United States Patent Office 3,394,759 Patented July 30, 1968

3,394,759

SHORT-TERM MULTICYCLE COMBUSTION STIMULATION OF OIL WELLS

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No Drawing. Filed Nov. 17, 1965, Ser. No. 508,375
6 Claims. (Cl. 166—39)

ABSTRACT OF THE DISCLOSURE

A method of stimulating an oil-containing formation surrounding a well by a multicycle in situ combustion technique in which in each cycle a short period of burn is followed by a short shut-in soak period. During the soak period the hot combustion gases and any unburned oxygen occupying the burned zone migrate upstructure and the burned zone is resaturated with formation oil. The well is returned to production. Air injection is resumed while the reservoir temperature is sufficiently high to ignite spontaneously the reservoir oil, and then the cycle is repeated.

The present invention concerns an improved method of well stimulation. More particularly, the present invention relates to improvements in oil well stimulation by underground or in situ combustion.

Well stimulation by in situ combustion refers to a well-known process in which a portion of the underground hydrocarbons in the reservoir or formation, particularly heavy viscous oils, are burned in place to provide high temperatures and heat and thereby cause a reduction in viscosity of the formation hydrocarbon oil which is adjacent the burned-out interval or which enters the burned-out interval. In such a process an oxidizing gas, such as air or a mixture of air and oxygen or other gases capable of sustaining combustion of the formation hydrocarbons, is introduced into the subsurface formation through the production wellbore. The combustible mixture in the formation is ignited in any desired manner, as by electric borehole heaters or chemical catalysts, such as phosphorous, triethylborane, or linseed oil. The oxidizing gas is continuously supplied to the formation to maintain combustion of the subsurface hydrocarbons. The amount of oxidizing gas injected may range from 60 to 180 million cubic feet over a period of one to three months. When the desired quantity of heat has been generated by such combustion, injection of the oxidizing gas is discontinued and burning ceases.

Prior to returning the well to production, a bottom hole choke is installed because of the hazardous combustible gas mixture (20 percent oxygen) initially produced from the formation. Thereafter, the well is immediately returned to production of hydrocarbons through the bottom hole choke. After producing for several weeks or months until the reservoir pressure is no longer capable of sustaining production, a pump and rods are run into the well to initiate artificial lift of the oil production. Then, when production diminishes or ceases and it is desired to again stimulate the well, the aforementioned steps are repeated.

Although this conventional process successfully stimulates oil production, it has several limitations, the foremost of which is high operating costs. The principal costs of operation are (1) preparation of the well for air injection; (2) use of a catalytic or other igniter; (3) compressor operation for 30 to 90 days of air injection; (4) bottom hole choke installation prior to flowback; and (5) running pump and rods into a well several weeks after burning to initiate artificial lift of the oil production.

A primary object of the present invention is to improve in situ operating procedure of the individual well cyclic combustion stimulation process in order to attain (1) production stimulation similar in magnitude to that achieved by a conventional in situ procedure, such as described above; and (2) reduction in operating costs such that the overall operation is profitable.

The process of the invention operates as follows. A conventional 30- to 90-day first cycle burn is initially conducted. In preparing the well for a second cycle burn, the rods and pump are pulled, and air (or other oxidizing gas) injection is commenced. An ignition catalyst may be required in this cycle. After injecting about 14 million cubic feet of air into the well (e.g., seven days at 2.0M c.f./d.), the well is shut-in for another seven days. The shut-in period is known as the "soak" period. During this time, the hot combustion gases and any unburned oxygen occupying the burned zone migrate up-structure and the burned zone is resaturated with formation oil. Following the "soak" period, the well is returned to production. It is produced for several weeks or months until reservoir energy no longer sustains flowing production and while the reservoir temperature is sufficiently high to spontaneously ignite upon resumption of air injection. Then, air injection is resumed and the entire cycle is repeated. Preferably, about eight wells are operated in series, thereby making each complete individual well cycle of two-month duration.

Numerous advantages which result from the improved process include:

(1) Little well preparation is needed for the first short cycle burn and none is required for subsequent cycle burns.

(2) Following the first short cycle burn, ambient reservoir temperature is sufficient to initiate combustion simply upon resumption of air injection, thereby eliminating the need for a supplemental igniting catalyst.

(3) Significantly less air injection is required per cycle to achieve stimulation similar to that which results from the longer cycle conventional operation. The heat and pressure previously dissipated when hot combustion gases and unburned oxygen were produced immediately following termination of air injection are conserved in the reservoir when these gases migrate up-structure during the short (seven-day) "soak" period which follows air injection. This feature of the process tends to provide greater and more lasting production stimulation of the well.

(4) The producing hazard created by initial production of a combustible gas mixture containing hot hydrocarbons and about 20 percent oxygen, previously counteracted by running and producing through a bottom hole choke, is eliminated. Since in the improved process initial production consists of mostly liquid and since the small amount of gas produced contains less than one percent oxygen, there is no need for the installation of a bottom hole choke during the early phases of flowback.

(5) Since all production under the improved process is flowing production, the work and expense of running pumps and rods to place a well on artificial lift have been eliminated.

Additional benefits realized from the improved process are easier surface handling and treating of the produced oil and an increased gravity of the produced oil which makes it more valuable. These two benefits result from thermal cracking of the crude hydrocarbons during flow-back through the burned zone, which remains considerably hotter for the short, more frequent burns than for longer, less frequent ones.

Thus, the process of the invention improves over previous in situ combustion techniques in including shorter

and more frequent burn cycles to sustain flowing production from the wells. Preferably, the burn period may be between four and ten days at an air injection rate of two million cubic feet per day. A short shut-in "soak" period follows the burn period. The length of the soak period is chosen sufficiently long to allow the burned zone to become resaturated by capillarity and down-structure gravity drainage and to allow the combustion gases to migrate up-structure out of the burned zone. Electrical or chemical ignition elements are eliminated (after the second cycle) because of the high reactivity of the native formation crude oil at the elevated temperatures. Ingition is attained spontaneously upon resumption of air injection. An example of the cyclic operation in accordance with the method of the present invention follows.

Well A was flowing and production was low. No work had been done on Well A since it had been burned previously. Well A was shut-in, the production line disconnected and the injection line connected. No igniter was necessary because the producing period since the previous cycle was short enough so that the formation temperature was still sufficiently hot to ignite the formation crude oil spontaneously. Air was injected for seven days at a rate of 2 million cubic feet per day. At the end of this period, air injection was switched to Well B and a soda ash solution was pumped into Well A for corrosion control. Well A was then shut-in for seven days to soak, allowing the combustion gases to migrate up-structure and the burned zone to resaturate with hydrocarbons. Then Well B was shut-in and Well A was opened for production. No bottom hole choke was run and liquid production was obtained within two hours. Oxygen content of the produced gas was below 1 percent in eight hours. Oil gravity was around 30° API, as compared to the normal 18°.

Having fully described the method, operation, objectives and advantages of our invention, we claim:

1. A method of well stimulation comprising the steps of:
   - igniting formation hydrocarbons contained in a subsurface formation surrounding a production well;
   - injecting an oxidizing gas into said formation through said well and burning a portion of the resident reservoir hydrocarbons to raise the temperature of the reservoir rock remote from the wellbore;
   - halting injection of said oxidizing gas;
   - shutting-in said well for a period of time sufficiently long to allow the burned zone to become resaturated by capillarity and down-structure gravity drainage and to allow the combustion gases to migrate out of the burned zone;
   - producing said formation hydrocarbons through said production well so long as reservoir energy sustains flowing production essentially in the liquid phase;
   - the length of said shut-in and production periods also being selected such that upon resumption of the injection of said oxidizing gas following termination of production, said formation hydrocarbons remaining in said formation spontaneously ignite; and
   - then repeating the above steps of injecting oxidizing gas, shutting-in said well and producing formation hydrocarbons.

2. A method as recited in claim 1 in which said oxidizing gas is injected into said subsurface formation for from about four to ten days at a rate of about 2.0 million cubic feet per day in each cycle.

3. A method of well stimulation as recited in claim 1 in which prior to the first cycle recited therein, the following steps are carried out:
   - igniting said formation hydrocarbons and injecting oxidizing gas and burning a portion of said resident formation hydrocarbons to raise the temperature of the reservoir rock remote from the wellbore, thereby reducing the viscosity of the remaining reservoir hydrocarbons;
   - halting injection of said oxidizing gas;
   - installing a bottom hole choke in said well;
   - producing said formation hydrocarbons through said production well until reservoir energy no longer sustains flowing production;
   - running a pump and rods into said well and artificially lifting oil production;
   - halting artificial lifting of production; and
   - removing said pump and rods from said well.

4. A method of well stimulation comprising the steps of:
   - igniting formation hydrocarbons contained in a subsurface formation surrounding a production well and injecting oxidizing gas into said formation through said well and burning a portion of said resident formation hydrocarbons to raise the temperature of the reservoir rock remote from the wellbore, thereby reducing the viscosity of the remaining hydrocarbons;
   - halting injection of said oxidizing gas;
   - installing a bottom hole choke in said well;
   - producing said formation hydrocarbons through said production well until reservoir energy no longer sustains flowing production;
   - running a pump and rods into said well and artificially lifting oil production;
   - halting artificial lifting of production;
   - removing said pump and rods from said well;
   - igniting said formation hydrocarbons;
   - injecting an oxidizing gas into said formation through said well and burning a portion of the resident hydrocarbons to raise the temperature of the reservoir rock remote from the wellbore;
   - halting injection of said oxidizing gas;
   - shutting-in said well for a period of time sufficiently long to allow the burned zone to become resaturated by capillarity and down-structure gravity drainage and to allow the combustion gases to migrate out of the burned zone;
   - producing said formation hydrocarbons through said production well so long as reservoir energy sustains flowing production;
   - the length of said shut-in and production periods also being selected such that upon resumption of the injection of said oxidizing gas following termination of production, said formation hydrocarbons remaining in said formation spontaneously ignite; and
   - then repeating the above steps of injecting oxidizing gas, shutting-in said well and producing formation hydrocarbons.

5. A method as recited in claim 4 in which said injection of said oxidizing gas prior to the shutting-in of said well is continued for about seven days at an injection rate of about 2.0 million cubic feet per day.

6. A method as recited in claim 5 in which said formation hydrocarbons produced following said shut-in period are produced essentially in the liquid state.

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