

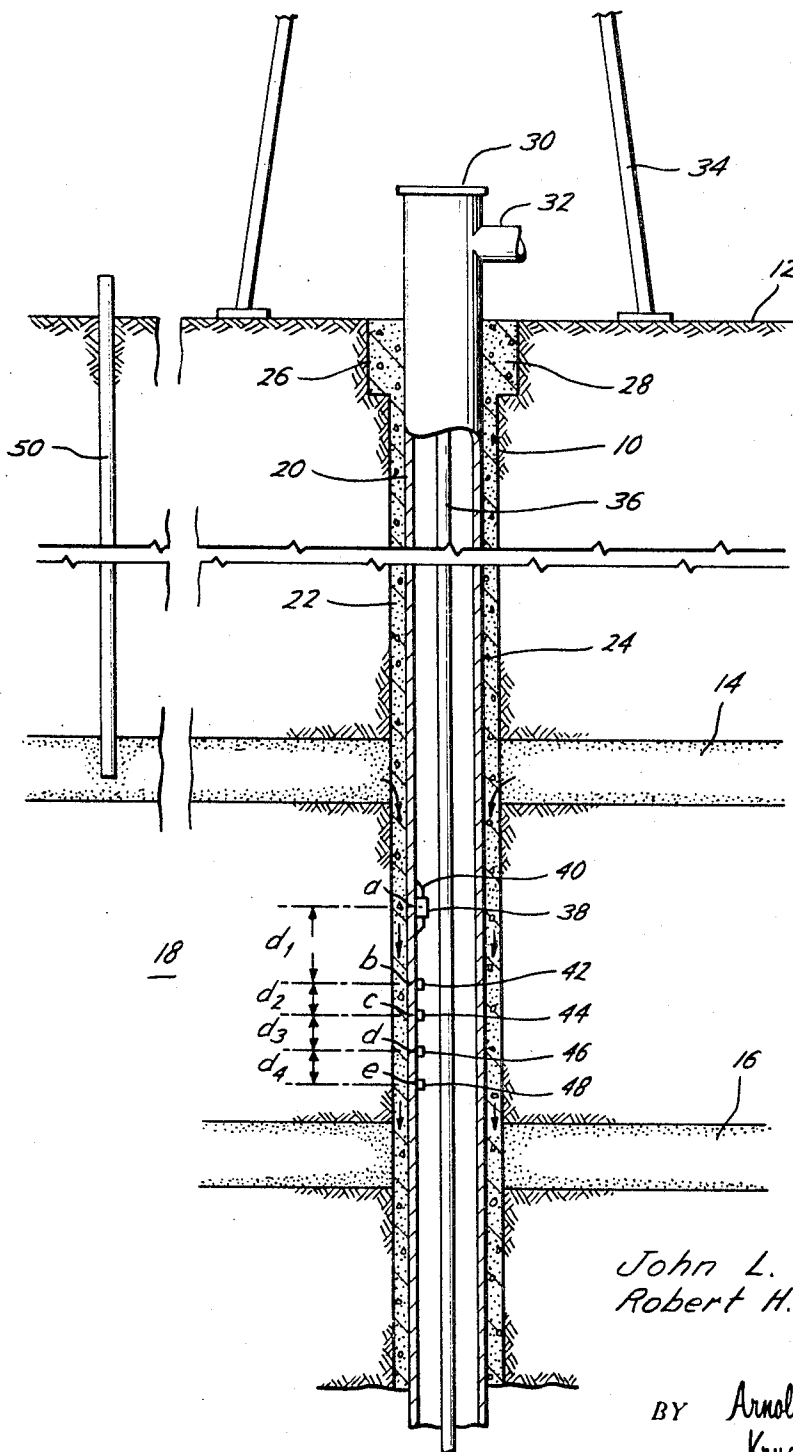
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WATERFLOODING METHOD AND METHOD OF DETECTING FLUID FLOW
BETWEEN ZONES OF DIFFERENT PRESSURE

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3,454,094

**WATERFLOODING METHOD AND METHOD OF
DETECTING FLUID FLOW BETWEEN ZONES
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ABSTRACT OF THE DISCLOSURE

A method is provided for waterflooding porous earth formations to enhance the recovery of petroleum oil therefrom, which includes heating the casing in the well bore, and taking temperature measurements at points spaced from the heater. Such temperature measurements reveal whether there is fluid flow in the space behind the casing. A method is provided for determining whether undesired fluid flow exists between two porous zones separated by an impermeable strata.

BACKGROUND OF THE INVENTION

This invention concerns methods of flooding an oil producing formation with a suitable fluid such as water to enhance the recovery of oil therefrom; the invention further concerns methods for detecting undesired flow of fluids behind a casing disposed in a well bore penetrating a petroleum oil or gas producing formation.

The problem has to do with wells penetrating porous formations of different pressure.

Generally, a relatively large tubular conduit known as casing is disposed in a well borehole communicating to an oil or gas producing formation. Since the borehole is at least somewhat larger than the casing, there is defined an annulus between the casing and wall of the borehole, such annulus extending longitudinally throughout the length of the casing. Inside the casing there is usually disposed a production string of tubing and associated apparatus. On some occasions, however, only a single conduit may be employed for communication to the producing formation. The term "casing" is used herein to include any conduit disposed longitudinally in a well borehole adjacent the wall of the borehole.

This annulus between casing and borehole wall is at present generally cemented by filling it with a hardenable cementitious material after the casing has been installed. But many older wells, from which it is desired to produce, are either not cemented at all or else are cemented only in certain zones. Fluid may thus flow through the annular area between casing and well bore of such wells in the noncemented zones.

Even cementing the complete annulus does not insure a permanent and perfect seal between casing and borehole wall, since it often happens that at least some of the cementitious material deteriorates after a period of time because of the various pressures and erosive forces existing in the formation. For this and other reasons, the seal between casing and borehole wall—even if present—is often imperfect, thereby permitting fluid flow through the annulus.

In these wells wherein there is either no seal, or an imperfect seal, between casing and borehole wall, unwanted fluid flow is likely to exist if the borehole communicates through two porous strata or zones of differing pressure separated by an impermeable zone. Fluids in a relatively high pressure zone which are exposed to the

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opening provided by the well borehole will readily flow through an imperfectly sealed, or unsealed, annulus either upwardly or downwardly to a zone of lower pressure. The problem is compounded by the utilization of fluid flooding methods.

There are several reasons why the flow of well fluids as above described is distinctly undesirable in most instances. For instance, transfer of fluids from one zone to another may be illegal under state laws and regulations governing field operations (thereby making the utilization of waterflooding, for example, impossible). Also, loss of well fluids and/or flooding fluids into a low pressure zone may make it difficult or even impossible to recover such fluids—thereby adversely affecting the economies of the well. And if one of the formations is flooded, the valuable flooding energy may be dissipated into the low pressure zone, thereby defeating the purpose of the relatively expensive flooding operation.

The problem of undesired flow of fluids in this manner has become significantly more important recently due to the increasing incidence of wells which penetrate more than one producing zone, and further due to the rapidly increasing use of waterflooding (and gasflooding) in multi-zone fields. The problem is already extremely serious in certain oil producing fields, and will be an even more serious problem in the future as the use of waterflooding methods increases.

The present invention provides a solution to this problem which is plaguing the petroleum industry, a preferred embodiment of the present invention comprising in its broadest terms a method of detecting undesired fluid flow of the type described, by the use of heating means and temperature sensing elements within the well casing.

Numerous prior art methods have employed temperature sensors or monitoring devices of various types, with or without heating elements, in well bores. Some of these prior art methods, such as those disclosed by U.S. Patents Nos. 2,697,941 and 2,787,906, are directed to the purpose of determining the location of sources of entry or exit of well fluids from the borehole, and for locating leaks in the casing or tubing. Others, such as those disclosed in U.S. Patents 2,290,075 and 2,311,757, are directed toward determining the nature of the formations traversed by the borehole. At least one prior art method, viz., that disclosed in U.S. Patent No. 2,977,792, is directed to an object similar to that of applicants.

For various reasons, none of the prior art efforts known to applicants, including those disclosed in each of the above patents, has proved entirely satisfactory. Some of these prior art methods are, it is true, satisfactory for limited purposes, including some of the purposes outlined in the patents mentioned above. But it has been determined that none of them are capable of giving results satisfactory to accurately tell whether or not fluid flows between a first zone and a second zone behind the well casing. It has been found that methods such as disclosed in Patent No. 2,977,792, for example, are totally inoperative when there is convection inside the casing, which is quite common in practice. Further, such methods are quite inaccurate and therefore of limited utility at best even in many contexts of use where there is not significant convection inside the casing. As a result, none of these prior art methods is really useful in common field operations to detect undesired fluid flow behind a well casing. The present invention overcomes the difficulties of the prior art and provides a solution to this important problem.

Likewise, prior art waterflooding (and gasflooding) methods, of which there are many, are limited to use in those areas in which there are no unsealed (or imperfectly

sealed) well bores penetrating plural formations of different pressure. This restriction on the use of such prior art waterflooding methods has created a serious problem in some fields and will continue to pose difficulties in many areas wherein waterflooding methods would be otherwise desirable. The present invention provides waterflooding methods which are not so limited, and consequently solve these prior art problems.

SUMMARY OF THE INVENTION

Broadly speaking, the present invention includes the heating of a casing in a well bore communicating to a first zone and a second zone, at a first point intermediate the first and second zones. The heating is continued at a temperature and for a time sufficient to establish a discernible elevated temperature at a plurality of points longitudinally disposed along the casing from the first point, should there be fluid flow in contact with the casing. The temperature of the casing at points between the first and second zones, longitudinally spaced from the first point, is measured and recorded both during and after the heating period. By observation of the temperature measurements at such locations, it can be readily ascertained whether or not fluid is flowing behind the casing between the first and second zones. In most instances, the temperature measurements will also indicate the approximate volume of fluid flow.

The method has been found to give reliable results even when there is convection inside the casing.

In another embodiment, the invention includes the injection of a fluid such as water in large quantities into a porous earth formation through an injection well drilled into such formation, wherein the fluid injection occurs in the vicinity of a well bore communicating not only with such porous earth formation, but also with another formation of different pressure. In accordance with this embodiment of the invention, fluid flow from the porous earth formation into a formation of lower pressure is readily detected by the method outlined above. Recovery of oil from the fluid flooded porous earth formation through a producing well results in enhancement of oil recovery from the reservoir.

BRIEF DESCRIPTION OF THE DRAWING

The figure which forms a part of this specification is a schematic, elevational view, partly in section, of a borehole communicating to first and second producing zones in the earth, and having therein apparatus suitable for use in performing the methods in accordance with this invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now in more detail to the drawing, preferred embodiments of the present invention will be discussed with reference thereto. The drawing shows a well borehole 10 communicating from the earth's surface 12 through a first zone 14 and a second zone 16.

As will be readily apparent to those skilled in the art, the zones 14 and 16 are relatively porous formations of the type from which oil and gas are commonly produced. These zones are separated by a relatively impermeable strata or zone 18. It is quite common for the formation pressure of one of these zones to be quite different from the formation pressure in the other zone. This may be due to such reasons as the natural pressures gradient and to the existence of high pressure gas pockets in the formations. In this embodiment, it will be assumed that the pressure in zone 14 is greater than the pressure in zone 16.

Although the drawing shows only a couple of porous zones 14 and 16, it will be readily understood that it is quite common for a borehole to penetrate a much larger number of such zones. One instance in which

the present invention is particularly useful, for example, is that context wherein production is from a deep zone (not shown in the drawing) and there is undesired fluid flow between a couple of upper zones, such as 14 and 16.

Inside the borehole 10, which is typically irregular in configuration, is disposed an elongate conduit or casing 20, thus defining an annulus 22 between the outer surface of the casing 20 and the wall of the borehole 10. It is common practice in the industry to fill this annulus 22 with a cementitious material 24 to seal the outer surface of the casing to the wall of the borehole.

The borehole 10 may be formed with an enlarged portion 26 adjacent the earth's surface, and this enlarged area may be filled with cement 28. The casing 20 may be suitably capped as illustrated at 30 at the wellhead and any suitable equipment such as blowout preventers may be installed. Suitable outlet and inlet openings such as illustrated at 32 are provided for withdrawing well fluids from the well. Also, a suitable wellhead superstructure 34 may be employed if desired.

At least one tubing string 36 may be disposed within the casing 20, such tubing generally representing the producing conduit in the well.

As illustrated in the drawing, the present invention contemplates the use of heating means such as the heater 38 in contact with the wall of casing 20 at an intermediate point between the zones 14 and 16. The heater is desirably contacted with the wall of the casing by any suitable means such as attaching the heater to a spring-loaded downhole tool which upon actuation directs the heating means outwardly into contact with the wall of the casing. Alternatively, a suitable electromagnetic tool could be used to assure such contact. As another alternative, even though it is presently not economically desirable in most contexts, the heater 38 may be cemented to the wall of the casing 20 by suitable means such as Thermon heat-transfer cement 40. It is emphasized that any suitable means may be provided for contacting the heater with the wall of the casing, and the particular means employed is not critical to this invention. Suitable actuating means are attached to the heater 38 so that it may be turned on and off by an operator at the earth's surface.

Longitudinally spaced from the heater 38 a distance d_1 toward the zone 16 of lower pressure, and in intimate contact with the casing 20, is a first temperature sensing element 42. Although the invention is not limited to the use of any certain number of temperature sensing elements, three additional such elements 44, 46 and 48, are illustrated in the drawing as a preferred embodiment. The element 44 is longitudinally spaced from the element 42 a distance d_2 , the element 46 is longitudinally spaced from the element 44 a distance d_3 , and the element 48 is longitudinally spaced from the element 46 a distance d_4 , each being positioned between the heater and the low pressure zone. The distances d_2 , d_3 and d_4 are desirably approximately equal.

Each of the elements 44, 46 and 48 is desirably in intimate contact with the wall of casing 20. These elements, and the element 42, may be any suitable elements for measuring temperature, for example, suitable thermocouples such as iron-constantan thermocouples. Various of the sensing elements disclosed in the aforementioned prior art patents may be utilized as the sensing elements in the present invention. It is noted, however, that it is important that such elements be quite sensitive to fairly small changes in temperature. Suitable recording apparatus is desirably operably connected to each of the sensing elements in a manner well known to those of skill in the art.

The sensors may be contacted with the casing wall by any suitable means, for example the means described above in connection with contacting the heater 38 with the casing wall. Here again, it is noted that the particular means of contacting is not critical to the invention.

It is believed necessary for best results in most operations that the sensors be in actual contact with the casing wall. It is possible in some contexts, however, that satisfactory results could be obtained if the sensors are disposed in close proximity and there is no fluid flow in the casing. This could be assured, for example, by disposing the sensors in small recesses in the outer surface of a polyurethane foam cylinder having a diameter approximately equal to the inside diameter of the casing. In this manner, the foam cylinder would prevent any possibility of fluid flow, and the sensors would be disposed in close proximity to the inside of the casing wall and insulated on all sides except adjacent the casing wall.

As previously mentioned, the annulus 22 is generally filled with a cementitious material 24. If such material forms a seal between casing and borehole wall between the zones 14 and 16, then there can be no fluid communication between the zones 14 and 16 along the outside of the casing, even if the pressure in the two zones is radically different. If, on the other hand, there is no seal in the annulus 22, either due to the fact that the annulus was never sealed in the first place or due to the fact that the annulus was sealed but the sealing material has deteriorated, fluid communication will likely exist behind the casing. The extent of such communication will depend for example on the pressure differential between the zones, the permeability of the formations, and the viscosity of the flowing fluid.

It will be understood that the zones 14 and 16 are representative only; the borehole 10 may communicate through any number of such zones, and undesired fluid flow between any two such zones may be detected using the method of this invention.

In accordance with one embodiment of the invention, assume that it is desired to detect any fluid flow through the annulus 22 between the zone 14 and the zone 16. A point *a* intermediate the zone 14 and the zone 16 is selected. Suitable heating means, such as an electrical resistance heater, is provided. The heater provided must be capable of heating the casing to an extent sufficient to produce a discernible temperature rise in the casing and in the liquid outside the casing. Satisfactory results have been achieved with an electrical resistance heater capable of heating the casing to a temperature slightly greater than the temperature of the adjacent formation, for example about 10 F. degrees greater. The amount of such temperature differential necessary will depend on the sensitivity of the sensors used. Suitable actuating means are operably connected with the heater so that the heater can be turned on and off by an operator at the earth's surface. Such suitable actuating means are conventional and well known in the art.

Before installing the heater downhole, it is generally desirable to pull the tubing 36 to a level above the point *a*. The heater thus provided is then affixed to the inner wall of the casing at the point *a*, in a suitable manner such as described above.

Another point *b* between the zones 14 and 16 is then selected, this point being located on the casing a distance d_1 from the heater. The distance d_1 should be great enough so that the temperature of the casing at the point *b* will not be significantly affected by conduction of heat through the casing from localized heating at the point *a*. The distance should be sufficiently small, however, to allow for a discernible temperature elevation at the point *b* from localized heating at the point *a* if there is fluid convection along the exterior of the casing wall between the points *a* and *b*. For best results applicants prefer that d_1 be in the range of about 0.5 to 5 feet.

A suitable temperature sensing element, such as an iron-constantan thermocouple is provided and this sensing element is affixed to the casing wall, in intimate contact therewith, at the point *b*.

It is preferred to select a plurality of other points, such as *c*, *d*, and *e*, each of these points being spaced longi-

tudinally from the heater and from the point *b*, between *b* and lower pressure zone 16. (In practice, since it is not generally known whether any flow would be upward or downward, it can be assured that sensors are placed on the proper side of the heater in various ways. One such way is the selection of points on both sides of the heater. Another is by first selecting points on one side and taking measurements. From a standard temperature calibration curve, or from observation of the results of such measurements, it can be ascertained whether the sensors are directed toward or away from the flow. If the first selection of points was incorrect, points are then selected on the opposite side.) The point *c* is a distance d_2 from point *b*; *b*; the point *d* is a distance d_3 from the point *c*; and the point *e* is a distance d_4 from the point *d*. While it is not necessary that the distances d_2 , d_3 and d_4 be equal, this is generally preferred. In general, the distances d_2 , d_3 and d_4 will be less than the distance d_1 . For best results, applicants prefer that the distances d_2 , d_3 and d_4 be on the order of about 0.5 to 5 feet.

Temperature sensing elements are installed in the same manner as mentioned above, at each of the points *c*, *d* and *e*. Suitable means are included for recording the temperature from each of these sensing elements.

The heater is then actuated and the casing at the point *a* is heated for a suitable time period, for example, for about 0.5–3 hours, to a temperature of at least about 10° F. above the temperature of the adjacent formation. As one specific example, the casing at point *a* is heated for about 1 hour at 225° F., when the temperature of the adjacent formation is 210° F. During the heating period, the temperature is measured at each of the points *b*, *c*, *d* and *e*. The temperatures thus measured are recorded, substantially continuously, to give a temperature v. time correlation, during the heating period.

The heating of the casing is then terminated, but the measurement of temperatures at the points *b*, *c*, *d* and *e*, is desirably continued for an extended time period, for example a period twice the length of the heating period. During this subsequent time period, the measurements thus taken are recorded, substantially continuously. It is not necessary that the temperature measurements be continued after termination of the heating. It will be understood, however, that best results will be obtained when temperature measurement readings over a fairly lengthy time period after termination of the heating, are available.

The rate of change of temperature at the points *b*, *c*, *d* and *e* is then determined (as a function of time). From the results thus obtained, the presence of fluid flow behind the casing in the annulus 22, between the zone 14 and the zone 16, can be ascertained.

In accordance with another embodiment of the invention, a method of flooding with a suitable fluid such as water, is provided. Waterflooding is a process commonly practiced in the petroleum industry in what is generally called the "secondary recovery" of oil. The difficulty with the practicing of waterflooding or gasflooding into a porous zone such as 14 in the vicinity of a well bore such as that illustrated in the accompanying drawing, has been the escape of the flooded zone fluid, through the annulus 22, into a porous zone of lower pressure, such as the zone 16. This is especially true since the flooding process itself increases the pressure in the zone in which it is used.

In accordance with this embodiment of the invention, an injection well 50 is provided to communicate with the porous earth formation to be flooded, here indicated as the zone 14. An injection fluid, for example water, is injected through the well 50 into the zone 14. Large quantities of such fluid are injected, as is well known in the art, over a time period that may last many months. During the injection, a heater and temperature sensing elements such as described above are installed and measurements taken and recorded, also such as described above.

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The well fluids in the zone 14, pressurized and pushed along by the injected fluid, may then be produced through the tubing 36, or through any other producing well communicating with the zone 14.

If there is any undesired fluid flow from the zone 14 toward the zone 16, such flow can be detected by the above process, and corrective measures taken.

A number of experiments have been made in the laboratory, simulating actual field conditions. A representative sample of such experiments follows, such examples being included for completeness of description and illustration of the usefulness of the invention. These examples are not to be construed as limiting the invention. The dimensions, temperatures, etc., given below correspond to actual field conditions.

Example I

A scaled laboratory model was constructed. A water-saturated sand-pack formation was contained in a 14-inch (outside diameter) steel pipe, three feet in length. A thin glass tube, with thermal characteristics like those of the formation, retained the sand pack. The inner diameter of the glass tube formed the well bore. A thin steel tube, scaled in diameter and thickness to represent a 7-inch (outside diameter), 23 lb./ft. casing, was centered in the well bore.

An electrical resistance heating element scaled to represent a capacity of 2000 watts was cemented inside the casing at a point corresponding to the point *a* on the accompanying drawing, by the use of Thermon heat-transfer cement. Five iron-constantan thermocouples were silver-soldered to the casing wall, four at locations roughly corresponding to the points *b*, *c*, *d*, and *e* on the accompanying drawing, the other thermocouple being positioned just beneath the point *a*. The scaled distances of such thermocouples from the heater represented 0.5 feet, 4 feet, 7.5 feet, 11.0 feet, and 14.5 feet.

Water was allowed to flow in the annulus, in the direction (relative to the heater and temperature sensors) indicated by the arrows in the drawing, at a field flow rate of 3.7 barrels per day. The positioning of heater and sensors in the laboratory model was actually such that the heater was beneath the sensors (flow being upward).

Sand was placed in the annulus to simulate permeable "cavings" or "fill-up." Air was present in the casing.

The casing was heated and temperature measurements were continuously taken and recorded at each of the five thermocouples over a time period of about twenty five hours. The results were as follows:

0.5 FEET FROM HEATER		50
Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	4	
0.6	6	55
0.8	8	
1.0	10	
2.0	28	
4.0	60	
6.0	74	60
8.0	80	
10.0	84	
20.0	90	

4.0 FEET FROM HEATER		65
0.4	0	
0.6	0	
0.8	0	
1.0	0	
2.0	0	70
4.0	8	
6.0	24	
8.0	35	
10.0	42	
20.0	54	75

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7.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees
0.4 -----	0
0.6 -----	0
0.8 -----	0
1.0 -----	0
2.0 -----	0
4.0 -----	0
6.0 -----	4
8.0 -----	10
10.0 -----	16
20.0 -----	32

11.0 FEET FROM HEATER

0.4	0
0.6	0
0.8	0
1.0	0
2.0	0
4.0	0
6.0	0
8.0	2
10.0	4
20.0	17

14.5 FEET FROM HEATER

0.4	0
0.6	0
0.8	0
1.0	0
2.0	0
4.0	0
6.0	0
8.0	0
10.0	2
20.0	8

Example II

Example I was repeated using a flow rate of 9.3 barrels per day. The results were as follows:

0.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees
0.4	4
0.6	8
0.8	12
1.0	16
2.0	38
4.0	52
6.0	54
8.0	55
10.0	56
20.0	56

0.4 FEET FROM HEATER

0.4	0
0.6	0
0.8	0
1.0	1
2.0	7
4.0	26
6.0	33
8.0	36
10.0	37
20.0	37

7.5 FEET FROM HEATER

0.4	0
0.6	0
0.8	0
1.0	0
2.0	0
4.0	10
6.0	22
8.0	27
10.0	28
20.0	29

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11.0 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	0	
0.6	0	
0.8	0	5
1.0	0	
2.0	0	
4.0	2	
6.0	13	10
8.0	18	
10.0	20	
20.0	22	

14.5 FEET FROM HEATER

0.4	0	15
0.6	0	
0.8	0	
1.0	0	
2.0	0	
4.0	0	20
6.0	5	
8.0	11	
10.0	14	
20.0	18	25

Example III

Example I was repeated using a flow rate of 23.4 barrels per day. The results were as follows:

0.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	4	
0.6	11	
0.8	18	
1.0	22	35
2.0	30	
4.0	33	
6.0	33	
8.0	33	
10.0	33	40
20.0	33	

4.0 FEET FROM HEATER

0.4	0	
0.6	2	
0.8	5	45
1.0	9	
2.0	18	
4.0	23	
6.0	23	
8.0	23	50
10.0	23	
20.0	23	

7.5 FEET FROM HEATER

0.4	0	
0.6	0	55
0.8	0	
1.0	3	
2.0	12	
4.0	18	
6.0	19	60
8.0	20	
10.0	20	
20.0	20	

11.0 FEET FROM HEATER

0.4	0	65
0.6	0	
0.8	0	
1.0	0	
2.0	7	70
4.0	16	
6.0	17	
8.0	17	
10.0	17	
20.0	18	75

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14.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees
0.4	0
0.6	0
0.8	0
1.0	0
2.0	3
4.0	13
6.0	16
8.0	16
10.0	16
20.0	17

Example IV

Example I was repeated, except there was no flow through the annulus. The following results were realized:

0.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees
0.4	1
0.6	1
0.8	1
1.0	2
2.0	3
4.0	6
6.0	10
8.0	19
10.0	32
20.0	100

4.0, 7.5, 11.0 AND 14.5 FEET FROM HEATER

0.4	0
0.6	0
0.8	0
1.0	0
2.0	0
4.0	0
6.0	0
8.0	0
10.0	0
20.0	0

Example IV reveals that, in the absence of flow and with fillup behind the casing, no measurable temperature rise is observed (within an extended time period) outside the heated zone. The rise in temperature very close to the heater is attributable to heat transfer through the casing by conduction.

In each of the Examples I, II and III, however, specific heat fronts are observed which are directly proportional to the flow rate in the area behind the casing.

Example V

Example I was repeated, except that the annulus was left open and not filled with sand. This experiment simulated the conditions down-hole when fill-up or cavings are absent. The results were as follows:

0.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees
0.4	6
0.6	7
0.8	8
1.0	9
2.0	20
4.0	41
6.0	54
8.0	62
10.0	67
20.0	78

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4.0 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	4	5
0.6	5	
0.8	6	
1.0	7	10
2.0	16	
4.0	33	
6.0	44	10
8.0	52	
10.0	56	
20.0	63	

7.5 FEET FROM HEATER

0.4	3	15
0.6	3	
0.8	4	
1.0	5	20
2.0	10	
4.0	23	
6.0	30	25
8.0	34	
10.0	37	
20.0	43	

11.0 FEET FROM HEATER

0.4	3	30
0.6	3	
0.8	4	
1.0	5	35
2.0	8	
4.0	17	
6.0	23	35
8.0	27	
10.0	29	
20.0	33	

14.5 FEET FROM HEATER

0.4	2	40
0.6	2	
0.8	3	
1.0	4	45
2.0	7	
4.0	10	
6.0	15	45
8.0	18	
10.0	20	
20.0	24	

Example VI

Example V was repeated using a flow rate of 9.3 barrels per day. The results were as follows:

0.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	3	55
0.6	13	
0.8	21	
1.0	28	60
2.0	44	
4.0	52	
6.0	52	65
8.0	52	
10.0	52	
20.0	52	

4.0 FEET FROM HEATER

0.4	2	70
0.6	6	
0.8	10	
1.0	13	75
2.0	23	
4.0	34	
6.0	37	75
8.0	38	
10.0	38	
20.0	38	

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7.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	1	3
0.6	3	
0.8	5	
1.0	9	20
2.0	20	
4.0	31	
6.0	34	35
8.0	35	
10.0	35	
20.0	35	

11.0 FEET FROM HEATER

0.4	0	4
0.6	2	
0.8	4	
1.0	6	15
2.0	15	
4.0	27	
6.0	31	33
8.0	32	
10.0	33	
20.0	33	

14.5 FEET FROM HEATER

0.4	0	3
0.6	0	
0.8	2	
1.0	3	11
2.0	11	
4.0	22	
6.0	27	28
8.0	28	
10.0	28	
20.0	28	

Example VII

Example V was repeated, except that the flow rate was 23.4 barrels per day. The results were as follows:

0.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	8	16
0.6	16	
0.8	22	
1.0	27	39
2.0	39	
4.0	43	
6.0	44	44
8.0	44	
10.0	44	
20.0	44	

4.0 FEET FROM HEATER

0.4	3	7
0.6	7	
0.8	11	
1.0	16	27
2.0	27	
4.0	32	
6.0	32	32
8.0	32	
10.0	32	
20.0	32	

7.5 FEET FROM HEATER

0.4	2	7
0.6	4	
0.8	7	
1.0	10	19
2.0	19	
4.0	25	
6.0	25	26
8.0	26	
10.0	26	
20.0	27	

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11.0 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	1	
0.6	2	5
0.8	4	
1.0	7	
2.0	16	
4.0	21	
6.0	22	10
8.0	22	
10.0	22	
20.0	23	

14.5 FEET FROM HEATER

0.4	1	15
0.6	2	
0.8	4	
1.0	6	
2.0	13	
4.0	18	20
6.0	19	
8.0	20	
10.0	20	
20.0	21	25

Example VIII

Example V was repeated, except there was no flow through the annulus. The following results were obtained:

0.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees	
0.4	4	30
0.6	5	
0.8	6	
1.0	7	35
2.0	13	
4.0	27	
6.0	42	
8.0	56	40
10.0	66	
20.0	95	

4.0 FEET FROM HEATER

0.4	2	
0.6	2	
0.8	2	45
1.0	3	
2.0	7	
4.0	15	
6.0	22	
8.0	28	50
10.0	33	
20.0	50	

7.5 FEET FROM HEATER

0.4	1	55
0.6	1	
0.8	1	
1.0	2	
2.0	4	
4.0	9	60
6.0	13	
8.0	16	
10.0	18	
20.0	25	

11.0 FEET FROM HEATER

0.4	1	65
0.6	1	
0.8	1	
1.0	1	
2.0	2	70
4.0	6	
6.0	9	
8.0	11	
10.0	13	
20.0	19	75

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14.5 FEET FROM HEATER

Time, hours:	Temperature rise, Fahrenheit degrees
0.4	0
0.6	0
0.8	0
1.0	0
2.0	1
4.0	3
6.0	4
8.0	5
10.0	6
20.0	10

The Examples V through VIII give a type of curve different from that obtained from Examples I through IV. In the V-VIII examples, almost immediate temperature rise is noted at those sensors several feet away from the heater, while in the I-IV examples such elevation in temperature was delayed usually for several hours. It is therefore easy for one to tell, depending upon the type of curve obtained when carrying out the methods described above, whether or not there is fill-up behind the casing.

If there is fill-up, then the results obtained are both qualitative and quantitative. If there is no fill-up, then the results are qualitative but are not generally reliable from a quantitative standpoint.

In Example VIII above, a temperature rise of less than five degrees was recorded at the end of the first hour by all stations more than one foot from the heater—while in the Examples V, VI and VIII, significant temperature rises had been obtained at all stations by this time. Thus, it is easy to ascertain that there is no fluid flow even though temperature rise curves were obtained for the stations more than one foot from the heater. Such curves are believed attributable to the convection caused by the heating of the standing fluid outside of the casing above the heater. And the temperature curve for the location nearest the heater is due also to conduction of heat through the casing.

Satisfactory results were obtained with each of these experiments and with other experiments in which the flow was upward (but the relationship of heater, sensors, and direction of flow remain constant), and in which the fluid flow was oil rather than water.

Other laboratory experiments were performed wherein the heat was terminated and temperature measurements continued for extended periods after such termination. The temperature decline curves obtained on cooling are useful in quantitative determination, and therefore desirable, but are not necessary for qualitative analysis.

Still other laboratory experiments were performed, including some in which the casing was filled with fluid, and the temperature of the casing fluid rather than the temperature of the casing, was measured. It was determined that if the fluid was a low viscosity fluid, and the heater was located below the sensors, the results were completely unreliable. Since flow which is to be detected by this invention might just as readily be upward flow as downward flow (which is illustrated in the drawing) it is concluded that any system which is inoperable when there is upward flow, is greatly undesirable and, for all intents and purposes, inoperable at all. If the fluid is a high viscosity fluid, such as drilling mud, the convection problem is largely overcome, but best results are still not obtained unless the sensors are in contact with or close proximity to the casing, because of the difficulties encountered with heat transfer through the high viscosity fluid. Results of these other experiments were thus not satisfactory.

While the invention has been described in terms of particularly preferred embodiments, it will be recognized by those of skill in the art that various changes and modifications may be made in such embodiments without departing from the scope of the invention, which is defined by the following claims.

We claim:

1. A method for enhancing the recovery of oil from a reservoir by flooding with a suitable fluid a porous earth formation having an injection well drilled therein, in the vicinity of a well bore having a casing therein, said well bore communicating in the earth to said porous earth formation and to at least one other porous zone separated from said porous earth formation by a relatively impermeable strata, comprising:

selecting a first point to said casing between said porous earth formation and said other porous zone;
providing heating means adapted to heat said casing and also adapted to be actuated from a remote location;

installing said heating means at said first point;

selecting at least a second point on said casing between said porous earth formation and said other porous zone, said second point being longitudinally spaced from said first point;

providing a temperature sensing device suitable for detecting the temperature at said second point;

installing said temperature sensing device at said second point;

injecting a suitable flooding fluid into said porous earth formation through said injecting well;

actuating said heating means to heat the casing at said first point;

measuring the temperatures at said second point with said sensing device, and substantially continuously recording said temperature during the heating of said casing;

terminating the heating of said casing;

determining the rate of change of temperature at said second point to thereby detect any undesired flow of fluid in the space between said casing and said well bore from said porous earth formation toward said other porous zone; and,

producing well fluid from said porous earth formation.

2. A method of flooding a porous earth formation in accordance with claim 1, wherein said temperature sensors are maintained in intimate contact with said casing during the measurement and recording of said temperatures.

3. A method of flooding a porous earth formation in accordance with claim 1, wherein temperature sensing devices are located at a plurality of points between said porous earth formation and said other porous zone, said points being longitudinally spaced from said heating means between said heating means and said other porous zone.

4. A method of flooding a porous earth formation in accordance with claim 1, wherein the flooding fluid is water.

5. In a well bore having a casing disposed therein, said well bore communicating in the earth to at least a first zone and a second zone longitudinally spaced from said first zone, the method for detecting fluid flow between said casing and the wall of said well bore, comprising:

providing heating means adapted to heat said casing and also adapted to be actuated from a remote location;

installing said heating means at a first point on said casing intermediate said first and second zones;

providing at least one temperature sensing device suitable for detecting the temperature of the casing at a point longitudinally spaced from said heating means;

installing said temperature sensing device at a point on said casing intermediate said first and second zones and longitudinally spaced from said heating means, in a manner such that said device is in intimate contact with said casing;

actuating said heating means to heat said casing at said first point;

measuring the temperatures at said temperature sensing device, and substantially continuously recording said temperatures during the heating of said casing;

terminating the heating of said casing; and

determining the rate of change of temperature of said temperature sensing device to thereby detect any undesired flow of fluid in the space between said casing and said borehole wall, between said first and second zones.

6. The method for detecting fluid flow according to claim 5, wherein a plurality of temperature sensing devices are installed within said casing.

7. The method of claim 6, wherein temperature sensing devices are placed at at least three points longitudinally spaced from the heater, and wherein the distance between each such point is substantially equal.

8. The method of claim 5, wherein said heating means is actuated at the earth's surface.

9. In a well bore having a casing disposed therein, said well bore communicating in the earth to at least a first zone and a second zone, said second zone being longitudinally spaced from said first zone and having a formation pressure different from the formation pressure in said first zone, the method for detecting fluid flow in the space between said casing and the wall of said well bore, comprising:

selecting a first point on said casing between said first zone and said second zone;

providing heating means adapted to heat said casing and also adapted to be actuated from a remote location;

installing said heat means at said first point in contact with said casing;

selecting at least two other points on said casing between said first zone and said second zone, each of said points being longitudinally spaced from said first point, and said points being longitudinally spaced with respect to one another;

providing temperature sensing devices suitable for detecting the temperature at said other points;

installing said temperature sensing devices at said other points in a manner such that each of said devices is in intimate contact with said casing;

actuating said heating means to heat said casing at said first point;

measuring the temperatures at said other points with said sensing devices, and substantially continuously recording said temperatures during the heating of said casing;

terminating the heating of said casing; and

determining the rate of change of temperature at said other points to thereby detect any undesired flow of fluid in the space between said casing and said borehole wall, between said first and second zones.

10. The method for detecting fluid flow according to claim 9, wherein said other points are longitudinally spaced from said first point in a direction toward the zone of lower pressure.

11. In a well bore having a casing disposed therein, said well bore communicating in the earth to at least a first zone and a second zone, said second zone being longitudinally spaced from said first zone and having a formation pressure different from the formation pressure in said first zone, the method for detecting fluid flow in the space between said casing and the wall of said well bore, comprising:

selecting a first point within said casing between said first zone and said second zone;

providing heating means adapted to heat said casing and also adapted to be actuated from a remote location;

installing said heating means at said first point;

selecting at least two other points within said casing between said first zone and said second zone, each of said points being longitudinally spaced from said first point in a direction toward the zone of lower pressure, and said points being longitudinally spaced with respect to one another;

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providing temperature sensing devices suitable for detecting the temperature at said other points;
installing said temperature sensing devices at said other points;

actuating said heating means to heat said casing adjacent said first point for a period of at least about 30 minutes;

measuring the temperatures at said other points with said sensing devices, and substantially continuously recording said temperatures during the heating of said casing;

terminating the heating of said casing; and

determining the rate of change of temperature at said other points to thereby detect any undesired flow of fluid in the space between said casing and the wall of said borehole, between said first and second zones.

12. The method according to claim 11, wherein the temperatures at said other points are substantially continuously recorded for a period of time after termination of the heating of said casing.

13. The method according to claim 11, wherein said sensing devices are installed in at least close proximity to said casing wall.

14. The method according to claim 11, wherein said sensing devices are installed in intimate contact with said casing wall.

15. In a well bore having a casing disposed therein, said well bore communicating in the earth to at least a first zone and a second zone, said second zone having a formation pressure different from the pressure in said first zone, the method for detecting fluid flow in the space between said casing and the wall of said borehole, comprising:

selecting a first point on said casing between said first zone and said second zone;

providing heating means adapted to heat said casing and also adapted to be actuated from a remote location;
installing said heat means at said first point on said casing;

selecting at least two other points on said casing between said first zone and said second zone, each of said points being longitudinally spaced at least about six inches from said first point in a direction toward

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the zone of lower pressure, and said points being longitudinally spaced apart by at least about six inches;

providing temperature sensing devices suitable for detecting temperature at said other points;

installing said temperature sensing devices at said other points in a manner such that each of said devices is in intimate contact with said casing;

actuating said heating means and allowing said means to heat said casing in said first point for a period of about 5.0-3.0 hours at a temperature of at least about 10° F. greater than the temperature of the adjacent formation;

measuring said temperature at said other points by use of said sensing devices, and substantially continuously recording said temperatures during said heating period; and

determining the rate of change of temperature at said other points to thereby detect any undesired flow of fluid in the space between said casing and said borehole wall, between said first and second zones.

16. The method according to claim 15, wherein the temperatures at said other points are substantially continuously recorded for at least about one hour after termination of the heating of said casing.

References Cited

UNITED STATES PATENTS

2,669,872	2/1954	Hartweg	73—155
2,685,930	8/1954	Albaugh	166—60 X
2,697,941	12/1954	Moore et al.	73—155
2,733,605	2/1956	Buck	73—155
2,787,906	4/1957	Piety	73—155
2,977,792	4/1961	Simm	73—155
3,072,189	1/1963	MacSporran	166—39
3,135,324	6/1964	Marx	166—11 X
3,372,754	3/1968	McDonald	166—64 X

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73—155; 166—64, 272, 302