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2,796,935

INCREASING PRODUCTION RATES OF GAS AND OIL WELLS

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1 Claim. (Cl. 166—39)

The invention relates to a method of increasing the production rates of oil and gas wells by propagating a zone of combustion through the producing formation in the vicinity of the well bore and, more particularly, relates to a method of increasing the permeability of bentonitic earth formations or any sand containing clay which swells upon hydration by irreversible dehydration of the formations through controlled combustion of the interstitial oil therein.

It becomes then a principal object of this invention to provide a process for increasing the permeability of clay formations which swell upon hydration or bentonitic type earth formations.

The problem of recovering petroleum or hydrocarbon gases from subterranean formations after substantial depletion of gas pressure, rock pressure, or failure of natural water drive or secondary recovery operations is one of long standing. After pumping fails to recover the oil at an economical rate and secondary recovery operations such as gas drive or water drive no longer are feasible, there still remains a considerable portion of oil or gas in the formations.

It has long been known that, by heating underground earth formations, such materials as wax, sulfur, and other deposits can be removed. By using high temperatures the exposed surfaces of the formations can be spalled off or melted to renew the surfaces of the interior walls of the well bore. Such processes entail merely injecting gaseous or liquid fuel into the well bore, igniting it, forcing air down to support combustion and causing upward circulation of the air therethrough to maintain combustion.

It has been proposed to increase the recovery of the oil by combustion or burning of a part of the oil in place in the reservoir. Such combustion is supported by the continuous injection of air or other oxidizing gas mixtures through an input well or wells. By these methods, the heat of combustion causes decrease in viscosity of the oil, initiates distillation and viscosity breaking to release products which are forced to and recovered from one or more output wells. To initiate such combustion it has been suggested to place charcoal in the input well adjacent the formation to be treated and igniting the charcoal. This method is not always reliable since combustion is not always uniform and the temperatures attained may be so high in certain areas, that is, up to 109° C., as to cause fusion of the formation with resulting impedance of the flow of air to the combustion zone. In certain cases, this type of combustion causes caving or disintegration of parts of the walls of the well bore cavity so that it is necessary to clean or rebore the well before completing the combustion process. In some instances, the burning of the well has been found to result in plugging of the well bore with loose sand where temperatures of 538° C. or more were attained. Investigators of this problem have suggested the use of a combustible material comprising a mixture of solid combustible coke, coal, or charcoal with a granular refractory material such as sand, stone, pebbles, etc. Mixtures of air, natural gas, and production gas have been used as the injection medium. Dependence is had on the distillation and/or cracking of the

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petroleum to allow the products to be forced to an output well for recovery in this method.

These prior art methods of initiating combustion in a well bore are generally conducted without regard to the temperatures attained, irrespective of the type of formation being treated and have as their primary purpose the propagation of the combustion entirely through the formation, using the combustion to force the oil from the formation to an output well in one form or another.

It has been found that indiscriminate burning of combustibles in a well bore to the point where spalling off or melting of the exposed surfaces occurs does not obtain the desired increase in production. Further, many earth formations are not pervious enough to allow the propagation of a flame therethrough from one input well to an output well. In studying the combustion of oil in various types of formations, it was found that certain bentonitic formations and associated clay formations may be heated to temperatures as high as 100–200° C. without effecting appreciable increases in permeability. Heating to these temperatures apparently causes the loss of "lamellar" water of hydration and the process is reversible so that subsequent contact with water causes hydration with return of impermeability.

However, the discovery was made that if the bentonitic formations are heated to temperatures above 200° C., more water is lost and the structure is changed irreversibly so that on subsequent contact with water the clays do not hydrate and swell. Thus, the presence of hydrated clay in the reservoir formation greatly reduces the permeability and by irreversible dehydration in accordance with this invention the permeability is greatly increased even though the rock later comes in contact with connate water from an untreated section thereof. On the other hand, it has been found that if the temperature of the earth formation is raised to about 500° to 600° C. there is a tendency for the oil therein to crack and form coke, which plugs the formation to some extent. Accordingly, the amount of air introduced into the well is regulated so that the temperature of the rock is high enough to dehydrate the clays irreversibly but low enough to prevent coking entirely or keep it at a minimum. The temperature required to accomplish this purpose will depend somewhat on the nature of the oil and combustibles in the formation treated. In some instances a small amount of coke may form at temperatures as low as 300° C. to 400° C. In general, however, temperatures from about 200° C. to 500° C. can be used to accomplish the results of this invention.

To illustrate the effectiveness of the method, experiments were made on five 1" diameter x 1" long cores from the Lewisville section of the Woodbine sand, Van Field. This formation is bentonitic in nature. The cores were extracted with toluene, dried at 110° C., subjected to permeability determination, then heated to 538° C. in a muffle furnace for 48 hours, and again subjected to permeability determination, followed by passage of 100 cc. of distilled water through the core, then dried at 110° C. and subjected to permeability determination, with the following results:

Core #	Permeability to Nitrogen, millidarcies		
	After Toluene Extraction and Drying	After Heating to 538° C.	After Contact with Water and Drying at 110° C.
1	0.86	4.2	1.8
2	5.7	9.0	4.2
3	2.4	7.1	3.8
4	4.7	11.7	(¹)
5	0.34	1.8	1.1

¹ Core fractured by heat.

It is seen that heating to 538° C. caused permeability increases of 100% to 400% or more. Even after the core was subsequently contacted with water, a large permeability increase was retained in most cases; if brine had been used instead of distilled water, this latter contact with water would have had even less effect on the permeability. In some cases heating the rock to 538° C. or so will cause the rock to fracture, especially if the clay content of the rock is high. This will cause much larger increases in the overall permeability of the rock, with corresponding increases in production rate of the well.

The effect of heat on clays is also shown by the following: 3 cc. of "Aquagel" (bentonite) was placed in a 50 cc. graduated cylinder and the cylinder was filled with distilled water. After 72 hours the bentonite had swollen to 12 cc. Some of the original bentonite was heated to 538° C. for 24 hours. 3 cc. of the heated bentonite was placed in a cylinder and covered with water; after 72 hours this had swollen to 4 cc. This shows that heating greatly reduces swelling of bentonite, which is the clay generally found in oil-bearing sands. Furthermore, the bentonite, after heating, was very porous and permeable, whereas the original bentonite was practically impermeable when wet with water.

In carrying out the invention, the well to be treated is fitted with a bridge at the top of the oil sand in which combustion is to be initiated. A casing may be lowered to the bridge by underreaming, and the well bore is cemented and cleaned. The injection capacity of the well may then be tested. A burner of the type described in United States Patent 2,668,592 is installed. The type of burner used should be designed to operate with gaseous fuels under injection pressures up to 500 p. s. i. and be able to withstand heat release rates of up to 500,000 B. t. u. per hour. Provision is made for control of burner ignition at the well head and also control of the final combustion temperatures. The burner is placed in the well bore at a point about 8 to 10 feet below the bridge and cement area so as to not expose the casing and cement to direct contact with the combustion area. The well bore is next pressured with air to drive out water and moisture. The combustion material, preferably a mixture of hydrocarbon gases and air, used to initiate the burning may be separately introduced inside the well casing or supplied by a separate conduit. In some instances, a mixture of gaseous combustible material or materials thereof and air may be injected into the well bore by means of a single conduit and ignited to initiate combustion. A thermocouple is provided, located below the top of the burner so that observations of the temperature may be made.

Combustion gases with admixed air are then injected and the mixture is ignited by a high tension spark. Observations of the temperature are made and, as soon as the thermocouple below the top of the burner indicates a rise in temperature, the gas and air injection rates are adjusted to give a controlled hourly heat release rate so that the flue gas temperatures are maintained at between about 200° C. to 500° C. under an operating pressure of from 100 to 800 p. s. i. After combustion has been initiated, the injection of the mixture of gas and air is continued at a rate of about 1000 to 2000 cubic feet per day per foot of oil-producing formation being treated. The gas-air mixture is adjusted so that it contains from about 2-6 percent by volume of oxygen.

After about 40 to 50 million B. t. u. of heat has been transferred to the formation, the combustion can be transferred to the formation itself by the injection of a non-combustible gas. This creates a heat wave within the formation. This is accomplished by shutting off the fuel gas supply and continuing the injection with air alone. At this point it will be found that the temperature in the combustion chamber will fall but the burning will continue in the earth formation as evidenced by the consumption of oxygen and the appearance of carbon dioxide

in the exhaust gases. It will be found expedient to hollow the course of the combustion by analysis of the gases taken from an observation well located a short distance from the combustion well. A mixture of air and hydrocarbon gas having a hydrocarbon content equivalent to about 80 B. t. u./cubic foot and containing about 6 percent of oxygen is best for causing the combustion to proceed in the formation. Injection of a gas of this composition after the injection of air for a period of about 4 hours may be used to insure that the combustion penetrates the formation. Oxygen contents over about 6 percent by volume with an 80/B. t. u. gas are to be avoided since explosive mixtures may result or "flash back." The amounts of air and gas are adjusted to provide an amount of oxygen to stoichiometrically combine with the gas for complete combustion. The injection takes place at pressures from 100 p. s. i. g. to 500 p. s. i. g., depending on the well bore pressure which must be overcome. Also, the combustion may be carried out in accordance with United States Patent 2,642,943 provided the temperature limitations of the present invention are followed.

Injection of the gas is continued until the heat wave has been forced to a distance of 10 to 50 feet from the well bore. This is accomplished by continuing the injection for a period of from one day to a few weeks. The well is then produced in the usual manner. In most instances where fairly permeable bentonitic formations are concerned, irreversible dehydration can be accomplished and the heat wave transferred from the combustion zone into the formation itself, where the oil content of the formation actually supports combustion, without a separate step of stopping the injection of a fuel gas and injecting air alone. Fuel gases used may comprise produced gas from the field, mixtures including natural gas, synthetic hydrocarbon gas, and liquefied petroleum gases and including methane, ethane, propane, and butane. Air or any mixture containing up to 6 percent by volume of oxygen may be used, as the source of oxidizing material. Such factors as the volume of oil productive sand in acre feet, average porosity (percent), interstitial water content, calculated initial oil content of the formation are taken into effect when establishing the amount of heat necessary to effect sufficient dehydration of the formation. Considering a bentonitic formation of 1000 acre feet having a permeability of 100 to 300 millidarcies and an assumed interstitial water content of 20 percent of the pore space, it is sufficient to accomplish the results of this invention to introduce a combustion gas having a heat of combustion of 60 to 90 B. t. u. per cubic foot admixed with about 6 percent by volume of oxygen to attain a temperature of about 450° C. within 2 hours. Combustion temperatures between 200° to 500° C. can be maintained by varying the oxygen content between 2 to 6 volume percent. Increase in permeabilities of from 100 to 400 percent may be attained by this method.

The invention is applicable to bentonitic type formations, especially those having permeabilities in the order of 1.0 to 6.0 millidarcies. The bentonitic formations or bentonite as meant by this invention has been defined as a rock compound essentially of a crystalline, clay-like mineral formed by the devitrification and the accompanying chemical alteration of a glass igneous material, which may be tuff or volcanic ash. Bentonite often contains variable proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass. Bentonite is a characteristic clay-like mineral having a micaceous habit, facile cleavage, and high birefringence. This description of bentonite is taken from "Minerals of Bentonite and Related Clays and Their Physical Properties," by C. S. Ross, A. A. P. C., vol. 12, 1926, page 65. In general, bentonite is a mixture of aluminum silicates characterized by an alkaline oxide and alkaline earth content of 5-10 percent, fine grain size, high adsorptive powers, and usually very stringy colloidal properties. Bentonite is composed principally of montmorillonite

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clay. Montmorillonite clay is composed of units made up of two silica tetrahedron sheets with a central alumina octahedron sheet. The outstanding feature of the montmorillonite structure is that water and the other polar substances can enter between the layers causing the latter to expand in the C-direction (for further descriptions of the type of clay involved see pp. 55-64, "Clay Mineralogy," by Ralph A. Grim, published by McGraw-Hill, 1953).

What is claimed is:

The method of increasing the permeability of bentonitic type earth formations for the purpose of increasing the production of oil or gas therefrom consisting of propagating a zone of combustion in a well bore drilled through said formation by injecting a fuel mixture of a combustible gas and oxygen into the well bore adjacent said for-

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mation, said fuel mixture containing no more than about 6 vol. percent of oxygen, controlling the temperature of said combustible within the range of about 200° to 500° C. for at least about 2 hours by maintaining the amount of oxygen in the fuel mixture to between about 2 to 6 vol. percent, causing said zone of combustion to penetrate said formation to a depth of 10 to 50 feet from said well bore thereby to irreversibly dehydrate said formation so that subsequent contact of the formation with water will not rehydrate the formation.

References Cited in the file of this patent

UNITED STATES PATENTS

15	2,642,943	Smith	June 23, 1953
	2,685,930	Albaugh	Aug. 10, 1954