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ENGINEERING REPORT ON

THE SMACKOVER OIL AND GAS FIELD,

UNION AND OUACHITA COUNTIES, ARKANSAS

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BY

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ENGINEERING REPORT ON THE SMACKOVER OIL AND GAS FIELD,
UNION AND ^AOUCHITA COUNTIES, ARKANSAS.

By
P. S. HAURY and R. B. KELLY.

INTRODUCTION

This report deals with the engineering studies of underground conditions and their application to drilling and production problems in the Smackover, Arkansas field. Sufficient information was obtained from the study of a large number of wells so that it was possible to determine the definite relations between the several oil and gas bearing sands and the water sands. The report is published with a three-fold purpose: (1) To aid in establishing more exact control of drilling and thereby to reduce the hazard of developing areas that are undrilled; (2) As a guide for repairing faulty wells; (3) To illustrate the application of engineering methods to specific drilling and production problems. Field work for this report was completed during the month of October, 1923.

SUMMARY AND CONCLUSIONS

Since the publication of the first report on the Smackover field, the three important oil zones have undergone considerable development. The present report sets forth the results of a sub-surface study involving these zones and describes the relation between the several oil and gas sands and certain water sands.

An important gas zone, which probably underlies a large area, is outlined. It is shown that much new production can be won from the three oil zones in the undrilled parts of the proved field and that the field will probably be extended beyond the present proved area. Recommendations for future drilling and repair of wells are made on the basis of the engineering study here presented.

To obtain a good recovery oil at a reasonable cost from this field is not an easy operating problem, due to the close stratigraphic position of the water and oil bearing strata. Therefore the question of financial profit or loss in producing operations is largely dependent on the care exercised by producers. In order to obtain the best results from the field care must be directed as much toward conformable water shut offs in adjacent wells as to careful exclusion of water in the individual wells.

GENERAL DESCRIPTION

Location and Extent of Field

The Smackover oil and gas field lies in Union and Ouachita Counties, Arkansas. The proven area covers approximately 39,000 acres in parts of Townships 15 and 16 south of the National base line and Ranges 15, 16 and 17 west of the fifth principal meridian. The town of Smackover is near the center of the field. The City of El Dorado, 10 miles southeast, is the supply point and business center of the district.

Transportation

The Gurdon to Natchez branch of the Missouri Pacific Railroad runs diagonally across the field from northwest to southeast. Louann, Griffin, Smackover, Kenova, Lege, and Norphlet are stations along the railroad that serve as distributing points.

Character of the Surface

Surface elevations range from 85 feet to about 220 feet above sea-level. Much of the surface is comparatively flat and presents the appearance, in wet weather, of a swamp broken by small hills and knolls. The ground is covered with second growth timber except where an occasional field has been cleared. Smackover Creek runs across the oil field from west to east. During periods of rainy weather this creek sometimes spreads to a mile in width.

DEVELOPMENT AND RELATION OF SANDS

More than 1200 wells have been drilled in the Smackover Field. The total production to January 1, 1924, amounts to about 40,000,000 barrels. The highest daily rate of production, 112,000 barrels, was obtained in the month of June, 1923. The present rate, February 1, 1924, is about 100,000 barrels. The production statistics on Table 1, were prepared from figures supplied by the Standard Oil Company of Louisiana.

TABLE 1

PRODUCING AND PRICE RECORD OF THE SMACKOVER FIELD

1922	Total Monthly Prod. in Bbls.	Avg. Daily Prod. in Bbls.	Avg. Price 26 ⁵ & above Dollars per bbl.	Avg. Price Below 24 ⁰ Dollars per bbl.
Sept.	60,000	2,000	0.75	0.75
Oct.	345,062	11,131	.75	.75
Nov.	1,750,980	58,366	.40	.40
Dec.	2,302,091	74,261	.35	.35
1923				
Jan.	2,646,361	85,366	.90	.45
Feb.	2,303,616	82,272	1.30	.85
Mar.	2,721,862	87,802	1.35	.90
Apr.	2,738,610	91,287	1.25	.75
May	2,750,325	88,075	.90	.45
June	3,357,360	111,912	.85	.40
July	3,227,379	104,109	.85	.40
Aug.	3,087,600	99,600	.85	.40
Sept.	3,160,770	105,359	.80	.40
Oct.	3,267,679	105,409	.75	.40
Nov.	3,125,940	104,198	.75	.40
Dec.	3,032,575	97,825	.77	.42

Production Zones

For convenience the productive horizon of this field is divided into three zones each with its distinctive productive sands merging into edge water and its water sands in which no production, either gas or oil, had been developed when the field work on which this report is based was completed. (See Plate VII and Table II.)

First Zone: Oil

The first zone production is obtained from sands that correlate with the Nacatoch formation as found in the El Dorado, Arkansas field. This zone has been developed to a much greater extent than the others. Within the 30,000 acres of its proven area nearly a thousand wells have been completed. Present (February, 1924) production from the first zone is at the rate of about 80,000 barrels per day and its total production amounted to about 37,000,000 barrels, January 1, 1924. The most of this production is obtained from 15,000 acres in the eastern part of the Smackover field. The production from this zone in the western part of the Smackover field is relatively unimportant. Nearly all oil from the eastern part of the field has a gravity of about 20° A.P.I., while that in the west field varies in

gravity from 24° to 26° A.P.I. The formation is composed largely of sand with some shale and sandy shale breaks. Frequent limestone caps are present, some of which are apparently continuous over wide areas.

First Zone: Water

The Nacatoch edge waters constitute the top of the first zone water. Thus the top of this water lies at variable stratigraphic depth according to the position of structure. This depth ranges from the top of the Nacatoch sand at the edges of the first zone to 100 feet below the top of the Nacatoch sand where only the fourth Nacatoch edge water is present. Deeper water sands in the first zone occur only in the structural basin that centers in the northwest quarter of section 4 - T. 16 S. - R. 16 W., and on the lowest parts of the Smackover structure. Over most of the Smackover field the fourth edge water is the lowest water in the first zone. On the higher parts of the West Smackover structure there is no water between the first and second zones.

The lowest Nacatoch water was called bottom water in the earlier report as it was thought to underly the whole of the East Smackover field. However, additional information shows that this water is not present on the higher parts of the West field. In this report the lowest Nacatoch water is called fourth Nacatoch edge water. Edge water is defined as water contained in a stratum that also carried oil or gas at higher elevation or further up the dip. The first, second, third and fourth Nacatoch edge waters lie at depths of 20, 42, 72 and 100 feet respectively, below the top of the Nacatoch sand as contoured. Their limits are shown, on Plate I, by the broken edge water lines marked "B", "C", "D" and "E", respectively. The line marked "A" indicates the position of oil and water at the top of the Nacatoch sand or the outer limit of first zone production.

Second Zone: Oil and Gas

The oil and gas produced from the second zone is commonly accepted to be from sands at the base of the Marlbrook formation or in the top of the Annona chalk.

Primm Gas Zone The gas sands of this zone lie between 315 feet and 341 feet below the top of the Nacatoch sand on the north flank of the East Smackover structure. In the eastern part of the field no oil in the second sand has been produced but several large gas wells have been completed in the second zone in section 31, T. 15 S. - R. 15 W. and sections 6 and 7 - T. 16 S. - R. 15 W. and section 1 - T. 16 S. - R. 16 W. An edge water was found at a depth of 341 feet below the top of the Nacatoch sand in the Simms Oil Company, F.A. Laney 2, and Sure Oil Company, B.T. Laney B-2. Both these wells are in section 31 - T. 15 S. - R. 15 W. The limits of this edge water have not been determined in other directions. On the west flank of the East Smackover structure, the Primm gas zone lies between depths of 330 and 365 feet below the top of the Nacatoch sand. The gas is produced from a sandy formation varying in thickness from 35 to 50 feet, lying immediately over the Meekin sand and is here called the Primm gas zone. The stratigraphic relation of the second zone sands is shown on the cross sections and on Plate VII (in pocket). The rock pressure in the Primm gas zone is 1000 pounds or more per square inch and the wells have an open flow capacity of 20,000,000 to 40,000,000 cubic feet per day. This gas

zone has been proved over an area of about 1760 acres. The volume of the wells and the sustained rock pressure indicate that the gas reservoir is large, and its probable productive area has been estimated to be about 14,000 acres.⁴

Meekin Oil Sand

In the West Smackover Field most of the oil is produced from a sand in the second zone, called the Meekin sand, that lies 365 feet below the top of the Nacatoch. About 225 wells have been completed in the Meekin sand over a proven area of about 15,250 acres. On January 1, 1924, it was producing at the rate of about 18,000 barrels per day and the total amount of oil produced from this sand is about 2,750,000 barrels. The gravity of the oil from the Meekin sand varies from 26° to 28° A.P.I. The sand is productive for a depth of 35 feet, in the northwest part of the field, higher on structure than the second edge water line marked "G" on Plate II. There the Meekin water sand lies about 38 feet below the top of the Meekin oil sand. (See Plate IV).

One well in section 26 - T. 15 S. - R. 17 W. was completed in oil sand at 62 to 83 feet below the top of the Meekin sand and seems to indicate that the Meekin in water sand is missing in that locality. The productive Meekin sand is limited to about 10 feet between the edge water lines, marked "F" and "G" on Plate II. The approximate limits of production are roughly defined on Plate II, by the broken edge water line marked "F". The entire Meekin sand carries water in the broad synclinal depression that lies between the East and the West Smackover fields. Water is also trapped in the sand in the structural basin around the northwest corner of section 4 - T. 16 S. - R. 15 W. and the Meekin sand is not productive inside the edge water line surrounding this basin. The edge water conditions in the Meekin sand are shown on the cross-sections, Plates III, V and VI.

Second Zone: Water

The edge waters of the second zone constitute the top of the second zone water, which varies from 341 feet on the north flank of the East Smackover structure to 400 feet below the top of the Nacatoch sand on the West flank of the East Smackover structure. The deepest water of this zone lies at 610 feet below the top of the Nacatoch sand.

Third Zone: Oil

Most geologists agree that the Blossom series of sands constitute the third producing zone. Present development in this zone is relatively unimportant. Twenty-five wells have been drilled to it and only six have been completed as producers, all located in the western part of the field. The third zone consists of 115 feet of sandy formation that lies 627 to 649 feet below the top of the Nacatoch sand and is approximately 22 feet thick. It contains two oil sands; one at the top which yields 19° to 21° Baume oil, and the other at the bottom, yielding 25° to 27° Baume oil. The lower oil sand lies at 715 to 742 feet below the top of the Nacatoch sand. (See Plates III and V). Its productive thickness averages 27 feet. These sands are separated by formation which is predominately shale with breaks of lime and sand. The wells are capable of producing 60 to 80 barrels per day on the pump.

⁴ Press notice issued by the Bureau of Mines, December, 1923.

Third Zone: Water

Two known water sands occur in the third zone, between the upper and lower third zone oil sands. The highest third zone water logged lies at a depth of about 649 feet below the top of the Macatoch sand or 22 feet below the top of the third oil zone. The deepest third zone water lies 709 feet below the top of the Macatoch sand, only six feet above the lower third zone oil sand. The thickness of these two water sands varies from 10 to 20 feet.

Water Below the Third Oil Zone

Water is logged in one well at a depth of 27 feet below the top of the third zone oil sand.

The depths, thicknesses and the relative positions of the several oil zones and water in the various zones are shown on the composite log, Plate VII, and on Table II.

OIL ANALYSES⁵

Following the general Mid-Continent practice, pipe line companies purchase the oil from this field on the gravity basis. In general however this crude falls into two classes:

Smackover heavy about 20° A.P.I.

Smackover light above 26° A.P.I.

grades do not correspond exactly to geological horizons. For example in the eastern part of the field the oil from the first zone (Macatoch sand) runs 18° to 20° A.P.I. while in areas of the western field the oil from this sand runs as high as 26° A.P.I. These instances are in the nature of exceptions and as a rule one may expect the following relation of crude to stratification:

Smackover heavy (About 20° A.P.I.)

First Zone (Macatoch)

Upper 3rd Zone (Blossom)

Smackover light (26° to 28° A.P.I.)

Second Zone (Meekin)

Lower 3rd Zone (Blossom)

Smackover heavy crude is represented by the sample from Sure Oil Company Rhodes 4, Section 16, T. 16 S., R. 15 W. (first zone). This same kind of crude is also found in the Irma field, the East El Dorado field, the Woodley field and in the deeper sands of the El Dorado field, all of which are in Arkansas.

⁵ Notes on the character of the oils were prepared by N.A.C. Smith, chief petroleum chemist of the Bureau of Mines.

TABLE II - TABULATION OF WATERS IN SMACKOVER FIELD

	Feet Below Top of <u>Nacatoch Sand</u>	Location on Map <u>See Plates I and II</u>
Edgewater at Top of Nacatoch Sand	0	Outside line "A"
First Nacatoch Edge Water	20	Outside line "B"
Second Nacatoch Edge Water	42	Outside line "C"
First Zone Third Nacatoch Edge Water	72	Outside line "D"
Fourth Nacatoch Edge Water	100	Outside line "E"
Bottom Water (below Nacatoch)	180	No first zone water present on high part of West Smackover structure
Top of Primm Gas Zone	330	315' on North flank on East Smackover structure
Primm Gas Zone Edge Water	341	Encountered in Simms Oil Co., F.A. Laney 2, Sec. 31-15-15 and Sure Oil Co., B.T. Laney E-2 Sec. 31-15-15
First Meekin Edge Water	365	Outside line "F"
Second Zone Second Meekin Edge Water	375	Outside line "G"
Meekin Water	400	Encountered in Turner, Laney 2 and 3, Sec. 8-16-16, El Dor. Nat. Gas Co. Tatum 1, Sec. 11-16-16, and others.
Lowest Water in Second Zone	610	Encountered in majority of wells drilled to third zone.
Top Upper Oil Sand	627	No edge water encountered to 1-1-24
Third Zone Top Third Zone Water	649	Encountered in Texas Saxon B-1 Sec. 9-16-16, Arkansas Natural Gas Co., Murphy 1 Sec. 10-16-16 and others.
Deepest Water in Third Zone	709	Encountered in one well drilled below third zone.
Bottom Water Below Third Zone	712	Encountered in one well drilled below third zone.

Smackover light crude is represented by the samples from Sun Oil Company, Section 1, Section 5, T. 16 S., R. 16 W., (second zone); Simms Oil Company, Childs Section 8, T. 16 S., R. 16 W., (lower third zone); and Texas Company, Hugh McKenzie 4, Section 36, T. 16 S., R. 16 W., (first zone).

The heavy grade of oil has a gravity from 19° to 21° or less, sulphur 2.3 to 2.5 per cent, no light gasoline, sometimes no naphtha fraction at all, or at most a naphtha fraction of 7 or 8 per cent. There is no wax present and the viscosity of the lubricating fractions is fairly high. In other words, this grade of oil is somewhat like the Gulf Coast and California oils and could be considered as asphaltic base crude.

The second of these oils has a gravity around 26° , sulphur from 1.8 to 2.0 per cent, a gasoline content of 15 per cent or better, and contains a medium amount of wax as indicated by the cloud test of the vacuum fractions. The lubricating distillates are medium in viscosity. Except for the high sulphur, this oil is very much like mixed base crudes found generally throughout the Mid-Continent. The high percentage of sulphur indicates that this oil is more asphaltic than most of the Mid-Continent production.

The analyses made by the Bureau of Mines indicate that there are three grades of crude produced in Arkansas, which might be considered as 35° , 26° and 20° gravity respectively. The 35° gravity crude from the El Dorado field very closely resembles the oil from the Hewitt and Healdton fields in Oklahoma. This grade has not yet been found in Smackover. The 26° gravity crude might easily be the 35° gravity oil which has lost considerably of its gasoline content. The 20° gravity crude, however, is more like some of the Gulf Coast oils. It approaches in quality the high sulphur crude found in the Spindle top field of Texas, although the lubricating fractions are not as viscous as those from the Spindle Top oil. Some of the California crudes are also very similar.

Sample 23503

Sample from Sun Oil Co. - Meekin 1 - Sec. 5- T. 16 S. - R. 16 W.

Well producing from depth of 2270-2230 feet - Meekin sand.

Specific gravity, .896	A.P.I. gravity, 26.4
Per cent sulphur, 1.88	Per cent water, 4.7
Saybolt Universal viscosity at 70° F. 227 Sec.	Four point below 5°F
Saybolt Universal viscosity at 100° F. 111 Sec.	

Distillation, Bureau of Mines Hempel Method.

Air Distillation			Barometer, 747 mm.		First Drop 42°C (108°F)		
Temperature °C	Per Cent Cut	Sum Per Cent	Sp. Gr. Cut	°A.P.I. Cut	Viscosity 100°F	at 212 °F	Cloud Test °F
Up to 50	0.3	0.3)					Up to 122
50 - 75	1.2	1.5)	.689	73.9			122 - 167
75 - 100	2.4	3.9)					167 - 212
100 - 125	2.7	6.6	.729	62.6			212 - 257
125 - 150	3.9	10.5	.756	55.7			257 - 302
150 - 175	3.0	13.5	.783	49.2			302 - 347
175 - 200	2.8	16.3	.804	44.5			347 - 392
200 - 225	3.1	19.4	.821	40.9			392 - 437
225 - 250	4.1	23.5	.834	38.2			437 - 482
250 - 275	5.8	29.3	.844	36.2			482 - 527

Vacuum Distillation at 40 mm.

Up to 200	3.9	3.9	.867	31.7	40	Below 5	Up to 392
200 - 225	6.1	10.0	.874	30.4	50	22	392 - 437
225 - 250	7.0	17.0	.882	28.9	57	42	437 - 482
250 - 275	5.9	22.9	.894	26.8	88	60	482 - 527
275 - 300	7.8	30.7	.907	24.5	142	78	527 - 572

Carbon residue of residuum 12.3%

Approximate Summary

	Per cent	Sp. Gr.	°A.P.I.	Viscosity
Gasoline and naphtha	16.3	0.749	57.4	
Kerosene distillate	3.1	0.821	40.9	
Gas oil	16.8	0.854	34.2	
Nonviscous lubricating distillate	14.7	0.874-0.905	30.4-24.9	50-100
Medium lubricating distillate	9.1	0.905-0.968	24.9-14.7	100-200

Sample 23507

Sample from Simms Oil Co. - Childs 1 - Sec. 8-T. 16 S.-R. 16 W.

Well producing depth of 2620-2656 feet. - Lower third zone oil sand.

Specific gravity .899 A.P.I. gravity, 25.9
 Per cent sulphur 2.01 Per cent water, 1.0
 Saybolt Universal viscosity at 70° F. 308 Sec. Pour point below 5° F.
 Saybolt Universal viscosity at 100° F. 145 Sec.

Distillation, Bureau of Mines Hempel Method.

Air Distillation			Barometer, 741 mm.		First drop 68°C (145°F)		
Temperature °C	Per Cent Cut	Cum Per Cent	Sp. Gr. Cut	°A.P.I. Cut	Viscosity at 100 °F	212 °F	Cloud Test °F
Up to 50							Up to 122
50 - 75	0.3	0.3)	.703	69.8			122 - 167
75 - 100	1.7	2.0)					167 - 212
100 - 125	2.6	4.6	.727	63.1			212 - 257
125 - 150	2.6	7.2	.745	58.4			257 - 302
150 - 175	2.9	10.1	.767	53.0			302 - 347
175 - 200	3.3	13.4	.791	47.4			347 - 392
200 - 225	3.9	17.3	.807	43.8			392 - 437
225 - 250	4.7	22.0	.824	40.2			437 - 482
250 - 275	6.2	28.2	.841	36.8			482 - 527

Vacuum Distillation at 40 mm.

Up to 200	3.3	3.3	.864	32.3	41	Below 5	Up to 392
200 - 225	6.3	9.6	.873	30.6	48	8	392 - 437
225 - 250	6.3	15.9	.889	27.7	61	34	437 - 482
250 - 275	6.0	21.9	.903	25.2	92	56	482 - 527
275 - 300	5.9	27.8	.909	24.2	158	76	527 - 572

Carbon residue of residuum 12.9%

Approximate Summary

	Per cent	Sp. Gr.	°A.P.I.	Viscosity
Gasoline and naphtha	13.4	0.751	56.9	
Kerosene distillate	8.6	0.816	41.9	
Gas oil	13.7	0.856	33.8	
Nonviscous lubricating distillate	12.2	0.875-0.903	30.2-25.2	50-100
Medium lubricating distillate	8.1	0.903-0.911	25.2-23.8	100-200

Sample from Sure Oil Corp. - Rhodes 4, Sec. 16 - T. 16 S. - R. 15 W.

Well producing from depth of 2045 - 2096 feet. First oil zone.

State: Arkansas

Smackover field, Morphlet Area

Union County

Specific gravity: 0.935

A.P.I. gravity 19.8

Per cent sulphur: 2.37

Per cent water 3.6

Saybolt Universal viscosity at 70°F 870

Pour point, below 5°F

Saybolt Universal viscosity at 100°F 339

Distillation, Bureau of Mines Hempel Method

Air Distillation			Barometer 742 mm.			First Drop 88°C 190°F		
Temperature °C	Per cent cut	Sum Per Cent	Sp. Gr. Cut	°A.P.I. Cut	Viscosity 100°F	Cloud Test °F	Temperature °F	
Up to 50							Up to 122	
50 - 75							122 - 167	
75 - 100	0.4	0.4)					167 - 212	
100 - 125	1.5	1.9)	0.752	56.7			212 - 257	
125 - 150	1.1	3.0)	0.774	51.3			257 - 302	
150 - 175	1.8	4.8)					302 - 347	
175 - 200	2.5	7.3	0.804	44.5			347 - 392	
200 - 225	3.1	10.4	0.834	38.2			392 - 437	
225 - 250	4.3	14.7	0.849	35.2			437 - 482	
250 - 275	4.3	19.0	0.861	32.8			482 - 527	

Vacuum Distillation at 40 mm.

Up to 200	2.4	2.4	0.890	27.5	42	Below 5	Up to 392
200 - 225	6.6	9.0	0.897	26.3	49	"	392 - 437
225 - 250	6.1	15.1	0.915	23.1	66	"	437 - 482
250 - 275	6.2	21.3	0.923	21.8	111	"	482 - 527
275 - 300	7.9	29.2	0.936	19.7	228	"	527 - 572

Carbon residue of residuum 13.4%

Approximate Summary

	Per cent	Sp. Gr.	°A.P.I.	Viscosity
Gasoline and naphtha	7.3	0.778	50.4	
Kerosene distillate	-	-	-	
Gas oil	17.8	0.864	32.3	
Light lubricating distillate	10.6	0.893-0.921	26.1-22.1	50-100
Medium lubricating distillate	6.9	0.921-0.933	22.1-20.2	100-200
Heavy lubricating distillate	5.6	0.933-0.943	20.2-18.6	above 200

Sample 24.27

Sample from Danciger Oil & Refining Company, Saxon A-2, Sec. 4-E, 16 S.--R.16W.

Well producing from depth of 2614-2620 feet - Upper Third Zone Oil Sand.

Specific gravity 0.955

A.P.I. gravity 16.7

Per cent sulphur 2.17

Per cent water, 18.8

Saybolt Universal viscosity at 70°F 1890 Sec.

Pour point, below 5°F

Saybolt Universal viscosity at 100°F 730 Sec.

Distillation, Bureau of Mines Hempel Method

Air Distillation

Barometer, 755 mm.

First Drop, 92°C (198°F)

Temperature °C	Per Cent Cut	Sum Per Cent	Sp. Gr. Cut	°A.P.I. Cut	Viscosity	Cloud Test °F	Temperature °F
Up to 50							Up to 122
50 - 75							122 - 167
75 - 100	0.3	0.3					167 - 212
100 - 125	0.6	0.9					212 - 257
125 - 150	1.0	1.9	0.789	47.8			257 - 302
150 - 175	1.5	3.4					302 - 347
175 - 200	2.1	5.5					347 - 392
200 - 225	3.2	8.7	0.834	38.2			392 - 437
225 - 250	3.5	12.2	0.846	35.8			437 - 482
250 - 275	6.3	18.5	0.873	30.6			482 - 527

Vacuum Distillation at 40 mm.

Up to 200	2.3	2.3	0.894	26.8	42	Below 5	Up to 392
200 - 225	5.9	8.2	0.906	24.7	52	do	392 - 437
225 - 250	6.5	14.7	0.913	23.5	72	do	437 - 482
250 - 275	5.6	20.3	0.921	22.1	122	do	482 - 527
275 - 300	7.5	27.8	0.925	21.5	188	do	527 - 572

Carbon residue of residuum, 14.5%

Approximate Summary

	Per cent	Sp. Gr.	°A.P.I.	Viscosity
Gasoline and naphtha	5.5	0.789	47.8	
Gasoline distillate				
Gas oil	17.5	0.866	31.9	
Viscous lubricating distillate	10.4	0.903-0.917	25.2-22.8	50-100
Medium lubricating distillate	10.4	0.917-0.926	22.8-21.3	100-200
Viscous lubricating distillate	2.5	0.926-0.927	21.3-21.1	above 200

Sample from The Texas Co. - Hugh McKenzie No. 4 - Sec. 36 - T. 15 S. - R. 16

Well producing from depth of 1940-2020 feet. First Oil Zone.

Specific gravity 0.916	A.P.I. gravity 23.0
Per cent sulphur 2.07	Per cent water 9.0
Saybolt Universal viscosity at 70°F 914	Pour point, below 5°F
Saybolt Universal viscosity at 100°F 203	

Distillation, Bureau of Mines Hempel Method

Air Distillation,			Barometer, 739 mm.	First drop 53°C 127°F			
Temperature °C	Per Cent Cut	Sum Per Cent	Sp. Gr. Cut	°A.P.I. Cut	Viscosity 100°F	Cloud Test °F	Temperature °F
Up to 50							Up to 122
50 - 75	0.4	0.4)	0.720	65.0			122 - 167
75 - 100	1.6	2.0)					167 - 212
100 - 125	2.5	4.5	0.736	60.8			212 - 257
125 - 150	2.3	7.3	0.757	55.4			257 - 302
150 - 175	3.7	11.0	0.782	49.5			302 - 347
175 - 200	2.9	13.9	0.804	44.5			347 - 392
200 - 225	3.5	17.4	0.824	40.2			392 - 437
225 - 250	4.4	21.8	0.839	37.2			437 - 482
250 - 275	5.5	27.3	0.852	34.6			482 - 527

Vacuum Distillation at 40 mm.

Up to 200	3.4	3.4	0.872	30.8	40	15°	Up to 392
200 - 225	5.5	8.9	0.834	28.6	47	32°	392 - 437
225 - 250	5.7	14.6	0.899	25.9	67	39°	437 - 482
250 - 275	5.8	20.4	0.912	23.7	101	45°	482 - 527
275 - 300	6.4	26.8	0.920	22.3	160	65°	527 - 572

Carbon residue of residuum 14.6%

Approximate Summary

	Per cent	Sp. Gr.	°A.P.I.
Gasoline and naphtha	13.9	.765	53.5
Kerosene	3.5	.824	40.2
Gas oil	17.1	.854	34.2
Light lubricating distillate	10.1	.873-.898	30.6-26.1
Medium lubricating distillate	9.5	.898-.910	26.1-24.0

CHARACTER OF PRODUCING SANDS

Nacatoch Sand

A study of the well logs indicate that the productive Nacatoch formation varies lithologically from place to place in the Smackover field. The greatest variation is noted at the top of the sand series. There the transition from sandy beds to shale and clay is not uniform over the field. It begins much earlier, or lower in the series at some places than at others. This variable deposition is most prominent in the western and especially the northwestern part of the field. Westward and northwestward from the middle of sections 25 and 36, T. 15 S., R. 16 W., the sand series of the Nacatoch formation becomes progressively finer grained; the ratio of shale, clay, and other impervious rocks to sand increases and the individual sand lenses are more isolated. No doubt such differences in sand texture are partially responsible for the wide variation in production obtained from neighboring wells producing from the same sand and drilled in to the same relative depth.

Another, and it is believed a more important cause for this variation in productivity, is the depletion of gas pressure by the early well or wells. Otherwise one would be forced to the assumption that these early wells always encountered the productive sand at points of maximum porosity as these wells are almost without exception the best producers. The decline in the production of the wells in this sand was more rapid in the West field than in the East field.

The Nacatoch sand also varies considerably in hardness and porosity within short distances. This is especially noticeable in the central and southern parts of the East Field. There a number of wells penetrated loose sand and yielded large quantities of oil while other wells near by encountered hard, cemented sand and yielded small quantities of oil or only gas. (See Plates III to VI, in pocket)

The Nacatoch sand at Smackover is found productive as high as 1740 feet and as low as 1900 feet below sea-level. The average depth below surface is about 2000 feet and the maximum productive sand thickness about 100 feet.

Second Producing Zone

The second oil zone consists of the Primm gas zone and the Meekin oil sand.

Primm Gas Zone

The sands of the Primm gas zone appear to be quite variable in position. The stratigraphic depth of this zone varies also. In sections 1, T. 16 S., R. 16 W.; sections 6 and 7 T. 16 S., R. 15 W., and section 36 T. 15 S., R. 16 W., the top of the gas zone lies about 335 feet below the top of the Nacatoch sand. On the north flank of the East Smackover structure gas sand was found at a depth of 315 feet below the top of the Nacatoch sand in Simms Oil Company, Reynolds 1, section 32, T. 15 S., R. 15 W. Twenty-three feet is the maximum thickness of sand encountered in this zone in the wells completed before January 20, 1924.

The Primm gas zone appears to contain only an occasional sand lense in the West Smackover field. Smitherman and McDonald, Saxon A-1, Section 32, T. 15 S., R. 16 W., produces oil from this zone (see Plate VI). An oil sand was logged in the Primm gas zone, but not produced, in Federal Oil Company, Childs 1, Section 8, T. 16 S., R. 16 W., and Arkansas Natural Gas Company, Murphy 1, section 5, T. 16 S., R. 16 W. (See Plate III). Production of oil and gas from the Primm Gas zone is unimportant however, in the West field.

Meekin Oil Sand

The Meekin oil sand is the most uniform of any sand in the Smackover field. It is divided by two shells and is separated from an underlying water by a shell. This sand has been found in all parts of the field where wells have been drilled to the second oil zone.

Third Producing Zone

The third oil zone about 115 feet thick is logged as sandy shale interstratified with thin beds of sand and shale which appear to be lenticular and irregular. It contains an oil sand at the top and bottom with at least two intervening water sands. Present production from the third oil zone is not important. Twenty-five wells have been drilled to this zone or through it, six of which are productive, all in the southwest part of the field. Three of these wells were completed in the upper 18 feet of the zone and three in the lowest 11 feet. An oil sand has been logged in the middle part of the zone but no well was successfully completed in it.

STRUCTURE

The Smackover structure is divided into two parts, the East field, consisting of a large dome centered in section 8, T. 16 S., R. 15 W., and the West field, which has two smaller domes and a sharp terrace, facing east and running through sections 20, 17, 16, 9, 4, and 3, T. 16 S., R. 16 W., and sections 34, 27, 26, 23, and 24, T. 15 S., R. 16 W. A broad shallow syncline separates the East and West Smackover structures.

Structural Contour Maps. (In pocket)

The depth below sea level to the top of the Nacatoch sand is shown by the sub-surface contour lines on the map of the Smackover Field, Plate I (in pocket). The depth below sea level to the top of the Meekin sand is shown on Plate II (in pocket) and represents the area over which the second zone has been proven to be productive. In Plate I all the wells of the field are shown but only those wells that were drilled to the second or third producing zones are shown on Plate II.

Method Employed in Working out the Structure and the Stratigraphy

The contour lines on top of the Nacatoch productive zone and the Meekin sand were determined entirely from subsurface data. The logs of most of the wells in the field and all available production records were used for this purpose. In constructing the two contour maps, points of equal elevation were taken from more than 100 working cross-sections which were used in developing the correlation. These were plotted to a vertical scale of 100 feet to the inch and a horizontal scale of 500 feet to the inch. The horizontal distances were scaled from the field map and the vertical taken from the drilling logs of the various wells. The history and data as to oil and water production of individual wells was found so useful in correlating the various productive zones that it was written below each graphic log whenever available. Four of these cross sections Plates III to VI (in pocket) have been selected to accompany this report as samples of the net work of sections which by making intersections afforded numerous control points and covered the entire field.

Composite Log

Plate VII is a comparison of a composite graphic log of the Snackover field prepared by H.G. Schneider of the Amerada Petroleum Corporation with a similar log made by the Bureau of Mines, Department of the Interior. The two are shown together with a graphic log of the nearby El Dorado field, developed by the U.S. Geological Survey from microscopic examinations of samples of a well in that field. The composite log made by the Bureau of Mines represents the seventy-three logs shown on the cross sections accompanying this report together with a large number of logs selected at random from the entire field. The proportions of sand, shale, limestone, etc., occurring at the various stratigraphic depths were estimated by inspection in order to reach a fair percentage of the various constituents present. The top of the Nacatoch sand was taken as zero for measurements of the stratigraphic column, as was done with respect to all other vertical measurements throughout this report. The composite log should be of value to the operator in determining the amounts of casing to be used, as the water sands are believed to be located very accurately. Likewise, indications are shown where the most favorable casing seats can be expected.

ENGINEERING METHODS

A study of the cross-sections that accompany this report (Plates III to VI) will show that frequently an oil sand logged in a neighboring well will be unrecorded in the adjacent well. Such discrepancies were adjusted by averaging the logs of many wells and by checking intervals against the top of the Nacatoch sand or other key beds. The intervals between the several oil producing zones and the water sands have been checked over the entire field and the positions of the several sands are accurately determined where solid contour lines have been drawn on the subsurface structural maps, whereas dotted contours indicate that the probable position of these sands is still indeterminate. Such engineering studies will save oil operators large sums of money by reducing the number of wells that are failures or are drilled into water.

Two wells, shown graphically on Plate IV, illustrate the value of such engineering studies when applied to drilling. In Gulf Refining Company, Fincher section 28, T. 15 S., R. 16 W., the oil sand was not observed in drilling the first 24 feet of the Meekin sand and the well was drilled into the Meekin water sand. Later the correct position of the Meekin oil sand was calculated from correlations made by Gulf engineers, the bottom of the well was then plugged with cement, and the casing perforated at the top of the Meekin oil sand. Since the well was repaired it has been producing at the rate of 125 barrels of clean oil per day, from a depth at which no sand was logged. The Meekin oil sand was missed entirely in drilling Forrest Oil Company, Hardin 3, section 28 T. 15 S., R. 16 W., and the well was deepened through the underlying water sand. Later the well was repaired under the direct supervision of the Bureau of Mines and is now producing clean oil, at the rate of 120 barrels per day, from formation that was recorded as shale in the well log. W.H. Johnston, driller of the Dallas office, supervised this work, and as a policy of the Bureau of Mines, his services are at all times available for advice on mechanical problems relating to oil wells.

DRILLING METHODS

Nearly all the wells in the Smackover field were drilled with rotary tools. A few were drilled into the oil sand with cable tools.

Drilling Equipment

The important items of the drilling equipment, that is commonly used, are:

- 112-foot, 24 foot base, open derrick, without sway braces;
- Texas type draw works and rotary tools;
- 10 by 5-3/4 by 12 inch mud pumps;
- 4-inch, 12-1/2 or 15-pound, drill pipe;
- One 66-horsepower boiler or two 45-horsepower boilers.

Generally, drilling is not difficult in the Smackover field although some trouble was experienced in drilling a few of the earlier wells, on or near section 8, T. 16 S., R. 15 W., through shallow water sands.

The difficulty was due to the high pressure Nacatoch gas that had migrated into the shallow sands from the Murphy crater well. This gas built up high pressures in the shallow sands and caused large flows of water and sand. The gas pressure is now reduced.

About thirty days are required for drilling a well to the first or second zone. These wells are put down at a total cost ranging from about \$8000 to \$15000. The few third zone wells, drilled under variable conditions and handicapped by indefinite information of the relative positions of the third zone oil sands and water sands, do not serve as a basis for estimating the time required to drill third zone wells.

Casing Methods

First Zone Wells: Six-inch line pipe or 6-5/8-inch casing is set in most first zone wells, at 50 to 100 feet above the top of the Nacatoch sand and cemented with 10 to 100 sacks of cement. Recently many operators have been setting 8 1/2-inch casing above the Nacatoch sand in anticipation of later deepening the wells.

Second Zone Wells: Two casing methods are followed in drilling second zone wells. (1) In wells situated on the higher parts of the West Smackover structure, where there is no water between the top of the Nacatoch sand and the Meekin sand, the water strings are usually set and cemented above the Nacatoch sand, as in first zone wells. Six-inch line pipe, 6-5/8-inch casing or 8 1/2-inch casing is used for these water strings. The wells are then finished with about 100 feet of liner which has one or more joints of perforated casing at the bottom and is connected at the top inside the water string, with a lead seal. The liners are usually of 4 1/2-inch line pipe. (2) Unusually large quantities of oil were recovered from second zone wells in the West Smackover field by one operator who finished the wells in such a way that gas from the Nacatoch sand could be utilized in causing the oil to flow from the Meekin sand. The water string, of 8 1/2-inch casing, was set above the Nacatoch sand; 7-5/8-inch hole was drilled into the Meekin sand; and the well was finished with 4 1/2-inch liner, which has one or two joints perforated at the bottom and is sealed off, at the top, inside the 8 1/2-inch casing. This arrangement allowed gas from the Nacatoch sand to pass down outside the liner and flow the oil that entered the well from the Meekin sand. The second zone gas wells, in the central part of the Smackover field, were originally completed in the first oil zone and had 6-inch or 6-5/8 inch casing set above the Nacatoch sand. They were deepened to the Primm gas zone and 4 1/2-inch casing was cemented at some intermediate depth between the fourth Nacatoch edge-water (100 feet below the top of the Nacatoch sand) and the Primm gas zone. These wells were then finished with 4-inch liners, perforated at the bottom.

Third Zone Wells: The twenty-five wells that were carried below the second oil zone in search of deeper production were drilled under varying conditions and no standardized casing method was adopted for them. A number of these wells were finished with two strings of casing, the 6-5/8-inch casing being set with cement above the Nacatoch sand and 4 1/2-inch casing cemented above the upper sand in the third zone with sufficient cement to reach into the 6-5/8-inch casing in an effort to prevent the intermingling of oil and water from the various sands penetrated.

TREATMENT OF CUT OIL

The treatment of cut oil presents two problems in the Smackover field:

- (1) The treatment of the emulsion fresh from the wells, large quantities of which are produced on some leases.
- (2) The treatment of oil that is stored in open pits, much of which contains entrained rain water. The treatment of fresh emulsion is generally not difficult but the same methods of treatment had to be modified when used to remove the water from stored oil.

Three methods of treatment are successfully used. These are "cooking", electric dehydration, and chemical treatment.

"Cooking"

When it was found that usual methods at ordinary temperatures would not clean the pit oil, the water was evaporated from the oil by heating the oil in open pits with steam coils. Some of the cooking plants are equipped with heat interchanges to increase their efficiency. The reported costs at different plants range from 3.1 cents to 6 cents per barrel of clean oil. The chief item of expense in this operation is the cost of fuel. The above costs were developed with fuel oil at 40 cents per barrel.

Electric Dehydration

A total cost of 2.9 cents per barrel of clean oil is reported from one 2-unit electric dehydrator, treating 2,200 barrels per day. The average B. S. and water in this emulsion runs about 52 per cent. The plant treats successfully a mixture of fresh emulsion and pit oil.

Chemical Treatment

The Simms Oil Company at first treated the oil by "cooking". This was not entirely satisfactory as it lowered the quality of oil and lost about 10 per cent of it by evaporation. To avoid such losses a method for treating emulsion with chemicals was developed after several months of experimenting. The early tests showed that the chemicals would break up the emulsion but the water would not settle out. This problem was solved by packing the settling tank with excelsior from about 3 feet above the bottom to near the top. The chemically treated mixture, which has been heated to 130° F. - 180° F., enters this tank at the bottom. The excelsior serves to collect the globules of water in the emulsified oil and as the fluid level rises, clean pipeline oil is collected at the top of the tank which overflows into the gage tanks. A mixture of fresh emulsion and pit oil is treated in these plants. The cost for chemicals ranges from 2.4 cents to 2.9 cents per barrel of clean oil recovered.

USE OF THE PLATES TO DETERMINE CASING AND COMPLETION DEPTHS

The subsurface contour maps, Plates I and II, can be used for calculating the casing depth and safe finishing depths of wells to be drilled to the first and second zones.

First Zone Wells.

The water string is cemented above the top of the Nacatoch sand in first zone wells. In order to calculate the depth of the top of the Nacatoch sand below the derrick floor, at any location, the place where the well is to be drilled should be found on Plate I, the depth below sea-level of the contour horizon is then read, and the elevation at the derrick floor of the well added. An interpolation can be made when the location falls between two contour lines on the map.

For example; if the well location falls between the 1820-foot and the 1830-foot contour lines and is $\frac{1}{2}$ of the total distance between these lines, the depth below sea level of the top of the Nacatoch sand at this location will be 1825 feet. If the elevation of the derrick floor is 150 feet, the depth of the top of the Nacatoch sand below the derrick floor will be 1975 feet.

The safe drilling depth can be calculated in the same way. At locations between the edge water lines "A" and "B", Plate I, the well should be drilled only a few feet below the top of the Nacatoch sand. At locations between the edge water lines "B" and "C", the well should not be drilled deeper than 40 feet below the top of the Nacatoch sand. The position of the edge water line "B" has not been determined on the south flank of the structure. At locations between the edge water lines "C" and "D", a well should not be drilled more than 70 feet below the top of the Nacatoch sand. At the locations between the edge water lines "D" and "E", a well should not be drilled deeper than about 95 feet below the top of the Nacatoch sand. The depth of the first zone wells is not limited by underlying water at locations higher on the structure than the edge water line "E". It should be remembered that the locations of these edge water lines are approximate, in many places. Therefore as a factor of safety it is recommended that if a well is only a short distance within an edge water line it should be drilled as though it were actually outside the line. It should also be kept in mind that the various edge waters have advanced to higher levels on structure since the field work on this report was completed.

Second Zone Wells

Second zone wells located higher on structure than the edge water line "E" on Plate I do not require a second water string but a second water string should be set above the Prima gas zone or about 300 feet below the top of the Nacatoch sand, at locations east or south of the line "E".

The successful completion of second zone wells requires care. At points higher on structure than the edge water line "G", the wells should not be drilled deeper than 35 feet below the top of the Meekin sand, as shown by the contour lines on Plate II. The west flank of the structural high in section 24 - T. 15 S. - R. 17 W. may be an exception. The Klotz-Thomas well in section 26 - T. 15 S. - R. 17 W. seems to indicate that the Meekin water sand is missing there. (See Page 6). At locations between the edge water lines "F" and "G", the wells should be drilled only about eight feet below the top of the Meekin sand. At locations lower on structure than the edge water line "F", on Plate II, second zone wells will have to be finished in the Primm gas zone above the Meekin sand. On parts of the north flank of the East Smackover structure, the depth of second zone wells will be limited by an edge water that lies 341 feet below the top of the Nacatoch sand. This edge water was found in two wells, located near the 1850-foot contour line. The top of the Meekin sand lies 365 feet below the top of the Nacatoch sand and Plate I can be used for estimating the depth to which may be drilled in parts of the field outside the area covered by Plate II.

Third Zone Wells

A water string should be cemented at a depth of about 625 feet below the top of the Nacatoch sand in wells drilled to produce from the upper oil sand of the third zone in order to shut off the last water in the second zone. It is important that these wells should not be completed deeper than 645 feet below the top of the Nacatoch sand. To produce the lower third zone sand, a water shut-off must be effected at 715-720 feet below the top of the Nacatoch sand and to avoid bottom water the well should not be drilled deeper than 740 feet below the top of the Nacatoch sand.

Drilling in Unproven Parts of the Field

It is believed that the composite log on Plate VII can be used to advantage for the control of drilling in unproven parts of the field. Some of the shallower water sands are fairly persistent throughout the Smackover field. The hard bed of limestone at the base of the Midway formation is probably present at most locations in the Smackover and El Dorado fields. An oil show is noted at this horizon in many wells. The shallower strata, over the entire district adjacent to the Smackover field, appears to be parallel to the Nacatoch formation. If this is true and formations down to the base of the Midway formations are carefully logged the depth to the top of the Nacatoch sand can be estimated with a fair degree of accuracy by the use of the composite log. While some well logs of the Smackover field record a cap rock or shell above the Nacatoch sand it is not sufficiently general to be relied upon solely as a marker. However if the driller has an approximate idea at what depth this important bed may be expected and is observing formation changes closely he should have no difficulty in detecting the transition from the shale or gumbo of the arkadelphia formation to sands of the Nacatoch.

FORMATION SAMPLING AND MEASURING BELOW NACATOCH SAND

The oil sands and water sands lie so close together in the second and third zones that accurate logs will be needed to complete all wells successfully. An accurate drilling record is difficult to obtain when drilling with rotary tools through small casing. Core samples, taken at critical points, will overcome this difficulty if the depths are determined accurately by checking with steel line measurements, when core samples are taken. This work is relatively inexpensive and is strongly recommended for future wells in the undeveloped parts of the field. True, some time is taken in running the core-barrel but as success is dependent upon definite knowledge of the formations encountered, this delay is not to be considered. If such precautions are followed it should not be difficult to properly complete second and third zone wells. The logs of wells in which important sands have been located are valuable for determining future drilling operations.

RECOMMENDATIONS FOR DRILLING

The Smackover field has passed the promotion stage and has settled to a producing business and it should be possible for neighboring operators to cooperate for the purpose of drilling the undeveloped part of the field in a manner that will give the greatest stability to their several investments.

For convenience in discussing the casing programs, the field is divided into two areas. The first area consists of the part of the field that lies northwest of the Nacatoch edge water line "E" (Plate I.), running through sections 20, 16, 10 and section 3, Township 16 South, Range 16 West and sections 34, 26, 23 and section 24, Township 15 South, Range 16 West. The second area comprises all of the Smackover field east of this edge water line. The drilling, to date, has not given sufficient information to delimit this edge water exactly although the line "E" marks its approximate western limit.

First Area

The absence of the first intermediate water makes it possible to test both the first and the second oil zones, in the first area, by cementing one water string above the Nacatoch sand. The following drilling program is recommended:

- (1) The $8\frac{1}{4}$ -inch, 32-pound casing is cemented above the Nacatoch sand.
- (2) Careful sampling should be done while drilling through the first zone, and tests made if oil or gas is noted. It is anticipated that the Nacatoch sand will yield profitable production for a time at some places in this area.
- (3) If the Nacatoch sand yields an appreciable amount of gas, the operator may drill a large hole into the Meekin sand and set $4\frac{1}{2}$ -inch liner with one to three joints perforated at the bottom and seal the liner off at the top inside the $8\frac{1}{4}$ -inch water string. The gas thus utilized to lift oil may be recovered by suitable gas trap installation. This method of casing will use the gas from the Nacatoch sand to flow the oil from the Meekin sand.
- (4) When production from the Meekin sand has declined to a point where it is unprofitable, the $4\frac{1}{2}$ -inch liner can be pulled or sidetracked and the well deepened to the third oil zone.

Completing Third Zone Wells

It is believed that the most satisfactory method of casing third zone wells, all factors considered, is to cement a 6-5/8 inch, 24-pound water string at about 625 feet below the top of the Nacatoch sand, or just above the third zone. The hole is then drilled into the upper third zone oil sand from which production is taken as long as it is profitable. The well is then deepened to the top of the lower third zone oil sand and a liner is cemented at 715-720 feet below the top of the Nacatoch sand. The lowest water was shut off by cementing a liner in two of the six wells now producing from the third oil zone. It is advisable, when cementing a liner, to use a full string of casing with a left hand nipple at the top of the liner and back the casing off after the cement has set. If the cement fails to seal the top of the liner, the well may be saved by screwing the casing back into the liner.

Second Area

The presence of water in all zones in this area makes it necessary to set one water string above each sand from which production is anticipated.

The first casing program recommended is as follows: (1) A string of 10-inch, 45-pound casing is cemented above the Nacatoch sand which should be exhausted before the hole is deepened. (2) The liner must then be fished out or sidetracked and a string of 8 $\frac{1}{4}$ -inch, 32-pound casing cemented above the Primm gas zone at about 300 feet below the top of the Nacatoch sand. The Primm gas zone is produced until it is no longer profitable and then the well is deepened into the Meekin sand, if the Meekin sand carries oil at that location. (3) When deepening to the Blossom sand, the 6-5/8 inch, 24-pound casing is cemented above the third oil zone, at about 625 feet below the top of the Nacatoch sand and the well drilled into the upper third zone oil sand. (4) When deepening to the lower third zone oil sand, the 4 $\frac{1}{2}$ -inch liner is cemented at a depth 715-720 feet below the top of the Nacatoch sand. Each of these deepening jobs involves the fishing out of a liner or drilling it up.

The second program recommended substitutes smaller casing as follows:

- (1) 8 $\frac{1}{4}$ -inch, 32-pound casing, cemented above the first oil zone.
- (2) 6-5/8-inch, 24-pound casing, cemented above the second oil zone.
- (3) 5-3/16-inch, 17-pound casing, cemented at the top of the lower third zone oil sand.

Future drilling may demonstrate that one or another of the oil zones will not yield profitable production in some parts of the field. This will simplify the casing program for such areas.

When setting any string of casing that has both oil sand and water sand behind it, regardless of the location of the well, sufficient cement should be used to fill the hole outside of this casing up into the next larger (water) string in order to protect the upper oil sand from the water that is cased off with it. High pressure pumps will be required to force the cement to the required height when the hole is not much larger than the casing or between two strings of pipe. Table III can be used for calculating the amount of cement required to fill the space between two strings of casing to a given height. Additional cement to fill the cavities should be used, when the hole has been drilled through cavy formation or when the casing is set through a sand from which the well has produced and in which the hole was enlarged by channeling.

TABLE III - NUMBER OF LINEAR FEET OF SPACE BETWEEN CASING AND HOLE FILLED BY ONE SACK OF CEMENT.

Actual Outside Diam. (inches)	Diameter (in inches) of hole in which casing is set.	15	11	9 7/8	8 1/2	7 7/8	6 1/8	5 7/8	Kind of Casing
5.000						5.4	16.1	21.2	Line Pipe or Drill Pipe
4.750						5.1	13.5	16.9	Casing
5.500						6.3	27.8		Casing
6.625				3.8	7.1	11.1			Line Pipe or Drill Pipe
7.000			2.8	4.2	8.7	15.5			Casing
8.625			4.3	8.7					Casing
10.750	1.8								Line Pipe or Casing

Note:- One sack of cement, when set, occupies 1.1 cu. ft. of space.

Weight of Casing

Care should be taken to select casing with sufficient strength to withstand maximum pressure that can be exerted by the water column outside the casing. Failure from collapsed casing is usually due to using too light a casing for the depth at which it is set. It is good practice to use casing heavy enough to withstand the pressure of a water column twice as high as the depth at which the casing is to be set. Table IV will aid in selecting the proper casings.

TABLE IV - COLLAPSING PRESSURES AND CAPACITIES OF CASING USED IN THE SMACKOVER FIELD

Kind	Nominal size	Weight per foot with collars	Actual Outside diam.	Actual Inside diam.	Outside diam. of collars	Collapsing pressure per sq. in.	Equivalent water column	Water safety factor 2	Capacity per linear foot	Capacity per 100 linear feet
	Inches	Pounds	Inches	Inches	Inches	Pounds	Feet	Feet	U.S. Gal.	Barrels
D.B.X.	(a) 4-1/2	16.000	4.750	4.082	5.304	4,710	10,850	5,425	.679	1.62
"	(a) 6-5/8	20.000	7.000	6.456	7.698	1,980	4,560	2,280	1.6988	4.04
"	(a) 6-5/8	24.000	7.000	6.336	7.698	2,730	6,280	3,140	1.6379	3.90
"	(a) 3-1/4	28.000	8.625	8.017	9.627	1,670	3,850	1,925	2.6204	6.24
"	(a) 8-1/4	32.000	8.625	7.921	9.627	2,150	4,950	2,475	2.5583	6.09
"	(a) 10-	40.000	10.750	10.054	11.866	1,420	3,270	1,635	4.1210	9.81
"	(a) 10-	45.000	10.750	9.960	11.866	1,800	4,150	2,075	4.0440	9.63
South Penn	(b) 5-3/16	13.000	5.500	5.044	6.050	2,210	5,090	2,545	1.0380	2.47
"	(b) 5-3/16	17.000	5.500	4.892	6.155	3,400	7,840	3,922	.9764	2.32
"	(a) 6-5/8	20.000	7.000	6.456	7.699	1,980	4,560	2,280	1.6988	4.04
"	(a) 6-5/8	24.000	7.000	6.336	7.699	2,730	6,280	3,140	1.6379	3.90
"	(c) 8-1/4	28.000	8.625	8.003	9.358	1,670	3,850	1,925	2.6204	6.24
"	(c) 8-1/4	32.000	8.625	7.921	9.358	2,150	4,950	2,475	2.5583	6.09
"	(c) 10	35.000	10.750	10.146	11.953	1,050	2,420	1,210	4.200	9.99
"	(c) 10	40.000	10.750	10.054	11.953	1,420	3,270	1,635	4.1210	9.81
Line Pipe	(c) 4-1/2	12.742	5.000	4.506	5.733	2,900	6,680	3,340	.8281	1.97
"	(c) 6	19.367	6.625	6.065	7.482	2,280	5,260	2,630	1.501	3.57
"	(c) 8	25.414	8.625	8.071	9.596	1,395	3,220	1,610	2.658	6.33
"	(c) 8	29.213	8.625	7.981	9.596	1,845	4,260	2,130	2.599	6.19
"	(c) 10	35.504	10.750	10.136	11.953	1,085	2,500	1,250	4.192	9.98
"	(c) 10	41.644	10.750	10.020	11.953	1,555	3,580	1,790	4.096	9.76
Drill Pipe	(c) 4	12.500	4.500	3.958	5.228	3,835	8,830	4,415	.624	1.437
"	(c) 4	15.000	4.500	3.326	5.240	5,105	11,750	5,875	.597	1.42
"	(c) 4-1/2	13.000	5.000	4.506	5.803	2,900	6,680	3,340	.828	1.97
"	(c) 4-1/2	15.500	5.000	4.338	5.604	3,915	9,000	4,500	.785	1.87
"	(c) 6	19.551	6.625	6.065	7.350	2,280	5,260	2,630	1.501	3.57
"	(c) 6	23.500	6.625	5.937	7.435	2,980	6,870	3,435	1.436	3.42

(a) - 10 threads per inch. (b) - 11½ threads per inch. (c) - 8 threads per inch.

Notes: Equivalent water column is figured on basis of water with specific gravity of 1.
The formulae used in calculating the collapsing pressures are credited to R.T. Stewart.

REPAIR WORK

Many wells in the Smackover field have been drilled into water and nearly all of these could be repaired at comparatively small cost. In their present condition some of these wells are non-productive and a total loss as an investment and are a menace to the productivity of neighboring wells. Others produce water and B.S. with the oil, thereby increasing the lifting and treating cost. Some wells that produce large quantities of water are blown with compressed air. This is a costly method of production but may be economically justifiable in a few special cases in which this method would greatly increase the production of oil over the amount recoverable by other means and make the operation profitable. In general, however, it would be more profitable to exclude the water from the well by proper repair work. Such repair work will usually extend the productive life of the well and increase the total recovery.

Repair of First Zone Wells

Nearly all the first zone wells that produce water were drilled into at least one of the Macatoch edge waters. The most of these wells are in the East Smackover field. Their repair was fully discussed in the preliminary report on the eastern part of the Smackover field and the status of the wells with respect to the several water sands, on July 1, 1923, as shown on the Map (Plate I) accompanying that report.

Such wells are repaired by plugging the bottom of the hole to a point several feet above the water sand. W.H. Johnston, driller for the Bureau of Mines, has performed twelve such plugging jobs in the Smackover field. Three of these jobs have not yet been tested. Eight of the nine jobs tested were completely successful and the wells are producing pipe line oil. The water was not shut off in the ninth well. Several operators have studied the practical application of this method and have used it with success in their own wells.

The Bureau of Mines has found that the method of plugging with cement, introduced under pressure through tubing, is most successful for shutting off water in the loose sands of the Arkansas and East Texas fields. This method is fully described in the preliminary report cited above.

Repair of Second and Third Zone Wells

The status of second and third zone wells with respect to the several oil sands and water sands is shown by symbols on Plate II. Many of these wells could doubtless be profitably repaired. When the water is entering the well from beneath the oil sand, the well can be repaired cheaply by plugging with cement. When the water enters the well from above the oil sand, the repair of the well will involve cementing a string of casing or a liner. The operator must judge from the performance of neighboring wells whether the probable production will justify the expense of the work. If such water is not cased off, the well should be plugged with cement

5 Preliminary report on the eastern part of the Smackover, Arkansas, oil and gas field; by H.W. Bell, P.S. Haury and R.B. Kelly. Published by Arkansas State Bureau of Mines, Manufactures and Agriculture.
7 Work cited. pp. 30-32

through the oil sands and filled with heavy mud fluid to the surface in order to protect the oil sands from the overlying water.

Determination of the source of water found in production is in itself a problem and often requires great care and skill. Ambrose⁸ has thoroughly described various tests for tracing the movement of underground waters. Chemical analyses and temperatures have been found valuable in many fields in ascertaining the source of infiltrating water.

FUTURE POSSIBILITIES OF THE SMACKOVER FIELD

In spite of rapid and extensive developments, the Smackover field has attractive possibilities of future expansion.

First Zone Possibilities

Large areas within the proven field remain to be drilled for production from the Nacatoch. At only two places has the edge water line at the top of the Nacatoch sand been determined. (See line "A", Plate I). This line is drawn fairly accurately for about two miles on the north flank of the East Smackover structure in sections 28 and 29, Township 15 South, Range 15 West. Nearly two square miles of additional acreage, in sections 19, 24, 25 and section 30, Township 15 South, Range 15 West, will probably yield production from the Nacatoch sand.

The line "A" that marks the limits of the edge water at the top of the Nacatoch sand is determined around the south end of the East Smackover structure by the following wells: Fickett, Burton 1, Section 25, Township 16 South, Range 16 West; Rica Oil Company, Burton 1, Section 30, Township 16 South, Range 15 West; Marr Oil Corporation, Armstrong 1, Section 27, Township 16 South, Range 15 West; and the wells near the Northwest corner of Section 23, Township 16 South, Range 15 West. This line indicates that about six square miles of undrilled territory in this area will probably yield oil from the Nacatoch sand.

On the West Smackover structure the limits of the productive Nacatoch sand are determined by sand conditions. North of Sections 26, 27 and Section 28, Township 15 South, Range 16 West, the Nacatoch sand pinches out and in most places will not yield profitable production. This same situation is true of most of the area west of sections 28 and 33, Township 15 South, Range 16 West and Sections 4, 9, and Section 16, Township 16 South, Range 16 West. Several wells near Louann, in section 30, Township 15 South, Range 16 West, have produced oil from the Nacatoch sand. One of the wells produced two thousand barrels of oil per day at the start and continued flowing at a notable rate for several months.

The productive possibilities of the Nacatoch sand in the broad syncline between the West and the West Smackover structures have not been adequately tested. The flat structure in Sections 11 and 12, Township 16 South, Range 16 West and parts of Sections 1, 2 and Section 10, Township 16 South, Range 16 West is not

⁸ Ambrose, A.W. Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1921, p. 106.

favorable for large accumulations of oil. Further, the Nacatoch sand seems to be present in parts of this area. However, several notable gas wells have been completed in the Nacatoch sand in this part of the field.

The structure is more favorable in sections 13, 24 and section 25, Township 16 South, Range 16 West and on the nose extending from section 10, Township 16 South, Range 16 West toward section 25, Township 16 South, Range 16 West. It is likely that much of this area will yield profitable production from the Nacatoch sand because sand of a texture that yields oil readily was found at the top of the sandstone in section 25 and near the bottom of the first zone in the Southeast corner of Section 16, Township 16, Range 16 West.

Wells that yield comparatively small amounts of oil could not be produced at a profit with the low price of Smackover crude that has hitherto prevailed. It is unlikely that much of the middle synclinal area will be developed and found to yield profitable production from the Nacatoch sand when the price of low gravity oil is maintained at a higher level.

Meekin Zone Possibilities

The Meekin sand has productive possibilities on all the structure higher than the limits of the first Meekin sand edge water, marked on Plate II by the line that encircles most of the West Smackover structure. The position of the line is only approximate as the drilling to date has given but little definite indication to mark the position of the first Meekin sand edge water. All the Meekin sand contains water in the area within the closed line "F", (Plate II) near the center of the West field.

In the East Smackover field the Meekin sand will probably yield production in an area that is bounded roughly by the 1820-foot contour line on Plate I.

The sands of the Primm gas zone are missing in a large part of the West Smackover field but will probably yield paying gas production at most places on the north part of the East Smackover structure that is bounded by the 1840-foot contour line on Plate I. It is significant that the water and oil flowing from the E.M. Goodwin 1, Section 16, Township 16 South, Range 14 West, appears to be lifted from the Primm zone. This zone may yield oil lower on structure than the 1820-foot contour line but that possibility is limited on the north flank of the East Smackover structure by an edge water which lies 341 feet below the top of the Nacatoch sand. An oil sand was logged in this formation at Simms Oil Company, Lacey 2, Section 31, Township 15 South, Range 15 West and C.H. Murphy, Trust-Section 2, Section 7, Township 16 South, Range 15 West. A good showing of oil in the Primm gas zone was reported at one of the holes drilled in Section 11, Township 16 South, Range 16 West and it is possible that this zone will yield oil in much of the middle synclinal area.

Oil Zone Possibilities

It is impossible at this time to estimate the possible productive area of the third oil zone. The oil that is flowing from the E.M. Brown well, in Section 11, Township 16 South, Range 14 West, is probably coming from the top of the third

zone. This would indicate that the possible productive area of this zone may be great. Third zone possibilities should be considered in planning the casing program for first and second zone wells in all parts of the Smackover field.

Other Sands

The possibilities of production from deeper horizons than the third zone had not been tested at the time the field work on this report was completed.

Operators should not assume that all sands, capable of producing oil, have been tested in the Smackover field. It should be remembered that the sands are variable throughout the district and that in some parts of the field considerable bodies of sand occur at other horizons than those that are proven to be oil bearing. A series of sands that were found at a depth of 100 to 155 feet below the top of the Meekin sand (465 to 520 feet below the top of the Nacatoch sand) in nearly all third zone wells is worthy of attention. Gas was logged in this sand at two wells in section 11, Township 16 South, Range 16 West and oil was recorded in the same sand at one well in section 9, Township 16 South, Range 16 West, and another well in section 20, Township 15 South, Range 16 West.

POSSIBLE EXTENSIONS OF THE FIELD

It is probable that the axis of a structural high extends from the vicinity of Crawford and Sebastian, Giller 1, section 14, Township 16 South, Range 15 West, east southeast to or beyond a point south of the E.M. Brown, Goodwin 1, Section 16, Township 16 South, Range 14 West, near the town of Calion. Other small domes, similar to the one in section 3, Township 16 South, Range 15 West, may be found that will extend the production from the Nacatoch sand to the east. The land lying between Smackover Creek and Cuachita River, east of the proved Smackover field is suggested as a possible extension. There may be such a dome between the present north limit of the East field and the Cuachita River, in line with the structural nose that trends northeast into Section 19, Township 15 South, Range 15 West.

Structure is not the only factor controlling the productive possibilities, however. If the producing sands are present they must have sufficient open texture to yield oil in commercial quantities. Drilling alone will determine this as the sands of the Smackover field vary in short distances.

The undeveloped resources of the proven Smackover field and the possibilities of extending the field are so favorable that production can probably be maintained near the present level of about 100,000 barrels per day for a considerable time.