Patented July 4, 1944

2,352,638

UNITED STATES PATENT OFFICE

2,352,638

CONNATE WATER DETERMINATION

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No Drawing. Application October 24, 1940, Serial No. 362,609

2 Claims. (Cl. 73—51)

This invention relates to oil and gas recovery from subterranean deposits, and more particularly to a method of determining quantitatively the fluid contents of subterranean formations drilled through for production of hydrocarbons.

Such hydrocarbons are found underground in the interstices of porous formations commonly referred to as "sand formations" or "sands." These hydrocarbons may be in the form of gas under pressure, or in the form of a mixture of gas and oil in which the gas is dissolved in the oil. Water also is generally present with the gas and oil, such water being commonly called "connate" water. These sand formations are usually disposed in separated layers called "horizons" of various degrees of thickness. After a well is drilled through such a sand formation it may be first operated to produce oil and gas by maintaining the pressure at the well bottom below the natural pressure but above the saturation pressure, i. e. the pressure below which the gas would come out of solution in the oil, in which event the oil and gas solution flows into the well without the gas coming out of solution until it rises considerably within the well. Or the well may be operated in such manner that the bottom hole pressure is reduced below the saturation pressure so that the gas comes out of solution and expands into the well carrying the oil along with it. Such production operations are referred to as "primary" recovery of oil. After the gas pressure in the sand is reduced to atmospheric pressure by such production, more oil may be produced by an artificial fluid drive using either water or gas which is pumped into the sand through an intake well and which forces the oil to flow through the sand to an output well. This method of production is called "secondary" recovery.

Under natural conditions where the fluid contents of oil sands comprise water, oil, and gas dissolved in the oil, the pores of the sand are completely filled with these liquids. In order to estimate the amount of oil that can eventually be recovered by both of the above recovery methods it is necessary to know the percentage of the pore spaced occupied by hydrocarbons in addition to knowing the dimensions of the sand formation (i. e. its thickness) and its pore space. One way of determining the percentage of hydrocarbons is to determine the connate water content of the pore space because the remainder of the pore space is occupied by hydrocarbons. The present invention is directed to a method of quantitatively determining connate water content of sands containing gas or gas and oil under pressure by analysis of "core samples" cut from the sand formation during the drilling operation.

It has long been customary when wells are being drilled through sands thought to have gas and/or oil-producing possibilities to use special annular drills to cut cylindrical core samples from the sand formation. The samples are brought to the surface and tested for permeability, porosity and fluid content, which factors have in the past been used to aid the operator in making a rough approximation of certain characteristics of the sand relative to its production characteristics. But the fluid content of a core sample (cut from sand containing gas under pressure) when brought above ground is not the same as the fluid content of the sand in situ from which the sample was cut. During the cutting of the core drilling-mud is commonly circulated through the well to wash out the drill cuttings and to prevent "blow outs" and the hydrostatic pressure of this drilling mud water is usually greater than the formation pressure of the hydrocarbons at the well bottom. The drilling-mud water consequently enters the pores of the sand ahead of the cutting bit if the sand is permeable, displacing fluid originally present in the sand. Also, as the core is raised to the well surface, the hydrostatic pressure reduces, and gas under pressure and in solution in oil in the core sample escapes from the pores of the core and pushes out with it some of the liquid present in the pores of the core after the cutting operation and before the core is raised from the well bottom. For the above reasons, although core samples have furnished probably the most accurate information about some of the characteristics of the sand through which the well is drilled, they have not furnished information as to the quantitative fluid content of the sand. By practicing the method of the present invention the fluid contents of the core samples in situ before the cutting operation may be determined.

In practicing the method of the present invention, core samples cut from sands containing gas under pressure are quantitatively analyzed for the following characteristics:

(*a*) Permeability, i. e., the fluid conductivity of the sand. Thus a sand having a high permeability will pass more fluid for a given pressure drop than a sand having a low permeability.

(*b*) Porosity, i. e., the volume of space in the sand which may be occupied by fluid.

(*c*) The fluid content of this space, i. e., quantity of oil, of water and of "free" gas, i. e., undissolved gas.

But, as above indicated, the fluid content of such a core sample is not the same as that of the sand from which the core is cut because the infiltration of drilling water displaces hydrocarbons originally present and because the escaping gas (which occurs during the raising of the core to the surface) displaces water from the core sample.

I have discovered that a well defined relationship exists between the fluid contents of the sand in situ under reservoir conditions in which gas is under pressure sufficient to maintain the gas in solution in oil present in the sand, and the fluid contents of a "contaminated core" sample after it has been cored from the sand and brought to the well surface. By the term "contaminated core" sample is meant a core which has been flushed with drilling-mud water before cutting and in which the gas pressure has been reduced to atmospheric pressure during the process of raising the core to the surface of the well while submerged in drilling water. Thus, by determining quantitatively the fluid content of a contaminated core sample and its permeability and porosity, it is now possible to determine quantitatively within a reasonable degree of accuracy the connate water content of the sand in situ from which the contaminated core is cut. By subtracting the connate water saturation from the amount of pore space the amount of hydrocarbon saturation in situ may be obtained.

Thus I have discovered that in contaminated cores of the type above described a well defined relationship exists between the "free" gas content of the core sample, the free water content of the core sample (i. e., the water content exclusive of chemically combined water), the porosity of the core sample, all of which quantities are measurable, and the connate water content of the sand in situ from which the core sample is cut. This definite relationship, however, is varied unless the core sample is so flushed by the drilling-mud water prior to and during the cutting as to drive all fluids from the core sample that can be driven out by flow of the drilling-mud water through the core, as usually occurs in normal drilling operation.

The general relationship may be expressed as follows:

C=a function of V, W and P

Where

C=the cubic centimeters of connate water per hundred cubic centimeters of the sand sample;
V=the cubic centimeters of free gas per hundred cubic centimeters of core sample;
W=the cubic centimeters of "free" water per hundred cubic centimeters of the sand sample; and
P=fractional porosity, i. e. the fraction of the sand that is pore space.

V, W and P are of course determined from "contaminated cores." The nature of the equation thus expressed has been found to be such that

1. When V alone increases (W and P being constant), C decreases;
2. When W alone increases (V and P being constant), C increases; and
3. When P alone increases (W and V being constant), C decreases.

This relationship may be expressed more definitely by a preferred equation such as follows:

(1) $$C=W10^{a+bV+cP^2}$$

The constants a, b and c are numbers and have no units. This relationship or equation was derived by the method of "least squares" from a large number of instances where, in addition to the known quantities V, W and P, the connate water content C of the core was also known, having been determined by independent procedure. The values of the constants for the above equation are as follows:

$a=0.1223$
$b=-0.0118$ and
$c=-2.312$

These constants were calculated as described from the results of core analyses published by Messrs. Pyle and Jones in an article entitled "Quantitative determination of the connate water content of oil sands," and reprinted on pages 46 through 52 of the Oil Weekly under issue date of November 16, 1936.

However, should this definite relationship between C, V, W and P have been expressed in a different mathematical form or equation, the constants for that equation would have been different, but, because of the relationship that exists, the equation if its form is chosen judiciously will still give substantially the same value of C for the given values of V, W and P. Thus, for example, other forms of equation which do not fit as well as Equation (1) but which express the relationship within useful limits of accuracy are:

(2) $$C=W(1+aV)+bP^2$$

or

(3) $$C=W[1-V(a+bP)]$$

This relationship, as expressed in Equation (1), is generally applicable to the determination of connate water content indirectly from measurements of fluid contents of contaminated cores where a direct measurement of connate water content would be impossible or commercially impracticable.

I claim:

1. The method of determining quantitatively the connate water content of a sand formation containing natural gas under pressure comprising the steps of, cutting core samples from the sand formation while exposed to drilling-mud water under a hydrostatic pressure greater than the pressure of the natural gas in the sand formation, raising the core samples through the well while exposed to the drilling-mud water whereby the hydrostatic pressure upon said sample decreases as the samples rise in the well, determining for each core sample its free water content per unit of core sample, its free gas content per unit of core sample, its pore space per unit of core sample, and employing the respective determinations of each sample in a mathematical relationship which states that the connate water content increases if the free water content increases (the free gas and pore space values remaining constant), and decreases if the free gas content increases (the free water content and pore space values remaining constant) and decreases if the pore space value increases (the free water content and free gas content remaining constant), to obtain the amount of connate water per unit of sand formation of the respective levels of sand formation from which the core samples were cut.

2. The method of determining quantitatively the connate water content of a sand formation containing natural gas under pressure comprising the steps of, cutting core samples from the sand formation while exposed to drilling-mud water under a hydrostatic pressure greater than the pressure of the natural gas in the sand formation, raising the core samples through the well while exposed to the drilling-mud water whereby the hydrostatic pressure upon said samples decreases as the samples rise in the well, determining for each core sample the cubic centimeters of free water content per hundred cubic centimeters of core sample, the cubic centimeters of free gas content per hundred cubic centimeters of core sample, the fraction of core sample occupied by pore space, and determining the connate water content of each core sample in situ by employing the respective determinations of each sample according to the equation

$$C=W(10^{0.1228-0.0118V-2.812P^2})$$

where

C=cubic centimeters of connate water per hundred cubic centimeters of sand;
W=cubic centimeters of free water per hundred cubic centimeters of core sample;
V=cubic centimeters of free gas per hundred cubic centimeters of core sample; and
P=fraction of the core sample occupied by pore space.

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