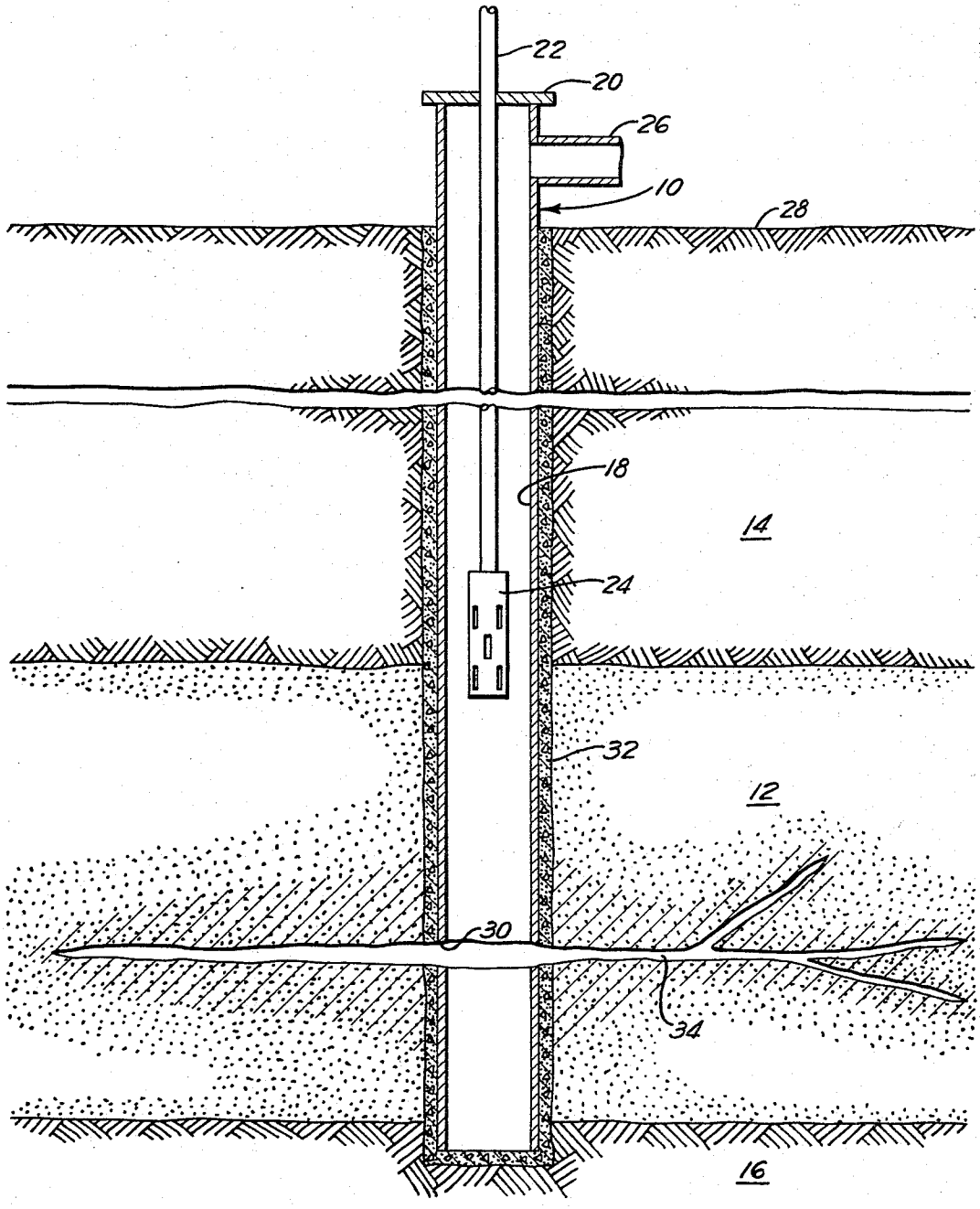
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METHOD FOR CONSOLIDATING INCOMPETENT SUBSURFACE FORMATIONS

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METHOD FOR CONSOLIDATING INCOMPETENT SUBSURFACE FORMATIONS

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This invention relates to a method of treating incompetent oil- or gas-bearing subterranean formations. It is particularly concerned with a method of bonding particles of such formations into a strong permeable mass through which passages of high fluid flow capacity extend.

Many subsurface formations from which oil or gas is produced are incompetent formations in which the individual sand particles of the formation are weakly bonded to one another. The term "incompetent formations" is used to designate any formation in which excessive quantities of sand particles move into a well during production of fluids through the well, and includes formations ranging from those in which the sand particles are substantially entirely uncemented to substantially rigid formations in which the particles while cemented one to another do not have adequate strength to withstand the erosive forces that occur during production of fluids from the formation into the well. Sand particles carried by the fluids into the borehole of the well from such formations may plug the well or production tubing and prevent production of oil from the well. If the oil- or gas-bearing formation is under a high pressure, the sand carried into the well frequently flows at a high velocity through borehole equipment and causes serious erosion of the equipment. Both plugging and erosion of the well equipment make expensive shutdown and workover of the well necessary to allow further production from the well.

Several methods have been used to combat the flow of sands into the well from unconsolidated formations. One of the techniques is to install a slotted liner in the borehole of the well through the pay zone. The slots of the liner are narrow enough to prevent flow of sand through them. Slotted liners frequently fail to accomplish the desired purpose because the movement of the sand around the liner may block the passages in the liner and prevent flow into the well.

Another technique that is employed is to pack fine gravel around a liner to produce a filter bed with small openings through which the sand particles cannot move. The gravel packing technique has the advantage of providing some support to the unconsolidated formation, but suffers the same disadvantage as the unconsolidated formation that the sand particles are not bonded together and may move to plug passages through which oil flows into the well.

It has also been suggested that the particles of the formation or in a gravel pack be treated by displacing a resin-forming liquid into the gravel pack to coat the particles, and thereafter setting the resin-forming liquid such as by condensation or polymerization to bond the particles into a unitary mass. Care must be taken to insure preservation of the permeability of the formation after the resin treatment. One of the difficulties with such a method is finding a suitable resin which can be made to set at conditions existing in the pay zone to form a resin of adequate strength and insolubility in formation fluids to produce a bond which will hold the particles together for long periods. One problem encountered in forming a mass of adequate strength is in obtaining satisfactory adhesion of the resin to the particles which are ordinarily covered with oil and water, or both, when the resin-forming liquid is displaced through the gravel pack. Moreover, when oil in the formation is highly viscous, the resin-forming liquid may finger through the formation, rather than displace the oil, and wet only a small part of the formation. Because of these difficulties, and the relatively high cost of the large amount of resin required, the use of resins to consolidate formations has not been widely adopted.

Another method that has been employed to restrict the production of sand from an incompetent formation is to heat the sand, by passing a hot gas through it, to temperatures at which oil in the formation is coked and bonds the particles together. The incompetent formation may not have adequate permeability to permit production of fluids at economical rates, and the deposition of coke in the formation usually further restricts permeability. Fracturing the portion of the formation bonded by the coke to increase the capacity of the formation to carry fluids into the well is hazardous in that it may destroy all of the benefits of sand consolidation gained from the coking operation by opening channels extending from the well to the unconsolidated area beyond the coke.

This invention relates to a method of consolidating an incompetent subterranean oil-bearing formation penetrated by a well and providing passages of high flow capacity through the formation by injecting a gas into the formation at a rate high enough to create a fracture in the formation and, while holding the fracture open by continued injection of the gas, controlling the temperature of the injected gas to coke oil present in the formation to bond particles of the formation together. In a preferred embodiment of this invention, an oxygen-containing gas, such as air, is injected into the formation at a rate higher than fluids can be displaced from the formation adjacent the borehole of a well thereby fracturing the formation to carry the injected air from the well. The temperature of the injected oxygen-containing gas is gradually increased at a carefully controlled rate to a maximum temperature of 350° to 600° F. to cause conversion to coke of oil in the formation. The deposition of coke in the formation to bond the particles together can also be accomplished by the injection of inert gases such as flue gases, at a temperature in the range of 500° to 1000° F. and at a rate adequate to create a fracture and hold the fracture open.

The single figure of the drawing is a diagrammatic view, partially in vertical section, of a well penetrating an incompetent formation which has been treated by the method of this invention.

For convenience in description, this invention will be described with reference to the drawing for that embodiment in which the gas injected is air heated by admixture with hot combustion products. Referring to the drawing, a well indicated generally by reference numeral **10** is shown penetrating an incompetent formation **12** between a cap rock **14** and base rock **16**. Well **10** is illustrated with casing **18** extending from the surface through the incompetent formation **12** into the base rock **16**. In the embodiment shown in the drawing, casing **18** is cemented in place in the borehole completely to the surface by any conventional cementing procedure.

The incompetent formation **12** can be any formation that will benefit from an increase in the strength of bonding of the particles comprising the formation. The process of this invention can be used on relatively hard, substantially self-supporting formations, but little is to be gained unless the formation **12** has insufficient strength to prevent movement of particles of the formation into the well as fluids are produced through the well. The in-

competent formation 12 also may be substantially uncemented, and resemble quicksand.

The upper end of the casing 18 is closed by a suitable cap 20 through which a fuel line 22 extends to supply fuel to a burner 24. An inlet line 26 opens into casing 18 above the surface 28 of the ground to supply air for the coking operation. Fuel line 22 and line 26 are connected with suitable sources of fuel and air, respectively. The fuel and air sources are not shown in the drawing.

In the preferred embodiment of the invention illustrated in the drawing, a ring is cut from casing 18 at the desired location in an interval of incompetent formation 12 to form an opening 30 through the casing. A notch is cut through opening 30 and the surrounding cement sheath 32 to provide access of air which is to be injected at a later stage of this process, into the incompetent formation 12. A single circumferential opening 30 of the type illustrated in the drawing is preferred because it insures flow of air to the desired location in the formation at closely controlled conditions which are substantially uniform in those areas of the formation treated. However, this invention can be used with the single opening 30 replaced by a plurality of perforations through the casing 18. Although the invention is illustrated in a well in which casing is set through the incompetent formation, the invention is not limited to that type of well completion and may be used in a well which is completed with an open hole through the incompetent oil-bearing formation 12 if the incompetent formation has adequate strength to prevent collapse of the formation during the drilling and consolidation process. Because of the very large area exposed when the well is completed as an open hole, high compressor capacities would be required during the air injection steps to insure treatment of the entire area of formation 12 exposed to the borehole of the well in accordance with this invention. If a long interval of the formation is exposed by an open hole, the static pressure in the formation near the top of the exposed interval is substantially less than near the bottom and may cause a fracture to be created near the top of the exposed interval with the result that very little, if any, of the injected gas enters the lower portion of the exposed interval. For this reason the process is limited to use in open hole where the exposed interval is less than one hundred feet, and preferably less than fifty feet.

During the drilling of the well 10 and the cutting of the opening 30, it is desirable to maintain a liquid within the well under a pressure higher than the pressure of fluids in formation 12 to prevent flow of fluids from the formation into the well. The higher pressure in the borehole of the well may cause displacement of some of the oil from the formation 12 adjacent the well. In some instances oil present in formation 12 may not contain enough heavy residual oils to create a strong bond of coke. If for either reason there is insufficient cokable oil in the formation 12 adjacent the well, it will be desirable to displace a readily cokable liquid, preferably a heavy crude oil or residual oil from the well 10 into the formation 12 surrounding the well. Thereafter air is displaced down the casing and a suitable fuel such as natural gas or LPG is displaced through fuel line 22 into burner 24 where the fuel is ignited. The relative rates of displacement of the fuel and air into the well are adjusted to provide an oxygen-containing gas having a temperature within the desired range, as hereinafter described. If desired, an electric heater can be substituted for the burner 24 to heat the oxygen-containing gas to the desired temperature. Coking of oil in the formation is not sensitive to the concentration of oxygen in the injected gas when the oxygen concentration is in the range from the concentration in air down to about one percent of the injected gas. Because of the lack of sensitivity to the oxygen concentration, the necessary temperature control can be obtained by dilution of the combustion products from a burner with cold air and the changing oxygen concentration does not interfere with control of the coking. A preferred method of controlling the temperature is to inject air at a rate adequate to fracture the formation and then inject fuel, which is burned at the burner 24, at a gradually increasing rate to obtain the desired temperature of the gases passing through notch 30. When an electric heater is used for heating and controlling the temperature, the injected gas can be substantially undiluted air.

The air is injected from the well into the formation at a high rate which will create a fracture 34 in the formation. Whether the rate of injection of the air is adequate to create the desired fracture can easily be ascertained by observation of the pressure within the well as air injection continues. If the formation surrounding the well is relatively open and will accept air from the formation, the rate of flow of air from the well into the formation is substantially directly proportional to the pressure within the well prior to the creation of any fracture. Once a fracture or open channel through the incompetent formation 12 is formed, no substantial increase in the pressure within the well will be obtained in spite of large increases in the rate of injection of the air into the well.

In some instances, the formation surrounding the well will be plugged during the drilling or cementing operations and formation 12 will initially not readily accept air. Continued injection of air through line 26 into the well causes the pressure within the well to increase until a pressure break, which indicates the creation of a fracture within the incompetent formation, occurs. The rate of displacement of air into the well can then be greatly increased without increasing the pressure in the well to a pressure as high as the pressure prior to the pressure break.

It is essential when injecting oxygen-containing gases into an oil-bearing formation to control the temperature of the injected gas carefully in accordance with a predetermined schedule to cause the formation of a coke of the desired characteristics and yet avoid burning coke from the formation. In the preferred embodiment of the process of this invention, an oxygen-containing gas, which may be air or air diluted with inert fluids, such as flue gas, is displaced from the borehole of a well outwardly through the incompetent formation containing oil. The oxygen-containing gas is initially displaced into the formation at a temperature below about 225° F. It is the usual practice to begin the operation by the displacement of the oxygen-containing gas at substantially the temperature of the incompetent formation and raise the oxygen-containing gas temperature rather quickly to 225° F. Further increases in temperature are made more slowly. A period of about four hours should be used to raise the temperature of the oxygen-containing gas from the initial injection temperature to 250° F. The particular time-temperature schedule of the injected gas below 250° F. is not highly critical, but it is preferred that the rate of temperature increase to that temperature be substantially uniform. For example, if the temperature increase is stepwise, three or more substantially equal steps should be used. The period for increasing the temperature from 250° F. to the final temperature at which the oxygen-containing gas is displaced into the formation is preferably at least about 48 hours. It will be desirable to run preliminary tests on oil from the unconsolidated sands whenever a coking operation is to be performed to aid in selection of the desired time-temperature schedule, but the schedule of four hours to 250° F. and 48 hours to the final temperature has an adequate margin of safety to permit its use on virtually all crude oils without danger of initiating combustion, either too close to, or which would move too close to, the borehole wall, which would destroy coke formed adjacent the borehole wall. The high gas flux required to hold the fracture open carries heat from the coking zone at a high rate which allows raising the temperature of the injected oxygen-containing gas faster than when there is no fracturing, and makes

it possible to raise the temperature from 250° F. to the final temperature in 24 hours in some instances.

The temperature and pressure of the incompetent formation will also influence the rate at which the temperature of the injected gas can be raised. Increases in temperature or increases in pressure of the incompetent formation increase the reaction rate and make necessary slower initial raising of the temperature of the injected oxygen-containing gas; however, the effect of pressure is relatively minor compared to the effect of temperature on the rate of reaction between the oil and the oxygen-containing gas. If the process is used in a deep formation initially at a high temperature, the formation can be cooled, for example, by injection of a cool inert gas or liquid, such as water, before displacing an oxygen-containing gas into the formation.

The temperature of the oxygen-containing gas displaced into the formation is gradually increased at a substantially uniform rate in either a continuous or stepwise manner to a final temperature in the range of 350° to 500° F. adapted to produce a coke having adequate strength and a low solubility in oil bonding together the particles of the formation adjacent the faces of fracture **34**, as illustrated by the shading in the drawing.

Tests on cores of unconsolidated sands saturated with a readily cokable oil in which air is displaced through the unconsolidated sand at a maximum temperature of approximately 300° F. have resulted in the formation of little, if any, coke, and have not produced the desired consolidation of the sand. In those experimental runs at air injection temperatures less than 350° F. in which coke was formed, the coke was soluble in hydrocarbon solvents. The temperature of the air displaced from the borehole into the formation should not exceed 500° to 600° F. It has been found that oxygen-containing gas temperatures in excess of 600° F. cause a marked decrease in the strength of the coked mass adjacent the borehole. The following examples illustrate the necessity of increasing the temperature at a controlled rate to the desired final temperature.

Example 1

A thin-walled stainless steel tube, 5 inches in diameter and 5 feet long, was packed with sand and saturated with a crude oil having a gravity of 15.8° API from the Fruitvale field in California. A jacket around the tube provided an annular space surrounding the tube into which nitrogen was introduced to permit maintenance of the desired pressure within the tube without exposing the thin-walled tube to high pressure differences. Thermocouples were located at regular intervals through the packed sand. After air flow through the tube was established, the air was heated prior to displacement into the sand in accordance with the schedule set forth in Table I. The run was ended when temperatures within the 5-inch tube indicated that combustion was occurring. The air flux through the tubing was maintained at approximately 29,000 std. cu. ft./sq. ft./hr. and the outlet pressure of the tubing was maintained at approximately 750 lbs./sq. in.

Example 2

A 5-inch tube, 5 feet long, was packed with sand which was then saturated with a Fruitvale crude oil having a gravity of 15.8° API. Thermocouples were positioned at regular intervals along the length of the tubing and the tubing provided with a jacket suitably connected with a source of nitrogen for maintaining the desired pressure on the outer surface of the tube. Air was passed through the tube to establish permeability and thereafter adjusted to maintain an air flux of approximately 30,000 std. cu. ft./sq. ft./hr. The pressure at the outlet of the tube was maintained at approximately 400 lbs./sq. in gauge. The temperature of the air introduced into the tube was gradually increased in accordance with the schedule set forth in Table I and the temperatures indicated by the thermocouples recorded. The results of the tests of Examples 1 and 2 are presented in Table I.

TABLE I

Time, min.	T., ° F., Injected Air	T. max., ° F.
Example 1		
45	<65	<65
75	165	170
105	165	165
135	300	295
152	385	395
160	395	1,440
161	400	1,700
Example 2		
0	180	180
55	210	210
115	230	230
175	250	240
235	280	280
295	310	310
355	320	335
475	390	420
535	395	410
595	390	400
655	380	390

It will be noted from Table I that the rapid increase to an air inlet temperature of 395° F. in 2 hours and 40 minutes resulted in the initiation of combustion within the tubing, as indicated by a maximum temperature of 1700° F. The maximum temperature was indicated at a thermocouple located at a point about two-thirds of the distance to the outlet end of the tube. Similar tests have shown that if the injection of oxygen-containing gases is continued after a temperature of the type indicated in Example 1 occurs, reverse combustion is initiated and the peak temperature moves toward the inlet end of the tube. When the temperature of the inlet air was increased more slowly, as in Example 2, in which approximately 8 hours were required to reach a temperature of 390° F., combustion was not initiated in the tube and a strong unitary mass of sand particles bonded with coke was produced.

The rates of raising the temperature of the injected air set forth in Table I are somewhat higher than are possible in subsurface formations. The radial flow pattern of gases displaced from a well into a formation causes a rapid reduction in the flux as the distance into the formation increases and prevents maintenance of the high air flux used in the experimental tubes. Field tests have indicated that slower rates of increasing the temperature of the injected oxygen-containing gas are required in the field than in the experimental cores.

In the Santiago field in California, air was injected into an incompetent oil-bearing formation at a rate of 1,170,000 cubic feet per day when a pressure drop indicated that the formation had fractured. The borehole pressure just before the pressure break was 560 pounds per square inch. After the pressure break air was injected at a rate of 1,400,000 cubic feet per day and a borehole pressure of 535 pounds per square inch. Air injection at the increased rate was continued for 24 hours at the reservoir temperature. The temperature of the air was then increased to 150° F. by control of the rate of supplying propane gas to a burner in the borehole. The temperature of the injected gas was increased to 200° F. over an 8-hour period by increasing the rate of fuel supply to the burner and then held for 16 hours at 200° F. The temperature of the injected gas was then increased to 250° F. over an 8-hour period and held for 16 hours at 250° F. The sequence of raising the temperature and then holding the temperature was continued until the tem-

perature of the gases displaced into the formation reached 400° F. Throughout the air-injection procedure, the air-injection rate was high enough to maintain the pressure in the borehole at the fracturing pressure. No detrimental combustion of the oil in the formation surrounding the borehole was experienecd, and subsequent production of oil from the well indicated that the sands were consolidated adequately to prevent flow of sand into the well. The procedure in the Santiago field was conservatively designed to prevent detrimental combustion. Subsequent laboratory tests show that more rapid increases in the temperature of the air displaced into the formation can be used without causing destructive combustion of coke formed adjacent the borehole wall.

Suitable consolidation of the formation and prevention of forward burning which destroys coke formed adjacent to the borehole of the well cannot be obtained merely by maintaining a low temperature of oxygen-containing gas displaced into the formation. A number of field tests of in-situ combustion processes have shown that continued injection of oxygen-containing gases at the formation temperature into the formation will eventually cause combustion to be initiated at some distance from the injection well. Once the combustion is initiated, the temperature will build up to excessive levels and eventually reverse combustion occurs causing the combustion front to move to the injection well. Continued displacement of oxygen-containing gas after the combustion front reaches or approaches the injection well causes a second reversal in the direction of movement of the combustion front to forward combustion which completely consumes any coke deposited adjacent the injection well. It is necessary to raise the temperature of the injected gas to condition the oil in the formation adjacent the injection borehole, whereby the subsequent combustion will not travel by reverse combustion to destroy coke reaching the desired thickness of the sleeve of coke bonded particles surrounding the borehole.

The coke bond created by the hot air injection is physically strong and chemically stable. After a period of production of oil, the well in the Santiago field described in the specific embodiment was stimulated by the injection of air through the well into the formation to cause in-situ combustion of oil in the oil-bearing formation remote from the well. After the combustion had proceeded for a time adequate to heat the formation, the well was again placed on production. No sand flowed into the well during the subsequent production thereby indicating that the coke bond was not destroyed.

Although the deposition of coke to consolidate the formation is preferably accomplished by the injection of an oxygen-containing gas at a controlled, gradually increasing temperature because of the greater strength of the resultant consolidated formation, the coke can also be produced by the injection of hot insert gases under a pressure and at a rate adequate to fracture the incompetent formation and maintain the fracture open during the deposition of the coke. The term "inert gases" is used to designate gases having an oxygen concentration below about one percent. Such gases can be obtained, for example, from the exhaust of gas or gasoline fueled internal combustion engines, or the burning of a suitable rocket fuel. Because of the low oxygen concentration in the inert gases, danger of burning coke deposited in the formation is avoided, and it is possible to proceed immediately with the injection of high temperature inert gases. The temperature of the inert gases may range from approximately 400° to 1300° F. and is preferably in the range of 650° to 1000° F. Because of the high temperature of the inert gas, the injection of the gas will create the desired coke bond in a short time compared with the time required for the coking operation with the oxygen-containing gas. For example, if the inert gases are injected at a temperature of 1000° F., an adequate zone of consolidation is obtained in a period of eight hours.

The creation of a coke bond by the injection of hot gases while holding the fracture open apparently results in a zone of consolidated formation completely encasing the fracture. Subsequent production of oil through the fracture into the well is obtained without the flow of sand from the incompetent formation into the well. Moreover, the high flow capacity into the well is obtained without the necessity of propping the fracture open. The reason for the high flow capacity without propping agents is not known with certainty, but it is believed that during the coking operation there is sufficient spalling and erosion of the surfaces of the fracture and shrinkage of clays in the formation to prevent the surfaces from mating when the pressure is released and the well is placed on production. In the process herein described, there is no danger of destroying the consolidation of the formation; whereas if attempts are made to fracture formations after they have consolidated by the deposition of coke, the benefits derived from the consolidation ordinarily are destroyed.

The rate at which the gas is injected into the formation to create the fracture and maintain the fracture open during the deposition of the coke will depend upon the permeability of the formation and the mobility of the oil in the formation. It is not possible to specify a particular rate of gas injection that is applicable to all incompetent formations to be treated by this invention; however, the rate of gas injection must exceed the rate at which liquids in the formation can be made to flow away from the borehole through the formation when the borehole pressure is below the minimum pressure required to fracture the formation. No difficulty is encountered in determining whether or not the injection rate is adequate to create a fracture. A pressure break as the gas injection rate is increased or a change in the rate of increase of pressure with increased gas injection rate gives a quick and accurate indication of the creation of a fracture. Maintenance of the gas injection rate to maintain the borehole pressure at or above the pressure at which the break occurs will insure holding the fracture open during the conversion of heavy oils to coke to consolidate the formation.

We claim:

1. A method of consolidating and increasing the flow capacity of an incompetent underground oil-bearing formation penetrated by a well comprising injecting a gas down the well and into the formation at a rate creating a fracture in the formation, continuing the injection of the gas at a rate maintaining the fracture open, and while maintaining the fracture open by the injection of gas increasing the temperature of the injected gas to above 350° F. to deposit coke in the formation adjacent the fracture and bond the particels of the formation into a consolidated mass.

2. A method of consolidating and increasing the fluid flow capacity of an incompetent underground oil-bearing formation penetrated by a well comprising injecting gas down the well and into the formation at a rate faster than formation fluids will flow through the formation in the absence of a fracture whereby said formation is fractured, continuing the injection of the gas at a rate holding the fracture open, and while maintaining the fracture open by the injection of gas increasing the temperature of the gas to a final temperature above 350° F. at a rate to avoid ignition of the oil in the formation adjacent the fracture whereby coke is deposited in the formation adjacent the fracture to consolidate the formation.

3. A method of consolidating an incompetent underground oil-bearing formation penetrated by a well and increasing the flow capacity of the formation into the well comprising injecting an oxygen-containing gas down the well and into the formation at a rate causing fracturing of the formation, continuing the injection of the oxygen-containing gas at a rate to hold the fracture open, and increasing the temperature of said oxygen-containing gas to approximately 250° F. in a period of at least about four hours, thereafter gradually increasing the temperature of

the injected gas to a final temperature in the range of 350° to 500° F. adapted to convert hydrocarbons adjacent the fracture in the formation to coke to consolidate the formation while injecting the gas at a rate maintaining the fracture open.

4. A method as set forth in claim **3** in which the temperature of the injected gas is raised from 250° F. at a substantially uniform rate to a final temperature in the range of 350° to 500° F. over a period of at least about 48 hours.

5. A method as set forth in claim **3** in which the temperature of the injected gas is raised from 250° F. at a substantially uniform rate to a final temperature in the range of 350° to 500° F. over a period of at least about 24 hours.

6. A method of consolidating an incompetent underground oil-bearing formation penetrated by the borehole of a well and increasing the flow capacity of said formation into said borehole comprising displacing air down the well and into said formation at a rate creating a fracture in the formation, continuing the injection of air at a rate to hold the fracture open while burning fuel in the borehole to raise the temperature of the gas injected into the formation, and periodically increasing the ratio of fuel to air to increase the temperature of the air and combustion products to a final temperature in the range of 350° to 500° F. whereby oil in the formation is coked to consolidate the formation, the rate of increasing the ratio of fuel to air being controlled to avoid ignition of oil adjacent the fracture.

7. A method of consolidating an incompetent underground oil-bearing formation penetrated by the borehole of a well and increasing the flow capacity of the formation into said borehole comprising injecting a gas from the borehole of the well into the formation at a rate creating a fracture in the formation, continuing the injection of the gas at a rate maintaining the fracture open while heating said gas with an electric heater suspended in the borehole of the well adjacent the formation, and gradually increasing the temperature of the gas injected into the formation to a final temperature exceeding 350° F. to convert oil in the formation to coke and thereby consolidate said formation.

8. A method of consolidating an incompetent underground oil-bearing formation penetrated by the borehole of a well comprising injecting a gas down the well and into the formation at a rate creating a fracture in said formation, injecting an inert gas at a temperature in the range of 400° to 1300° F. down the well and into the formation at a rate maintaining the fracture open to convert oil in said formation adjacent the fracture to coke to consolidate the formation.

9. A method as set forth in claim **8** in which the inert gas is the exhaust gas from an internal combustion engine.

10. A method as set forth in claim **8** in which the inert gas is the exhaust gas from a rocket fuel.

11. A method of consolidating an incompetent underground oil-bearing formation penetrated by the borehole of a well comprising setting casing in said borehole through the incompetent formation, cutting a notch in the casing opposite the incompetent formation, injecting a gas down the well and through the notch into the formation at a rate creating a fracture in the formation, continuing the injection of the gas at a rate adapted to maintain the fracture open while increasing the temperature of the gas to at least 350° F. at a rate avoiding combustion of oil adjacent the fracture to convert oil in the formation adjacent the fracture to coke and thereby consolidate the formation.

12. A method as set forth in claim **11** in which the gas is an oxygen-containing gas and the final temperature is 350° to 500° F.

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