MATERIAL BALANCE ANALYSIS

of the

TOCITO SAND RESERVOIR

for

LOWRY ET AL OPERATING ACCOUNT

MATERIAL BALANCE ANALYSIS

of the

TOCITO SAND RESERVOIR

LOWRY ET AL PROPERTIES

in the

DOGIE CANYON FIELD

RIO ARRIBA COUNTY, NEW MEXICO

As of

August 18, 1952

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AMSTUTZ AND YATES, INC.

October 23, 1952

Mr. Gail F. Moulton
Rockefeller Brothers, Inc.
30 Rockefeller Plaza
New York 20, N. Y.

Dear Sir:

On August 15 you authorized us to make a study of the performance of the Tocito oil reservoir in the Dogie Canyon Field located in Township 26 north, Range 6 west, Rio Arriba County, New Mexico. The object of this analysis was to attempt to determine the magnitude of the reservoir using material balance calculations. The purpose of this letter is to report our conclusions and recommendations and to discuss the calculations briefly.

Our preliminary conclusions, based on the performance data from the discovery of the field in July, 1951, to August 18, 1952, are set forth below.

(1) The entire Tocito sand reservoir of the Dogie Canyon Field originally contained approximately 15,000,000 barrels of stock tank oil in place.

(2) Calculations concerning the relative permeability of the gas to the oil indicate a lower recovery than might normally be anticipated for this type of reservoir. Our best estimate at this time is that a recovery factor on the order of fifteen per cent (95 barrels per acre foot) of the stock tank oil originally

in place may be expected by primary production. This implies a total recovery from the reservoir of approximately 2,200,000 barrels of stock tank oil

(3) Preliminary calculations indicate that the total recovery of casing-head gas from the entire reservoir will be approximately 10 to 12 billion cubic feet. At an assumed price of ten cents per thousand cubic feet, a total gas revenue on the order of $1,000,000 is indicated, provided the gas is marketed.

As a result of our analysis we have the following recommendations to make.

(a) In order to alleviate excessive production rates for the present wells, we reiterate our previous recommendation, made orally to you and Mr. Lowry, that at least one and possibly two additional wells be drilled immediately. In our opinion the first well should be located in the center of the NW/4 NW/4 of Section 9 - T26N-R6W. Final selection of the location for the second well should be held in abeyance pending analysis of the information gained from the first one. Valuable additional data on the reservoir would also be secured by an analysis of a diamond core of the Tocito sand in this well.

(b) In view of the general increase in gas-oil ratios experienced to date and the resultant increased voidage of reservoir space per barrel of oil produced, more accurate gas production data are necessary if future material balance calculations are to be reliable. We therefore recommend that gas-oil ratio tests, at the normal producing rates, be made at frequent intervals on each well.

(c) Because of the short performance history and the incomplete development of the reservoir, the conclusions set forth in this report must be considered preliminary and subject to correction as more performance history becomes available and development of the reservoir progresses. It is our recommendation therefore that upon the completion of the next well the entire field be shut in and another complete bottom hole pressure and gas-oil ratio survey be made, after which our preliminary conclusions of this report should be checked by additional calculations.

(d) Serious consideration should be given to installing a casing-head gas gathering system and compressor to permit selling the gas produced with the oil, since it appears that its value would appromimate one-fifth of the anticipated net operating income to be derived from the future oil production under primary production methods.

(e) If the low recovery efficiency now indicated is corroborated by later analyses, early consideration should be given to a program of pressure maintenance, possibly by water injection, to increase the recoverable oil from the reservoir.

The basic data used in our analysis were furnished by your office and by Mr. Holland of the Lowry Oil Company. The information consisted of the complete production history of each well up to August 18, 1952, initial and periodic gas-oil ratio tests on all wells, initial bottom hole pressure tests on each well, two complete bottom hole pressure surveys made on May 1, and August 18, 1952, productivity tests on several of the wells, interference tests between some of the wells, two bottom hole fluid sample analyses, core analyses of the Tocito sand on two wells, electric logs on all of the wells, a map of the field, and other pertinent information.

The material balance method of reservoir analysis can be most useful, but must be carefully applied if reliable results are to be obtained. Predictions of future reservoir performance and calculations of the amount of active oil in place which are made during the early life of a reservoir, are less accurate than those which are possible from similar calculations made later in the productive life. For this reason it is important that all data used in the calculations be carefully examined and analyzed for accuracy and validity. The three basic factors in all material balance calculations are the pressure-volume-temperature relationships of the reservoir fluids, the reservoir pressures, and the gas, oil, and water production. In the following paragraphs our analysis of these basic data is briefly discussed.

All material balance equations are predicated upon the assumption that the reservoir is in complete pressure equilibrium, that is, that the static reservoir pressures at a given datum are equal throughout the reservoir. Though this is seldom true in actual practice, satisfactory accuracy in the calculations can be obtained if the individual well pressures are properly weighted. Areally weighted average bottom hole pressures are generally satisfactory for this purpose, and this method of averaging was used in this analysis. In order to arrive at a reasonable approximation of the extent of the total reservoir in light of the presently available data, a sand volume (isopachous) map of the net pay thickness was constructed and is included herein as Figure 1. The area enclosed within the zero contour on the isopachous map is 2,730 acres, and this projected total area of the reservoir has been used in determining the areally weighted average bottom hole pressures. All pressures reported to us and used in these calculations were at a subsea datum of 100 feet. The first bottom hole pressure measured on the discovery well (No. 179) was 2,197 pounds per square inch gauge (psig) after a total of 6,000 barrels of oil had been produced. From this and the later performance history, we estimate that the virgin reservoir pressure was 2,200 psig, and this figure was used in our calculations. The first significant bottom hole pressure survey was made May 1, 1952, at which time a total of 129,770 barrels of stock tank oil had been produced from the reservoir. The arithmetic average of the four pressures was 2,100 psig. However, the attached isobaric map (Figure 2) indicates that when these pressures are weighted areally over the entire reservoir, the average reservoir pressure is 2,159 psig, and this figure was used. The next general bottom hole pressure survey was made August 18 to 20, 1952. The arithmetic average bottom hole pressure at that time was 2,041 psig, and the areally weighted average pressure of the reservoir was 2,112 psig. A cumulative oil production of 233,049 barrels had been produced to the time of this survey. The isobaric map (Figure 3) used to determine this average pressure is attached.

A second factor in these calculations was the pressure-volume-temperature relationships of the reservoir fluid as revealed by the two bottom hole fluid sample analyses. The first sample was taken on well No. 132 on January 2, 1952, after the well had been produced for over a month and had then been shut in for 24 hours prior to sampling. The saturation pressure indicated by this analysis was 2,054 psig, the formation volume factor was 1.526 barrels of reservoir oil per barrel of stock tank oil, and the solution gas-oil ratio was 862 cubic feet per barrel. Since the well had been produced at a fairly high rate just previous to being shut in and at a gas-oil ratio materially in excess of the indicated solution gas-oil ratio, the pressure in the well opposite the formation was drawn down considerably below the static reservoir pressure at the time the well was shut in. The shut in period, prior to sampling, of 24 hours is believed to have been insufficient to permit equilibrium conditions to have been reached betweenthe static reservoir and the well bore. Hence it would have been impossible to have obtained a sample of fluid which would be truly representative of the static reservoir fluid. It is our opinion therefore that, while the solubility-shrinkage relationships below the indicated saturation pressure are reliable, the saturation pressure itself could easily be in error by 150 pounds per square inch. For the purpose of checking the original fluid sample analysis, another sample was taken on well No. 182 on August 19, 1952, the results of which apparently corroborated those secured in the first analysis since a saturation pressure of 2,051 psig, a formation volume factor of 1.512 barrels of reservoir fluid per barrel of stock tank oil, and a solubility of 862 standard cubic feet of gas per barrel of stock tank oil were obtained. However, it should be observed that the saturation pressure obtained by the laboratory analysis could not exceed the bottom hole pressure at the point of sampling so long as the sample was representative of equilibrium conditions at that pressure. This can be seen readily from the fact that, had the original saturation pressure been greater than the sampling pressure, some gas would have been evolved from the fluid at the sampling point, but that gas would have separated out and moved on up the hole prior to sampling. Hence, the sample can be representative of sampling conditions only, and the similar sampling conditions can account nicely for the agreement in the bottom hole sample analyses. In addition, practically all gas-oil ratios have been materially in excess of the solution gas-oil ratio at the saturation pressure. Likewise, other tangible evidence from some of the calculations points to a reservoir fluid which was saturated at virgin reservoir conditions. We therefore believe that the oil in the reservoir was saturated at the original reservoir pressure of 2,200 psig, and this saturation pressure has been assumed in the material balance calculations reported herein.

A series of four material balance calculations were made on the Tocito reservoir covering the performance up to August 18, 1952. In all of these calculations the Schilthuis formula and nomenclature were used. In the following paragraphs each of these calculations is briefly discussed and the basic conditions and assumptions and answers derived therefrom are set forth.

The first of these calculations covers the entire producing life of the field from July, 1951, to August 18, 1952. It assumes that there was no gas cap present initially, and that there is no effective water drive in the reservoir. The original saturation pressure used was 2,200 psig and the solubility obtained by extrapolating the fluid sample analysis of Well No. 182 to 2,200 psig indicated a solution gas-oil ratio of 923 standard cubic feet per barrel of stock tank oil. The formation volume factor curve on the above mentioned analysis was also extrapolated to 2,200 psig and was 1.542 at this pressure. The total gas production was estimated to be 282,100,000 standard cubic feet, as determined by the various gas-oil ratio surveys. Since the cumulative oil production was 233,049, the cumulative gas-oil ratio was 1,210 standard cubic feet per barrel of stock tank oil. On this basis the total volume of stock tank oil originally in place in the Tocito reservoir was calculated to be 13,800,000 barrels.

The second material balance calculation covered the period from the intiial discovery of the field to May 1, 1952. The average reservoir pressure on that date was 2,159 psig and the cumulative oil production was 129,770 barrels while the estimated cumulative gas production was 139,000,000 standard cubic feet. Except for these items, the other basic figures and assumptions of the first calculation were used here. The total volume of stock tank oil originally in the reservoir was calculated to be 14,100,000 barrels.

The third calculation covered the period from May 1 to August 18, 1952. During this time the average reservoir pressure dropped from 2,159 pounds to 2,112 psig and 103,279 barrels of stock tank oil were produced. The total gas production during the same period amounted to 143,000,000 standard cubic feet. These calculations indicated that 10,500,000 barrels of stock tank oil were originally in place in the reservoir.

In view of the relatively low pressure drop covered by these calculations, amounting to 8.5, 1.9, and 2.1 per cent of the total initial reservoir pressure, we believe that the agreement in the answers is good.

However, it should be realized that these answers are probably minimum figures, and it is our opinion that the actual total volume of stock tank oil originally in place in the reservoir is approximately 15,000,000 barrels.

A fourth material balance calculation was made assuming that the saturation pressure of the oil was 2,054 psig, and that inasmuch as the latest pressure survey revealed a static average bottom hole pressure of 2,112 psig, the entire production up to August 18, 1952, had resulted from liquid expansion of the reservoir fluids. These calculations indicated that there were originally 136,000,000 barrels of stock tank oil in place in the reservoir. Based on core analysis data, this volume of oil would require 215,900 acre feet of net reservoir volume. If the average thickness of the reservoir were assumed to be 10 feet, a total productive area of 33.7 square miles would be required to contain this oil. In light of our present knowledge of the reservoir, this size does not appear to be reasonable.

Prior to our material balance calculations, we analysed the two core analyses available on the Tocito sand and electric logs on all the other wells and prepared an isopachous map of the net sand pay, and this is attached (Figure 1) to this report. The total volume of pay sand included in the reservoir, as projected, was 24,100 acre feet. The two core analyses available indicated an average porosity of 16 per cent and a connate water saturation of 22 per cent. The formation volume factor used in our material balance work (1.542 barrels of reservoir oil per barrel of stock tank oil) was applied here. On this basis, 630 barrels of stock tank oil per acre foot were calculated to have been in place in the reservoir originally. Applying these figures, the total volume of stock tank oil originally in the reservoir is 15,200,000 barrels. This figure corroborates the results of the first three material balance calculations.

By use of material balance it is also possible to make reasonable predictions of the performance characteristics of the field once the developmental phase is past. This presupposes that the necessary data are obtained which, beside all those already innumerated, include relative permeability data on the reservoir rock. A number of exhaustive relative permeability studies have been made on other reservoirs, and where such data are not available on the reservoir being analyzed, the usual practice is to select a Kg/Ko versus fluid saturation curve from what is considered a similar reservoir rock. Later a Kg/Ko curve can be constructed from the actual field performance and this curve can then be utilized to complete the prediction.

We have made a calculation of the Kg/Ko relationship for the Dogie Canyon Tocito reservoir assuming the initial active oil in place was 10,200,000 (note that this is the lowest of the several calculations and would give the highest gas-oil ratio predictions). The free-gas saturation in the reservoir on August 18, 1952, was calculated to be 2.7 per cent and the corresponding Kg/Ko was 0.023. The actual gas-oil ratio is unusually high for such a low free-gas saturation and from our knowledge of the performance of other reservoirs a low primary recovery is implied.

Conservation of the reservoir energy to permit improving the low per cent recovery indicated is of paramount importance. This will require careful study to determine the optimum flowing rates (minimum gas-oil ratios and drawdowns of bottom hole pressure). The magnitude of possible benefits seems to justify the necessary field tests and application of production rates thus determined as best. The low per acre yield suggested by our estimate of 2,200,000 barrels of oil to be recovered by primary means, will require wide spacing of wells in order that the over all program will have shown a profit commensurate with the risks. The recommendation to drill in the center of the NW/4 NW/4 of Section 9 constitutes a recommendation to continue development on a spacing of 160 acres per well. This procedure could be modified when the economics of closer spacing are better known.

Pressure maintenance by return of gas to the reservoir does not appear to be attractive. The rapid rise in gas-oil ratios are indicative of higher gas saturation near the wells, which has resulted from producing the wells at high rates. Thus a wide variation in gas saturations in the reservoir must be expected to develop as time goes on, which would tend to promote gas channelling and ineffective recycling. Water injection in structurally low wells might be beneficial if sufficient quantities of water can be handled.

The detailed calculations discussed in this report are available in our office if you care to review them with us.

Yours very truly,

AMSTUTZ AND YATES, INC.

/s/ George L. Yates

George L. Yates

cc: Mr. Tim G. Lowry
Eckert, Peterson & Leeming
135 South La Salle Street
Chicago, 3, Illinois

FORM F-11A

CORE LABORATORIES, INC.

Petroleum Reservoir Engineering

DALLAS

File FNML-56 FC

Well Federal 22-45-207

CORE SUMMARY AND CALCULATED RECOVERABLE OIL

CORE SUMMARY

FORMATION NAME	Tocito			
DEPTH, FEET	6644.0-6661.0			
% CORE RECOVERY	100	12'		
FEET OF PERMEABLE, PRODUCTIVE FORMATION RECOVERED	12.0			
AVERAGE PERMEABILITY MILLIDARCYS	78			
CAPACITY — AVERAGE PERMEABILITY × FEET PRODUCTIVE FORMATION	936			
AVERAGE POROSITY, PERCENT	16.8			
AVERAGE RESIDUAL OIL SATURATION, % PORE SPACE	22.2			
GRAVITY OF OIL, °A.P.I.	40			
AVERAGE TOTAL WATER SATURATION, % PORE SPACE	24.5			
AVERAGE CALCULATED CONNATE WATER SATURATION, % PORE SPACE	22			
SOLUTION GAS-OIL RATIO, CUBIC FEET PER BARREL (1)	790			
FORMATION VOLUME FACTOR—VOLUME THAT ONE BARREL OF STOCK TANK OIL OCCUPIES IN RESERVOIR (1)	1.46			

CALCULATED RECOVERABLE OIL

Prediction dependent upon complete isolation of each division. Structural position of well, total permeable thickness of oil zone and drainage area of well should be considered.

BY NATURAL OR GAS EXPANSION, BBLS. PER ACRE FOOT (2)	154			
INCREASE DUE TO WATER DRIVE, BBLS. PER ACRE FOOT	253			
TOTAL AFTER COMPLETE WATER DRIVE, BBLS. PER ACRE FOOT (3)	407			

Core Laboratories, Inc.

J D Harris (PG)

J. D. Harris

NOTE:

(*) REFER TO ATTACHED LETTER.

(1) REDUCTION IN PRESSURE FROM estimated SATURATION PRESSURE TO ATMOSPHERIC PRESSURE.

(2) AFTER REDUCTION FROM ORIGINAL RESERVOIR PRESSURE TO ZERO POUNDS PER SQUARE INCH.

(3) RESERVOIR PRESSURE MAINTAINED BY WATER DRIVE AT OR ABOVE estimated ORIGINAL SATURATION PRESSURE.

(4) NO ESTIMATE FOR GAS PHASE RESERVOIRS.