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Ex # 3
Case 377

PRODUCTION RESEARCH TESTS

GALLEGOS CANYON UNITS NO. 2, 3, 4, 5, AND 7

WEST KUTZ FIELD
SAN JUAN COUNTY, NEW MEXICO

FOR

BENSON AND MONTIN

DALLAS, TEXAS

CORE

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

April 29, 1952

Benson and Montin
502 Continental Building
Dallas, Texas

Attention: Mr. A. R Greer, Jr.

Subject: Production Research Tests
Gallegos Canyon Units No. 2, 3, 4, 5 and 7
West Kutz Field
San Juan County, New Mexico
Our File No. PR-5209 CP

Gentlemen:

We submit herewith results of special production research measurements on core samples from five wells, listed above, in the West Kutz Field, New Mexico. Included are data on capillary pressure tests, formation resistivities, and porosity and permeability tests. A discussion is given in regard to comparisons of these data with data from conventional and special (large core) analysis on the wells.

Table 1 shows the results of single point capillary pressure measurements, sometimes called restored state tests, on fifteen samples. These samples were permeability plugs from the conventional core analysis. The permeabilities measured in the conventional core analysis are also shown in this table; these values were checked to within a few per cent by this laboratory.

The capillary pressure data were obtained in the conventional manner by displacing brine from the saturated samples on a porous plate with air at 30 PSI. The connate water saturations thus obtained showed satisfactory agreement with permeability; the average relationship is shown in Table 2 where values of connate water are given for varying permeabilities.

The samples used in the above tests were prepared, after extraction, by evacuating and then saturating with a brine of approximately 68,000 parts per million sodium chloride. The porosities of these samples were obtained from the difference of the dry weights and saturated weights, and these porosities are shown in Table 3. It was noted that the average porosity, 17.7 per cent, was in excellent agreement with the average porosity obtained by large core analysis on the five wells; this point will be discussed in more detail subsequently.

The formation resistivity factors, also shown in Table 3, were obtained by measuring the electrical resistance of the saturated samples, correcting for length and area to obtain unit resistivity in ohm-meters, and dividing by the resistivity of the saturating brine. The resistivities of eight of the samples were also obtained after their water saturation had been reduced to connate water saturation. The resistivity ratio, i.e. the ratio of R_o, the resistivity at 100 per cent brine saturation to R_s, the resistivity at connate water saturation S, is shown in Table 3.

The resistivity measurements were measured in case it is desired to obtain an independent check on connate water saturations in the formation by utilizing electrical log data. For this purpose the correlation of formation factor with porosity, shown in Table 4, may be used if it is desired to make detailed calculations; otherwise, the average formation factor, 23, may be used. In this connection it is necessary to know also the exponent n in the equation $R_o/R_s = S^n$. From the resistivity ratios shown in Table 3 the best value of n was found to be 1.95.

The resistivity of a water sample from Gallegos Canyon Unit No. 7 well was measured and found to correspond to a sodium chloride concentration of 68,000 parts per million. A water sample from Unit No. 6 well showed 73,000 parts per million. If these are representative samples, the formation water would have an electrical resistivity corresponding to an average 70,500 parts per million sodium chloride. This brine resistivity would be 0.1031 ohm-meters at 70° F., 0.0921 at 80° F., and 0.0832 at 90° F., based on data from the International Critical Tables.

When the five subject wells were cored, spot samples were selected (from all except Unit No. 3) and sent to our Farmington, New Mexico, laboratory for conventional core analysis. The remainder of the cores were sent

$S = \left(\frac{R_o}{R_t}\right)^{\frac{1}{1.95}}$ $\frac{1}{1.95} = .513$

to our Worland, Wyoming, laboratory for large-core analysis. A summary of average data obtained on these analyses is shown is shown in Table 5.

It may be noted that the average permeability obtained by large-core analysis was less then 0.1 millidarcys on each well. It was suspected that the procedure involved in the special analysis had altered the samples due to their clay content. Three perm plugs were subsequently drilled from the large cores on each of the five wells and sent to Dallas for checking of permeability. Twelve out of the fifteen plugs showed 0.000 millidarcys, and the other three had only a low permeability. This confirmed our belief that the analysis procedure had lowered the permeability of the samples. In this procedure fresh water is introduced into the cores by a vacuum-pressure treatment and the cores subsequently stay under hot toluene at 230^{o} F. for one to two weeks. Such alteration of permeability had never been previously observed in this special analysis which is nearly always used only for limestone and dolomite samples and only rarely for sands. It is believed therefore that the permeabilities obtained in the conventional analyses are most representative of the true formation permeabilities.

Before proceeding to a discussion of further comparison of conventional and special analyses, a brief description of these analysis procedures is given as follows. In the conventional analysis, a representative portion of the core sample, usually 180 grams, is retorted to obtain the oil and water content in terms of per cent bulk volume of the rock, i.e. cubic centimeters of oil and of water per 100 cubic centimeters of rock. A separate portion is taken and subjected to mercury under 750 PSI pressure to measure the mercury penetration and thereby determine the gas content of this sample. The oil, water and gas contents are then added to obtain the porosity. A separate plug is drilled and tested for permeability. In the special or large-core analysis used on these samples, the entire core, in lengths up to about one and one half feet, is subjected to vacuum for a brief period to remove essentially all the gas, and is then saturated with water under pressure, up to 100 per cent liquid saturation. The sample is then placed under toluene and a modified Dean-Stark distillation carried out wherein the toluene is refluxed and carries the water out of the sample over a period of usually a week or two, or until all the water is removed. The amount of water collected, less the amount introduced to replace the gas, gives the amount originally in the sample. The oil content is obtained from the weight difference of the saturated and extracted sample, less the weight of water removed. Permeability is obtained in two directions diametrically across the whole sample after placing the sample in a special holder.

As these are two entirely different types of core analysis, each has its own inherent experimental errors. Previous research has indicated that the conventional analysis may give porosity values that are too high in bentonitic sands or sands of high clay content. The large-core analysis, on the other hand, may give porosities that are slightly on the low side, but which in general are considered to be closer to the true porosities than the values obtained by conventional analysis. The total water content shown by large-core analysis is very exact, and includes only the free water or water not chemically bound to the clay content.

In view of the above observations, plus the excellent agreement between the average porosity shown by the large-core analysis and the average porosity obtained on the fifteen samples used for capillary pressure tests, it is concluded that the porosities obtained by large-core analysis are the more correct values, and closer to the true porosities than the ones obtained by conventional analysis.

If it is desired to obtain point-by-point permeabilities from the large-core analysis data, it is suggested that Table 6 be used, which is a correlation of the permeabilities vs. porosities measured on the fifteen samples used for the capillary pressure tests.

One more point of comparison between the core analysis data and the data obtained during these production research tests is worth noting. In Table 5 the average total water content of the cores analyzed from each well is shown, expressed as a percentage of total bulk volume of the rock. This is obtained by multiplying the porosity by the per cent total water saturation. Also shown expressed in the same units is the calculated connate water from the core analysis data. This calculated connate water is obtained by the method which we have used for years to obtain a first approximation of connate water in the absence of direct data. It is based on an empirical formula, and is not claimed to possess any high accuracy.

However, it would seem significant that the values from the conventional and the large-core analysis are in reasonable agreement with each other and with the average value, 10.3 per cent, from the capillary pressure data. The latter figure is not shown in the tables, but is the average of the individual values obtained by multiplying the porosity of each of the fifteen samples (Table 3) by the corresponding connate water saturation (Table 1).

We trust these data will be useful in the evaluation of this field.

Very truly yours,

Core Laboratories, Inc.

Frank C. Kelton

Frank C. Kelton,
Manager of Research

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Table 1

Water Saturations at 30 PSI
Single Point Capillary Pressure Tests

Gallegos Canyon Units, West Kutz Field

Sample No.	Well: Unit No.:	Depth, Feet	Permeability, Millidarcys	Water Saturation at 30 PSI, % Pore Space
1	2	1338.0	1.8	69.0
2	2	1350.0	4.3	55.5
3	2	1354.0	8.7	38.5
4	2	1440.0	1.1	65.0
5	2	1445.0	5.3	50.3
6	4	1604.5	2.8	70.0
7	5	1395.5	33	44.4
8	5	1403.5	10	53.8
9	5	1435.5	2.5	60.1
10	7	1406.5	21	49.2
11	7	1408.0	5.9	55.9
12	7	1414.5	1.3	80.5
13	7	1433.5	1.3	88.7
14	7	1465.5	11	47.8
15	7	1475.5	6.1	55.6
Average			7.7	59.0

Table 2

Connate Water Saturation vs. Permeability

Gallegos Canyon Units, West Kutz Field

Permeability, Millidarcys	Connate Water Saturations, Per Cent Pore Space
1	71.8
2	64.5
3	60.4
4	57.6
6	53.8
8	51.0
10	49.1
15	45.7
20	43.3
30	40.4
40	38.7

Table 3

Resistivity Measurements

Gallegos Canyon Units, West Kutz Field

Sample No.	Porosity, Per Cent	Formation Resistivity Factor, R_o/R_w	Resistivity Ratio* at Connate Water, R_o/R_s
1	15.9	30.3	0.494
2	17.3	31.2	.378
3	15.1	16.0	.245
4	17.8	28.6	.303
5	17.5	21.5	.340
6	16.1	25.0	.460
7	21.1	18.4	.208
8	19.1	18.6	.345
9	18.3	20.6	-
10	21.2	17.3	-
11	18.8	19.1	-
12	15.3	24.7	-
13	16.1	29.6	-
14	17.7	22.0	-
15	17.6	21.5	-
Average	17.7	23.0	

*Best fit of data is to equation $R_o/R_s = S^{1.95}$,

where R_o = Resistivity at 100 % water saturation

R_s = Resistivity at connate water saturation

S = Connate water saturation (as fraction of pore space)

Table 4

Formation Resistivity Factors vs. Porosity

Gallegos Canyon Units, West Kutz Field

Porosity, Per Cent	Formation Resistivity Factor
15	32.6
16	28.7
17	25.3
18	22.6
19	20.3
20	18.3
21	16.6
22	15.1

Table 5

Summary of Conventional and Special Core Analyses

Gallegos Canyon Units, West Kutz Field

				Average Water Saturations			
Well: Unit:	Number of Samples	Porosity, Per Cent	Perm. Md.	Total, % Pore	Calc. Connate, % Pore	Total, % Bulk	Calc. Connate, % Bulk
Conventional Analysis:							
2	15	20.9	2.5*	58.8	49.8	12.3	10.4
4	5	22.4	9.5*	49.7	37.2	11.1	8.3
5	12	22.1	6.1*	66.2	55.7	14.6	12.3
7	12	21.8	5.4*	57.5	45.4	12.5	9.9
Average		21.8	5.9*			12.6	10.2**
Special Analysis:							
2	42	17.0***	<0.1	61.5	61.5	10.4	10.4
3	21	16.6***	<0.1	68.9	68.9	11.4	11.4
4	56	17.9***	<0.1	62.5	58	11.2	10.4
5	75	17.8***	<0.1	72.9	71	13.0	12.6
7	86	18.1***	<0.1	74.8	73	13.5	13.2
Average		17.5***				11.9	11.6**

* Considered most accurate permeability values, for reasons outlined in report

** Note that the average connate water from capillary pressure tests is 10.3 per cent bulk volume

*** Considered the most accurate porosity values, for reasons outlined in report

Table 6

Correlation of Permeability vs. Porosity of Perm Plugs
Taken From Average Curve

Gallegos Canyon Units, West Kutz Field

Porosity, Per Cent	Permeability, Millidarcys
13.0	0.4
14.0	0.8
15.0	1.1
16.0	1.9
17.0	3.4
18.0	5.9
19.0	10
20.0	18
21.0	31
22.0	51
23.0	88