

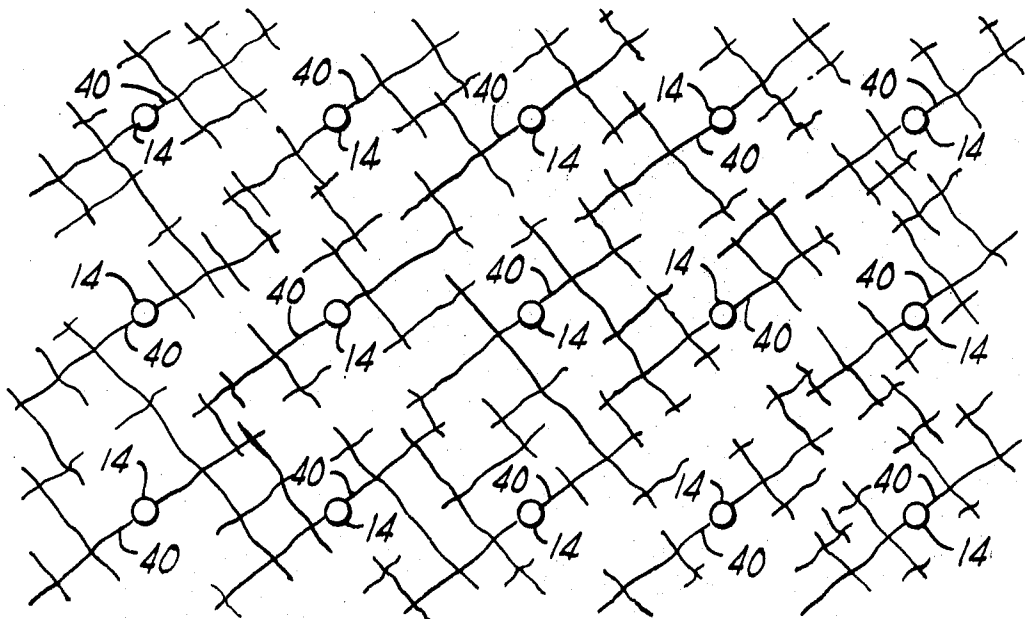
United States Patent [19]**Maguire, Jr.**[11] **3,822,747**[45] **July 9, 1974****[54] METHOD OF FRACTURING AND
REPRESSURING SUBSURFACE
GEOLOGICAL FORMATIONS EMPLOYING
LIQUIFIED GAS****[76] Inventor: James Q. Maguire, Jr., 210 N.
Sherry, Norman, Okla. 73069****[22] Filed: May 18, 1973****[21] Appl. No.: 361,475****[52] U.S. Cl. 166/259, 166/303, 166/308,
166/314****[51] Int. Cl. E21b 43/26, E21b 43/24****[58] Field of Search 166/308, 259, 302, 314,
166/303****[56]****References Cited****UNITED STATES PATENTS**

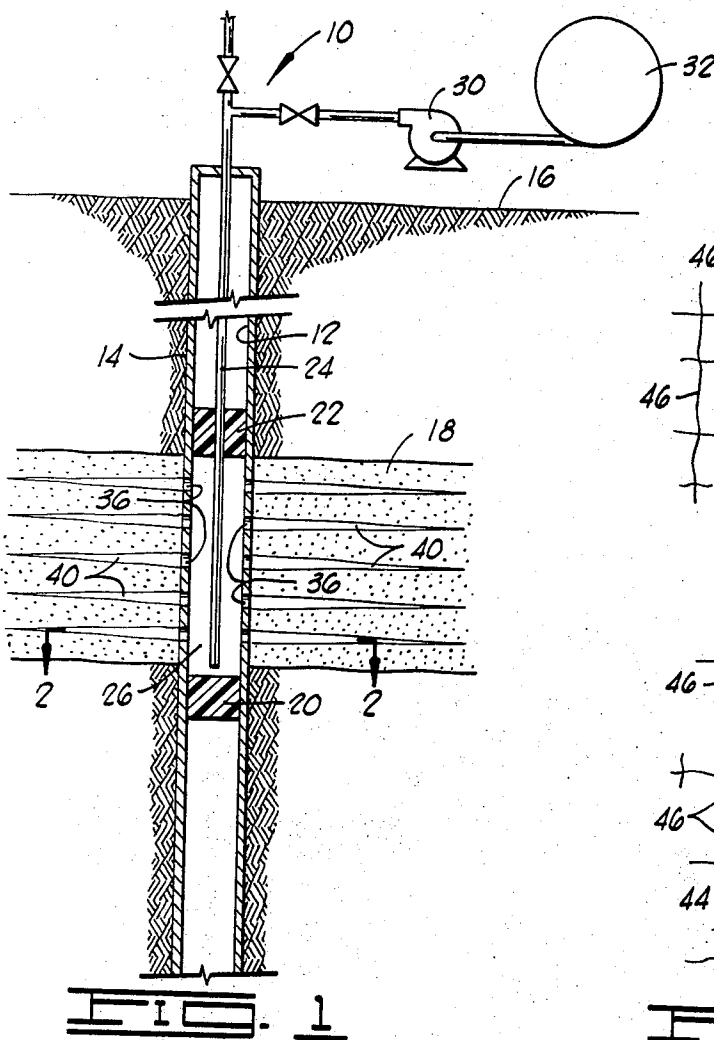
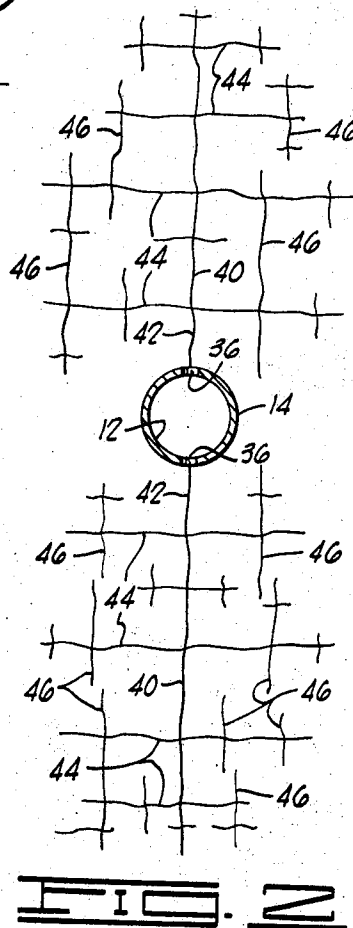
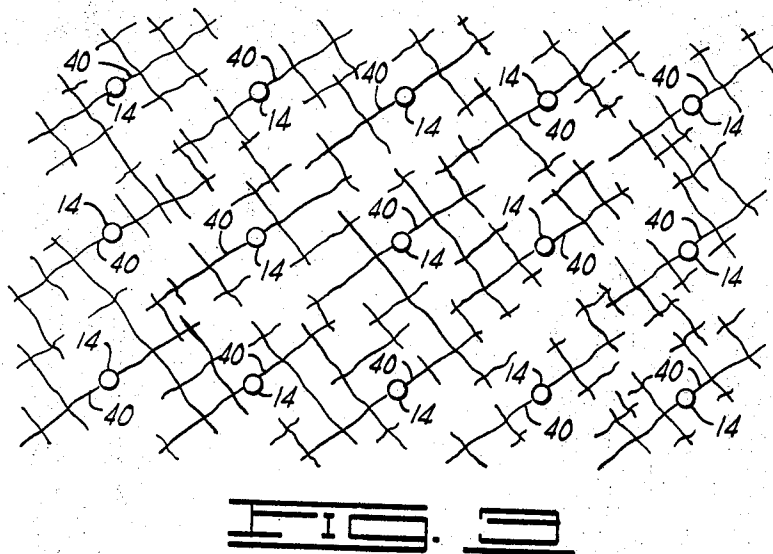
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Primary Examiner—David H. Brown*Attorney, Agent, or Firm*—Dunlap, Laney, Hessin,
Dougherty & Coddling**[57]****ABSTRACT**

A method of forming a fracture system in a fracturable subsurface geological formation intersecting a closed borehole including introducing a quantity of liquified gas into the closed borehole to communicate

with the fracturable formation; allowing the quantity of liquified gas to vaporize in the closed borehole whereby the resulting increase in pressure exceeds the fracture pressure of the formation to form an initial group of fractures of a fracture system in the formation; rapidly introducing an additional quantity of liquified gas into the initial fractures in the formation; allowing the additional liquified gas in the initial fractures to rapidly vaporize therein to form a second group of fractures in the fracture system, some of which being aligned substantially normal to the initial fractures; rapidly introducing a third quantity of liquified gas through the initial fractures into the second group of fractures; and allowing the liquified gas within the second group of fractures to rapidly vaporize therein to form a third group of fractures in the fracture system, some of which being aligned substantially normal to the second group of fractures. The method also includes the steps of allowing the liquified gas in the fracture system to completely vaporize therein; allowing the pressure in the borehole to decrease relative to increased gas pressure in the formation whereby a portion of the oil in the formation is driven therefrom into the borehole; and producing the oil from the borehole to the ground surface. The method also includes introducing pressurized steam into the fracture system to thermally stimulate the flow of oil from the formation into the borehole. The method also discloses introducing air into the fracture system; and burning the oil on the fracture faces to thermally stimulate flow of oil from the formation into the borehole. The method further includes introducing pressurized steam into the fracture system to thermally stimulate flow of oil from the formation into the borehole.

12 Claims, 3 Drawing Figures



METHOD OF FRACTURING AND REPRESSURING SUBSURFACE GEOLOGICAL FORMATIONS EMPLOYING LIQUIFIED GAS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to improvements in fracturing and repressuring subsurface geological formations, and more particularly, but not by way of limitation, to fracturing and repressuring subsurface geological formations by employing liquified gas to form a fracture system through rapid vaporization of the liquified gas in the subsurface geological formation.

2. Description of the Prior Art

The known methods of fracturing oil and gas-bearing formations usually result in a single, vertical fracture being created in a preferred azimuthal direction along a plane normal to the direction of the least principal stress in the formation being fractured. Although many of the known methods of fracturing such formations have proven highly successful, serious limitations still exist. The inability to create more than one vertical fracture has limited the drainage efficiency of the prior methods, and the tendency for these vertical fractures to orient themselves in a preferred azimuth creates additional drainage problems when considering a multi-well fracturing program.

SUMMARY OF THE INVENTION

The present invention contemplates a method of forming a fracture system in a fracturable subsurface geological formation intersecting a closed borehole comprising the steps of introducing a quantity of liquified gas into the closed borehole to communicate with the fracturable formation, and allowing the quantity of liquified gas to vaporize in the closed borehole whereby the resulting increase in pressure in the closed borehole exceeds the fracture pressure of the formation thereby forming an initial group of fractures of a fracture system in the formation proximate to the borehole. The method further includes the steps of rapidly introducing an additional quantity of liquified gas through the closed borehole and into the initial fractures in the formation, and allowing the additional quantity of liquified gas within the initial fractures to rapidly vaporize within the initial fractures whereby the resulting rapid increase in pressure within the initial fractures exceeds the fracture pressure of the formation thereby forming a second group of fractures in the fracture system, at least a portion of the second group of fractures being aligned substantially normal to the initial fractures of the fracture system. The method also includes the additional steps of rapidly introducing a third quantity of liquified gas through the closed borehole and through the initial fractures into the second group of fractures in the fracture system, and allowing the third quantity of liquified gas within the second group of fractures to rapidly vaporize within the second group of fractures whereby the resulting rapid increase of pressure within the second group of fractures exceeds the fracture pressure of the formation thereby forming a third group of fractures in the fracture system, at least a portion of the third group of fractures being aligned substantially normal to the second group of fractures of the fracture system.

An object of the invention is to provide a method for increasing the efficiency of production from oil or gas wells.

Another object of the invention is to provide a method of forming a fracture system in a fracturable subsurface geological formation comprising a multiplicity of multi-directional fractures in the formation.

A further object of the invention is to provide a method of re-saturating a depleted oil reservoir by first creating a multiple, multi-directional fracture system in the reservoir through the use of cryogenic liquids and dispersing the vaporized gases in the fracture system so that the drive mechanism for propelling the oil to the wellbore area is improved.

A still further object of the invention is to provide a method of forming a multiple, multi-directional fracture system in an oil-bearing formation through which hot gases or steam can be circulated to provide an in-situ recovery of oil in place.

Other objects and advantages of the invention will be evident from the following detailed description when read in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram depicting a typical apparatus suitable for practicing the method of the present invention.

FIG. 2 is a schematic cross-sectional view taken along line 2—2 of FIG. 1 depicting the fracture system in the fracturable formation.

FIG. 3 is a schematic cross-sectional view similar to FIG. 2 depicting the communication of a plurality of fracture systems forming a larger fracture system in an oil or gas reservoir.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawing and to FIG. 1 in particular, there is schematically illustrated therein apparatus suitable for performing the fracturing method of the present invention. The apparatus will be generally designated by the reference character 10. The apparatus 10 includes a casing 12 positioned in and cemented in a wellbore or borehole 14 communicating between the ground surface 16 and an oil or gas bearing formation 18.

A conventional packer 20, or the like, is positioned in sealing engagement with the interior of the casing 12 at a point below the intersection of the formation 18 and the wellbore 14. Another conventional packer 22, or the like, is sealingly engaged within the interior of the casing 12 at a point just above the intersection of the formation 18 and the wellbore 14.

A tubing string 24 extends from the ground surface 16 downwardly through the casing 12 and through the packer 22 into the fracturing zone 26 between the packers 20 and 22. The upper end of the tubing string 24 is connected to the outlet of a high pressure cryogenic liquid pump 30 by means of a suitable conduit. The inlet of the pump 30 is connected by suitable conduit to the outlet of a cryogenic liquid storage tank 32.

The casing 12 in the fracturing zone 26 between the packers 20 and 22 is perforated as shown at 36 to provide communication between the interior of the casing 12 and the formation 18.

METHOD OF THE PRESENT INVENTION

The present invention is directed to a method of fracturing an oil or gas bearing formation through the application of a cryogenic liquid thereto and its subsequent vaporization in the formation and in the fracture system formed therein. The method is predicated on the use of liquified gases in the cryogenic state to accomplish such fracturing of oil and gas bearing formations. Suitable liquified gases for use in the present method include, but are not limited to, nitrogen, natural gas, oxygen, and the like.

Assuming that nitrogen is the gas to be used in practicing the method of the present invention, the cryogenic liquid storage tank 32 would first be filled with liquid nitrogen at a temperature of approximately -320° F. or lower and at a pressure near or above its critical pressure of 441 psia. The liquid nitrogen is then pumped from the storage tank 32 by the pump 30 down the tubing 24 at a temperature of approximately -320° F. and at a pressure near or above 440 psia. This initial volume of liquid nitrogen will be vaporized by heat absorbed from the tubing 24 until the tubing 24 is sufficiently cooled down. After the tubing 24 reaches a temperature of approximately -232° F., subsequent nitrogen passing therethrough will reach the fracturing zone 26 in the liquid state. The initial volume of nitrogen vaporized in the tubing 24 during cool down is utilized to create the initial fracture in the formation 18 by sealing the nitrogen in the fracturing zone 26 between the packers 20 and 22. After the initial fracture is formed in the formation 18, liquid nitrogen enters the initial fracture of the fracture system 40 at a temperature below -232° F. where the liquid nitrogen encounters the hot fracture faces of the formation 18 and is vaporized when it reaches a temperature of approximately -232° F.

Since each cubic foot of liquid nitrogen injected into the fracturing zone 26 contains approximately 696 standard cubic feet of gas, upon vaporization the nitrogen will tend to expand very rapidly. If, however, the gas is unable to expand from its original liquid volume it will tend to very rapidly reach a pressure of approximately 15,000 psia. Before reaching this pressure, however, the formation 18 will fracture at its particular fracturing pressure and additional fractures sufficient to accommodate the increased volume of vaporized nitrogen will result. While these additional fractures are being formed in the formation, additional amounts of liquid nitrogen are continuously injected at a high rate into the fracturing zone 26 and into the fracture system 40 thus causing the fracturing process of the present invention to be on the level of a continuous low-level explosion in the formation 18.

As seen in FIG. 2, the fracture system 40 obtained by the present method comprises multiple multidirectional fractures including initial fractures 42 emanating from the well bore 14 and secondary fractures 44 extending at substantially right angles from the initial fractures 42. Similarly, tertiary fractures 46 will be formed substantially at right angles to the secondary fractures 44 as liquid nitrogen continues to be pumped into the fracture system 40 at high pressure and at a rapid rate.

Since the fracture widths in the fracture system 40 will generally be on the order of no more than 0.10 inches, exceptionally high friction losses greatly in ex-

cess of the fracturing pressure of the formation 18 will occur. These high friction losses preclude the vaporized nitrogen from expanding fast enough in the fracture system, thus the subsequent pressure increase in the fractures 42, 44 and 46 causes local fracturing to occur at right angles to the original fractures. Vaporized nitrogen then enters the newly formed fractures and extends them so that sufficient volume is created to equalize the pressures in the fracture system 40 as shown in FIG. 2. As subsequent volumes of liquid nitrogen are injected into the fracture system 40, fracture face cool down permits further penetration of the cryogenic liquid nitrogen into the fracture system 40 before vaporization occurs so that extremely deep penetration of fractures into the formation 18 is possible.

As an alternative to liquid nitrogen, liquified methane or natural gas may be the preferred liquified cryogenic gas for use in the reservoirs of higher oil viscosity because of the increased solubility of methane in crude oil. The dissolving of methane in low-gravity crudes lowers the viscosity of the crude oil and hence increases its flow rate from the oil-bearing formation or reservoir 18.

The above-described method of forming a fracture system in an oil or gas-bearing formation is well adapted for repressuring an oil-bearing reservoir for secondary or tertiary recovery. In solution gas drive reservoirs 75 percent to 85 percent of the original oil in place is left in the reservoir when the original volume of solution gas has been produced. By applying the previously described method of injection of liquified gas such as liquid nitrogen into such a reservoir, then a very extensive fracture system as described above would be created therein. Upon warming of the cryogenic liquid nitrogen in the fracture system to reservoir temperature, large quantities of this inert gas will be distributed throughout the drainage area of the wellbore 14 in approximate conformance to the fracture system geometry. This gas is then allowed to expand back toward the wellbore area 14 driving gas-free oil with it in what is known as a huff and puff operation. The nitrogen passes from the fracturing zone 26 through the tubing 24 and is vented to the atmosphere or otherwise suitably disposed of. The oil will also be produced through tubing 24 from the fracturing zone 26. When all or nearly all of the nitrogen is expended, the operation can be repeated for subsequent cycles.

This method provides means for widely distributing an inert gas throughout a fracture system which provides reservoir energy and increases reservoir production. The last-described method differs from the conventional fluid injection program in which gas or water is injected in a fluid injection program into a wellbore and is displaced in a radial manner from the wellbore and channels down layers of high permeability in the formation. The present method, however, provides better distribution of the inert gas nitrogen in conformance with the geometry of the multiple fracture system created by the rapid injection of liquid nitrogen into the fracture system 40.

Another aspect of the method of the present invention is to utilize the multiple fracture system, created as described above, for the injection of steam or air into a hydrocarbon-bearing formation for thermal recovery operations. When large quantities of liquid nitrogen are injected at high injection rates, as described above, into the multiple wellbores in a shale oil reservoir, heavy oil

reservoir, or tar sand reservoir, a large fracture system, as described above, will be created around each wellbore into which the liquid nitrogen was injected. These fracture systems will, in many cases, communicate with the next adjacent fracture systems forming a larger fracture system throughout the reservoir. See FIG. 3. If steam is then injected into one or more of a number of such adjacent wellbores, it will travel to the adjacent producing wells down the fracture system previously created by the rapid injection of liquid nitrogen into the formation. This technique provides a much larger area of the reservoir in contact with the steam than has been previously possible with conventional methods thus providing a much larger recovery from thermal stimulation in the formation. An additional advantage of this method of steam flooding is that the previously injected nitrogen furnishes reservoir energy to assist in the expulsion of the heat-thinned oil from the formation. After the nitrogen is expended, other cycles may be attempted.

In a similar manner, air may be injected into the fracture system formed by the rapid injection of liquid nitrogen into the formation, and a fire flood may be conducted in the fracture system by burning at the fracture faces. Again, the previously injected nitrogen in the formation will furnish reservoir energy to assist in the expulsion of the heat-thinned oil from the reservoir.

Another aspect of the present invention involves the application of the above described multiple fracture system in a huff and puff thermal operation to improve recovery of oil from a high viscosity oil reservoir. The reservoir is first fractured utilizing the above described method employing liquified gas. After the formation has been fractured, the liquified gas in the formation and the wellbore is allowed to completely vaporize therein and heat up to normal formation temperature. Steam is then injected into the fracture system against the pressure of the vaporized gas in the conventional manner to lower the viscosity of the reservoir oil. The previously injected liquified gas, now vaporized, furnishes additional reservoir pressure to expel the heat-thinned oil from the formation at a greater rate than is available in a conventional steam operation. Since the viscosity of the oil remains lowered for a finite period of time after the application of the steam, the increased production rate of the reservoir oil resulting from the injection and vaporization of liquified gas in the formation results in increased oil recoveries.

It will be seen from the foregoing detailed description of the method of the present invention that the method described therein readily obtains the objectives set forth above. Changes may be made in the construction and arrangement of parts or elements of the embodiments described above without departing from the spirit and scope of the present invention as defined herein.

What is claimed is:

1. A method of forming fractures in a subsurface formation intersecting a closed borehole comprising the steps of:

introducing a quantity of liquified gas into the closed borehole to communicate with the formation;
allowing the quantity of liquified gas to vaporize in the closed borehole whereby the resulting increase in pressure in the closed borehole forms an initial group of fractures in the formation proximate to the borehole;

rapidly introducing an additional quantity of liquified gas through the closed borehole and into the initial fractures in the formation; and

allowing the additional quantity of liquified gas within the initial fractures to rapidly vaporize whereby the resulting rapid increase in pressure forms a second group of fractures.

2. The method as defined in claim 1 characterized further to include the additional steps of:

rapidly introducing a third quantity of liquified gas through the closed borehole and through the initial fractures into the second group of fractures; and allowing the third quantity of liquified gas within the second group of fractures to rapidly vaporize whereby the resulting rapid increase in pressure forms a third group of fractures.

3. A method of improving the recovery of oil from an oil-bearing formation beneath the ground surface and intersecting a closed borehole comprising the steps of:

introducing a quantity of liquified gas into the closed borehole to communicate with the formation;
allowing the quantity of liquified gas to vaporize in the closed borehole whereby the resulting increase in pressure in the closed borehole forms an initial group of fractures in the formation proximate to the borehole;

rapidly introducing an additional quantity of liquified gas through the closed borehole and into the initial fractures in the formation;

allowing that portion of the additional quantity of liquified gas within the initial fractures to rapidly vaporize whereby the resulting rapid increase in pressure forms a second group of fractures;

rapidly introducing a third quantity of liquified gas through the closed borehole and through the initial fractures into the second group of fractures; and allowing that portion of the third quantity of liquified gas within the second group of fractures to rapidly vaporize within the second group of fractures whereby the resulting rapid increase in pressure within the second group of fractures forms a third group of fractures.

4. The method as defined in claim 3 characterized further to include the additional step of:

introducing pressurized steam into the fractures to thermally stimulate the flow of oil from the formation into the borehole.

5. The method as defined in claim 3 characterized further to include the additional steps of:

introducing air into the fractures; and burning the oil on the fracture faces to thermally stimulate the flow of oil from the formation into the borehole.

6. The method as defined in claim 3 characterized further to include the additional steps of:

allowing the liquified gas in the formation and in the closed borehole to completely vaporize therein thereby increasing the gas pressure in the formation; and

decreasing the pressure in the borehole relative to the increased gas pressure in the formation whereby a portion of the oil in the formation is driven therefrom into the borehole.

7. The method as defined in claim 6 characterized further to include the additional step of:

introducing pressurized steam into the fractures to thermally stimulate the flow of oil from the formation into the borehole.

8. A method of improving the recovery of oil from an oil-bearing formation beneath the ground surface and intersecting a plurality of closed boreholes comprising the steps of:

introducing a quantity of liquified gas into each of the closed boreholes to communicate with the formation;

allowing the quantity of liquified gas to vaporize in each of the closed boreholes whereby the resulting increase in pressure in the closed boreholes forms an initial group of fractures in the formation proximate to the boreholes;

rapidly introducing an additional quantity of liquified gas through the closed boreholes and into the initial fractures in the formation;

allowing that portion of the additional quantity of liquified gas within the initial fractures to rapidly vaporize whereby the resulting rapid increase in pressure within the initial fractures forms a second group of fractures;

rapidly introducing a third quantity of liquified gas through the closed boreholes and through the initial fractures into the second group of fractures; and

allowing that portion of the third quantity of liquified gas within the second group of fractures to rapidly vaporize whereby the resulting rapid increase in

pressure within the second group of fractures forms a third group of fractures.

9. The method as defined in claim 8 characterized further to include the additional step of:

introducing pressurized steam into the fractures to thermally stimulate the flow of oil from the formation into the boreholes.

10. The method as defined in claim 8 characterized further to include the additional steps of:

introducing air into the fractures; and
burning the oil on the fracture faces to thermally stimulate the flow of oil from the formation into the boreholes.

11. The method as defined in claim 8 characterized further to include the additional steps of:

allowing the liquified gas in the formation and in the closed boreholes to completely vaporize therein thereby increasing the gas pressure in the formation; and

decreasing the pressure in the boreholes relative to the increased gas pressure in the formation whereby a portion of the oil in the formation is driven therefrom into the boreholes.

12. The method as defined in claim 11 characterized further to include the additional step of:

introducing pressurized steam into the fractures to thermally stimulate the flow of oil from the formation into the boreholes.

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