United States Patent [19]

Willhite

[11] **3,766,985**

[45] **Oct. 23, 1973**

[54] **PRODUCTION OF OIL FROM WELL CASED IN PERMAFROST**

[75] Inventor: **Glen Paul Willhite,** Lawrence, Kans.

[73] Assignee: **The Kansas University Endowment Association,** Lawrence, Kans.

[22] Filed: **Dec. 1, 1971**

[21] Appl. No.: **203,605**

[52] **U.S. Cl.** **166/302,** 166/DIG. 1

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

[58] **Field of Search** ..... 166/302, DIG. 1, 166/75, 57

[56] **References Cited**

UNITED STATES PATENTS

3,662,832	5/1972	Keeler et al.	166/302
3,613,792	10/1971	Hyde et al.	166/315
3,703,929	11/1972	Rardin	166/302
3,642,065	2/1972	Blount	166/244 R
3,217,791	11/1965	Long	165/45

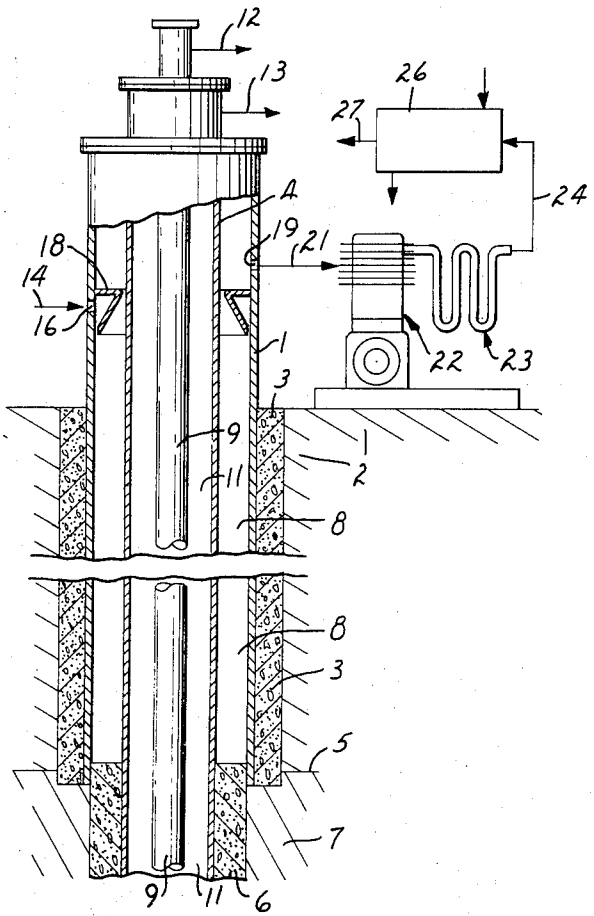
Primary Examiner—Stephen J. Novosad

Attorney—William G. Ewert

[57] **ABSTRACT**

Thawing of permafrost surrounding a surface casing of a wellbore is minimized during production of hot oil by injecting liquid refrigerant in an annulus between the surface casing and the production casing, allowing heat from the hot oil to vaporize the refrigerant as it descends in said annulus, and removing the resulting vaporized refrigerant at the well-head, thereby maintaining the surface casing at a temperature of 32° F. or lower.

15 Claims, 5 Drawing Figures



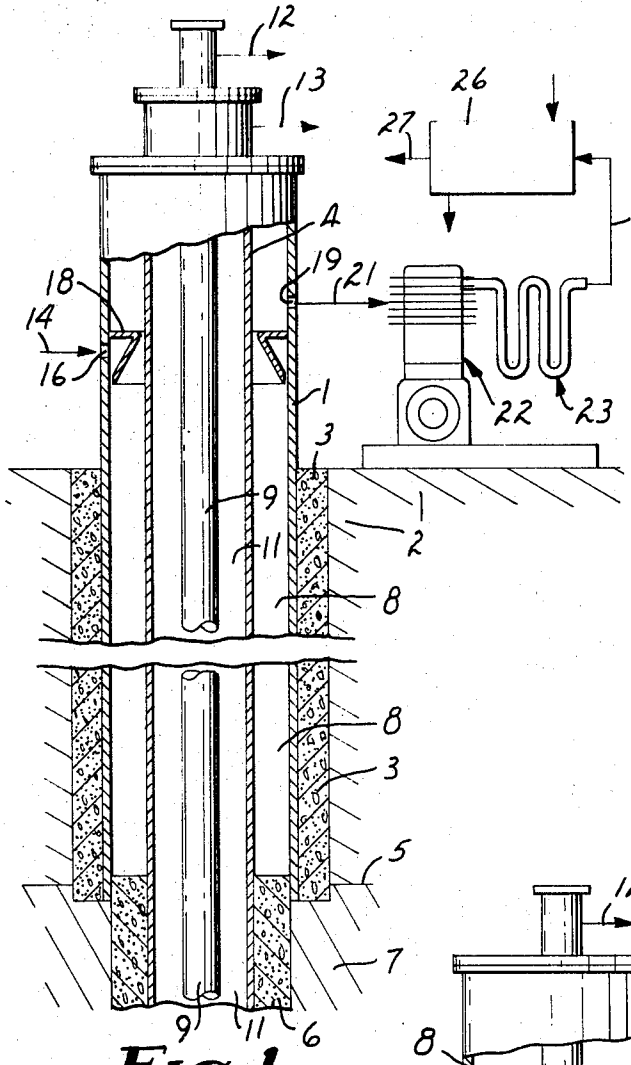


FIG. 1

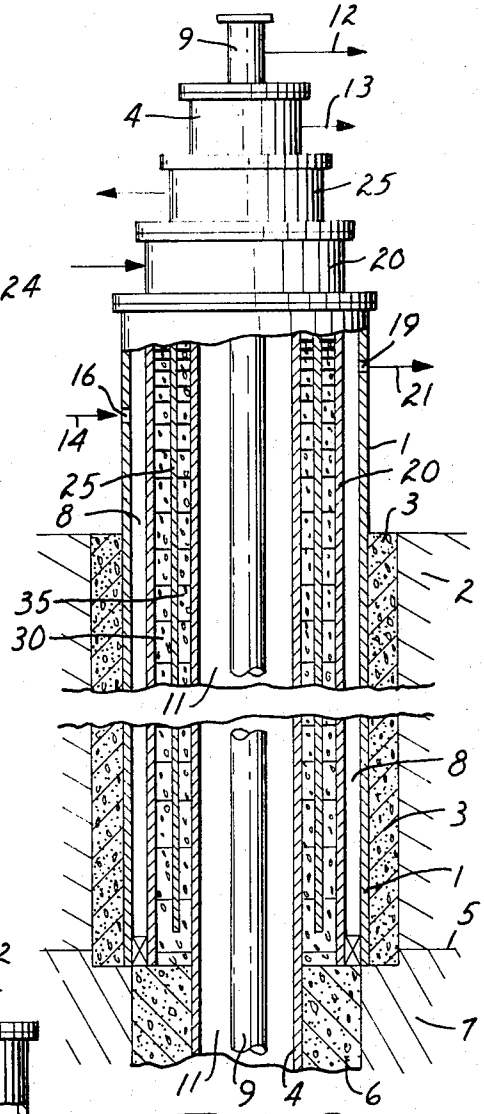


FIG. 3

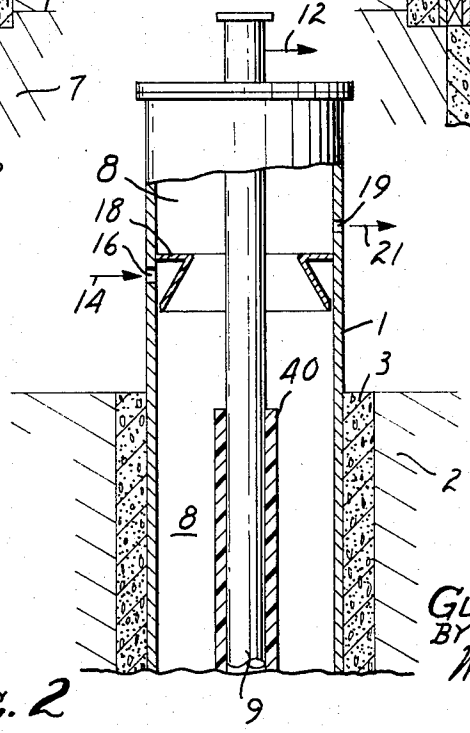


FIG. 2

INVENTOR
GLEN PAUL WILLHITE
BY
William G. Ewert
ATTORNEY

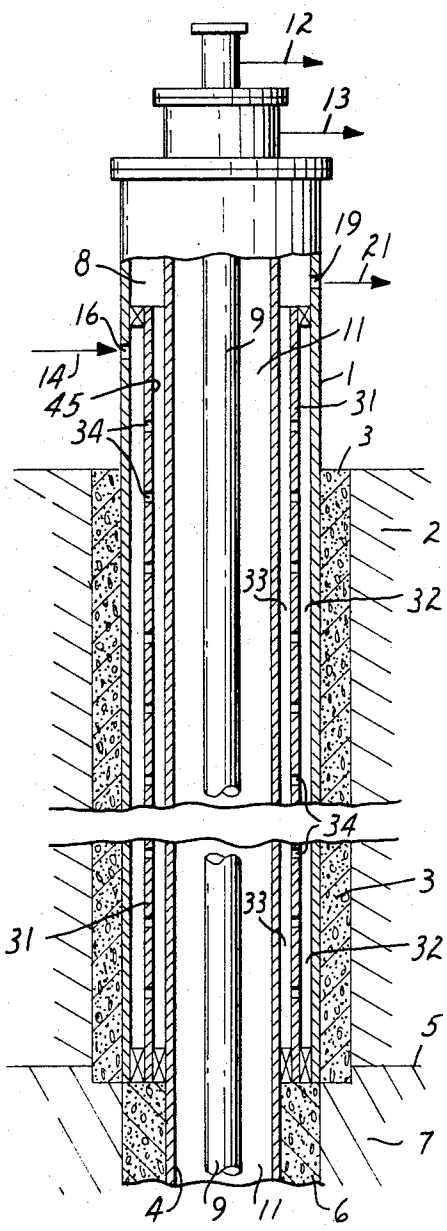


FIG. 4

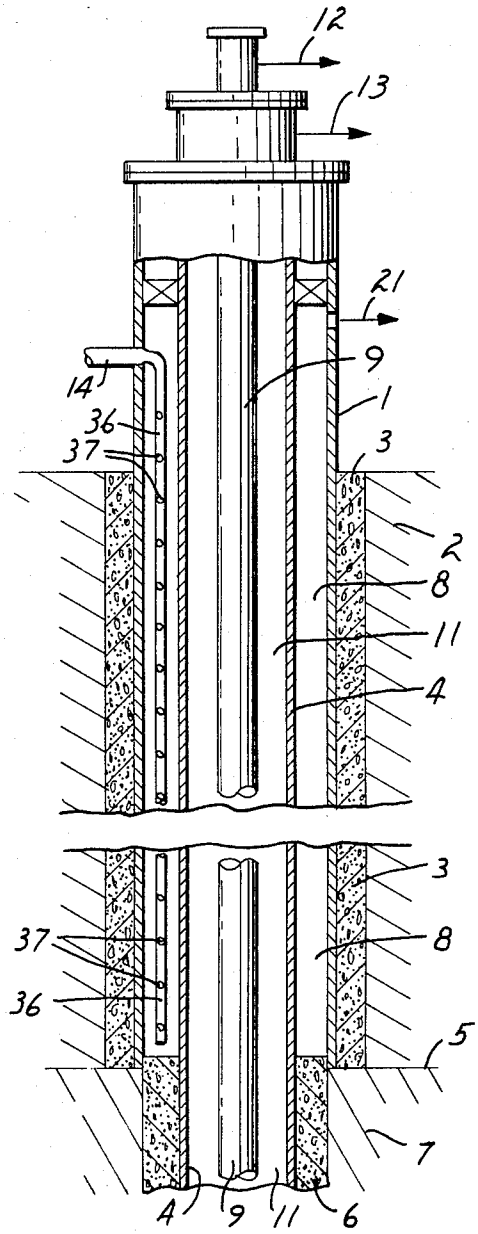


FIG. 5

INVENTOR
GLEN PAUL WILLHITE
BY
William D. Ewert
ATTORNEY

PRODUCTION OF OIL FROM WELL CASED IN PERMAFROST

This invention relates to the production of oil. In another aspect it relates to a method and means for the production of oil from a well cased in permafrost while minimizing the thawing of the permafrost.

Several years ago, a major oil discovery was made in an arctic region in Alaska now known as the North Slope. The oil reservoirs of this discovery are located at depths ranging from 8,000 to 10,000 feet. The remote region in which this discovery was made is an unusual environment for well completion in that permanently frozen earth (or permafrost), comprising a frozen non-uniform aggregation of ice, sand, gravel, or sediment, extends over the region with thicknesses up to 2,300 feet, the upper 50–200 feet often containing a high percentage of ice (e.g. 40 percent), the average temperature of the permafrost being about 16° F. and increasing linearly with depth at a rate of about 0.016° F. per foot from 0–15° F. at the surface. The load-bearing strength of the permafrost depends upon the extent it is frozen.

Oil wells are drilled through the permafrost to deeper oil-bearing strata or reservoirs to produce oil at high rates. The temperatures of the reservoirs are in the vicinity of 150° F. to 200° F. and the high rates of production (e.g., 2,000 to 15,000 barrels per day) generally keep the temperature of the produced fluids from decreasing significantly as they ascend from the reservoir to the wellhead. The produced oil, being significantly higher in temperature than the permafrost surrounding the well casing, causes thawing or melting around the wellbore and destruction of the cement bond at the cement-permafrost interface. The resulting thawed permafrost shrinks and subsides and the downdrag force or movement of the thawed permafrost exerts a frictional force or mechanical stress on the surface casing, for example a force of 2,000 lbs./ft² down to about 500 ft. This downdrag can damage the well casing (e.g.causing crumpling, twisting, or collapse thereof) and necessitate premature abandonment of the well and the subsidence resulting from an extensive thawed zone (e.g. with a radius of up to 20 feet) will induce soil erosion when spring thaw or rains come.

Several solutions have been proposed to prevent thawing of permafrost during oil production (see *The Oil and Gas Journal*, Dec. 8, 1969, page 69 and Paper No. 3251 (1971) of the Society of Petroleum Engineers of AIME). Such solutions include the use of insulation (polyurethane) to limit the thaw radius or keep the upper portion of the permafrost from thawing and the circulation of a cooling liquid down the hole and back to maintain temperatures below 32° F. The art also discloses a number of techniques for controlling the temperature of a well in connection with conventional production of oil (see U.S. Pat. Nos. 3,004,601, 3,013,609, 3,259,185, 3,433,641, and 3,456,734). But the heretofore proposed solutions to the thawing permafrost problem and the techniques used in conventional production are limited and have several disadvantages which make them impractical or inefficient, insofar as minimizing the thawing of permafrost is concerned.

Briefly, according to this invention, the thawing of permafrost surrounding a surface casing of a wellbore is minimized to a desired degree by continuously injecting subcooled liquid refrigerant into the upper end of an annulus extending through all or the upper portion of the permafrost interval between the surface casing and the production or completion string disposed within the surface casing (the string comprising a production casing and/or one or more production tubings), allowing the heat from the produced fluid flowing through the wellbore to vaporize the refrigerant as it descends in said annulus, and continuously removing the resulting vaporized refrigerant from the wellhead, thereby maintaining the temperature from the casing, adjacent the locus of vaporization, at about 32° F. or lower.

The injection of the liquid refrigerant and its vaporization can be carried out in a number of different ways. The injected liquid refrigerant can be allowed to descend in said annulus as a falling film on the inner wall of the surface casing, the heat from produced fluid (oil and/or gas) flowing through the production string (which can be encircled by insulating medium) causing the vaporization of the falling film over the course of its descent. Alternatively, a perforated or slotted pipe can be disposed in an annulus between the surface casing and production string, and liquid refrigerant can be injected into the upper end of the perforated pipe with each of the perforations in the pipe functioning in effect as an expansion valve for the vaporization of the liquid refrigerant in the annulus. Another way of accomplishing the temperature control of this invention is to hang or dispose within said annulus a perforated or slotted casing or sleeve so as to divide the annulus into an outer annular region and an inner angular region, with communication between the two regions being had by the perforations in the perforated casing, such perforations also acting in effect as expansion valves; liquid refrigerant is introduced into the upper end of the outer annular region, filling the outer annular region, and the liquid refrigerant is passed through the perforations and vaporizes into the inner annular region. The rates of injection of the liquid refrigerant by these various techniques, as well as the pressure maintained in the annulus, are chosen so as to prevent or minimize the accumulation of the liquid refrigerant at the lower terminus of the annulus, and the method of operating and means employed are such as to prevent any commingling of the liquid or vaporized refrigerant with any production fluids. The vaporized refrigerant removed at the wellhead can be compressed and liquefied and recycled to the annulus.

In the accompanying drawing, the various figures schematically illustrate in elevation and partial section wells cased in permafrost provided with means in accordance with this invention to minimize the thawing of the permafrost. In these various figures, the same reference numbers have been used to designate like parts.

Referring to the embodiment shown in FIG. 1, a surface casing (or "permafrost casing") 1 can penetrate part or, as shown, all of permafrost stratum or interval 2 and is cased or cemented 3 thereto, preferably, as shown, from its lower end to the surface. Disposed within the surface casing 1 is a production casing 4, the lower portion of the production casing depending below surface casing 1 and the lower boundary 5 or bottom of the permafrost. Production casing is cemented 6 to the strata 7 below the permafrost stratum, an annular space or annulus 8 being formed between the two casings 1,4 with the lower end of the annulus being closed by cement 6 or the like (such as a packer).

Though the lower end of annulus 8 is shown sealed by cement at a depth coincident with the bottom of the permafrost zone 5, it can be sealed at a point thereabove (e.g. with cement or a suitable packer) so as to keep only the upper portion of the surrounding permafrost zone frozen, e.g., to a depth of 500 to 1,000 feet, since it is the upper portion of the permafrost zone where the most severe thawing is normally encountered during production. One or several producting tubings, such as illustrated by reference number 9, can depend within the production casing 4 forming an annulus 11. (The outer wall of the production string, such as production tubing 9, can be encased with or encircled by one or several layers of insulation as described below.) Suitable conventional exit pipes 12, 13 are connected to the upper ends of the production casing 4 and tubing 9. For example, surface casing 1 can have a diameter of 20 inches and can be set in a 26 inch hole at a depth of 2,300 feet; production casing 4 can have a diameter of 13 ⅜ inches and can be set at a depth of 8,000 feet; and the production tubing 9 can have a diameter of 7 inches. The production casing and tubing extend to the oil (and/or gas)-bearing strata but such has been omitted in the interest of brevity together with the conventional appurtenances used in a producing well, such as a surface conductor, casinghead collar, etc.

The liquid refrigerant used in this invention, for example sub-cooled liquefied propane, can be supplied by line 14 and injected via opening 16 at the upper end of annulus 8. An annular deflection plate or collar 18 can be hung from the upper end of casing 1 at the locus of injection so as to distribute the liquid refrigerant around the upper end of annulus 8 and direct it to the inner wall of the surface casing 1. The injected liquid refrigerant descends along the inner wall of surface casing 1 in the form of a falling film, the heat in the wellbore, such as that emanating from hot oil being produced by production tube 9 and/or annulus 11 in the production casing 4, causing vaporization of the falling film as it descends. In order to ensure substantially uniform or continuous film or liquid refrigerant on the inner wall of surface casing 1, and avoid hot spots due to non-uniform liquid vaporization, a plurality of annular distributor or redistributor plates can be affixed within annulus 8 to surface casing 1 or production casing 4, for example at the collars joining the casing sections (each section being for example 30–35 feet in length). Other means will be obvious to those skilled in the art for ensuring uniform liquid distribution for the refrigerant as it courses down the inner wall of the surface casing. The vaporized refrigerant flowing upward and countercurrent to the flow of liquid refrigerant, can be removed at the upper end of annulus 8 via opening 19 in surface casing 1 and conveyed via pipe 21 to a compressor or pump 22, such as used in mechanical refrigeration systems, and the compressed gas cooled by heat exchanger 23 and passed via line 24 to a second heat exchanger 26 where it is liquefied, the liquefied refrigerant 27 then being recycled to supply line 14.

The rate of injection of the liquid refrigerant can be controlled to retain free gas space within the annulus 8. The injection rate should be controlled to prevent or minimize the accumulation of any liquid refrigerant at the lower terminus of annulus 8. Such accumulation should be avoided since even a small head of liquid would increase the saturation temperature, i.e., the temperature at which vaporization begins, and consequently increase the temperature of the permafrost at that depth, causing thawing thereof. Stated otherwise, the rate of injection is controlled so as to prevent any accumulation of any liquid refrigerant in the annulus, since a liquid-filled annulus would not prevent thawing of the permafrost at the locus of accumulation unless the boiling point of the liquid is less than 32° F. at the maximum pressure exerted by the head of accumulated liquid refrigerant.

The drag force of the ascending vaporized refrigerant in annulus 8 on the descending liquid film will be at its maximum near the surface where the mass flow rate of the vaporized refrigerant is at its maximum. However, this drag force will not be significant or a limiting factor on the flow rate of the liquid refrigerant necessary to ensure substantially complete coverage of the inner wall of surface casing 1 with a falling film of liquid refrigerant

The heat from the hot produced oil in production tubing 9 will flow by conduction, natural convection, and radiation to the production casing 4 and heat from the latter will flow by forced convection and radiation into the annulus 8 to the surface of the falling film of liquid refrigerant, causing vaporization of the latter at or below the surface of the falling film. The injection rate of the liquid refrigerant can be determined by equating the rate of heat flow from the hot oil to the rate of heat absorbed by vaporization, the total rate of heat flow being proportional to depth. The maximum depth at which vaporization can be controlled within the annulus will be determined by such factors as the rate of heat flow from production tubing 9 to production casing 4, the extent that the inner wall of the surface casing is covered by the falling film, the free gas space in the annulus, and the downward liquid flow of the refrigerant. The force of gravity on the descending liquid will exceed the friction between the falling film and the surface casing as well as exceed the drag force exerted by the rising vaporized refrigerant or gas at the gas-liquid interface, which would entrain some of the liquid. Thus, for more efficient operation, the falling film of liquid refrigerant should be distributed over a substantial portion of the inner wall of the surface casing. The vaporization temperature of the refrigerant will be determined by the thermodynamic properties of the liquid refrigerant and the pressure that is maintained in the annulus. In order to keep the permafrost from melting, the vaporization temperature should be 32° F. or less.

Ammonia, carbon dioxide, and propane have suitable thermodynamic properties for use as a liquid refrigerant. Propane will be a preferred refrigerant because of its desired properties and because it probably will be available at the well-site where it can be obtained from the gas produced with the crude oil. In the Table I below, the saturation temperatures and pressures for propane are given.

TABLE I

Thermodynamic Data for Propane

Temp. °F.	Sat. Press. p.s.i.a.	Temp. °F.	Sat. Press. p.s.i.a.
−10	30.95	40	77.80
0	37.81	50	91.50
10	45.85	60	106.90
20	55.00	70	124.30
30	65.70	80	143.60

At 30° F., the saturation pressure of propane is 65.7 psia. This should be ample pressure to push the vaporized propane out the annulus at the anticipated vaporization rates.

Calculations were made to determine surface refrigeration capacity and the rate of flow of liquid refrigerant (propane) necessary to maintain the surface casing **1** of FIG. **1** at a temperature of 32° F. for various permafrost thicknesses (i.e., the rate necessary to prevent any heat flowing from the surface casing to the surrounding permafrost **2** at certain thicknesses of the permafrost). In these calculations, the surface casing **1** was assumed to have a diameter of 16 inches and cemented through the permafrost interval. The production casing **4** was assumed to be 13 ⅜ in diameter (and was not covered by an insulation layer) and the production tubing **9** was assumed to be 7 inch in diameter with oil flowing therethrough at 180° F. The permafrost temperature was assumed to be 32° F. through the entire permafrost interval. The results of these calculations are presented below in Table II, with 200 ft. deducted to approximate the effect of vertical heat flow.

TABLE II

Rate of liquid refrigerant, lbs./hr.	Surface refrigeration capacity BTU/hr.	Depth of permafrost maintained at 32°F. Ft.
1250	203,400	512
1500	244,000	629
1750	284,000	744.6
2000	325,000	858
2250	366,000	970
2500	407,000	1081
2750	447,500	1191
3000	488,000	1300
3250	528,000	1408
3500	569,000	1516
3750	610,000	1623
4000	650,000	1730
4250	691,000	1836
4500	731,000	1941

The data of Table II show that permafrost thawing can be prevented at all depths by controlling the injection rate of the liquid refrigerant.

As shown in FIG.**2**, the outer surface of production tubing **9** can be adhesively bonded to a layer **40** of insulation material such as a 1 to 3-inch thick layer of polyurethane foam (having a density of 2–6 lbs./ft^3), which can extend over only the upper portion of the permafrost (e.g. 500–1,000 ft.) or extend down as low as the lower boundary **5** of the permafrost, or lower. Such insulation can be covered on its exterior or wrapped with an aluminized Mylar film, or the like, to serve as a barrier to heat radiation. Such embodiment will permit the use of lower refrigerant rates, and thus decrease the operating costs. The liquid refrigerat introduced into the annulus **8** can be allowed to fall as a film on the interior of the surface casing **1** or as a film on the exposed surface of the insulation. Calculations were made for this embodiment like those given above in Table II, assuming a surface casing having a diameter of 13 ⅜ inches and a production tubing having a diameter of 7 inches and covered with a 1 inch layer of polyurethane foam insulation (density 4 lbs./ft^3, thermal conductivity 0.015 BTU/hr. ft. ° F.) extending the entire length of the permafrost stratum, the falling film of liquid refrigerant (either propane or ammonia) descending on the inner wall of the surface casing. Refrigeration requirements necessary to keep various thicknesses of permafrost from thawing are set forth in Table III. Again, the temperature of the permafrost interval was assumed to be 32° F.

TABLE III

	Rate of liquid refrigerant lbs./hr.	Surface refrigeration capacity, BTU/hr.	Depth of permafrost maintained at 32° F., ft.
Propane			
	250	40,700	659
	350	56,900	1067
	450	73,200	1471
	550	89,500	1872
	650	106,000	2272
Ammonia			
	100	54,310	435
	150	81,500	1170
	200	108,620	1840
	250	135,810	2500

The data of Table III show that refrigerant rates are quite low, compared to those of Table II, and thus the operating costs should also be low. Similar results were obtained when the surface casing diameters were 16 inches and 20 inches.

Referring now to FIG. **3**, instead of using a layer of solid insulation material to lower the refrigeration requirements, two further strings of casing **20,25** can be disposed within annulus **8**, so as to form an inner annulus **35** and an outer annulus **30**, which communicate at their lower ends and are filled with a non-circulating insulating liquid, such as gelled oil, or the like. The insulating liquid can be placed by pumping it down the outer annulus **30** and returning it via the inner annulus **35**, suitable supply and withdrawal pipes being connected to the upper ends of these annuli, as shown, for placement purposes. In such embodiment, the refrigerating liquid can be allowed to descend on the inner wall of the surface casing **1** or the outer wall of casing string **20**. Calculations were made like those given above in Table II, assuming a surface casing having a diameter of 20 inches, insulating fluid placement casings having diameters of 13 ⅜ inches and 9 inches, and a production string having a diameter of 7 inches, and using gelled oil as the insulating liquid. Refrigeration requirements for this embodiment are shown in Table IV, using propane as the liquid refrigerant. The permafrost temperature was assumed to be 32° F.

TABLE IV

Rate of liquid refrigerant, lbs./hr.	Surface refrigerant capacity, BTU/hr.	Depth of permafrost at 32°F., ft.
400	65,000	377
600	97,500	660
800	130,000	937
1000	162,800	1210
1200	195,000	1479
1400	228,000	1745
1600	260,000	2009
1800	292,000	2270

Referring now to FIG. **4**, another embodiment of this invention is shown. In this embodiment, a perforated or slotted casing or sleeve **31** is mounted within the annulus **8** between surface casing **1** and production casing **4** and depends therein forming an outer annular region **32** and an inner annular region **33**, the lower ends of which are sealed. Slotted casing **31** is provided with a plurality of slots or perforations **34** along its length. Liquid refrigerant is supplied via pipe **14** and opening **16** to the upper end of the outer annular region **32** at a temperature below 32° F. and fills that region. The liquid refrigerant is forced from the annular region **32**

via slots 34 into the inner annular region 33, a portion of the liquid refrigerant vaporizing as it enters the latter and a portion of it descending along the inner wall 45 of the slotted casing in the form of a falling film in a manner described in connection with the embodiment shown in FIG. 1. The heat flow from the production casing causes vaporization of this falling film as it descends. The temperature of the slotted casing 31 is controlled at 32° F. or less by the pressure in annulus 32 between the production casing 4 and the surface of the falling film of the refrigerant on the inner wall 35 of the slotted casing. The flow of the falling film of liquid is controlled by the pressure in the outer and inner annular regions 32, 33, the size of the slots or openings 34, and the distribution of the slots with respect to depth. Since the pressure in the liquid-filled annulus 32 will increase with depth, the size or the number of slots 34 should decrease with depth. In lieu of mere openings or slots in casing 31, those skilled in the art will recognize that other equivalent means can be used, such as spray nozzles or porous metal discs.

Referring now to the embodiment shown in FIG. 5, a perforated string of tubing or pipe 36 is disposed within annulus 8. Liquefied refrigerant is supplied via line 14 to the upper end of perforated tubing 36, the holes or openings 37 therein being used to spray the liquid refrigerant on the inner wall of surface casing 1 and the outer wall of production casing 4, vaporization of the liquid refrigerant occuring on these walls, thus removing heat emanating from the production casing, such heat being removed as latent heat in the vaporized refrigerant as it is removed via line 21 from the upper end of annulus 8. The pressure in annulus 8 is regulated so that the vaporization temperature is 32° F. less. In order to operate at temperatures lower than 32° F., and thereby keep the entire surface casing temperature at a temperature less than 32° F., it may be desirable to dispose within annulus 8 a plurality of such perforated tubings.

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention.

What is claimed is:

1. A method of minimizing the thawing of permafrost surrounding a wellbore in which are disposed a surface casing adjacent said permafrost and production string disposed within said surface casing with an annulus between said casing and said production string, which comprises, during production, injecting liquefied refrigerant into said annulus, passing said injected refrigerant downwardly in said annulus as a falling film on the inner wall of said surface casing while retaining free gas space in said annulus, allowing the heat emanating from said production string to vaporize said falling film of said injected refrigerant as it descends on said inner wall over a finite distance, and removing the resulting vaporized refrigerant from the upper end of said annulus without commingling the same with production fluid and without accumulating liquid refrigerant within said annulus.

2. The method according to claim 1, wherein said production string is encircled by insulation medium, such as foamed polyurethane or gelled oil.

3. The method according to claim 1, wherein said liquefied refrigerant is propane or ammonia.

4. The method according to claim 1, wherein said injected liquefied refrigerant is injected at a rate sufficient to ensure substantially complete coverage of said inner wall of said surface casing with said falling film of refrigerant.

5. The method according to claim 4, wherein said production string comprises a production casing which can have one or more production tubings disposed therein, and wherein said annulus is between said surface casing and said production casing.

6. The method according to claim 1, wherein said production string comprises a production tubing, the outer surface of which is bonded to a layer of foamed polyurethane insulation extending over the upper portion of all of said permafrost.

7. Apparatus for producing fluids from reservoirs penetrated by a wellbore surrounded at its upper end by permafrost, which comprises surface casing and production string depending within said surface casing with an annulus therebetween, means to inject liquefied refrigerant in said annulus, means to direct said injected liquefied refrigerant to the inner wall of said surface casing to cause said injected refrigerant to descend thereon as a falling film, and means for withdrawing vaporized refrigerant from the upper end of said annulus.

8. Apparatus according to claim 7, further comprising insulation means, such as polyurethane foam or gelled oil, encircling said production string.

9. Apparatus according to claim 7, wherein said production string comprises a production casing which can have one or more production tubings disposed therein, said annulus being between said surface casing and said production casing.

10. Apparatus according to claim 7, further comprising a perforated sleeve depending within said annulus and dividing the same into an outer annular region and an inner annular region, said means for injecting communicating with the upper end of said outer annular region, and said means for withdrawing vaporized refrigerant communicating with said inner annular region.

11. Apparatus according to claim 7, further comprising perforated tubing depending within said annulus, said means for injecting communicating with the upper end of said perforated tubing.

12. Apparatus according to claim 7, further comprising two concentric insulating placement casings encircling said production string with an outer annular region between the said placement casings and an inner annular region between said production string and the innermost of said placement casings, said annular regions being filled with insulation fluid, said annulus in which said liquid refrigerant is injected being between said surface casing and the outermost of said placement casings.

13. Apparatus according to claim 7, further comprising means for compressing and liquefying said withdrawn vaporized refrigerant and means for recycling the resulting reliquefied refrigerant to said means for injecting.

14. Apparatus according to claim 7 wherein said production string comprises a production tubing having a layer of foamed polyurethane insulation bonded to the outer surface of said production tubing and extending over the upper portion or all of said permafrost.

15. A method of minimizing the thawing of permafrost surrounding a wellbore in which are disposed a surface casing adjacent said permafrost and produc-

tion string disposed within said surface casing with an annulus between said casing and said production string, wherein said annulus is divided into an inner annular region and an outer annular region by means of a perforated sleeve depending within said annulus, which method comprises, during production, injecting liquefied refrigerant into the upper end of said outer annular region, filling the same, passing said liquiefied refrigerant from said outer annular region into said inner annular region through perforations in said perforated sleeve whereby a portion of said liquid refrigerant vaporizes as it passes through said perforations and a portion of it passes downwardly in said inner annular region as a falling film on the inner wall of said perforated sleeve while retaining free gas space in said inner annular region, heat emanating from said production string vaporizing said falling film as it descends within said inner annular region, the resulting vaporized refrigerant ascending in said inner annular region and being removed from the upper end thereof without commingling the same with production fluid and without accumulating liquid refrigerant within said inner annular region.

* * * * *