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Robinson

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[54] METHOD AND APPARATUS FOR REFRIGERATING WELLS BY GAS EXPANSION

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[52] **U.S. Cl.** .... **166/267;** 61/36 A; 62/260; 166/DIG. 1; 166/57; 165/45

[51] **Int. Cl.** **E21b 43/24;** E21b 43/00

[58] **Field of Search** .... 61/.5, 36 A; 62/260; 165/45; 166/DIG. 1, 57, 63, 267, 265, 266, 222, 302; 175/17

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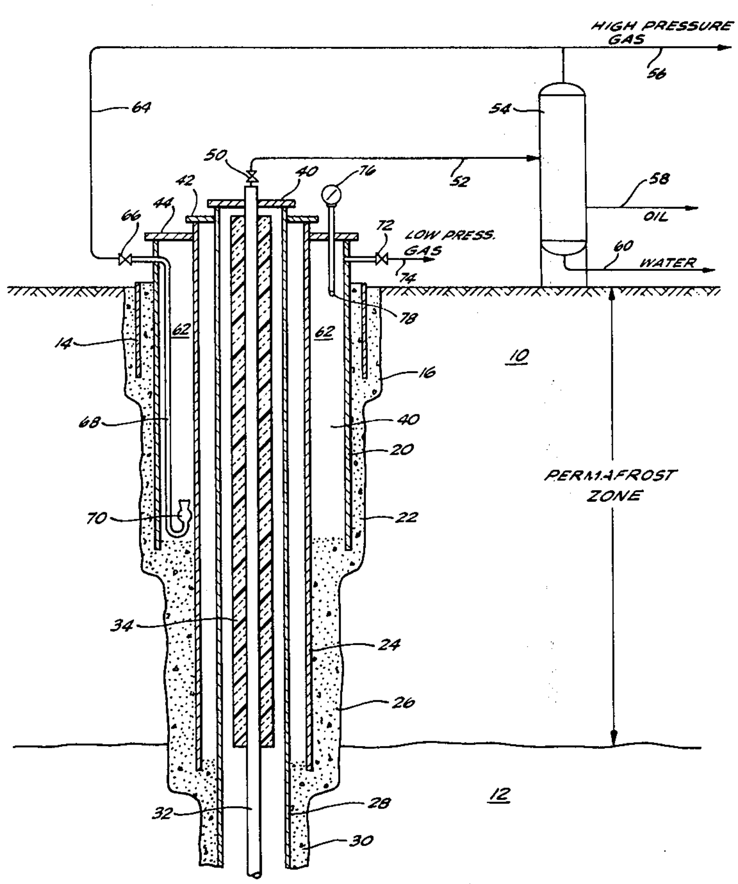
[57] **ABSTRACT**

Thawing of the permafrost around a well transporting hot fluids through a permafrost zone is prevented by refrigerating a section of the well to prevent the flow of heat from the well to the surrounding permafrost. Refrigeration is provided by expanding gas into a well annulus extending through a substantial part of the permafrost. The refrigerant gas can be a portion of the produced gas separated from the produced fluids at the surface or in a downhole separator.

19 Claims, 2 Drawing Figures



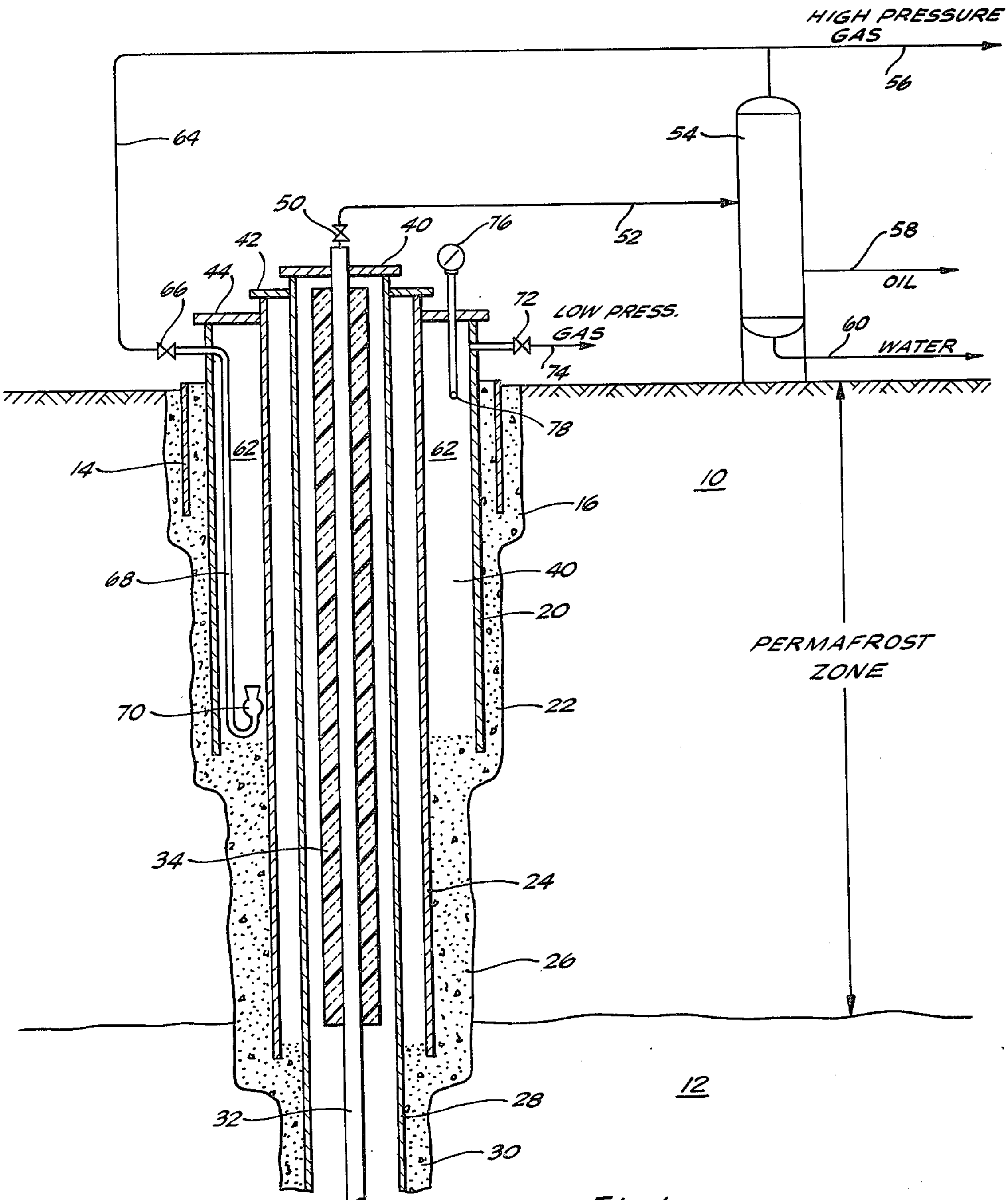

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Fig 1

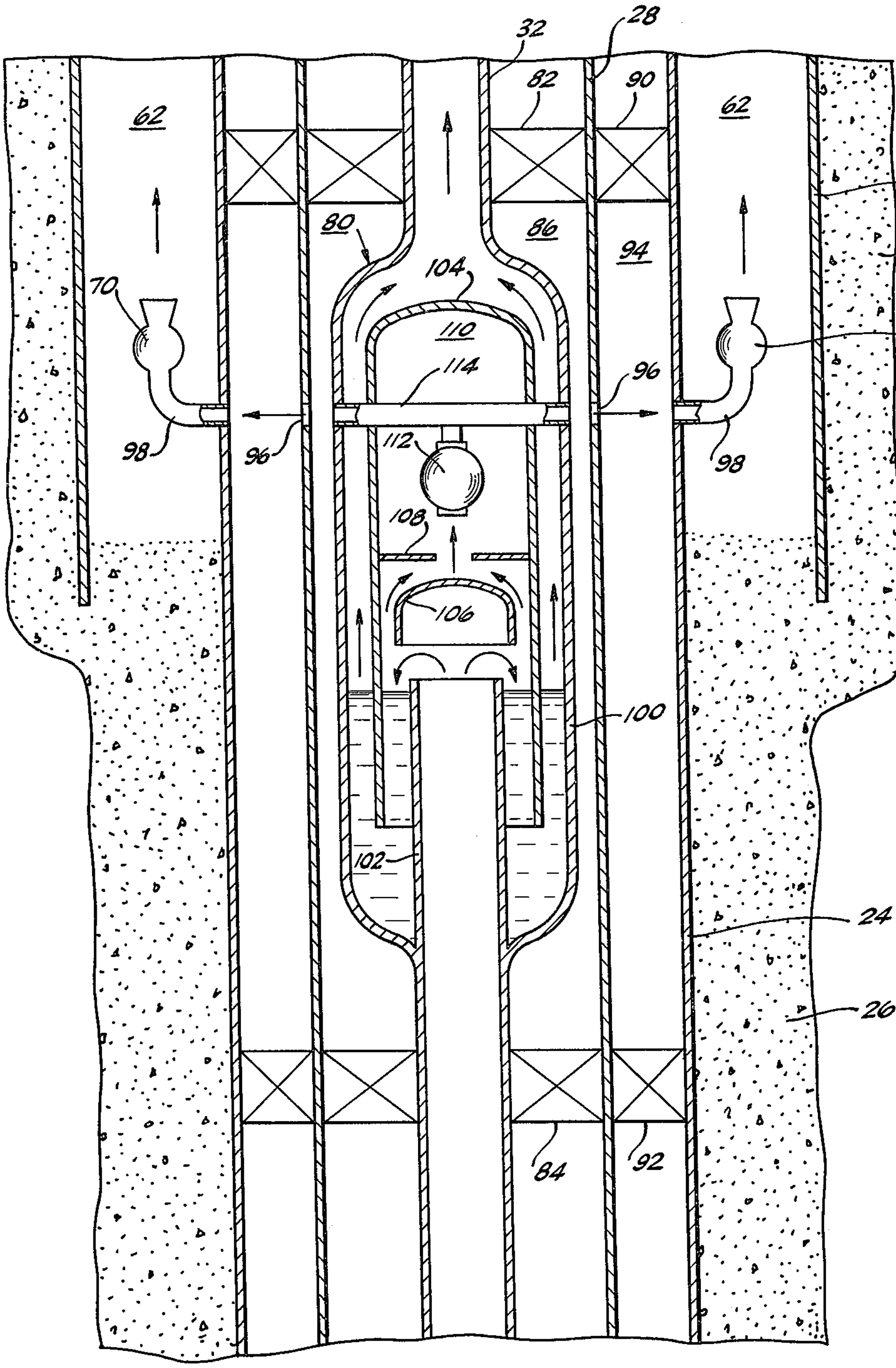
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Fig 2

METHOD AND APPARATUS FOR REFRIGERATING WELLS BY GAS EXPANSION

This invention relates to wells for recovering earth fluids, and more particularly to wells for transporting hot fluids through a permafrost zone.

Permafrost is perennially frozen ground found in the Arctic regions. The permafrost zone contains some layers of gravel free of ice known as "dry permafrost," but the bulk of the zone is composed of rocks or of unconsolidated aggregates of sand, silt and gravel in which the interstitial water is frozen to ice. Permafrost is formed by cooling from the surface during the Arctic winters, particularly in regions of low snow fall. Cooling of the upper earth strata to below freezing temperatures to form permafrost continues until an equilibrium is reached with the heat flow from the earth's interior. There is seasonal thawing and freezing at the surface, but thawing rarely penetrates more than 18 inches where the permafrost is protected by tundra or vegetation. Thus, the permafrost zone consists of frozen earth, the bulk of which remains permanently frozen unless some external source of heat is introduced that alters the temperature equilibrium. The thickness of the permafrost zone varies with latitude and with the particular geographic location.

Permafrost generally has sufficient strength to support oil exploration and recovery operations, so long as it remains frozen. However, when melted, unconsolidated permafrost shrinks and subsides causing a downdrag force on well casings passing through the permafrost zone. Drilling operations can generally be conducted without causing any substantial melting of the permafrost. However, melting of the permafrost is experienced around wells conducting hot fluids through the permafrost zones, and this melting must be prevented or retarded sufficiently so that subsidence does not occur during the life of the well.

Heat loss from a hot fluid transported through the permafrost can be substantially reduced by insulating the conduit carrying the hot fluid. In some cases, insulation alone reduces heat loss to the permafrost sufficiently to avoid melting the permafrost. However, insulation alone is generally not sufficient where the heat loss is relatively high or where the permafrost is initially relatively warm, i.e., where the permafrost is at a temperature only slightly below the freezing point of water. Various mechanical means such as slip joint casing and the like, which would not be damaged by subsidence, have been proposed for use in transporting hot fluids through permafrost. However, such devices are expensive to construct and install, and are not yet reliable. Mechanical refrigeration, usually in conjunction with insulation of the conduit carrying the hot fluid, can be employed to effectively prevent heat loss from the well to the surrounding permafrost. Although various methods of refrigerating the well have been proposed which are effective in preventing melting of the permafrost, mechanical refrigeration equipment is expensive to install and operate, requires a source of power at the well site, and requires at least the periodic attention of an operator. Thus, need exists for a simpler and less costly method for refrigerating wells traversing a permafrost zone.

Accordingly, it is a principal object of this invention to provide a simple, low cost method for conducting hot fluids through a well traversing a permafrost zone

that substantially prevents thawing of the permafrost around the well.

Another object of the invention is to provide a method for preventing thawing of the permafrost adjacent to a well transporting hot fluid through a permafrost zone.

Still another object of the invention is to provide a method for producing hot oil from a reservoir underlying a permafrost zone that prevents thawing of the permafrost surrounding the well.

A further object of the invention is to provide a method for injecting hot fluids into an earth formation underlying a permafrost zone without thawing the permafrost surrounding the injection well.

A still further object of the invention is to provide an improved method for operating a refrigerated well conducting hot fluids through a permafrost zone.

An even further object is to provide a refrigerated well for transporting hot fluids through a permafrost zone.

Other objects and advantages of the invention will be apparent from the following description.

In brief, this invention concerns a method and apparatus for preventing thawing of the permafrost around a well transporting hot fluids through a permafrost zone. Thawing is prevented by expanding a gas into a well annulus extending through a substantial part of the permafrost. The refrigerant gas can be a portion of the produced gas separated from the produced fluids at the surface or in a downhole separator.

The manner of accomplishing the foregoing objects as well as other objects and advantages of the invention will be apparent from the following description taken in conjunction with the drawings, wherein like numerals refer to corresponding parts, and in which:

FIG. 1 is a schematic vertical sectional view illustrating one embodiment of the well assembly of this invention installed in a permafrost zone; and

FIG. 2 is an enlarged schematic vertical sectional view of another embodiment of the invention employing a downhole gas separator installed in a permafrost zone.

Referring specifically to FIG. 1 of the drawings, there is illustrated a well completed in an earth formation comprised of an upper permanently frozen permafrost zone **10** and a lower earth strata **12** that overlies a petroleum reservoir, not shown. The well is comprised of surface conductor **14** cemented in the upper strata of permafrost zone **10** with cement **16.** Surface conductor **14** is run to eliminate the possibility of a wash out or severe melting around the cellar area directly adjacent to the well bore. Typically, surface conductor **14** is comprised of a length of relatively large diameter pipe, such as a 30-inch diameter casing, 20 to 60 feet in length, and preferably about 40 feet in length.

Casing **20** is set in permafrost **10** to the depth at which refrigeration of the well is to be maintained and is cemented to the surface by means of cement **22.** The permafrost surrounding casing **20** is maintained permanently frozen over substantially its entire length to provide the necessary support for the well. In a typical installation, casing **20** extends to a depth of about 200 to 700 feet, and most typically to a depth of about 300 feet, and can extend completely through the permafrost, if desired. Maintaining the permafrost frozen to a depth of at least about 200 feet should provide adequate support for the well, and any thawing below this point is considered harmless. Although the diameter and weight of casing employed in this string will depend upon the targeted drilling depth, the types of formations traversed, and the total number of casing strings to be run; in a typical installation for many wells, casing **20** is a 20-inch diameter casing.

Surface casing **24** is the primary pressure string and provides an anchor for blowout preventer equipment, and is run deep enough for protection of fresh-water sands and deep enough to extend through the entire permafrost section. Casing **24** is cemented back to the bottom of casing **20** with cement **26** which forms a sheath surrounding casing **24.** While the use of casing **24** is optional unless required by a regulatory authority, and may be omitted where the well can be drilled from the bottom of the permafrost through the producing interval without intermediate casing, in most instances it is preferred to employ a surface casing terminating shortly below the bottom of the permafrost. Also, additional intermediate strings of casing may be installed where necessitated by conditions encountered in the drilling operation.

Production casing **28** extends from the surface to the producing strata and is cemented back to the bottom of casing **24,** or alternatively, if casing **24** is omitted, to the bottom of casing **20,** with cement **30** which forms a sheath surrounding casing **28.** The well is completed in conventional manner by extending casing **28** through the productive zones and perforating at selected intervals, or by terminating the casing above the productive zone and hanging a preslotted or pre-perforated liner in these zones. Production tubing **32** conveys produced fluids from the producing zone to the surface, or flow from the surface to the producing zones in the case of an injection well. That portion of production tubing **32** lying within the permafrost zone can be provided with insulation **34** to reduce the amount of heat transferred from the hot fluid flowing through tubing **32.** Insulation **34** can be any type of thermal insulating material, such as polyurethane foam and the like, that is suitable for installation in a well. Insulation **34** extends at least the length of casing **20,** and preferably extends from the surface to the bottom of permafrost zone **10.**

The well is fitted with a conventional well head including means **40** to seal the annulus between tubing **32** and producing casing **28,** means **42** to seal the annulus between production casing **28** and surface casing **24,** and means **44** to seal the annulus between surface casing **24** and casing **20.** FIG. **1** illustrates the practice of the invention in conjunction with a producing well. In the conventional operation of a producing oil well, produced fluids consisting of a mixture of oil, gas and water flow from tubing **32** through valve **50** and conduit **52** to field separator **54.** High pressure gas is separated from the fluid mixture and withdrawn through conduit **56,** produced oil is withdrawn through conduit **58,** and water is produced through conduit **60.** This production equipment can receive the production of a single well, or the produced fluids from a number of wells can be combined and processed.

The annulus between surface casing **24** and production casing **28** can be filled with gelled diesel oil, or similar packing fluid, in conventional manner. The annulus between casing **20** and surface casing **24** is closed at the bottom by cement **26,** or by a mechanical packer, not shown, to provide a closed refrigeration chamber **62** surrounding surface casing **24** and extending from the surface to a substantial depth in permafrost zone **10.** The well is refrigerated over the length of annular chamber **62** by expanding high pressure gas into the chamber in an amount sufficient to maintain the temperature in the chamber below the melting temperature of the surrounding permafrost. Fail safe pressure control and/or over pressure safety devices, not shown, must be provided to assure that the casing strings forming annulus **62** will not be subjected to excessive pressure.

In the embodiment of the invention illustrated in FIG. **1,** the high pressure refrigerant gas from separator **54** is conducted through conduit **64** and introduced into the well through valve **66** and small diameter tubing **68** which extends to the bottom of annular chamber **62** and terminates in expansion nozzle **70.** High pressure refrigerant gas is expanded into chamber **62** and the expanded and cooled gas flows upwardly through annular chamber **62** around the exterior of casing **24.** Low pressure gas is exhausted from refrigeration chamber **62** through valve **72** communicating with low pressure gas conduit **74.** The well can be fitted with a temperature measuring instrument **76,** such as a thermometer or temperature recorder, responsive to a temperature detecting element **78** extending into refrigeration chamber **62.**

The embodiment of the invention illustrated in FIG. **1** can be employed to refrigerate either producing wells or injection wells penetrating a permafrost zone, the only requirement being that a suitable supply of refrigerant gas is available for expansion in the refrigeration chamber of the well.

In another embodiment of the invention applicable to producing wells, a downhole separator is employed to separate high pressure gas from the produced fluids to provide a source of refrigerant gas. The high pressure gas is conducted to the gas expansion nozzle and discharged into the annular refrigerant chamber to effect cooling of the refrigerant gas to a temperature below the permafrost temperature.

Downhole apparatus for separating gas from the produced fluids is illustrated in FIG. **2.** In the illustrated embodiment, gas separator **80** is installed in production tubing **32** and positioned adjacent to the bottom of annular refrigerant chamber **62.** Packers **82** and **84** are set in the annulus between tubing **32** and production casing **28,** above and below separator **80,** respectively, so as to define a closed annular chamber **86.** Packers **90** and **92** are set in the annulus between production casing **28** and surface casing **24,** above and below separator **80,** respectively, so as to define closed annular chamber **94.** Apertures **96** in the production casing communicate chambers **86** and **94,** and nozzles **70** are mounted on conduits **98** which connect the inlets of the nozzles to chamber **94.**

Separator **80** is comprised of a closed cylindrical member **100** having a lower inlet connection and an upper outlet connection adapted for mounting between joints of tubing **32.** An internal standpipe **102** extends upwardly from the inlet into cylindrical member **100,** and inverted cap **104** is mounted above standpipe **102** so as to extend downwardly around the open end of the standpipe. Inverted cup-shaped diverter **106** is mounted immediately above the open end of standpipe **102** by a suitable mounting bracket, not shown, and apertured baffle plate **108** is provided within cap **104** to define upper gas chamber **110.** Float-type valve **112** is mounted in gas chamber **110** and connected to the exterior of cylindrical member **100** by conduit **114.** Valve **112** closes upon the raise of liquid to a level above the valve, thereby preventing the discharge of liquid through the gas conduit.

In operation, produced fluids passing upwardly through production tubing **32** are introduced into separator **80** through inlet standpipe **102.** A portion of the gas contained in the produced fluids is disengaged and flowed around diverter **106** and through the aperture in baffle **108** into upper gas chamber **110.** The liquid portion of the produced fluid and the remainder of the gas flows around the bottom lip of cup **104** and upwardly through the annular passage between cylindrical member **100** and cup **104.** The disengaged gas exits chamber **110** and through valve **112** and conduit **114** and passes into annular chamber **86.** This gas flows from chamber **86** through apertures **96** and into chamber **94,** from where it is subsequently discharged through conduits **98** and gas expansion nozzles **70** into annular refrigeration chamber **62.**

The temperature of the expanded gas discharged into refrigeration chamber **62** is affected by the temperature and pressure of the high pressure gas supplied to the nozzle, the rate of gas flow through the nozzle, the pressure in refrigeration chamber **62** at the exit of the nozzle, the composition of the refrigerant gas, the nozzle efficiency, the temperature of the permafrost, and the rate of heat flow from the hot oil. The amount of gas expanded into refrigeration chamber must be sufficient to prevent refrigerant gas from being warmed in refrigeration chamber **62** to a temperature above the melting point of the permafrost, i.e., the refrigerant gas exiting the refrigeration chamber should be at a temperature below about 32° F.

Although the refrigerant gas can be any of a wide variety of gases that cool upon expansion, such as air, nitrogen, oxygen, or mixtures of these gases; as a practical matter, it is most advantageous to employ produced gas as the refrigerant gas. Produced gas consists primarily of methane, and contains lesser amounts of ethane, propane, and higher molecular weight hydrocarbons. It also can contain varying amounts of hydrogen sulfide, carbon dioxide, water, and minor amounts of other impurities. This gas can be used directly as produced in the field or after processing through gas absorption plants for the removal of various of the high molecular weight hydrocarbons and other constituents to produce a pipeline grade natural gas. The produced field gas, or natural gas, employed in the well refrigeration technique of this invention generally exhibit specific gravities between about 0.60 and 1.0, and most typically between about 0.65 and 0.80.

Under certain conditions of temperature and pressure, hydrocarbon gases containing liquid water form solid hydrates that could cause plugging of the refrigeration chamber and other gas flow passages. Accordingly, it is preferred that the water content of the gas be maintained below that amount that will condense to form liquid water. The water content of a produced gas can be reduced by contacting the gas with ethylene glycol or other desiccant material that preferentially absorbs water from the gas. The dry gas having a reduced water content can then be employed to refrigerate the well.

The high pressure gas employed as the refrigerant gas must be available at a pressure sufficiently high that the requisite cooling can be obtained by expansion of the gas. Generally, the gas must be available at a pressure of at least about 200 psig, and preferably at a pressure of about 400 to 800 psig. The temperature of the high pressure gas is usually between about 50° F. and 150° F.

The low pressure gas exhausted from the refrigeration chamber is collected and employed as a boiler or internal combustion engine fuel, or for other uses, or the low pressure gas can be recompressed for pipeline delivery. Also, where the produced gas available in a particular field is not sufficient to provide the necessary refrigeration, it is within the scope of this invention to recompress the low pressure gas and recycle this gas through the expansion nozzle. The pressure to which the refrigerant gas is expanded and the utilization of the refrigerant gas in any particular oil field will depend upon the availability of produced gas in that field, the utilization of the low pressure gas, and the particular economics involved. In typical applications, the refrigerant gas will be expanded to a pressure of about 100 to 300 psig, although this pressure will depend upon the particular circumstances of each application.

Although nozzle **70** can be any gas expansion nozzle, the amount of cooling obtained and the efficiency of the process is dependent upon the design of the nozzle. Maximum cooling is obtained when the gas passing through the nozzle expands isentropically, i.e., expands by a reversible process at constant entropy. This is an idealized condition that cannot be attained in practice. However, it is within the skill of the nozzle art to design highly efficient gas nozzles for expanding gases substantially isentropically. The efficiency of a nozzle can be characterized by the nozzle coefficient ηn, which is defined as

$$\eta_n = \frac{V_s\,(\text{actual})}{V_s\,(\text{ideal})}$$

in which V_s(actual) is the actual gas velocity attained in the nozzle and V_s(ideal) is the ideal velocity theoretically attained by a gas isentropically expanding through the nozzle. The term "substantially isentropic" as used herein is meant to define a gas expansion through a nozzle having a nozzle coefficient of 0.95 or higher, and more preferably 0.98 or higher.

The nozzle design and operating conditions must be selected so that the expanded refrigerant gas is introduced into the refrigeration chamber at a temperature sufficiently below the melting temperature of the permafrost that the gas does not warm to a temperature above the melting temperature during passage through the refrigeration chamber. The amount of the refrigerant gas expanded into the refrigeration chamber will depend upon the magnitude of the heat flux from the hot fluid flowing through the tubing string. In a typical well having a well insulated tubing string, the heat flux is generally about 10 to 30 BTU/Hr per foot of well. Depending upon the particular conditions encountered, this amount of heat can be removed by expanding about 900 to 1,800 pounds per hour of refrigerant gas into the refrigeration chamber.

In operation, the refrigeration obtained with any particular system can be controlled by adjusting either the inlet pressure of the gas supplied to the nozzle, the exhaust pressure in the refrigeration chamber, or both of these pressures. An increase in inlet pressure and a decrease in exhaust pressure result in additional cooling, with an opposite effect being obtained by a reduction in inlet pressure or an increase in the exhaust pressure.

The improved well refrigeration method of this invention is further demonstrated by the following examples which are presented by way of illustration, and are not intended as limiting the spirit and scope of the invention as defined by the appended claims.

EXAMPLE 1

This example illustrates the application of the well refrigeration method of this invention to a producing well completed in a petroleum reservoir underlying a frozen permafrost zone approximately 2,000 feet thick. The well is completed substantially as illustrated in FIG. **1**, with refrigeration chamber **62** extending from the surface to a depth of approximately 300 feet. Fluids are produced from the underlying reservoir at a temperature of 125° F. and transported to the surface. Primary treatment includes separation of the gas, oil and water phases. High pressure gas is produced from the separator at 125° F. and 485 psig. This gas consists primarily of methane and contains ethane and other light hydrocarbons, and exhibits a specific gravity of 0.70.

Refrigeration of the well is accomplished by recycling a portion of the produced high pressure gas to the well and substantially isentropically expanding this gas into the refrigeration chamber through a single gas expansion nozzle having a nozzle efficiency of 0.98. The refrigerant gas is dried by contact with ethylene glycol prior to recycle to the well to avoid the formation of hydrates in the refrigeration chamber. Approximately 500 MSCF/D of the high pressure gas at 125° F. and 485 psig is expanded to 185 psig in the refrigeration chamber to provide cooling for the well. The expanded gas exits the expansion nozzle at a temperature of 20° F., and is warmed to about 30° F. during its passage through the refrigeration chamber. The refrigerant gas removes sufficient heat from the well to prevent thawing of the permafrost adjacent to the well.

EXAMPLE 2

This example illustrates another embodiment of the invention in which the well is cooled by expanding a high pressure refrigerant gas separated from the produced fluids in a downhole separator located 300 feet below the surface. Approximately 500 MSCF/D of gas is separated from the produced fluids at a temperature of 125° F. and a pressure of 485 psig. This gas is expanded, without drying, into the refrigeration chamber of a well completed substantially as illustrated in FIG. **2**. The refrigerant is cooled to a temperature of about 20° F. on expanding to a pressure of 175 psig., and is warmed about 10° F. on passage through the refrigeration zone. The pressure in the refrigeration chamber is controlled to maintain the temperature of the gas exiting the refrigeration chamber below about 32° F.

Various embodiments and modifications of this invention have been described in the foregoing specification, and further modifications will be apparent to those skilled in the art. Such modifications are included within the scope of this invention as defined by the following claims.

Having now described the invention, I claim:

1. A refrigerated well extending from the surface to an underlying petroleum reservoir for conducting hot fluids through a permafrost zone, which comprises:

a closed annular refrigeration chamber defined by inner and outer concentric casings extending a substantial distance into said permafrost zone, said refrigeration chamber lying between said hot fluids conducted through said well and said permafrost;

a production tubing within said inner casing to conduct fluids from said underlying petroleum reservoir to the surface, or vice versa;

at least one gas expansion nozzle located within said refrigeration chamber and adjacent to the bottom thereof, and discharging into said chamber;

gas conduit means to conduct high pressure gas from a source of high pressure gas to said gas expansion nozzle; and

means for exhausting low pressure gas from said refrigeration chamber;

whereby high pressure gas discharged through said gas expansion nozzle into said refrigeration chamber is cooled to a temperature below the permafrost temperature and flowed upwardly through said refrigeration chamber to prevent the transfer of heat from said hot fluids conducted through said well to the surrounding permafrost.

2. The apparatus defined in claim **1** wherein said annular refrigeration chamber has a length of about 200 to 700 feet.

3. The apparatus defined in claim **1** wherein said gas expansion nozzle substantially isentropically expands gas into said refrigeration chamber.

4. The apparatus defined in claim **1** including a gas separator located at the surface to separate high pressure gas from fluids produced from said underlying petroleum reservoir, wherein said gas conduit means conducts said high pressure gas from said gas separator to said gas expansion nozzle, and wherein said gas conduit means includes a high pressure gas conduit in said refrigeration chamber extending from the surface to said gas expansion nozzle.

5. The apparatus defined in claim **1** including a downhole gas separator in fluid communication with said production tubing to separate high pressure gas from fluids produced from said underlying petroleum reservoir, said separator being located adjacent to the bottom of said refrigeration chamber, and wherein said gas conduit means conducts high pressure gas from said gas separator to said gas expansion nozzle.

6. A refrigerated well for conducting hot fluids through a permafrost zone, which comprises:

a first casing extending a substantial distance into said permafrost zone and cemented therein;

a second casing placed concentrically within said first casing, said second casing extending below said first casing and said second casing being cemented below the bottom of said first casing;

sealing means at the top of said first casing to provide a fluid-tight closure between said first and second casings so as to form a closed annular refrigeration chamber;

a production tubing within said second casing to convey fluids from an underlying producing strata to the surface, or vice versa, said tubing being insulated through said permafrost zone;

at least one gas expansion nozzle located within said refrigeration chamber and adjacent to the bottom thereof, and discharging into said chamber;

gas conduit means to conduct high pressure gas from a source of high pressure gas to said gas expansion nozzle; and

means for exhausting low pressure gas from said refrigeration chamber.

7. The apparatus defined in claim 6 including a gas separator located at the surface to separate high pressure gas from fluids produced from said underlying producing strata, wherein said gas conduit means conducts said high pressure gas from said gas separator to said gas expansion nozzle, and wherein said gas conduit means includes a high pressure gas conduit in said refrigeration chamber extending from the surface to said gas expansion nozzle.

8. The apparatus defined in claim 6 including a downhole gas separator in fluid communication with said production tubing to separate a portion of the gas from the fluids produced from said underlying producing strata, said separator being located in said second casing adjacent to the bottom of said refrigeration chamber, and wherein said gas conduit means conducts high pressure gas from said gas separator to said gas expansion nozzle.

9. The apparatus defined in claim 6 wherein said gas expansion nozzle expands the gas passing therethrough substantially isentropically.

10. The apparatus defined in claim 6 including a production casing placed concentrically within said second casing, said production casing extending from the surface to said underlying producing strata and said production casing being cemented below the bottom of said second casing.

11. The apparatus defined in claim 6 wherein said second casing extends at least to the bottom of said permafrost zone.

12. A refrigerated well for conducting hot fluids through a permafrost zone, which comprises:

a surface conductor cemented in the permafrost;

a first casing placed concentrically within said surface conductor and extending about 200 to 700 feet into said permafrost zone, said first casing being cemented to the surface;

a second casing placed concentrically within said first casing, said second casing extending at least through said permafrost zone and said second casing being cemented below the bottom of said first casing;

sealing means at the top of said first casing to provide a fluid-tight closure between said first and second casings so as to form a closed annular refrigeration chamber;

a production casing placed concentrically within said second casing and extending from the surface to an underlying petroleum reservoir, said production casing being cemented below the bottom of said second casing;

a production tubing within said production casing to convey fluids from an underlying petroleum reservoir to the surface, or vice versa, said tubing being insulated through said permafrost zone;

at least one gas expansion nozzle located with said refrigeration chamber and adjacent to the bottom thereof, to substantially isentropically expand high pressure gas into said chamber;

a gas conduit in said refrigeration chamber to conduct high pressure gas from the surface to said gas expansion nozzle; and

means to exhaust low pressure gas from said refrigeration chamber.

13. A refrigerated well penetrating a permafrost zone for producing hot fluids from an underlying petroleum reservoir, which comprises:

a surface conductor cemented in the permafrost;

a first casing placed concentrically within said surface conductor and extending about 200 to 700 feet into said permafrost zone, said first casing being cemented to the surface;

a second casing placed concentrically within said first casing, said second casing extending at least through said permafrost zone and said second casing being cemented below the bottom of said first casing;

sealing means at the top of said first casing to provide a fluid-tight closure between said first and second casings so as to form a closed annular refrigeration chamber;

a production casing placed concentrically within said second casing and extending from the surface to an underlying petroleum reservoir, said production casing being cemented below the bottom of said second casing;

a production tubing within said production casing to convey fluids from said underlying petroleum reservoir to the surface, said tubing being insulated through the permafrost zone;

a downhole gas separator in said production casing adjacent to the bottom of said refrigeration chamber to receive produced fluids flowing upwardly through said production tubing, disengage a portion of the gas from said produced fluids, and discharge the residual produced fluids up said production tubing;

at least one gas expansion nozzle located within said refrigeration chamber and adjacent to the bottom thereof, to substantially isentropically expand high pressure gas into said chamber;

gas conduit means to conduct gas from said downhole gas separator to said gas expansion nozzle; and

means to exhaust low pressure gas from said refrigeration chamber.

14. The apparatus defined in claim 13 wherein said gas conduit means includes (1) first and second packers set in the annulus between said production tubing and said production casing, above and below said downhole gas separator, respectively, to define an enclosed annular first chamber; (2) third and fourth packers set in the annulus between said production casing and said second casing to define an enclosed second annular chamber surrounding said first annular chamber; (3) an aperture in said production casing communicating said first and second annular chambers; and (4) a conduit communicating said second annular chamber to the inlet of said gas expansion nozzle.

15. The apparatus defined in claim 14 wherein said downhole separator includes (1) an outer cylindrical shell having an inlet at its bottom and an outlet at its top for connection, respectively, to said production tubing; (2) an internal standpipe extending above said inlet; (3) an inverted cap extending downwardly below the lip of said standpipe; (4) an inverted cup-shaped diverter supported immediately above said standpipe; (5) an apertured baffle separating said cap into a lower section and an upper gas chamber; and (6) a float-type

valve in said gas chamber having an outlet connected to the exterior of said cylindrical shell.

16. A method for conducting hot fluids through a well traversing a permafrost zone without melting the permafrost surrounding the well, which comprises:

flowing the hot fluid through an insulated first tubular member within said well, said fluid being either injected into or produced from an underlying petroleum reservoir;

introducing and expanding a high pressure gas in the bottom of an annular refrigeration chamber defined by inner and outer concentric casings surrounding said first tubular member and lying between said first tubular member and said permafrost, to provide a cooled, low pressure gas having a temperature below the melting point of said permafrost;

flowing said cooled gas upwardly through said annular refrigeration chamber; and

withdrawing said low pressure gas from the upper end of said refrigeration chamber.

17. The method defined in claim **16** wherein said high pressure gas is produced gas separated from fluids produced from a petroleum reservoir.

18. The method defined in claim **16** wherein said high pressure gas is substantially isentropically expanded into said refrigeration chamber.

19. The method defined in claim **16** wherein said low temperature gas is withdrawn from said refrigeration chamber at a temperature below about 32° F.

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