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(54) **METHOD OF HEATING HYDROCARBONS**

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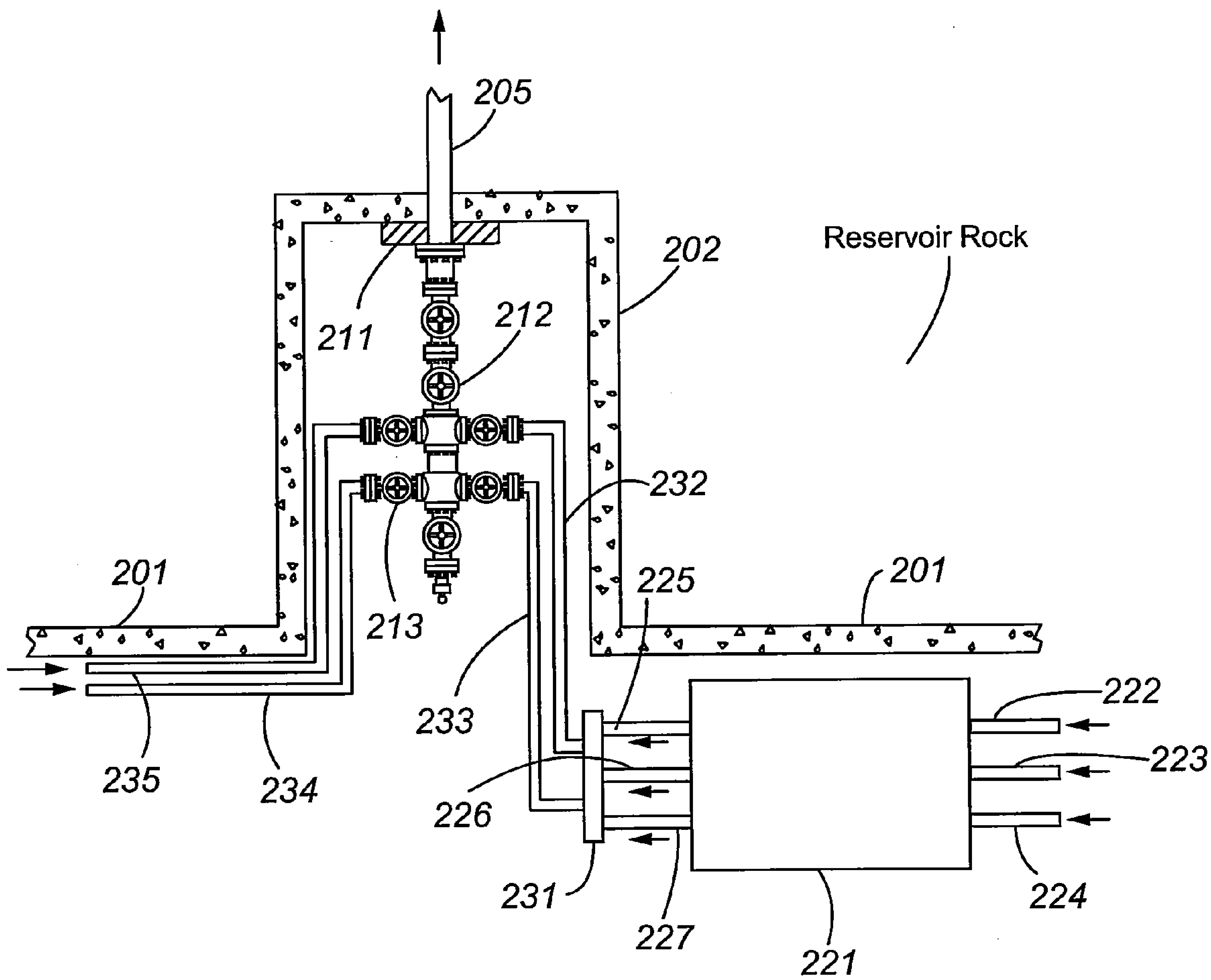
(57) **ABSTRACT**

The present invention relates generally to a method and means of injecting hot fluids into a hydrocarbon formation using a combustion and steam generating device installed at or near the well-head of an injector well. The various embodiments are directed generally to substantially increasing energy efficiency of thermal recovery operations by efficiently utilizing the energy of the combustion products and waste heat from the generator. The generator apparatuses can be installed at the well-head which, in turn, can be located close to the producing formation. The combustion products may be injected into a well along with steam or sequestered at another location.



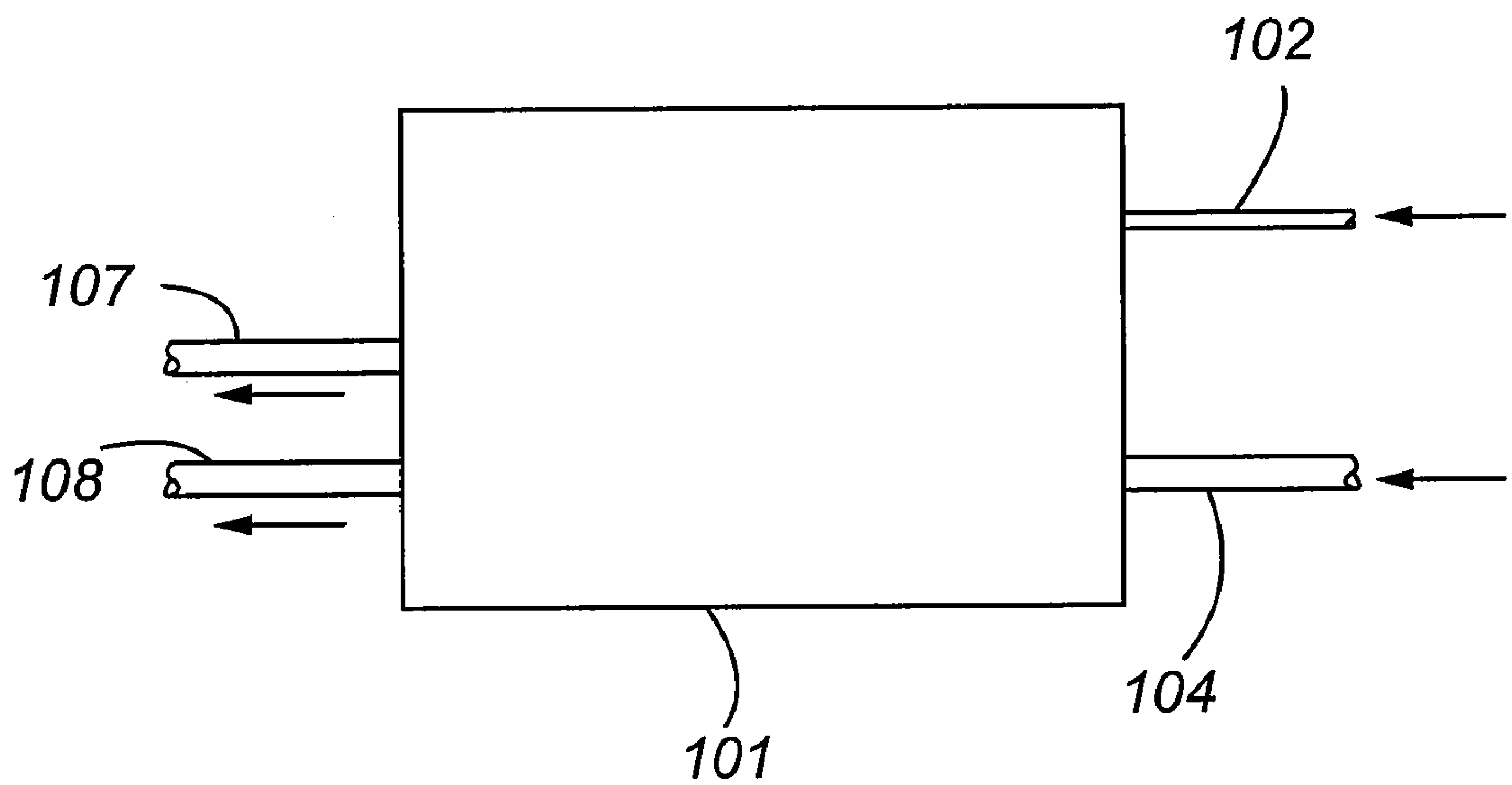


Fig. 1A

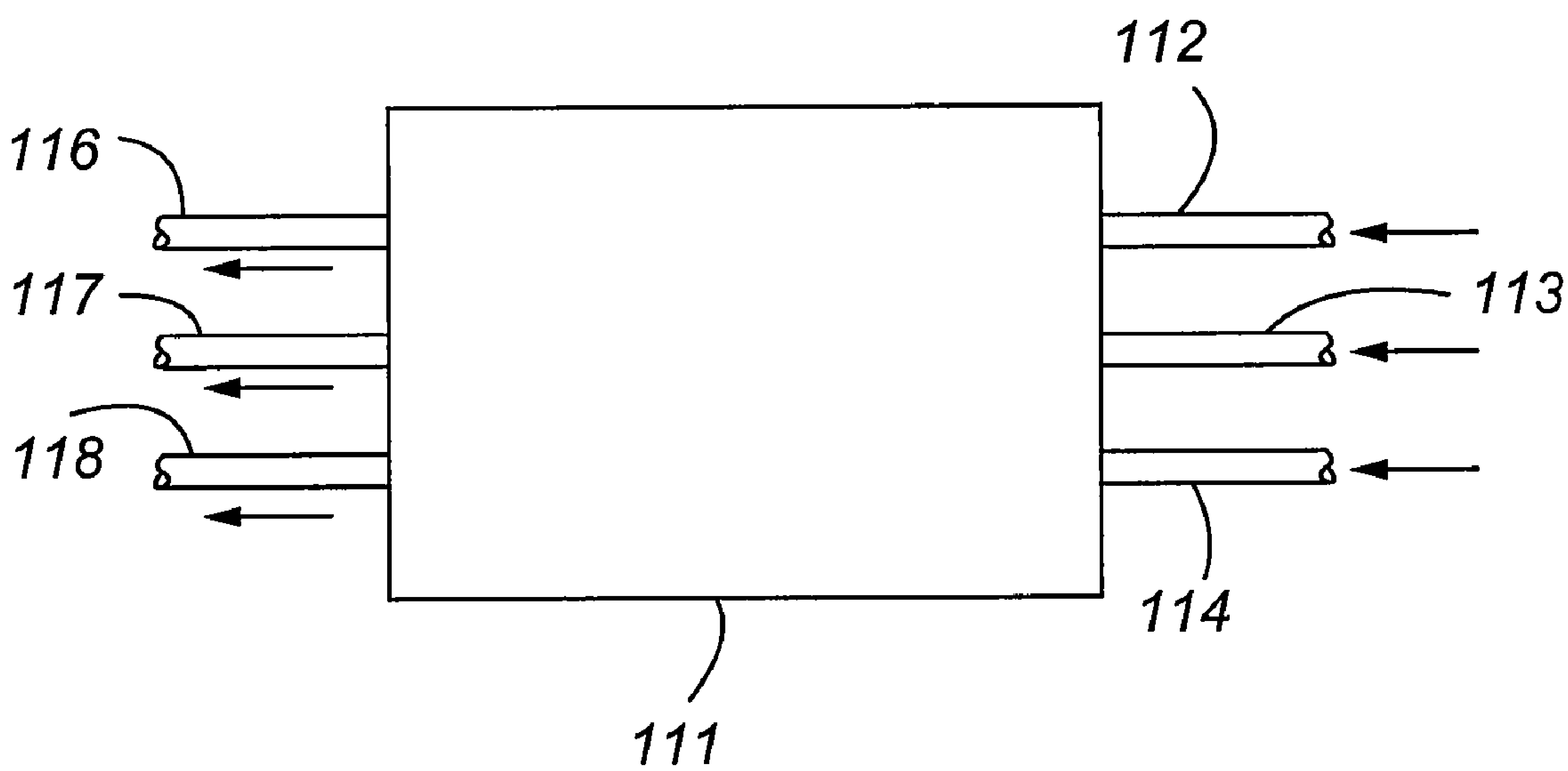


Fig. 1B

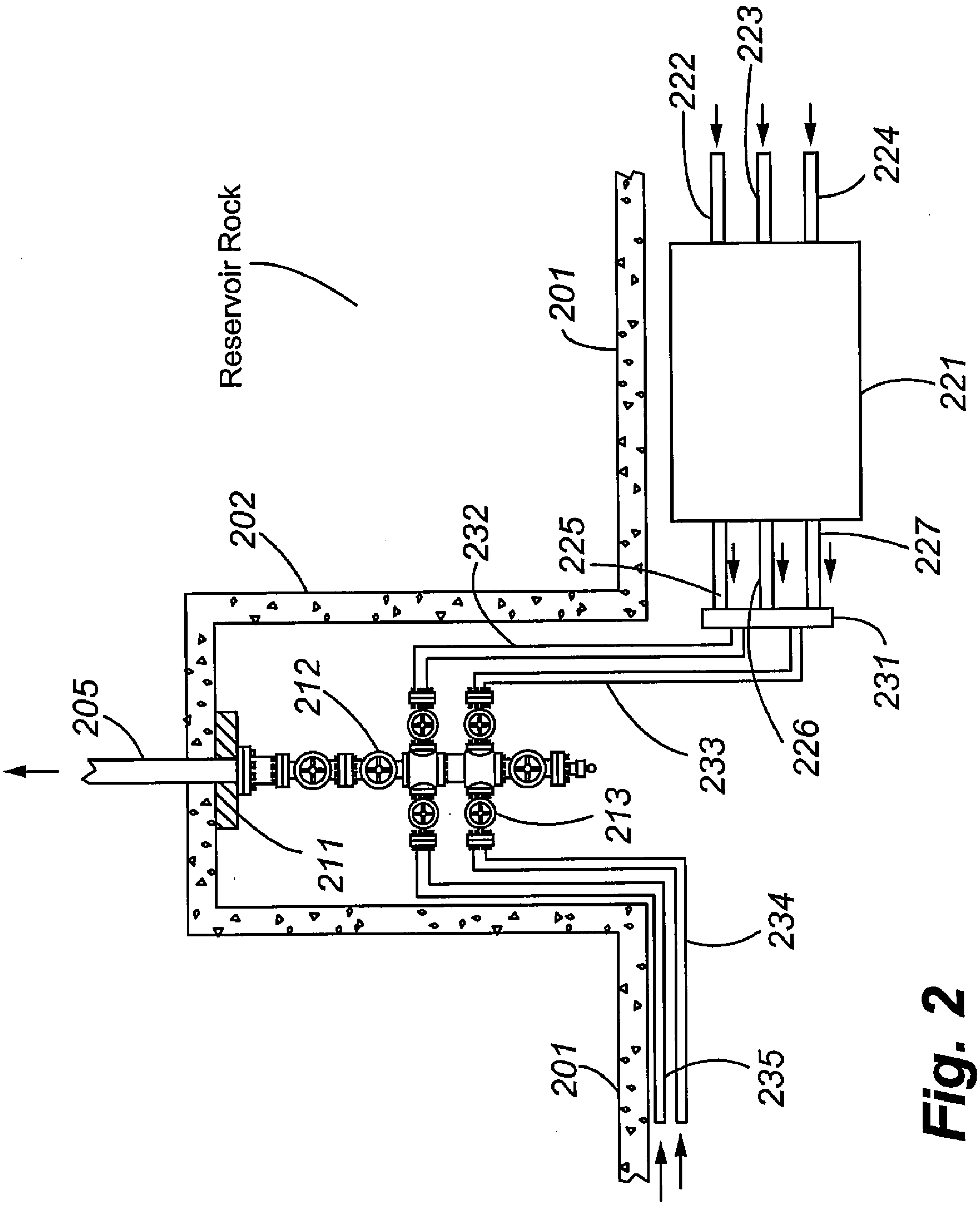

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Fig. 2

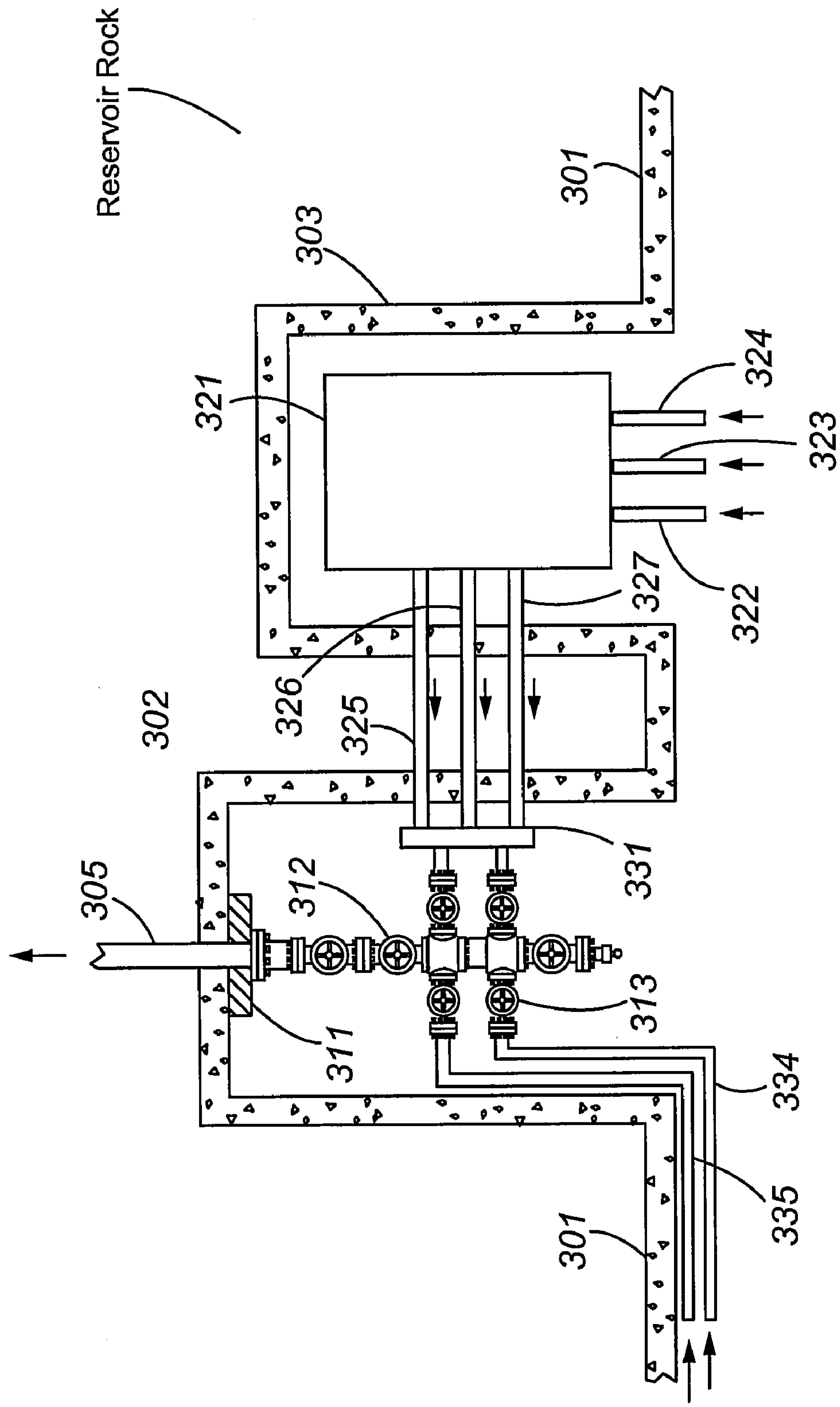
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Fig. 3

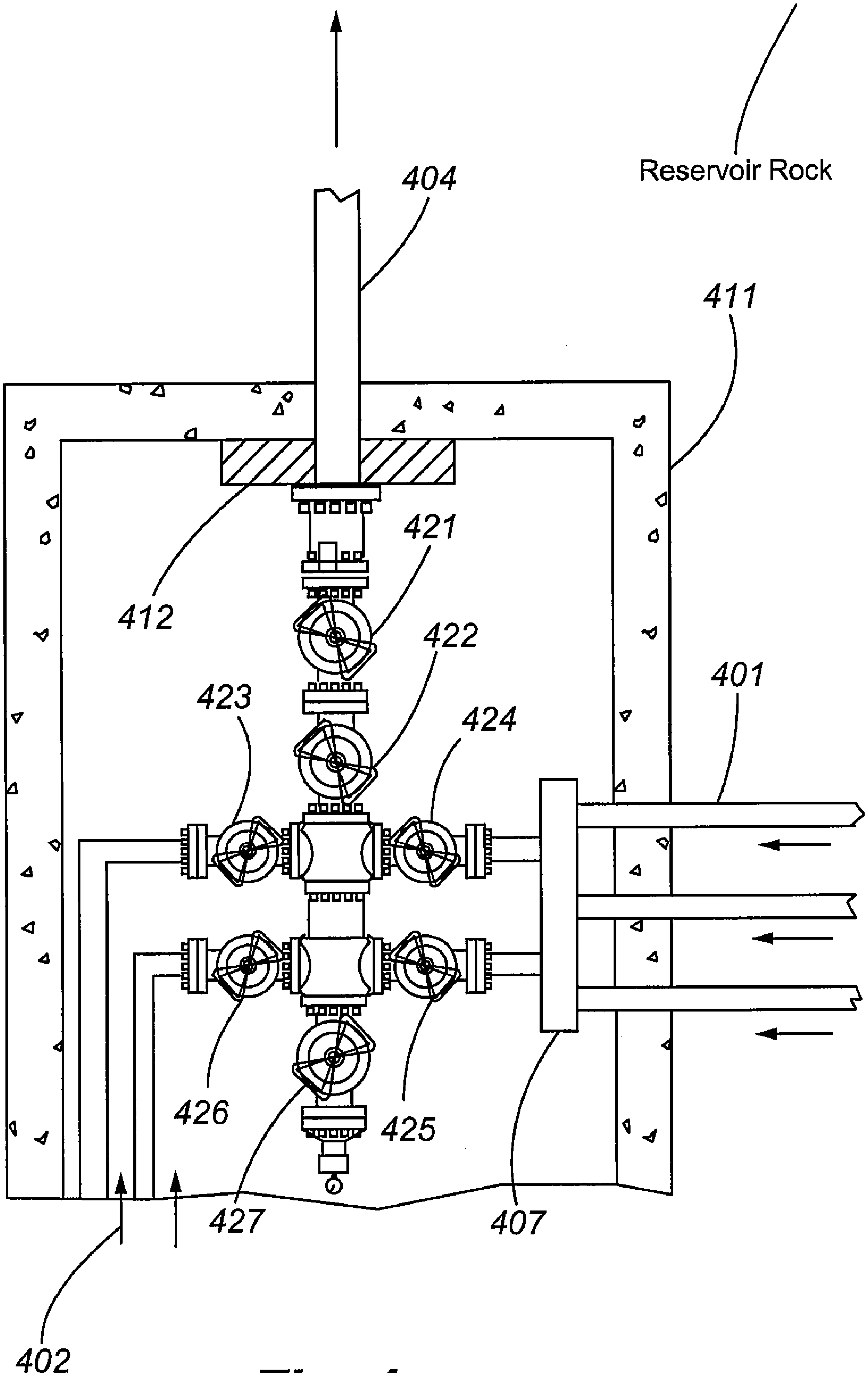
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Fig. 4

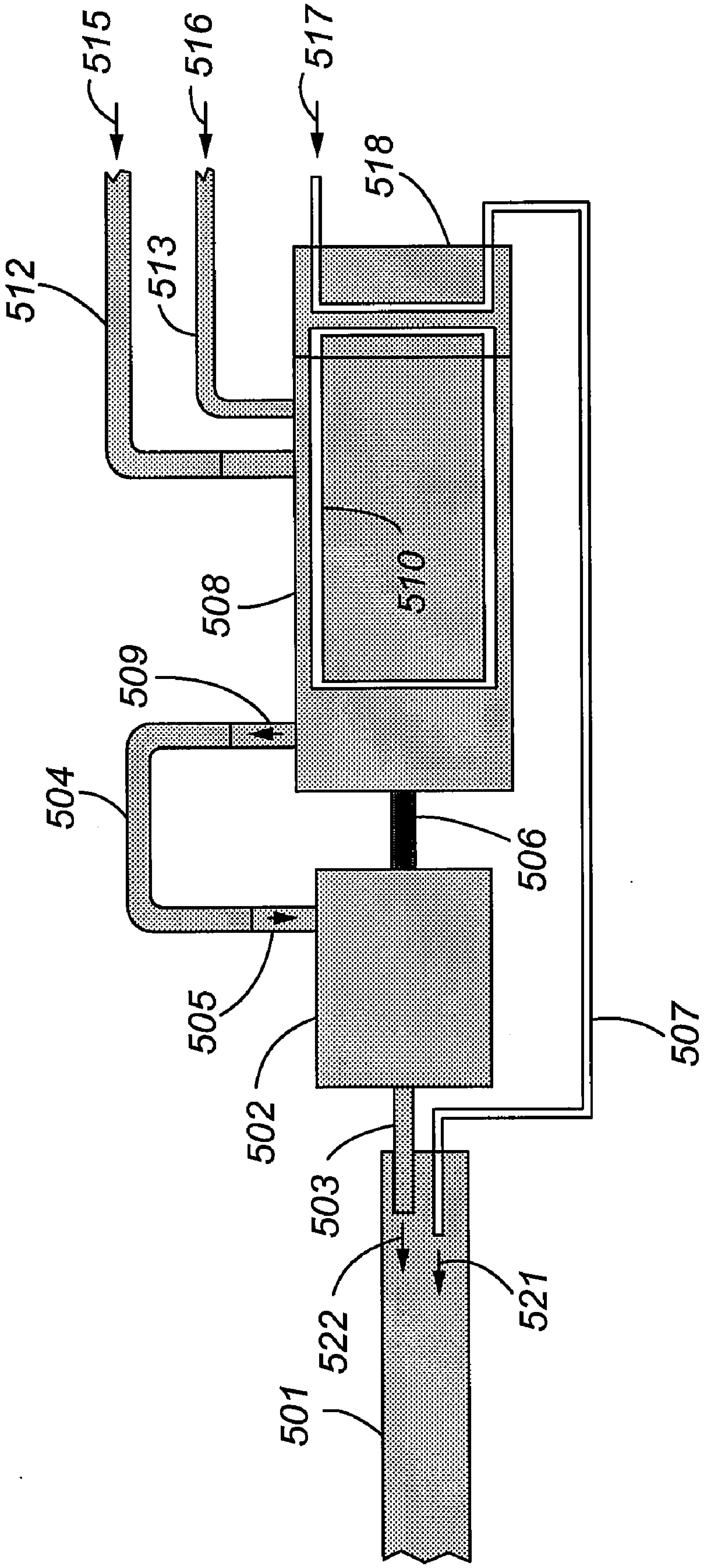
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Fig. 5

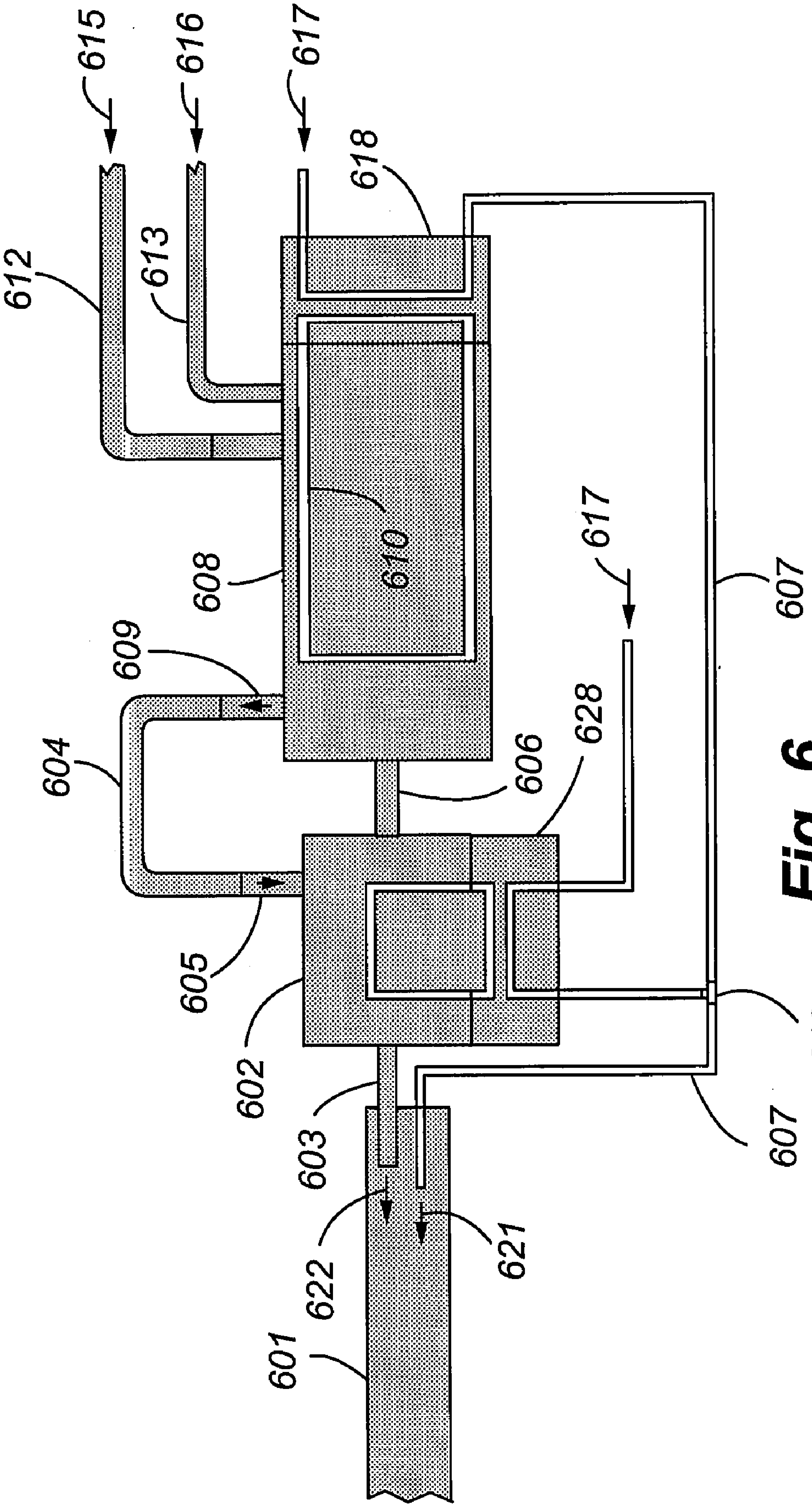
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Fig. 6

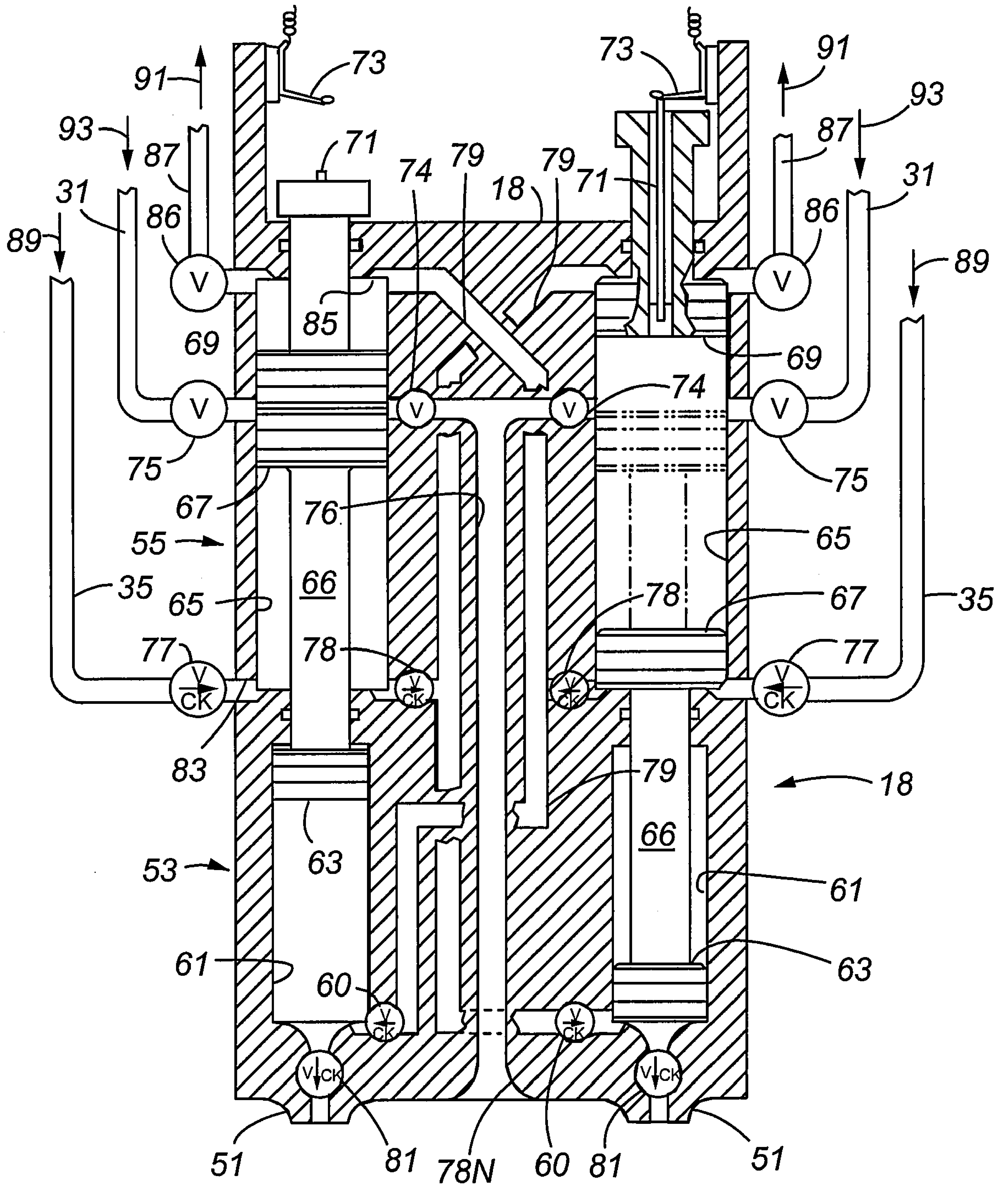

Fig. 7

Prior Art

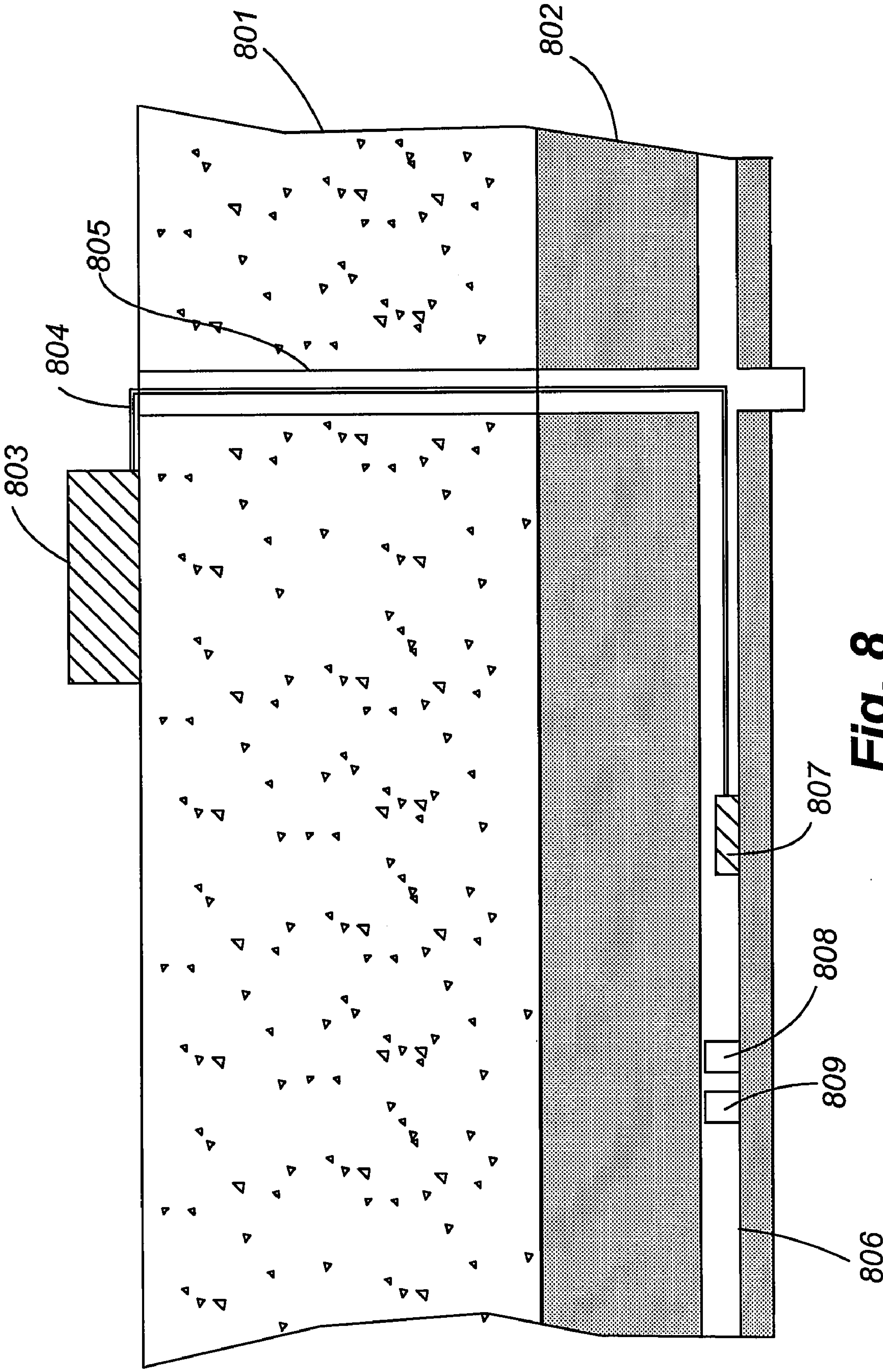

Fig. 8

METHOD OF HEATING HYDROCARBONS

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefits, under 35 U.S.C. §119(e), of U.S. Provisional Application Ser. No. 60/827,608 filed Sep. 29, 2006, entitled "Method of Heating Hydrocarbons" to Brock, Donnelly, Kobler, Squires and Watson which is incorporated herein by these references.

[0002] Cross reference is made to U.S. patent application Ser. No. 11/737,578 filed Apr. 19, 2006 entitled "Method of Drilling from a Shaft" and U.S. patent application Ser. No. 11/441,929 filed May 25, 2006, entitled "Method for Underground Recovery of Hydrocarbons", both of which are also incorporated herein by this reference.

FIELD

[0003] The present invention relates generally to a method and means of injecting hot fluids into a hydrocarbon formation using a combustion and steam generating device installed at or near the well-head of an injector well.

BACKGROUND

[0004] Oil is a nonrenewable natural resource having great importance to the industrialized world. The increased demand for and decreasing supplies of conventional oil has led to the development of alternate sources of oil such as deposits of heavy crude and bitumen and to a search for more efficient methods for recovery from such hydrocarbon deposits.

[0005] Examples of efficient method for recovery methods of unconventional oil deposits are the Steam Assisted Gravity Drain ("SAGD") process which uses steam as the fluid injected into the hydrocarbon formation and the VAPEX process which uses a diluent as the fluid injected into the hydrocarbon formation. In both methods, horizontal well pairs are typically installed at the bottom of a heavy oil or bitumen reservoir. A well pair is typically comprised of a first well which may be a steam or diluent injector well and a second well which may be a fluid collector well. The horizontal portion of the injector well is commonly installed above the producer well, separated by about 1 to about 5 meters. A mobilizing fluid is introduced into the injector well and injected into the heavy oil or bitumen formation where it is used to heat or dilute the heavy oil or bitumen in order to mobilize (reduce its viscosity) and allow the hydrocarbon to flow more readily (such as the case for heavy crude) or flow at all (the case for bitumen which is normally an in-situ solid).

[0006] When steam is used as the injected fluid, it is typically generated in a large boiler on the surface and is typically transmitted by an insulated piping system to a manifold feeding six or eight near-by wells for injection into the formation. The injected steam must travel from the surface down to a horizontal section of the well in the hydrocarbon deposit where it is forced by pressure into the formation through many narrow slits in the horizontal portion of the well pipe.

[0007] The SAGD method has been applied to heavy oil and bitumen recovery with varying degrees of success, both in terms of total recovery factor and economics. A SAGD operation may be characterized by its Steam-Oil-Ratio ("SOR") which is a measure of how much steam is used to recover a barrel of heavy oil or bitumen (the SOR is determined by the number of barrels of water required to produce the steam divided by the number of barrels of oil or bitumen recovered). Thus, an SOR of 3 means that 3 barrels of water are required to be injected as steam to recover 1 barrel of oil or bitumen). This ratio is often determined by geological factors within the reservoir and therefore may be beyond the control of the operator. Examples of these geological factors are clay, mudstone or shale lenses that impede the migration of steam upwards and the flow of mobilized oil downwards; or thief zones comprised of lenses of formation waters. An acceptable SOR may be in the range of 2 to 3 whereas an uneconomical SOR is commonly 3 or higher. In addition to good reservoir geology, a low SOR reflects good energy efficiency in the use of steam. If steam could be generated and delivered to the formation at significantly higher efficiencies than is currently achieved, then SAGD operations characterized by high average SOR would become more economically viable, even if the geology of the reservoir remains non-optimal.

[0008] In current practice, steam is generated in a large boiler or boilers located on the surface. Boilers powered by natural gas, for example, have efficiencies in the range of about 75% to 90%. The remainder of the energy consumed by the boiler is typically scrubbed and released into the atmosphere as flue gases. These flue gases not only add to local air pollution and greenhouse gases but represent lost energy. The generated steam typically loses an additional 10% to 20% of its energy as it is transmitted from the boiler downhole to the horizontal section of the SAGD injectors. For example, if a boiler is 80% efficient and there are an additional 15% transmission losses, then only 68% of the fuel energy consumed by the boiler is delivered into the formation in the form of hot steam. Some of the remaining 32% of waste energy may be used to generate electrical energy by any number of co-generation methods.

[0009] Another technology proposed for recovery of hydrocarbons, including heavy oil and bitumen, is based on mining for access to the producing formation. For example, a system of underground shafts and tunnels has been proposed to allow wells to be installed from under or from within a reservoir. This approach overcomes a number of problems such as surface access, product lifting difficulties and reliability of downhole pumps. In these mining for access technologies, the wellhead and its associated equipment is readily accessible and is typically in close proximity to the formation. Also, the wells are installed from the underground workspace either horizontally or inclined upwards. A discussion of these mining for access methods can be found in U.S. patent application Ser. No. 11/737,578 filed Apr. 19, 2006 entitled "Method of Drilling from a Shaft" and U.S. patent application Ser. No. 11/441,929 filed May 25, 2006, entitled "Method for Underground Recovery of Hydrocarbons".

[0010] Installing wells from an underground workspace opens up possibilities for improving steam generation efficiencies. For example, the steam boilers may be installed underground, shortening the transmission distances and thereby reducing transmission losses. The combustion products from these boilers may be captured and injected into the producing formation or into an underground sequestering repository if the geology is favorable.

[0011] Reference 1 ("Thermal Recovery of Oil and Bitumen" by Roger M. Butler) describes several methods and devices for downhole (located in the well itself) steam generation including devices that inject their products of combustion into the formation along with steam. If these devices are installed downhole near the entrance to the horizontal injection section, then they are difficult to service because they have to be withdrawn to the surface or they can cause a production shut down if they fail while in service. If these devices are installed on the surface at the well-head, then they are subject to transmission losses in the portion of the well connecting the surface to the underground horizontal. Additionally, these devices are generally not be able to generate sufficient power to produce the quantity and quality of steam required for a stimulation of a SAGD well that may produce several hundred barrels of oil per day.

[0012] There remains, therefore, a need for a method and system to: (1) reduce or eliminate the energy losses from the process of energizing and transmitting the injection fluids; (2) eliminating greenhouse gas emissions; and (3) maintain the ability to rapidly service or replace steam generation equipment without disrupting well injection and production operations. There also remains a need for large horsepower steam generators that can utilize untreated water and utilize technology that can reduce capital costs of the steam generating function.

SUMMARY

[0013] These and other needs are addressed by the present inventions. The various inventions are directed generally to substantially increasing energy efficiency of thermal recovery operations by utilizing the energy of the combustion products while simultaneously sequestering them underground.

[0014] In a first invention, a method for recovering a hydrocarbon from an underground hydrocarbon-containing material is provided that includes the steps:

[0015] (a) in a manned excavation positioned in proximity to the hydrocarbon-containing material, generating a heated hydrocarbon production fluid;

[0016] (b) introducing, via a wellhead positioned in the manned excavation, the heated hydrocarbon production fluid into the hydrocarbon-containing material to mobilize at least part of the hydrocarbons in the hydrocarbon-containing material; and

[0017] (c) thereafter recovering the mobilized hydrocarbon from the hydrocarbon-containing material.

[0018] In one configuration, each well-head has its own steam generator, and the steam generator is capable of simulating a substantial zone of the formation by steam stimulation and/or flooding.

[0019] In one configuration, the heated hydrocarbon production fluid is steam, the wellhead is positioned adjacent to a liner of the manned excavation, an injection well passes from the wellhead, through the liner, and into the hydrocarbon-containing material, and the generating step (a) is performed by a steam generating device positioned in the manned excavation.

[0020] Waste heat from the steam generating device can be used to preheat at least a portion of input water to the device. In one configuration, a heat exchanger is used to transfer heat from the engine to pre-heat water prior to converting it to steam and injecting it into the hydrocarbon-containing material. In one configuration, a heat exchanger is used to transfer waste heat energy from the compressor to the water prior to converting it to steam and injecting it into the hydrocarbon-containing material.

[0021] An exhaust gas of the steam generating device can be combined with the production fluid and introduced into the hydrocarbon-containing material in step (b).

[0022] The steam generating device is commonly positioned at a distance of no more than about 20 meters from the wellhead and a distance of no more than about 200 meters from the hydrocarbon-containing material. In some applications, the manned excavation is at least about 150 meters from the heated formation to comply with safety regulations.

[0023] The wellhead can include a controllable wellhead apparatus. The apparatus includes a first input for the heated hydrocarbon production fluid, a second input for a heated gaseous exhaust products, a third input for water, and a manifold in communication with the first, second, and third inputs to introduce, in step (b), a mixture of the heated hydrocarbon production fluid, heated gaseous exhaust products carbon oxide, and water into the hydrocarbon-containing material. Separate provisions may be made for adding other gaseous products such as carbon dioxide and additional water into the wellhead apparatus, for example for well servicing.

[0024] In a second invention, a hydrocarbon production system is provided that includes:

[0025] (a) a manned excavation positioned in proximity to a hydrocarbon-containing material;

[0026] (b) a generating device, positioned in the manned excavation, operable to generate a heated hydrocarbon production fluid;

[0027] (c) an injection well comprising a wellhead, the wellhead being positioned in the manned excavation and the injection well extending from the manned excavation, the injection well being operable to introduce the heated hydrocarbon production fluid into the hydrocarbon-containing material to mobilize at least part of the hydrocarbons in the hydrocarbon-containing material; and

[0028] (c) a collector well operable to recover the mobilized hydrocarbon from the hydrocarbon-containing material.

[0029] The generating device can have many different configurations. For example, the generator may be a robust burner device, such as known in the art, that burns any of a number of gaseous, liquid or solid fuels propellants and can work at reasonably high injection pressures. In yet another configuration, the generator may be a robust device that burns any of a number of liquid propellants and can work at much higher injection pressures than, for example a diesel engine, and therefore be applied to formations at pressures as high as about 50,000 psi.

[0030] These gas and/or steam generators can be installed in or near the wellhead. Their combustion products can be directed into the injection well along with steam. The generators can utilize essentially all the energy of combustion to heat the heavy oil or bitumen deposit, thus converting almost all of the generated energy into energy delivered into the formation. Further, the generators can dispose of the combustion products by sequestering most or all of them in the reservoir pore space from which heavy oil or bitumen has been displaced and recovered by the collector wells. Even further, the generators can eliminate a significant SAGD steam generation problem. The generators can be substantially unaffected by precipitation and scaling problems common to steam boilers and steam transmission piping and thus can minimize or eliminate the need for water treatment. The generators can be located very near the horizontal section of injector well and readily serviced or replaced while maintaining the well at pressure and temperature. Servicing or replacing well-head components can be accomplished in a very short time so that production is not interrupted and the temperature in the injector well can be maintained at a level at which the bitumen remains fluid in the injector well. The generators can allow full control over injection fluid pressure and temperatures, which is not possible with injection wells operated from the surface. Finally, when the gas and/or steam generators is located underground approximately at the level of the reservoir, it can utilize a substantial pressure head for injection fluids stored on the surface.

[0031] In a third invention, a hydrocarbon production system is provided that includes:

[0032] (a) a diesel engine;

[0033] (b) a compressor;

[0034] (c) a drive shaft interconnecting the diesel engine to the compressor; and

[0035] (d) a conduit transporting an exhaust gas of the diesel engine to the compressor for injection, by an injection well, into a hydrocarbon-containing material to mobilize the hydrocarbons.

[0036] A heat exchanger can be used to transfer heat from the engine to pre-heat water prior to converting it to steam and injecting it into the hydrocarbon-containing material.

[0037] In a fourth invention, a hydrocarbon production method includes the steps:

[0038] (a) operating a diesel engine to produce an exhaust gas comprising carbon oxides and a rotating drive shaft;

[0039] (b) operating a compressor, by the rotating drive shaft, to form a compressed gas, the compressed gas comprising at least part of the exhaust gas from the diesel engine; and

[0040] (c) introducing the compressed gas into a hydrocarbon-containing material to mobilize the hydrocarbons for production.

[0041] In one configuration, the generator is based on a diesel engine where the load on the diesel engine is provided by the work to maintain or compress its own exhaust combustion products to the desired injection well pressure. In this configuration, heat accumulated in the engine's cooling system is used, via a heat exchanger apparatus, to transfer energy otherwise lost to heat inlet water before injection into a well. A heat exchanger can also be used to transfer waste heat energy from the compressor to the water prior to converting it to steam and injecting it into the hydrocarbon-containing material.

[0042] As can be seen from the above inventions, the well-head gas and steam generators may be operated on a variety of fuels and oxidizers. For example, the generator may be operated on a natural gas/air combustion system; a diesel/air combustion system; a gasoline/air combustion system; a heavy oil/diluent/air combustion system; or a bitumen/diluent/air combustion system. Further, the air used in combustion can be oxygen-enriched or replaced entirely by oxygen to reduce or eliminate unwanted flue gas components, especially nitrogen. The combustion system may use a gaseous fuel system but preferably uses a liquid or solid fuel system when operated underground.

[0043] Although the various inventions may be applied to surface wellheads, in this configuration transmission energy losses remain, and there remains the possibility of precipitation and scaling problems in the non-horizontal portions of the well. In addition, it can be more difficult to service the well casing in the event of corrosion, precipitation, scaling and the like.

[0044] It is therefore preferable, though not necessary, to apply the present invention to wellheads installed from an underground workspace where the wellhead is typically within a few to several meters of the reservoir.

[0045] Finally, the present invention allows the use of large horsepower, high-efficiency boilers and engines to produce the quantities and qualities of steam necessary to operate SAGD wells capable of producing several hundred barrels of oil per day.

[0046] The following definitions are used herein:

[0047] It is to be noted that the term "a" or "an" entity refers to one or more of that entity. As such, the terms "a" (or "an"), "one or more" and "at least one" can be used interchangeably herein. It is also to be noted that the terms "comprising", "including", and "having" can be used interchangeably.

[0048] A blow out preventer or BOP is a large valve at the top of a well that may be closed if the drilling crew loses control of formation fluids. By closing this valve (usually operated remotely via hydraulic actuators), the drilling crew usually regains control of the reservoir, and procedures can then be initiated to increase the mud density until it is possible to open the BOP and retain pressure control of the formation. Some can effectively close over an open wellbore, some are designed to seal around tubular components in the well (drillpipe, casing or tubing) and others are fitted with hardened steel shearing surfaces that can actually cut through drillpipe.

[0049] A Christmas tree (also Subsea Tree or Surface Tree) in petroleum and natural gas extraction, a christmas tree is an assembly of valves, spools and fittings for an oil well, named for its resemblance to a decorated tree. The function of a Christmas tree is to both prevent the release of oil or gas from an oil well into the environment and also to direct and control the flow of formation fluids from the well. When the well is ready to produce oil or gas, valves are opened and the release of the formation fluids is allowed through a pipeline leading to a refinery, or to a platform or to a storage vessel. It may also be used to control the injection of gas or water injection application on a none-producing well in order to sustain producer volumes. On producing wells injection of chemicals or alcohols or oil distillates to solve production problems (such as blockages) may be used.

[0050] A downhole steam generator as used herein is a steam generator that is installed in the bore of a well.

[0051] A drilling room as used herein is any self-supporting space that can be used to drill one or more wells through its floor, walls or ceiling. The drilling room is typically sealed from formation pressures and fluids.

[0052] A hydrocarbon is an organic compound that includes primarily, if not exclusively, of the elements hydrogen and carbon. Hydrocarbons generally fall into two classes, namely aliphatic, or straight chain, hydrocarbons, cyclic, or closed ring, hydrocarbons, and cyclic terpenes. Examples of hydrocarbon-containing materials include any form of natural gas, oil, coal, and bitumen that can be used as a fuel or upgraded into a fuel. Hydrocarbons are principally derived from petroleum, coal, tar, and plant sources.

[0053] Hydrocarbon production or extraction refers to any activity associated with extracting hydrocarbons from a well or other opening. Hydrocarbon production normally refers to any activity conducted in or on the well after the well is completed. Accordingly, hydrocarbon production or extraction includes not only primary hydrocarbon extraction but also secondary and tertiary production techniques, such as injection of gas or liquid for increasing drive pressure, mobilizing the hydrocarbon or treating by, for example chemicals or hydraulic fracturing the well bore to promote increased flow, well servicing, well logging, and other well and wellbore treatments.

[0054] A liner as defined for the present invention is any artificial layer, membrane, or other type of structure installed inside or applied to the inside of an excavation to provide at least one of ground support, isolation from ground fluids (any liquid or gas in the ground), and thermal protection. As used in the present invention, a liner is typically installed to line a shaft or a tunnel, either having a circular or elliptical cross-section. Liners are commonly formed by pre-cast concrete segments and less commonly by pouring or extruding concrete into a form in which the concrete can solidify and attain the desired mechanical strength.

[0055] A liner tool is generally any feature in a tunnel or shaft liner that self-performs or facilitates the performance of work. Examples of such tools include access ports, injection ports, collection ports, attachment points (such as attachment flanges and attachment rings), and the like.

[0056] A manned excavation refers to an excavation that is accessible directly by personnel. The manned excavation can have any orientation or set of orientations. For example, the manned excavation can be an incline, decline, shaft, tunnel, stope, and the like. A typical manned excavation has at least one dimension normal to the excavation heading that is at least about 1.5 meters.

[0057] A mobilized hydrocarbon is a hydrocarbon that has been made flowable by some means. For example, some heavy oils and bitumen may be mobilized by heating them or mixing them with a diluent to reduce their viscosities and allow them to flow under the prevailing drive pressure. Most liquid hydrocarbons may be mobilized by increasing the drive pressure on them, for example by water or gas floods, so that they can overcome interfacial and/or surface tensions and begin to flow. Bitumen particles may be mobilized by some hydraulic mining techniques using cold water.

[0058] Primary production or recovery is the first stage of hydrocarbon production, in which natural reservoir energy, such as gasdrive, waterdrive or gravity drainage, displaces hydrocarbons from the reservoir, into the wellbore and up to surface. Production using an artificial lift system, such as a rod pump, an electrical submersible pump or a gas-lift installation is considered primary recovery. Secondary production or recovery methods frequently involve an artificial-lift system and/or reservoir injection for pressure maintenance. The purpose of secondary recovery is to maintain reservoir pressure and to displace hydrocarbons toward the wellbore. Tertiary production or recovery is the third stage of hydrocarbon production during which sophisticated techniques that alter the original properties of the oil are used. Enhanced oil recovery can begin after a secondary recovery process or at any time during the productive life of an oil reservoir. Its purpose is not only to restore formation pressure, but also to improve oil displacement or fluid flow in the reservoir. The three major types of enhanced oil recovery operations are chemical flooding, miscible displacement and thermal recovery.

[0059] A seal is a device or substance used in a joint between two apparatuses where the device or substance makes the joint substantially impervious to or otherwise substantially inhibits, over a selected time period, the passage through the joint of a target material, e.g., a solid, liquid and/or gas. As used herein, a seal may reduce the in-flow of a liquid or gas over a selected period of time to an amount that can be readily controlled or is otherwise deemed acceptable. For example, a seal between sections of a tunnel may be sealed so as to (1) not allow large water in-flows but may allow water seepage which can be controlled by pumps and (2) not allow large gas in-flows but may allow small gas leakages which can be controlled by a ventilation system.

[0060] A shaft is a long approximately vertical underground opening commonly having a circular cross-section that is large enough for personnel and/or large equipment. A shaft typically connects one underground level with another underground level or the ground surface.

[0061] Steam flooding as used herein means using steam to drive a hydrocarbon through the producing formation to a production well.

[0062] Steam stimulation as used herein means using steam to heat a producing formation to mobilize the hydrocarbon in order to allow the steam to drive a hydrocarbon through the producing formation to a production well.

[0063] A tunnel is a long approximately horizontal underground opening having a circular, elliptical or horseshoe-shaped cross-section that is large enough for personnel and/or vehicles. A tunnel typically connects one underground location with another.

[0064] An underground workspace as used in the present invention is any excavated opening that is effectively sealed from the formation pressure and/or fluids and has a connection to at least one entry point to the ground surface.

[0065] A well is a long underground opening commonly having a circular cross-section that is typically not large enough for personnel and/or vehicles and is commonly used to collect and transport liquids, gases or slurries from a ground formation to an accessible location and to inject liquids, gases or slurries into a ground formation from an accessible location.

[0066] Well drilling is the activity of collaring and drilling a well to a desired length or depth.

[0067] Well completion refers to any activity or operation that is used to place the drilled well in condition for production. Well completion, for example, includes the activities of open-hole well logging, casing, cementing the casing, cased hole logging, perforating the casing, measuring shut-in pressures and production rates, gas or hydraulic fracturing and other well and well bore treatments and any other commonly applied techniques to prepare a well for production.

[0068] A wellhead consists of the pieces of equipment mounted at the opening of the well to regulate and monitor the extraction of hydrocarbons from the underground formation. It also prevents leaking of oil or natural gas out of the well, and prevents blowouts due to high pressure formations. Formations that are under high pressure typically require wellheads that can withstand a great deal of upward pressure from the escaping gases and liquids. These wellheads must be able to withstand pressures of up to 20,000 psi (pounds per square inch). The wellhead consists of three components: the casing head, the tubing head, and the 'christmas tree'. The casing head consists of heavy fittings that provide a seal between the casing and the surface. The casing head also serves to support the entire length of casing that is run all the way down the well. This piece of equipment typically contains a gripping mechanism that ensures a tight seal between the head and the casing itself.

[0069] Wellhead control assembly as used in the present invention joins the manned sections of the underground workspace with and isolates the manned sections of the workspace from the well installed in the formation. The wellhead control assembly can perform functions including: allowing well drilling, and well completion operations to be carried out under formation pressure; controlling the flow of fluids into or out of the well, including shutting off the flow; effecting a rapid shutdown of fluid flows commonly known as blow out prevention; and controlling hydrocarbon production operations.

[0070] It is to be understood that a reference to oil herein is intended to include low API hydrocarbons such as bitumen (API less than ~10°) and heavy crude oils (API from ~10° to ~20°) as well as higher API hydrocarbons such as medium crude oils (API from ~20° to ~35°) and light crude oils (API higher than ~35°).

[0071] As used herein, "at least one", "one or more", and "and/or" are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions "at least one of A, B and C", "at least one of A, B, or C", "one or more of A, B, and C", "one or more of A, B, or C" and "A, B, and/or C" means A alone, B alone, C alone, A and B together, A and C together, B and C together, or A, B and C together.

BRIEF DESCRIPTION OF THE DRAWINGS

[0072] FIGS. **1**A and B are schematics of generic steam generators.

[0073] FIG. **2** is a schematic of an underground placement of a steam generator apparatus.

[0074] FIG. **3** is a schematic of an alternate underground placement of a steam generator apparatus.

[0075] FIG. **4** is a schematic of a controllable injector well-head apparatus.

[0076] FIG. **5** is a schematic of a steam generator based on a diesel engine.

[0077] FIG. **6** is a schematic of an alternate configuration of a steam generator based on a diesel engine.

[0078] FIG. **7** is a schematic of a steam generator based on a liquid propellant injector system.

[0079] FIG. **8** illustrates a method of pressurizing injection fluids when operating underground.

DETAILED DESCRIPTION

[0080] The well-head gas and steam generator apparatus of the present invention may be operated on a variety of fuels and oxidizers. For example, the generator may be operated on a natural gas/air combustion system; a diesel/air combustion system; a gasoline/air combustion system; a heavy oil/diluent/air combustion system; or a bitumen/diluent/air combustion system. Further, the air used in combustion can be oxygen enriched or replaced entirely by oxygen to reduce or eliminate unwanted flue gas components, especially nitrogen. The combustion system preferably uses a liquid or solid fuel system when operated underground.

[0081] In one configuration, the generator is based on a diesel engine where the load on the diesel engine is provided by the work to maintain or compress its own exhaust combustion products to the desired injection well pressure. In this configuration, heat accumulated in the engine's cooling system is used, via a heat exchanger apparatus, to transfer energy otherwise lost to heat inlet water before injection into a well.

[0082] In another configuration, the generator may be a robust burner device, such as known in the art, that burns any of a number of gaseous, liquid or solid fuels propellants and can work at reasonably high injection pressures.

[0083] In yet another configuration, the generator may be a robust device that burns any of a number of liquid propellants and can work at much higher injection pressures than, for example a diesel engine, and therefore be applied to formations at pressures as high as about 50,000 psi.

[0084] The present invention may be applied to surface wellheads but in this configuration, transmission energy losses remain and there remains the possibility of precipitation and scaling problems in the non-horizontal portions of the well. In addition, it is more difficult to service the well casing in the event of corrosion, precipitation, scaling and the like.

[0085] It is therefore preferable to apply the present invention to wellheads installed from an underground workspace where the wellhead is typically within a few to several meters of the reservoir.

[0086] Finally, the present invention allows the use of large horsepower, high-efficiency engines to produce the quantities and qualities of steam necessary to operate SAGD wells capable of producing several hundred barrels of oil per day.

[0087] As described in "Thermal Recovery of Oil and Bitumen", Roger M. Butler, ISBN 0-9682563-0-9, 2nd Printing by GravDrain, Inc. Calgary, Alberta 1998, there has been a significant effort to develop downhole steam generators for oil field steam generation. One of the main advantages seen for this approach is the reduction of well-bore heat losses and, because of this, improved economics for production in very deep deposits.

[0088] There are two basic approaches:

[0089] 1. Low-pressure combustion, in which the downhole combustion is carried out at relatively low pressure and in which the flue gas products are vented up the injection well. This approach requires a heat exchanger down the well to isolate the low-pressure combustion zone from the high-pressure steam.

[0090] 2. High-pressure combustion, in which the products of combustion are mixed directly with the steam and pass into the reservoir to be collected at the production or collector wells.

[0091] An important possible variation of the second approach involves the use of oxygen-enriched air or primarily oxygen rather than air for the combustion. This also has the potential advantage that the resulting high concentration of carbon dioxide may improve the effect of the steam in recovering oil.

[0092] A major advantage seen for the use of downhole steam generators with the direct injection of the flue gas into the reservoir is that the sulphur and nitrogen oxides can be absorbed in the reservoir, either as anions in the water or by the rocks directly and flue gas scrubbing is avoided. An example is a high-pressure downhole steam generator developed by Sandia National Laboratories in the DOE "Deep Steam" project (1982). Another example is a high-pressure downhole generator developed by the Chemical Oil Recovery Co. (1982). The Zimpro-AEC steam generator is yet another device in which steam mixed with flue gas is produced for injection into a reservoir. Up until now, downhole steam generation has not advanced to the point where it is accepted as a commercial alternative. The equipment that has evolved is complicated and not easily serviceable. Although the use of downhole steam generators may become practical for steam flooding, it is unlikely to be so for steam stimulation, where the requirement for large quantities of steam cannot be met. Steam stimulation typically requires steam generators of several hundreds to several thousands of horsepower per producing well.

[0093] This prior art shows however, that the concept of a downhole steam generator that also injects its combustion products can have significant operational and environmental advantages. However, as noted, they have proved impractical because they must be large to provide the quantities of steam for a typical SAGD well and they would most likely have to be installed on the surface near the wellhead where they would be subject to energy transmission losses before the steam is delivered to the horizontal portion of the well where the steam is to be injected.

[0094] Consider an example of a SAGD operation where a typical producer well yields 500 barrels of oil per day at Steam-Oil-Ratio ("SOR") of 3 and where the steam is injected at a temperature of 200 C. If the water must be heated from room temperature, a surface boiler operating at 85% efficiency with energy transmission losses of 15% to get to the horizontal portion of the injector well have to generate 34.3 million BTUs per hour. If 500 barrels per day of heavy crude are produced, then the energy content of the produced oil is 135.1 million BTUs per hour. This means that 25% of the recovered energy in the heavy crude (or its equivalent of another boiler fuel) must be consumed to produce the next barrel of heavy crude.

[0095] If a steam generator is located at the entrance to the horizontal portion of the injector well and all the generator's produced energy including its flue gases are injected into the formation, then the generator, assuming 95% overall energy efficiency, will have to generate 26.1 million BTUs per hour. This means that 19% of the recovered energy in the heavy crude (or its equivalent of another generator fuel) must be consumed to produce the next barrel of heavy crude.

[0096] Thus a generator located near the horizontal portion of the injector well and injecting all its flue gases into the reservoir saves on the order of 25% of the energy required by a surface boiler and does not release flue gases into the atmosphere.

[0097] Although the present invention, which also seeks to increase energy efficiency and sequester flue gases into the formation, can be applied at the surface, it is preferable to apply it to wells installed from a shaft or tunnel in or near the producing formation. In this case, the underground workspace can be utilized to accommodate generators large enough to sustain production rates in the range of 100 to 1,000 barrels per producer well per day.

[0098] FIGS. **1**A and B are schematics of two types of generic steam generators such as might be located underground for producing steam for injection into an injector well. FIG. **1**A illustrates an electrically-powered steam generator **101**. Electrical energy **102** is input as the energy source and water **104** is input as the mass source. The generator outputs steam **107** and possibly some water **108**. In addition, some waste heat energy is produced in the steam generator much of which can be captured using a heat exchanger to preheat all or a portion of the input water **104**. Typically an electrically powered steam generator is in the range of 80% to about 90% efficient at converting electrical energy to energy of steam for injection into an injector well. With a heat exchanger to preheat the input water, it is possible to convert over about 95% of the input electrical energy to energy of steam for injection into an injector well. At such high energy conversion efficiencies the amount of output water **108** is essentially zero. The input electrical energy **102** may be obtained, for example, from an external electric generating source such as an on-site surface generator facility or distant power generating plant.

[0099] FIG. **1**B illustrates a prime-power steam generator **111** which uses a fuel **112** and oxidant **113** to generate power. Water **114** is input separately from the fuel **112** and oxidant **113** so the mass inputs are water, fuel and oxidant. The generator outputs exhaust gases **116**, steam **117** and possibly some water **118**. In addition, waste heat energy is generated in the steam generator much of which can be captured using a heat exchanger to preheat all or a portion of the input water **114**. Typically a prime power steam generator can convert about 25% to 45% of the total energy the energy of combusted fuel into mechanical energy (typically rotating shaft energy), approximately 25% to 30% to energy of exhaust gases and the remainder to waste heat produced mainly in the generator cooling system. If the exhaust gases **116** are combined with the produced steam **117** and water **118**, and if the waste heat energy produced in the generator cooling system is captured using a heat exchanger to preheat all or a portion of the input water **114**, then about 90% to about 95% of the energy of combusted fuel can be captured and made available for injecting energized steam and other gases into an injector well.

[0100] Examples of low cost fuel/oxidant combinations are: diesel fuel/air; diesel fuel/oxygen; methane/air; methane/oxygen; various emulsion fuels/air; various emulsion fuels/oxygen; JP4/red fuming nitric acid; and the like.

[0101] A principal objective of the present invention is to locate a steam generator in close proximity to an injector well-head and to produce steam at high levels of conversion efficiency. If exhaust gases, waste energy and some water are captured and controlled, they can be injected along with the produced steam so that the final injected mixture is an energetic gas in the desired temperature and pressure range and with a mixture of gaseous constituents compatible with the reservoir geology. Examples of well-head generators will be provided (FIGS. **5**, **6** and **7**) for controlling a high efficiency steam generator so that pressure, temperature, mass and gas constituents can be tailored to conditions required for thermal recovery in a heavy hydrocarbon reservoir.

[0102] FIG. **2** is a plan view schematic of an example of a one of a number of possible placements for the downhole combustion apparatus of the present invention. The interior workspace of a tunnel or shaft is shown enclosed, for example, by concrete walls **201** and an alcove formed by walls **202**. A wellhead apparatus **212**, sometimes known as a christmas tree, modified for the present invention, is shown secured to the alcove wall **202** by a flange **211**. The alcove wall **202** is formed and sealed into the shaft or tunnel liner. A method of installing such recesses under formation pressure is fully described in U.S. patent application Ser. No. 11/737,578 filed Apr. 19, 2006 entitled "Method of Drilling from a Shaft". The height and widths of the recesses **202** are in the range of about 2 meter to about 5 meters. The lengths of the recesses **202** are in the range of about 4 meters to about 10 meters. Once installed, the recesses **202** serve as the working space for installing, operating and servicing the well-head equipment. In the present invention, this wellhead apparatus **212** is adapted for use with an injector well where water, flue gases and other gases may be injected into a well. The equipment such as valves **213** can be utilized to help control the injection process as well as shut down the well so that the downhole steam and flue gas generator can be serviced or replaced. This process of well-head control is described more fully in FIG. **4**. In the configuration shown in FIG. **2**, a generator **221** is shown positioned in the tunnel or shaft with its steam, flue gas and water outlets (conduits **225**, **227** and **227**) connected to a manifold **231** which is, in turn, attached to the well-head apparatus **212** and controlled by valves as described in FIG. **4**. The generator **221** consumes fuel and all the mechanical and exhaust energy produced by the generator **221** is injected through manifold **231**. In addition, supplementary water may be injected through conduit **234** and optional gases (CO_2 for example) may be injected through conduit **235**. The steam, water and other gases from the generator are mixed in a manifold **231** which is, in turn, attached to the well-head apparatus **212** and controlled by valves. The steam, water and other gases from the generator may be mixed in any combination and then injected into the formation (reservoir rock) via injector well **205**. It is appreciated that the supplementary water in conduit **234** may routed to the generator **221** and used as coolant for the generator **221** so that the injected water is at a higher temperature when injected ultimately injected into well **205**. If the water is used as a coolant for the generator **221** then it is preferable that the cooling system for generator **221** is operable with untreated water. In the event that the generator has to be serviced or replaced, then well **205** can be shut in at approximately normal operating pressure and temperature by a method further described in FIG. **4**.

[0103] FIG. **3** is similar to FIG. **2** except that the generator **321** is placed in an alcove **303** and thus will be out of the general traffic, ventilation ducts and utility conduits in the tunnel or shaft. The generator **331** is shown with its steam, flue gas and water outlets (conduits **325**, **327** and **327**) connected to a manifold **331** which is, in turn, attached to the well-head apparatus **312** and controlled by valves as described in FIG. **4**. Conduits **325**, **327** and **327** are preferably connected to the well-head apparatus **312** through a hole or holes drilled between alcove **303** and the well-head recess **302**.

[0104] FIG. **4** is a schematic of a controllable injector well-head apparatus and illustrates an example of how an injector well can be controlled, serviced or its steam generator replaced while maintaining the injector well at operating pressure and temperature. The rate of injection of steam and, in some cases, hot combustion products, from a steam generator is controlled by the fuel/air input to the steam generator. The output of the steam generator may include steam, some water and some combustion products which are fed via conduits **401** to manifold **407**. In the example of FIG. **4**, the manifold is shown injecting steam and other gases via valve **424** and residual water by valve **425**. The flow of supplementary water and optional gases in conduits **402** can also be controlled from their respective underground or surface storage sources by valves. For example, supplementary water is injected into well **404** via valve **423** and optional gases, such as for example CO_2, injected into well **404** via valve **424**. The injector well can be shut-in by closing valve **421** and shutting of the generator and flow of combustion products by closing valves **424** and **425**, and shutting of the flow of optional supplementary water and optional gases by closing valves **423** and **426**. The upper master valve **422** and lower master valve **421** can also be shut, thus fully and safely shutting in the well. Once this is accomplished, the generator can be serviced or replaced. If necessary, scale and precipitates can be removed from the well-head apparatus, at least down to master valve **422** or **421**.

[0105] FIG. **5** is a schematic of a steam/gas generator based on a diesel engine. The apparatus is designed to utilize all of the fuel energy consumed by the engine and inject all its produced energy and exhaust gases into a well along with water to create high pressure, high temperature steam that can be used to heat and mobilize heavy oil or bitumen in a reservoir. Typically, about 40% to about 45% of the fuel energy supplied to a diesel is transformed into mechanical shaft energy; about 30% appears as energy of exhaust products and the remainder as heat energy in the cooling system of the engine (these percentages vary somewhat with the type of fuel used in the diesel).

[0106] In this concept, a diesel engine **508** is shown driving a compressor **502** via drive shaft **506**. The diesel **508** is powered by a fuel supply **516** and oxidant supply **515**. The fuel may be diesel fuel, natural gas or another fuel, for example, made from a bitumen, heavy oil or bio-feedstock. The oxidant may be air, oxygen only or oxygen-enriched air. The choice of fuel and oxidant changes the mechanical efficiency and mix of exhaust products of the engine and so allows some control over the composition of injected gases. In the present invention, the exhaust **509** from the diesel is routed to the compressor **502** via conduit **504**. The compressor **502** compresses the exhaust **505** and injects the compressed hot exhaust gases **522** into a well **501** via conduit **503**. Treated or untreated water **517** is fed through a heat exchanger **518** where it becomes heated from hot water in a closed cooling system **510** of the engine **508**. This heated water is injected **521** into the well **501** via conduit **507**. Thus, almost all the energy from combustion of the fuel **516**/oxidant **515** mixture is injected into the well **501** where it is mixed with the injected steam and water.

[0107] When the well-head steam generator is a diesel engine that is modified to inject its own combustion gases into the injector well, then an approximately 4,100 horsepower engine would be required to maintain a production or collector well of 500 barrels per day, where the Steam-Oil-Ratio is about 3. This well-head system would require approximately 6.1 gallons of diesel fuel per minute and 10.4 gallons of water per minute. This size of system, while more efficient than used in current practice, is much too large to place downhole from a well installed from the surface. If placed on the surface, it would lose about 15% of its energy in transmission losses and so would have to be still larger to compensate. So the preferable placement of such a generator would be in an underground workspace in close proximity to a well-head.

[0108] FIG. **6** is a schematic of an alternate configuration of a steam/gas generator based on a diesel engine. This configuration is similar to that of FIG. **5** except an additional heat exchanger **628** is added to a compressor **602** to moderate the temperature of the hot compressed exhaust gases **605** from the engine **608** and to transfer heat from the compressor **602** to additional treated or untreated water **617**. The water heated in compressor heat exchanger **628** is added to the water heated in engine heat exchanger **608** at junction **619**.

[0109] FIG. **7** is an example of liquid propellant gun technology adapted to form a downhole water jet that can work against extremely high back pressures. These back pressures can be in the range of about 10,000 psi to about 50,000 psi. The liquid propellant jet drill shown in FIG. **7** can be modified so that it functions like the diesel engine shown in FIGS. **5** and **6**. The pistons are driven by combustion of a suitable liquid propellant in chambers **65** and pressure water or steam in chambers **61** which is then injected into an injector well. Although not shown, the combustion products may be exhausted into the injector well to add their energy to the process. The liquid propellant water jet drill shown in FIG. **7** was taken from FIG. 5 of U.S. Pat. No. 3,620,313.

[0110] Another advantage of the present invention is illustrated in FIG. **8**. Since the present invention is preferably practiced underground, water, for example, may be stored in a tank **803** on the surface. The water can be sent underground via conduit **804** down shaft **805** where it will arrive at the bottom of the shaft **805** with a substantial pressure head. These shafts are typically in the range of 100 meters to over 500 meters deep so this represents a water pressure head in the range of about 140 psi to about 700 psi. This pressurized water can be fed into an underground storage tank **807** and from there can be injected into a nearby injector well with little or no additional pressurizing. This capability can also be used for pressurizing liquid or gaseous fuels, if necessary, for a selected generator.

[0111] A number of variations and modifications of the above inventions can be used. As will be appreciated, it would be possible to provide for some features of the invention without providing others. For example, large prior-art gas burners can be used. Other injectors based on, for example, a free piston engine can also be modified and used to compress their own exhaust products. In another variation, exhaust gases other than steam can be routed and sequestered in geological repositories distant from the producing reservoir. Before re-routing these gases, energy can be extracted and transferred to heat a water supply using a heat exchanger apparatus. The present invention, in various embodiments, includes components, methods, processes, systems and/or apparatus substantially as depicted and described herein, including various embodiments, sub-combinations, and subsets thereof. Those of skill in the art will understand how to make and use the present invention after understanding the present disclosure. The present invention, in various embodiments, includes providing devices and processes in the absence of items not depicted and/or described herein or in various embodiments hereof, including in the absence of such items as may have been used in previous devices or processes, for example for improving performance, achieving ease and\or reducing cost of implementation.

[0112] The foregoing discussion of the invention has been presented for purposes of illustration and description. The foregoing is not intended to limit the invention to the form or forms disclosed herein. In the foregoing Detailed Description for example, various features of the invention are grouped together in one or more embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the following claims are hereby incorporated into this Detailed Description, with each claim standing on its own as a separate preferred embodiment of the invention.

[0113] Moreover though the description of the invention has included description of one or more embodiments and certain variations and modifications, other variations and modifications are within the scope of the invention, e.g., as may be within the skill and knowledge of those in the art, after understanding the present disclosure. It is intended to obtain rights which include alternative embodiments to the extent permitted, including alternate, interchangeable and/or equivalent structures, functions, ranges or steps to those claimed, whether or not such alternate, interchangeable and/or equivalent structures, functions, ranges or steps are disclosed herein, and without intending to publicly dedicate any patentable subject matter.

[0114] In one configuration, a heat exchanger is used to transfer heat from the engine to pre-heat water prior to converting it to steam and injecting it into the hydrocarbon-containing material.

[0115] In one configuration, a used to transfer waste heat energy from the compressor to the water prior to converting it to steam and injecting it into the hydrocarbon-containing material.

What is claimed is:

1. A method for recovering a hydrocarbon from an underground hydrocarbon-containing material, comprising:

(a) in a manned excavation positioned in proximity to the hydrocarbon-containing material, generating a heated hydrocarbon production fluid;

(b) introducing, via a wellhead positioned in the manned excavation, the heated hydrocarbon production fluid into the hydrocarbon-containing material to mobilize at least part of the hydrocarbons in the hydrocarbon-containing material; and

(c) thereafter recovering the mobilized hydrocarbon from the hydrocarbon-containing material.

2. The method of claim 1, wherein the heated hydrocarbon production fluid is steam, wherein the wellhead is positioned adjacent to a liner of the manned excavation, wherein an injection well passes from the wellhead, through the liner, and into the hydrocarbon-containing material, and wherein the generating step (a) is performed by a steam generating device positioned in the manned excavation.

3. The method of claim 2, wherein waste heat from the steam generating device is used to preheat at least a portion of input water to the device.

4. The method of claim 2, wherein an exhaust gas of the steam generating device is combined with the production fluid and introduced into the hydrocarbon-containing material in step (b).

5. The method of claim 2, wherein the steam generating device is positioned at a distance of no more than about 20 meters from the wellhead and a distance of no more than about 200 meters from the hydrocarbon-containing material; wherein the manned excavation comprises multiple wellheads and steam generating devices, wherein each wellhead is in communication with a respective steam generating device, and wherein the steam generating device performs at least one of steam stimulation and flooding.

6. The method of claim 1, wherein the wellhead comprises a controllable wellhead apparatus, the apparatus comprising a first input for the heated hydrocarbon production fluid, a second input for heated gaseous exhaust products, a third input for water, and a manifold in communication with the first, second, and third inputs to introduce, in step (b), a mixture of the heated hydrocarbon production fluid, heated gaseous exhaust products, and water into the hydrocarbon-containing material.

7. The method of claim 1, wherein the generating step is performed by a generating device, wherein the generating device comprises a diesel engine, a compressor, and a drive shaft extending therebetween to enable the diesel engine to drive the compressor, wherein an exhaust gas from the engine is routed to the compressor to be incorporated into the heated hydrocarbon production fluid, and wherein a heat exchanger is in thermal communication with the engine to heat water, using waste heat from the engine, for introduction into the hydrocarbon-containing material.

8. The method of claim 8, wherein the generating device comprises a further heat exchanger in communication with the compressor and the water to transfer heat from the compressor to the water.

9. The method of claim 1, wherein the generating step is performed by a generating device is a liquid propellant motor having one or more pistons being configured to compress water or steam for introduction into the hydrocarbon-containing material.

10. A hydrocarbon production system, comprising:

(a) a manned excavation positioned in proximity to a hydrocarbon-containing material;

(b) a generating device, positioned in the manned excavation, operable to generate a heated hydrocarbon production fluid;

(c) an injection well comprising a wellhead, the wellhead being positioned in the manned excavation and the injection well extending from the manned excavation, the injection well being operable to introduce the heated hydrocarbon production fluid into the hydrocarbon-containing material to mobilize at least part of the hydrocarbons in the hydrocarbon-containing material; and

(c) a collector well operable to recover the mobilized hydrocarbon from the hydrocarbon-containing material.

11. The system of claim 10, wherein the heated hydrocarbon production fluid is steam, wherein the wellhead is positioned adjacent to a liner of the manned excavation, wherein the injection well passes from the wellhead, through the liner, and into the hydrocarbon-containing material, wherein the heated hydrocarbon production fluid is primarily steam, and wherein the manned excavation comprises multiple wellheads and steam generating devices, wherein each wellhead is in communication with a respective steam generating device, and wherein the steam generating device performs at least one of steam stimulation and flooding.

12. The system of claim 11, wherein waste heat from the steam generating device is used to preheat at least a portion of input water to the device, wherein an exhaust gas of the steam generating device is combined with the production fluid and introduced into the hydrocarbon-containing material, and wherein the steam generating device is positioned at a distance of no more than about 20 meters from the wellhead and a distance of no more than about 200 meters from the hydrocarbon-containing material.

13. The system of claim 10, wherein the wellhead comprises a controllable wellhead apparatus, the apparatus comprising a first input for the heated hydrocarbon production fluid, a second input for heated gaseous exhaust products, a third input for water, and a manifold in communication with the first, second, and third inputs to introduce, simultaneously, a mixture of the heated hydrocarbon production fluid, heated gaseous exhaust products, and water into the injection well.

14. The system of claim 10, wherein the generating device comprises a diesel engine, a compressor, and a drive shaft extending therebetween to enable the diesel engine to drive the compressor, wherein an exhaust gas from the engine is routed to the compressor to be incorporated into the heated hydrocarbon production fluid, and wherein a heat exchanger is in thermal communication with the engine to heat water, using waste heat from the engine, for introduction into the hydrocarbon-containing material.

15. The system of claim 14, wherein the generating device comprises a further heat exchanger in communication with the compressor and the water to transfer heat from the compressor to the water.

16. The system of claim 10, wherein the generating device is a liquid propellant motor having one or more pistons being configured to compress water or steam for introduction into the hydrocarbon-containing material.

17. A hydrocarbon production system, comprising:

(a) a diesel engine;

(b) a compressor;

(c) a drive shaft interconnecting the diesel engine to the compressor; and

(d) a conduit transporting an exhaust gas of the diesel engine to the compressor for injection, by an injection well, into a hydrocarbon-containing material to mobilize the hydrocarbons.

18. The system of claim 17, further comprising a heat exchanger is in thermal communication with the engine to heat water, using waste heat from the engine, for introduction into the hydrocarbon-containing material.

19. The system of claim 17, wherein the generating device comprises a heat exchanger in communication with the compressor and the water to transfer heat from the compressor to the water and wherein the heated water is introduced into the hydrocarbon-containing material.

20. A hydrocarbon production method, comprising:

(a) operating a diesel engine to produce an exhaust gas comprising carbon oxides and a rotating drive shaft;

(b) operating a compressor, by the rotating drive shaft, to form a compressed gas, the compressed gas comprising at least part of the exhaust gas from the diesel engine; and

(c) introducing the compressed gas into a hydrocarbon-containing material to mobilize the hydrocarbons for production.

21. The method of claim 20, wherein a heat exchanger is in thermal communication with the engine to transfer heat from the engine to the water for introduction of the heated water into the hydrocarbon-containing material.

22. The method of claim 20, wherein a heat exchanger is in thermal communication with the compressor and the water to transfer heat from the compressor to the water for introduction of the heated water into the hydrocarbon-containing material.

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