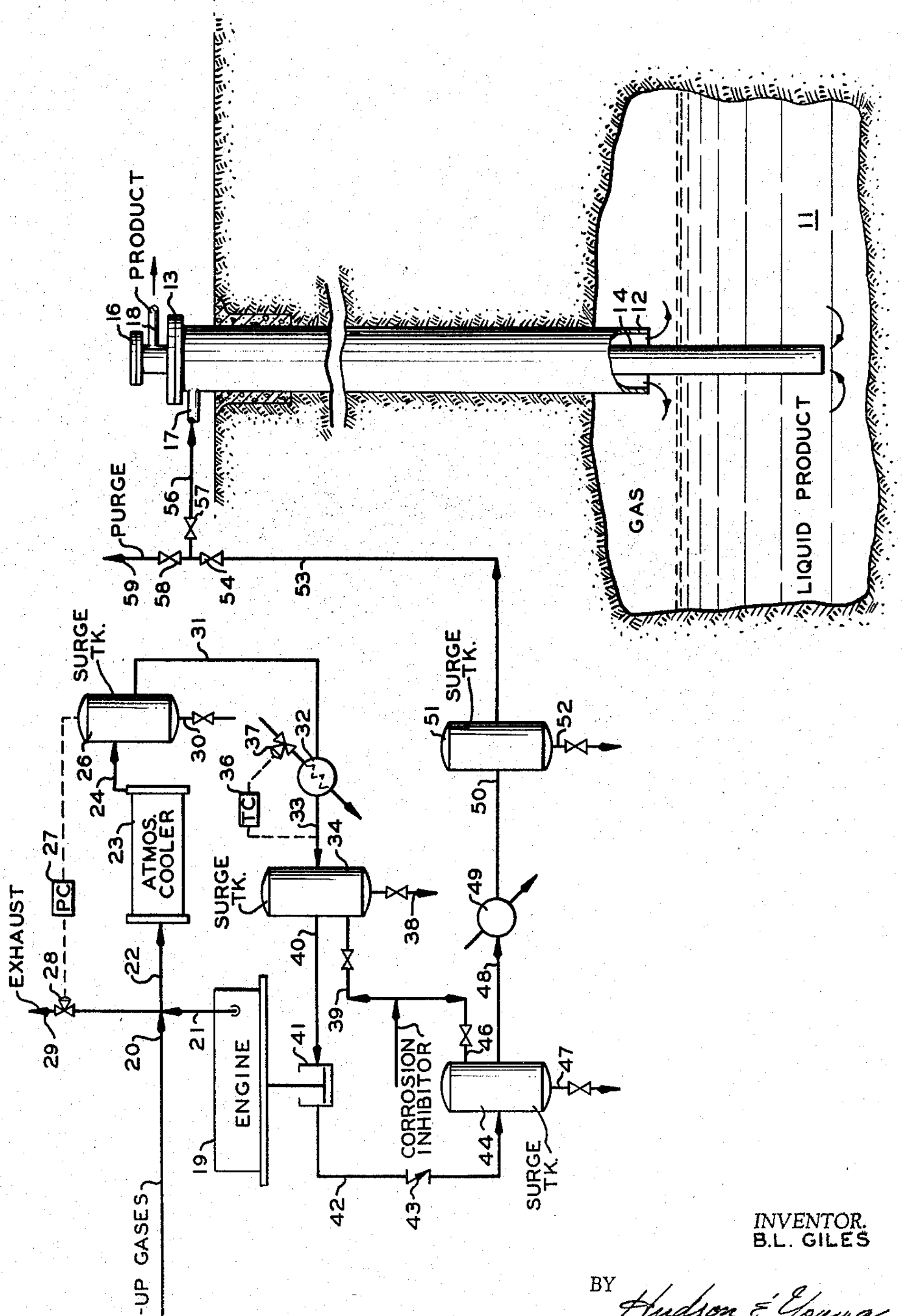
Nov. 29, 1960 B. L. GILES 2,961,841

UNDERGROUND STORAGE PRODUCT REMOVAL

Filed Aug. 7, 1957



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United States Patent Office

2,961,841

Patented Nov. 29, 1960

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UNDERGROUND STORAGE PRODUCT REMOVAL

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Filed Aug. 7, 1957, Ser. No. 676,856

7 Claims. (Cl. 62—48)

This invention relates to a method of removing liquid product from underground storage. In another aspect it relates to a method of pressurizing an underground storage cavern to displace inflammable, volatile liquid therefrom. In another aspect this invention relates to a system for supplying and compressing an inert gas for use in pressurizing an underground storage cavern.

The use of underground caverns in impervious formations has gained considerable favor for the storage of large quantities of volatile liquids or liquefied gases such as L.P.G. (liquefied petroleum gases) or ammonia. Such caverns are formed by mining or by dissolution of a soluble formation to form a cavity therein. Products stored within such caverns are normally removed by pumping or by displacement with brine. The use of bottom hole pumps presents a maintenance problem and when brine is employed it is generally necessary to employ a water separation step to remove water from the stored product. To eliminate these problems displacement of the volatile liquid by pressurizing the cavern with air has been considered; but, when the product is inflammable, as is the case with L.P.G., an explosion or fire hazard is introduced which offsets the other advantages gained.

According to my invention liquid product is removed from an underground cavern by pressurizing the cavern with gases which are products of combustion, such as flue gases and exhaust from internal combustion engines. I prefer the latter type of gas because of its normally low concentration of oxygen. According to my invention exhaust gases and/or flue gases are collected, compressed and passed to the cavern thereby displacing liquid product. It is preferable to remove water formed as a product of combustion from these gases by condensation or other means prior to passing them in contact with the product. According to a preferred embodiment of my invention an internal combustion engine is employed to power a compressor and the exhaust gases from this engine are collected, cooled and passed to said compressor with which they are forced into the underground storage cavern.

It is an object of my invention to provide a method of removing liquid product from an underground storage cavern. It is another object to provide a method of pressurizing an underground storage cavern to remove an inflammable, volatile liquid therefrom without the hazard of explosion. It is still another object to provide a method of supplying a high pressure, inert gas with which an underground storage cavern can be pressurized. Another object of my invention is to provide a system which is capable of both supplying and compressing such an inert gas. Other objects, advantages and features of my invention will be apparent from the following discussion, claims and drawing which depicts schematically a preferred embodiment of my invention.

Broadly, my invention embodies the use of gaseous products of combustion to pressurize an underground storage cavern and displace liquid therefrom. By removing the water which is formed as a combustion product from such gases, liquid product can be removed from the cavern in a substantially dry state and the separation problem which normally accompanies the use of brine as a displacement medium is obviated. Products which can be advantageously removed from underground storage according to my invention include propane, butane, anhydrous ammonia, and the like.

Because of its low oxygen content I prefer to use the exhaust gases of engines such as gas, diesel, L.P.G. or gasoline engines. Preferably such an engine is employed to power the compressor and thereby the system both supplies and compresses the inert gas. In some applications it is advantageous to collect additional exhaust gases from other engines in order to employ the full power potential of the compressor engine. It is also within the scope of my invention to employ exhaust gases mixed with air in such a manner that an atmosphere which will not support combustion is formed. For example, at atmospheric pressure, atmospheres containing less than about 10 volume percent of oxygen will not support the combustion of propane or butane. Thus a mixture of about equal volumes of dry exhaust gas with air would supply a suitably safe atmosphere for pressurizing a cavern for removal of L.P.G. therefrom. A typical exhaust gas analysis on a dry basis is as follows:

Constituent:	Volume percent
Carbon dioxide	13.2
Carbon monoxide	2.2
Oxygen	0.3
Hydrogen	0.4
Methane	0.3
Nitrogen	83.6

To further describe my invention reference is made to the accompanying drawing which shows schematically a preferred embodiment. An underground cavern **11** formed in an impervious formation, such as salt or shale, contains a volatile liquid product stored under pressure with the vapors of said product occupying the space in the cavern above the liquid level. A casing **12** in a shaft forms the entrance to cavern **11**, casing **12** being cemented to the surrounding formation and sealed with a casing head **13** at the surface of the earth. Within casing **12** a conduit **14** extends from the lower portion of cavern **11** through casing head **13**. Conduit **14** serves as product removal or introduction line. Conduit **14** is sealed at the surface by flange and plate **16**.

Product is removed from the cavern by introducing the inert combustion gases through conduit **17**. These combustion gases pass in the annular space between casing **12** and conduit **14** and enter the gas phase in the cavern **12** displacing liquid product from the cavern through conduit **14** and exit pipe **18**. Product is then conveyed to any suitable point of usage and is normally passed into an intermediate aboveground storage container from which it can be conveniently pumped or withdrawn in any known manner.

Inert combustion gases are supplied by engine **19** and, if desired, additional make up gases from the exhausts of other engines can be collected for combination with the exhaust of engine **19** in conduit **20**. Exhaust from engine **19** is withdrawn by conduit **21** and passes through conduit **22** to an atmospheric cooler **23**. Exhaust gases leave the internal combustion engines at a temperature of about 950° F. and can be readily cooled to about 200° F. in such an atmospheric cooler. Cooled gases thus pass through line **24** to surge tank **26** which is maintained at a constant pressure by pressure controller **27** in communication with tank **26** and controlling valve **28** in exhaust line **29**. When the pressure in surge tank **26** exceeds the point suitable for efficient operation of the engines, the exhaust valve **28** is opened, thus permitting the engines to operate without a back pressure. Some moisture formed in the combustion of the fuel is condensed in cooler 23 and separates from the gas in surge tank 26. This moisture can be drained through valved conduit 30.

Gases then pass through line 31 to heat exchanger 32 wherein they are cooled further for more efficient compressor operation. For example, the exhaust gases can be conveniently cooled to about 90° F. They then pass from the heat exchanger 33 to surge tank 34. Temperature controller 36 in line 33 controls valve 37 on the inlet line of the cooling medium, normally water, to heat exchanger 32. Additional moisture condensed is drained from surge tank 34 through valved drain line 38. At this point it may be desirable to introduce into the exhaust gases a corrosion inhibitor such as caustic soda, borax, or chromates (for example, about 300 parts per million) to prevent corrosion from carbonic acid formed in the exhaust gases. The corrosion inhibitor is introduced into surge tank 34 through injection line 39. Normally cooling the exhaust gases to below about 50 percent humidity will remove sufficient water to obviate the corrosion problem.

Cooled exhaust gases pass through conduit 40 to compressor 41 which is powered by engine 19. Compressed gases then pass through conduit 42, check valve 43 and into surge tank 44. It may be desirable to introduce additional corrosion inhibitor through injection line 46. Moisture condensed in the compression stage can be drained by line 47 and the gases passed through conduit 48 to cooler 49 and thence through line 50 to surge tank 51 where additional water can be separated and drained from the system through line 52. Essentially dry exhaust gases then pass through conduit 53, valve 54, line 56 and valve 57 to inlet 17, and thence into the underground cavern as previously described.

When starting up the system, it is desirable to purge the equipment through purge valve 58 and line 59 before directing the gases into cavern 11. In this manner dry, inert gases are supplied at high pressure to an underground cavern containing inflammable fluids without danger of explosion or contamination of the product with moisture. When the cavern is to be refilled with product, exhaust gases are vented through lines 56 and 59. The advantage over the use of bottom hole pumps is evident since all of the operating equipment is located at ground level and is easily accessible for repair.

To further explain and describe the advantages of my invention the following examples are presented which are illustrative only and should not be interpreted to limit my invention unduly.

Example I

An internal combustion engine using propane as a fuel is employed to power a compressor. The engine has a rating of 100 brake horsepower and a brake specific fuel consumption of 0.5 pound of propane per brake horsepower hour. An air-fuel ratio of 16 to 1 by weight is established with the resultant production of dry exhaust gas at a rate of 165 cubic feet per minute (standard temperature and pressure. This exhaust gas consists primarily of nitrogen and carbon dioxide. The efficiency of the engine is 75 percent. Propane is displaced from an underground cavern having an average depth below the surface of the earth of 500 feet and is passed to an aboveground utilization point in which the vapor pressure is approximately equal to that in cavern. The friction loss in the effluent lines is about 5 pounds per square inch absolute. Thus employing only the exhaust gases from the engine operating the compressor, a pressure of 116 pounds per square inch absolute is developed and the propane is displaced from the cavern at a rate of 156 gallons per minute.

Employing the same system as above described, it is possible to remove propane from an underground cavern having a depth as great as 4,370 feet at displacement rates of about 19 gallons per minute.

Example II

The same engine as employed in Example I is used to displace propane from an underground cavern having an average depth of 2,000 feet. Pressure required to displace propane therefrom is 447 pounds per square inch absolute and the displacement rate is 40.5 gallons per minute. Employing the full capacity of the engine by adding air or make-up exhaust gases from other sources at a rate of 60 cubic feet per minute, a propane displacement rate of 55 gallons per minute as realized from the 2000 foot depth. In such a system there is substantially no explosion hazard, even when air is used to supply the additional 60 cubic feet per minute of intake gas required to utilize the full capacity of the engine.

As will be evident to those skilled in the art, various modifications of this invention can be made or followed in the light of the foregoing disclosure and discussion without departing from the spirit or scope thereof. For example, one or more cooling and water separation stages can be omitted or added, and other steps can be used to separate product contaminants from the exhaust gases, such as oily products which might be present in diesel exhaust.

I claim:

1. A method of removing inflammable volatile liquid from an underground storage cavern which comprises compressing gases subsequently described, supplying power for said compressing step by operating internal combustion engine, collecting exhaust gases from said engine, cooling said exhaust gases thereby condensing water formed as a product of combustion, separating water thus condensed from said exhaust gases thereby forming the above mentioned gases, passing said gases to said compressing step, cooling said gases thus compressed, separating additional water condensed upon cooling said compressed gases, and passing said compressed gases to said cavern thereby displacing said liquid therefrom.

2. A method according to claim 1 wherein said volatile liquid is L.P.G.

3. A system for pressurizing an underground storage cavern comprising, in combination, a compressor, an internal combustion engine powering said compressor, first conduit means conveying exhaust gases from said engine to said compressor and second conduit means conveying compressed gases from said compressor to said underground storage cavern.

4. A system for removing volatile and inflammable liquid from an underground storage cavern comprising, in combination, a compressor, an internal combustion engine powering said compressor, a conduit communicating with said engine to collect exhaust gases therefrom, cooling means associated with said conduit, a surge tank positioned to receive cooled gases from said conduit, a second conduit establishing communication between said tank and said compressor, and means for passing compressed gases from said compressor to said underground cavern.

5. In an underground storage system comprising an underground cavern containing a volatile and inflammable liquid, a casing extending from the surface of the earth to the upper portion of said cavern and a pipe concentrically positioned in said casing extending from the surface of the earth to the lower portion of said cavern, the improved apparatus for pressurizing said cavern for removal of said volatile and flammable liquid from said cavern comprising, in combination, an internal combustion engine, a gas compressor operated by said internal combustion engine, a first conduit extending from the exhaust of said engine to a first heat exchanger, a vent line extending from said conduit and open to the atmosphere, a motor valve in said vent line, a first surge tank equipped with a water draw-off line, a second conduit connecting said first heat exchanger and said first surge tank, a pressure controller connected to sense the pressure in said first surge tank and operatively connected to

said motor valve, a second surge tank equipped with a water draw-off line, a second heat exchanger, a third conduit connecting said first surge tank with said second surge tank and passing through said second heat exchanger, temperature controlling means controlling the flow of coolant to said second heat exchanger in response to the temperature in said third conduit downstream from said second heat exchanger, a fourth conduit connecting said second surge tank with the intake of said compressor, a third surge tank equipped with a water draw-off line, a fifth conduit carrying a check valve and connecting the outlet of said compressor with said third surge tank, a fourth surge tank, a third heat exchanger, a sixth conduit connecting said third surge tank with said fourth surge tank and passing through said third heat exchanger, said fourth surge tank equipped with a water draw-off line, a seventh conduit connecting said fourth surge tank with said casing, and a valved purge line open to the atmosphere and connected to said seventh conduit.

6. The method of pressurizing an underground storage cavern containing inflammable volatile liquid stored therein which comprises compressing gases subsequently de-

scribed, supplying power for said compressing step by operating an internal combustion engine, collecting exhaust gases from said engine and passing same to the compression step, and passing the resulting compressed gases to the cavern to displace liquid therefrom.

7. The method of pressurizing an underground storage cavern containing inflammable volatile liquid stored therein which comprises collecting engine exhaust gases, cooling said gases thereby condensing water, separating from said gases water condensed in said cooling step, mixing said engine exhaust gases with air to produce a gaseous mixture which will not support combustion, compressing said gaseous mixture, and passing said gaseous mixture thus compressed to said cavern.

References Cited in the file of this patent

UNITED STATES PATENTS

2,143,283	Schmidt	Jan. 10, 1939
2,433,896	Gay	Jan. 6, 1948
2,525,802	Joerren	Oct. 17, 1950
2,543,653	Woog	Feb. 27, 1951
2,552,472	Whidden	May 8, 1951