Sept. 28, 1965 J. H. BAYLESS 3,208,527

METHOD AND APPARATUS FOR CONTROLLING FLOW OF WELL FLUIDS

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FIG. 1.

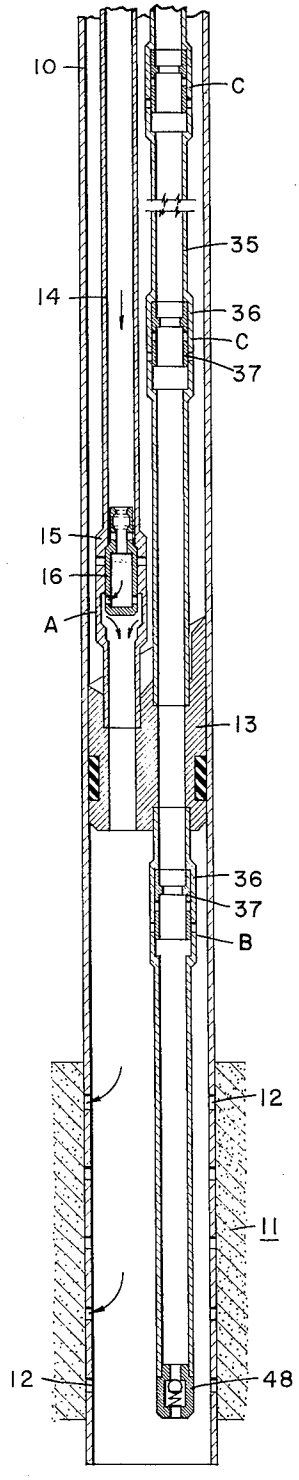


FIG. 2.

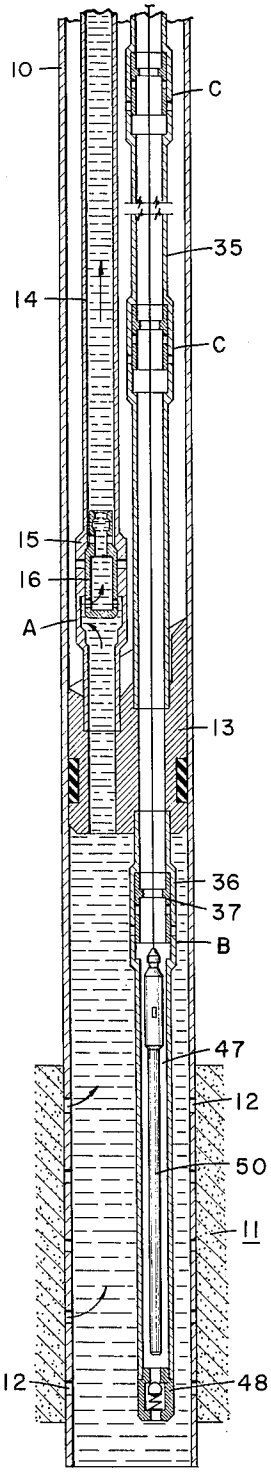
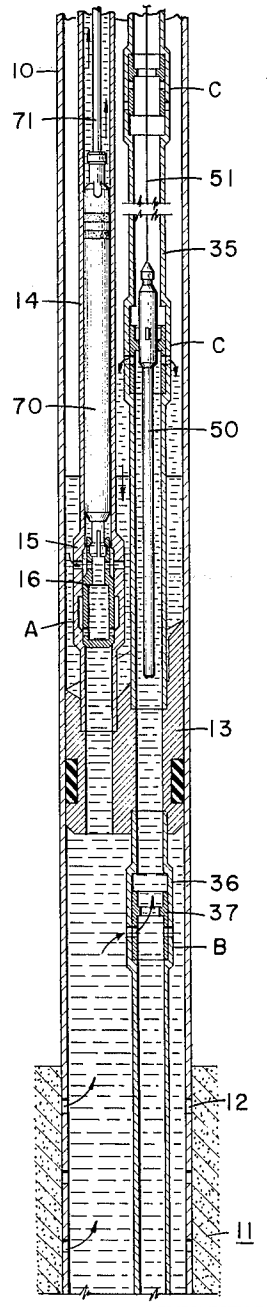


FIG. 3.



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FIG. 4.

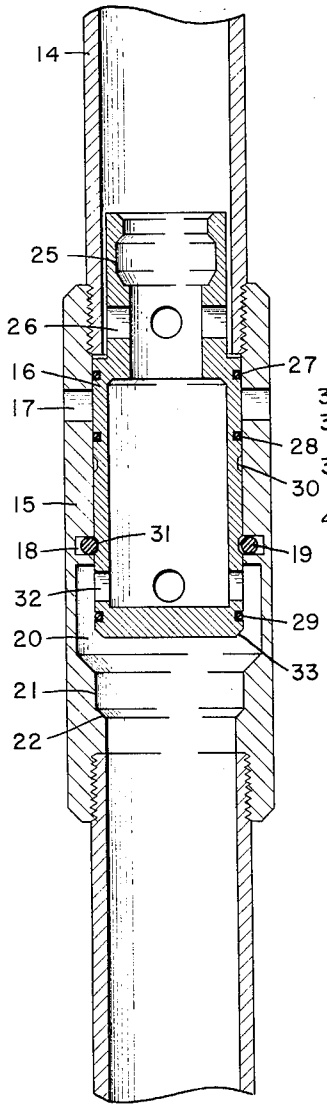


FIG. 5.

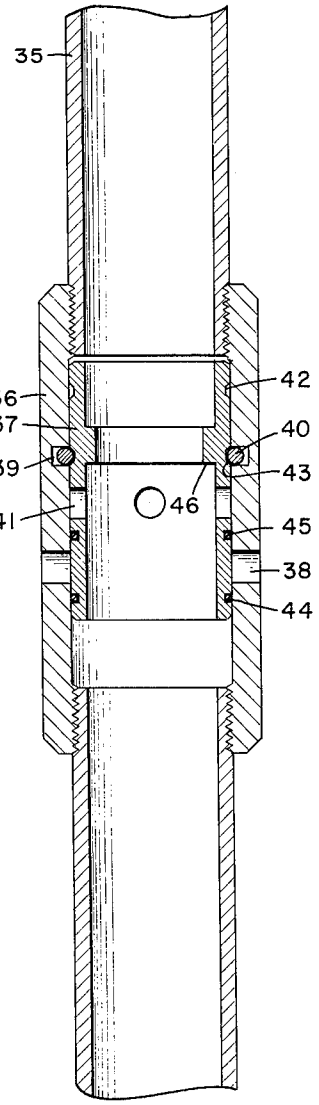
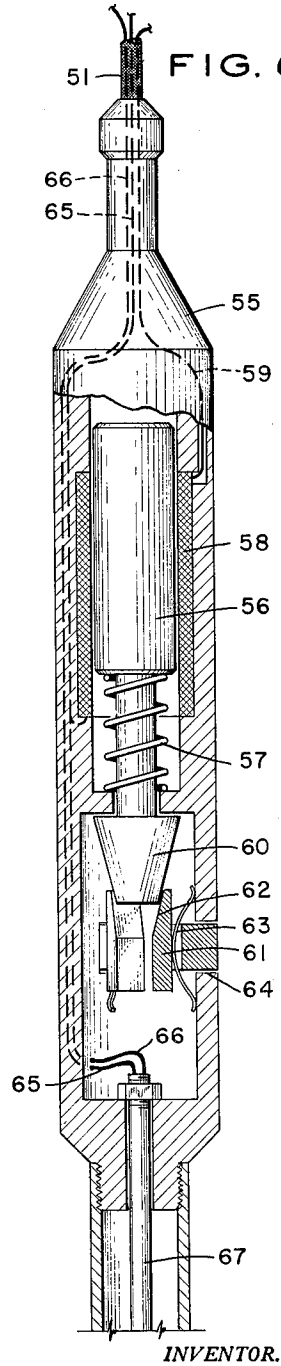


FIG. 6.



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METHOD AND APPARATUS FOR CONTROLLING FLOW OF WELL FLUIDS

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10 Claims. (Cl. 166—39)

The present invention relates to an assembly of downhole equipment designed for use with a multiple-phase cyclic in-situ well stimulation technique in which each cycle consists of injection of air into and production of oil from the same well with constant temperature monitoring.

In the stimulation of wells by in-situ combustion techniques, it is costly and time consuming and consequently quite undesirable to work over the well for each phase of the stimulation cycle. In the past, in this type of operation is has been necessary to initially work over the well in order to install a thermowell, injection and production strings, and then work over the well again when installing a pump. These procedures caused the loss of temperature measuring equipment and damage to production capacity, and further, subsequent stimulation required still another workover.

A primary object of the invention described herein is to avoid working over the well for each phase of the in-situ combustion stimulation cycle and to permit complete freedom in the many required operations. Only the intial workover is required when the arrangement of well equipment in accordance with the invention is employed.

The well assembly apparatus for use with the multiple phase cyclic in-situ combustion subsurface formation stimulation technique comprises two spaced-apart pipe strings extending from the earth's surface downwardly in a well bore; a packer arranged in the well bore closing off the space between said pipe strings and the wall of the well bore; a first valve arranged in one of said pipe strings above the packer and movable between one position which establishes a first flow path between the surface of the earth and the formation isolated from the space surrounding said pipe strings above the packer and extending through the packer, the first valve, and said one pipe string; and another position which prevents fluid communication between the formation and the earth's surface through said packer and said first valve but which also establishes a second flow path between the earth's surface and the space surrounding said pipe strings above said packer through said first valve and said one pipe string; means lowerable through said one pipe string for moving said first valve between its two positions; at least one second valve arranged in said other pipe string above said first valve and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which establishes a third flow path between said formation and the space surrounding said pipe strings above said packer through said other pipe string and said second valve; and means lowerable through the other pipe string for moving said second valve between its two positions. A pump is lowerable through said one pipe string to adjacent said first valve and the pump also may be used as the means for moving the first valve between its two positions. Also, a thermocouple is lowerable through the other string to a position adjacent the formation for supplying temperature indications to the earth's surface. The thermocouple may be provided with electromagnetic valve operating means which may be used as the means for moving the second valve between its two positions. The operation is as follows: with the first

valve in its one position, air is injected from the earth's surface into the formation along the first flow path to initiate and maintain in-situ combustion for a desired period of time. Injection of air is halted when it is desired to terminate the combustion phase, and following completion of the combustion phase, oil is produced from the formation to the earth's surface also along the first flow path until production ceases. Then the pump is lowered through the one pipe string, and the first valve is moved to its other position to establish the second flow path through the first valve and the pump and the one pipe string. The second valve at this time is in its other position, which establishes the third flow path. Hydrocarbons are produced from the formation through the other pipe string to the second valve, at which point gas separates from oil. The gas passes upwardly through the space between the pipe strings and the well bore wall to the earth's surface, and the oil passes from the third flow path into the second flow path to the earth's surface. Temperature readings may be taken by means of the thermocouple at any time during the cycle of operations. A third valve may be provided in the other pipe string below the packer. This third valve is movable in the same way the second valve is movable between one position which prevents fluid communication between the interior of the other pipe string and the space surrounding it and another position which permits such communication. This valve is used to provide access to the interior of the other pipe string for production through the third and second flow paths, as described supra. In this arrangement, a one-way check valve is positioned on the lower end of the other pipe string and functions to prevent well fluid from entering the other pipe string when injecting fluids such as corrosion inhibitors into the well bore through the other pipe string.

The above and other objects and advantages of the invention will be apparent from a more detailed description thereof taken in conjunction with the drawings in which:

FIGS. 1, 2, and 3 schematically show a cross section of the earth's surface penetrated by a well bore in which is arranged dual pipe strings, a thermowell, and other equipment for carrying out the method of operation of the invention, which is illustrated in stages in these figures;

FIG. 4 is a cross-sectional view of a portion of the injection-production tubing showing its sliding sleeve valve arranged in closed position;

FIG. 5 is a cross-sectional view of a portion of the thermowell-separator tubing showing one of its sleeve valves in closed position; and

FIG. 6 is a cross-sectional view of the thermocouple showing details of the valve locking mechanism.

Referring to the drawings in greater detail, in FIGS. 1 to 3 there is shown a casing pipe string **10** penetrating a subsurface producing formation **11**. Perforations **12** are formed in pipe string **10** adjacent formation **11**. A dual-bore packer **13** is positioned in pipe string **10** above formation **11**. An injection-production pipe string **14** terminates in one of the bores of packer **13**. A sliding sleeve valve A is connected into pipe string **14** adjacent packer **13**.

The details of valve A, which consists of a coupling **15** screw threaded to pipe string **14** and a sleeve **16** vertically slidable in it, are shown in FIG. 4; and as seen therein, coupling **15** is provided with ports **17** adjacent the upper end thereof, a recess **18** formed on the interior surface thereof, in which is arranged a snap ring **19**, an enlarged interior area portion **20**, a sealing surface **21**, and a seating surface **22** adjacent the lower end thereof. Sleeve **15** is provided at its upper end with a pump-landing recess **25** formed to engage and land the bottom

of a pump barrel and ports **26** formed below the pump-landing recess. These ports align with ports **17** in coupling **15** when sleeve **16** is in its lower position (not shown). Seals **27**, **28**, and **29** are provided on the outer surface of sleeve **16**. Also provided on the outer surface are indents **30** and **31**. Lower ports **32** are formed in sleeve **16**, and the lower end thereof is beveled to form a seat **33**.

Referring again to FIGS. 1 to 3, a thermowell separator string **35** is arranged in pipe string **10** and extends through packer **13**. The lower part of tubing string **35** below packer **13** forms a thermowell **47**. Optionally, a check valve **48** may be positioned on the lower open end of pipe string **35**. When running the equipment into pipe string **10** preferably dual bore packer **13** with the thermowell **47** portion of tubing string **35** attached to it is lowered and set such that the valve B is positioned at a desired location above formation **11**. Then the upper portion of tubing **35** and tubing **14** can be run and lodged in packer **13** with valves C and A suitably positioned; or if desired, the entire tubing **35** can be run into the well with packer **13** separate from or together with the running of tubing **14**. These techniques are conventional practice, and the equipment for accomplishing them is commercially available.

Pipe string **35** is provided with at least two sleeve valves B and C, one of which B is located below packer **13**. Each valve includes, as seen in detail in FIG. 5, a coupling or collar **36** screw threaded to pipe string **35**, within which vertically slides a sleeve **37**. Coupling **36** is provided with ports **38** and also on the interior surface thereof with an indent **39** in which is arranged a snap ring **40**. Sleeve **37** is provided with ports **41** which, when sleeve **37** is in its lower position, align with ports **38**. Also, sleeve **37** is provided with indents or grooves **42** and **43** and seals **44** and **45** on the outer surface thereof and an engaging ring **46** on the interior surface thereof.

As seen in FIGS. 2 and 3, a thermocouple **50** is suspended in tubing string **35** on an electrically conductive cable **51**. The details of the electromagnetic portion of the thermocouple head are shown in FIG. 6. The thermocouple head forms a housing **55** in which is arranged a plunger **56** biased upwardly by means of a spring **57** and surrounded by copper coils **58**, which are electrically connected to a source of energy at the surface through one of the leads or conductors **59** of cable **51**. The lower end **60** of plunger **56** is tapered, and this end contacts a plurality of latches **61** provided with tapered surfaces **62**, which engage the tapered surface of plunger **56**. Latches **61** are spring biased inwardly by bow springs **63**, and the latches when extended protrude through openings **64** in housing **55**. Leads **65** and **66**, one constantan and one copper, connect to the thermocouple element **67** through housing **55**.

To illustrate the operation and the utility of the invention, a complete stimulation cycle now will be described. In the in-situ combustion step (FIG. 1), air is injected through tubing string **14** into formation **11** through perforations **12** (the path of air flow is designated by the arrows), and during this phase of a cycle, the sliding sleeve valve A of tubing **14** and valves B and C in the separator thermocouple tubing **35** are in the positions shown in FIGS. 4 and 5, respectively. In this position of valve A, snap ring **19** fits into indent **31** and retains sliding sleeve **16** in its upper position; seals **27** and **28**, which may be suitably O-ring seals, seal off and isolate ports **17**; and in this position of valve B or C, snap ring **40** fits into indent **39** and retains sleeve **37** in the upper position and seals **44** and **45**, which may be O-ring seals, seal off openings **38** in coupling **36**.

When the air injection phase is terminated, the well is placed on production on a flowing basis, which lasts for several days to several weeks. In this phase, well fluids are produced through perforations **12** in pipe string **10** and upwardly through tubing string **14** (the path of flow of production fluid is designated by the arrows), as seen in FIG. 2. Valves A and B, C remain in the positions shown in FIGS. 4 and 5, respectively.

When the well finally stops flowing, the pump barrel **70** is lowered on the sucker rod string **71** through production tubing string **14** and, as seen in FIG. 3, is landed in the pump-landing recess **25** of sleeve **16**. Sleeve **16** is moved downwardly by the pump until surface **33** engages surface **22** (see FIG. 4). In this position, seal **29** seals off against surface **21** to thereby seal off fluid flow through ports **32**. Also, indent **30** engages snap ring **19** to latch sleeve **16** in its lowermost position, and seal **27** is positioned then below ports **17**; and ports **26** and **17** are aligned and in fluid communication. The lower end of the pump barrel is firmly latched to sleeve **16**.

Oil production in this type stimulation is very gassy, and consequently inefficient pumping results. Therefore, after the pump is set, the lowermost sliding sleeve valve B in the thermowell portion of tubing **35** is opened by the electromagnetic latch in the thermocouple head energized by current in the two copper leads **59** and **65**. Thus, by moving plunger **56** downwardly against the bias of spring **57** by energizing coil **58**, surface **60** urges latches **61** outwardly against the bias of springs **63** and engages the topside of rings **46**; the weight of the tool or downward jarring unlatches snap ring **39** and moves sleeve **37** downwardly until ports **41** and **38** are aligned. In this position, O-ring **45** is below opening **38**. An indent **42** latches sleeve **37** in its lowermost position. As seen in FIG. 3, lower sleeve valve B is open. Then, one of the upper sleeve valves C is opened in a similar manner, as illustrated, to allow production to rise through the thermowell to any of the preset heights. If desired, sleeve valves B and C may be opened by wire line equipment other than the thermocouple. The gas in the production fluids passes upwardly through the casing annulus, while the oil flows downwardly and collects above packer **13** and is picked up by pump **70**. The height of the gas-oil separator can be adjusted by opening and closing different sliding sleeve valves C.

It is seen that temperature surveys with the wire line thermocouple may be made at any time in the cycle. In another air injection cycle, all sliding sleeves in tubing **35** can be closed and pump **70** in tubing **14** unseated, raising sleeve **16** of valve A to its position in FIG. 4 to allow injection of air down tubing **14**. Although it is preferable, as described, to inject the air through tubing string **14**, if desired air may be injected through tubing string **35** instead.

The optional check valve **48** at the bottom of the thermowell may be used to permit injection of corrosion inhibitor during the initial flowback if that is desired or to permit the alternate operation of air injection through tubing **35**.

Having fully described the apparatus, objects, method of operation, and nature of my invention, I claim:

1. A well assembly for use with a multiple phase cyclic in situ combustion subsurface formation stimulation technique comprising:

two spaced-apart pipe strings extending from the earth's surface downwardly in a well bore;

a packer arranged in said well bore above said formation and closing off the space between said pipe strings and the wall of said well bore;

first valve means arranged in one of said pipe strings above said packer and movable between one position which establishes a first flow path between the surface of the earth and said formation isolated from the space surrounding said pipe strings above the packer and extending through said packer, said first valve means and said one pipe string, and another position which prevents fluid communication between said formation and the earth's surface through said packer and said first valve means, but which establishes a second flow path between the earth's surface

and the space surrounding said pipe strings above said packer through said first valve means and said one pipe string;

means lowerable through said one pipe string for moving said first valve means from its one position to its other position and vice versa;

at least one second valve means arranged in said other pipe string above said first valve means and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which establishes a third flow path between said formation and the space surrounding said pipe string above said packer through said other pipe string and said second valve means; and

means lowerable through said other pipe string to a position adjacent said formation for moving said second valve means from its one to its other position and vice versa;

whereby when said first valve means is in its one position, air may be injected from the earth's surface into said formation along said first flow path to initiate and maintain in situ combustion for a selected time, after which injection of air may be terminated to complete the combustion phase, and following completion of the combustion phase, oil may be produced from said formation to the earth's surface also along said first flow path until production thereof ceases; then said first valve means may be moved to its other position to establish said second flow path through said first valve means and said one pipe string, said second valve means being in its other position to establish said third flow path and oil may then be pumped to the earth's surface from adjacent said first valve means, said hydrocarbons produced from said formation flowing upwardly therefrom through said third flow path into the space surrounding said pipe strings above said packer where gas separates from oil, the gas flowing upwardly through the annulus between said other pipe string and the well bore wall to the earth's surface and oil flowing from said third flow path into said second flow path and, thence, upwardly to the earth's surface.

2. A well assembly as recited in claim 1 wherein said means lowerable through said one pipe string for moving said first valve means to its different positions includes a pump used to pump oil to the earth's surface during the pumping phase of the cycle and said means for moving said second valve means to its different positions includes a thermocouple having an electromagnetic valve operating means arranged therein, said thermocouple providing temperature readings at any desired time.

3. A well assembly as recited in claim 1 wherein said means for moving said second valve means to its different positions comprises a combination thermocouple and valve operating means for measuring temperatures in the well and for use in manipulating movable well pipe valve elements which comprises:

a thermocouple element;

valve operating means attached to said thermocouple element and including a spring-biased plunger;

electrical means for moving said plunger against the bias of said spring;

latch means engaging said plunger and adapted to move outwardly on movement of said plunger against the bias of said spring to engage said second valve means for operation thereof;

biasing means adapted to urge said latch means inwardly out of engagement with said second valve means; and

an electrical conductor cable connected to said thermocouple element and to said electrical means for suspending said thermocouple element and valve operating means in a well and for transmitting temperature indications and for supplying electrical energy to said electrical means for actuating it to move said plunger.

4. A well assembly for use with a multiple phase cyclic in situ combustion subsurface formation stimulation technique comprising:

two spaced-apart pipe strings extending from the earth's surface downwardly in a well bore;

a packer arranged in said well bore above said formation and closing off the space between said pipe strings and the wall of said well bore;

first valve means arranged in one of said pipe strings above said packer and movable between one position which establishes a first flow path between the surface of the earth and said formation isolated from the space surrounding said pipe strings above said packer and extending through said packer, said first valve means and said one pipe string, and another position which prevents fluid communication between said formation and the earth's surface through said packer and said first valve means, but which establishes a second flow path between the earth's surface and the space surrounding said pipe strings above said packer through said first valve means and said one pipe string;

means lowerable through said one pipe string for moving said first valve means from its one position to its other position and vice versa;

at least one second valve means arranged in said other pipe string above said first valve means and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which permits fluid communication between the interior of said other pipe string and the space surrounding it;

third valve means arranged in said other pipe string below said packer and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which in cooperation with said second valve means and said other pipe string between said second and third valve means establishes a third flow path between said formation and the space surrounding said pipe strings above said packer; and

means lowerable through said other pipe string for moving said second and third valve means between the two positions of each;

whereby when said first valve means is in its one position air may be injected from the earth's surface into said formation along said first flow path to initiate and maintain in situ combustion for a selected time, after which injection of air may be terminated to complete the combustion phase and following completion of the combustion phase, oil may be produced from said formation to the earth's surface also along said first flow path until production thereof ceases; then said first valve means may be moved to its other position to establish said second flow path through said first valve means and said one pipe string, said second valve means and said third valve means being in their other positions to establish said third flow path and oil may then be pumped to the earth's surface from adjacent said first valve means, said hydrocarbons produced from said formation flowing upwardly therefrom through said third flow path into the space surrounding said pipe strings above said packer where gas separates from oil, the gas flowing upwardly from the annulus between said other pipe string and the well bore wall to the earth's surface and oil flowing from said third flow path into said second flow path and, thence, upwardly to the earth's surface.

5. A well assembly as recited in claim 4 wherein said

means lowerable through said one pipe string for moving said first valve means to its different positions includes a pump for pumping oil to the earth's surface during the pumping phase of the cycle and said means for moving said second valve means and said third valve means to the different positions of each comprising a thermocouple having an electromagnetic valve operating means arranged therein, said thermocouple providing temperature readings at any desired time.

6. A well assembly as recited in claim 5 including a one-way valve arranged on the lower end of said other pipe string adapted to permit fluid to flow from the interior of said other pipe string and prevent fluid flow to the interior of said other pipe string.

7. A well assembly comprising:

two spaced-apart pipe strings extending from the earth's surface downwardly in a well bore;

a packer arranged in said well bore above a subsurface formation and closing off the space between said pipe strings and the wall of said well bore;

first valve means arranged in one of said pipe strings above said packer and movable between one position which establishes a first flow path between the surface of the earth and said formation isolated from the space surrounding said pipe strings above the packer and extending through said packer, said first valve means and said one pipe string, and another position which prevents fluid communication between said formation and the earth's surface through said packer and said first valve means but which establishes a second flow path between the earth's surface and the space surrounding said pipe strings above said packer through said first valve means and said one pipe string;

means including a pump adapted to pump oil to the earth's surface, lowerable through said one pipe string for moving said first valve means from its one position to its other position and vice versa;

at least one second valve means arranged in said other pipe string above said first valve means and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which establishes a third flow path between said formation and the space surrounding said pipe strings above said packer through said other pipe string and said second valve means; and

means including a thermocouple having an electromagnetic valve operating means arranged therein lowerable through said other pipe string to a position adjacent said formation for moving said second valve means from its one to its other position and vice versa;

whereby positioning of said first and second valve means in a selected manner controls flow of fluids between the earth's surface and said formation while said thermocouple provides temperature readings at any desired time.

8. A well assembly comprising:

two spaced-apart pipe strings extending from the earth's surface downwardly in a well bore;

a packer arranged in said well bore above a subsurface formation and closing off the space between said pipe strings and the wall of said well bore;

first valve means arranged in one of said pipe strings above said packer and movable between one position which establishes a first flow path between the surface of the earth and said formation isolated from the space surrounding said pipe strings above said packer and extending through said packer, said first valve means and said one pipe string, and another position which prevents fluid communication between said formation and the earth's surface through said packer and said first valve means but which establishes a second flow path between the earth's surface and the space surrounding said pipe strings above said packer through said first valve means and said one pipe string;

means including a pump adapted to pump oil to the earth's surface, lowerable through said one pipe string for moving said first valve means from its one position to its other position and vice versa;

at least one second valve means arranged in said other pipe string above said first valve means and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which permits fluid communication between the interior of said other pipe string and the space surrounding it;

third valve means arranged in said other pipe string below said packer and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which in cooperation with said second valve means and said other pipe string between said second and third valve means establishes a third flow path between said formation and the space surrounding said pipe strings above said packer; and

means including a thermocouple having an electromagnetic valve operating means arranged therein lowerable through said other pipe string for moving said second and third valve means to the different positions of each;

whereby positioning of said first, second, and third valve means in a selected manner controls flow of fluids between the earth's surface and said formation while said thermocouple provides temperature readings at any desired time.

9. In a multiple phase cyclic in situ combustion subsurface formation stimulation method utilizing two spaced-apart pipe strings extending from the earth's surface downwardly in a well bore; a packer arranged in said well bore above said subsurface formation and closing off the space between said pipe strings and the wall of said well bore; first valve means arranged in one of said pipe strings above said packer and movable between one position which establishes a first flow path between the surface of the earth and said formation isolated from the space surrounding said pipe strings above the packer and extending through said packer, said first valve means and said one pipe string, and another position which prevents fluid communication between said formation and the earth's surface through said packer and said first valve means but which establishes a second flow path between the earth's surface and the space surrounding said pipe strings above said packer through said first valve means and said one pipe string; means lowerable through said one pipe string for moving said first valve means from its one position to its other position and vice versa; at least one second valve means arranged in said other pipe string above said first valve means and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which establishes a third flow path between said formation and the space surrounding said pipe strings above said packer through said other pipe string and said second valve means; and means lowerable through said other pipe string to a position adjacent said formation for moving said second valve means from its one to its other position and vice versa, the steps comprising:

positioning said first valve means in its one position;

injecting air from the earth's surface into said formation along said first flow path to initiate and maintain in situ combustion for a selected time;

terminating said injection of air after said selected time to complete the combustion phase;

producing oil from said formation to the earth's sur-

face along said first flow path until production ceases;

positioning said first valve means in its other position to establish said second flow path;

positioning said second valve means in its other position to establish said third flow path; and

pumping oil to the earth's surface from adjacent said first valve means, said hydrocarbons produced from said formation flowing upwardly therefrom through said third flow path into the space surrounding said pipe strings above said packer where gas separates from oil, the gas flowing upwardly through the annulus between said other pipe string and the well bore wall to the earth's surface and the oil flowing from said third flow path into said second flow path and, thence, upwardly to the earth's surface.

10. In a multiple phase cyclic in situ combustion subsurface formation stimulation method utilizing two spaced-apart pipe strings extending from the earth's surface downwardly in a well bore; a packer arranged in said well bore above said formation and closing off the space between said pipe strings and the wall of said well bore; first valve means arranged in one of said pipe strings above said packer and movable between one position which establishes a first flow path between the surface of the earth and said formation isolated from the space surrounding said pipe strings above said packer and extending through said packer, said first valve means and said one pipe string, and another position which prevents fluid communication between said formation and the earth's surface through said packer and said first valve means, but which establishes a second flow path between the earth's surface and the space surrounding said pipe strings above said packer through said first valve means and said one pipe string; means lowerable through said one pipe string for moving said first valve means from its one position to its other position and vice versa; at least one second valve means arranged in said other pipe string above said first valve means and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which permits fluid communication between the interior of said other pipe string and the space surrounding it; third valve means arranged in said other pipe string below said packer and movable between one position which prevents fluid communication between the interior of said other pipe string and the space surrounding it and another position which in cooperation with said second valve means and said other pipe string between said second and third valve means establishes a third flow path between said formation and the space surrounding said pipe strings above said packer; and means lowerable through said other pipe string for moving said second and third valve means to the positions of each, the steps comprising:

positioning said first valve means in its one position;

injecting air from the earth's surface into said formation along said first flow path to initiate and maintain in situ combustion for a selected time;

terminating injection of air after said selected time to complete the combustion phase;

producing oil upon completion of the combustion phase from said formation to the earth's surface along said first flow path until production ceases;

positioning said first valve means in its other position to establish said second flow path;

positioning said second valve means and said third valve means in their other positions to establish said third flow path; and

pumping oil to the earth's surface from adjacent said first valve means; said hydrocarbons produced from said formation flowing upwardly therefrom through said third flow path into the space surrounding said pipe string above said packer where gas separates from oil, the gas flowing upwardly from the annulus between said other pipe string and the well bore wall to the earth's surface and the oil flowing from said third flow path into said second flow path and, thence, upwardly to the earth's surface.

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