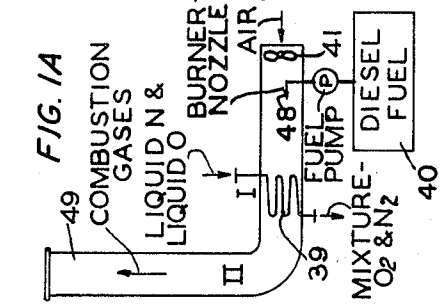
Jan. 21, 1969 H. B. BRYANT, JR 3,422,892

SUPPLY OF HIGH-PRESSURE COMBUSTION-SUPPORTING GAS TO WELLS

Filed March 29, 1965 Sheet 1 of 3



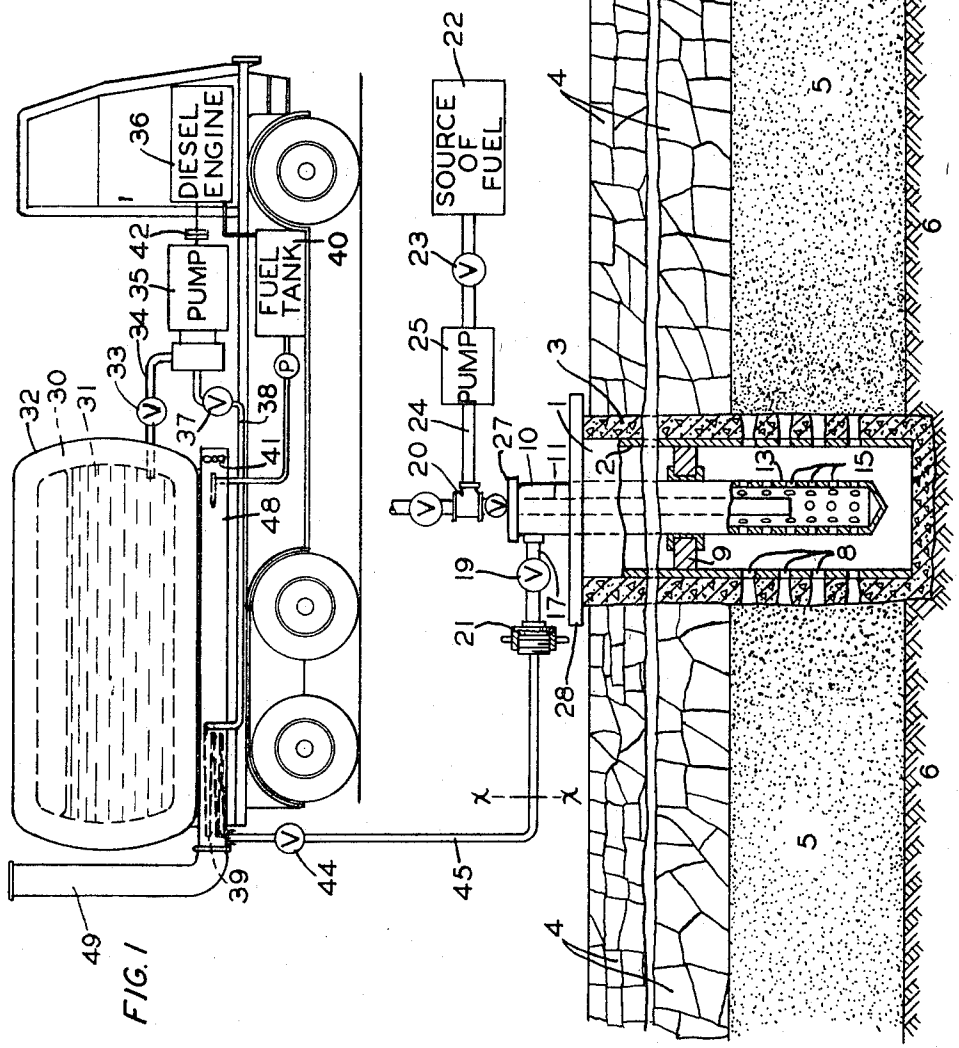




FIG. 1

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SUPPLY OF HIGH-PRESSURE COMBUSTION-SUPPORTING GAS TO WELLS

Filed March 29, 1965 Sheet 2 of 3

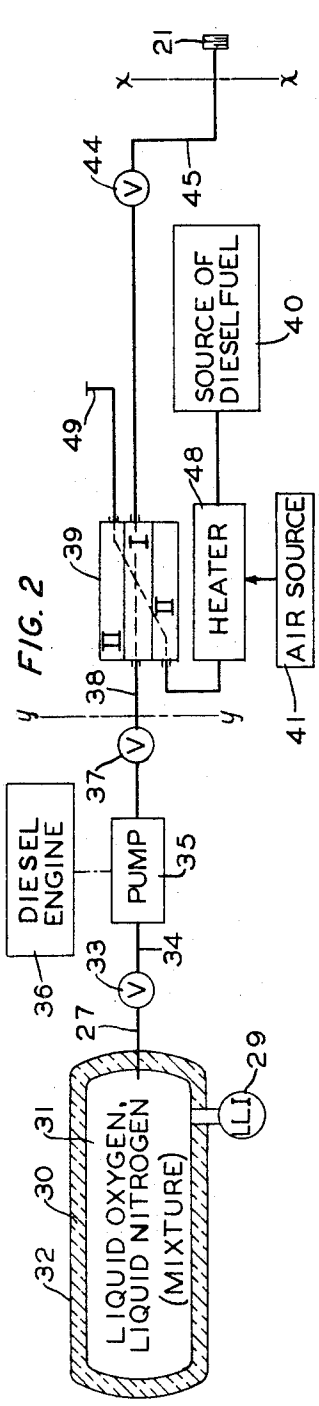



FIG. 2

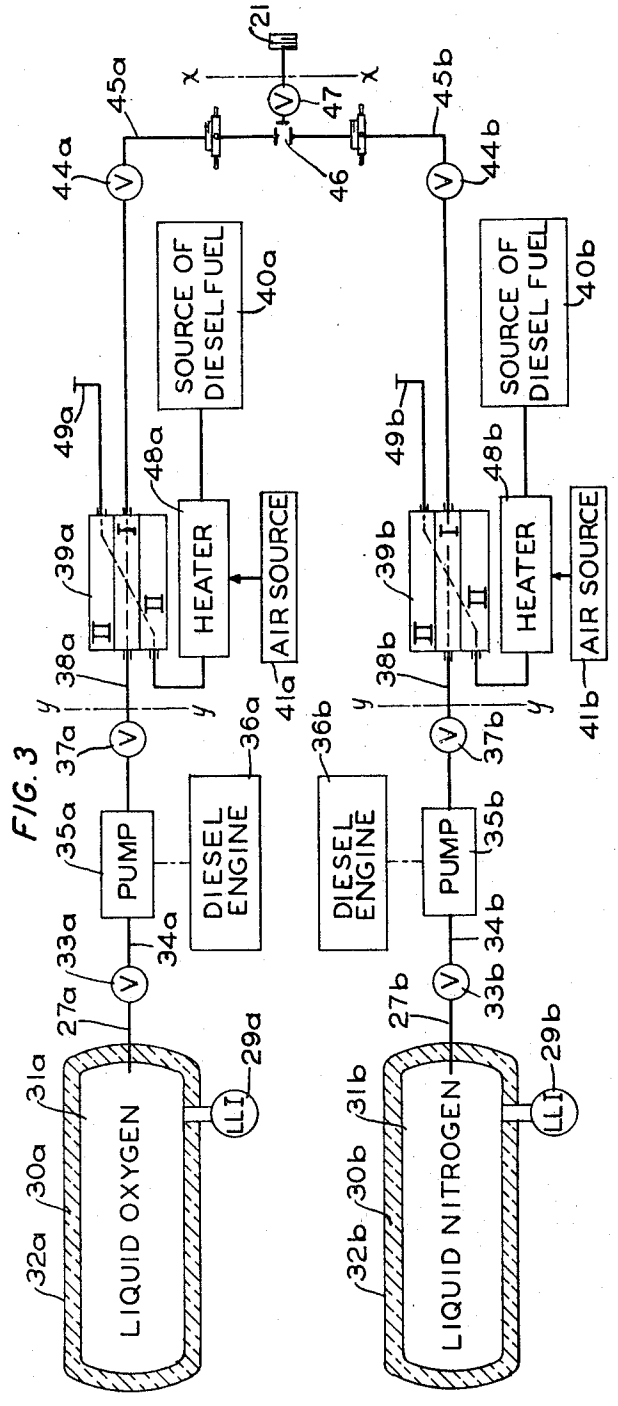



FIG. 3

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Jan. 21, 1969 H. B. BRYANT, JR 3,422,892

SUPPLY OF HIGH-PRESSURE COMBUSTION-SUPPORTING GAS TO WELLS

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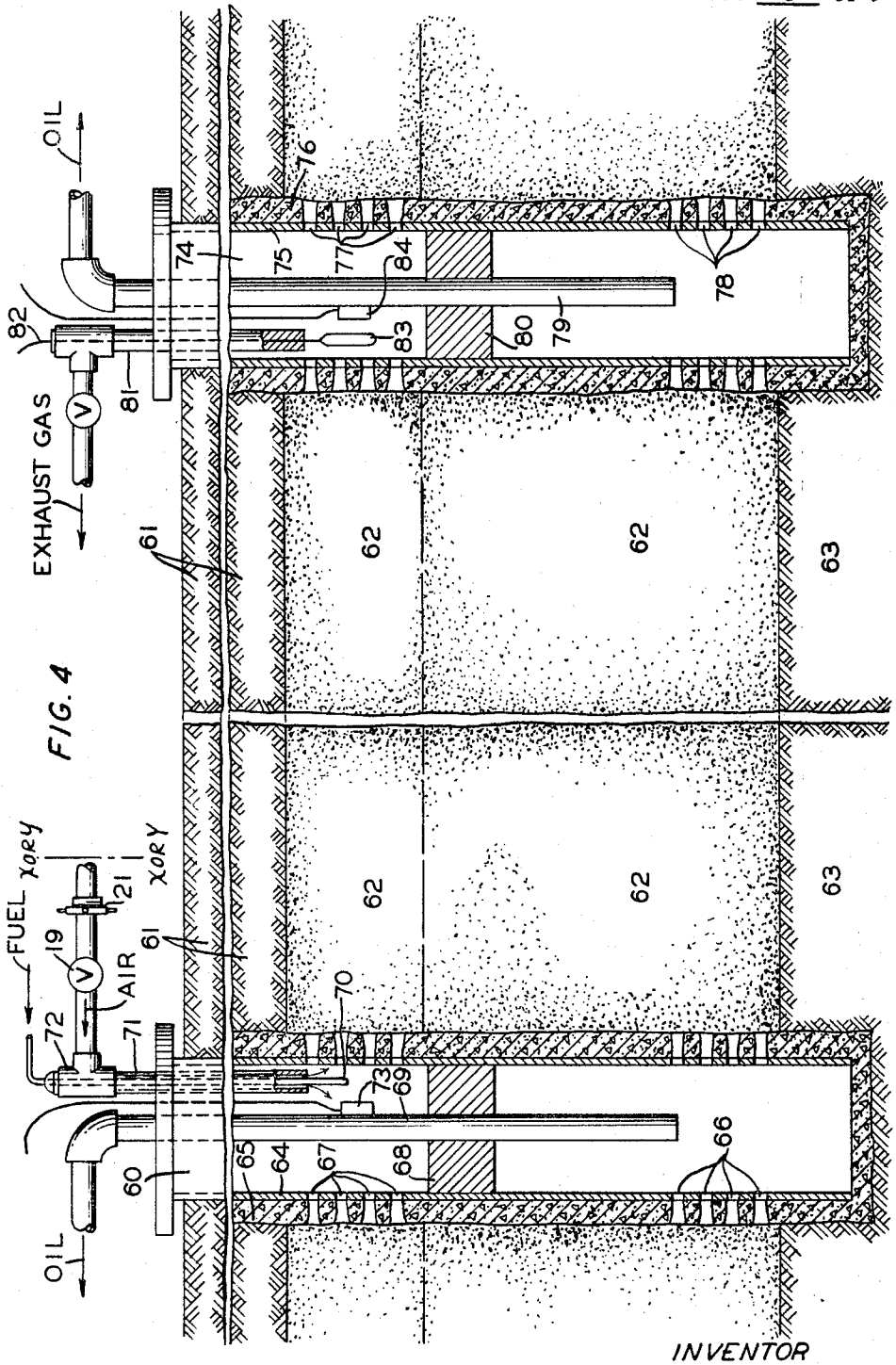



FIG. 4

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United States Patent Office 3,422,892 Patented Jan. 21, 1969



3,422,892

# SUPPLY OF HIGH-PRESSURE COMBUSTION-SUPPORTING GAS TO WELLS

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Filed Mar. 29, 1965, Ser. No. 443,545
U.S. Cl. 166—40 3 Claims
Int. Cl. E21b 43/24

## ABSTRACT OF THE DISCLOSURE

System and method for supporting combustion in the down-hole portion of an oil well by supplying at elevated pressure a combustion-supporting mixture of oxygen and an inert gas, preferably nitrogen, in liquid form at the site of the well. The mixture may be supplied in the necessary proportions either to support combustion in a down-hole burner or to initiate and maintain in situ combustion in the formations adjacent the well. The combustion-supporting mixture of liquid oxygen and liquid nitrogen may be supplied either from a single tank or separate tanks trucked to the well-site. In one form of the invention, the components of the combustion-supporting mixture may be vaporized in a high pressure vaporizer connected above ground to the head of the well. Alternatively, the liquid mixture may be supplied to the down-hole portion of the well through casings resistant to low temperature, and permitted to vaporize below ground from the heat of the earth.

This invention relates to supplying combustion supporting gases under high pressure to the down-hole portions of oil and gas wells and adjacent formations.

It is customary to inject large quantities of air or an oxygen-containing gas down-hole in oil or gas wells for performing any of a number of different functions. These include, for example, supplying combustion supporting gas to down-hole burners; supporting combustion in or adjacent the well-hole and including radial outward flow of hot gases to stabilize unconsolidated formations; and initiating and maintaining in situ combustion in underground formations for flushing out deposits of high viscosity oil, and for increasing production of petroleum from formations subject to plugging by waxy petroliferous deposits.

For such applications it is desirable to supply the air, or combustion-supporting gas, at pressures ranging from, say, 100 to 10,000 pounds per square inch gauge and at flow rates up to 400,000 standard cubic feet per hour. Accordingly, air-compression costs are a critical factor in the many oil-producing operations using pressurized air or a similar combustion supporting gas mixture, especially for short duration pumping situations.

Among the problems arising in prior art applications involving high pressure air injection are that compressors large enough to handle pressures within the ranges up to 10,000 pounds per square inch at flow rates up to, say, 400,000 standard cubic feet per hour, are costly and not readily available, and are, in any case, heavy and unwieldly to handle at the well sites, and require unusual power requirements. Moreover, it would probably take several of these units to handle the large quantities of air at the high rates of flow which are optimal for the applications named. In addition, it has been difficult to control the humidity or hydrocarbon content of the air supplied by such compressors, or to regulate the concentration of oxygen therein to conform to the unique requirements of the various applications. Moreover, it has been found difficult to vary the flow-rates in such



compressors. A particular difficulty which arises in in situ combustion processes is the actual initiation of combustion and controlling the rate and location of combustion.

Accordingly, it is the general object of this invention to provide for simpler and more efficient delivery of high pressure air or combustion-supporting gas for various down-hole applications in oil and gas wells and their environs, than has been heretofore available. A more particular object of this invention is to provide for injection of air or combustion-supporting gas into the wells at higher flow rates and under higher pressures than heretofore feasible. Another object of the invention is to simplify and consolidate the instrumentation and power requirements needed at the well-site for supplying high pressure combustion-supporting gas down-hole in the well. A further object is to provide a greater degree of control of the purity and general composition of combustion-supporting gases supplied to the wells for various underground applications. Still another object of the invention is to simplify initiation and control of in situ combustion.

These and other objects are realized in accordance with the present invention by providing the combustion-supporting mixture, or its components, in liquid form at the well site. In a preferred procedure, in accordance with this invention, the liquid is pumped through a liquid-pump to an elevated pressure within the range 100 and 10,000 pounds per square inch gauge, and then vaporized in a high-pressure vaporizer, the mixture being supplied in the desired proportions either to support combustion in a down-hole burner, or to initiate and maintain in situ combustion in the formations adjacent the well. Alternatively, provided that the well casings are of materials highly resistant to low temperatures, the liquid mixture can be supplied directly to the well from the pump, vaporization taking place below ground from the heat of the earth.

In a specific disclosed embodiment, a mixture of liquid oxygen and liquid nitrogen, combined to approximate the proportions of liquid air, is brought to the well-site in a single insulated vessel which is connected to a pump and vaporizer. All of these elements may be mounted for convenience on a single truck-body from which a suitable connection is made between the vaporizer and the system of pipes extending into the well, although weight limitations may dictate the mounting of the pump and vaporizer on a separate truck-body. In another alternative embodiment, the liquid oxygen and liquid nitrogen are brought to the site in separate containers, which may be mounted on separate trucks, each liquid being pumped to the desired pressure and vaporized through a separate pump and vaporizer, the pressurized gases being that mixed in the desired proportions before introduction into the well.

In the first example described, the gaseous mixture is delivered into the well at a gauge pressure of, say, 2,000 pounds per square inch and at an average flow rate of 40,000 standard cubic feet per hour. Assuming that each delivery truck is designed to accommodate a liquid load of 2,000 gallons ,it is contemplated that nearly 200,000 standard cubic feet of the above proportioned mixture will be delivered into the well in the period of, say, 5 hours from a single truck, which also includes pumping and vaporizing equipment. Alternatively, the latter are housed in a separate truck or trailer.

The disclosed method and apparatus have a number of advantages over the prior art. They provide for simpler, more compact, and less expensive instrumentation at the well-site, substituting a single truck or trailer, or possibly two, to do the job which might require several conventional compressor units. Furthermore, the gases thus provided may be to any prescribed purity, and free

from all but traces of water vapor and hydrocarbons, in sharp contrast to the contaminated output of the compressors. Furthermore, oxygen and nitrogen may be mixed in any desired proportion, which may be varied from time-to-time, to control the rate or direction of combustion in the well. In addition, using this method, a combustion-supporting mixture of gases may be supplied at higher flow rates and at higher pressures than are economically feasible using conventional compressors at well sites. An advantage to be derived from the specific application in which liquid products are supplied to the immediate well head area is that highly concentrated oxygen can thus be supplied directly to the underground formations to bring about in situ combustion spontaneously and without additional means for igniting the gases below ground.

Other objects, features and advantages will occur to those skilled in the art after a study of the specification and drawings hereinafter, in which:

FIGURE 1 is a sectional showing of an oil well containing a deep-hole burner serviced by high pressure combustion-supporting gas supplied at the surface through a system of the present invention, including a single truck-mounted tank of liquid, together with pumping and vaporizing equipment.

FIGURE 1A is an enlarged detailed showing of the vaporization system of FIGURE 1 including heat exchanger **34**.

FIGURE 2 is a schematic showing of one embodiment of the system of surface elements connected from the line X—X of FIGURE 1, which includes a single tank for supplying a mixture of oxygen and nitrogen in accordance with the present invention;

FIGURE 3 is a modification of the single-unit system of FIGURES 1 and 2 connected from the line X—X of FIGURE 1 in which oxygen and nitrogen are supplied in separate liquid tanks and separately pressured and vaporized before they are mixed; and

FIGURE 4 is a modification of the invention in which the high pressure combustion-supporting gas supply system indicated to the left of line X—X in FIGURES 1, 2, or 3 is applied to an injection well for in situ combustion; or, alternatively, wherein high pressure liquid is supplied directly to the mouth of the well from the pumping equipment to the left of line Y—Y of FIGURES 2 or 3.

Referring now to the drawings, FIGURE 1 shows, in longitudinal section, the shaft of a conventional oil well **1** which has been drilled through a substantial depth of non-oil bearing strata **4** to a petroliferous stratum **5**. A base rock stratum **6** underlies the petroliferous zone **5**. The shaft **1** is lined with a conventional metal casing **2** which is embedded in a conventional manner in a cement lining **3**. A series of perforations **8** are blasted in the casing **2** and cement lining **3** of the petroliferous zone **5**, for providing escape for hot gases from the well into the formations adjacent the well. The casing **2** is extended for a convenient height above the surface of the earth and sealed with a metal cap **28**, or alternatively, is closed with a conventional type of valve.

A down-hole gas-air burner **13** is disposed in the bore **1**, in an axial position, adjacent the petroliferous layer **5**. The burner **13** may assume any of the forms well known in the art for such applications, such as, for example, the type disclosed by C. L. De Priester in U.S. Patent No. 2,895,555, issued July 21, 1959. Heated high pressure gases flowing out of the perforations **15** in the shell of heater **13** are forced out radially through the perforations **8** in the casing, and into the oil-bearing stratum **5**. The conventional packing element **9**, which is interposed in the annular space between the pipe **10** and the well casing **2**, prevents the gases from flowing upward and out through the well shaft.

Such high pressure gases may serve any one of a number of different functions below ground, such as melting waxes, paraffins, and the like which clog formations adjacent the well, decreasing the viscosity and therefore, increasing the pumpability of adjacent oil deposits; or, initiating a combustion process to stabilize unconsolidated formations adjacent the well in the manner disclosed, for example, by M. R. J. Wyllie in U.S. Patent No. 3,134,435, issued May 26, 1964.

The perforated outer shell of the burner **13** is connected to the pipe **10** which extends to the top of the well shaft, and through a fluid tight seal in the metal cap **28** on the surface and is closed by a second metal cap **27**. A fuel line **11**, of substantially smaller diameter than the pipe **10** and coaxial therewith, extends upward from the heater **13** through a fluid tight seal in the cap **27**, where it is connected through a valve and T connection **20**, a conduit system **24** and an auxiliary pump **25** to a fuel source **22**, under control of valve **23**. The fuel may be propane or any similar hydrocarbon fuel.

Air, or a similar combustion supporting mixture, under a pressure which in general may assume any value between 100 and 10,000 pounds per square inch, gauge, but which, for the purposes of the present illustrations, is 2,000 pounds per square inch, gauge, is supplied to heater **13** through the annular space between pipes **10** and **11** from a lateral above-ground connecting pipe **17** which terminates in a high pressure valve **19**. The outlet pipe from the latter is connected through the internally screw-threaded cap of a conventional gas-tight pipe-union **21** which is designed to withstand pressures between 100 and 10,000 pounds per square inch gauge at a peak flow rate up to 400,000 standard cubic feet per hour.

Pipe-union **21** constitutes the above-ground installation for connection, in accordance with the present invention, to one or more mobile units comprising a mixture of liquid oxygen and liquid nitrogen, or the separated components thereof, and pumping and vaporizing means for converting this liquid at the well site to high pressure gas.

For a better understanding of this arrangement, let us refer to the schematic showing of FIGURE 2, together with the more graphic showing of FIGURE 1. In one embodiment, which is described by way of illustrative example, a truck-trailer is mounted with a Dewar-type storage tank **32** having a capacity of, say, 2,000 gallons, which is roughly cylindrical in shape, but with hemispherical ends, having an over-all length of, say, seventeen feet, three and one-half inches, and a diameter of six and one-half feet. For the purposes of the present illustrative example, it will be assumed that the details of storage tank **32**, together with the truck mounting, pumping and vaporizing equipment, including the pump **35** and the heat-exchanger **39**, is generally similar to that indicated in published Bulletin 3011 (copyright 1962) of the Hofman Laboratories, 225 Parkhurst St., Newark, N.J., now the Hofman-Paul cryogenic division of Air Reduction Company, Incorporated.

The over-all, or insulating outer tank **32**, which in this example is formed of carbon steel, encloses an inner tank **31**, formed, for example, of stainless steel or some other metal suitable for cryogenic applications, having an over-all length of fifteen feet, nine and one-half inches and a diameter of five feet. The clearance **30** between the inner and outer tank is filled with any of the heat-insulating means well-known in the art, such as, for example, perlite, fiberglass-aluminum foil, or the like. The intervening space between the layers of insulation is maintained evacuated to a level of about 35 microns of mercury, or lower.

Assuming that in the mixture prescribed the gaseous ratio of nitrogen to oxygen is respectively 80 to 20 percent by volume, the liquid mixture in tank **31** will consist of approximately 1,662 gallons of liquid nitrogen and 338 gallons of liquid oxygen. For the purposes of the present illustration, these liquids are manufactured

by the Air Reduction Company, Incorporated, to the following specifications:

| | | |
|---|---|---|
| Liquid oxygen | percent pure | 99.5 |
| Typical analysis impurity content: | | |
| Argon | percent (by volume) | 0.15–0.3 |
| Carbon dioxide | do | 0.0005 |
| Hydrocarbon ($C_2H_4$) | do | 0.00002 |
| Nitrogen | do | 0.1–0.25 |
| Maximum dew point, ° F. | | +80 |
| Water vapor | p.p.m. | 7.8 |
| Liquid nitrogen | percent pure | 99.997 |
| Typical analysis impurity content: | | |
| Oxygen | percent (by volume) | 0.00005–0.0002 |
| Argon | do | 0.0005 |
| Carbon dioxide | do | 0.00005 |
| Hydrocarbon ($C_2H_4$) | do | 0.0005 |
| Helium | do | 0.0006 |
| Neon | do | 0.0012 |
| Dew point, ° F. | | −90 |
| Water vapor | p.p.m. | 3.4 |

(The average water vapor content for this mixture is approximately five parts per million.)

In order to provide a net positive suction head, the liquid mixture is maintained in storage tank **31** under a gauge pressure of 15 to 50 pounds per square inch.

In filling the inner tank **31**, liquid nitrogen is first put into the tank to cool it down to −320° F. Sufficient liquid nitrogen is then added or subtracted to bring the level up to that prescribed, taking account of evaporation. The liquid oxygen is then added in the prescribed amount. This order of procedure minimizes evaporation of liquid oxygen. However, the liquids can be mixed by adding oxygen first if so desired. Tank **31** is provided with a conventional gauge or liquid level indicator **29**, of one of the types well-known in the art, to enable operators to keep track of the quantity of liquid in the tank; or alternatively, the unit may be weighed to keep track of the liquid.

It will be apparent that as the tank **32** is trucked to the site of the oil well, the liquid oxygen and liquid nitrogen become thoroughly mixed in the process.

The outlet from tank **31** is controlled by means of an extended bonnet valve **33** especially designed for cryogenic applications. A flexible metal hose **34** which is two inches in outer diameter, one and one-half inches in inner diameter, and two to ten feet long, connects valve **33** to pump **35**. Hose **34** may be of any design suitable for transmitting cryogenic liquid of the temperatures here involved without substantial heat loss, such as, for example, the flexible cryogenic line shown in Bulletin 3025 (copyright 1964) of the Hofman Laboratories, supra.

Pump **35**, which is driven to operate by a conventional gasoline or diesel engine **36**, is a positive displacement type. Engine **36** may be the same one used to drive the transport truck, in which case it is disengaged from the drive shaft and engaged to the driving mechanism of pump **35** by operation of clutch **42**, or a power take off system. Pump **35** is designed to handle a peak load of approximately 400 gallons per hour of the liquid mixture described, and to raise the same from a gauge pressure of 15 or 50 pounds, at which the liquid in the tank is maintained, to a gauge pressure of 2,000 pounds per square inch, selected for the present example, but which alternatively may be anywhere within the range 100 to 10,000 pounds per square inch. The pump is designed and constructed to operate at temperatures ranging down to −320° F. A type suitable for the purposes of the present invention is manufactured by The Paul Chemical Company, a division of Air Reduction Company, Incorporated, and, may be of the general form shown in the pump catalogue of that company under the title "Installation–2 MPD Hydraulic Drive," Drawing No. D–10740. To achieve the above described flow rate, it may be desirable to use two together. It will be apparent to those skilled in the art that this pump installation can be readily modified to utilize a mechanical drive powered by a gasoline, diesel, or electric motor.



The high pressure liquid output of pump **35**, which has been raised to a gauge pressure of, say, 2,000 pounds per square inch, at a temperature of approximately −300° F. or higher, passes out through the extended bonnet valve **37** to the heat-exchanger **39** for evaporation. In the illustrative example under description, the heat-exchanger or vaporizer **39** consists of a continuous coil of high pressure tubes, comprising passage I, which are cast into an aluminum block. Hot gas is passed through passage II around the aluminum block, which in turn, heats the high pressure tubes, thus vaporizing the liquid passing through them.

Referring to the detailed showing of FIGURE 1A, liquid at the above temperature and pressure, and flowing at the rate of, say, 400 gallons per hour, is converted in the high pressure tubes of passage I to gas flowing at, say, 40,000 standard cubic feet per hour, and having a gauge pressure of, say, 2,000 pounds per square inch, at 70° F. This vaporization may be brought about by heat exchange with some type of counterflowing fluid, in passage II of heat-exchanger **39**. In the example under description, hot combustion gases are used for this purpose, in the following manner. Diesel fuel (or gasoline) is derived from the tank **40**. This is mixed in the burner **48** with an excess of air to produce combustion. The air is sucked in from the atmosphere by means of fan **41**. While the exhaust gases pass around the aluminum block giving up their heat to vaporize the high pressure liquids flowing through the tubes of passage I and bring the resultant gases up to ambient temperature, they are cooled before they pass to the atmosphere through the flue **49**.

Alternatively, instead of hot combustion gases, hot liquid, such as a one-to-one mixture of water and ethylene glycol, can be pumped by an auxiliary pump through a heater and through passage II where it gives up sufficient heat to vaporize the mixture of liquid oxygen and liquid nitrogen flowing in the high pressure tubes of passage I of heat-exchanger **39**, and to raise the same to approximately ambient temperature.

A sectioned outlet pipe **45**, comprising, for example, stainless or carbon steel, and having an outer diameter of from three-fourths of an inch to one inch, and an inner diameter of one-quarter inch to three-eighths of an inch, respectively, and for convenience, equipped with conventional swivel joints, is constructed to with stand gauge pressures up to, say, 10,000 pounds per square inch. This is connected to the output of passage I of heat-exchanger **39** under control of valve **44**.

High pressure pipe **45** is connected into an externally-threaded portion of union **21**, which fits into an internally-threaded cap of the latter. Preferably, the union **21** is what is known in the art as a hammer-wing fitting, the cap of which is equipped with peripheral projections which are hammered to apply a substantial torque to the fitting so that the latter can withstand the high pressures imposed on the pipe without springing a leak. The union **21** is disposed just ahead of valve **19** leading into pipe **10** at the well-head.

It will be apparent that all of the components described for supplying combustion-sustaining gas to the well-site can be mounted on a single trailer body; or, they can be divided among several trailer bodies as convenient.

The mixture described by way of illustration, although given as 20 to 80 percent by volume of oxygen to nitrogen, respectively, can comprise any convenient proportions, from pure oxygen, to any mixture of oxygen and an inert gas which will support combustion with the fuel to be burned. Using propane as a fuel, it is calculated that the mixture must contain at least about 11.6 percent by volume of oxygen to sustain combustion at atmospheric temperature and pressure; and, probably five to eight percent by volume of oxygen at the elevated temperatures

and pressures which obtain at the down-hole burner, or in the formations of the well.

In order to facilitate variations in the proportions of oxygen and nitrogen, or other inert gas, which are fed into the well under pressure, thereby to control the rate of burning in the well, the oxygen and nitrogen, or other inert gas, may be brought to the well-site in separate containers.

Such an arrangement is indicated schematically in FIGURE 3 of the drawings, in which the liquid oxygen and liquid nitrogen are in separate insulated containers **31***a* and **31***b*, respectively, which correspond to the inner tank **31** of FIGURE 2. These two separate containers may be mounted on separate trailers. If it is desired to keep the ultimate ratio of gases delivered to the well substantially the same as that of air, the pumping rates for each of the separate gases are adjusted accordingly.

Pumps **35***a* and **35***b* are substantially the same in function as pump **35**, except for the different capacities. Alternatively, a single pump of modulate design can be used to pump the two liquids, each barrel pumping a separate liquid. Separate heat exchangers **39***a* and **39***b* are similar in function to heat exchanger **39**. It will be noted that heat exchanger **39***b* will consume much larger amounts of energy than **39***a*, as it must heat up a much larger quantity of liquid than the latter.

Ultimately, gaseous oxygen, under a gauge pressure of, say, 2,000 pounds per square inch, passes through check valve **44***a*; and, liquid nitrogen at a similar pressure passes through check valve **44***b*. Check valves **44***a* and **44***b* lead into a Y connection **46**, the common portion of which leads through valve **47** into the screw-in union **21**, and to the well **1**, through valve **19**, as indicated to the right of line X—X in FIGURE 1.

While the invention has been described with reference to FIGURES 1, 2 and 3 as supplying combustion-supporting gas to a down-hole burner **13** which is fueled by propane, or a similar hydrocarbon fuel, it will be apparent that a similar means of providing compressed air or other combustion-supporting gas can be applied to other types of underground combustion in oil wells.

For example, P. L. Terwilliger et al., Patent No. 3,097,690, issued July 16, 1963, discloses a process for heating a subsurface formation to facilitate the production of crude oil and tar and other viscous fluids by injecting into the reservoir a mixture of fluid fuel and air at an injection well and burning the fuel in a channel through the reservoir. The gaseous products of combustion are discharged from the reservoir at a production well spaced from the injection well. The combustion front is made to travel back and forth between the production well and the injection well by controlling the fuel-air ratio injected into the reservoir. In this arrangement, the combustion of fuel is continued until the oil in the reservoir adjacent the channel in which combustion occurs is heated by conduction to a temperature at which it can be produced economically.

Referring to FIGURE 4 of the drawings, an injection well **60** is drilled through overlying rock strata **61** and a petroliferous stratum **62** to an underlying rock formation **63**. The well casing **64** is sunk into the bore, and embedded in a lining of cement **65**. Casing **64** and the cement lining **65** are perforated by perforations **66** near the bottom of the petroliferous zone, and perforations **67** near the top of the zone. A packer **68** of heat resistant material separates the area of the lower perforations **66** from that of the upper perforations **67**. Production tubing **69**, open at its lower end, runs through packer **68** and terminates near the lower perforations **66**.

Adjacent the production tubing **69** in injection well **60** is a fuel-gas line **70** which extends down to a level adjacent the upper perforations **67** and which, at its upper end, is connected to a source of fuel-gas (not shown). Fuel-gas line **70** is surrounded coaxially by a supply line **71** for air, or a combustion-supporting gas mixture, which is connected at the above ground T connection **72**, and beyond the line X—X, to connection **21** leading to the system for producing high pressure gas in the manner indicated in FIGURES 1 and 2, or alternatively, in FIGURE 3.

A thermocouple **73** is disposed adjacent the lower end of the fuel line **70** in injection well **60**.

As explained in detail in Terwilliger et al., Patent No. 3,097,690, a production well **74** is drilled in an area spaced from injection well **60**, through rock strata **61** and petroliferous stratum **62**, terminating in underlying bed rock **63**. As in the previously described wells, this is lined with a casing **75** embedded in cement **76**. Adjacent the upper part of the petroliferous stratum, well **74** includes communicating perforations **77**; and, adjacent the lower level thereof, similar perforations **78**. Well **74** includes production tubing **79** extending from an area adjacent lower perforations **78** to an above ground level, the lower area of the well being separated from the upper area by conventional packing means **80**. An exhaust line **81** extends from the upper area of well **74** to suitable vents above ground for controlling pressure in that area. Pipe **81** also encloses a lead line **82** which terminates in an igniter **83** adjacent the upper perforations **77** for igniting the fuel-air mixture from a source of electrical energy, not shown. A thermocouple **84** is also disposed in well **74** adjacent the area of perforations **77**.

Initially, air (or any combustion-supporting mixture of oxygen and an inert gas) is injected through air supply line **71**, from a system of apparatus in accordance with FIGURE 1, 2, or 3, at pressures of between 100 and 10,000 pounds per square inch gauge, and flowing at rates up to 400,000 standard cubic feet per hour. Assuming that the petroliferous stratum includes sufficient volatile hydrocarbons to form a combustible mixture, this is ignited at the production well **74** by means of igniter **83**. If the concentration of hydrocarbons is high enough, reverse combustion then proceeds from the production well **74** to the injection well **60**. When a sufficient amount of the volatile hydrocarbon content has been consumed or driven out of the formation to reduce the fuel-air ratio, forward combustion may take place.

It will be apparent that the rate and direction of burning can be largely controlled from above ground by control of the fuel-air ratio injected into the well, and by controlling the oxygen-to-nitrogen ratio, pressure and rate of flow of the injected combustion-supporting gas, which is so readily achieved in accordance with the teachings of the present invention, utilizing the supply equipment indicated in FIGURES 1, 2 and 3 and described hereinbefore.

In accordance with a further modification of the invention, instead of supplying a combustible mixture to the well head of injection well **60** in the form of high pressure gas, it is contemplated that for certain types of applications it may be desirable to supply the mixture at that point in the form of liquid, relying on the high temperatures underground to effect vaporization. For this purpose, connection to the junction point **21** would be made just beyond the valve **37**, as shown in FIGURE 2. This would connect to the well-head the equipment to the left of dotted line Y—Y, so that the well head would receive the high pressure liquid output from the pump **35**. It will be understood that for such an application of well-casings and other down-hole installations would necessarily be constructed of materials designed to withstand the low temperatures involved.

An advantageous method of initiating in situ combustion spontaneously in the formations adjacent the well head is achieved by injecting into the well high pressure oxygen consisting exclusively of oxygen of a commercial grade of purity or higher.

It is understood that throughout the specification and claims which follow, when the term "oil well" or "gas

well" is used, it is meant to encompass both oil and gas producing wells.

The present invention is not limited to the specific apparatus or applications, or to the specific quantities disclosed herein by way of illustrating its operation; but rather, the scope of the present invention is limited and defined only by the appended claims.

I claim:

1. The method of supplying a combustion-supporting mixture comprising oxygen and an inert gas at a pressure within the elevated range 100 to 10,000 pounds per square inch, gauge, to an oil well and the adjacent underground formations which comprises: supplying said oxygen and said inert gas as separate liquid components each maintained slightly above atmospheric pressure in a separate heat-insulated environment at the site of said oil well, raising each of said liquid components to substantially the same pressure within said range, heating each of said pressurized components to form a gaseous component at substantially similar pressures within said range at substantially ambient temperature, combining said gaseous components to form a mixture comprising combustion-supporting proportions, delivering said pressurized combustion-supporting mixture through the channels of said well to an area including the deep portions of said well and adjacent underground formations, initiating combustion between said combustion-supporting mixture and combustible material at same point in the area including the deep portions of said well and adjacent formations and controlling the rate and direction of said combustion by regulating the oxygen to inert gas ratio.

2. The method in accordance with claim 1 wherein said components consist essentially of oxygen and nitrogen substantially in the proportions 20 to 80 percent by volume.

3. The method of supporting combustion in an oil well and adjacent underground formations which comprises supplying the components of a combustion-supporting mixture at the site of said well in the form of liquid, raising said liquid to an elevated pressure, and subsequently performing a series of steps which include introducing said mixture at said elevated pressure into said oil well in liquid form, utilizing the temperature underground to convert said mixture to gas, and utilizing said gas for supporting combustion in said well and adjacent underground formations.

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