

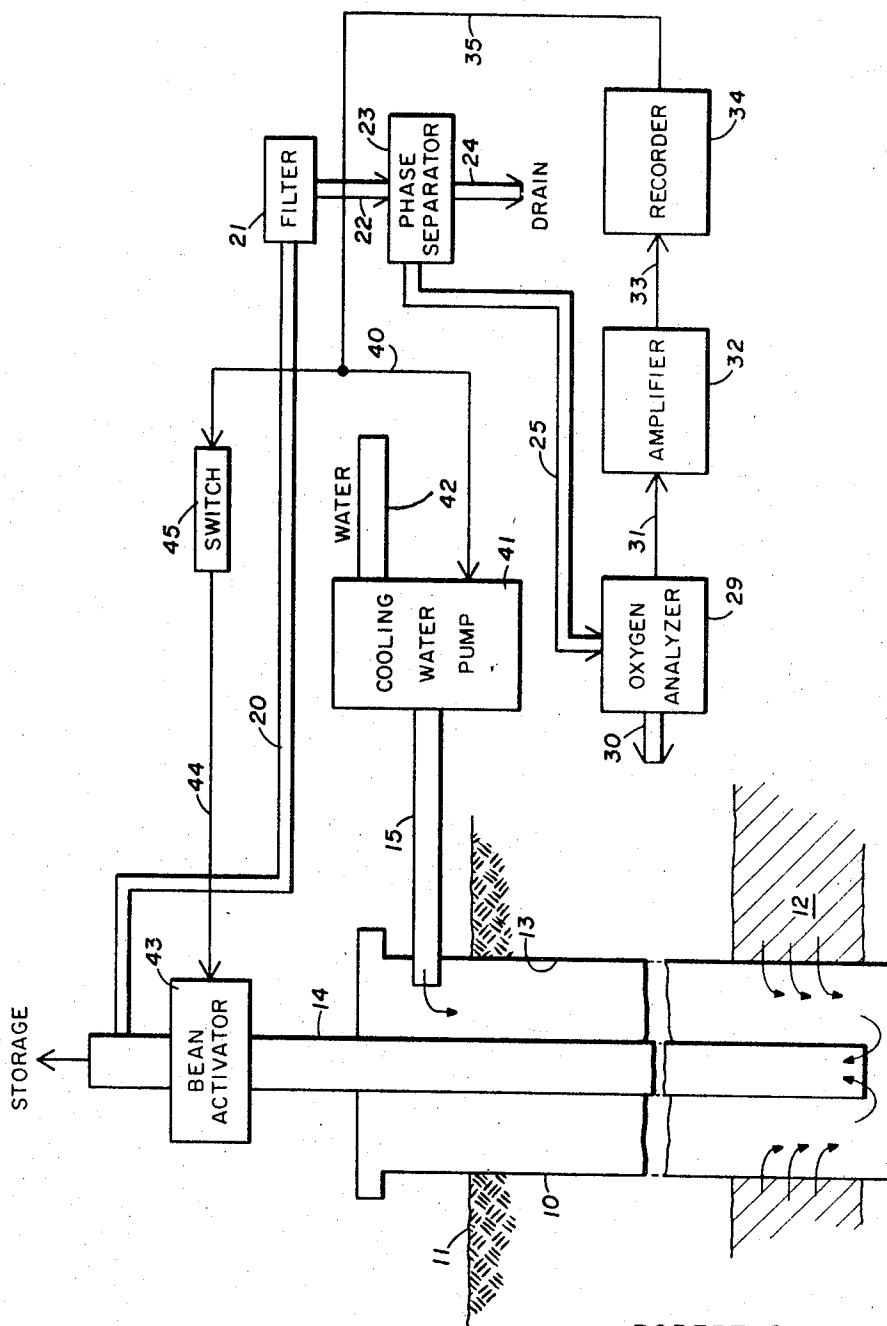
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TEMPERATURE CONTROL IN AN IN-SITU COMBUSTION PRODUCTION WELL

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1

2

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TEMPERATURE CONTROL IN AN IN SITU COMBUSTION PRODUCTION WELL

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Continuation-in-part of application Ser. No. 604,371, Dec. 23, 1966. This application Oct. 16, 1968, Ser. No. 772,459

Int. Cl. E21b 47/00, 43/24

U.S. Cl. 166—251

20 Claims

ABSTRACT OF THE DISCLOSURE

This specification discloses a method and system of temperature reduction control in a production well leading from a subterranean formation undergoing in situ combustion for the recovery of hydrocarbons. The method and system are based upon a change in the composition of the effluent from the production well, such as a change in the oxygen content, for effecting operation of the temperature reduction control means. Temperature reduction control is through the media of introduction of a coolant, such as water, into the well. Additionally, the flux rate of the effluent into the well can be reduced.

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my co-pending application Ser. No. 604,371, filed Dec. 23, 1966, and now abandoned.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to the recovery of hydrocarbons from a subterranean formation by the procedure involving in situ combustion and relates more particularly to the control of the temperature within a production well leading from the formation undergoing in situ combustion.

Description of the prior art

Hydrocarbon liquid, more particularly oil, in many instances can be recovered from a subterranean formation through a well penetrating the formation by utilizing the natural energy within the formation. However, as the natural energy within the formation declines, or where the natural energy originally is insufficient to effect recovery of the hydrocarbon liquid, recovery methods involving addition of extrinsic energy to the formation can be employed. One of these methods, called the in situ combustion method, as disclosed in U.S. Patent No. 2,670,047, involves supplying an oxidizing medium to the formation and effecting combustion in place within the formation of a portion of the hydrocarbon liquid or of a carbonaceous residue formed from a portion of the hydrocarbon liquid. A combustion front migrates through the formation and the remainder of the hydrocarbon liquid, along with gaseous effluent, passes from the formation to a production well. The heat produced by the combustion reduces the viscosity of the hydrocarbon liquid and this, along with the increase in pressure within the formation, the driving force provided by the supply of the oxidizing medium, and the generation of steam from any water within the formation, effects recovery of a greater portion of the hydrocarbon liquid within the formation than would be obtained in the absence of the combustion method.

While the in situ combustion method is effective from the standpoint of the additional recovery of hydrocarbon liquid obtained, it is not without its difficulties. One of these arises from the high temperatures encountered in

the wells. With supply of the oxidizing medium to the formation, and ignition of the hydrocarbon liquid or carbonaceous residue, a combustion zone is created within the formation. This combustion zone will have a temperature between 300° F. and 1200° F. and can be even higher. In the indirect combustion method, where the oxidizing medium is supplied to the formation through an injection well and ignition is effected in the formation at a production well, the combustion zone migrates from the production well to the injection well. As a result of the creation of the combustion zone in the formation at the production well, the production well immediately becomes hot and approaches the temperature of the combustion front. However, with migration of the combustion front to the injection well, the temperature at the production well can decrease. In the direct combustion process, where the oxidizing medium is also supplied to the formation through an injection well but ignition is effected at the injection well rather than at a production well, the combustion zone migrates from the injection well to a production well. With the eventual approach of the combustion zone to the production well, the production well becomes hot and approaches the temperature of the combustion front.

With the production well becoming hot, various deleterious results are encountered. For example, the temperatures may become so high as to effect destruction of the liner, tubing, and other equipment in the well with possible consequent loss of the well. Further, where bypassing of the combustion zone by a portion of the oxidizing medium occurs, which is quite common, combustion within the well of the hydrocarbons, both liquid and gas, produced from the formation ensues with resulting loss of these hydrocarbons along with the attainment of still higher temperatures which practically insure destruction of the well.

In order to avoid the difficulties arising from the high temperatures encountered in the production wells in the in situ combustion process, it has been proposed to effect a temperature reduction control in these wells. Ordinarily, temperature reduction control is effected by introducing a coolant into the production wells. Commonly, as disclosed in U.S. Patent No. 3,259,185, the coolant has been water. Temperature reduction control ordinarily is effective in maintaining the temperature within a well below that at which destruction occurs. On the other hand, temperature reduction control presents some problems. For example, temperature reduction control adds to the cost of carrying out the in situ combustion process. Further, where a coolant is employed, the coolant subsequently must be separated from the produced hydrocarbons. Thus, where water is employed as the coolant, the water, upon mixing with the hydrocarbon liquids in the well, can form an emulsion with the liquids and the emulsion, which can be relatively stable, requires treatment to break it so as to release the hydrocarbon liquids from the water. Accordingly, except possibly upon initiation of combustion in the indirect combustion process when it is known that deleteriously high temperatures may be encountered, temperature reduction control, particularly by introduction of cooling water or other coolant, is desirably minimized. On the other hand, when the danger of encountering excessively high temperatures becomes imminent, the introduction of cooling water or other coolant, or the use of other means for controlling the temperature, is required.

Commonly, temperature reduction control in a production well is delayed until a predetermined temperature increase within the production well is noted. Along this line, various systems have been proposed for detecting the increase in the temperature within the production well. Such a system is disclosed in U.S. Patent No. 3,357,490. The

increase in the temperature creates a signal and the signal actuates the temperature control. Thus, the signal may actuate pumping means for introducing cooling water into the well. However, effecting temperature reduction control by monitoring the temperature within the production well is not always entirely satisfactory. For example, often by the time the temperature within the well at the point where the detecting means is located becomes sufficiently high to create the signal to actuate the temperature reduction control means, partial destruction of the well or combustion of hydrocarbon liquids or both may have already occurred.

SUMMARY OF THE INVENTION

In accordance with the invention, there is provided a method and system whereby the gaseous effluent from the production well leading to a formation undergoing in situ combustion is monitored for the proportion of at least one component therein and, upon a change in the proportion of the component in the gaseous effluent, temperature reduction control is effected in the well. In a specific embodiment of the invention, the gaseous effluent from the production well is monitored for the proportion of oxygen therein and, upon a change in the proportion of the oxygen, cooling water is introduced into the well.

BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawing is a schematic representation illustrating a specific embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention is predicted upon the proposition that a change in the proportion of a component in the gaseous effluent from the production well leading to a formation undergoing in situ combustion is indicative of the approach of, or presages, a high temperature within the well. For purposes of description at this point this component will be assumed to be oxygen. However, as will be explained hereinafter, a change in the proportion of any component will be related to the change in the proportion of oxygen and thus will be indicative of the approach of a high temperature within the well. Further, for purposes of description at this point, temperature reduction control will be specifically set forth in terms of introduction of cooling water into the well.

In both the indirect and direct combustion methods, with the introduction of the oxidizing gas into the formation through an injection well, and migration of the combustion within the formation, a small amount of the oxidizing gas bypasses the combustion front. Thus, under normal conditions, the gaseous effluent from the production well will contain oxygen but the proportion will be low. For example, ordinarily, the oxygen content of the gaseous effluent from the production well will be about 1 percent by volume. Frequently, however, during the in situ combustion operation, a greater portion of the oxidizing gas introduced into the injection well will bypass the combustion front and will enter the production well. Under these conditions, the proportion of oxygen in the gaseous effluent can be much higher than the proportion under more normal conditions. For example, depending upon the extent to which the oxidizing gas bypasses the combustion front, the proportion of oxygen in the effluent gas from the production well can approach that in the oxidizing gas injected into the injection well. Where the oxidizing gas is air, this proportion can be as high as 21 percent. Where the proportion of oxygen in the gaseous effluent from the production well is about 5 percent by volume or higher, auto-oxidation of the hydrocarbon liquid within the formation can occur and the auto-oxidation can occur to the extent that it can cause combustion of the hydrocarbon liquid. This auto-oxidation occurs in the formation around the production well as well as further into the formation and, accordingly, can cause burning in the neighborhood of the production well. The burn-

ing can then extend to within the well. Thus, an increase in the proportion of oxygen in the gaseous effluent from a production well can lead to combustion within the formation in the neighborhood of the production well or within the well. Stated otherwise, in the indirect and the direct combustion methods, an increase in the proportion of oxygen in the gaseous effluent from a production well presages high temperature conditions at the well requiring the introduction of cooling water to the well.

Further, in the direct combustion process, when the combustion front, or a portion thereof where the combustion front is not completely perpendicular, reaches or passes the production well, the proportion of oxidizing gas passing from the injection well to the production well and entering the production well without having passed through the combustion front increases. This is for the reason that the combustion front does not occupy the entire perpendicular area, or any of the perpendicular area, of the path of the oxidizing gas. Accordingly, over that portion of the path of the oxidizing gas between the injection well and the production well not occupied by the combustion front, the oxidizing gas is virtually unused and in this state enters the production well. Thus, an increase in the proportion of the oxygen in the effluent gas from the production well from that occurring under more normal conditions indicates that the combustion front has reached or passed the production well with the imminent danger of combustion occurring in the production well. Stated otherwise, in the direct combustion method, an increase in the proportion of oxygen in the gaseous effluent from a production well presages high temperature conditions at the well requiring introduction of cooling water to the well.

In both the indirect and direct combustion methods, combustion can occur in the formation in the immediate vicinity of the production well or in the well. With such combustion, the proportion of oxygen in the gaseous effluent from the production well will decrease. Thus, in both the indirect and direct combustion methods, a decrease in the proportion of oxygen in the gaseous effluent from a production well indicates the requirement of introduction of cooling water into the well.

To summarize, in the in situ combustion method, a change occurring in the proportion of oxygen in the effluent gas from the production well, whether this change is an increase in the oxygen content or a decrease in the oxygen content, can presage high temperature conditions at the production well and indicate the requirement of introduction of cooling water to the well.

In the practice of the invention, temperature reduction control in the production well is effected whenever the proportion of oxygen in the gaseous effluent changes by at least 1 percent by volume. However, the temperature reduction control may be effected whenever the proportion of oxygen in the gaseous effluent changes by at least 2 percent by volume. In any case, it is preferred to effect temperature reduction control in the production well whenever the proportion of oxygen in the gaseous effluent decreases to below about 1 percent by volume or increases to above 3 percent by volume. However, depending upon specialized conditions in a particular in situ combustion operation, temperature reduction control may be effected when the decrease in the proportion of oxygen is to a figure greater or lesser than about 1 percent by volume or the increase is to a figure which is greater or lesser than about 3 percent by volume.

Under some circumstances, temperature reduction control by the introduction of a coolant is ineffective from the standpoint of preventing damage to the well. Occasionally, combustion at a localized portion of the formation near or at the surface of the well can form a localized hot spot in the well liner. The heating at the localized hot spot can be sufficiently great that a coolant contacting the hot spot may be unable to carry away the heat sufficiently rapidly to reduce its temperature below that

5

at which damage to the liner can occur. In such situations, and in others where the introduction of a coolant into the well is not sufficient to effect the desired temperature reduction control or it is desired to supplement the coolant, it is preferred to reduce the flux rate of the gaseous effluent into the well. This can be effected by imposing a back pressure upon the production well. Conveniently, this can be effected by changing the bean size in the wellhead of the production well. In this connection, the temperature reduction control may include, as indicated by experience, completely shutting in the well.

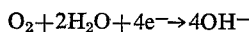
Referring to the drawing, well 10 leads to the surface of the earth 11 from formation 12. The well 10 is provided with casing 13 and with production tubing 14. The production tubing extends to a point near the bottom of the well. The well is also provided with line 15.

Well 10 is a production well. It will be assumed that formation 12 is undergoing in situ combustion by the direct combustion method for the recovery of liquid hydrocarbons from the formation. In this method, the combustion front migrates through the formation 12 to the well 10 from an injection well (not shown) into which an oxygen-containing gas, ordinarily air, is injected and hydrocarbon products displaced from the formation by the combustion procedure, along with combustion products and bypassed air, enter the well through perforations (not shown) in the casing 13. These materials pass upwardly through the well through the production tubing 14 to storage after suitable treatment for separation of gas and water from the hydrocarbon liquids or otherwise.

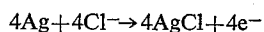
Attached to tubing 14 is a pipeline, or other conduit, 20 leading to filter 21. A portion of the gases produced from the formation 12 and passing through the tubing 14 passes through the line 20. In the filter 21, any solid matter, such as sand fines, coke, or other, are removed from the gases, and the filtered gases pass out of the filter 21 through pipeline 22 and enter phase separator 23. In the phase separator 23, the gases are separated from any liquids that may be contained in the gases and the liquids pass out of the separator through drainline 24. The gases, now free of solid matter and liquid, pass through pipeline 25 and enter oxygen analyzer 29.

In oxygen analyzer 29, the gases are analyzed for the proportion of oxygen. Oxygen analyzer 29 may be any type of analyzer capable of analyzing the gases for the proportion of oxygen. Analyzers of this sort such as the Beckman Model 956 are commercially available. This instrument contains an oxygen sensor comprising a gold cathode surrounded by an annular silver anode. The body of the sensor is made of epoxy. The cathode communicates electrically with the anode through the medium of a thin film of potassium chloride gel which is spread over the top of the sensor. Placed over this assembly is a plastic membrane held in place with a neoprene O-ring. The membrane serves two purposes. It allows oxygen to diffuse into the sensor and it acts as a barrier which keeps the gel in place around the electrodes and foreign matter out. Also contained within the epoxy body of the sensor is a thermistor. The varying resistance of the thermistor automatically compensates the sensor output for changes in temperature.

In operation of the analyzer, a polarizing voltage is applied to the sensor. The reactions which take place when oxygen comes in contact with the polarized electrodes are, at the cathode and anode, respectively:



and



When oxygen diffuses through the membrane and contacts the gold cathode, it is reduced to a hydroxide, releasing 4 electrons for each molecule of oxygen that takes part in the reaction. The free electrons released in the

6

reaction at the electrodes cause a current to flow from the sensor. The greater the number of oxygen molecules in the gas stream from line 25, the greater will be the increase in current and the increase will be proportional to the quantity of oxygen present. The gases, after analysis in the analyzer, are vented through line 30.

The electrical current generated by the analyzer 29 proportional to the quantity of oxygen in the gas stream is transmitted through line 31 to amplifier 32. Amplifier 32 is any type of amplifier capable of amplifying the current from the oxygen analyzer sufficiently to operate an indicating meter and a recorder. An amplifier capable of amplifying the maximum current from the oxygen analyzer to 50 millivolts is satisfactory.

The amplified electrical current from the amplifier 32 is transmitted through line 33 to recorder 34. Recorder 34 is any type of recorder that will make a record of the oxygen content of the gaseous effluent from the well as represented by the electrical current produced by the analyzer. A potentiometric recorder, such as a Honeywell recorder, is satisfactory.

Recorder 34 also provides an electrical current through line 35, through high and low switches, for example, whenever there is a change in the proportion of oxygen in the gaseous effluent from the well 10 and this latter electrical current effects introduction of cooling water to the well. When the proportion of oxygen in the gaseous effluent changes beyond the figure selected as presaging an undesirably high temperature in the well, the recorder 34 sends an electrical current through the line 35 and thence to the line 40 to cooling water pump 41. This electrical current operates as a signal to start the pump 41. With operation of pump 41, cooling water entering the pump from pipeline 42 is pumped into the well 10 through the line 15.

As mentioned previously, with a change in the proportion of oxygen in the gaseous effluent from the well 10, the flux rate into the well may also be reduced. The well 10 is provided with a bean activator 43 to control the back pressure on the well. With an increase in the back pressure, the rate of flow of the gaseous as well as the other products from the formation into the well is reduced. The bean activator may be any type of bean activator such as a Willis bean activator and may be pneumatically operated. The bean activator is connected through line 44 containing switch 45 to line 35. With switch 45 closed, the current from line 35 will pass through the line 44 to the bean activator and act as a signal to the bean activator to change the bean size to increase the back pressure on the well 10. The electrical current, i.e., the signal from the recorder 34 may vary in intensity depending upon the proportion of oxygen in the gaseous effluent from the well. Thus, the change in bean size effected by the bean activator, and thus the extent to which the back pressure on the well is increased, may be made proportional to the intensity of the electrical current. Where the introduction of the cooling water and the reduction in flux rate are not sufficient to result in a desired proportion of oxygen in the gaseous effluent, the tubing may be entirely closed to shut in the well completely. Whenever it is desired not to change the bean size with a change in the proportion of oxygen in the gaseous effluent from the well 10, the switch 45 may be opened.

Various modifications to the system illustrated in the figure will be apparent to those skilled in the art. For example, the oxygen analyzer 29 may be connected to a plurality of wells through a sample selector which will automatically select wells in sequence for analysis of the proportion of oxygen in the gaseous effluent from each well. Any suitable type of commercial sample selector may be employed. The sample selector will, at the same time, connect the line 35 from the recorder 34 to means for introducing cooling water to the well, as a pump such as pump 41 or a line from pump 41 to the well. The sample selector can sequentially switch the wells to the

oxygen analyzer for any predetermined period of time. This period of time should be sufficiently long to effect an accurate analysis of the proportion of oxygen in the gas. For example, this time can be about twelve minutes. On the other hand, the time should not be too long because the time before another well is connected to the analyzer might be sufficiently great for the proportion of oxygen to increase and the temperature to rise to excessive heights before it would be connected to the analyzer. If the latter danger exists, regardless of how short the time might be, each well can be connected to a separate analyzer.

As indicated previously, the invention has been described specifically in terms of monitoring the gaseous effluent from the production well for the proportion of oxygen. Monitoring for the proportion of oxygen is preferred. However, the gaseous effluent from the production well may be monitored for the proportion of any one or more other components. In the in situ combustion procedure, the oxidizing medium may be air or may be oxygen-enriched air or air to which an inert gas, such as nitrogen, carbon dioxide, or flue gas, or other, may have been added to decrease the proportion of oxygen. Oxygen per se may be used but economics as well as other considerations would preclude the use of such an oxidizing medium. Accordingly, the components in the gaseous effluent from the production well will ordinarily include oxygen, carbon dioxide, carbon monoxide, and nitrogen. A decrease in the proportion of oxygen will be represented by an increase in the proportion of the carbon dioxide or the carbon monoxide. Similarly, an increase in the proportion of oxygen will be represented by a decrease in the proportion of the carbon dioxide or the carbon monoxide. Thus, the gaseous effluent from the production well can be monitored for a change in the proportion of carbon dioxide or carbon monoxide. The gaseous effluent can also be monitored for a change in the proportion of the sum of the carbon dioxide and the carbon monoxide. This is to be preferred to monitoring the gaseous effluent for either the carbon dioxide or the carbon monoxide, since under certain conditions, a change in the proportion of oxygen may be represented only by a change in either the carbon dioxide or carbon monoxide but not by a change in both. The gaseous effluent may also be monitored for a change in the proportion of nitrogen although this is not always dependable since a change in the proportion of oxygen with a resulting change in the proportion of carbon dioxide and carbon monoxide can occur without a change in the proportion of nitrogen. For analyzing the gaseous effluent for carbon dioxide, carbon monoxide, or nitrogen, a mass spectrograph may be employed.

Temperature reduction control may be effected, as has been described hereinabove, by employing a coolant, or reducing the flux rate of the gaseous effluent into the well, or both. The particular coolant described was water. Ordinarily, water is the most effective, available, and economical coolant. Other coolants, however, may be employed. Diethylene glycol and similar polyhydric alcohols are costly but may be recirculated virtually without loss because of their low volatility and their insolubility in hydrocarbons. They have the advantage of permitting control through a wider range of pressure-temperature conditions than is possible when water is the coolant. In a high pressure well wherein the boiling point of water is greater than the ignition point of the liquid hydrocarbons, it may be desirable to replace a portion of the water with another fluid having the ability to reduce the average boiling point of the coolant, to increase the ignition point of the liquid hydrocarbons, or both. For example, a pressure condensate prepared from the gases produced by the well, which include water, carbon dioxide, and lower hydrocarbons, may be employed. The fact that the lower hydrocarbons are combustible does not preclude them for this purpose.

The invention may be employed in connection with the

production of hydrocarbons by in situ combustion from any type of subterranean formation. Thus, the invention may be employed in connection with in situ combustion for the production of petroleum. Further, the invention may be employed in connection with the production of hydrocarbon material by combustion within a shale oil formation or within a tar sand.

I claim:

1. In a method for the recovery of hydrocarbons by in situ combustion from a subterranean formation through a production well leading from said formation, the steps comprising monitoring gaseous effluent from said well for the proportion of at least one component therein and, upon a change in the proportion of said component, effecting temperature reduction control in said well by introducing a coolant into said well.

2. The method of claim 1 wherein said coolant is water.

3. The method of claim 1 wherein said temperature reduction control is effected by introducing a coolant into said well when said change in the proportion of said component is at least 1 percent by volume.

4. The method of claim 1 wherein said component is oxygen.

5. The method of claim 4 wherein said temperature reduction control is effected by introducing a coolant into said well when said change in the proportion of said oxygen reduces the proportion of said oxygen to below about 1 percent by volume or increases the proportion of said oxygen to above about 3 percent by volume.

6. The method of claim 5 wherein said temperature reduction control is effected by introducing a coolant into said well when said change in the proportion of said oxygen is at least 1 percent by volume.

7. The method of claim 1 wherein said component is carbon dioxide.

8. The method of claim 1 wherein said component is carbon monoxide.

9. The method of claim 1 wherein said gaseous effluent is monitored for the proportion of both carbon dioxide and carbon monoxide.

10. In a method for the recovery of hydrocarbons by in situ combustion from a subterranean formation through a production well leading from said formation, the steps comprising monitoring gaseous effluent from said well for the proportion of oxygen therein and, when a change in the proportion of said oxygen reduces the proportion of said oxygen to below about 1 percent by volume or increases the proportion of said oxygen to above about 3 percent by volume, effecting temperature reduction control in said well.

11. The method of claim 10 wherein said temperature reduction control is effected when said change in the proportion of said oxygen is at least 1 percent by volume.

12. The method of claim 10 wherein said temperature reduction control is effected by introducing water into said production well.

13. The method of claim 10 wherein said temperature reduction control is effected by introducing water in said production well and reducing the flux rate from said subterranean formation to said production well.

14. A system for effecting temperature reduction control in a production well for the recovery of hydrocarbons by in situ combustion from a subterranean formation, comprising in combination:

means for removing gaseous effluent from said well, means for analyzing said gaseous effluent for the proportion therein of at least one component, means for creating a signal upon a change in the proportion of said component, and means responsive to said signal for reducing the temperature in said well including means for introducing a coolant into said well.

15. The system of claim 14 wherein said means for analyzing said gaseous effluent is an oxygen analyzer.

16. The system of claim 14 wherein said means for introducing a coolant into said well is means for introducing water into said well.

17. The system of claim 14 wherein said means responsive to said signal for reducing the temperature in said well includes additionally means for reducing the flux rate of gaseous effluent from said formation into said well.

18. The system of claim 17 wherein said means for reducing the flux rate from said formation into said well is a bean activator.

19. The system of claim 14 including additionally:
a line from the production tubing of said well leading to an oxygen analyzer,
an amplifier for amplifying electrical current produced by said analyzer responsive to the proportion of oxygen in said gaseous effluent,
a recorder for recording said electrical current,
means associated with said recorder for creating a signal upon a change in the proportion of said oxygen of at least 1 percent by volume and reduction in the proportion of oxygen to below about 1 percent by volume or increase in the proportion of said oxygen to above about 3 percent by volume,

a supply of cooling water, and
means responsive to said signal for pumping said water into said well.

20. The system of claim 19 including additionally a bean activator provided with a switch also responsive to said signal.

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I. A. CALVERT, Assistant Examiner

U.S. Cl. X.R.

166—53, 57, 302

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,470,954

Dated October 7, 1969

Inventor(s) Robert B. Hartley

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

- Column 3, line 25, "watre" should be --water--;
line 33, "predicted" should be --predicated--;
line 41, "hte" should be --the--.
Column 4, line 52, "geseous" should be --gaseous--;
line 60, before "3 percent" insert --about--.
Column 8, line 59, after "water", "in" should be --into--.

SIGNED AND
SEALED
MAY 19 1970

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents