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CROSS REFERENCE SEARCH ROOM

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HIGH-TEMPERATURE WATER INJECTION

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ABSTRACT OF THE DISCLOSURE

A method of heating an oil-bearing subsurface formation to increase the rate of flow of oil therefrom in which water at a temperature of 500° to 700° F. is displaced down a well and into the formation at a rate causing fracturing of the formation. The pressure on the hot water is maintained at a level which will maintain the water in the liquid phase while it is in the well. Larger quantities of heat can be delivered to the formation by the hot water at the conditions specified than by steam.

This invention relates to a method for increasing the rate of production of oil from wells and more particularly to a method for thermal stimulation of wells penetrating underground reservoirs containing viscous oils.

A method that has been used for increasing the rate of production of oil wells is to displace steam down the well and outwardly into the oil-bearing formation. After the steam injection has continued for a period long enough to increase the temperature of the well and at least a portion of the underground reservoir, the pressure within the well is decreased to allow fluids to flow from the formation into the well.

The thermal stimulation by steam injection increases the productivity of wells in several ways. The high temperature of the steam melts paraffin, and the steam and condensed water remove the paraffin and other deposited solids from the well. The steam heats the oil in the formation and thereby reduces its viscosity. The oil then flows more readily through the formation when the direction of pressure differential is reversed. Large decreases in viscosity are possible when the oil in the reservoir has a high viscosity; hence, the method is particularly effective in stimulating wells penetrating reservoirs containing viscous oils. Additionally, the water resulting from condensation of the steam in the formation occupies a portion of the space in the formation and thereby increases the pressure in the formation.

It is usually recommended that the steam displaced down a well and into a formation be superheated to increase the amount of heat in each pound of the steam. In U.S. Patent No. 3,193,009, however, a process is described in which a mixture of steam and hot water containing relatively minor amounts of water is displaced down a well and into the underground formation. The water is mixed with the steam only to provide a means of disposing of the solids or soluble salts in the boiler feed water.

The thermal stimulation of wells by steam injection is limited to use in relatively shallow formations because the high pressure existing in deeper formations cannot be produced in boilers suitable for use in oil fields. Because of the high compressibility of steam, increasing the pressure on the steam by compressing superheated steam is too expensive to be feasible.

This invention resides in a method for the thermal stimulation of wells in which water is heated to a temperature of at least 500° F. and preferably in the range of 550° to 700° F. at a pressure exceeding the saturation pressure of water at the highest temperature attained by the water. The hot water is then displaced down a well and into an oil-bearing formation at a pressure high enough to fracture the formation. After continuing to inject the hot water into the formation for a period adequate to introduce the desired amount of heat into the formation, the direction of pressure differential between the well and the formation is reversed and the formation fluids produced through the well. In one embodiment of this invention, the water discharged from the heater is substantially saturated and the pressure on the water is thereafter increased by means of a pump to provide a pressure high enough to fracture the formation.

The water to be injected is heated to a temperature above 500° F. in a heater capable of withstanding a pressure in excess of the saturation pressure of water at the temperature to which the water is heated. A fired heater in which the water is circulated through tubes is preferred. When the productive formation penetrated by the well to be stimulated is rather shallow, for example, at a depth of 2,000 feet or less, the water may be pumped to the desired pressure for fracturing the formation before being heated to a temperature of 500° F. or higher. Ordinarily a pressure in the range of about 0.6 to 0.85 p.s.i. per foot of depth is required to fracture formations. Water heaters suitable for operation in an oil field and capable of heating water to the desired temperature and of withstanding any desirable pressure can be obtained without difficulty. Pressures of 5000 p.s.i. cause no difficulty and even higher pressures can be obtained. In contrast, steam generators suitable for oil field operation are limited to a maximum pressure of approximately 2500 p.s.i. Because of the low density of steam the pressure supplied by the static head of steam above the formation is relatively small.

The hot water is displaced down the well and into the oil-bearing formation at a rate higher than the oil in the formation can flow outwardly through the naturally occurring passages in the formation. In this manner, the formation is fractured to provide channels capable of delivering the hot water outwardly into the formation for substantial distances from the well. The rate of injection required for fracturing can be readily determined. Before a fracture has been created, the rate of displacement of liquid into the fracture is substantially proportional to the pressure applied to the liquid. After a fracture is created, increases in the rate of injection do not result in any substantial increase in the pressure. It is desirable to displace the hot water downwardly through tubing in the well rather than through casing, to decrease loss of heat to formations between the productive formation and the ground surface. The actual rate of displacement of hot water to fracture the formation will depend on the permeability and strength of the formation. A rate in the range of 1 to 20 barrels per minute may be required. The fracture can be initiated with cold water which is followed by the hot water. If high flow rates are required to initiate fracturing, it may be desirable to bypass the water heater initially.

Displacement of heat into formation is continued for a period adequate to cause a temperature rise in the formation that will increase the fluidity of the formation fluids sufficiently that the fluids will flow readily to the well on reduction in pressure in the well. The length of time that injection is continued will depend upon the characteristics of the oil reservoir such as the thickness of the oil sands, the viscosity reduction required for acceptable production rates, the well spacing, etc. and the amount of stimulation desired. It is usually desirable to continue the injection of hot water for at least two weeks before turning the well around and producing formation fluids. Continued injection of hot water for periods as

long as two months before reversing the direction of flow can be used. After injection of the hot water has been completed, the pressure within the well is reversed to cause flow from the formation into the well. The reversal of flow can follow immediately the injection of hot water, or the well may be shut in for a period to allow dissemination of heat more widely through the formation before flow from the formation to the well is begun.

The method of this invention permits the delivery of heat into subsurface formations at higher rates than are possible by the injection of steam. At temperatures above 500° F., the difference between the enthalpy of saturated steam and saturated water decreases rapidly. The high density of water produces a high static head in the well at the level of injection into the formation that is available to increase the rate of flow of water from the wellhead to the productive formation. The higher density of water also reduces the velocity through the well tubing required for delivery of a given number of pounds of hot fluid into the formation. Although the amount of heat that can be released from a pound of steam is substantially higher than the amount of heat that can be released by a pound of water, the number of pounds of water that can be delivered into the formation with a given wellhead pressure is enough greater than the number of pounds of steam to allow an increased delivery of heat to the formation by means of the hot water. Because of the higher pressure at which water heaters can operate as compared to steam generators, a further increase in rate of heat delivery is possible by using higher wellhead pressures for hot water injection. Moreover, because steam delivered into the formation condenses, the volume of injected fluids in the formation at completion of the heating step is higher when water is used as a heating medium.

The increased rate of delivery of heat possible by hot water as compared with steam is illustrated by the following example.

In a well penetrating a formation at a depth of 2000 feet, a bottom hole pressure of 2000 p.s.i. is required to fracture the formation. The maximum operating pressure for the steam generator is 2500 p.s.i. The density of steam at 2250 p.s.i. and 652° F. is 6.5 lbs./cu. ft. A column of that steam 2000 feet high has a static head of $6.5/144\times2000=90$ p.s.i. At a bottom hole pressure of 2000 p.s.i. for the fracturing operation, the pressure drop in the tubing from the wellhead is

$$\Delta P=2500+90-2000=590 \text{ p.s.i.}$$

ΔP per 100 feet of length$=30=C_1C_2C_3\times V$. From the Crane Company Piping Book for 2-inch schedule 40 tubing

$$c_1=\frac{30}{213\times1.05}=0.133$$

From the chart on page 534 of the above reference the rate of flow=13,000 lbs. of steam/hr.

$$\text{B.t.u./day}=13{,}000\times24\ (Hg-Hr)$$

Hg=enthalpy of saturated steam at 2500 p.s.i.=1091
Hr=enthalpy of saturated water at reservoir temperature=70

$$13{,}000\times24\ (1091-70)=322\times10^6 \text{ B.t.u./day}$$

If hot water (liquid) is displaced down the well into the formation:

The density of water at 2500 p.s.i. and 668° F.=35 lbs./cu. ft.

Static head of the water$=35/144\times2000=486$ p.s.i.

$$\Delta P \text{ in tubing}=2500+486-2000=986 \text{ p.s.i.}$$

For an estimated flow rate of 10,000 b./d.:

$$U=\frac{10{,}000\times5.61\times144}{24\times3600\times0.785\times4}=30 \text{ ft./sec.}$$

$$N_R{}^*=928\frac{dU\rho}{\mu}=\frac{928\times2\times30\times4.65}{0.5}=258{,}000$$

$$f=0.0045$$

$$\Delta P=\frac{fL\rho v^2}{25.8d}=\frac{0.0045\times2000\times4.66\times900}{25.8\times2}=723 \text{ p.s.i.}$$

$$\text{at } \Delta P=986 \text{ p.s.i., } v^2=900\times\frac{986}{723}=1230$$

$$v=34.6$$

$$\text{Rate}=10{,}000\times\frac{34.6}{30}=11{,}500 \text{ b./d.}$$

*Craft, Holden & Graves; Well Design; Drilling and Production, 1962.

Hw=enthalpy of water at 2500 p.s.i. and 688=730; Hr=70

11,500 b./d.$\times$350 #/b. (730—70)$=2660\times10^6$ B.t.u./day

N_R is Reynolds number
d is pipe diameter, inches
U is velocity, ft./sec.
ρ is density, #/gal.
μ is viscosity, cps.
f is friction factor
L is length, ft.

As shown by the above calculations, the displacement of hot water allows injection of 2660×10^6 B.t.u./day into the formation whereas with steam generating equipment capable of operating at the same pressure only 322×10^6 B.t.u. can be supplied to the formation by the injection of steam. The injection of hot water makes possible further increases in heat injection by pumping the hot water to higher pressures either before delivery to, or after leaving, the heater. Increasing pressure on steam after it is generated is not feasible because of its high compressibility. Injection of the hot water at a rate high enough to fracture the formation minimizes displacement of oil away from the well and causes delivery of heat to portions of the formation remote from the well.

The requirement that the hot water be injected at a rate high enough to cause fracturing will usually insure a pressure in the well high enough to prevent vaporization of the water in the well. If the temperature of the water at the level at which it enters the formation is 500° F., a pressure of 700 p.s.i. is adequate to prevent vaporization of the water.

I claim.

1. A method of increasing production of oil from an oil-bearing subsurface formation comprising pumping water down a well and into the oil-bearing formation at a rate causing creation of a fracture in the formation, heating the water to a temperature of 500° to 700° F. before delivery of the water into the well, the pressure on the water being high enough to maintain the water in the liquid phase until it is discharged from the well into the oil-bearing formation, continuing the injection of water into the formation for a period adapted to transfer a desired quantity of heat to the oil-bearing formation, lowering the pressure in the well to a pressure lower than the pressure in the oil-bearing formation, and producing liquids flowing from the formation into the well.

2. A method as set forth in claim 1 in which the well is shut in after completion of the injection of hot water and before commencing production of formation fluids through the well for a period to increase dissemination of heat through the formation.

3. A method of heating an oil-bearing formation penetrated by a well to stimulate flow of oil therefrom comprising displacing water down the well and into the formation at a rate causing initiation of a fracture in the formation, displacing down the well water at a tempera-

ture in the range of 500° to 700° F. and at a pressure adapted to maintain the water in the liquid phase while in the well at a rate adapted to hold the fracture open, continuing the injection of the hot water at a rate adapted to hold the fracture open for a period adapted to deliver the desired quantity of heat to the formation, reducing the pressure in the well to a pressure lower than the pressure in the formation, and producing fluids flowing from the formation into the well.

4. A method of heating an oil-bearning formation penetrated by a well to stimulate flow of oil therefrom comprising displacing unheated water down the well and into the formation causing initiation of a fracture in the formation, displacing down the well and into the fracture water at a temperature in the range of 500° to700° F. and at a pressure of at least 700 p.s.i. adapted to maintain the water in the liquid phase while in the well, the rate of displacement of the water at a temperature in the range of 500° to 700° F. being high enough to hold the fracture open, continuing the injection of hot water at a rate adapted to hold the fracture open for a period

to deliver the desired quantity of heat into the formation, shutting in the well for a period to disseminate heat through the formation, reducing the pressure in the well to a pressure lower than the pressure in the formation, and producing fluids flowing from the formation into the well.

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