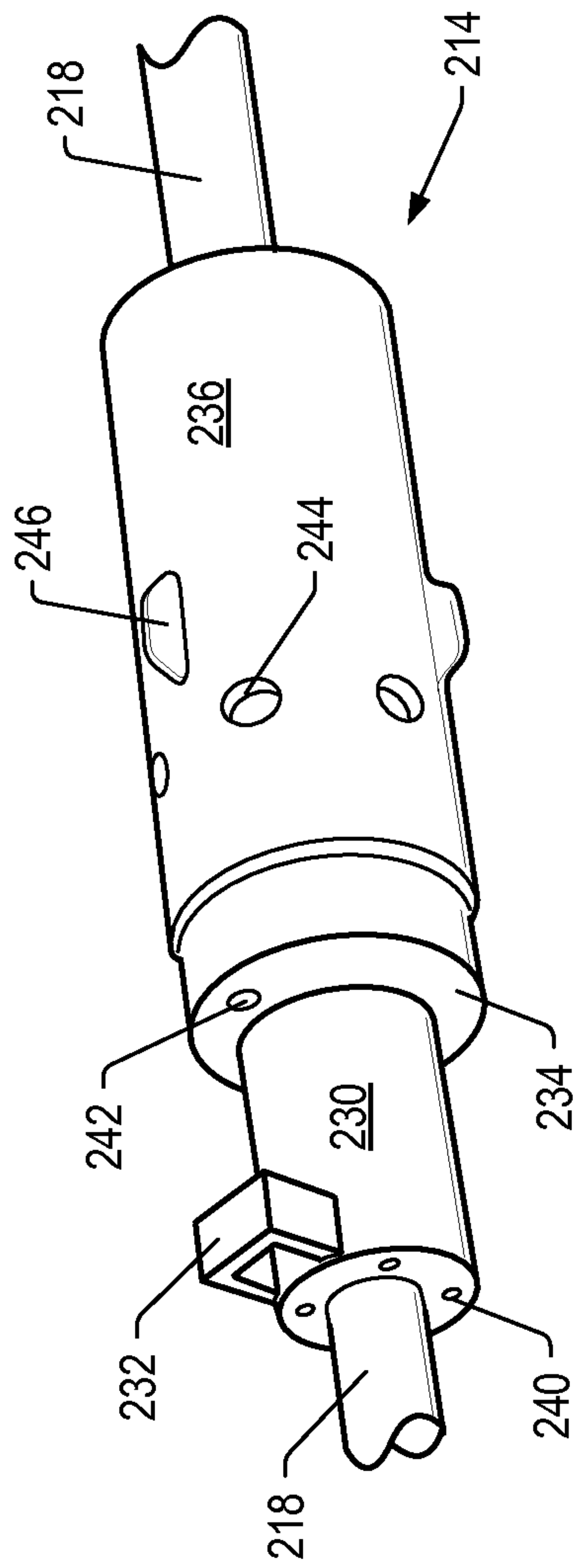


FIG. 4

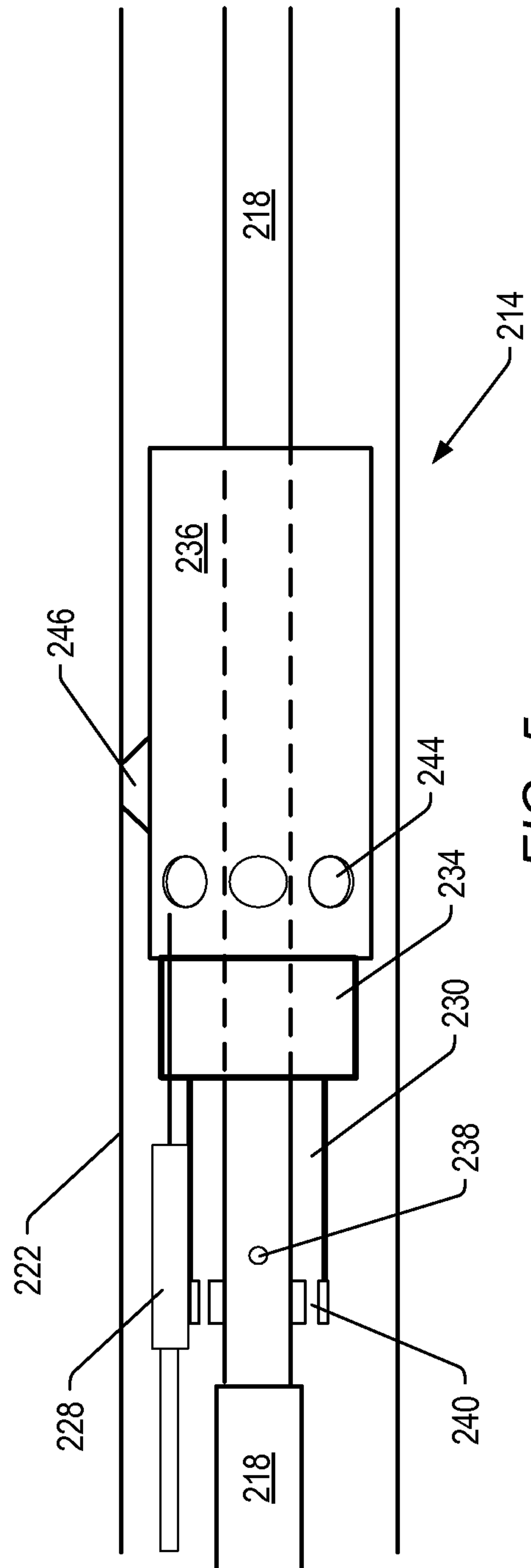


FIG. 5

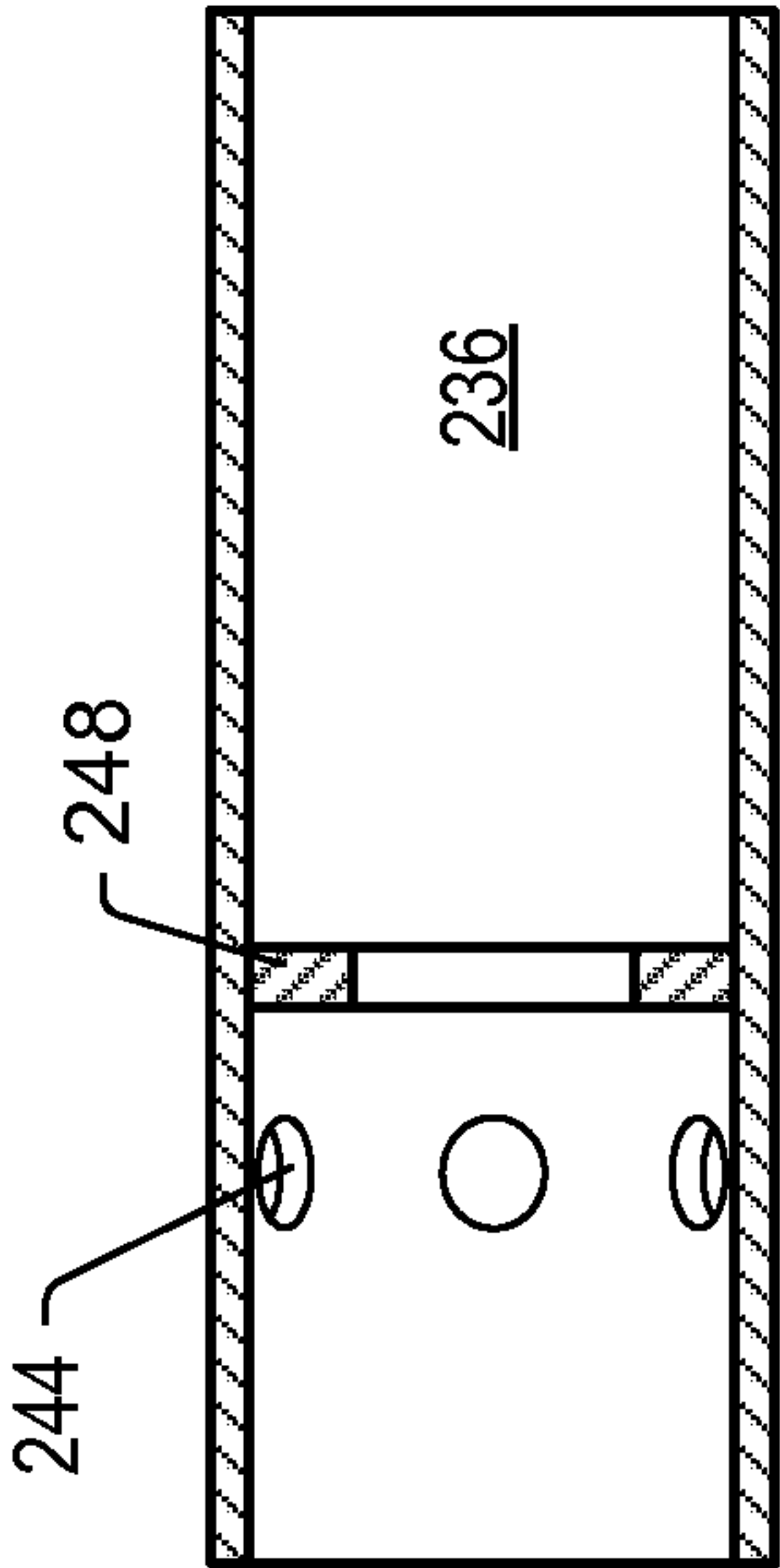


FIG. 6

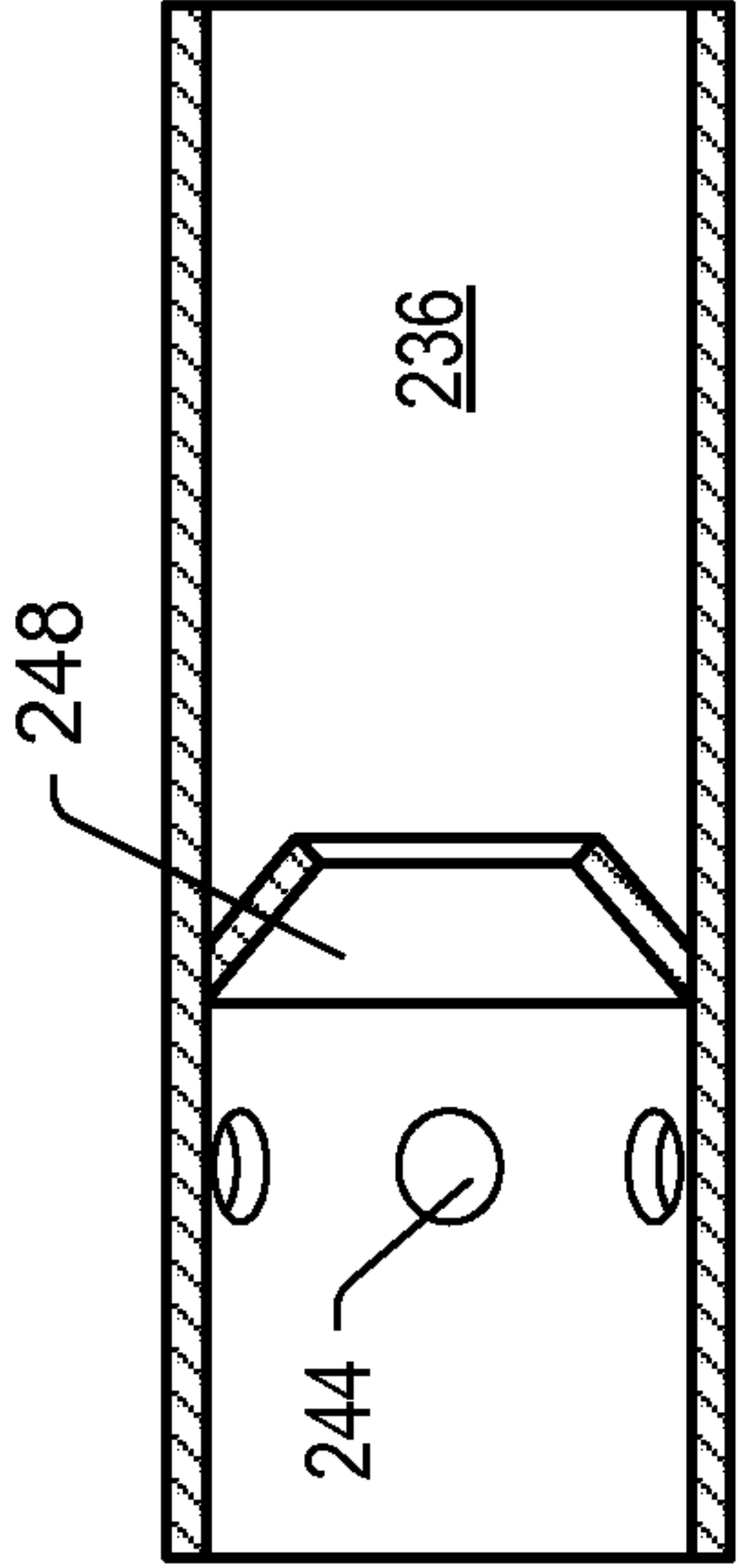


FIG. 7

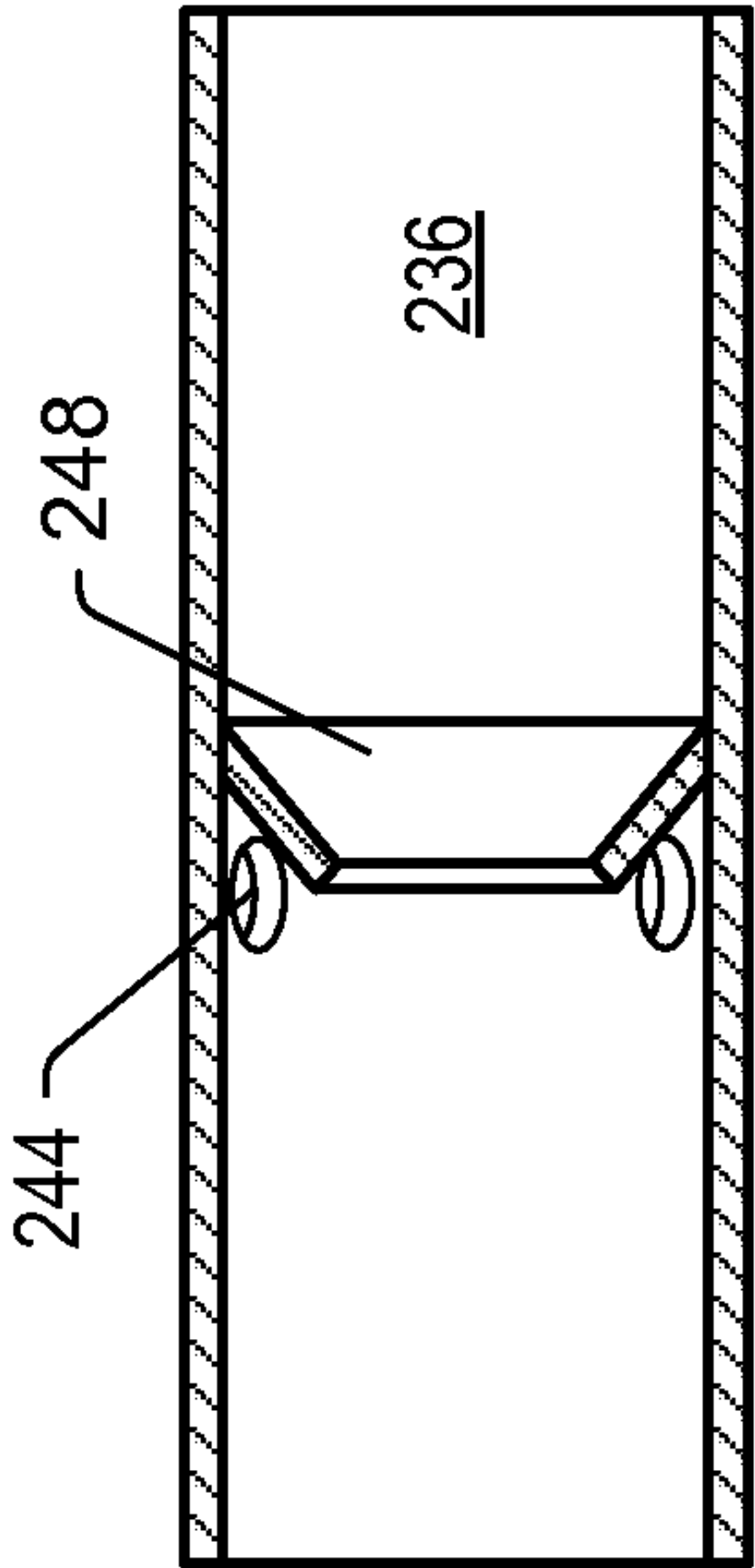


FIG. 8

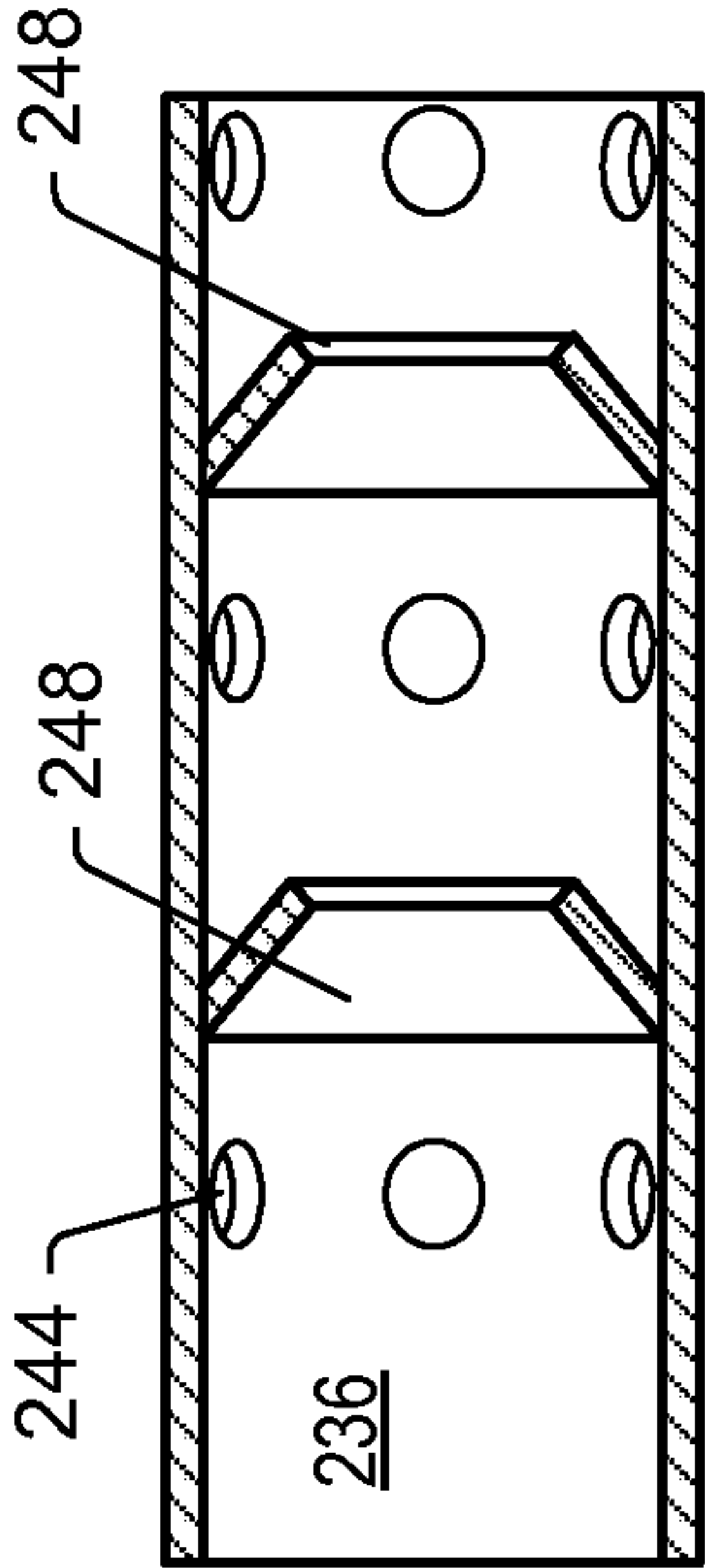


FIG. 9

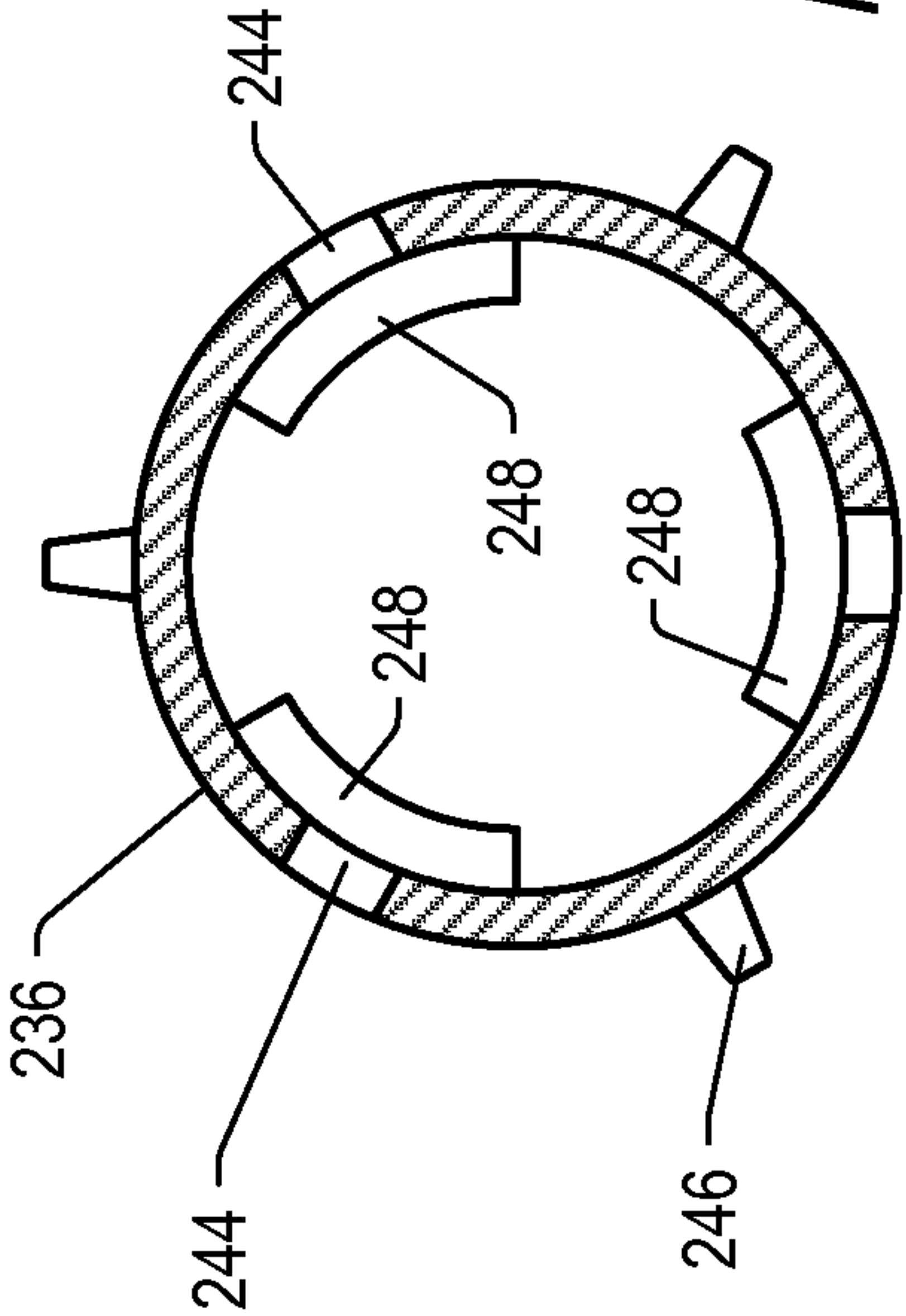


FIG. 10

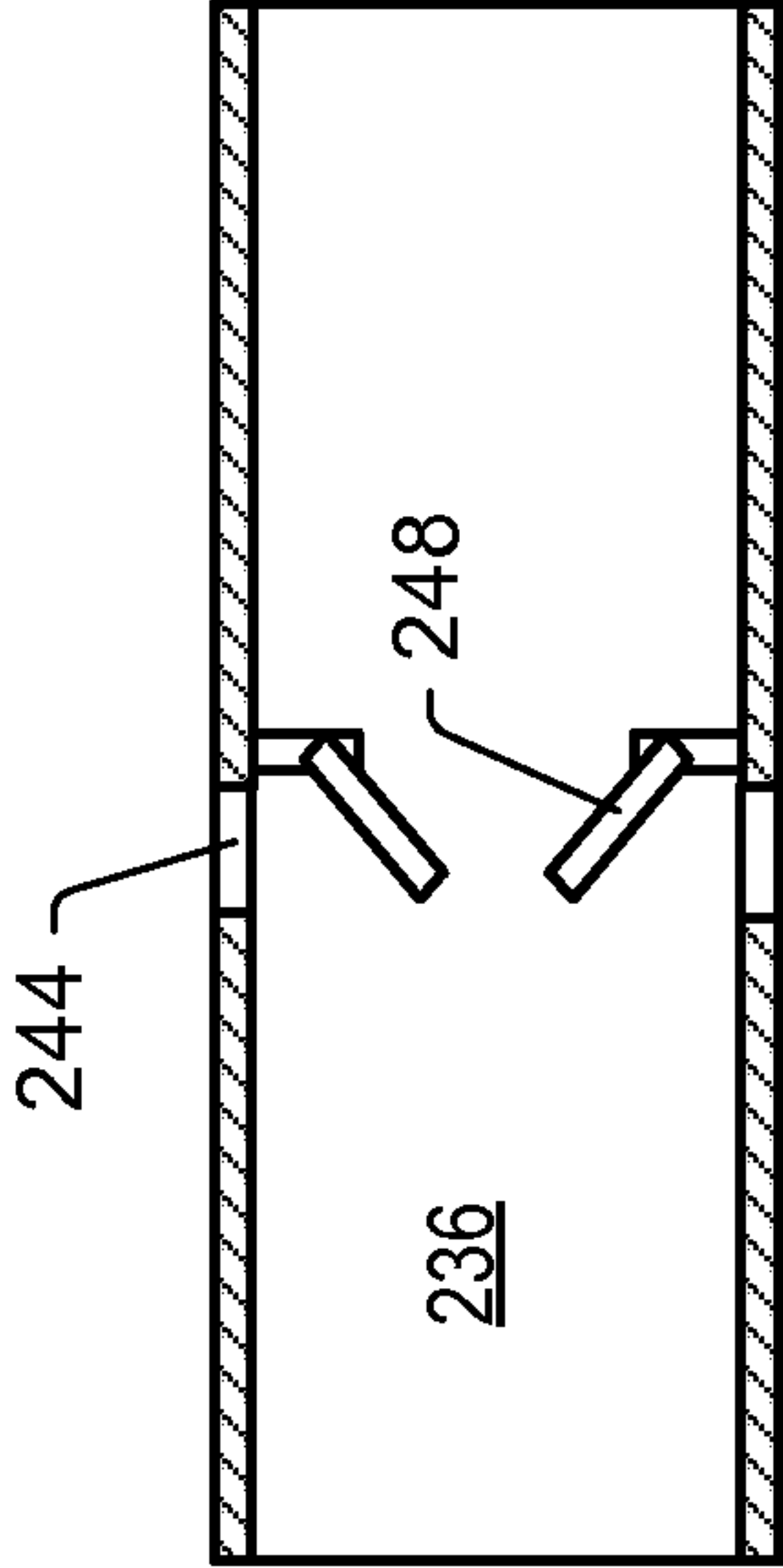


FIG. 11

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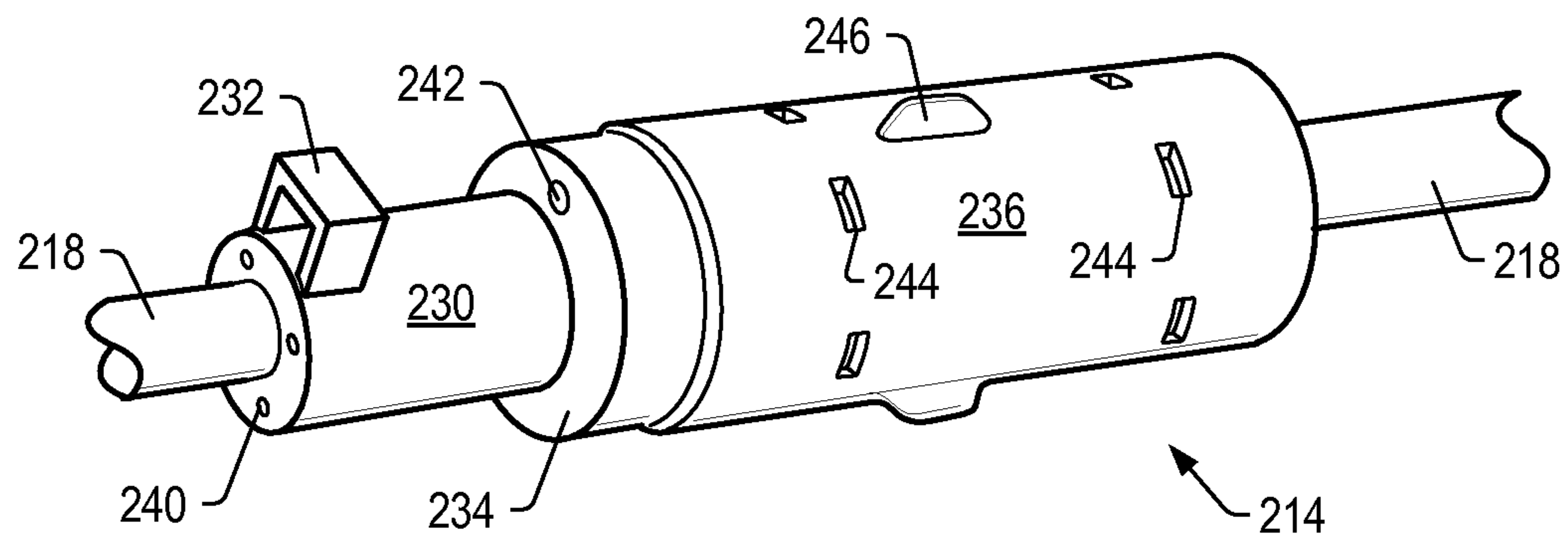


FIG. 12

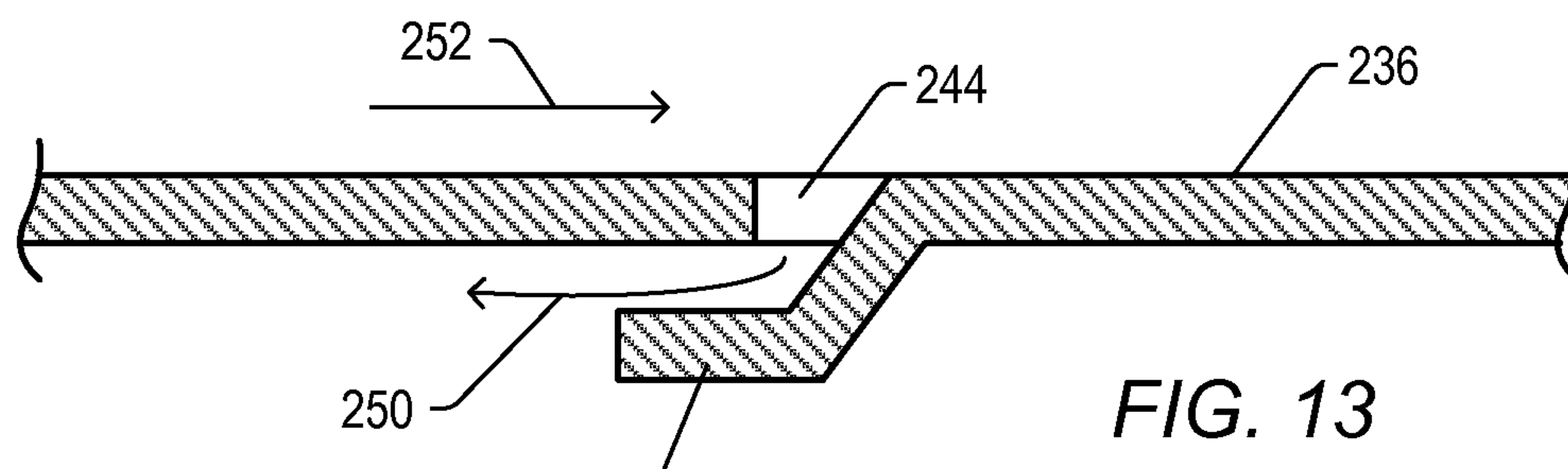


FIG. 13

