Bureau of Mines
Report of Investigations 5106

A NEW METHOD OF DETERMINING VARIATIONS IN PHYSICAL PROPERTIES OF OIL IN A RESERVOIR, WITH APPLICATION TO THE SCURRY REEF FIELD, SCURRY COUNTY, TEX.

BY ALTON B. COOK, G. B. SPENCER, F. P. BOBROWSKI, AND TIM CHIN

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UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary
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Alton B. Cook,[1/] G. B. Spencer,[1/] F. P. Bobrowski,[1/] and Tim Chin[1/]

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INTRODUCTION

In the Scurry Reef field, Scurry County, Tex., a study was made to determine the physical properties of the oil in all parts of the reservoir by a new method developed for this study. The method involved correlation of data from a survey of the gravity of the produced oil, from measurements of gas-oil ratios on key wells selected to give representative data for the entire reservoir, and from laboratory analyses of reservoir oil samples. A field survey was made of the API gravities of the produced oil by testing oil samples from 107 key wells. Precise gas-oil-ratio tests were made on 45 key wells that were producing under comparable separator-operating conditions. Subsurface-oil samples were obtained from seven wells, selected to provide reservoir oils ranging approximately from a minimum to a maximum in saturation pressure. The physical properties of the subsurface-oil samples were determined, and correlations were made of these laboratory data with the field gas-oil-ratio test data. These correlations were then used to estimate physical properties of the oil throughout the reservoir.

A logical procedure of determining the variations in physical properties of reservoir oils in most fields is to obtain and analyze subsurface-oil samples from enough key wells to provide an ample coverage of the field. Under this procedure, data from a large number of samples would be needed to provide the desired information on the Scurry Reef field, as it is one of the largest known in the United States.

The Scurry Reef oil reservoir is about 25 miles long and ranges from 4 to 7 miles in width. This reservoir comprises 2 areas, the Kelly-Snyder and the Diamond M, with 1,660 productive wells on approximately 67,000 acres. The discovery well in the Kelly-Snyder area was the Standard of Texas, Jessie Brown No. 2-1, completed November 19, 1948, about 9 miles north of Snyder, Tex. The discovery well in the Diamond M area was the Lion Oil Co., C. T. McLaughlin well No. 2, completed December 19, 1948, about 12 miles southwest of Snyder.

Data on subsurface-oil samples from the Scurry Reef field were available from industry, but small variations shown in these analyses in the physical properties of the oil from different parts of the reservoir could not be relied upon because standardized equipment and analytical techniques had not been adopted. For the same reason these data could not be used to supplement data obtained by Bureau engineers. As too much time would have been necessary to obtain the desired information by taking and analyzing enough reservoir oil samples, the new procedure was developed by necessity.

Analyses of subsurface-oil samples, with data on reservoir pressures and temperatures, showed that the Scurry Reef reservoir oil was initially undersaturated with gas. Thus, when the flowing bottom-hole pressure during a well test was above the saturation pressure of the reservoir oil, the gas produced would be entirely solution gas that had been liberated from the reservoir oil after it had entered the well bore of the producing well. Therefore, the production gas-oil ratio under these conditions also would be the solution gas-oil ratio; and variations in production gas-oil ratios, as well as API gravities of the produced oil, from wells throughout the Scurry Reef area would be indicative of variations in the physical properties of the reservoir oil. However, it was recognized that the surface equipment and the method of operating it could cause appreciable differences in production gas-oil ratios and oil gravities. Thus, comparable data could be obtained only by applying standardized testing procedures, such as were used throughout this study.

SUMMARY OF RESULTS

Normal differences in either separator pressure or temperature as found in the Scurry Reef field materially influenced the measured production gas-oil ratios, stock-tank-oil gravities, separator-gas gravities, and relative oil volumes (formation-volume factors). For example, the gas-oil ratio for a well under test was found to be 744 cubic feet per barrel when producing through 2 separators operating in series and without external heat added; the gas from both separators was included. In another test on this well, the gas-oil ratio was 1,068 cubic feet per barrel when the produced fluid was heated before it entered the single separator being used - an increase of 44 percent in the measured gas-oil ratio. The effect of varying separator temperatures was determined from field gas-oil-ratio tests, and the effect of varying separator pressures was determined from flash-gas-liberation experiments conducted in the laboratory on portions of the subsurface-oil samples.

A study of the well-test and well-completion data indicated that there is a trend in the form of gravitational concentration gradients[2] (a progressive decrease in the mole fraction of the gases from methane through the butanes with increasing depth in the reservoir, accompanied by a corresponding increase in the amount of the heavier components making up the system) in the physical properties of the reservoir oil in the northern part of the Scurry Reef field (the Kelly-Snyder area). Each of the gas-oil ratios obtained from testing 45 wells was corrected to operating separator conditions of 40 p.s.i. pressure and 60° F. A plot of gas-oil ratio against the weighted average subsea depth of the reef formation open to production indicated that oil in the top of the reef contained more gas than did that near the oil-water contact in the Kelly-Snyder area. The variation amounted to 46 cubic feet of separator gas per barrel of stock-tank oil for 100 feet change in subsea depth.

Each of the gas-oil ratios obtained in the field was corrected for the gravitational concentration effect to a depth of 4,300 feet subsea, the datum point established by the Texas Railroad Commission for reservoir-pressure measurements. A study of these ratios shows considerable difference between the solution-gas content of the reservoir oil in three different areas of the field. The average gas-oil ratio was 838 cubic feet per barrel in the Kelly-Snyder area, 954 in the northern part of the Diamond M area, and 1,001 in the southern part of the Diamond M area. The oil-gravity data indicate a comparable difference in physical properties of the reservoir oil, as the average of the oil gravities in the Diamond M area was 43.5° API, as compared to 42.6° API in the Kelly-Snyder area.

Drilling and production records indicate that the Scurry Reef formation is continuous and oil-productive from the northeastern part of the Kelly-Snyder area to the southwestern part of the Diamond M area. Conversely, data obtained from the gas-oil-ratio survey and the oil-gravity survey indicate either that the reservoir is not continuous throughout the reef or that equilibrium or a near state of equilibrium conditions have not been established in the reservoir fluid. The limited data now available indicate that oils of different physical characteristics

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2/ Sage, B. H., and Lacey, W. N., Gravitational Concentration Gradients in Static Columns of Hydrocarbon Fluids: Petrol. Technol., Tech. Paper 1004, November 1938, 12 pp.

may either have migrated into or were formed within the Scurry Reef, and establishment of equilibrium conditions in the reservoir fluid has been prevented or restricted by a relatively impermeable section in the reef formation across the northern part of the Diamond M area.

Gas-oil-ratio data obtained by the Bureau are lacking in the northern part of the Diamond M area, where reservoir pressures had declined below the saturation pressures of the oil before the well tests were begun in May 1951. Although the exact location or the amount of gradation in the physical properties of the reservoir oil from one end of the reservoir to the other could not be determined from the gas-oil-ratio data, the gradation is indicated by the oil-gravity data. These data show that the gravities of oil produced in most of the Diamond M area are about 0.9° API higher than in the Kelly-Snyder area. The data indicate that the major changes in physical properties of the Scurry Reef reservoir oil from the southern part of the Diamond M area to the northern part of the Kelly-Snyder area occur in sections 199, 200, 201, 202, 203, and 194, Block 97, H & TC R.R. Co. survey.

Data from the laboratory tests on the subsurface-oil samples obtained from seven wells indicate that the physical properties of the oil throughout the reef reservoir have only minor differences, with the differences being directly related to the saturation pressure of the reservoir oil. The saturation pressures of the reservoir oil at 132° F., the average reservoir temperature of 32 wells tested, were 1,797, 1,816, 1,838, 1,855, 1,856, 1,910, and 1,975 p.s.i.a. for the 7 wells sampled.

A family of curves, with corresponding tables, was constructed from correlations of the physical properties of the oils with saturation pressures of the oils to present the data for 5 hypothetical oils having saturation pressures of 1,750, 1,850, 1,950, 2,050, and 2,150 p.s.i.a. This information was needed for estimating physical properties of the reservoir oil having saturation pressures differing from those sampled.

Production gas-oil ratios were correlated with saturation pressures of the reservoir oil. From these correlations the saturation pressures can be determined readily for the reservoir oil being produced from each of the 45 wells during the time the gas-oil-ratio tests were made. Then, with the saturation pressures of the reservoir oils represented by the 45 wells available, the physical properties of the reservoir oils from the 45 wells can be determined by referring to the appropriate tables and figures.

ACKNOWLEDGMENTS

Determination of the physical properties of the reservoir oil in the Scurry Reef was part of a joint study by the Bureau of Mines and the Geological Survey of the reef fields in Scurry County, Tex., undertaken at the request of the Petroleum Administration for Defense.

The Bureau of Mines wishes to acknowledge the wholehearted cooperation of the management of the 25 operators for making wells available for testing and to their field personnel for arranging for the tests.

DESCRIPTION OF SAMPLING AND TESTING PROCEDURE FOR OIL-GRAVITY SURVEY

The locations of wells sampled for the oil-gravity survey of the Kelly-Snyder and Diamond M areas are given in figure 1. A near uniform geographical spread of the field was obtained by sampling 107 key wells.

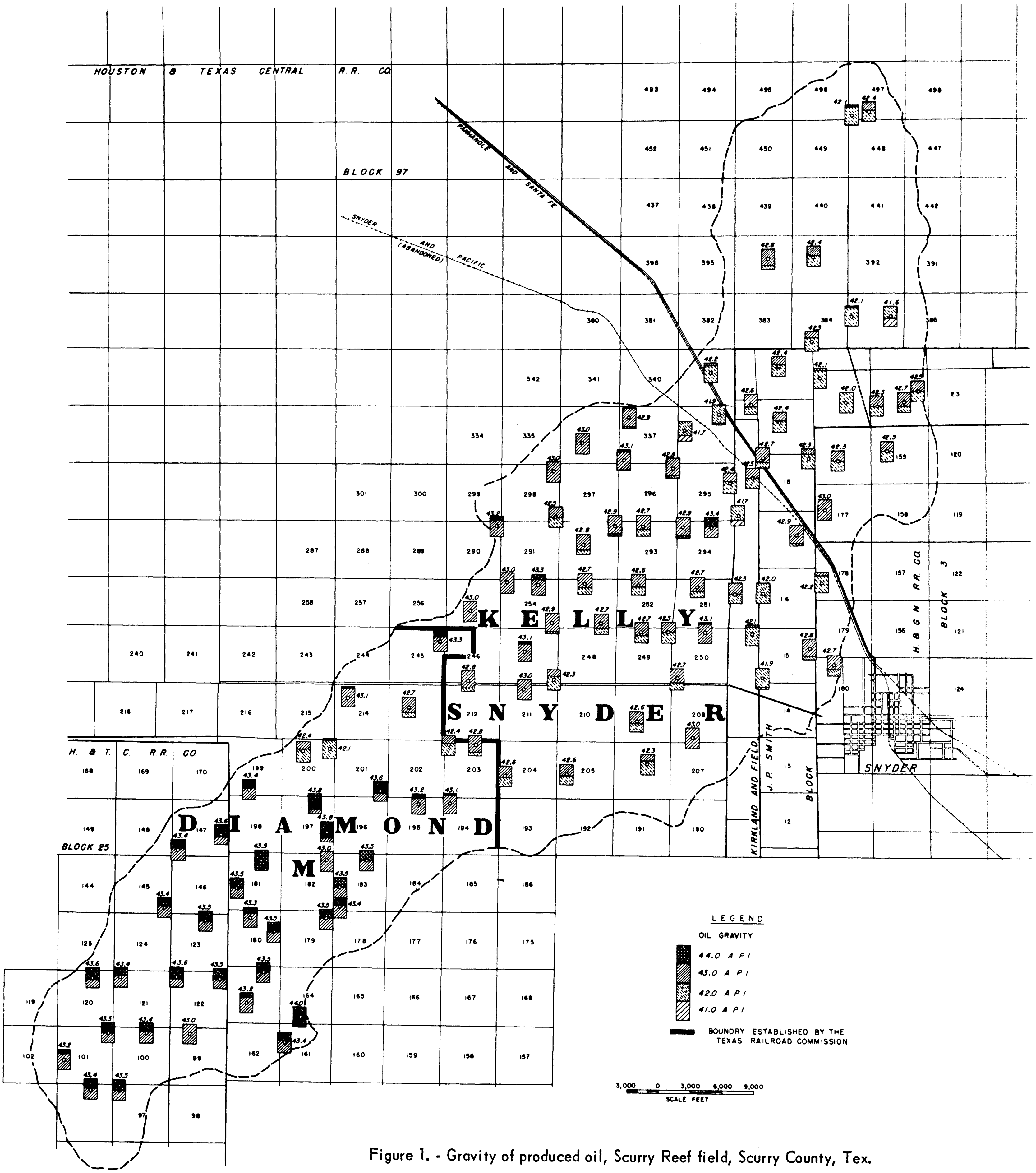

Figure 1. - Gravity of produced oil, Scurry Reef field, Scurry County, Tex.

The crude oil samples were obtained from separators adjusted to operate at 40 p.s.i. and with the wells flowing at a rate of approximately 80 barrels of stock-tank oil a day. If a test separator was not available, all wells producing through the lease separator were closed in except the well to be sampled, which was allowed to produce until the separator was thoroughly flushed before sampling. Also, heaters, if in use on the lease, were bypassed.

Two 1-quart samples of the oil were obtained from each well sampled; 1 quart was used immediately for the gravity determination and the other held in reserve. The samples generally were taken from the bottom drain valve of the gage glass on the separator while liquid level in the gage glass was maintained to prevent release of free gas; in a few exceptions where this procedure was not possible, the sample was obtained through an improvised separator connected to the bleeder valve on the wellhead.

The temperature of the oil passing through the separator could not be controlled, except for preventing elevated temperatures by eliminating heaters. Variations in atmospheric temperature and sunshine resulted in relatively wide variations in the temperature of the oil in the separators. This applied especially where lead lines were buried as compared with those exposed on the surface of the ground. To prevent serious discrepancies in the gravities of oil sampled at various temperatures, before the gravity determination the oil samples were stabilized in a constant-temperature water bath at 100° F. until no additional gas was released from the oil with agitation. The oil samples were then cooled in a water bath to approximately 70° F. and the gravity obtained with a large-scale hydrometer; all gravities subsequently were corrected to 60° F.

DISCUSSION OF OIL-GRAVITY DATA

The API gravity of oils taken from the wells listed in table 1 does not necessarily represent the gravity of the stock-tank oil. The standardized procedure of obtaining the samples and determining their gravity did not duplicate any of the field producing procedures and for that reason direct comparisons cannot be made between experimentally determined gravities and the gravity of oil obtained under field-production procedures.

The data on oil gravity in table 1 include the name of the operator, the lease name, the well location and number, the temperature of the oil in the separator when sampled, the gravity of a composite sample of stock-tank oil produced from the lease, and the gravity of the oil produced from the specific well sampled under controlled conditions. The gravity of the composite samples taken from the stock tanks is not of particular significance in this survey. However, it indicates to some extent the effect on gravity of variations in methods of heating and separation.

The map of the area surveyed (fig. 1) shows the wells sampled, with the gravity data from table 1 plotted. Lack of correlation in the gravity of the oil from a few wells with oil from wells in the immediate vicinity is illustrated. However, in general the gravities of oil from wells in the Kelly-Snyder area agree, the average being 42.6° API. The change in API gravities from the Kelly-Snyder area through the Diamond M area is evident in secs. 199, 200, 201, 202, 203, and 194, Block 97, H & TC R.R. Co survey. The gravities of oil south of this general area in Diamond M are in good agreement, the average being 43.5° API. The difference of 0.9° API (43.5 - 42.6) between the average gravity of the oils in the Diamond M area and the Kelly-Snyder area indicates a difference in the physical properties of the reservoir oils.

TABLE 1. - Oil gravity survey of the Scurry Reef Field, Scurry County, Tex.

Location Blk.	Location Sec.	Operator	Lease	Well No.	Sepr. temp., °F.	Oil Gravity, °API Oil from sepr.	Oil Gravity, °API Stock-tank oil
1	21	Barnsdall-Sunray	Womack	2	1/50	42.0	42.8
1	22	do.	L. S. Sental	5	1/70	42.5	43.1
1	18	Castleman And	Browning	1	1/65	42.7	44.8
3	177	O'Neill	Crowder	1	1/65	43.0	43.8
K&F	39	Cities Service	Austin	2	79	42.1	43.5
1	16	do.	Von Roeder	2	82	42.0	43.2
97	392	do.	Jolly	7	80	42.4	43.6
97	200	do.	Johnson "H"	2	92	42.1	43.1
97	2000	do.	do.	6	85	42.1	42.4
97	183	Hiawatha	Wilson "A"	1	70	43.5	40.8
97	183	do.	do.	2	1/70	43.4	40.8
3	180	do.	J. A. Clark	1	83	42.7	42.8
97	294	do.	Lewis	2	70	43.4	41.2
25	147	Honolulu	Strom	5	68	43.4	42.4
97	247	General Crude	Land	3	77	42.3	43.7
97	163	Humble	Wright Huddleston	6	70	43.2	44.7
25	99	do.	Ainsworth	1	80	43.0	43.5
25	100	do.	Sorrels	2	90	43.4	44.2
97	161	do.	Walker Huddleston "B"	3	86	43.4	44.6
25	97	do.	Richter	1	75	43.5	44.1
25	96	do.	do.	3	80	43.4	44.8
25	96	do.	Sorrels	6	65	43.6	44.1
97	199	Lion	Strom	22	78	43.4	42.4
97	201	do.	McLaughlin "3"	28	1/60	43.6	43.2
97	197	do.	McLaughlin	19	60	43.8	44.4
97	182	do.	do.	4	60	43.0	43.5
97	181	do.	Oldenbusch	2	60	43.9	43.6
25	147	do.	Zelma	2	64	43.6	43.4
97	183	do.	Thurston	1	50	43.5	43.4
97	197	do.	McLaughlin	3	50	43.8	44.4
97	164	do.	Marchbank	1	45	44.0	43.7
97	181	do.	Oldenbusch	8	60	43.5	43.6
1	17	Lone Star	R. W. Webb	5	75	42.9	42.5
K&F	40	do.	Von Roeder	4	1/79	42.5	42.7
97	253	do.	Bynum	4	80	42.7	42.7
97	253	do.	Davis A	1	1/60	42.7	43.3
97	255	do.	Davis B	3	1/60	43.0	42.2
97	209	Magnolia	Eicke	3	72	42.6	43.2
97	206	do.	Rosson B	3	73	42.3	43.0
97	292	do.	R. A. Smith	3	78	42.9	43.5
97	292	do.	Shuler	6	77	42.8	43.2
97	298	do.	McDonnell "H"	1	79	43.0	44.3
97	336	do.	McDonnell "B"	1	83	43.C	43.5
97	338	do.	Thrane "B"	2	78	41.7	42.4
97	294	do.	Noble	8	72	42.9	42.6
97	208	do.	Tate	4	62	43.0	42.9
97	250	do.	Lyons	4	62	43.1	42.7
97	338	do.	Van Winkle	6	61	41.9	43.2
1	19	do.	Collins	4	60	41.1	43.0
97	259	do.	McClinton	4	66	42.4	42.6
1	18	do.	Mimmie Smith	1	66	42.3	43.0
1	15	Moncrief et. al.	Harrell	4	78	41.9	42.8
3	178	do.	Country Club	2	71	42.2	41.6
1	15	do.	Joyce	6	69	42.8	42.4
97	249	Ohio	Hays	2	79	42.7	42.8
97	211	Pan American	J. E. Perry	1	60	43.0	44.4
97	254	do.	C. E. McCormick	1	62	42.9	43.2
97	254	do.	do.	6	56	43.3	43.2
97	254	do.	do.	9	60	43.0	43.2
97	247	do.	Casstevens	1	65	43.1	42.1
97	249	do.	Davis	2	53	42.5	44.2
97	394	Pure	C. V. Whatley	5	1/75	42.8	43.8
97	245	do.	Nellie Williamson	3	80	43.3	43.4
25	121	Shell	Thompson	8	79	43.4	43.9
97	250	Skelly	Harrell	1	70	42.7	44.1
97	290	do.	Head "A"	2	80	43.2	42.4
97	252	do.	Marg Fesmire	4	70	42.6	44.0
25	123	R. E. Smith	Clark	3	72	43.5	42.9
25	145	do.	Key	16	72	43.4	44.4
25	120	do.	Thompson "B"	17	74	43.6	44.1
97	298	Stanolind	Fowler	1	76	42.5	43.5
97	179	do.	McLaughlin	1	76	42.1	42.1
97	385	Sun	H. J. Brice	3	83	42.1	43.4
97	385	do.	do.	16	89	41.6	42.3
97	203	do.	Voss	1	75	42.8	43.1
97	203	do.	do.	3	80	42.4	43.0
97	204	do.	Bynum	2	72	42.6	42.8
97	194	do.	Fenton	2	77	43.1	43.4
97	195	do.	Rosenberg	7	77	43.2	43.0
97	205	do.	Lemons	4	80	42.6	42.7
3	159	Sunray	P. W. Cloud	3	1/50	42.5	42.5
1	21	do.	R. B. Brown "B"	4	??	42.1	44.0
3	160	do.	J. W. Newton	1	??	42.5	43.6
1	20	do.	Wren	2	72	42.4	43.5
1	19	do.	Collins	1	68	42.6	43.6
97	293	do.	Schulz	2	80	42.7	43.9
97	337	do.	Dennis	1	75	43.1	43.9
97	337	do.	do.	8	76	42.9	43.8
K&F	40	do.	Guy Stoker	3	1/45	41.7	42.8
97	339	do.	L. A. Hill	3	1/45	42.2	42.0
97	296	do.	Hardy "A"	2	1/50	42.8	43.1
97	246	do.	Williamson	1	1/60	42.8	43.0
25	101	do.	C. V. Thompson	8	75	43.2	42.6
25	122	Superior	Addison	1	70	43.5	43.3
25	122	do.	do.	4	70	43.6	43.8
97	163	do.	McLaughlin	2	68	43.5	44.5
97	180	do.	do.	8	72	43.5	44.2
97	180	do.	do.	3	74	43.3	44.0
97	497	Texas Co.	P. L. Fuller	1	1/65	42.1	41.8
97	497	do.	do.	11	1/65	42.4	41.8
97	213	do.	Holt	4	86	42.7	43.3
97	384	Tide Water	R. House	2	74	42.3	44.8
1	22	do.	F. G. Sears	4	76	42.5	44.6
1	22	do.	do.	8	76	42.7	44.6
97	214	do.	Pollard	4	72	43.1	42.4
25	101	Warren	Reynolds	3	75	43.5	44.5
97	251	Wilshire	Rinehart	1	80	42.7	44.8

1/ Estimated temperature.

DESCRIPTION OF TESTING PROCEDURE FOR GAS-OIL-RATIO SURVEY

Although surface equipment varied widely, oil and gas from the wells on a lease generally flowed to a manifold, where the production from any specified well could be directed through a single separator. During some tests all lease wells, except the one to be tested, had to be shut in. Where more than one well was on a lease and all wells were connected to a common manifold, the separator and flow system were tested for leaks to prevent fluid from entering or leaving the test system.

The gas was measured with an orifice meter when a test meter run was available; otherwise, the gas was measured through a critical-flow prover[3] and vented to the atmosphere. A typical installation for metering gas with an orifice meter is shown in figure 2. The oil production was gaged in a stock tank four or more times during each test. Before each gage, the separator was dumped to a specified common level so that oil-production rate would not be influenced by differences of oil volumes in the separator and to allow ample time for checking stock-tank gages. The temperature of the stock-tank oil was determined at the time of gaging. Stock-tank-oil gravities were determined at the start and completion of each test. The temperature of the fluid entering the separator and of the gas being metered was determined by calibrated recording thermometers. The specific gravity of the separator gas was determined once during each test with an ACME gravity balance. The static pressure-recording pen of the orifice meter and the pressure recorder used with the critical-flow prover were checked with a portable dead-weight tester (piston gage), accurate to ±0.1 p.s.i. The differential pressure-recording pen of the orifice meter was checked with a water manometer while the meter was in actual operation.

The gas-oil-ratio tests were made while producing through a single separator operated at an approximate pressure of 40 p.s.i. When the average separator pressure deviated from 40 p.s.i. and the average separator temperature deviated from 60° F., appropriate correction factors, discussed later, were applied to the results so that the arbitrarily selected standardized conditions of separator pressure and temperature of 40 p.s.i. and 60° F. could be met.

Wells for testing were selected based upon the following considerations: (1) Locations that would give a representative coverage of an area; (2) flowing bottom-hole pressure above the saturation pressure of the oil; (3) adequate lease surface equipment to permit reliable gas-oil-ratio test; and (4) availability of clearance and well-completion data from the operator. The reservoir pressure within most of the northern part of the Diamond M area was below the saturation pressure of the oil (during the period from May to September 1951), with the result that only three reliable gas-oil ratios were obtained in that area.

Subsurface pressure and temperature data were obtained on 32 of the 45 reported well tests to confirm that the flowing bottom-hole pressures were above the saturation pressure of the reservoir fluid. (An average of the 32 reservoir temperatures at 4,300 feet subsea was 132° F.) Pressure and temperature measurements were not made on 13 wells tested because company data indicated definitely that the flowing bottom-hole pressures were well above the saturation pressure of the reservoir fluid. Data on two wells tested were not included in this report because the measured flowing bottom-hole pressures were below the saturation pressure of the reservoir oil.

3/ Rawlins, E. L., and Shellhardt, M. A., Back-Pressure Data on Natural-Gas Wells and Their Application to Production Practices: Bureau of Mines Mono. 7, 1936, pp. 117-125.

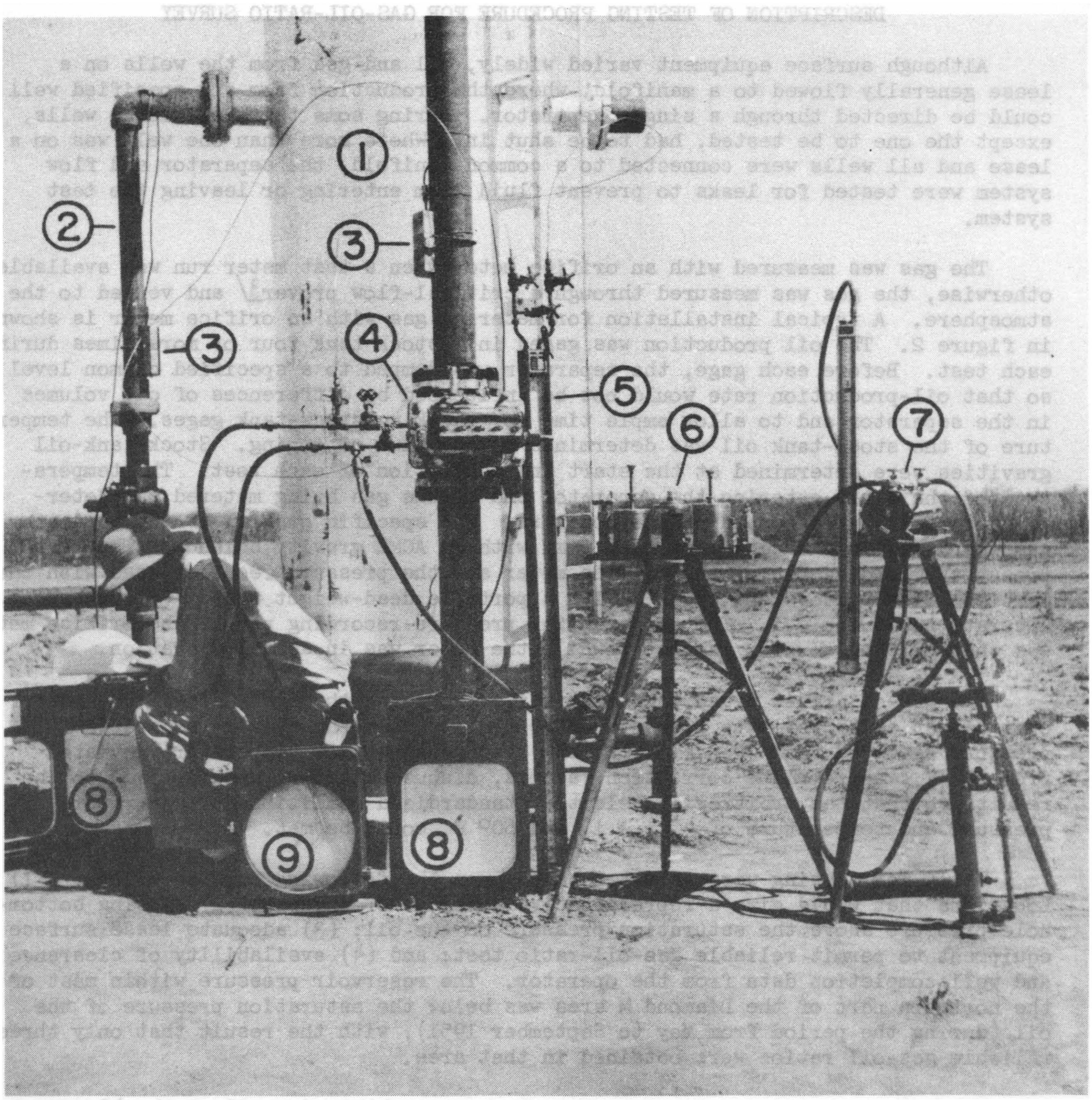

Figure 2. - Equipment used in metering separator gas.

(1) Gas-oil separator. (2) Fluid inlet. (3) Wooden insulator (housing for temperature recorder bulb). (4) Orifice meter flange. (5) Water manometer (designed for high-pressure use). (6) Portable deadweight piston pressure gage. (7) ACME gas-gravity balance. (8) Temperature recorder. (9) Portable orifice meter.

DISCUSSION OF GAS-OIL-RATIO DATA

The production gas-oil ratio of a well producing from an undersaturated oil reservoir (the initial pressure in the Scurry Reef reservoir was more than 1,000 p.s.i. greater than the saturation pressure of the reservoir oil) also is the solution gas-oil ratio of the reservoir oil. Therefore, comparisons of production gas-oil ratios from key wells throughout the Scurry County Reef area should indicate variations, if any, in the physical properties of the reservoir oil. However, detection of small variations was not expected unless the gas-oil ratios were obtained under comparable conditions of separator pressure and temperature. During each well test the gas-oil-separator pressure was maintained as close to 40 p.s.i. as possible. The lowest average pressure during a test was 28.0 p.s.i. and the highest 48.3 p.s.i. The average temperature ranged from a minimum of 64° F. to a maximum of 98° F., with no attempt to control temperature. Each gas-oil ratio was corrected to a common base of operating separator pressure and temperature of 40 p.s.i. and 60° F. by applying appropriate correction factors that were obtained from tests of the reservoir oil (figs. 3 and 4).[4]

Pertinent data on 45 well tests are shown in table 2. The first 34 wells listed in the table are in the Kelly-Snyder area, the next 3 wells are in the northern part of the Diamond M area, and the last 8 wells are in the southern part of the Diamond M area. The observed gas-oil ratios were corrected to the arbitrarily chosen standardized conditions of 40 p.s.i. pressure and 60° F. temperature by using the correction curves shown in figures 3 and 4.

The average subsea producing depth for each of the wells tested was estimated from electric logs and plotted against the appropriate gas-oil ratio (corrected to standard conditions), as shown in figure 5. These data points are grouped into three general production areas: (1) Kelly-Snyder; (2) northern part of Diamond M; and (3) southern part of Diamond M. A straight-line curve was drawn through the data points for the Kelly-Snyder wells; the curve was fitted through application of the method of "least squares," in which equal weight was given to the accuracy of both the abscissa and ordinate values. The data in figure 5 indicate that the reservoir oils differ in physical properties from those of the Kelly-Snyder area through the northern and southern parts of the Diamond M area. The curve for the Kelly-Snyder area shows the solution-gas content of the reservoir oil at depth of 4,300 feet subsea, when flashed to a separator pressure of 40 p.s.i. and a temperature of 60° F., to be 838 cubic feet per barrel of stock-tank oil for the Kelly-Snyder area. The slope of the curve indicates a variation in solution-gas content of the reservoir oil with depth, there being a decrease of 46 cubic feet per barrel for each 100-foot increase in subsea depth. On the assumption that the solution-gas content of the reservoir oil changed with depth for the Diamond M area the same as for the Kelly-Snyder area, the solution-gas content of the reservoir oil at 4,300 feet subsea was 954 cubic feet per barrel for the northern part and 1,001 for the southern part of the Diamond M area.

Lack of conformance in the data points to the gas-oil-ratio curve for wells in the Kelly-Snyder area (fig. 5) results from inaccuracies in gas measurement of possibly plus or minus 3 percent in combination with inaccuracies of selecting the average producing depths of the wells. The data in figure 5 also are presented in figure 6 with vertical lines defining the section of the Scurry Reef open to

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4/ Cook, Alton B., Spencer, G. B., Bobrowski, F. P., and Chin, Tim, Changes in Gas-Oil Ratios With Variations in Separator Pressures and Temperatures: Petrol. Eng., vol. 26, No. 3, March 1954, pp. B77-B82.

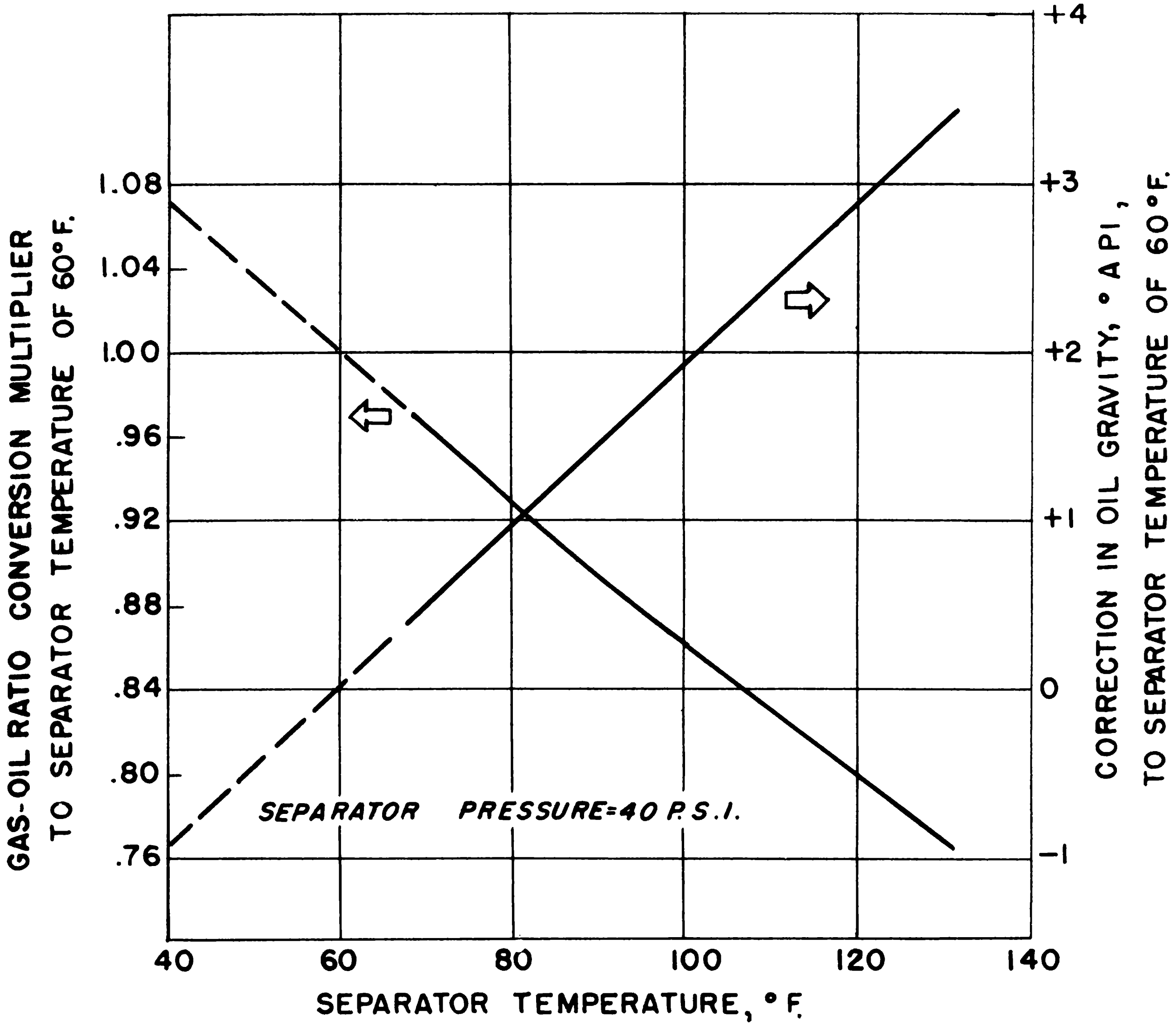

Figure 3. - Effect of separator temperature on gas-oil ratios and produced-oil gravities, Scurry Reef field, Scurry County, Tex.

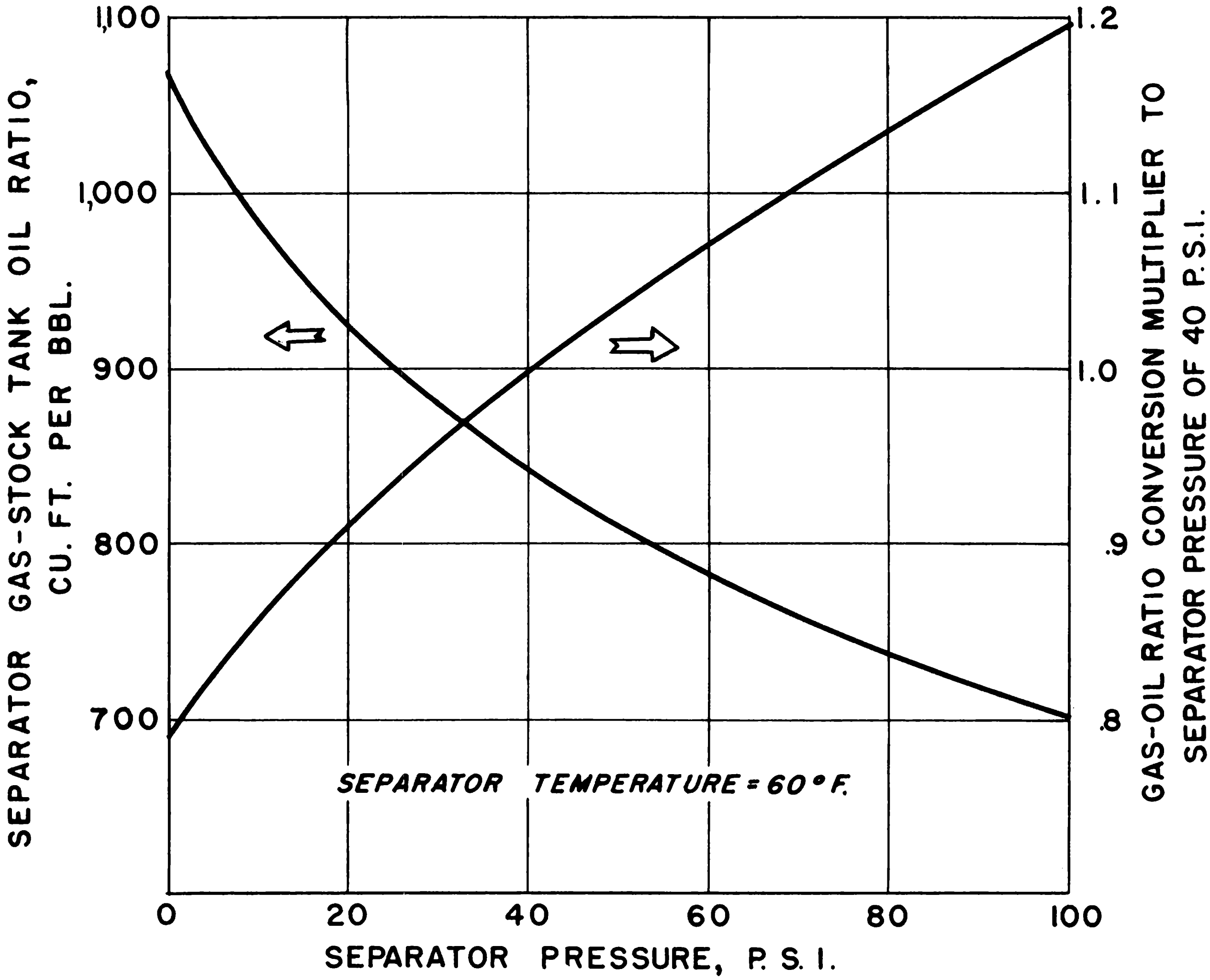

Figure 4. - Effect of separator pressure on gas-oil ratios, Scurry Reef field, Scurry County, Tex.

TABLE 2. - Gas-oil ratio Survey of the Scurry Reef Field, Scurry County, Tex.

Map location number	Location: Block	Location: Section	Company	Lease	Well No.	Average subsea producing depth, ft.1/	Date of test, 1951	Separator: Pressure, p.s.i.	Separator: Temp., °F.	Oil rate, bbl. per day	Gas gravity, air=1.0	Oil gravity, °API corrected to standard conditions2/	Gas-oil ratio, cu. ft. per bbl.: Observed3/	Gas-oil ratio, cu. ft. per bbl.: Corrected to standard conditions4/	Gas-oil ratio, cu. ft. per bbl.: Corrected to 4,300 ft. subsea5/	Sat. press. of reservoir oil at 4,300 ft. subsea. p.s.i.a.6/
1*	97	497	Texas Co.	P. L. Fuller	1	4,410	10-1	41.5	83	86.6	0.983	43.8	864	794	845	1,882
2*	97	394	Pure	Whatley	2	4,291	7-25	41.2	70	156.2	.981	43.9	826	794	790	1,812
3*	97	394	do.	do.	7	4,275	7-26	41.0	98	135.2	.999	43.8	940	816	805	1,832
4*	97	393	Cities Production	Jolly	2	4,234	7-20	45.4	83	108.2	.980	43.9	914	853	823	1,855
5*	97	393	do. do.	do.	4	4,322	7-19	36.0	80	88.4	1.006	43.6	902	821	831	1,866
6*	97	392	Sun	Brice	8	4,340	7-16	38.0	79	85.1	.994	43.8	885	814	832	1,867
7*	97	384	Tide Water	House	3	4,225	6-27	37.0	65	86.0	1.000	44.2	916	886	851	1,890
8*	97	385	Sun	Brice	7	4,240	7-17	38.0	80	94.1	.958	43.8	921	844	816	1,845
9*	97	336	Magnolia	Lefors-Mooars	B-3	4,364	8-17	41.7	75½	117.5	.992	43.8	858	813	842	1,877
10*	97	338	do.	Van Winkle	9	4,280	7-24	41.0	84	103.2	1.011	43.5	899	823	814	1,845
11*	1	19	do.	Collins	4	4,271	7-25	38.0	77	116.0	.991	42.8	880	817	804	1,830
12*	1	21	Sunray	Brown	B-9	4,356	8-2	40.8	78	116.1	.978	43.9	838	784	810	1,839
13*	97	298	Magnolia	McDonnell est.	H-1	4,367	8-16	36.1	70½	97.2	.980	43.3	894	841	872	1,915
14*	97	297	do.	T. J. McDonnell	2	4,329	8-20	42.3	75	117.5	.965	44.2	918	873	886	1,932
15*	97	296	do.	Logan	11	4,318	8-15	41.2	84	88.7	.986	44.2	945	864	872	1,915
16*	97	295	do.	McClinton	3	4,334	7-23	43.0	72	107.3	.991	43.6	874	841	857	1,897
17*	3	160	Sunray	Newton	3	4,408	8-6	38.0	86	108.4	.997	44.0	864	775	825	1,858
18*	3	159	do.	Cloud	8	4,384	8-3	41.3	88	110.6	1.010	43.8	865	781	820	1,851
19*	97	291	Phillips	Pate	4	4,378	7-9	45.0	71	180.6	.933	44.0	808	784	820	1,851
20*	97	292	Magnolia	Schuler	2	4,341	7-3	39.5	86	92.8	1.021	43.8	929	839	858	1,898
21*	97	293	Hiawatha	Garden	2	4,345	6-5	43.6	68½	135.7	.959	44.0	844	827	848	1,886
22*	97	294	Magnolia	Spence	1	4,326	8-22	44.7	74	120.7	.981	44.2	875	842	854	1,895
23*	K & F	40	Sunray	Stoker	1	4,403	8-7	38.2	77½	106.2	.983	44.1	881	816	863	1,905
24*	1	16	Cities Production	Von Roeder	3	4,338	9-25	39.5	68	207.8	.966	43.9	875	846	863	1,905
25*	97	247	General Crude	Land	1	4,250	6-2	40.0	64	146.9	.980	44.0	916	901	878	1,923
26*	97	248	Phillips	Huffman	1	4,353	7-10	32.0	69	130.0	.957	43.9	864	809	833	1,867
27*	97	249	Pan American	Davis	1	4,331	6-16	40.5	65	117.1	.970	43.2	817	802	816	1,845
28*	97	250	Skelly	Harral	2	4,310	5-30	38.0	74	123.0	1.001	43.1	862	808	813	1,843
29*	K & F	39	Cities Production	Austin	4	4,325	9-24	42.1	67	216.8	.955	43.1	892	872	883	1,930
30*	97	210	Phillips	Mebane	7	4,300	7-12	32.0	66	131.3	.957	44.4	844	795	795	1,819
31*	97	209	Magnolia	Haney	1	4,326	8-14	40.0	80	97.3	.976	43.6	900	833	845	1,882
32*	97	208	do.	Tate	3	4,341	8-21	47.5	78	90.8	.957	44.6	886	852	871	1,914
33*	97	205	Pan American	Biggs	A-1	4,359	6-16	41.7	68	114.7	.991	43.7	823	802	829	1,863
34*	97	206	Magnolia	Maxwell	4	4,386	8-21	48.3	66	146.4	.966	43.9	805	810	850	1,889
35**	97	195	Sun	Rosenberg	8	4,320	7-2	43.0	79	93.7	1.013	44.4	1,023	961	970	2,028
36**	97	203	do.	Voss	7	4,277	7-4	38.0	80	95.7	1.013	44.0	1,042	955	944	2,000
37**	97	185	do.	Arledge	C-1	4,383	7-5	37.0	88	85.7	1.003	43.7	1,024	910	948	2,005
38***	25	145	R. E. Smith	Key	14	4,364	9-6	35.7	79	75.4	1.000	44.5	1,085	988	1,017	2,079
39***	25	124	do.	do.	A-5	4,364	9-5	28.0	73	132.2	.980	44.2	1,073	972	1,001	2,062
40***	25	123	do.	Springer	7	4,405	9-7	31.8	74	69.5	.970	44.7	1,083	993	1,041	1,996
41***	25	120	do.	Thompson	B-15	4,366	9-4	38.8	78	84.2	.992	44.1	1,041	966	996	2,057
42***	97	163	Humble	Huddleston	2	4,401	8-29	40.8	84	112.1	.966	44.5	1,038	951	997	2,058
43***	25	101	do.	Gartner	2	4,395	8-29	40.1	81	106.9	.990	44.6	1,018	939	983	2,044
44***	25	99	do.	Ainsworth	B-3	4,406	9-3	38.7	81	88.7	.993	44.6	1,030	945	995	2,056
45***	25	96	do.	Richter	5	4,401	9-2	42.2	82	110.0	.983	44.6	1,009	935	981	2,041

1/ Average depth of the reef open to production, weighted on basis of productive section obtained from electric logs.
2/ Observed gravities (at 60°F.) corrected for the deviation of operating separator temperature from 60°F. (see fig. 3).
3/ Observed gas-oil ratios for indicated separator pressure and temperature corrected to 14.4 p.s.i.a. and 60°F.
4/ Observed gas-oil ratios corrected to standard separator conditions of 40 p.s.i. and 60°F. (see figs. 3 and 4).
5/ Gas-oil ratios at standard separator conditions corrected to a subsea depth of 4,300 feet (see fig. 5).
6/ Obtained from gas-oil ratio corrected to 4,300 ft., subsea and figure 19.

*Kelly-Snyder area **Northern part of Diamond M area ***Southern part of Diamond M area

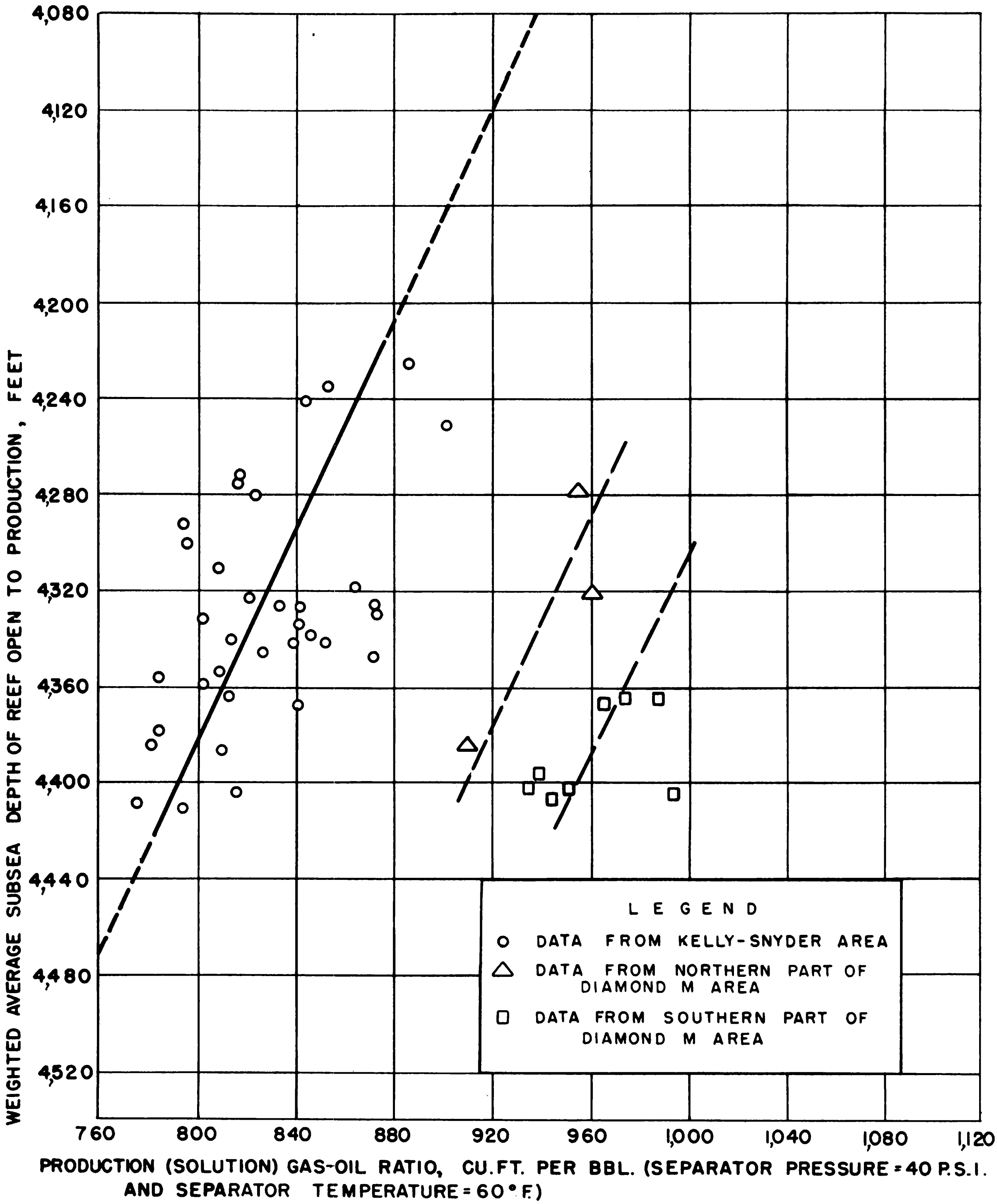

Figure 5. - Variations in solution-gas content of reef reservoir oil with depth, Scurry County, Tex.

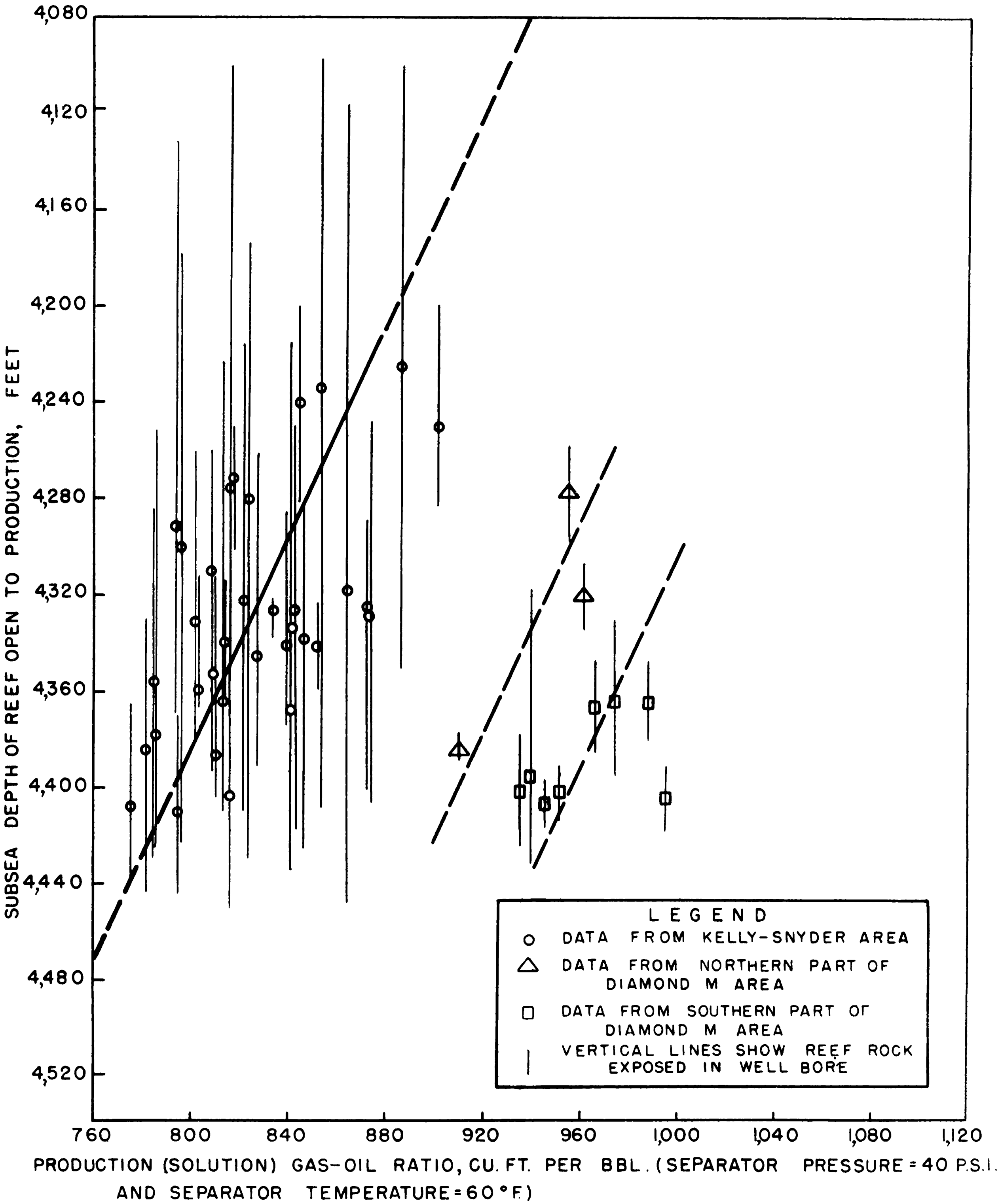

Figure 6. - Variations in solution-gas content of reef reservoir oil with depth and showing thickness of exposed zone, Scurry County, Tex.

production. Some wells tested in the Kelly-Snyder area had over 300 feet of reef open to production. When these wells were producing, the reservoir fluids may have entered the well bores uniformly distributed throughout all of the reef open to production, or all of the production may have come from a restricted section of the reef exposed in the well bore. Thus, it seems probable that estimated average producing depths of some may have been in error by 50 to 100 feet.

The production gas-oil ratios of the 45 wells tested and reported in table 2 were adjusted to a common producing depth of 4,300 feet subsea, according to the relationship of solution-gas content with depth, as shown in figures 5 and 6. These corrected gas-oil ratios, shown in the next to the last column of table 2, were plotted on a map of the Scurry Reef field (fig. 7). In the southern part of the Diamond M area the gas-oil ratios range from 981 to 1,041 cubic feet per barrel, a difference of 60 cubic feet per barrel. The gas-oil ratios in the northern part of the Diamond M area range from 944 to 970 cubic feet per barrel, a difference of 26 cubic feet per barrel. The gas-oil ratios in the Kelly-Snyder area range from 790 to 886 cubic feet per barrel, a difference of 96 cubic feet per barrel. Although this difference of 96 cubic feet per barrel may appear large, study of the data indicates no trend from one part of the area to another. A large part of the variations in the Kelly-Snyder area may result from inaccuracies in the method of selecting the depth from which the oil was being produced. Horizontally (at common depths) in the northern and in the southern parts of the reservoir, little or no variation is apparent in the physical properties of the oil produced. Throughout the horizontal distance of approximately 15 miles from the northern to the southern end of the Kelly-Snyder area, equilibrium conditions in the reservoir are indicated by close agreement of the gas-oil-ratio data. With equilibrium existing for a number of miles horizontally, then equilibrium should exist vertically for the comparatively small vertical distance between the top and bottom of the oil-bearing reef. Therefore, it appears probable that equilibrium exists in the northern and southern parts of the reservoir, but the oil is not identical throughout either part of the reservoir because gravitational concentration gradients[5] of the hydrocarbons are present, which result in the oil in the top of the reef containing more solution gas than that in the bottom of the reef.

Drilling records show the reef to be continuous and productive from the northern part of the Kelly-Snyder area to the southern part of the Diamond M area; nevertheless, the reservoir oil is not in equilibrium throughout the reservoir. Two possible explanations follow: (1) The process of the oil reaching equilibrium may have been retarded or stopped by one or more relatively impermeable streaks across the northern part of the reservoir in the Diamond M area, and (2) equilibrium may be in progress between the oil in the southern part of the Diamond M and Kelly-Snyder area, with a relatively wide section (3 to 4 miles) of low-permeability reef across the Diamond M area restricting the progress. Gas-oil-ratio data are limited to those obtained from three well tests in the northern part of the Diamond M area, because the pressure in most of the reservoir in this area during the time of the Bureau of Mines tests was below the saturation pressure of the reservoir oil. If additional gas-oil-ratio data were available for this area, a more definite explanation probably could be made regarding the difference in the physical properties of the reservoir oil in the Diamond M and Kelly-Snyder areas.

5/ See reference cited in footnote 2.

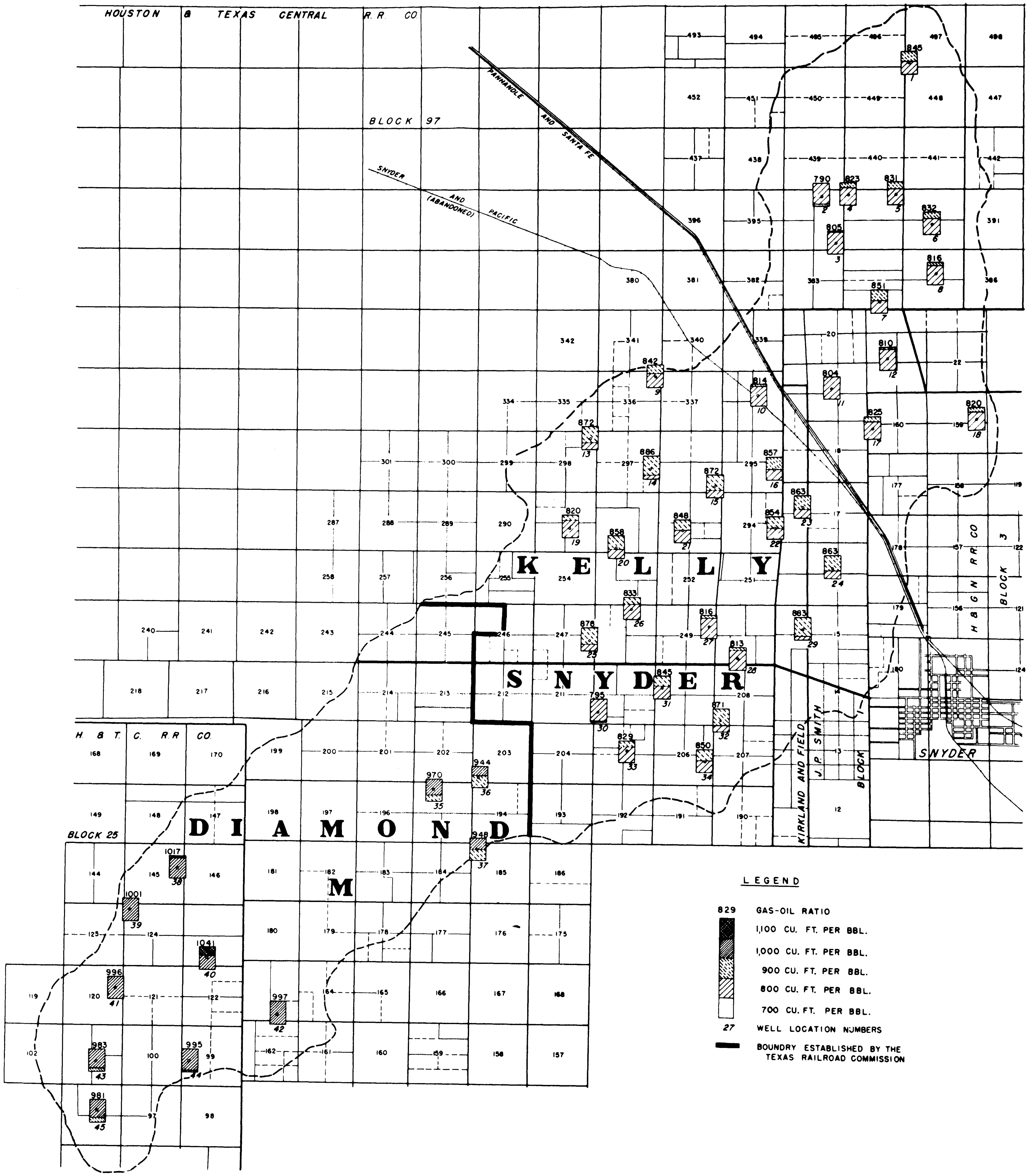

Figure 7. - Solution gas content of reef reservoir oil corrected to a common depth of 4,300 feet subsea, Scurry County, Tex.

SPECIAL TESTS TO DETERMINE GRAVITATIONAL CONCENTRATION GRADIENT IN KELLY-SNYDER AREA

Data from the gas-oil-ratio survey of the Scurry Reef field indicated that oil in the top part of the reservoir contained more solution gas than oil at greater depths. A graph was made by plotting the average producing depth from each test well against the production gas-oil ratio (see fig. 6). The plot indicated that, for each 100 feet increase in depth, the solution-gas content of the oil was 46 cubic feet less per barrel of stock-tank oil. As the change in solution-gas content of the oil with depth was determined by a new method, it was desirable to check the calculated change by measuring, at one location in the field, the solution-gas content of the oil both near the top and near the bottom of the pay section.

The Phillips Petroleum Co., Pate well No. 4, in sec. 291, block 97, was chosen for testing because of the operator's method of completing Scurry Reef wells. Casing in this well was set at the bottom of the hole and perforated in the pay section, except for 25 feet near the center of the pay section. Tubing was run almost to bottom, a tubing packer being placed opposite the portion of the casing in the pay section that was not perforated. The tubing contained an Otis side-door choke directly above the packer. With this equipment the side-door choke could be changed to permit oil production: (1) Only from the bottom part of the pay zone; (2) only from the top part of the pay zone; or (3) from both the bottom and top parts of the pay zone. The side-door choke was used to develop test data on oil production from the top and from the bottom of the reef in the test well to check the gravitational concentration gradient as evaluated from gas-oil-ratio tests.

Pate well No. 4 was chosen for testing after a review of the current bottom-hole pressure data, well-completion methods, electric logs, initial well tests, and previous Bureau of Mines tests on this and three other of the operator's wells. The well penetrated 187 feet of reef formation. The 5-1/2-inch casing, set on bottom at 4,425 feet subsea, was perforated from 4,253 to 4,326 feet (73-foot interval) and from 4,351 to 4,425 feet (74-foot interval) subsea. Thus 25 feet, 4,326 to 4,351 feet subsea, of the casing was blank. On the basis of the electric log of the well, a depth of 4,286 feet subsea was selected as the average from which the oil was being produced through the top perforations; a corresponding depth of 4,378 feet subsea was selected for the oil production through the bottom perforations. The interval between these 2 depths is 92 feet. Thus, the production gas-oil ratio from the top perforations was expected to be approximately 42 cubic feet per barrel greater than that from the bottom perforations, based upon the data plotted in figure 6 for a difference of 92 feet in average producing depth.

Four tests were made on this well to obtain gas-oil-ratio and subsurface pressure and temperature data and reservoir-oil samples. The side-door choke was adjusted so that the production of oil would be obtained from the lower zone (test 1), the upper zone (tests 2 and 3), and both upper and lower zones (test 4). The gas-oil ratios for the 4 tests were almost identical, being approximately 784 cubic feet per barrel when corrected to the standardized operating separator conditions of 40 p.s.i. and 60° F. Laboratory analyses of duplicate subsurface-oil samples obtained from both zones showed the saturation pressures at reservoir temperature to be 1,816 p.s.i.a. for the samples from the lower zone and 1,819 p.s.i.a. for the samples from the upper zone. The subsurface pressure and temperature data obtained from the test well at 4,300 feet, subsea, are presented in the following table:

Date, 1951	Production zone	Oil-production rate, bbl./day	Pressure at -4,300 ft., p.s.i.				Flowing temperature, °F.
				Hours shut in			
			Flowing	1	2	3	
9-13	Bottom	121.8	1,944	1,958	1,961	1,961	130.3
9-16	Top	112.0	1,840	-	-	-	130.2
9-18	do.	81.4	1,846	1,881	1,889	1,892	130.2
9-21	Composite	119.9	1,919	1,932	1,934	1,934	130.3

The highest flowing bottom-hole pressure, 1,944 p.s.i., was measured on September 13, 1951, when oil was flowing through only the bottom perforated section at a rate of 121.8 barrels of oil a day. The next highest flowing pressure, 1,919 p.s.i., was measured on September 21, 1951, when both top and bottom zones were open to production and the rate was 119.9 barrels of oil a day. The flowing pressure for the well producing from the top perforations only at a rate of 112.0 barrels of oil a day was considerably lower, being 1,840 p.s.i.

The data in the foregoing table indicate that the top zone was "thieving" oil from the bottom zone. Using present and previous reservoir-pressure data on the test well, the normal decline in reservoir pressure in the vicinity of the test well was calculated at 2-1/4 p.s.i. a day. The following table shows the reservoir-pressure data presented in the foregoing table, corrected for the normal decline rate in reservoir pressure to the date of the last test. In addition, the productivity index[6/] (PI) is shown for each test based upon an assumed static reservoir pressure of 1,943 p.s.i., the highest static pressure shown in the following table.

Production zone	Oil-production rate, bbl./day	Pressure at -4,300 ft., p.s.i.				Productivity index (PI)
			Hours shut in			
		Flowing	1	2	3	
Bottom	121.8	1,926	1,940	1,943	1,943	7.2
Top	112.0	1,829	-	-	-	1.0
Do.	81.4	1,839	1,874	1,882	1,885	.8
Composite	119.9	1,919	1,932	1,934	1,934	5.0

The foregoing data show that both the highest flowing bottom-hole pressure and the highest PI occurred when only the bottom zone was open to production. The effect of opening the top zone to production with the bottom zone was to reduce both the flowing bottom-hole pressure and the PI. Therefore, it was concluded that, when both zones were open to production (the normal producing procedure), the bottom zone furnished all of the produced oil and also fed oil into the top zone. Also, the data in the foregoing table show that during the test, when both zones were open to production, the flowing bottom-hole pressure, 1,919 p.s.i., was higher than the 3-hour static bottom-hole pressure, 1,885 p.s.i., for the top zone. This pressure differential shows that oil flowed into the top zone when both zones were open.

The rate at which oil was back flowing into the top zone during the test of the composite zones can be calculated from the data in the foregoing table. The difference between the assumed static pressure of the lower zone (1,943 p.s.i.) and the flowing pressure for the composite zones (1,919 p.s.i.) was 24 p.s.i. Thus,

6/ The productivity index of a well is calculated by dividing the barrels of oil produced a day by the difference in the static and flowing bottom-hole pressures measured, in pounds per square inch.

with the PI for the lower zone 7.2 and the difference between the static and flowing pressure 24 p.s.i. the production from the lower zone would have been 173 barrels a day (7.2 x 24). As the rate of stock-tank oil production during the flow test from the composite zones was only 119.9 barrels a day, the rate that the oil flowed into the top zone was 53 barrels a day (173-119.9).

The reservoir-pressure data indicate why the oils produced from both zones were alike, as shown by similar gas-oil ratios and saturation pressures of the reservoir oils; the oil produced during the test from the top zone was oil that had initially come from the bottom zone.

Data from other well tests indicating that a gravitational concentration gradient of the physical properties of the oil exists in the reef reservoir support the authors' theory that migration of oil from the lower to the upper oil-productive zone occurred in the vicinity of the well tested. Also, the curve in figure 5 shows a production depth of 4,420 feet subsea for a gas-oil ratio of 784 cubic feet per barrel, which located the oil production on the curve showing gravitational concentration gradients in the Kelly-Snyder area from the lower zone (4,351 to 4,425 feet subsea).

The tests on the Pate well No. 4 did not establish a gravitational concentration gradient in the Kelly-Snyder area. However, the test data were considered beneficial for the following reasons: (1) A method is presented for determining, under idealized conditions, gravitational concentration gradients in other fields; (2) an example is cited for calculating the amount of production coming from each of two zones producing simultaneously when the well being tested is completed similarly to the well used in these tests; (3) the data indicated that an impermeable or relatively impermeable horizontal layer of large areal extent separated the top and bottom of the oil-productive reef in the area of the test well. This knowledge is valuable in pressure-maintenance operations because the information indicates that a majority of the wells in the area of the test well are not producing from the zone exposed by the bottom perforations of the test well; (4) When gravitational concentration gradients are determined by the methods used to establish the curves in figures 5 and 6 it is desirable to select wells having only a thin section of the reservoir open to production, because otherwise the average producing depth, as selected from well logs, may deviate considerably from the actual depth of the source oil; and (5) it may be beneficial for operators periodically to conduct similar tests on "multizone" wells, with production comingling, to prevent thieving of the oil by a zone of lower pressure.

PHYSICAL PROPERTIES OF RESERVOIR OIL

Subsurface-oil samples were obtained from 7 reef wells in Scurry County, Tex. - 5 from the Kelly-Snyder area and 2 from the Diamond M area. Field data pertaining to the subsurface-oil samples are given in table 3.

The procedures and equipment used in obtaining and analyzing subsurface-oil samples were essentially the same as those described by Grandone and Cook.7/

The reservoir-oil samples were analyzed in the laboratory to furnish data on the following: (1) Differential-gas liberation; (2) flash-gas liberation; (3) pressure-viscosities; (4) pressure-volume relationship at 4 temperatures - 60°, 90°, 120°, and 132° F.; (5) low-temperature fractionation; (6) density of reservoir oil

7/ Grandone, Peter, and Cook, Alton B., Collecting and Examining Subsurface Samples of Petroleum: Bureau of Mines Tech. Paper 629, 1941, 68 pp.

TABLE 3. - Field data related to eight subsurface oil samples from reef wells, Scurry County, Tex.

Operator	Sunray	Phillips	Phillips	Texas Co.	Hiawatha	Cities Prod.	Humble	R.E. Smith
Lease	Cloud	Pate 1/	Pate 2/	Fuller	Carden	Jolly	Richter	Springer
Well No.	8	4	4	1	2	2	5	7
Survey	H&TC	H&TC	H&TC	H&TC	H&TC	H&TC	H&TC	H&TC
Block No.	3	97	97	97	97	97	25	25
Section	159	291	291	497	293	393	96	123
Location in the section	SE,NE	NW,SE	NW,SE	SW,SW	NE,SW	NW,NW	SW,NE	SE,SW
Average subsea depth of reef open to production, feet	4.384	4,378	4,286	4.410	4,345	4,234	4.401	4,405
Static pressure (24 hr.), p.s.i. 3/	1,932	1,961	6/ 1,892	5/ 1,950	2,148	2,126	2,406	2.202
Flowing pressure, p.s.i. 3/	1,917	1,944	1,840	5/ 1,850	2,140	2,106	2,399	2,114
Flow rate, bbl/day	110.6	121.8	112.0	86.6	135.7	108.2	110.0	69.5
Production G.O.R. 4/	781	784	784	794	827	853	935	993
Specific gravity of separator gas, air = 1.0	1.010	0.933	0.933	0.983	0.959	0.980	0.983	0.970
Gravity of Stock-tank oil at 60°F., °A.P.I.	43.8	44.0	44.0	43.8	44.0	43.9	44.6	44.7
Reservoir temperature at 4,300 feet, subsea	133	130	130	130	133	128	130	130
Date of G.O.R. test, 1951	8-3	9-13	9-16	10-1	6-5	7-20	9-2	9-7
Saturation pressure at 132° F. of subsurface oil samples, p.s.i.a.	1,797	1,816	1,819	1,838	1,855	1,856	1,910	1,975

1/ Lower zone.
2/ Upper zones.
3/ At a depth of 4,300 feet, subsea.
4/ Three hour static pressure.
5/ Estimated.
6/ Cubic feet of separator gas at 60° F. and 14.4 p.s.i.a. per bbl. of stock-tank oil at 60° F. (corrected to operating separator conditions of 60° F. and 40 p.s.i.).

from initial reservoir pressure to atmospheric pressure; and (7) density of gas liberated in the reservoir from saturation pressure to atmospheric pressure. A study of the data thus obtained showed that the physical properties of the oils were closely related and that these physical properties correlated closely with saturation pressures. The saturation pressures of the reservoir oil represented by these samples were 1,797, 1,816, 1,838, 1,855, 1,856, 1,910, and 1,975 p.s.i.a. It was desirable to be able to estimate physical properties of the reservoir oil having saturation pressures different from those represented by the 7 wells sampled. The range in saturation pressures of the oils from these wells was only 178 p.s.i. (1,797 to 1,975 p.s.i.a.), whereas the actual range in saturation pressures of the oil in the reservoir was estimated to be 424 p.s.i. (this calculation is explained in the section on Preparation of Data for Use in Material-Balance Calculations, and the values were obtained from the curve in fig. 19). The extremes of the saturation pressures are 1,738 and 2,162 p.s.i.a. Therefore, values of physical properties were estimated for 5 hypothetical oils having saturation pressures of 1,750, 1,850, 1,950, 2,050, and 2,150 p.s.i.a., using the data from the analyses of the 7 well samples as a basis. These values, in tabular and graphic form, are shown in tables 4 to 8, inclusive, and figures 8 to 16, inclusive.

Low-temperature fractional analyses were made on separator samples of both gas and oil from two wells (table 9). The saturation pressures of the reservoir oils from these 2 wells were 1,797 and 1,975 p.s.i.a., which represent the high and low saturation pressures of the 7 wells sampled. A series of 4 flash-gas liberation experiments were conducted on oil samples from 1 well producing reservoir oil with a saturation pressure of about average for the field to determine the effect of different gas-oil-separator pressures on the amount of gas liberated from the reservoir oil (see table 10 and fig. 17). In another series of experiments on these samples, the composition of the gas that will be in the free state in the reservoir at future reduced reservoir pressures was determined. These data were obtained by determining the composition of the gas liberated from a sample of reservoir oil at reservoir temperature in a series of steps from saturation pressure to atmospheric pressure; the gas liberated in each step was analyzed by low-temperature fractional distillation. These data were used to calculate the composition of gas corresponding to various liberation pressures. These data, with those on the composition of the initial reservoir oil, were used to calculate the composition of the reservoir oil corresponding to reduced reservoir pressures. The laboratory data are shown in table 11. Knowledge of the composition of the reservoir oil and of the gas is needed for calculating the volumes of recoverable hydrocarbon liquids derived from the production of solution gas that may be liberated in the reservoir at pressures below the saturation pressure of the oil.[8/] An analysis of a composite sample of crude oil representing the Kelly-Snyder area obtained from a pipeline, is shown in table 12.

PREPARATION OF DATA FOR USE IN MATERIAL-BALANCE CALCULATIONS

The expansion properties of the reservoir oil are used in one part of material-balance equations.[9/] Normally, the expansion properties are selected to correspond

8/ Cook, Alton B., Spencer, G. B., and Bobrowski, F. P., Special Considerations in Predicting Reservoir Performance of Highly Volatile Type Oil Reservoirs: AIME Tech. Paper 3017, Trans., vol. 192, 1951, pp. 37-46.

9/ Cook, Alton B., Derivation and Application of Material Balance Equations: Part II, Magnolia Oil Field, Columbia County, Ark., by Charles B. Carpenter, H. J. Schroeder, and Alton B. Cook: Bureau of Mines Rept. of Investigations 3720, 1943, pp. 84-99.

TABLE 4. - Differential gas-liberation data for reef reservoir oil, Scurry County, Tex.

Pressure, p.s.i.a.	Temp., °F.	Saturation press. at 132° F. 1,750	1,850	1,950	2,050	2,150
Gas in solution, cu. ft. per bbl. of residual oil at 60° F. (gas liberated at 132° F.)						
Solution gas at saturation press		910	1,010	1,120	1,237	1,362
1,700	132	893	953	1,015	1,076	1,136
1,500	132	822	875	931	985	1,040
1,200	132	716	760	805	850	898
900	132	607	643	678	715	754
600	132	490	521	547	577	612
300	132	348	371	393	420	449
100	132	188	205	225	240	259
14.4	132	0	0	0	0	0
Relative oil volume, volume of residual oil at 60° F. = 1.0						
Relative oil volume at saturation press.		1.524	1.578	1.635	1.693	1.756
3,136[2/]	132	1.498	1.555	1.606	1.665	1.727
2,800	132	1.503	1.561	1.615	1.675	1.737
2,400	132	1.511	1.568	1.624	1.684	1.749
2,000	132	1.519	1.575	1.634	1.683	1.723
1,800	132	1.522	1.568	1.607	1.643	1.678
1,500	132	1.484	1.517	1.550	1.582	1.613
1,200	132	1.437	1.465	1.493	1.522	1.549
900	132	1.389	1.413	1.436	1.461	1.485
600	132	1.340	1.360	1.378	1.400	1.420
300	132	1.270	1.286	1.303	1.318	1.336
100	132	1.180	1.192	1.203	1.212	1.224
14.4	132	1.038	1.039	1.039	1.039	1.040
14.4	60	1.000	1.000	1.000	1.000	1.000

Pressure, p.s.i.a.	Temp., °F.	Saturation press. at 132° F. 1,750	1,850	1,950	2,050	2,150
Density[1/] of gas liberated at indicated pressure, gram per liter corrected to 14.4 p.s.i.a. and 60° F.						
Gas density at saturation press.		0.920	0.931	0.941	0.951	0.963
1,700	132	0.918	0.925	0.931	0.937	0.945
1,500	132	.911	.917	.923	.928	.934
1,200	132	.913	.920	.926	.932	.940
900	132	.933	.943	.955	.966	.978
600	132	1.000	1.018	1.036	1.054	1.071
300	132	1.195	1.217	1.239	1.261	1.283
100	132	1.542	1.578	1.614	1.650	1.685
14.4	132	2.640	2.680	2.720	2.760	2.800
Density of gas saturated oil, grams per milliliter						
Gas density at saturation press.		0.6724	0.6630	0.6536	0.6438	0.6336
3,136[2/]	132	0.6850	0.6748	0.6648	0.6545	0.6440
2,800	132	.6825	.6720	.6620	.6516	.6410
2,400	132	.6790	.6686	.6584	.6476	.6369
2,000	132	.6750	.6648	.6542	.6454	.6390
1,800	132	.6730	.6647	.6586	.6525	.6464
1,500	132	.6805	.6745	.6687	.6632	.6577
1,200	132	.6905	.6849	.6792	.6744	.6692
900	132	.7016	.6961	.6910	.6862	.6812
600	132	.7149	.7096	.7042	.6997	.6949
300	132	.7316	.7269	.7220	.7172	.7130
100	132	.7540	.7499	.7447	.7402	.7361
14.4	132	.7900	.7870	.7845	.7824	.7800
14.4	60	.8188	.8165	.8140	.8114	.8093

1/ Gas density x 0.8344 = specific gravity (Air = 1.0).

2/ Initial reservoir pressure.

TABLE 5. - Flash gas-liberation data for reef reservoir oil, Scurry County, Tex.

Pressure, p.s.i.a.	Temp., ° F.					
Gas in solution, cu. ft. per bbl. of residual oil at 60° F.						
Saturation press. at 132° F.		1,750	1,850	1,950	2,050	2,150
Solution gas at saturation press.		798	877	960	1,052	1,148
1,700	132	782	823	863	903	943
1,500	132	715	750	783	818	853
1,200	132	613	638	665	690	717
900	132	509	527	545	563	583
600	132	405	415	425	436	447
54.4	60	53	55	57	58	59
14.4	60	0	0	0	0	0
Relative oil volume, volume of residual oil at 60° F. = 1.0						
Saturation press. at 132° F.		1,750	1,850	1,950	2,050	2,150
Relative oil volume at saturation press.		1.448	1.491	1.536	1.585	1.635
3,136 1/	132	1.421	1.464	1.509	1.555	1.610
2,800	132	1.427	1.472	1.516	1.565	1.618
2,400	132	1.435	1.480	1.525	1.575	1.628
2,000	132	1.442	1.488	1.535	1.575	1.604
1,800	132	1.447	1.483	1.510	1.536	1.562
1,600	132	1.426	1.450	1.473	1.498	1.522
1,200	132	1.367	1.384	1.403	1.422	1.440
900	132	1.320	1.335	1.350	1.364	1.380
600	132	1.272	1.285	1.297	1.308	1.322
54.4	60	1.030	1.034	1.037	1.042	1.045
14.4	60	1.000	1.000	1.000	1.000	1.000

1/ Initial reservoir pressure.

TABLE 6. - Pressure-viscosity data at 132° F. for reef reservoir oil, Scurry County, Tex.

	Viscosity in centipoises				
Saturation press. at 132° F. - - - - - -	1,750	1,850	1,950	2,050	2,150
Viscosity at saturation press. - -	0.405	0.381	0.353	0.327	0.301
Pressure, p.s.i.a.					
3,136 1/	0.450	0.422	0.388	0.358	0.328
2,800	.438	.412	.380	.350	.320
2,400	.425	.398	.368	.338	.310
2,000	.413	.386	.355	.332	.315
1,800	.406	.386	.368	.352	.336
1,400	.447	.432	.415	.399	.382
1,000	.514	.494	.474	.457	.439
600	.612	.590	.567	.547	.525
400	.686	.663	.643	.621	.599
200	.826	.800	.778	.757	.734
100	.960	.938	.916	.895	.875
14.4	1.656	1.615	1.570	1.527	1.483

1/ Initial reservoir pressure.

TABLE 7.—Pressure-volume-temperature relationships for reef reservoir oil, Scurry County, Tex.

Pressure, p.s.i.a.	Relative volume, volume at saturation pressure and 132° F. = 1.0				
	132° F.				
Saturation press.	1,750	1,850	1,950	2,050	2,150
Relative volume at saturation press.	1.0000	1.0000	1.0000	1.0000	1.0000
3,136[1/]	0.9827	0.9826	0.9828	0.9828	0.9830
2,800	.9865	.9868	.9873	.9877	.9883
2,400	.9913	.9922	.9931	.9940	.9952
2,000	.9966	.9978	.9992	1.0107	1.0300
1,950	.9973	.9985	1.0000	1.0215	1.0417
1,900	.9980	.9992	1.0105	1.0329	1.0543
1,850	.9986	1.0000	1.0216	1.0447	
1,800	.9993	1.0111	1.0331	1.0575	
1,750	1.0000	1.0228	1.0450		
1,700	1.0118	1.0353	1.0587		
1,650	1.0240	1.0483			
1,600	1.0370				
1,550	1.0505				
	120° F.				
Saturation press.	1,700	1,794	1,887	1,980	2,078
Relative volume at saturation press.	0.9917	0.9915	0.9910	0.9903	0.9901
3,136[1/]	0.9749	0.9747	0.9747	0.9745	0.9742
2,800	.9782	.9783	.9786	.9787	.9788
2,400	.9826	.9830	.9832	9843	.9848
2,000	.9875	.9883	.9894	.9904	1.0067
1,950	.9883	.9891	.9902	.9971	1.0178
1,900	.9889	.9898	.9908	1.0078	1 0290
1,850	.9896	.9905	.9986	1.0192	1 0410
1,800	.9903	.9913	1.0100	1.0308	1.0537
1,750	.9910	1.0013	1.0220	1.0428	
1,700	.9917	1.0135	1.0343	1.0552	
1,650	1.0037	1.0260	1.0472		
1,600	1.0171	1.0393			
1,550	1.0313	1.0535			
1,500	1.0460				

Pressure, p.s.i.a.	Relative volume, volume at saturation pressure and 132° F. = 1.0				
	90° F.				
Saturation press.	1,575	1,654	1,736	1,824	1,912
Relative volume at saturation press.	0.9715	0.9710	0.9705	0.9697	0.9690
3,136[1/]	0.9552	0.9548	0.9546	0.9540	0.9533
2,800	.9850	.9578	.9576	.9573	.9571
2,400	.9621	.9622	.9623	.9623	.9624
2,000	.9665	.9668	.9670	.9673	.9677
1,950	.9670	.9674	.9677	.9679	.9684
1,900	.9676	.9680	.9683	.9686	.9717
1,850	.9683	.9686	.9688	.9693	.9822
1,800	.9687	.9693	.9695	.9750	.9937
1,750	.9694	.9698	.9702	.9858	1.0055
1,700	.9700	.9704	.9775	.9973	1.0187
1,650	.9706	.9722	.9893	1.0092	1.0322
1,600	.9712	.9829	1.0017	1.0230	1.0465
1,550	.9763	.9950	1.0153	1.0367	
1,500	.9875	1.0085	1.0297	1.0518	
1,450	.9999	1.0225	1.0450		
1,400	1.0162	1.0383			
1,350	1.0287	1.0548			
1,300	1.0463				
	60° F.				
Saturation press.	1,445	1,510	1,577	,658	1,733
Relative volume at saturation press.	0.9523	0.9515	0.9505	0.9495	0.9485
3,136[1/]	0.9370	0.9364	0.9354	0.9345	0.9342
2,800	.9397	.9392	.9385	.9377	.9373
2,400	.9433	.9428	.9423	.9417	.9413
2,000	.9469	.9466	.9462	.9458	.9456
1,800	.9487	.9485	.9482	.9479	.9477
1,700	.9498	.9495	.9492	.9491	.9563
1,650	.9503	.9500	.9497	.9510	.9686
1,600	.9508	.9505	.9502	.9626	.9820
1,550	.9513	.9511	.9562	.9752	.9970
1,500	.9518	.9539	.9683	.9894	1.0133
1,450	.9523	.9656	.9817	1.0050	1.0308
1,400	.9617	.9788	.9967	1.0230	1.0508
1,350	.9736	.9937	1.0137	1.0422	
1,300	.9868	1.0105	1.0335		
1,250	1.0024	1.0293	1.0556		
1,200	1.0209	1.0505			
1,150	1.0440				

1/ Initial reservoir pressure.

TABLE 8. - Composition of reef reservoir oil, Scurry County, Tex.

Saturation press. at 132° F., p.s.i.a. - -	1,750	1,850	1,950	2,050	2,150
Component	Mole fraction				
Carbon dioxide	0.0021	0.0013	0.0072	0.0063	0.0056
Nitrogen	.0191	.0200	.0209	.0219	.0228
Methane	.2592	.2752	.2898	.3078	.3234
Ethane	.1057	.1132	.1198	.1272	.1349
Propane	.1262	.1234	.1198	.1172	.1135
Isobutane	.0148	.0154	.0162	.0170	.0179
Normal Butane	.0653	.0640	.0633	.0616	.0607
Isopentane	.0238	.0212	.0191	.0171	.0152
Normal pentane	.0270	.0269	.0263	.0258	.0253
Hexanes	.0538	.0510	.0479	.0457	.0426
Heptanes plus	.3030	.2884	.2697	.2524	.2381
	1.0000	1.0000	1.0000	1.0000	1.0000

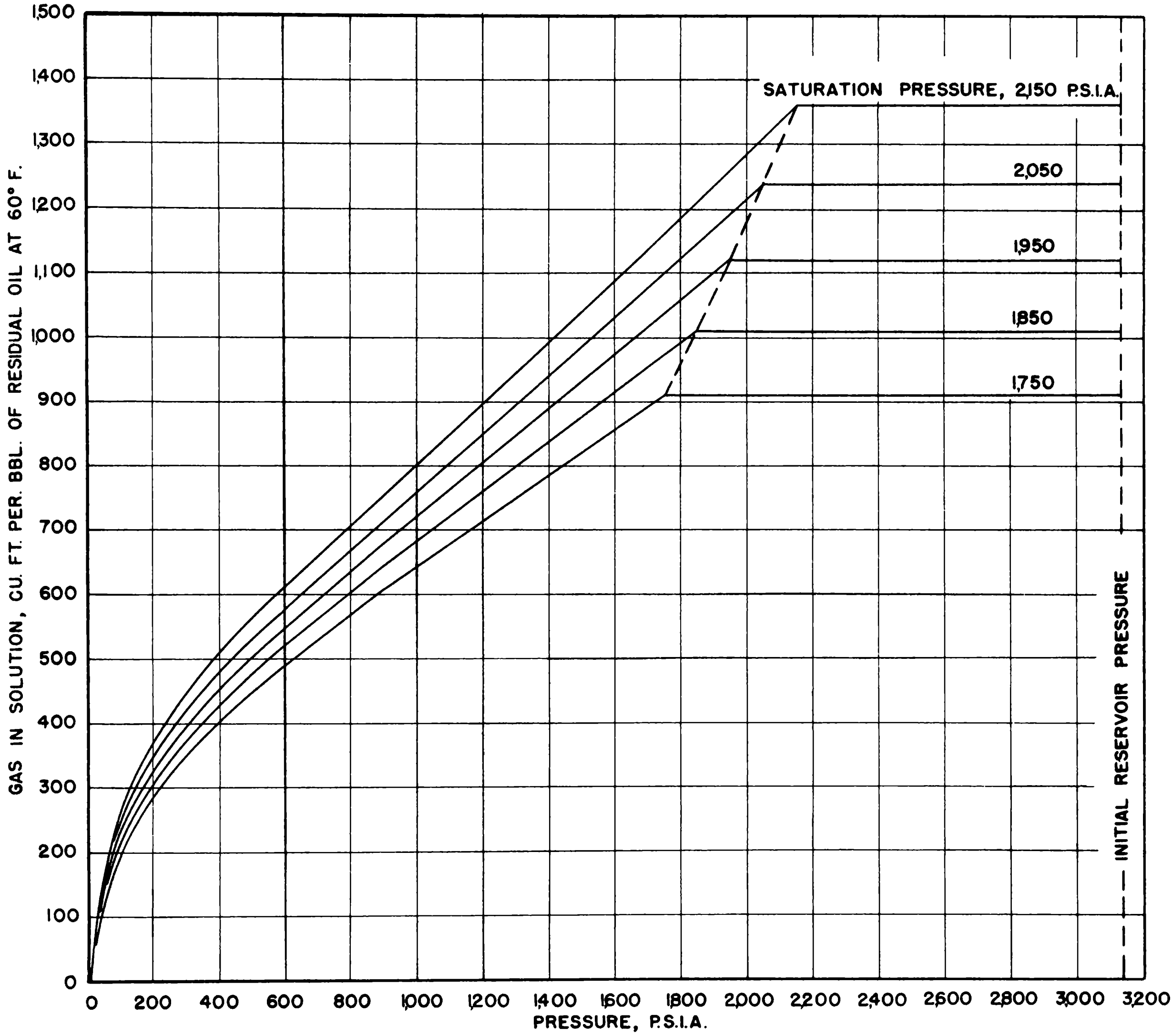

Figure 8. - Gas liberated from reef reservoir oil by the differential gas-liberation procedure, Scurry County, Tex.

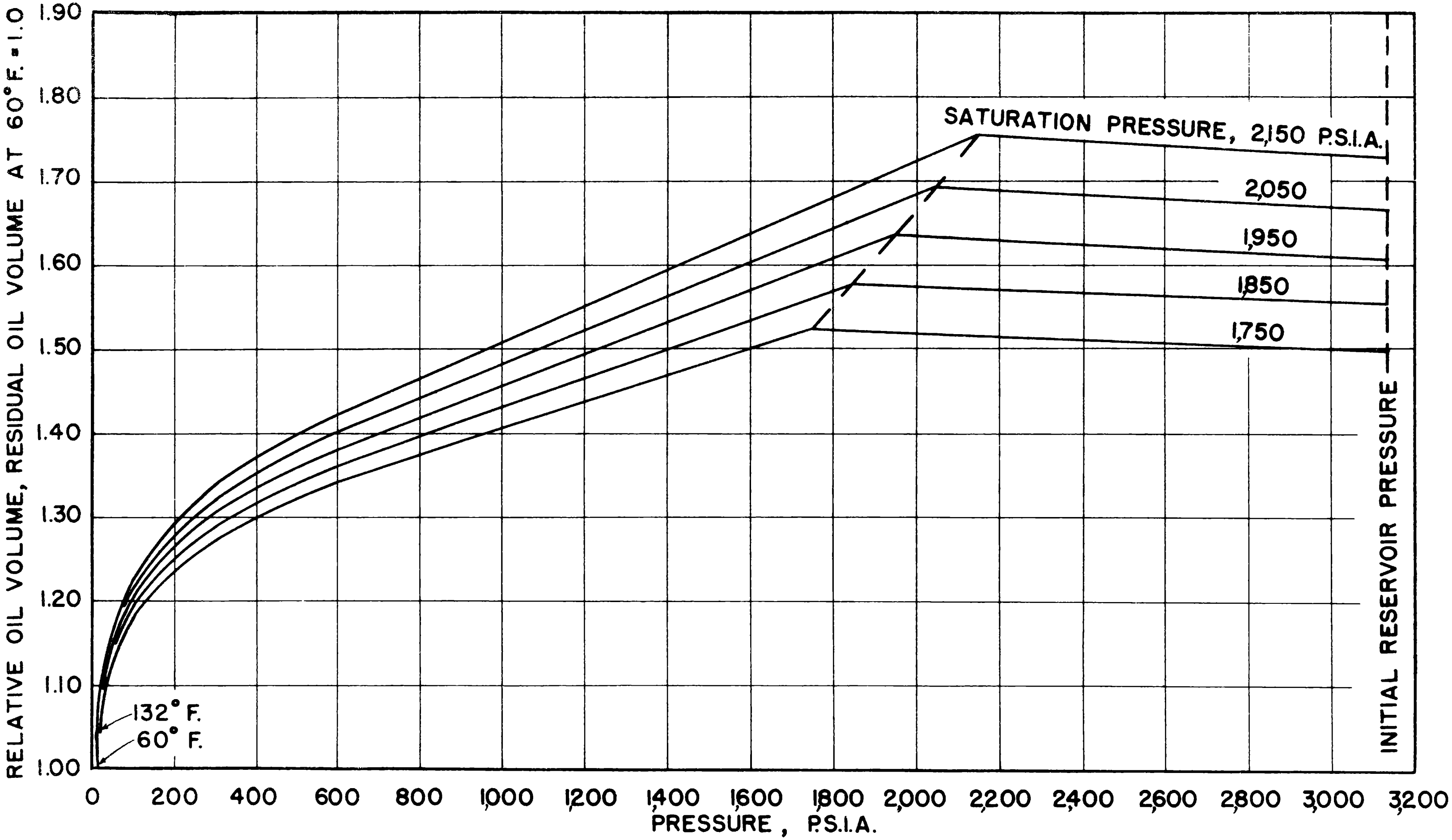

Figure 9. - Relative oil volume of reef reservoir oil obtained by the differential gas-liberation procedure at 132° F., Scurry County, Tex.

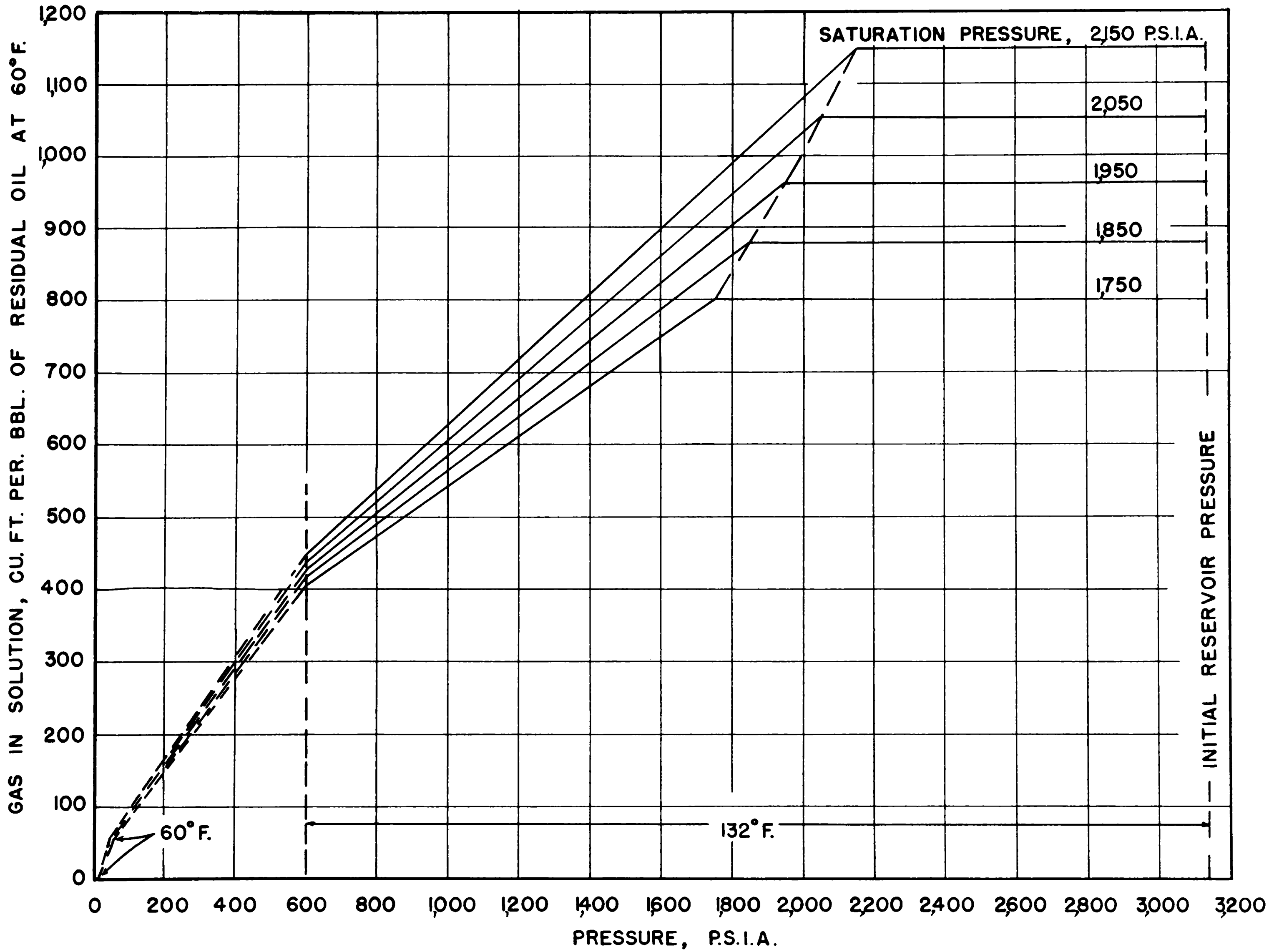

Figure 10. - Gas liberated from reef reservoir oil by flash gas-liberation procedure, Scurry County, Tex.

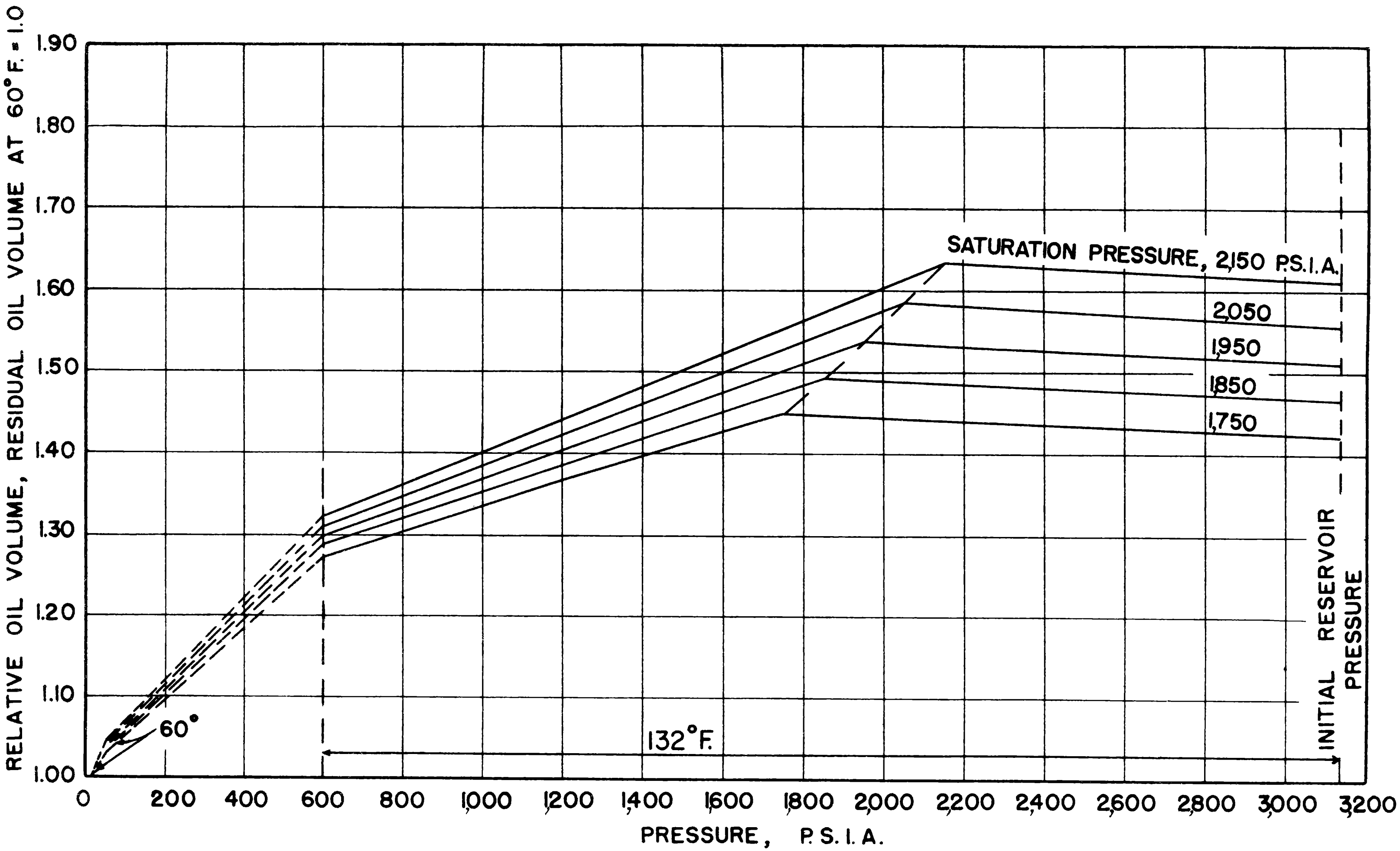

Figure 11. - Relative oil volume of reef reservoir oil obtained by the flash gas-liberation procedure, Scurry County, Tex.

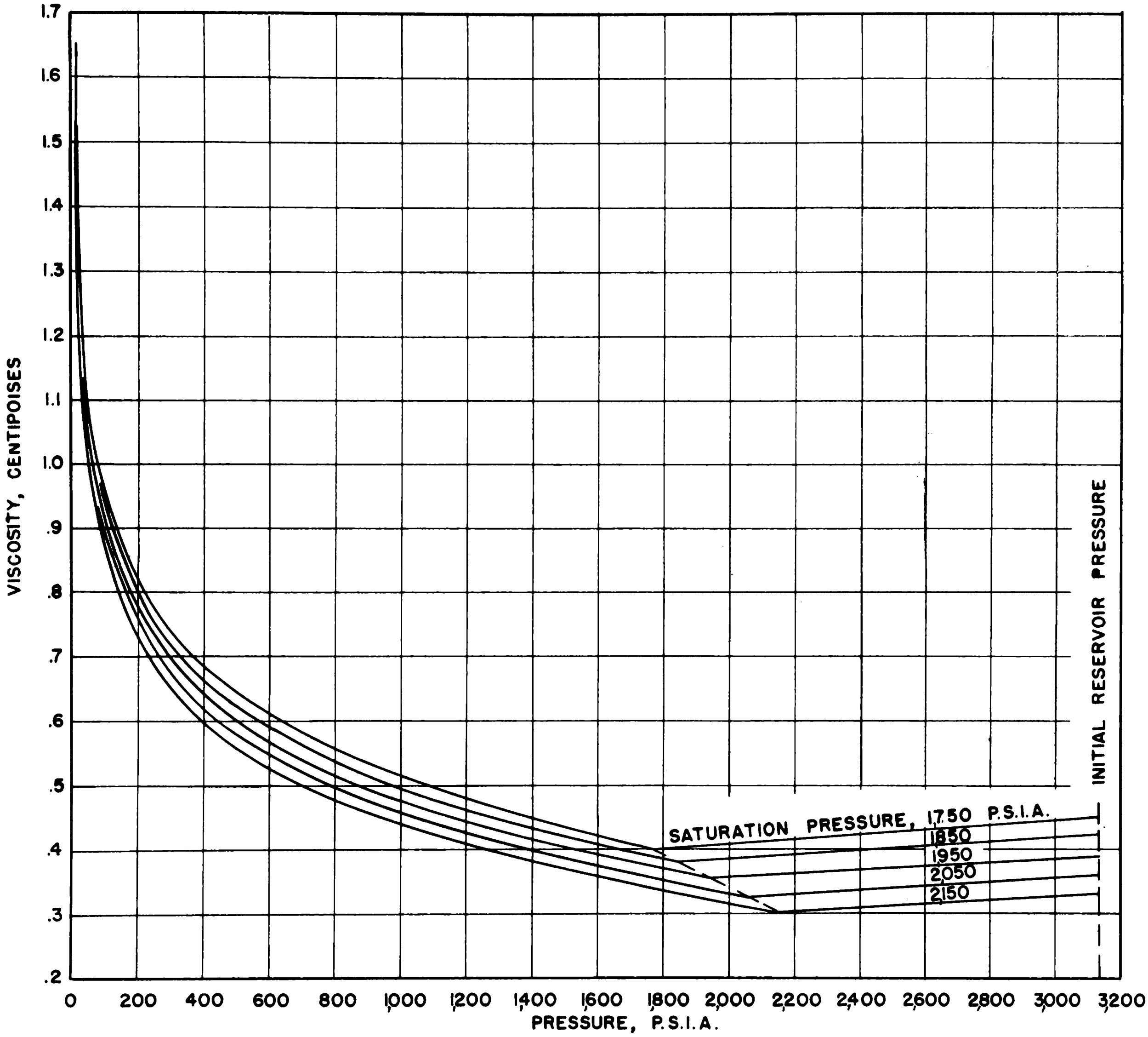

Figure 12. - Viscosity of reef reservoir oil, Scurry County, Tex.

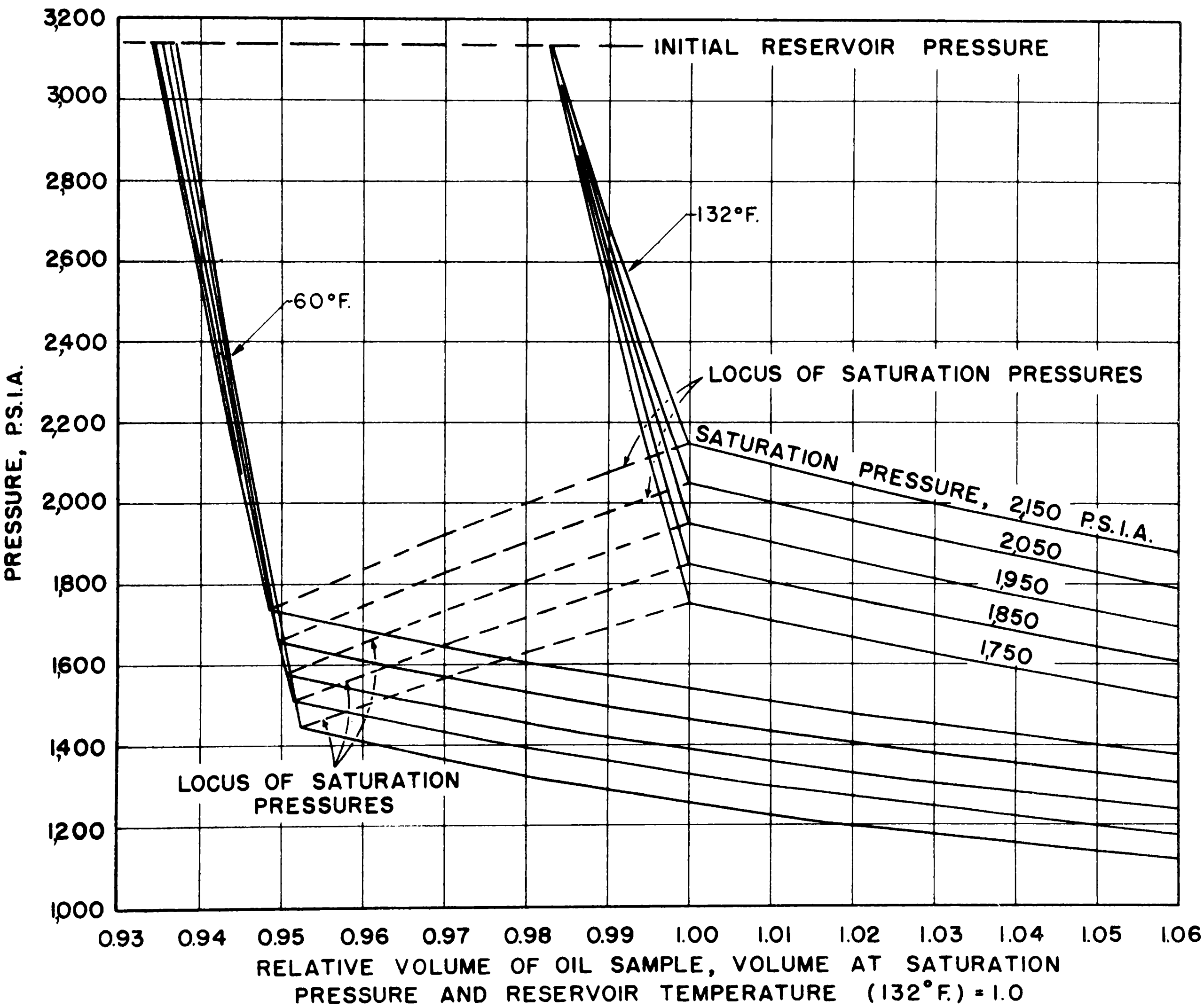

Figure 13. - Pressure-volume-temperature relationships of reef reservoir oils with saturation pressures at 132° F. of 2,150, 2,050, 1,950, 1,850, and 1,750 p.s.i.a., Scurry County, Tex.

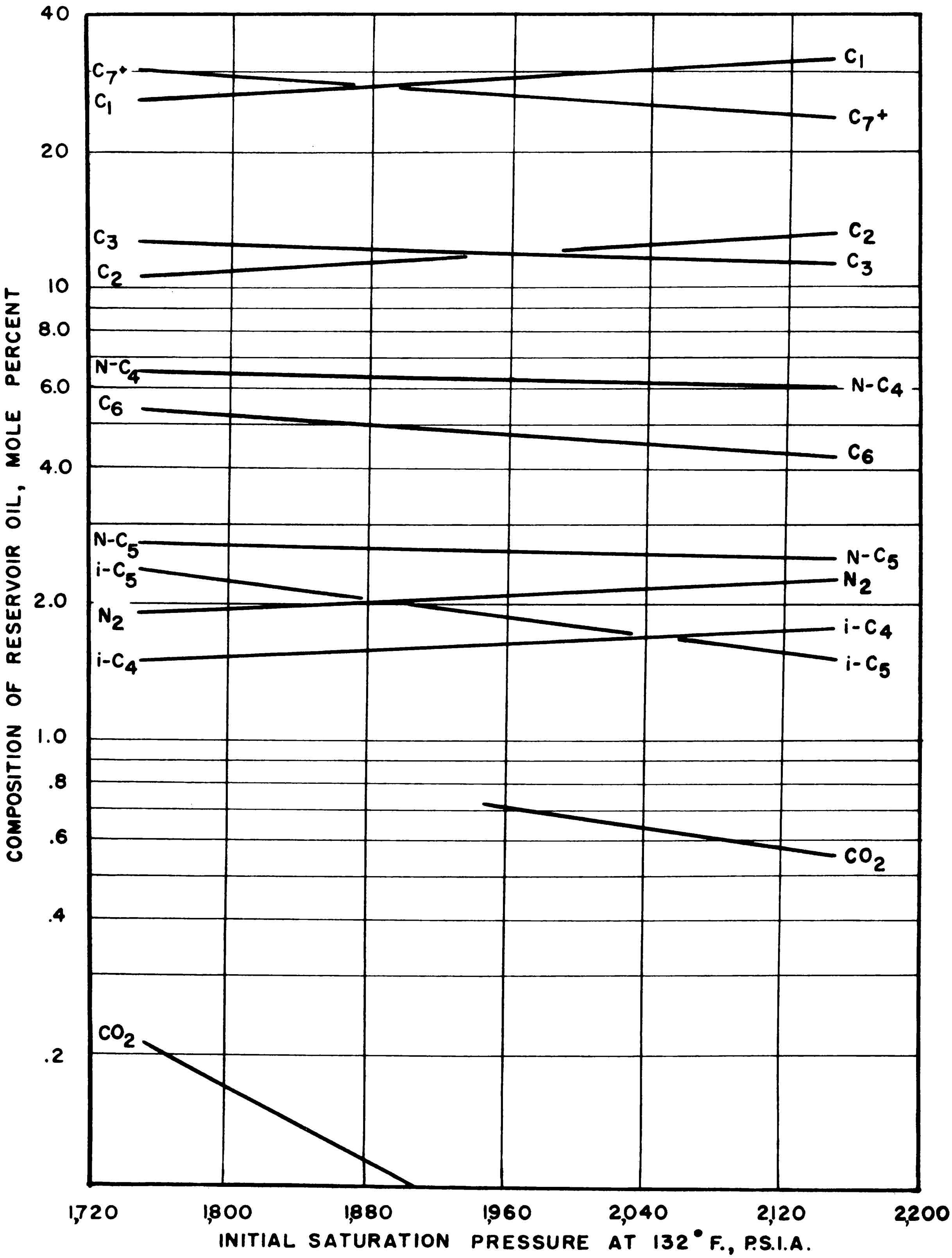

Figure 14. - Composition of reef reservoir oil, Scurry County, Tex.

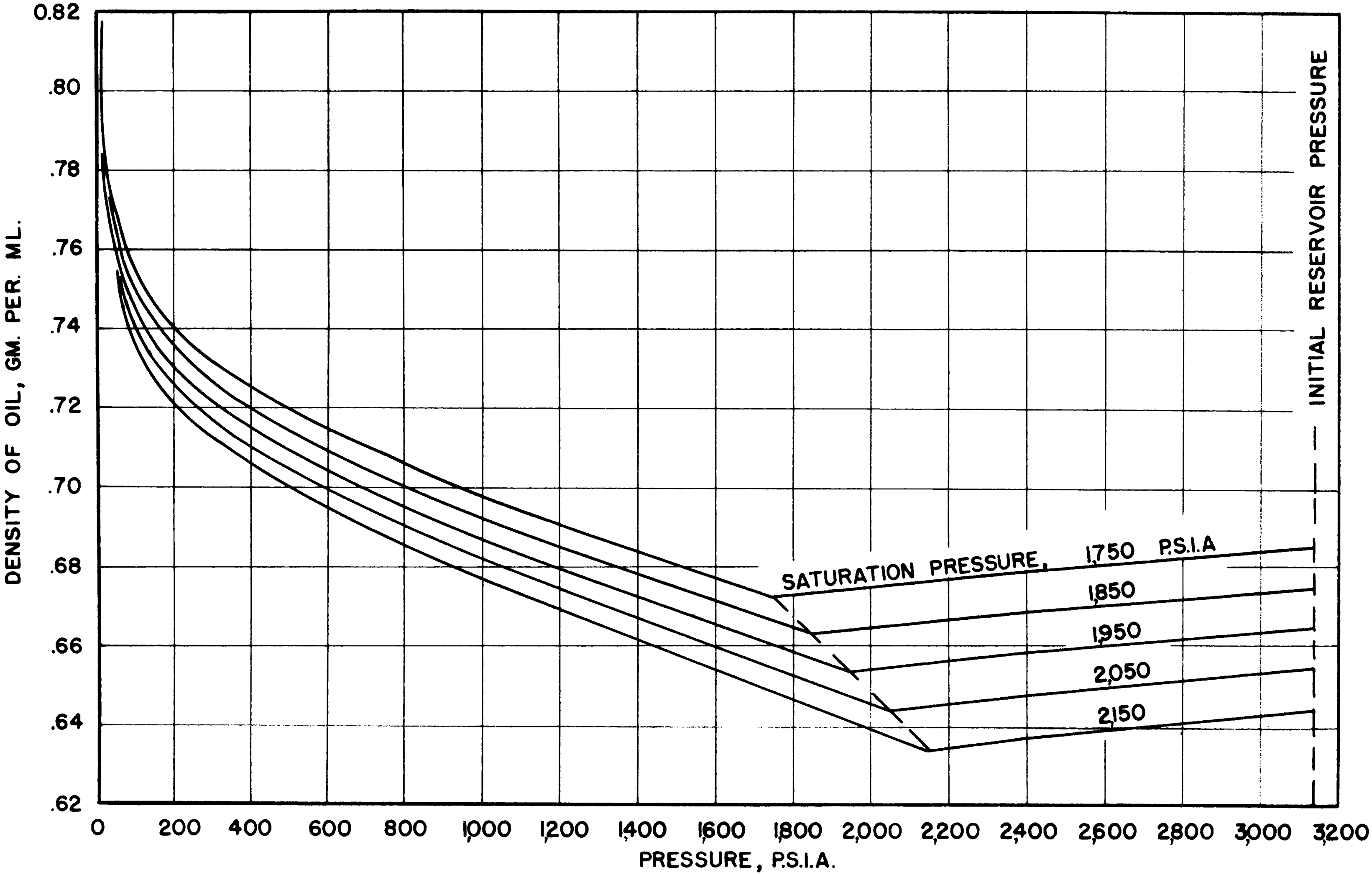

Figure 15. - Density of reef reservoir oil at 132° F., Scurry County, Tex.

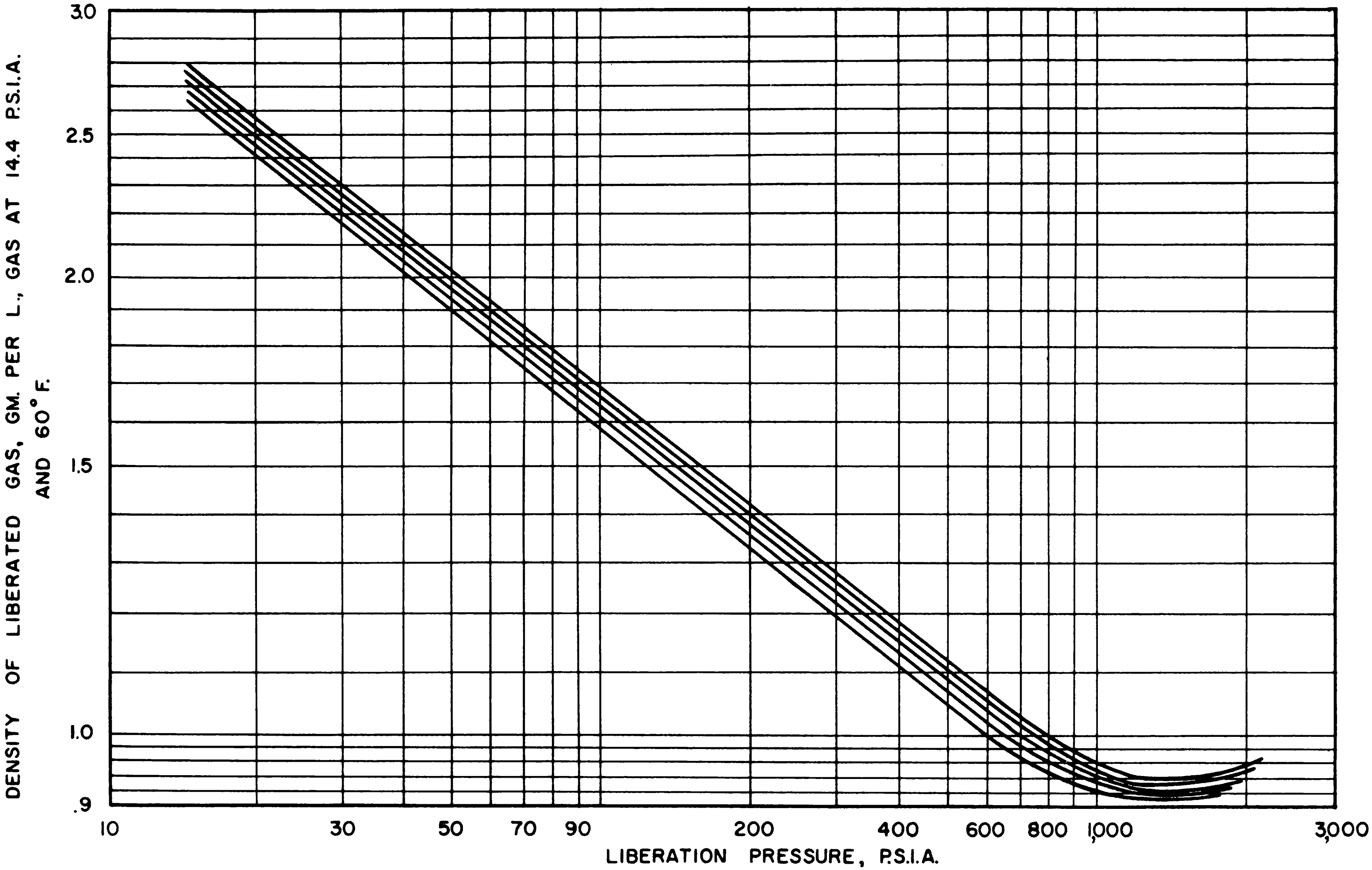

Figure 16. - Density of gas liberated from reef reservoir oil by the differential gas-liberation procedure at 132° F., Scurry County, Tex.

TABLE 9. - Composition of two separator oil samples and two separator gas samples from reef wells, Scurry County, Tex.

Well	Sunray Cloud No. 8		Smith Springer No. 7	
Separator pressure at time of sampling, p.s.i. - -	41		43	
Separator temp. at time of sampling °F. - - - -	75		79	
	Separator oil	Separator gas	Separator oil	Separator gas
Component	Mole fraction			
Carbon dioxide	—	0.0026	—	0.0089
Nitrogen	—	.0389	—	.0389
Methane	—	.5080	0.0055	.5022
Ethane	0.0193	.1907	.0232	.1931
Propane	.0685	.1694	.0746	.1632
Isobutane	.0157	.0124	.0123	.0171
Normal butane	.0786	.0527	.0809	.0498
Isopentane	.0353	.0095	.0332	.0095
Normal pentane	.0500	.0086	.0490	.0092
Hexanes	.1076	.0051	.1027	.0058
Heptanes plus	.6250	.0016	.6186	.0023
	1.0000	1.0000	1.0000	1.0000
Spec. grav. of C_7 + residue at 60/60°F.	0.8421	(1)	0.8388	(1)
Molecular wt. of C_7 + residue at	201	(1)	199	(1)

1/ Insufficient residue for determination of this value.

TABLE 10. - Effect of different gas-oil separator pressures on liberation of gas from reef reservoir oil, Scurry County, Tex.

Pressure, p.s.i.a.	Temp., °F.	Relative oil volume, residual oil volume at 60°F.= 1.0	Density 1/ of liberated gas, gm./liter (gas at 60°F. and 14.4 p.s.i.a.)	Oil density, gm./ml.	Oil gravity, °A.P.I.	Gas in solution, cu. ft. per bbl. of residual oil at 60°F. (gas at 60°F. and 14.4 p.s.i.a.)
		Gas-oil separator pressure at 214 p.s.i.				
1855 2/	132	1.4844		0.6653		871
228 3/	60	1.1463	4/ 0.9656	.7727		280
14.4	60	1.0000	5/ 1.6148	.8061	43.86	0
		Gas-oil separator pressure at 100 p.s.i.				
1855 2/	132	1.4726		0.6653		854
114 3/	60	1.0972	4/ 1.0339	.7751		152
114.4	60	1.0000	5/ 1.6819	.8050	44.10	0
		Gas-oil separator pressure at 40 p.s.i.				
1855 2	132	1.4867		0.6653		874
54 3/	60	1.0320	4/ 1.1396	.7968		52
14.4	60	1.0000	5/ 1.5877	.8075	43.56	0
		Gas-oil separator pressure at zero p.s.i.				
1855 2/	132	1.6122		0.6653		1065
14.4	60	1.0000	4/ 1.3261	.8211	40.66	0

1/ Gas density x 0.8344 = specific gravity (air = 1.0)
2/ Saturation pressure of sample at indicated temperature.
3/ Gas-oil separator pressure.
4/ Gas liberated from saturation pressure to gas-oil separator pressure.
5/ Gas liberated from gas-oil separator pressure to atmospheric pressure.

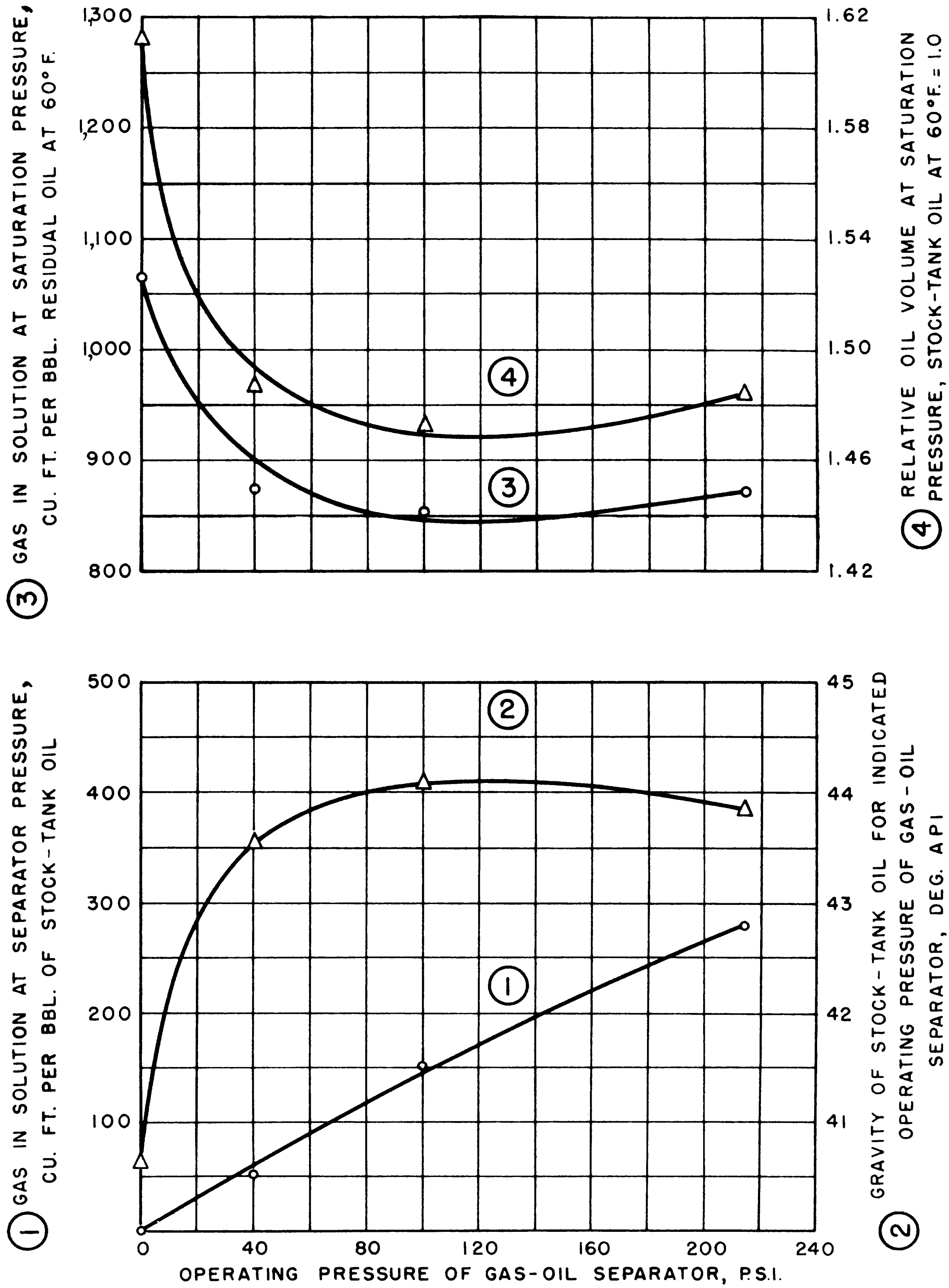

Figure 17. - Laboratory data showing effect of separator pressure on oil- and gas-production data, Scurry Reef field, Scurry County, Tex.

TABLE 11. - Composition of reef reservoir fluid, Scurry County, Tex.

Mole percentage composition

	Reservoir oil				
Pressure, p.s.i.a. - - - - - -	1,855	1,363	745	247	14.4
Component					
CO_2	0.13	0.08	0.05	--	--
N_2	2.06	1.15	.34	--	--
C_1	27.78	22.19	12.86	3.48	--
C_2	11.38	11.62	10.84	7.25	--
C_3	12.24	13.38	14.50	13.97	1.76
$i\text{-}C_4$	1.46	1.77	2.04	2.33	.47
$n\text{-}C_4$	6.65	7.27	8.36	9.32	4.65
$i\text{-}C_5$	2.08	2.45	2.84	3.45	2.97
$n\text{-}C_5$	2.77	2.97	3.47	4.15	3.92
C_6	5.03	5.24	6.25	7.69	9.85
$C_{7}+$	28.42	31.88	38.45	48.36	76.38
	100.00	100.00	100.00	100.00	100.00

Approximate values for heptanes-plus residue: Sp. gr. = 0.840 at 60/60° F. and mol. wt. = 204

Gas liberated between indicated pressures

Pressure, p.s.i.a. - - - - -	1,855 to 1,363	1,363 to 745	745 to 247	247 to 14.4
Component				
CO_2	0.22	0.22	0.24	--
N_2	9.66	5.09	1.63	--
C_1	68.82	67.17	48.88	9.27
C_2	11.28	15.33	24.64	19.30
C_3	5.84	7.95	16.54	34.25
$i\text{-}C_4$	.92	.49	.92	5.42
$n\text{-}C_4$	1.40	2.04	4.68	17.06
$i\text{-}C_5$	.51	.56	.51	4.26
$n\text{-}C_5$	.60	.53	.88	4.53
C_6	.49	.39	.70	4.11
$C_{7}+$	.26	.23	.38	1.80
	100.00	100.00	100.00	100.00

TABLE 12. - Crude-oil analysis, pipeline sample from the Kelly-Snyder area, Scurry County, Tex.

Kelly-Snyder area
Scurry Reef field
Specific gravity, 0.810
Sulfur, percent, 0.22
Saybolt Universal viscosity at 100° F., 36 sec.

Sample 53017

GENERAL CHARACTERISTICS
A.P.I. gravity 43.2°

Texas
Scurry County
Sample taken
Feb. 1953
Pour point, °F. below 5
Color, brownish green

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

Distillation at atmospheric pressure, 744 mm. Hg. First drop, 31°C. (88°F.)

Fraction No.	Cut at °C.	Cut at °F.	Percent	Sum, percent	Sp. Gr., 60/60°F.	°A.P.I. 60°F.	C.I.	Aniline point, °C.	S.U. Visc., 100°F.	Cloud test, °F.
1	50	122	4.5	4.5	0.639	89.9	-	51.4		
2	75	167	4.1	8.6	.674	78.4	9.4	-		
3	100	212	7.6	16.2	.723	64.2	23	52.7		
4	125	257	8.6	24.8	.748	57.7	26	51.4		
5	150	302	6.3	31.1	.767	53.0	27	51.2		
6	175	347	5.5	36.6	.785	48.8	29	50.6		
7	200	392	4.8	41.4	.800	45.4	30	54.0		
8	225	437	5.0	46.4	.814	42.3	31	58.7		
9	250	482	5.2	51.6	.828	39.4	32	62.8		
10	275	527	5.8	57.4	.841	36.8	33	67.0		
Distillation continued at 40 mm. Hg										
11	200	392	3.3	60.7	0.849	35.2	33	72.4	39	15
12	225	437	6.1	66.8	.859	33.2	34	76.6	45	30
13	250	482	4.8	71.6	.871	31.0	37		57	50
14	275	527	3.6	75.2	.885	28.4	40		81	65
15	300	572	4.5	79.7	.891	27.3	40		135	80
Residuum			16.9	96.6	.939	19.2				

Carbon residue Ramsbottom of residuum, 3.5 percent; carbon residue of crude, 0.7 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	16.2	0.687	74.5	
Total gasoline and naphtha	41.4	0.738	60.2	
Kerosine distillate	5.0	.814	42.3	
Gas oil	19.8	.844	36.2	
Nonviscous lubricating distillate	8.7	.864-.887	32.3-28.0	50-100
Medium lubricating distillate	4.8	.887-.894	28.0-26.8	100-200
Viscous lubricating distillate	-	-	-	Above 200
Residuum	16.9	.939	19.2	
Distillation loss	3.4			

to what is considered the average oil for the field and usually no further refinement is needed where there is little difference in subsea elevations between the top and bottom of an oil reservoir. However, when the difference in elevations is large, the difference in the saturation pressure of the oil in the top and in the bottom of the reservoir may be great enough to justify refinements for use in material-balance calculations. The initial saturation pressure of the oil in the upper part of the reservoir in the Kelly-Snyder area was 2,162 p.s.i.a. and in the lower part 1,738 p.s.i.a., a difference of 424 p.s.i. These saturation pressures were determined from flash-gas-liberation data (table 6) and a plot of production gas-oil ratio with subsea producing depth (fig. 5). At a specific saturation pressure, the difference between the total gas in solution and that in solution at separator pressure (table 6) is considered to be the production gas-oil ratio for that oil. Production gas-oil ratios were calculated from table 5 and plotted against the corresponding saturation pressures (fig. 18). The curves in figures 5 and 18 were used to construct a curve showing producing depth plotted against the saturation pressure of the oil (fig. 19).

The P-V data representative of the reservoir oil at the weighted average depth in the reservoir were used to construct graphs showing that the data would not represent actual reservoir conditions. P-V relationships applicable to a hypothetical composite oil in the reservoir were determined by dividing the reservoir into 50-foot intervals, at uniform subsea depths, by using data from electric logs and core analyses. Approximate oil volumes in the 50-foot intervals were converted to percentage of the total oil volume. The average saturation pressure of the oil for each interval was determined by reference to figure 19. Then, the gas in solution and relative oil volume factors by the flash-gas liberation procedure, and the pressure-volume relationships were determined for the oil in each interval from data shown in figures 10, 11, and 13. The products of the percentage of oil for each interval and the appropriate pressure-volume relationship value, the gas in solution, and the relative oil-volume factors furnished P-V data for the hypothetical composite oil. P-V values were calculated for the average reservoir oil (oil at the weighted average depth of the reservoir) and for the composite oil in the reservoir. Plots of these values are shown in figures 20, 21, and 22, where comparisons of P-V properties of the average oil and composite oil can readily be made.

The percentage of errors that would result in using the P-V data for the average reservoir oil instead of using the P-V data for the composite reservoir oil can be calculated from the pressure-volume curves in figure 20. The percentage of errors is calculated by comparing, at common pressures, the amounts of expansion as shown by curves 2 and 3. At pressures above that of the saturation pressure of the oil in the top part of the structure (2,162 p.s.i.a.), no error would be made because the two curves, from initial reservoir pressure to 2,162 p.s.i.a., are identical. The 2 curves virtually coincide also for pressures less than 1,738 p.s.i.a., the saturation pressure of the oil in the bottom part of the reservoir. Therefore, no appreciable errors would be expected because of using the P-V data for the average reservoir oil in material-balance equations corresponding to pressures below 1,738 p.s.i.a. As the 2 curves do not coincide in the pressure range between 2,162 and 1,738 p.s.i.a., errors would result in material-balance calculations for reservoir pressures in this range when P-V data for the average reservoir oil is used. Using data from the 2 curves in the pressure range from 2,162 to 1,738 p.s.i.a., the greatest discrepancy was found to be 27 percent.

Data on the composite reservoir oil should be used when it is highly desirable to make material-balance calculations for a reservoir in the pressure range from the highest to lowest saturation pressures of the reservoir. However, the difficulty in

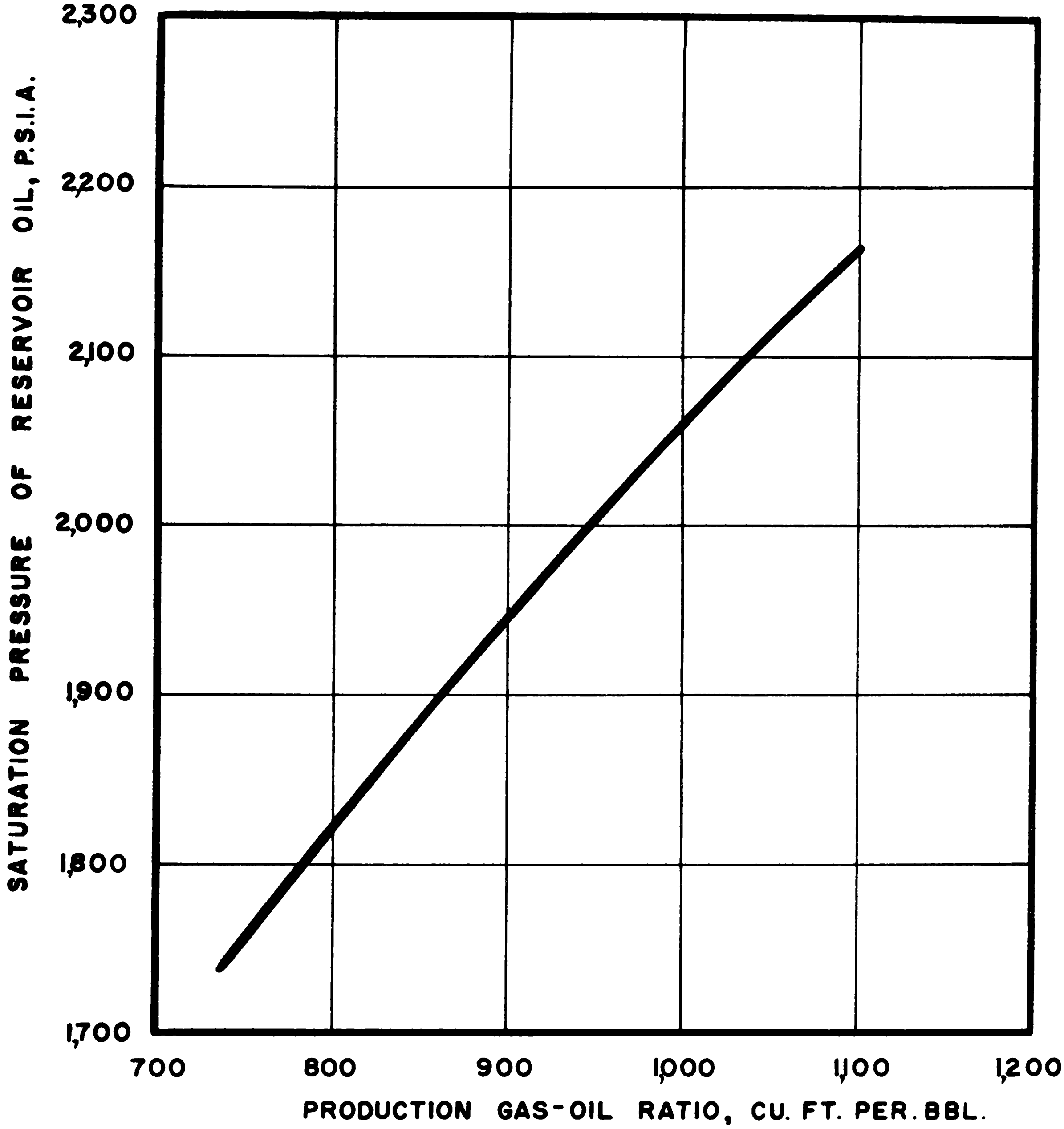

Figure 18. - Relationship of saturation pressures of reef reservoir oil with production (solution) gas-oil ratios, Kelly-Snyder area, Scurry County, Tex.

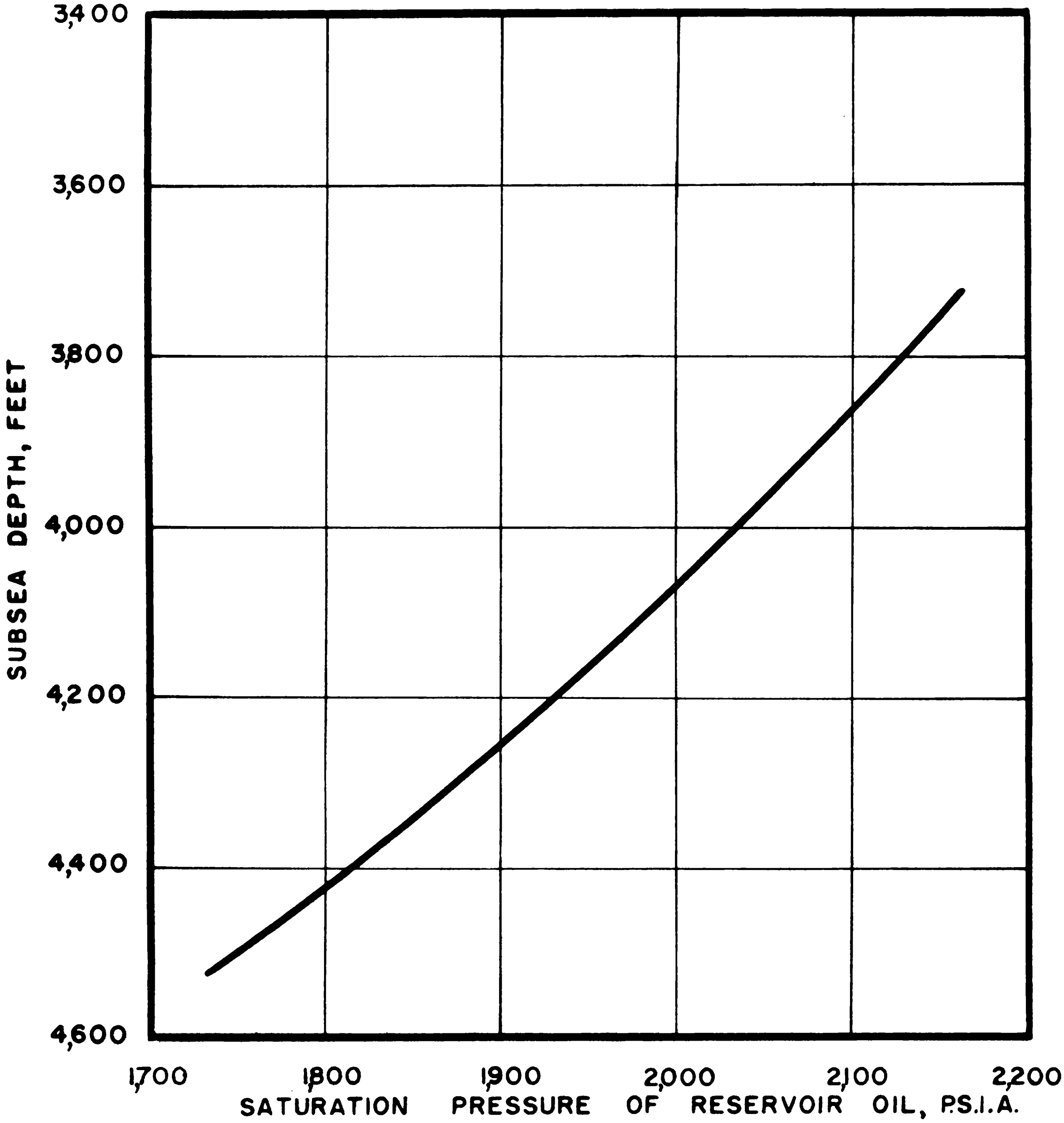

Figure 19. - Relationship of saturation pressure of reef reservoir oil with depth, Kelly-Snyder area, Scurry County, Tex.

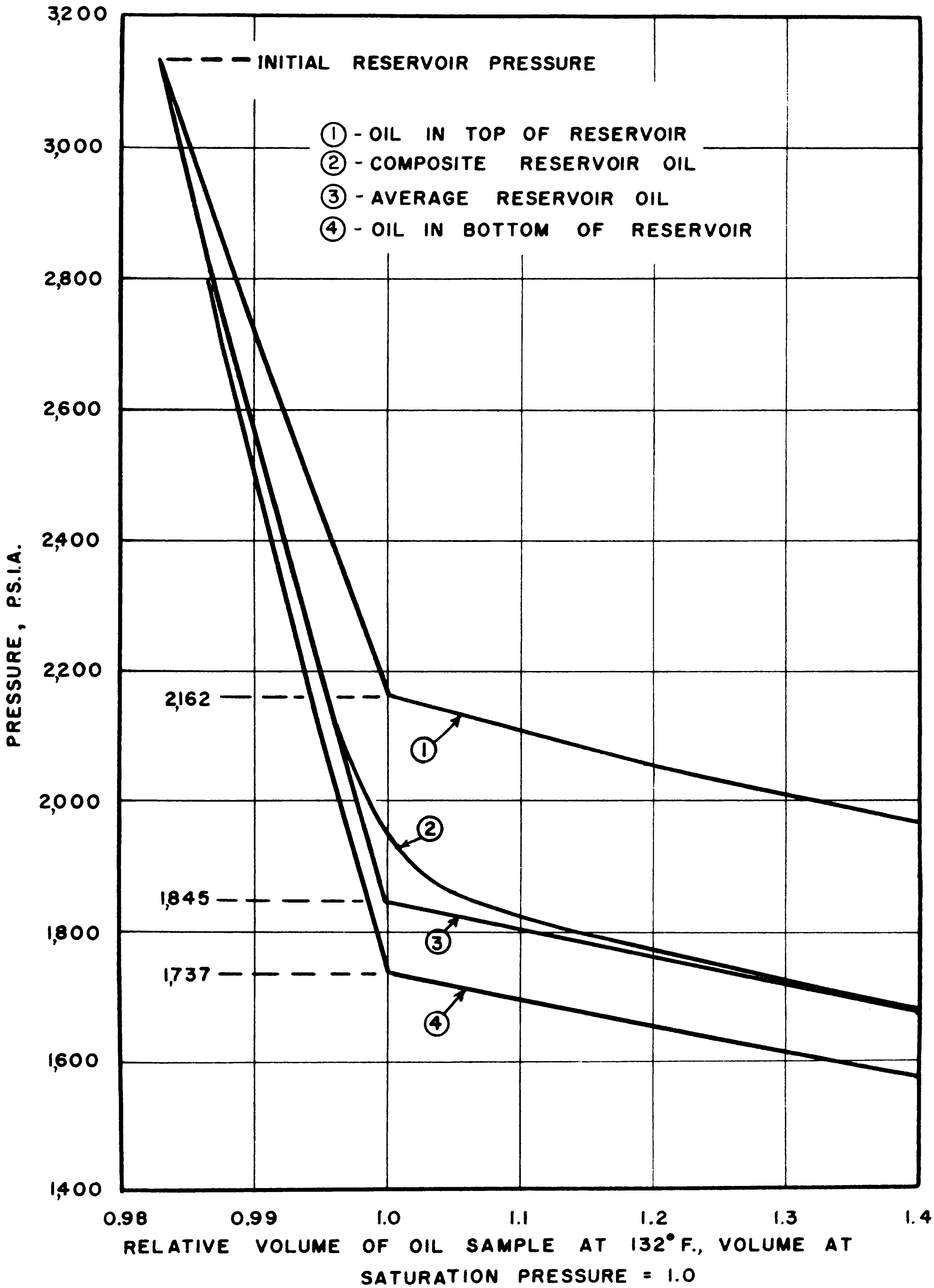

Figure 20. - Pressure-Volume relationships of reef reservoir oil, Kelly-Snyder area, Scurry County, Tex.

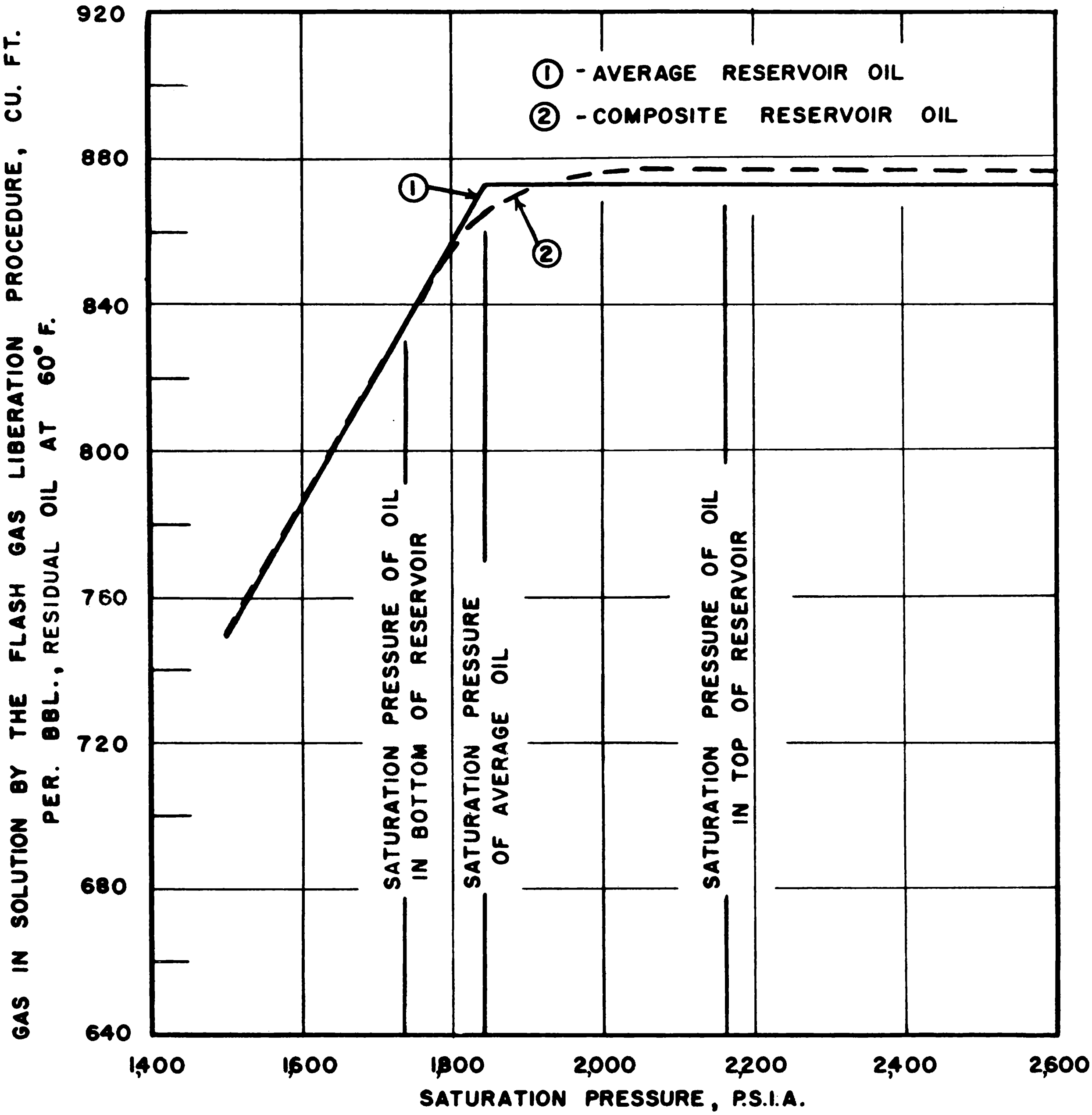

Figure 21. - Comparison of gas in solution for average and composite reef reservoir oils, Kelly-Snyder area, Scurry County, Tex.

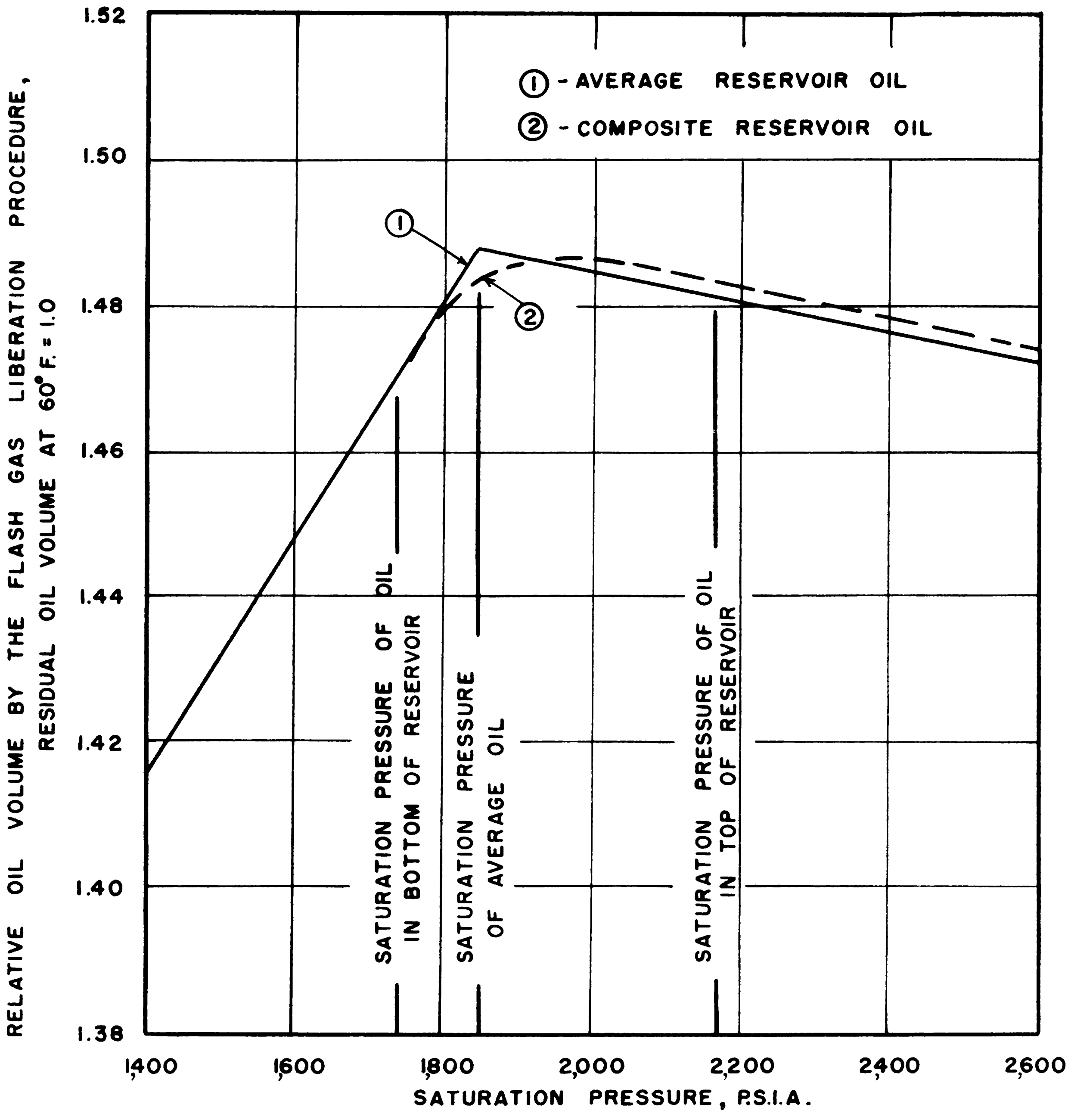

Figure 22. - Comparison of relative oil volume for average and composite reef reservoir oils, Kelly-Snyder area, Scurry County, Tex.

obtaining P-V data for a composite reservoir oil may be too great to be practical, especially where there is little difference between the elevations of the top and bottom of the reservoir. The need for P-V data on the composite reservoir oil can be eliminated if material-balance calculations are made when the reservoir pressure is not between the extreme of the high and low saturation pressures of the reservoir oils.

CONCLUSIONS

Because of the immense size of the Scurry County Reef reservoir a new procedure was developed to determine physical properties and the variations in physical properties of the oil throughout the reservoir. Subsurface-oil samples were obtained from seven wells and analyzed in the laboratory. An oil-gravity survey of the field was made in which oil samples were obtained from 107 key wells. A standardized sampling and testing procedure was followed to minimize the effect of variations in operating gas-oil separator pressures and temperatures on oil gravity. A production gas-oil-ratio survey was made of the field by testing 45 key wells, and these ratios were corrected to a common separator pressure of 40 p.s.i. and a temperature of 60° F. by applying appropriate corrections. Physical properties of the subsurface-oil samples were correlated with production gas-oil ratios. By referring to these correlations and the production gas-oil-ratio data, physical properties can be estimated for the reservoir oil represented by the production from any of the 45 wells tested.

"Production gas-oil ratio" was plotted versus "average subsea depth of the productive reef open in the well bore" for 34 wells tested in the Kelly-Snyder area. This plot indicated that the reservoir oil in the Kelly-Snyder area was in equilibrium or in a near state of equilibrium and that there was a variation in the solution-gas content of the oil with depth in which the content decreased 46 cubic feet per barrel of stock-tank oil for each 100 feet increase in subsea depth.

When there are variations in the physical properties of oil in a reservoir, care should be taken in selecting an "average" reservoir oil, the properties of which are to be used in making material-balance calculations. A method is presented in the report for determining physical properties for the composite of the total reservoir oil. Errors are minimized when these composite oil data are used in material-balance calculations.