University of Kentucky

College of Arts and Sciences

KENTUCKY GEOLOGICAL SURVEY

Lexington

In Cooperation With

KENTUCKY OIL AND GAS ASSOCIATION

SERIES IX

SPECIAL PUBLICATION—No. 3

Proceedings of the Technical Session, Kentucky Oil and Gas Association Annual Mid-Year Meeting June 5, 1953

Printed by the Authority of the State of Kentucky

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ARTHUR C. McFARLAN, Director

DANIEL J. JONES, State Geologist

KENTUCKY OIL AND GAS ASSOCIATION

GEORGE P. ELLISON, President

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LETTER OF TRANSMITTAL

August 14, 1953

Dean M. M. White
College of Arts and Sciences
University of Kentucky

Dear Dean White:

The Kentucky Geological Survey is publishing Special Publication No. 3, "Proceedings of the Technical Session Kentucky Oil and Gas Association Annual Mid-Year Meeting June 5, 1953." These papers are essentially as presented by the authors. They are definite contributions to the development of the oil and gas industry in Kentucky.

Sincerely yours,

ARTHUR C. MCFARLAN
Director

FOREWORD

The papers included in this publication were prepared and delivered at the technical session of June 5, 1953, annual meeting of the Kentucky Oil and Gas Association at Lexington, Kentucky.

Mr. Carl Temple, formerly of Owensboro, Kentucky, accepted the responsibility of planning and presiding over the meeting in which these papers were presented. The Association, as well as myself, extend our sincere thanks to Carl for a job well done. We also extend our thanks to those who so ably presented these papers, and also our appreciation to the various companies for their part in the preparation of them.

The unsettled condition throughout the world today makes it imperative that each of us employed in the crude oil and natural gas producing industry be as nearly prepared as possible to do our utmost when called upon for increased production for national defense. I believe these papers, as presented, can well serve as a big step in that direction.

George P. Ellison, President
Kentucky Oil and Gas Association

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WATER-FLOOD DEVELOPMENT IN WESTERN KENTUCKY

By F. E. MORAN*

Water-flood production accounts for 15.4% of the daily oil production in Western Kentucky, considering 10 counties, Butler, Daviess, Hancock, Henderson, Hopkins, Muhlenberg, Ohio, McLean, Union and Webster, as the principal producers. The daily average production was 25,800 barrels of which 4,000 barrels was produced by water-flood methods. Ohio County, which is a major water-flood producer, has a daily average production of 3,500 barrels, and 65% of this production is credited to water-flood oil.

Information was available on 35 sandstone floods and 6 limestone floods. These 41 projects have developed 5,100 effective acres and have an additional 2,100 acres to be developed. The gross water injected into these 41 projects is 31,500,000 barrels, currently having a daily average injection of 42,500 barrels. The gross water-flood oil accumulated from these projects is 4,400,000 barrels, currently having a daily average of 4,000 gross barrels. The ratio of accumulated injection water to oil is 7 to 1, and the ratio of the daily average injection water to oil is 10 to 1.

Considering the 35 sand projects, the average permeability is 107 millidarcys, and the average porosity is 19.3%. The average sand thickness is 18 feet. Primary production history was available on 25 of these projects. The gross primary production on these 25 projects was 17,000,000 barrels and the effective acreage was 6,300. Therefore, by primary production, these projects averaged 2,700 barrels per acre or 150 barrels per acre-foot.

The 35 sand projects averaged 5-acre spacing for primary development and 6-acre spacing for water-flood development. There are 720 producing wells which are currently producing 3,800 barrels per day or 5.3 barrels per well per day. There are 800 water-injection wells which are currently taking 40,000 barrels per day or 50 barrels per well per day. The ratio of water injection wells to oil wells is 1.12 to 1.

Considering the 6 limestone floods, no permeability or porosity figures are available. The average pay zone thickness is 8 feet. The primary production on these 6 projects was 1,750,000 barrels and the

*Consulting petroleum engineer, Owensboro, Ky.

effective acreage was 980. Therefore, by primary methods, these projects averaged 1,800 barrels per acre or 220 barrels per acre-foot. The gross water injected into these 6 projects is 1,650,000 barrels and currently having a daily average injection of 2,400 barrels. The gross accumulated oil from these projects is 127,000 barrels and currently having a daily average production of 140 barrels. The ratio of accumulated injection water to oil is 13 to 1, and the ratio of daily average injection water to oil is 17 to 1.

The 6 limestone projects averaged 17½-acre spacing for primary development and 40-acre spacing for water-flood development. There are 19 producing wells which are currently producing 140 barrels per day or 7.4 barrels per well per day. There are 19 water-injection wells which are taking 2,400 barrels per day or 125 barrels per well per day. The ratio of water injection wells to oil wells is 1 to 1.

Information was not available on all the flood projects, which I would estimate to cover an additional 500 effective acres. Primary investigation and early stages of development are being done on 5 projects, which I would estimate to cover an additional 2,000 acres. The additional primary production that would be subject to successful water-flood methods is a controversial figure; therefore, I will not hazard a guess.

The operators are becoming more aware of the reserves to be recovered by water flooding and therefore are practicing better reservoir engineering methods in drilling for primary oil. This practice will be of untold value in future recovery by water-flood methods.

RESUME OF WATER FLOODING IN EASTERN KENTUCKY, MAY, 1953

By ROBERT B. BOSSLER*

Tabular data are presented showing the extent of water flooding in progress in Magoffin and Lee Counties, Kentucky, as of May 1953. Six preliminary operations covering coring and testing in Johnson, Lawrence, and Lee Counties are briefly outlined. The balance of the paper is devoted to a description of the Oil Springs-Falcon field in eastern Magoffin County, giving details of sand and oil characteristics and flooding practices and procedures. A section is devoted to an appreciation of the work of J. S. Slagel of the Cumberland Petroleum Company whose initiative and persistence proved that the area could be successfully water-flooded.

The writer wishes to acknowledge the assistance of Mr. Tom Byrne of the Bradford Supply Company, Oil Springs, Kentucky, in gathering the information concerning the extent of developments, plant installations, and water-treatment, and thanks the various operators, including my own company, supply houses, and service companies for their courteous and willing cooperation in releasing and furnishing much of the information herein contained.

The title assigned to this paper is more comprehensive than will be included here, because of the fact that the author feels qualified to discuss at any length only the Oil Springs-Falcon area. The Oil Springs-Falcon area is here considered to include Mine Fork, Falcon, Wheelersburg, and Burton, but does not include the Burning Fork area southeast of Salyersville.

A table was prepared, following the A.P.I. and I.O.C.C., so that the data may be compared with that of other areas. Data concerning one flood in Lee County are included in the tabulation.

The composite of the information regarding the flooding now in progress in Magoffin County is as follows:

Leases, or parts of leases, developed or under development	16
Acres developed	754
Input wells operating	166
Input wells completed	209

*Chief Engineer and Vice-President, Brundred Oil Corporation, Oil City, Pa.

Producing wells affected	90
Water injected per day, bbls.	5,811
Pressure plants installed	6
Capacity of plants installed, bbl./day	23,950
Rigs running	26

Information was gathered concerning six cases in which preparatory work is being done or in which work has progressed to the point where definite plans for water flooding have been made.

The Rainbow Producing Company of Cleveland, Ohio, is reported to have 1,700 acres on Blaine Creek, Lawrence County, in the Martha pool. It is understood that a 49-acre development will be undertaken, involving the drilling of 22 new wells (input and producer). It is reported that three preliminary cores were taken and that road building is now in progress.

The Renwar Oil Corporation of Corpus Christi, Texas, is reported to be drilling three wells under option on properties of Mullins and West, consisting of 335 acres, part of which is located at Keaton, and part on the Gillam Branch in the Martha pool, Johnson County.

It is also reported that Hoit and Rotstein are testing water supply on the former Bailey and Jett Leases near Red Bush, Johnson County, Kentucky. One well was cored on these properties last year. The total reported acreage is 640, and a pilot area of 56 acres is under consideration.

In Lee County, H. W. Patterson of Buffalo, New York, is reported to be engaged in a coring operation on tracts covering about 1,000 acres in the Big Sinking Field. It is understood that two wells have been cored.

In Estill County near Ravenna, the South Central Petroleum Company is preparing to flood the Corniferous Lime at a depth of about 80 feet. Five input wells have been drilled. Water from the Kentucky River will be injected by means of a centrifugal pump.

Also reported in Lee County, an organization known as the W. P. Oil Project is proceeding with a development expected to include 35 input wells. Nine or ten are already completed, a plant is being built near Standing Rock, and an earthen dam confining about 140,000 barrels of water has been built. The producing formation to be flooded is reported to be the "Corniferous."

In addition to those here noted, numerous cores are being taken throughout the Eastern Kentucky fields for the purpose of determining values and floodability. A listing of these was not prepared for this report.

I would like now to discuss the Oil Springs-Falcon area in a little more detail.

The field is located almost entirely in Magoffin County, with a few wells and leases in Johnson County. These wells and leases are included in the figures which follow.

The field is located along the axis of the Paint Creek uplift, and, while structure was undoubtedly a factor in the accumulation, changes in lithology of the producing formations seems to have had as much or more effect on the distribution of production. The sand body pinches out along the east edge of the field, which is approximately parallel to the axis and at the top of the uplift. Thus, the entire field lies on the west slope of the structure. On the extreme west edge of the field, the sand is hard and tight, and production light, even though the reservoir maintains the same thickness as in the more productive parts of the field.

While there are a total of five spearate sands reported, namely the "Stray", "First", "Second", "Third", and "Fourth", there is a slight confusion regarding the nomenclature. Some operators call the "Stray" the "First", and so on. Other operators do not recognize the "Stray" as a sand and start naming the sands "First", "Second", "Third", and "Fourth."

However, all of the water-flooding now going on is restricted to what is referred to as the "First Weir," although one operator shoots the so-called "Stray" in most cases and sets the packer above the top of the "Stray." Testing during the early stages of their pilot development indicated that the "Stray" required pressures as great or greater than the Weir for equal injection, so that it is felt that no hazard is incurred in this procedure.

The two lower sands are not now being flooded because of lack of information as to their oil content and suitability from other aspects.

The Oil Springs-Falcon field covers an estimated productive area of about 5,600 acres, of which 5,200 acres are held by five companies, and the balance, or about 400 acres, is held by five or six individuals or companies. There were a total of 1,049 wells on these leases, 971 being on the 5,200 acres and the balance, or 78 wells, on smaller tracts. The total average well density before water flooding was 5.3 A/well.

The depth of the main producing sand varies from 900 to 1,300 feet, and the average probably will be somewhat over 1,000 feet.

The field was discovered in 1918 when the Bed Rock Petroleum Company drilled No. 1 on the Milt Wheeler lease in the northern end of the field. Activity expanded slowly until 1920 and 1921, and the peak of production occurred in 1923 when 1,324,600 barrels of oil were produced. Initial production of the wells seldom exceeded 100 barrels per day. Most of the wells in the better part of the field produced from 20 to 60 barrels per day. Few flowing wells were reported and these only after the shot.

The total recovery from this area, to 1951, is estimated to have been about 10½ million barrels, or an overall average of about 1,900 barrels per acre. This compares with 2,900 barrels per acre for the Bradford field up to about 1914 and prior to water flooding. However, there were comparatively few producing wells drilled in the interior of many of the properties in the Oil Springs-Falcon area, the main development being confined to protecting property lines.

The posted price of crude petroleum in the Eastern Kentucky area is $2.83 per barrel. State and local *ad valorem* taxes amount to 1½ percent or roughly $.04 per barrel, leaving a net price to the producer of $2.79.

All of the oil produced in the Oil Springs-Falcon field is purchased, gathered, and transported by the Ashland Oil Transportation Company, Inc., through field stations located at Wheelersburg, Oil Springs, Falcon, and Burton. This company has recently reworked its gathering system and has installed larger lines and some additional motor-driven pumps; it has also announced its intention to install some larger storage tanks for the purpose of handling the expected increase in crude production.

The oil is exceptionally free from wax, emulsion, and from water entrainment, with the result that generally there is no treatment problem whatsoever, and the oil does not require heating, even in winter.

Probably of greater interest to those attending this meeting are the sand characteristics, the drilling and completion practices, and the flooding procedures being followed by the different operators now active in the field.

Newell Wilder, describing secondary recovery in Kentucky in an A.P.I., volume entitled "Secondary Recovery of Oil in the United States" reports that the Weir sand is a fine-grained clean sand of a white-gray color and has the most uniform effective porosity and permeability of any producing sand in Kentucky. A screen analysis performed by him showed that 90 percent of the sand grains are 100-mesh size. Subsequent examinations by others have confirmed Wilder's findings as to porosity and permeability.

Cores taken in the field show that the permeability of the sand varies from wells with a high of 30 md. (millidarcys) and an average of 12 md., to wells having a high of 8 md. and an average of 1.6 md.

In one area, not yet flooded, values as high as 50 md. have been recorded, the upper portion of the sand having an average of above 30 md. This, however, is unusual. 'Commonly the sand would be considered tight.

The porosity varies from a high of 25 percent and an average of 22 percent to averages as low as 13 percent.

This combination of a relatively low permeability, relatively high porosity, and the indicated uniformity of permeability, forces the conclusion that the average pore radius is quite small and the pore-size distribution quite uniform. This is a condition which would lead one to expect relatively high water saturations but little or no water production, and such seems to be the case.

The old producing wells, in which there has been no history of leaking casing, produce little or no water. In fact, it was difficult to get a representative sample of what might be considered true connate water.

An indicated above, core water saturations are relatively high, ranging from 32 to 50 percent or more of pore space. However, this water appears to be immobile even under flooding conditions and is considered by some to be a favorable condition in that the water probably occupies the smaller pores and sharp angles between grains, thus forcing the oil to occupy the larger pores and thereby making it more accessible or recoverable.

A most interesting phenomenon concerning the produced water has been observed. When stimulation by the water flood is first felt, a notable increase in water production from certain wells may be observed. This usually decreases as the oil production increases, and in the cases where flood results have been had the water-oil ratio is exceedingly low. In one case, water production on October 11, 1952, showed a ratio of roughly 34 barrels of water per 100 barrels of oil. On May 9, 1953, this ratio was roughly 1 barrel of water per 100 barrels of oil produced. On the Cumberland Petroleum Company's water flood on the Bailey lease, started in September 1948, the water-oil ratio is now only 10 barrels of water per 100 barrels of oil.

Core oil saturations are uniformly low, ranging from 10-25% of pore space. It is difficult to reconcile these low oil saturations with the production history of the field or with cores of sands from other fields. It should be pointed out, however, that the reservoir viscosity of the oil is probably well below 5 cp. (centipoise) and that wells drilled into the sand may fill up as much as 200 feet if allowed to stand several days. This would indicate a reservoir pressure of about 70 pounds. Newly drilled wells produce fair quantities of gas, and the gas in solution in the oil at 70 pounds pressure may represent enough energy to drive out all but the residual oil.

The reservoir saturation, obviously, is much greater than that indicated by the cores, or no water flood production would be possible. The present saturation is, of course, unknown, and an approximate value can be obtained only by indirect methods such as a material balance calculation. This requires certain information regarding the reservoir and contents which can not now be obtained and must be inferred or assumed. This leaves the result somewhat in doubt.

A gas cap existed in the Mine Fork Dome at the north end of the field. It would, therefore, appear that the reservoir oil was originally gas-saturated. The rapid exhaustion of the gas cap by gas production probably resulted in a lower recovery from, and a high residual saturation in the oil reservoir.

As previously indicated, the "in place" viscosity may be less than 5 cp. A sample of fresh crude oil from a well strongly affected by a water flood, and carefully handled to prevent loss of gases, had a viscosity of 4.9 cp. at 75° F. when measured in a pressure viscosimeter. Twelve other samples, of which we have the viscosity, averaged 7.5 cp. However, we have no knowledge of their history except that they were secured from old stripper wells. The gravity of the single sample described above was 38.2 degrees API at 60° F. and 39.3 degrees API at a temperature of 75° F. From this we would conclude that for purpose of computation the reservoir gravity is about 40 degrees API, and the reservoir viscosity is about 4.5 cp.

Practically all inputs are newly drilled, although where patterns of spacing requires it, old producers are being converted to input, and as such, are found to be as good or better input wells than those newly drilled. All operators are completing their input wells by using 7-inch O.D. 17-pound seamless casing, which is withdrawn after the tubing is cemented. Three of the present operators are completing their inputs by using 4.6-pound 2-inch seamless tubing. One operator is using 2-inch line pipe in his input wells, and one is using 4-inch pipe. Three of the operators using 2-inch use rubber packers set on anchors, and one uses disc-wall packers. The tubing is cemented with 8 to 15 sacks of cement. In most cases the cement is piped to bottom through 1-inch pipe. The operator using 4-inch bridges the hole at the packer point, sets the 4-inch on the bridge, and pipes the cement to bottom through a 1-inch pipe inside the 4-inch. The 4-inch is raised a short distance and the cement displaced to the outside of the 4-inch with a water column. The bridge is later cleaned out with 4-inch tools.

One operator fills the annular space outside the tubing with an aquagel suspension before pulling the casing, in order to protect the tubing from contact with the "Salt Sand" water.

Oil wells are completed with 7-inch 17-pound seamless casing. However, one operator substitutes 4-inch line pipe for the casing after the well is cleaned out and before the tubing is run. The 4-inch pipe is set on a hook-wall packer set below the casing seat. Both input and producing wells are shot with liquid nitroglycerine, the charge ranging from 40 to 90 quarts and 2½ to 4 quarts per foot. The lower part of the sand is frequently shot more heavily than the upper part.

A procedure followed by many producers in Bradford is being applied by two producers here. This is the introduction of gas into the input wells ahead of the water. In one case, a portable gas compressor unit is installed for the purpose. Gas was secured from sources off the lease, and an effort was made to inject a volume of gas equal to the entire pore volume underlying the property. Initial pressures were about 75 pounds, increasing to about 150 pounds at the end of the operation. Gas was transported to the wells through the water distribution system. Individual wells were not metered or controlled. The producing wells were shut in and not operated during the injection period. In the other case, use was made of a compressor already installed on the property, using a mixture of casing-head and extraneous gas. Volumes ranging from 200,000 to 1,500,000 cubic feet are injected into each well, at pressures up to about 160 pounds.

One operator is installing individual electric pumping jacks on the producing wells. All others are pumping by means of central powers.

Water supply is chiefly from the so-called "Salt Sand", found 250 to 600 feet below surface. Reciprocating pumps operated by individual jacks and driven by electric motors or gas engines are the most common means of raising water. Two operators, however, use deep-well turbine pumps. The water is classified as fresh, but moderately hard, and requires only a small amount of treatment. Three operators use "open systems" in which the water is pumped to open storage or ponds. In two cases, the water is mixed with surface water. One plant operates in a completely closed system, in which the water passes from the supply well through a filter to the pressure pump. In two other cases, the system is open to the atmosphere at one point, but the water is maintained air-free by piping and handling arrangements.

So much for the record. What follows may, or may not, be included but certainly should be presented here. I refer to something without which there probably would be no, or very little, water flooding in Magoffin County today. That something was the foresight, courage, and persistence of J. E. Slagel, known to all of us as "Joe."

The Oil Springs-Falcon area was exhaustively studied by an experienced water-flooding company and less exhaustively studied by a quite successful individual water-flood operator around 1945-1946. Both of these operators surrendered their options and retired from the field. In spite of the adverse opinion of these expert and well-experienced water-flooders, Cumberland Petroleum Company and Joe decided to install a water-flood on the Bailey Farm.

Joe is a graduate engineer and had a thorough knowledge of his property. He was convinced that the adverse core reports resulted from a misinterpretation of the conditions existing and that in this case the experts were wrong. He convinced himself and his company of this, installed a pump and filter, converted seven or eight gas-intakes to water input, and proceeded to inject water. Water input rates were highly satisfactory and considerably above what would normally have been predicted, based on known permeabilities. He then had the pleasure of watching his production fall steadily for a period of sixteen months and having his friends question his judgment and even his sanity! However, his results to date fully justify his dogged persistence and the honest faith he had in his decision and judgment.

This talk about water-flooding in Eastern Kentucky logically, and by right of enterprise, should have been given by him. I feel that acknowledgement should be here made of our debt to Joe, and I feel honored to have been allowed to make this presentation.

GEOLOGICAL REVIEW OF ROUGH CREEK FAULT SYSTEM

By D. G. SUTTON*

The Rough Creek fault system has been known to be a complicated system of numerous types of faulting for years. In order to point out various ideas, I have checked through literature of such noted geologists as D. Owens, Norwood, C. Butts, Russell, Stuart and Marvin Weller, D. Hager, T. A. Link, Gardener, Clark and Royds, Bailey Willis, and Dr. McFarlan's *Geology of Kentucky*.

The Rough Creek fault zone or uplift was named by Norwood in 1884 as the Rough Creek anticline and was known to be an eastward continuation of the Shawneetown fault (or Gold Hill fault) named by Owens in 1856. The name Rough Creek comes from exposures along the creek of the same name in Ohio and Breckinridge Counties, Kentucky, and was recognized from Grayson County on the east to Union County on the west.

Various ideas have been presented throughout the past, some of which have been confirmed while others conflict with evidences as seen today. A general opinion is that numerous types of faulting occur throughout the zone such as thrusts, normal, shear, scissors, and block faulting. Only Bailey Willis recognized it and spoke of it as a normal fault. Whether he had made any field examination of the zone or not was not mentioned in his statements.

Majority of opinions, however, recognize that the fault has resulted from the compression and breaking of an anticline, and consequently it is probably a high-angle thrust fault with compression exerted from the south and southeast and is accompanied by en echelon normal faulting.

Uplift varies from a few hundred feet to 2,500 feet or more with as much as 3,500 feet in Illinois. There is some evidence of horizontal movement.

Gardener in 1915 called attention to a structural disturbance extending from central Pennsylvania, where it is known as the Chestnut Ridge anticline, across West Virginia and Kentucky into southern Illinois. In Kentucky this structural line includes the Warfield anticline, the Irvine-Paint Creek uplift and faults, the Kentucky River fault and the Rough Creek fault.

*Geologist, Sun Oil Company, Evansville, Ind.

Note the absence of faulting from Hart County to western Lincoln County. In a recent communication with D. J. Jones, State Geologist, Kentucky Geological Survey, he mentioned an east-west direction of faulting south of Magnolia in southern Larue and northern Hart Counties with a displacement of about 40 feet, and that the Magnolia Gas field is located on a fold against the south side of this fault. W. R. Jillson has recently published one of his pamphlets entitled *The Lesser Faults of Marion County*. D. J. Jones, as well as V. E. Nelson of the University of Kentucky, suggests the possibility of the eastern and western disturbances being the same. The faulting in Marion County would tend to help consolidate the two areas of disturbances.

In Illinois, the Cottage Grove fault to the west is in the same alignment as the Rough Creek-Shawneetown zone just before it bends to the southwest, west of the Shawneetown Hills. If this fault is taken into consideration and the Irvine-Paint Creek faults with the Warfield anticline is considered as a part of the Rough Creek fault system, the zone extends for approximately 400 miles. The system would be about 175 miles long if the faulting east of Hart County is not considered as the same. The Rough Creek zone and associated faults is nearly 50 miles wide on the west but is considerably less eastward.

The Kentucky River fault is a zone of en echelon normal faults which may be traced from southern Lincoln County northward to the vicinity of Mt. Sterling in Montgomery County. Its continuation northward is recognized in the monocline of the Ragland oil field of Bath County.

The Irvine-Paint Creek faults and anticline are an east-west anticline accompanied by normal faulting extending eastward from Lincoln County. The name Warfield anticline is applied to a continuation of the general Irvine-Paint Creek structure as it crosses Martin County into West Virginia. This structural trend is an important "Corniferous" oil-producing feature. Lying to the north, crossing Lawrence County and probably associated with the above-mentioned fault, is the Walbridge fault entering West Virginia near Louisa, Kentucky.

As for the age of the faulting, the concensus of opinion is that it is post-Pennsylvanian. Russell suggests pre-Pennsylvanian movements as indicated by shortening of Mississippian in places, but Wanless (1939) found essentially the same Pennsylvanian succession on opposite sides, which minimizes the probability of progressive development.

In summing up a discussion of the Fault system, I would like to refer to a few statements made by Dorsey Hager from a report on the *Tectonics of North-Central States*, which I believe fits the situation very well.

> "The complicated mass of folds and faults which occur in southeastern Illinois and which crosses into Kentucky is a most exceptional feature. The faults are mainly block faults, forming horsts and grabens. The strikes of the principal faults range from northeast to east, but many faults cut across that line of strike to form blocks of different sizes forming a mosaic with no set pattern. In places, some of the fault blocks are highly folded. Upthrusting of considerable magnitude must have occurred. Vertical throws are as large as 3500 feet. This system is the most exceptional geologic feature in the north-central states and the most difficult to interpret."

Mississippian rocks are exposed on both sides of the fault from nearly the central part of Ohio County eastward to where older beds are exposed coming up on the Cincinnati Arch. West of this point there are isolated Mississippian beds exposed along the south or upthrown side of the fault such as at Sebree, Tilden, Chalybeate Ridge, and southwest of Morganfield. Where these outcrops are present there is evidence of steeply dipping fault blocks. Dips up to nearly vertical can be seen in various places, but where strategic points are usually wanted no surface expressions are exposed. One nice exposure of minor folding showing compression is present in a new road cut southwest of the Bald Knob field west of Sebree, Webster County.

We know of numerous faults north of the main zone which are probably associated with the Rough Creek system. These are usually normal faults running north-northeast. In the vicinity of Beech Grove in McLean County there seems to be more block faulting than in places to the west. It is in this area where there are definitely blocks downdropped out of regional as shown by the Felmont well in 12-N-25 where the subsea depth of the Barlow is assumed to be below −2600 feet and by the Sohio well in 15-N-26. Otherwise north of the main fault the structure, with the exception of local faulting, is fairly regional, confirming the evidence of most of the movement being from the south and southeast.

A few examples from drilled wells showing reverse or thrust faulting are as follows: Sun Oil Company No. 1 Woods, 25-M-38, northwest of Leitchfield in Grayson County, in which portions of the Knox dolomite were tested twice; the Sun Oil Company No. 4 Bridwell, 21-N-23, Webster County, in which approximately 1,000 feet of section is repeated; the Noah No. 1 Kelley, 1-N-19, and the Sun Oil Company No. 1 Wathen, 2-N-19, both in Union County, where approximately 800 feet of Chester section is repeated; indications of repeated sections in the Sol Blue well, 21-O-18, Union County; and in the A. W. Cherry No. 1 Richards, 19-O-17, Union County, in which Glen Dean lay above the Menard lime section.

The Richards well drill-stem tested the Waltersburg for a possible producer, but when pipe was set commercial production could not be obtained. A possible theory is that the well, although high, was in a small confined block into which there was insufficient drainage. This will probably be the same condition that will be found at other places. Possibly core drilling will be a solution in helping to define the size of some of the blocks that are present below or south of the main fault.

It appears that where the faulting is rather confined to more or less one major fault that there has been considerable compaction and recementation which interferes with production possibilities. Possible Sandfrac or Hydrofrac procedures will be beneficial in these areas. Even north of the fault, as shown in some of our wells in the Morganfield South field, there is low permeability in some of the wells near the fault. This is evidently due to recementation.

The major recent developments associated with the Rough Creek system are the Guffie pool in McLean County and the Morganfield South field in Union County. Some recent Jackson production has been obtained in 17-N-26, McLean County. Two other spots resulting in one-well pools are in Union County, on the Cantebury No. 1 Richards, 19-O-17, producing from the Tar Springs and another one drilled by the Texas Company, a Pennsylvanian well in 3-N-18. Two other areas in McLean County are the Beech Grove East field in 13-N-26 and the Comer area in 8- and 12-N-25.

In our experience on drilling near or on the main fault, we used practically all types of drilling bits. The two cone bits were successful in helping to drill straight holes, and the most footage was obtained by a percussion bit, but the main trouble with this bit was keeping the percussion tool together. Diamond coring was not too successful because of fracturing in the formations. I believe drilling is going to be hard, but we will just have to put up with it where exploration is to be carried on close to the main faults of the system.

OIL EXPLORATION AND DEVELOPMENT IN SOUTHWESTERN KENTUCKY

By W. D. CHAWNER*

I have been asked to discuss today the oil exploration and development in southwest Kentucky. This area will include chiefly the southern counties of Kentucky on and west of the Cincinnati arch.

Referring to the geological map of Kentucky, the Cincinnati arch, the backbone of which runs northeast-southwest through Kentucky, is outlined by the outcrop of Chattanooga black shale. There is a saddle in this arch separating the Jessamine dome of Kentucky from the Nashville dome of Tennessee. On the west is the southern outline of the Western Kentucky Coal Basin as outlined by the outcrop edge of the Pennsylvanian Coal Measures. The Pennsylvanian beds and the underlying Mississippian beds dip northwestward and northward into this coal basin to form, with the Rough Creek fault on the north, the Moorman syncline. Fields of the Moorman syncline were discussed before this organization last year by W. W. Hagan, and I refer you to his paper, a mimeographed copy of which was distributed to the members of this Association a few months ago.

The production from the oil and gas pools of southern Kentucky has come from many different horizons, from Ordovician through Pennsylvanian age. Some of these are very old pools. The oldest known oil-producing well in southern Kentucky was drilled for salt brine in 1819 in McCreary County just east of the Cincinnati arch on the south fork of the Cumberland River. It struck oil at a depth of a few hundred feet. The oil was probably not used for any commercial purpose, but the knowledge of underground deposits of oil in this area was thus established.

The second oldest known producing well was also drilled for salt water, in Cumberland County, in 1829, on Rennox Creek near Burkesville. It became known as the Great American Well, and the oil was bottled and sold for medicinal purposes under the name of "American Oil." It was pumped until 1860, depth was 175 feet, and the producing horizon was probably the upper Sunnybrook of Trenton age.

When this well was first "drilled-in" the oil flowed into Rennox

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Creek and down to the Cumberland River, where it caught fire. It is said that the driller on spudding the well vowed he would strike salt water "or drill into hell," and the flaming oil on the river undoubtedly caused some people to believe he had indeed accomplished the latter.

Actual oil exploration and development in southwestern Kentucky began about, or shortly after, 1860, shortly following the discovery of uses for petroleum and its products and coinciding, in general, with the beginnings of the oil industry in other parts of the United States, especially Pennsylvania. A. C. McFarlan, in *Geology of Kentucky* is authority for the information that Kentucky's earliest oil exploration and development took place in Allen, Cumberland, Barren, Wayne, Russell, and Clinton Counties, and from these beginnings it has spread, as you know, to about half of the counties of Kentucky.

Now, let us have a closer look at the producing areas, past and present, and discuss briefly the present exploration and development.

CUMBERLAND AND MONROE COUNTIES

Oil production in Cumberland and Monroe Counties has come chiefly from rocks of Ordovician age in the Trenton and Stones River groups. In these counties these formations are only a few hundred feet below the surface. Production is usually from horizons 400 to 800 feet deep.

The old fields in the central and northern parts of Cumberland County produced mostly from the Sunnybrook or the Granville formations of Trenton age. Those in the southern part of the county produced chiefly from Stones River limestones.

Recent production from the southeastern corner of Monroe County is reported to be from the Granville (Trenton) and the Stones River.

Recent activity in Cumberland County has consisted chiefly of shallow tests of the Trenton, mostly near older areas of production, in an effort to extend those areas. Some of these wells have found considerable additional oil but no significant amount of reserves.

Beginning in October 1951, with the discovery of a new field on Little McFarland Creek in southeastern Monroe County, there was a considerable increase in activity in southeastern Monroe County and southwestern Cumberland County.

In southeastern Monroe, development centered around Little McFarland Creek with about 8 wells, and Capshaw Hollow (including Spears store) with 31 wells. The Capshaw Hollow pool produced about 500,000 barrels of oil from 31 wells 400 to 700 feet deep, from the Trenton. These wells initialed from 200 to 800 barrels of oil per day but dried up in 4 to 6 months. The drop in production came suddenly. One operator reported a well which produced 265 barrels of oil per day steadily for about six months, until it dried up, practically overnight, much as you would pump a tank dry.

In recent years one deeper test was drilled on the Meshack anticline in Cumberland County. It reached 2,260 feet, in the Knox, where it was reported to have found water.

ALLEN AND SIMPSON COUNTIES

Most, if not all, of the production in Allen and eastern Simpson Counties has come from rocks of Silurian age at or near the base of the Chattanooga black shale, at depths of 100 to 500 feet. Allen County is covered with old producing fields now largely played out. However, there has been some new production either close to or within old areas of production. One such area is located near the community of Halfway, in western Allen County, where Morgan Petroleum Company drilled about six or seven producing wells. One well in this pool, though not typical, was very interesting. It initially produced by pumping as much as 1,000 barrels of water and 500 barrels of oil per day, but as pumping continued, intermittently over a period of many months, the oil-water ratio decreased until the production was mostly water. Depths of production in this field were 350 to 450 feet.

WARREN COUNTY

Eastern Warren County production also has come chiefly from Silurian formations, or from a thin layer of Devonian limestone, often sandy, at or just below the base of the Chattanooga shale, and immediately and unconformably overlying Silurian limestones. There has been no recent new discovery in this area.

Central and western Warren County has probably been the largest oil-producing area in southern Kentucky west of the Cincinnati arch and south of the Rough Creek fault. The main Bowling Green pool, with its northeast extension, and several other smaller pools to the southwest, produced mainly from three or more zones of porosity in the Devonian limestone, from about 900 to 1,000 feet in depth. At least 10 million barrels of oil, and perhaps more, were produced from these fields.

In part overlying Devonian production, but usually scattered in a wide belt across Warren County, were many pools producing from the Mississippian, Warsaw formation, at depths of 400 to 500 feet.

This Warsaw production usually produced rapidly for a few days under heavy pressure and then played out. There were some exceptions to this rule, however, where wells of smaller initial production lasted a long time. A great deal of water was often encountered in this formation, and water and oil were produced together. In other cases no water was ever produced, only oil or gas or both.

Both the old Devonian production in the Bowling Green area, and the Warsaw production have largely played out. However, there has been a good deal of persistent drilling on the part of operators trying to extend the old areas of production or to find new pools in undrilled areas between the old pools. Some new oil has been found this way, chiefly from the Warsaw formation, but no significant pools have been found. The new oil production has been chiefly southwest of Bowling Green in the Rockfield and Lost River areas.

LOGAN COUNTY

Logan County has not received the same amount of drilling activity as has Warren County, largely because it is farther away from the old Warren County production. However, one new pool has been opened. This is the Shakertown pool, with nine producing wells from the Dutch Creek sand. The Dutch Creek sand is the basal member of the Devonian Jeffersonville limestone, found at about 1,000 feet. The discovery well was the S. W. Mitchell No. 1 Bogle, with an initial production of 10 barrels of oil and 2 million cubic feet of gas. Several of these wells made initials of 50 to 60 barrels per day, but now, 15 months after discovery, the pressure has dropped and wells are reported to produce 4 or 5 barrels of oil per day each.

It is reported that the old Gillispie pool, just over the line in Warren County, probably also produced from this Dutch Creek sand. This suggests the possibility that there may be other larger sand lenses at the Dutch Creek horizon which have not yet been found by the drill and which may some day produce oil.

Recently there has been a considerable amount of exploration in Logan County. Several wells have been drilled to the Devonian and the Silurian in the northeast part of the county near Richelieu, and others were drilled in the vicinity of Russellville. Many of these had significant and encouraging shows of oil, but there has not yet been any further discovery of commercial production. There are some small older pools in the northwestern part of Logan County. One, the Lewisburg pool, about a mile east of the town of that name, has several old wells still producing from the McClosky and the Bethel. The old Diamond Springs pool is located about four miles northwest of Lewisburg, and it has produced some oil from the St. Louis and the McClosky.

TODD COUNTY

Up until 1950 Todd County had no commercial production of oil. The so-called Elkton pool about one mile east of Elkton consisted of two noncommercial wells producing from the Devonian, and other noncommercial wells had been drilled to the Devonian a mile or two west of Elkton. There was also a small noncommercial well in southern Todd County on the Kennedy lease south of Hermon. The first commercial well was drilled in April 1950, on the Kennedy lease, number 3 well on that lease by Haley and Ware. This initialed 50 barrels of oil per day from Devonian limestone at 1202-09 feet. The pool was named after the community of Hermon, and finally nine producers were completed which have accumulated a modest 60,000 barrels of production, it is estimated.

Two miles northeast of the Hermon pool, four more wells were drilled in for 18 to 70 barrels of oil per day from the same Devonian horizon, and this pool was called Hermon East. In an attempt to extend this pool eastward in September of last year F. S. Stephenson drilled No. 1 Elmer Camp, which made a good well in the Silurian at 1239-52 feet, with initial production of 120 barrels of oil per day after 1,000 gallons of acid. Some dry holes have been drilled here since, but, nevertheless, it is expected that this area of production can be enlarged and extended.

BUTLER COUNTY

The Huntsville pool in southwestern Butler County was discovered in 1939 and has slowly expanded to over 200 wells producing from Chester sands, chiefly the Hardinsburg ("Jones") at depths of 350-500 feet. Ultimate recovery is roughly estimated at 1½ to 2 million barrels. Other small pools in this area producing from Chester sands are the Mt. Zion, Rochester, and Pleasant Hill pools producing from Tar Springs sand, and the South Hill pool producing from Hardinsburg. The latter has been recently extended southward near Beech Grove School, and there are probably more than fifty wells altogether, including old producers now abandoned in the older part of the field. A few of the more recent wells have also produced from higher Chester horizons. Average well production has been very low, but depths very shallow, 180 to 450 feet.

MUHLENBERG COUNTY

The old Greenville pool, about a mile south of the town, produced gas from the Pennsylvanian and oil from the Aux Vases and the Ste.

Genevieve. One well is reported to have produced 100,000 barrels, but that is unverified. I understand that there is still a small production from some of these wells which were drilled in 1930-1933.

More recently oil has been found in the Rhoades School pool, two miles southwest of Greenville. Seven wells are producing here now from Bethel (or Benoist) sandstone at about 1,550 feet. The discovery well, Hanley and Bird No. 1 Ringo, made 10 barrels of oil per day initial from a depth of 1,537-50 feet. The second Ringo well initialed 64 barrels of oil per day, and No. 3 made 260 barrels. All were initial pump tests.

Recently, two other areas east of Greenville have found new production—an eastern extension of the old Greenville pool on the Country Club Grounds, from the Bethel, and several others in the Buck Knob area produce from Paint Creek sand. Active exploration is in progress in these areas at the present time.

In eastern Muhlenberg County the Huntsville pool has been extended across the county line from Butler County, within the last two years, and an outlier extension to the southwest, the Roy or Hunts School pool, is producing from the "Jackson" (or Big Clifty) sand.

In conclusion I would like to say that it is difficult to gather together the necessary information in this southern part of Kentucky where there is no active scouting service. Such things as production figures, samples or sample logs and drillers' logs, are often not kept, or are inadequate or unavailable. Much information which would be valuable to the oil industry as a whole is therefore irretrievably lost. The Kentucky Geological Survey at Lexington accepts all well samples and well information of this type that is made available to it, and I would like to encourage all operators who drill in these areas to collect samples, together with drillers' logs, and turn them over to the Survey with adequate depths, names, and location descriptions properly affixed. The operators themselves will directly benefit from such a policy if generally applied and the information used by all operators.

Finally, I would like to leave you with a note of that quality essential to all oil men—optimism. We have seen that some new oil has recently been found in southwestern Kentucky and that, even though the new pools seem to be small and have not added much to future reserves, operators have been encouraged by results to continue the search for new production in the many large virtually untested areas which here exist. It can be safely said that there is plenty of room for the existence of some important, as yet undiscovered, oil pools within these large untested areas.

NATURAL GAS DEVELOPMENT IN SOUTHWESTERN VIRGINIA

By DAVID M. YOUNG*

INTRODUCTION

From the latter part of the last century when the Nettle Patch well was drilled in Wise County, Virginia, until 1948, only a few scattered tests were drilled in southwestern Virginia in the attempt to discover oil or gas in commercial amounts. During this period the only development of note occurred in two rather restricted areas, the Rose Hill oil field and the Early Grove gas field.

Serious attention from oil operators was first attracted to the region by the discovery of oil near the village of Rose Hill in Lee County, Virginia. This development was significant in that it was the first petroleum production to be secured, not only in Virginia, but in any area east of the Cumberland-Allegheny Plateaus. Intermittent drilling had occurred in Lee County since the year 1910, but the first important production was not secured until 1942. After fairly intensive development in subsequent years, production declined to a total of a little less than 10,000 barrels from 12 wells during 1952. This represented a decrease of about 1,000 barrels from the total produced during the year 1951. During recent months only one rig has been in operation in the area. This was drilling below the usual productive zones from fractures in the Trenton limestone in an attempt to test the Copper Ridge dolomite.

Small annual amounts of gas have been produced and marketed locally from the Early Grove gas field in Scott and Washington Counties since 1938. Less than 40 million cubic feet were sold from this field during 1952. Production from the Early Grove field is from sandy zones in the Little Valley limestone of Warsaw age.

Prior to 1948 these relatively small amounts of oil and gas from the Rose Hill and Early Grove fields comprised the total commercial production for the Commonwealth of Virginia.

In addition to the Rose Hill and Early Grove development, various scattered wildcats were drilled in southwestern Virginia during the years preceding 1948. Of these the following are worthy of note.

In 1932 and 1933 the Penn-Ohio Gas and Oil Company drilled a

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test in Russell County on the Sourwood Mountain anticline to a total depth of 6,002 feet through the Devonian shale. Although shows of gas were reported, the well was plugged and abandoned without shooting.

From 1932 to 1934 Benedum Trees were drilling and fishing on the Kaufman well 5 miles northeast of Norton in Wise County. Failure to set 7-inch casing in the top of the Big Lime below the Pencil Cave resulted in loss of the hole. The total depth was 3,670 feet and the well completed above the base of the St. Louis cherty limestone.

The Virginia Coal and Iron Company drilled 3 wells in the early forties on the plunging northeast end of the Powell Valley anticline. One was drilled through the horizon of the Oriskany to a total depth of 5,348 feet. Another of these wells made a heavy show of gas in the Ravencliff sand at a depth of 1,450 feet.

In 1949 the deepest test drilled in Virginia was completed by the California Company on a location 2 miles southwest of Blacksburg in Montgomery County. It was drilled with rotary tools to a total depth of 9,340 feet in the Moccasin limestone. An estimated 50 MCF of gas was reported at a depth of from 7,350 to 7,480 in the Martinsburg formation.

In 1950 the United Producing Company completed their No. 1 J. M. Hoge near the center of the Burkes Garden area in Tazewell County. The well was plugged and abandoned at a total depth of 5,632 feet in the Cambrian.

In 1951 the New York Mining and Manufacturing Company completed their No. 1 Graham at a depth of 6,057 feet through the horizon of the Oriskany. Although shows of gas were reported in the Devonian shale, the well was not shot and was finally plugged and abandoned. This last test was drilled in Wise County about 3 miles northeast of Norton.

Another noteworthy test was drilled in Wise County, Virginia, in 1949. Located in the vicinity of Big Stone Gap where Silurian and Devonian beds are exposed on the crest of the Powell Valley anticline, the well was drilled to a total depth of 4,862 feet in Cambrian dolomite. In all probability this well was bottomed at a depth above the sole of the Cumberland overthrust.

ROCKINGHAM COUNTY DEVELOPMENT

Although not located in southwestern Virginia, Rockingham County, in north-central Virginia in the Valley and Ridge province, was the scene of Oriskany sand exploration during 1951 and 1952.

The Souder well was deepened and completed as an Oriskany producer in November 1951. The total depth was 2,995 feet, initial openflow 1,043 MCF, and 48-hour rock pressure 1,300 p.s.i.

Three additional wells were completed in Rockingham County during 1952, one of which was dry at a total depth of 3,098 feet. This well was not shot. The United Fuel Gas Company completed the W. J. B. Moyers No. 1 at a total depth of 3,768 feet with the Oriskany sand from 3,563 to 3,761 feet. Oriskany gas gauged 158 MCF before shot and 286 MCF after. Snee and Eberly completed the S. L. Moyers No. 1 at a total depth of 3,077 feet with the Oriskany top at 3,036. The initial openflow was 9,700 MCF natural with a shut-in pressure of 1,310 p.s.i in 25 minutes. No new tests were started in Rockingham County following completion of the latter well.

BUCHANAN COUNTY DEVELOPMENT

The more or less intensive development that has been under way in southwestern Virginia during the past four years was started by the completion of the United Producing Company W. M. Ritter IV in January 1948. This well, located on Dismal Creek, about 7 miles southeast of Grundy (the county seat of Buchanan County), made 17 million cubic feet of gas from the Ravencliff sand of upper Mississippian age at a total depth of 2,301 feet. United Producing has continued development in Buchanan County during subsequent years, along with the Pipeline Construction and Drilling Company, the United Fuel Gas Company, and the Tate Oil and Gas Company.

By the end of 1952 a total of 61 wells had been completed in Buchanan County. Of these completions, 27 wells had a total initial openflow of 119 million cubic feet and 34 wells were dry or yielded only small shows. Additional drilling to May 10 of this year has increased the total initial openflow to 125 million.

With the exception of a few outlying wells, most of the development in Buchanan County has been in the Slate Creek and Knox Creek fields from 2 to 10 miles northeast of Grundy, and the Dismal Creek field about 7 miles southeast.

The greater part of Buchanan County production is from the Ravencliff sand and the Big Lime, with small openflows developed in the Salt Sand, Maxon, Berea, and the Devonian shale. Depths average about 2,500 feet for Ravencliff wells, 3,500 for Maxon, 4,000 for the Big Lime, 5,000 for Berea wells, and 6,000 feet for wells drilled through the Devonian shale. Ravencliff rock pressures range from 650 to 700 p.s.i. and those of Big Lime wells from 1,100 to 1,400 p.s.i.

The outstanding feature of development during recent months, not only in Buchanan County, but in all of southwestern Virginia, was the completion in 1952 of the 33 mile 8-, 10-, and 12-inch extension of the transmission system of the Hope Natural Gas Company. This line was terminated at a point in the Dismal Creek field near the discovery well about 7 miles southeast of Grundy. Deliveries began in November 1952, and totaled 1,135,545 MCF by December 31 of that year.

Currently, the United Producing Company reports 7 strings of tools in operation, Pipeline Construction 2, and the Clinchfield Coal Corporation 1, all on locations in Buchanan County.

DICKENSON COUNTY DEVELOPMENT

After United Producing was successful in their efforts to develop large volume gas in Buchanan County, the Clinchfield Coal Corporation spudded the first well on their property in Dickenson County, Virginia, in October 1948. The well completed in March 1949 as a producer in the Big Lime, and from that time until the present Clinchfield has carried on a fairly intensive development program on their fee and lease properties in Dickenson, Buchanan, and Wise Counties.

To May 10, 1953, 40 wells had been completed. Of these completions, 33 wells have been shut in with a total initial openflow of 58 million cubic feet and 7 have been plugged and abandoned.

Most of Clinchfield's development is in the Nora and Open Fork fields in south-central Dickenson County, although scattered wells have been drilled elsewhere in the county and in Buchanan County to the north.

During 1951 this company engaged in a program of seismic exploration over much of their property in Dickenson County. At that time the Nora Field had been almost completely delineated by development drilling, and this area was shot first for control.

Most of the developed gas reserves in Dickenson County are in the Big Lime, with smaller amounts in the Salt Sand, Ravencliff, Maxon, Berea, and the Devonian shale. Depths average about the same as in Buchanan County 4,000 feet to the base of the Big Lime and 6,000 feet through the Devonian shale. Rock pressures in the Big Lime range from 1,000 to 1,200 p.s.i and those in Devonian shale wells from 700 to 900 p.s.i. A recently completed Maxon well with a settled openflow of more than one-half million cubic feet "rocked" to 960 pounds in 5 days.

At the present time Clinchfield has in operation 12 strings of tools, of which 9 are in Dickenson County, 2 in Wise, and 1 in Buchanan County.

GEOLOGIC AND STRUCTURAL RELATIONSHIPS

The outstanding feature of the geology of that portion of southwestern Virginia being currently developed for natural gas is the fact that so much of the area lies within the confines of the Cumberland overthrust block. All of Dickenson and Wise Counties are within the block, but only a very small portion of Buchanan County is included.

Many authorities on Appalachian structure have published hundreds of pages concerning the mechanics of overthrusting involved in movements of the Cumberland overthrust block along the Pine Mountain fault. Nothing will be mentioned here other than the contribution to existing knowledge of this classic structure by some of the deeper drilling in southwestern Virginia.

It is routine procedure in Devonian shale wells drilled by Clinchfield in Dickenson and Wise Counties to bottom them in the top of the Corniferous lime before shooting the Devonian shale section. In so doing, all wells penetrate a shear zone from 60 to 100 feet above the top of the Corniferous, where strong gas blow-outs are encountered and tools frequently hung with resulting fishing jobs. The bituminous shale in this zone is highly slickensided, frequently almost coal-like in appearance, with numerous veinlets of calcite as much as one-half inch in thickness. This is, presumably, the position of the Pine Mountain fault or sole of the Cumberland overthrust block.

However, it is interesting to note that when one compares well sections in this area to those in eastern Kentucky and Buchanan County, Virginia, and allows for regional dip and formation thickening, the correlations are precisely what one would expect if faulted relationships did not exist.

The Cumberland block, from a point in Wise County on toward its southwestern end, exhibits the conspicuous Powell Valley anticline which brings rocks of Cambrian age to the surface in Lee County. Here, the overthrust block has been cut through by erosion to expose in a series of fensters rocks of Silurian and Ordovician age beneath the sole of the overthrust. It is in one of these fensters that the Rose Hill oil was discovered, and drilling outside the fensters in the overthrust block has penetrated the Pine Mountain fault to encounter both oil and gas.

When one traverses the axis of the Powell Valley anticline from a point near the fenster area of Lee County to the northeast in the vicinity of Big Stone Gap and beyond, where the older Paleozoic rocks plunge beneath the Coal Measures, one may see on outcrop all members of the section drilled in Dickenson County. Toward the base of the Devonian shale section the Genessee shale in this area exhibits conspicuous drag folds and shearing, with consequent slickensiding of the shale. This may not be the zone of blow-outs drilled in Dickenson County, but it is interesting to note that it occupies precisely the same stratigraphic position. And, reversing the traverse, one may from this point continue down the section to the southwest where the Copper Ridge dolomite is found resting upon rocks of Silurian and Ordovician age in the Lee County fensters.

Local shearing is not confined to the Devonian shale in the subsurface section of Dickenson County. The high-quality Widow Kennedy coal, widely exposed in Dickenson and Wise Counties, is a zone of horizontal shearing that has resulted in the coal thickness being so highly variable over short distances that it cannot be mined on a commercial scale.

PRODUCTION PROBLEMS

Drilling problems in southwestern Virginia are very much the same as those encountered elsewhere in the Appalachian Basin where cable tools are used, with the exception that regional dip and thickening cause drilling depths to be excessive. Long strings of 8 5/8- and 7-inch casing must be run, frequently in the neighborhood of the collapse limit. This difficulty is alleviated to a considerable extent by the use of suspension-type casing heads. Caving sections of red rock in the Pennington interval are thicker than in eastern Kentucky and consequently cause more trouble and require more cementing.

As most of the developed reserves in Dickenson County have been obtained in the Big Lime, obviously acidizing procedures are a primary consideration. It is the practice of Clinchfield to core all shows and pays in the Big Lime. The Baker core barrel has been used with a high degree of success at depths of more than 4,500 feet. If sufficient gas is obtained to warrant an acid treatment, the well is shut down until complete core analyses can be run. This work is done by Dowell, Incorporated, in the research lab in Tulsa, where every facility is available. Working in close cooperation with Dowell engineers after the results of core analyses have been obtained, a procedure is worked out for treating each well. Certainly each well poses an additional problem, and details of each acidizing procedure will vary from well to well. It has been our experience that it is well worth while to shut a well down and wait on the results of core analyses and sample studies before tubing and acidizing.

The Devonian shale section, frequently along with the Berea, is shot with 80% gelatine when drilled in Dickenson County. Again, because of the excessive shale thickness, frequently more than 1,200 feet, it is necessary to use very heavy shots.

CONCLUSION

In conclusion, it may be said that in southwestern Virginia the stratigraphy and lithology of gas reservoirs, surface and subsurface geology, and drilling and production problems differ very little from the situation in eastern Kentucky, West Virginia, and elsewhere in the Appalachian Basin. Although development is in its initial stages, it is continuing at a steady pace. Developed gas reserves for Dickenson and Buchanan Counties are estimated at 120,000,000 MCF and proven undeveloped reserves at 200,000,000 MCF.

THE USE OF RADIO IN NATURAL GAS OPERATION

By D. E. YORK*

RADIO, SECONDARY TO TELEPHONE AND TELEGRAPH

During the first world war radio was used only where telephone or telegraph could not be set up. It was not considered adequate for military use. Its first extensive use was for broadcast. Later, it was used by police for one-way signalling from headquarters to police cars. Most of the equipment used was constructed and maintained by the local amateurs. Of course, the shortcoming of this system was the fact that no acknowledgement could be transmitted from the cars.

The first two-way radio system ever installed was manufactured by Radio Equipment Laboratories and was installed for the police department at Bayonne, New Jersey, in 1931. It employed amplitude modulation and operated in the 31-Mc. region. At that time 31 Mc. was considered about the practical limit for high-frequency operation. Today we have systems operating on 8000 Mc. and know that sooner or later it will be practical to operate on even higher frequency.

Two-way radio soon proved its worth, but its growth was slow because of lack of experience. In 1935 Major Edwin H. Armstrong demonstrated a frequency modulated system which was less susceptible to static. This equipment was so elaborate that it left little room for the driver once it was installed in a vehicle.

FIRST PRACTICAL TWO-WAY FM SYSTEM

In 1938 Commissioner Edward J. Hickey engaged Dr. Daniel Noble to plan a statewide radio system for the Connecticut State Police. Dr. Noble recommended that frequency modulation be used to avoid static from co-channel operation. Since no FM equipment was available commercially, its development and manufacture was undertaken by Fred M. Link of Link Radio Corporation. This system consisted of 12 base stations and 250 mobile units. Its operation was satisfactory from the very start. Thus, FM two-way mobile radio became a reality.

Great strides were taken in the art of radio during the second world war. It was quite a different story from the first war when

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radio was not considered adequate for military use. Radar, which is merely another form of radio, was given credit for saving the British Isles from complete devastation by warning of the approach of German bombers.

After the war all the utilities, pipeline companies, taxicabs, and it seemed everyone else, made a mad scramble to install two-way radio. The available frequency assignments soon proved inadequate. In 1948 the F.C.C. made an exhaustive study to determine the requirements of the various services. This study was completed and put into effect on July 1, 1949.

This new frequency allocation plan gave the petroleum users a new lease on radio. Prior to the war they did not enjoy full recognition as a justifiable user of radio. Because of this fact the use of radio in the petroleum industry was confined to a few geophysical operations. Today it covers nearly every phase of the oil and gas industry. The new allocations provided for the operation of radio systems in the petroleum industry wherever they could be justified.

N.P.R.F.C.A. FORMED

It can be seen that some orderly procedure would have to be adopted for determining what frequency would be assigned to each applicant. To this end, the petroleum people met with authorities of the F.C.C. and formed the National Petroleum Radio Frequency Coordinating Association. This consists of seven regional committees and a national committee. The members of the national committee represent every segment of the oil and gas industry. There is one member from transmission, one from production, one from geophysical, and so forth.

The purpose of the committee, as the name implies, is to coordinate the use of available frequencies so that the least interference will be experienced from adjacent and co-channel operation. A company or person desiring to install a new radio system must first make application to the chairman of the N.P.R.F.C.A. in the region where he desires to operate. The chairman and his committee will then recommend a frequency which they consider best for the particular operation. This recommendation must be attached to the application to the F.C.C.

These regional committees meet annually to discuss their problems and prepare a report to the National Committee. Membership is free and every radio user is urged to participate. The State of Kentucky is in Region II.

The official organ of the petroleum industry is the Central Committee On Radio Facilities of the American Petroleum Institute. The N.P.R.F.C.A. is a cooperative organization to assist the F.C.C. in making maximum utilization of the available frequencies by coordinating their assignment and recommending efficient operating procedures. The A.P.I. Central Committee represents the petroleum industry on policy matters before the F.C.C. The close cooperation between these committees has made radio the valuable tool it is today in the petroleum industry.

The use of radio has grown so rapidly in the petroleum service that we are again faced with a serious frequency shortage. N.P.R.F.C.A records, as of June 1952, showed a total of 553 users employing 21,400 units. In spite of the good work which has been done by the frequency coordinating committees, it has been necessary to assign two users the same frequency in the same region. Several means of alleviating this situation have been considered by the Committee.

The most promising of these is splitting the present 40-kc. channels and assigning frequency on a 20-kc. separation. Also, consideration has been given to interservice frequency exchange on a geographical basis. These pitfalls should not discourage a prospective user in the petroleum radio service, because, to my knowledge, no justified application has been refused because of this frequency saturation.

Let us take a look at why the petroleum people think radio is so necessary to their operation—why they are so sold on radio that they spend considerable time and money to advance the art. This can best be explained by relating a single instance that happened shortly after Columbia Gas System inaugurated its radio system. In 1948, Columbia had 2 base stations and 5 mobile units which had been installed because we were unable to secure telephone right-of-way along a section of our gas pipeline leading to Washington, D. C. One cold morning in 1948, a header blew out at the Hazel River Crossing at a remote location 50 miles south of Washington, D. C.

The break was located by one of our radio equipped vehicles and the information was radioed immediately to his base station. The nearest telephone was an undependable line 5 miles way. During the 14 hours which is took to make repairs, over 300 transmissions were made. That means that if it had been necessary for a man to travel to that telephone and return each time it was necessary to relay information to headquarters, he would have driven 1,500 miles. This alone would have taken 50 hours. Also, by the use of radio it was possible to place men at strategic gates and through close coordination maintain gas service to Washington, D. C.

Only by use of radio is such coordination possible in the field during time of emergency. This one emergency convinced us that radio has a rightful place in natural gas operations.

V.H.F RADIO PRIMARILY BASE TO MOBILE

V.H.F. (very high frequency) radio is used in the gas industry primarily for communicating between base stations and mobile units. The base stations are usually located at compressor stations, district or sub-district offices. The mobile units are installed in vehicles patrolling the pipelines. These mobile units can keep in constant touch with their headquarters, giving them on-the-spot information and getting instructions directly from their supervisor. This saves both time and material.

V.H.F. radio is also used for communicating between base stations where no other form of communications is available or economically practical. An example of this would be between a compressor station and headquarters. In addition to these base stations and mobile units, we have the versatile "walkie-talkie." The latter are generally used for communicating with locations inaccessible to radio equipped vehicles. They are used frequently by line-walkers to report information to their foreman, who would be listening on a mobile unit.

ADVENT OF MICROWAVE

All the advantages of radio and telephone communication are combined in the use of microwave. The uses to which microwave can be put are so fantastic that it is hard to convince a layman that you are stating facts and not relating a radio man's dream. There are 20,000 miles of privately owned microwave systems authorized by the F.C.C. This represents a 1,000 percent increase since 1950. The longest of these systems is Transcontinental Gas Pipeline Co.'s 1,840 mile system between Falfurrias, Texas, and Newark, New Jersey.

All radio frequencies above 960 Mc. are considered microwave. The frequency band used is generally determined by the choice of equipment. Equipment is now available for operation on 960 Mc., 2,000 Mc., and 6,000 Mc. The 2,000 Mc. and 6,000 Mc. regions have the advantage of a wider band width, making more channels possible on a system. The channels are derived by the use of multiplex equipment which can be considered analogous to installing carrier on a telephone line.

Multiplex equipment divides the space assigned into small segments, using each segment for an operation. A single microwave circuit may afford as many facilities as a 24-channel wire-line circuit. This means it is possible to have 24 private voice channels, or these voice channels could be sub-divided, and as many as 18 signal circuits should be sub-divided, and as many as 18 signal circuits could be derived from each voice channel. These signal circuits are used for telemetering and remote control. Facsimile, teletype, and television are also transmitted over a microwave system.

THE DESIGN OF A MICROWAVE SYSTEM

A microwave system is usually designed as you would design an elaborate telephone system. You would have direct private talking channels between the general office and divisional offices. Party-line circuit would provide communication for district offices and compressor stations. One party line could be used for administrative work, while another could be used for reporting pressures. It would be possible to telemeter pressures along a pipeline or change the pressure or flow at any point by dialing a number or pressing a button in the office. Automatic alarm devices could warn you of any change from normal operation.

It is possible to start and stop booster stations by merely pressing a button in an office hundreds of miles away. It is even possible to to be viewed on a television receiver at headquarters. By the use of microwave it is possible to talk to the driver of a V.H.F. radio equipped vehicle while he is patrolling a pipeline hundreds of miles from headquarters.

The use of radio is considered a valuable asset to oil and gas operations. It is fast, dependable, and economical. Its growth and use since 1940 has been very encouraging. The advent of microwave and higher frequency equipment makes the future look even more promising.

REVIEW OF TECHNIQUES USED IN FLOODING LIMESTONE RESERVOIRS IN THE TRI-STATE AREA

By LEON KRAUSE*

INTRODUCTION

Considerable emphasis has been placed on waterflooding sand reservoirs; however, some lime "pays" are worthy of consideration as potential sources of secondary reserves.

In general, the results from flooding lime "pays" are not comparable in magnitude to the recoveries from sand reservoirs, but the intensity of development, the capital outlay, and the economics associated with the proposed project must be judged in terms of anticipated profit. As a rule, lime floods have an advantage in that a nominal capital investment is required to place this type of secondary recovery project in operation. Spacings ranging as high as 40 to 80 acres per input, and the conversion of present producers to injection wells reduce development costs to a nominal figure. High permeabilities, averaging in excess of 500 millidarcys, continuity of the porous zone over a large area, and the possibility of utilization of a high hydrostatic head enable the use of wide input spacing.

FAVORABLE LIME PAYS FOR FLOODING

The type of lime pays that have waterflooded successfully are:

(1) Oolitic—which is composed of spherical grains of carbonate bonded with calcite. This type has physical characteristics similar to a sandstone.
(2) Crystalline dolomites.
(3) Calcareous sands or sandy "limes".

Technological progress has not advanced to the point wherein it is considered advisable to flood the vugular and fractured lime "pays."

ENGINEERING STUDY

Prior to initiating the flood, an engineering study should be made of the limestone reservoir in order to establish the identity and conti-

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nuity of the pay zones in the formation. A structure map should be drawn on a well defined and blanket marker horizon. Wells tentatively chosen for conversion to injection should be selected to affect the largest number of producers surrounding the input. For example, if some wells are producing from the upper break, others from the lower, and a third possibility of both breaks, the selected input should service the largest number of producers in the area assigned to the injection well.

Structural position is of importance because it has been proven from field operations that it is advantageous to place the injection wells on the flanks and move the oil up structure.

Wells chosen for inputs should have a good primary production history or a high injective capacity. An examination of the electric log, initial potential, cumulative recovery, and present production will assist in determining the ability of the well to take water. Wells drilled into edge water and possessing sufficient capacity can be utilized to supplement a natural water encroachment, if present. Occasionally, a mistake is made in attempting to convert tight edge wells to water inputs. The prerequisite of a flood is to get repressuring media into the reservoir and this can only be accomplished by having good injection wells. Tight wells will function better as producers than inputs in a flood.

The ideal injection pattern for a limestone reservoir is to have widely spaced input wells on the flanks of the structure. The time required to cause migration toward the dome is longer than the period necessary to obtain an increase from a more intense spacing. However, the results of studies indicate that flank drives are more efficient and operating costs are less.

UNITIZATION

In general, it is necessary to unitize leases because of the strategic locations of the input wells which in turn would cause movement of oil across property lines. Common factors for participation formulae are cumulative recovery, present daily production, and number of wells.

MEANS OF INJECTION

Various modes of injection have been utilized in flooding the limestone reservoirs. The oldest and cheapest method of injection is called the "dump" flood. Pumping equipment is removed from the well, the casing opposite a water sand is ripped or perforated, and the brine pours down the casing into the "pay" under gravity or the hydrostatic head exerted by the water sand. With this system there is no control on the injection rate.

There are numerous dump floods in operation in the tri-state area. Some results have been favorable, and others adverse. Injection rates as high as 5,000 barrels daily per input well have been reported.

In order to secure information on injection rates for dump floods, a metering device may be used to measure and control the volume of water. The injection medium is obtained by perforating the casing opposite a suitable water sand and the pay is flooded by the hydrostatic pressure of the fluid column in the well. The metering device is run on tubing with a hook-wall packer set below the perforations in the casing. Water passing through the meter rotates a vertical shaft turbine which operates a set of reduction gears. A cam periodically releases a trip hammer which strikes a metallic block. The sound is transmitted to the surface and can be heard by ear or recorded by a surface instrument. By calibration of the meter, the number of hammer blows in a given period of time is converted to volume. The cost of the metering device and recorder, exclusive of the packer and tubing, approximates $1,500.00.

Some installations have a surface injection system which consists of a water source, pressure pump, and all the accessories common to a typical sand flood. Of local interest and an example to this type of installation is the Birk City flood, located in 18-P-27, Henderson and Daviess Counties, Kentucky. There was evidence of results from an accidental flood in this pool, and the various operators agreed to a co-operative plan of flooding. Five input wells were placed in operation to serve approximately 380 acres in the flood area. Water was pumped from the Green River, metered and injected into the inputs. Prior to the initiation of the planned flood, the pool had produced approximately 1,350,000 barrels of oil. Cumulative recovery to date is 1,780,000 barrels or 430,000 barrels of secondary oil. The flood oil recovered to date is 24 percent of the primary recovery prior to secondary operations.

The surface injection system has the advantages of control on rates and pressures, but is also expensive.

A modification of the surface injection system is a well equipped with a cross over packer and a conventional pumping unit. By means of a system of packers, water is obtained from perforations in the casing opposite a water sand, raised to the surface, run through a meter loop, and injected in the oil pay in the same well. The pumping unit and the in-well pump serve a dual purpose in lifting the water and injecting the same into the oil zone. An improvement on the dump flood method and a relatively inexpensive installation is the controlled subsurface injection system. A mechanism consisting of an orifice mounted in a cage and hold-down, and housed in a seating nippel is run on tubing in conjunction with a control head hook-wall packer (figure 1).

The pumping equipment is removed from the proposed input and the oil producing zone is given a wash with 2 or 3 barrels of acid. A brush or bridge-plug is placed below the selected water sand and the pipe is perforated to allow entrance of brine into the casing. The well is then swabbed to remove drilling mud and particles of cuttings and cement behind the pipe. The following data is recorded: the well is allowed to stand and reach equilibrium in order to determine the static fluid level in the hole. The well is then swabbed at a rate approximately equal to the desired daily injection volume for the well. Notation is made of the draw-down and the working fluid level for the withdrawal. From this information, the orifice and seating nipple depth is calculated. A given size orifice will have a through-put volume dependent upon the differential head; or with any two known factors of the following three namely: daily rate, orifice size, and differential head, the third factor can be calculated (figure 2 and table 1).

After the water data is secured, the bridge plug is knocked to bottom, and the packer on tubing and the seating nipple are set at the desired depth. The packer is set below the perforations in the casing. The brine enters through the perforations into the annulus between the casing and tubing, and rises to a set of open tees, a gas cage or perforated nipple, thence down the tubing through the orifice and into the pay zone. The orifice disc is substituted for the ball and seat in the cage and hold-down. A short piece of rod is screwed in the top of the cage to permit retrieving with a rod socket.

The installation depends on gravity, or the hydrostatic head of the column of water. Pressure on the downstream side of the orifice must approach zero because there are no means to measure the pressure with this arrangement. A well with a good primary history or of good injective capacity must be selected for conversion.

The installation has some measure of flexibility. If a large volume is desired, the cage is pulled and a larger orifice inserted. For smaller rates, a smaller orifice is used.

Cost of conversion, excluding the value of the tubing, is approximately $1,800 per well.

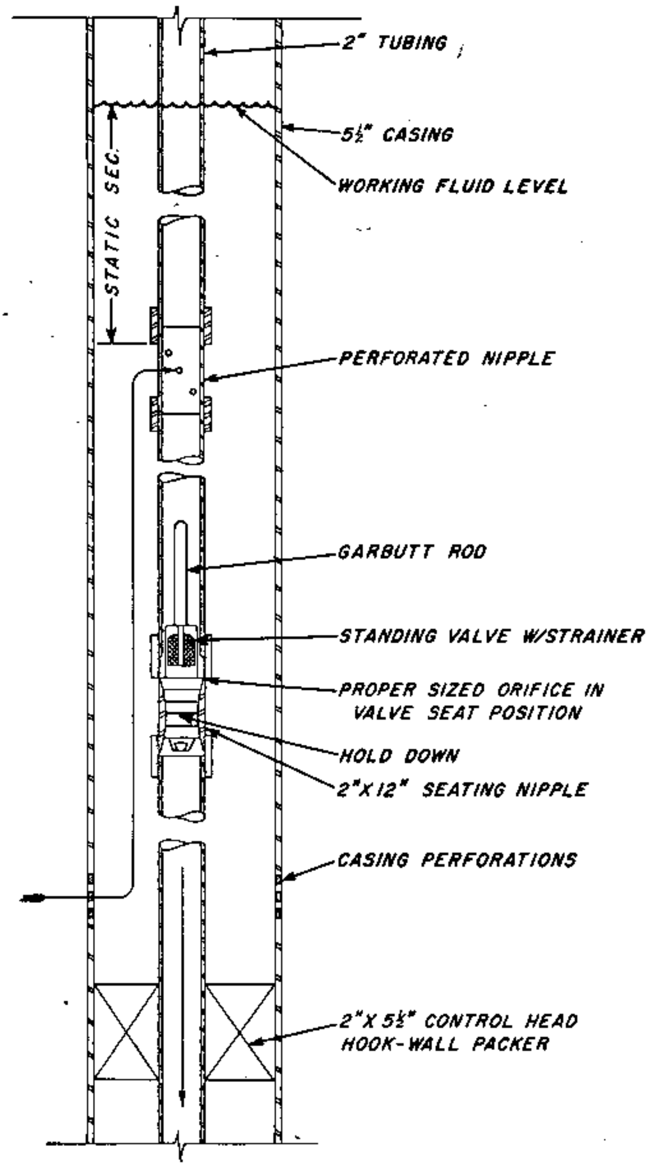

Fig. 1. Orifice control arrangement for subsurface injection. Control of injection is accomplished by placing an orifice of proper diameter at a pre-determined depth beneath the working level of the fluid in the casing. For example, approximately 250 barrels per day of water flows through a 3/16 inch orifice under a 300 foot head.

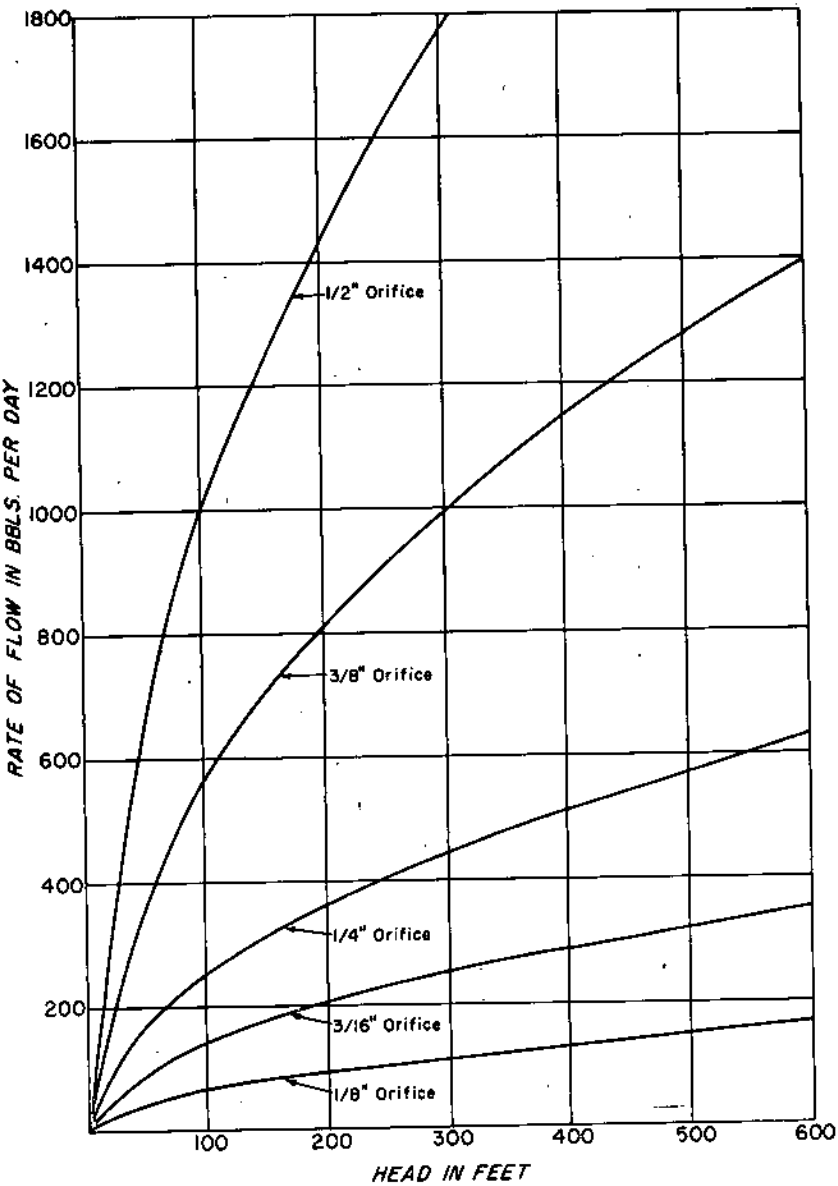

Fig. 2. Flow of water through sharp-edged orifice.

Major items of expense:

Cable tool rig—5 days @ $200.00	$1,000.00
Perforating	450.00
Packer	275.00
Orifice Control	60.00
Misc. supplies	25.00
Total	$1,810.00

Some reduction in cost could be affected by contracting a number of input wells in order to reduce the minimum rate on the rig. There are other expenses incident with operations which must be taken into consideration such as cat bills and similar items.

TABLE 1

Calculated Flow Through Orifices

Orifice dia. Inches	Head above Orifice—feet							
	100	150	175	200	250	300	350	400
	Volume—barrels per day							
1/8	65	78	84	91	102	110	119	128
3/16	144	174	188	203	228	248	268	287
1/4	255	310	335	360	405	440	475	510
3/8	575	705	760	815	910	995	1075	1150
1/2	1020	1240	1340	1440	1620	1775	1900	2040

OPERATIONAL NOTES FOR SUBSURFACE INJECTION

(1) Select a well that had been a good producer. Attempts to reacidize a poor well that had previously been given full treatment have been unsuccessful.

(2) Perforate the casing opposite the water sands where there is cement behind the pipe. Sloughing of mud and caving shales will plug-off perforations.

(3) Have a small petcock on casing head to vent dissolved gas in brine. If this precaution is not taken, the system will be gas locked. The whistling from the vent is an indication to the pumper that the well is working. Check for trouble if there is no sound.

(4) Use good clean tubing above orifice to reduce accumulation of pipe scale, paraffin, and B.S. on cage and orifice.

(5) Make provisions for fuel if dependent upon gas.

(6) Run float periodically. A rise in fluid level, approaching or equal to the static, indicates plugging of the orifice or pressuring-up of the formation. A serious drop in fluid level indicates plugging or perforations in the casing, a decrease in the productivity of the water sand, or a packer failure.

(7) Anticipate erratic behavior. Occasionally production will have a tendency to "slug" with total fluid produced in excess of the capacity of pumping equipment. Daily production curve will have peaks and depressions in spite of constant operating practices.

(8) Do not abandon a producer immediately offsetting an input. If the oil well has failed to respond, the others more distant have increased in production. The water may be moving down structure, or following the path of less resistance. Reservoir fill-up, vertical permeability, and control of rates on producing well will eventually cause the reluctant producer to respond.

(9) Watered-out producers occasionally can be brought back on oil production by rearranging inputs and exerting a drive from a different direction.

CONCLUSION

The preceding discourse is presented in the manner of suggestions. Economics are the controlling features which will ultimately decide the type of injection to use. Records to date, give recoveries for flooding limestones ranging from 15 to 35 percent of primary and in some isolated cases as high as 50%. Effective natural water drives augmented by the injection of extraneous water in the early life of a pool are in a separate classification with considerably higher recoveries.

Knowledge of the reservoir, characteristics of the pay zone, and production history are of prime importance in evaluating the secondary potential of a limestone reservoir.

HYDRAULIC FRACTURING IN THE TRI-STATE AREA OF ILLINOIS, INDIANA, AND KENTUCKY

By G. H. LINK*

Through March, 1953, approximately 1,000 wells had been hydraulically fractured in the tri-state area of Illinois, Indiana, and Kentucky. Of this total, approximately 75 percent were successful. It is evident, therefore, that hydraulic fracturing has grown from a new technique introduced to the industry in March, 1949, to a standard tool used in well completions and workovers. In this paper the following points concerning hydraulic fracturing will be covered. First, the theory behind this relatively new tool; second, a very general discussion of the various methods of fracturing available to the industry; third, an analysis of fracturing technique used in the tri-state area; and fourth, a discussion of actual case histories in an endeavor to ascertain the factors that should be considered in hydraulically fracturing a well.

THEORY AND PRINCIPAL OF HYDRAULIC FRACTURING

Originally the mathematical expression for the rupturing of rock adjacent to the well bore by fluid pressures was obtained by applying the principles defining elastic and inelastic behavior of thick-walled cylinders. The validity of this approach was based on the assumption that in either the elastic or plastic state, conditions of homogeneity, isotrophy, and impermeability existed. These conditions are never met and seldom approached in the field. It is not surprising, therefore, that to date no rigorous mathematical expression has been published which is directly applicable to field conditions.

Once the fracture has been formed as a result of fluid pressure, increased production is due to the very high effective permeability of the induced fracture even when of extremely small width. This is true even if the fracture extends through a rock of very low permeability. There are commercial wells producing in the United States today whose reservoir rock have permeability of less than 0.1 millidarcy yet due to fracture porosity exhibit extremely high potentials.

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HYDRAULIC FRACTURING METHODS AVAILABLE TO THE INDUSTRY

There are several processes available to the industry to achieve hydraulic fracturing. All techniques involve pumping a viscous fluid or gel into the well at a sufficient rate to rupture the formation. Most of the methods use the viscous fluid as a carrier for a sand propping agent which prevents the fracture from closing when the pressure is released. The fracturing fluid may consist of a napalm-kerosene mixture, a gel acid, or a crude oil having certain specific physical characteristics. The gel acid treatments are especially adaptable to limestone or calcareous sand. Consultation of the operator with service companies who handle the various treatments often prevents misapplication of a specific technique. In fact, it has only been through the cooperation of the operators and service companies that hydraulic fracturing has reached such a high degree of perfection in such a short time.

FRACTURING TECHNIQUE

The technique used to hydraulically fracture the formation can best be illustrated by a field example. The well, a portion of whose electric log is shown in Figure 1, was originally completed by shooting the Bethel sand in open hole below 2026 feet. The Hardinsburg sand shown in this illustration was opened through perforations from 1806-18 feet, or 10 feet above the original oil-water contact. No stimulation treatment was applied to the Hardinsburg originally because of the underlying water. Completion date was on July 26, 1949. In March of this year a decision was made to hydraulically fracture the Hardinsburg. A plug was set below the perforated interval. A 6-hour bailing test indicated a daily production potential of 8 barrels of oil and 0 barrels of water from the Hardinsburg. A retrievable packer was run in on tubing and set at 1,774 feet. This isolated the zone to be fractured. After pumping 840 gallons of clean crude oil into the formation and starting in the fracturing fluid, it was necessary to circulate out and reperforate the casing since the fracturing fluid would not go into the formation. Evidently a "gyp" deposit had formed on the casing perforations. After reperforating from 1,806-18 feet, 840 gallons of crude were pumped into the formation at a maximum pressure of 1,300 psi. A total of 1,500 gallons of fracturing fluid containing 1.3 pounds of sand per gallon were then pumped in, followed by 3,300 gallons of crude oil. The maximum pressure was 1,900 psi and it broke 1,400 psi. Injection rate was 150 gallons per

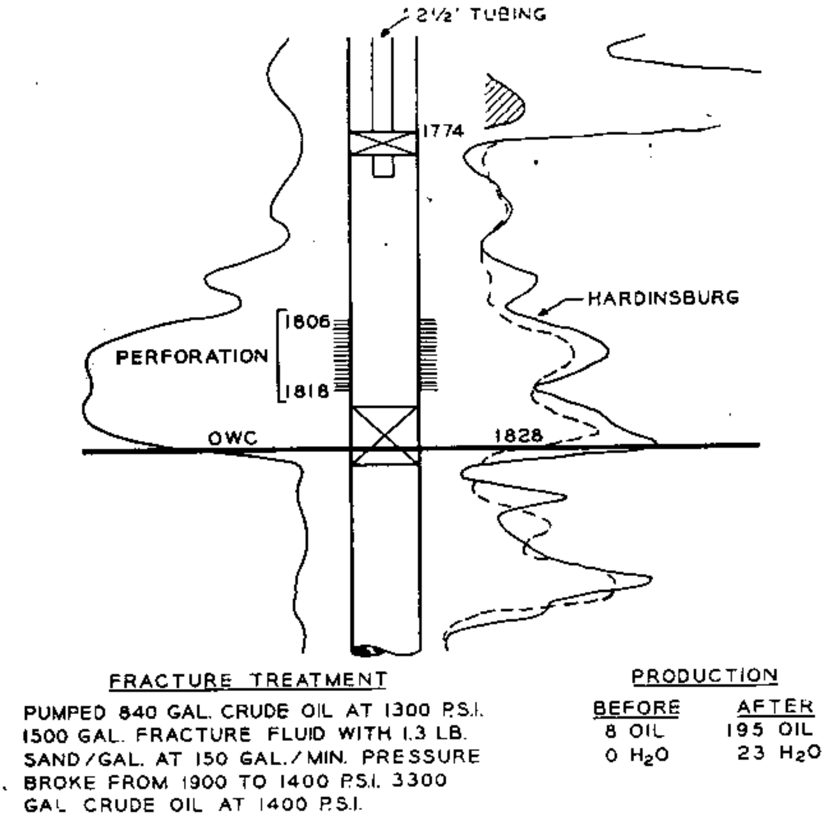


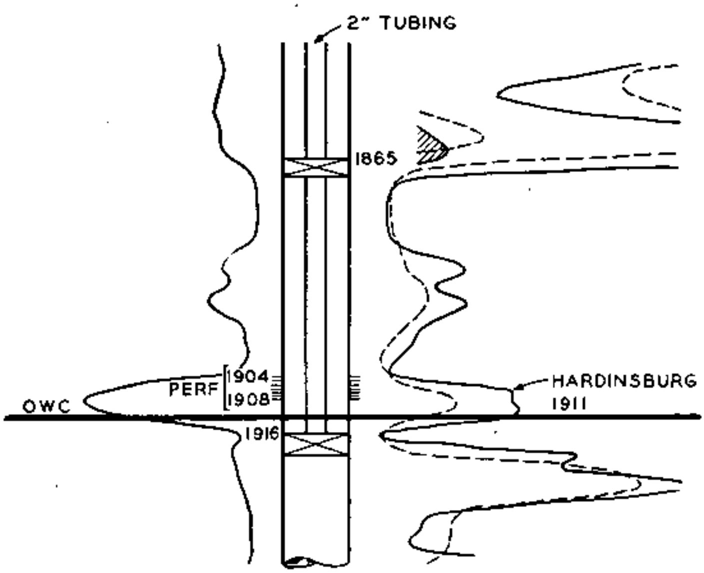
Figure 1

minute. A pumping test taken one month after treatment indicated a potential of 195 barrels of oil and 23 barrels of water in 24 hours, an increase in oil production of 2,300 percent.

Admittedly, this treatment gave exceptionally good results. It is pertinent, therefore, to consider the factors that contributed to the unusual success of this job. First of all, the accumulated production per acre foot from this well was low compared with other wells draining the same reservoir. Second, a drill stem test taken while drilling through the Hardinsburg flowed oil in 4 minutes. Furthermore, the average horizontal permeability in this particular reservoir, as determined from cores, is approximately 470 millidarcys and the vertical permeability 430 millidarcys. Thus, the reservoir contains a good sand capable of high producing rates. Third, the sand as shown in the electric log, was relatively clean and thick. Fourth, the treatment was confined to an interval of only 12 feet. Fifth, prior to treatment there had been no water production reported. The lowest perforation was 10 feet above the original oil-water contact. Sixth, a recent bottom hole pressure survey indicated a reservoir pressure in excess of 200 pounds in the area of this well. Indeed, this was an ideal well for stimulation treatment.

CASE HISTORIES

A review of some other field examples will illustrate that variation of certain of these six conditions has resulted in a less favorable response to treatment. Figure 2 tends to illustrate that you cannot make good producers by fracturing unless sand quality is favorable. This particular well which is draining the same reservoir as the previous well considered has, as shown by the electric log, a tighter, thinner sand. The oil-water contact was 3 feet below the lowest perforation. The initial potential of the well was approximately 5 barrels per day. In March, 1951, a decision was made to hydraulically fracture the Hardinsburg. A total of 1,600 gallons of fracturing fluid containing 0.4 pounds of sand per gallon of fracturing fluid was



FRACTURE TREATMENT

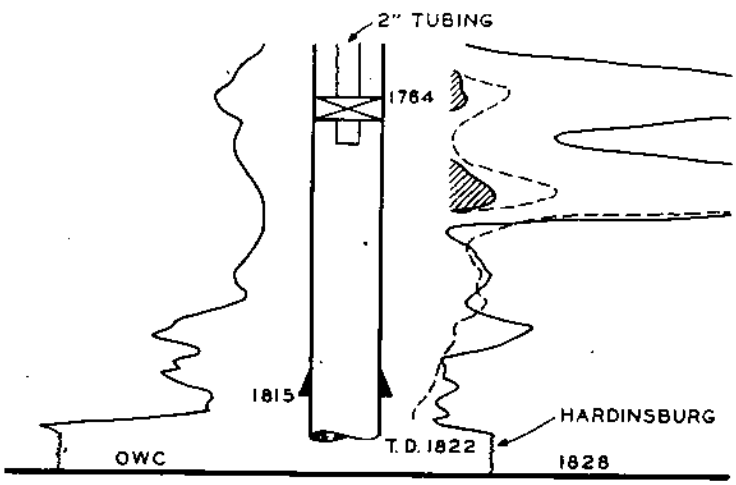
PUMPED 840 GAL. CRUDE OIL AT 1600 P.S.I. 1600 GAL. FRACTURE FLUID WITH 0.4 LB. SAND/GAL AT 160 GAL./MIN. PRESSURE INCREASED FROM 1600 TO 2400 P.S.I. 3000 GAL CRUDE OIL FROM 4000 TO 1700 P.S.I.

PRODUCTION	
BEFORE	AFTER
5. OIL	27 OIL
1 H_2O	26 H_2O

Figure 2

utilized. The fracturing fluid started into the formation of 1,600 psi and rose to 2,400 psi. Pumping rate was 160 gallons of fluid per minute. The 3,000 gallons of crude oil which followed in fracture fluid broke the formation from 4,000 to 1,200 psi. Production was increased from 5 barrels per day with 1 barrel of water to 27 barrels of oil and 26 barrels of water. However, based on current data the cost of reconditioning has not and will not be returned.

Figure 3 illustrates the danger of increasing water percentage. This particular well was completed in the Hardinsburg in the same reservoir and had casing set at 1,815 feet. Exposed immediately below the casing seat were over 3 feet of shaly sand interbedded with shale as determined from core descriptions. Total depth of the well was 6 feet above the oil-water contact. Other factors were favorable for a successful job. The fracturing fluid broke down the formation at a pressure of 1,700 psi with a final pressure of 1,400 psi. Fracture fluid containing 0.25 pounds of sand per gallon was pumped in at a rate of 160 gallons per minute. Production was increased from 5 barrels of oil and 8 barrels of water to 12 barrels of oil and 80 barrels of water. This indicates that even though over 3 feet of shaly sand and shale were present below the casing point at least one fracture was



FRACTURE TREATMENT

PUMPED 840 GAL. CRUDE OIL AT 800 P.S.I. 1600 GAL. FRACTURE FLUID WITH 0.25 LB. SAND/GAL. AT 160 GAL./MIN. PRESSURE BROKE 1700 TO 1400 P.S.I. 3000 GAL. CRUDE OIL FROM 2000 TO 1400 P.S.I.

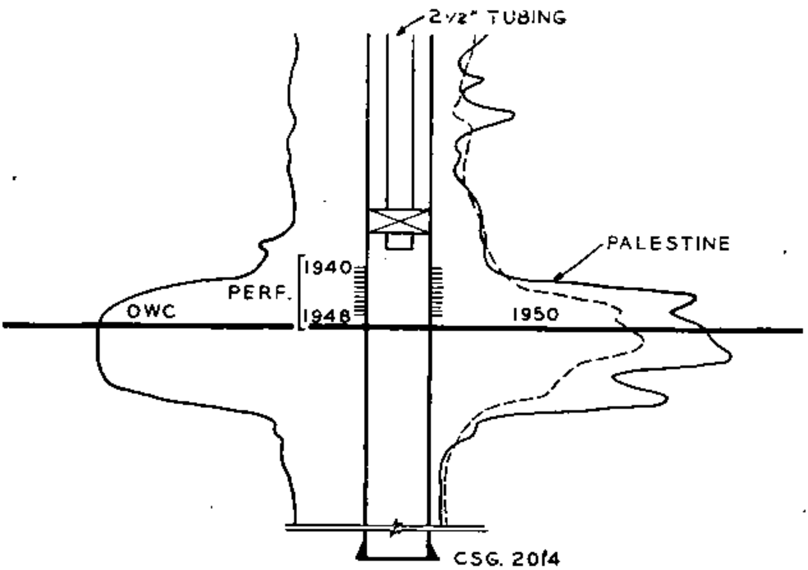
PRODUCTION

BEFORE	AFTER
5 OIL	12 OIL
8 H_2O	80 H_2O

Figure 3

made into the underlying aquifer. Although this treatment was not considered good, it was successful since the cost of fracturing has been returned in increased oil production.

Another field example is shown in Figure 4. This particular well was drilled to a total depth of 2,847 feet in the Aux Vases. No commercial production was encountered below the Palestine so casing was set at 2,014 feet through the sand due to underlying water. The Palestine, which is shown in Figure 4, tested 940 feet oil, 270 feet gas, and 30 feet oil-cut mud in 4 hours from 1938-50 feet with a bottom hole pressure of 342 pounds. The sand in an offset well which was cored revealed a horizontal permeability of 500 millidarcys. The well was perforated from 1940-44 feet and tested dry after pulling vacuum with a casing swab for 4 hours. The interval from 1944-48 feet was also perforated and the entire interval tested dry.



FRACTURE TREATMENT	PRODUCTION BEFORE	PRODUCTION AFTER
1-PUMPED 840 GAL. CRUDE OIL BROKE FROM 2400 TO 1700 P.S.I. 1000 GAL. FRACTURE FLUID WITH 1 LB. SAND/GAL. AT 66.6 GAL. PER MIN. PRESSURE BROKE 2700 TO 1500 P.S.I. 1000 GAL. CRUDE OIL AT 1500	0 OIL 0 H_2O	11 OIL 1 H_2O
2-PUMPED 840 GAL. CRUDE OIL AT 1800 P.S.I. 800 GAL. FRACTURE FLUID WITH 1.5 LB. SAND/GAL. AT 133 GAL./MIN. PRESSURE BROKE FROM 1950 TO 1200 1500 GAL. CRUDE OIL AT 1400 P.S.I.	11 OIL 1 H_2O	132 OIL 32 H_2O

Figure 4

Due to apprehension about the underlying water, only 800 gallons of fracturing fluid containing 1 pound of sand per gallon was pumped in at an injection rate of 66.6 gallons per minute. Although the fracturing media started in at 2,700 and broke to 1,500 pounds, disappointing results were obtained. The well was swabbed for 4 days and all fluid used in the previous treatment was finally obtained, plus some mud and sand. During the last 24 hours the well swabbed 11 barrels of oil and 1 barrel of water. In view of the initial potentials of other wells in the area, it was deemed prudent to refracture. The second treatment was performed using 800 gallons of fracturing agent containing 1.5 pounds of sand per gallon. The pressure broke from 1,950 to 1,200 pounds while pumping at a rate of 133 gallons per minute. The well was then completed for a pumping potential of 132 barrels of oil and 32 barrels of water per day. In the second treatment on this particular well, three factors were changed. The amount of sand was increased from 1 to 1.5 pounds per gallon, the sand had been thoroughly cleansed by the previous treatment, and the injection rate was greatly increased. The success of the second treatmnt is largely attributed to the increased injection rate plus the cleaner condition of the sand.

Now, that various case histories have been reviewed, it is pertinent to examine them in retrospect to determine if a check list can be made up to be used in the selection of a well for hydraulic fracturing. The first factor to be considered is accumulated production. If the well under question has a low accumulated production per acre-foot in comparison with other wells in the same reservoir, and the sand quality is good it is definitely a candidate for hydraulic fracturing. Second, all core and drill stems should be examined to determine sand quality. Third, an electrical log should also be examined to determine thickness, quality, and position of water table. Fourth, the interval opened for treatment should be examined with the thought in mind that a minimum interval should be opened to insure maximum fracturing benefits. Fifth, the water production history of the well should be examined as well as position of the water table. It has been demonstrated that water percentages in general will increase and if the water table is near there is a good possibility of fracturing into it. Sixth, the bottom hole pressure should be examined if data are available. Unless there is sufficient reservoir energy to force the oil into the reservoir a successful hydraulic fracturing job cannot be achieved.

The factors that should be considered in the actual hydraulic fracturing technique are: (1) as high a pumping rate as possible should be used to insure maximum fracturing; (2) field experience to date indicates that a sand content in the fracturing gel of at least 2 pounds per gallon will give better results. Some operators in the Basin have used as high as 4 to 4½ pounds per gallon; (3) the formation to be fractured should be clean. The presence of any mud, cement, paraffin, or salt deposits tends to minimize the possibility of a successful fracturing treatment.

SUMMARY

Through March, 1953, approximately 1,000 wells had been hydraulically fractured in the tri-state area. About three-fourths of these were successful. The hydraulic fracturing technique in the tri-state area involves isolation of the zone to be fractured and pumping a viscous fluid containing sand into the formation at a high rate. A study of field histories indicates that certain specific factors should be checked in the selection of a well for hydraulic fracturing. Experience also indicates that high pumping rates, high sand content of 2 pounds per gallon or more, and a clean formation tend to yield more successful results.

COMMENTS ON SHOOTING PRACTICE IN WATER-FLOOD AREAS

By G. C. ROBERTS*

I believe that papers such as this are generally presented by learned men who are adept with equations and skilled in theory. As a statement of fact I wish it distinctly understood that I am not an engineer, scientist, or even a college graduate. For the past 23 years I have been employed by the Independent Eastern Torpedo Company, and during that period of time I have made many observations of shooting practice in various oil fields in the country. Most of my work has been restricted to the shallow stripper areas of Kansas, Kentucky, Oklahoma, and Illinois, and it has been my good fortune to have worked in numerous fields where secondary recovery by water-flooding methods has been a proven success. I have watched with interest the development of these projects from their very beginning, and through the years I have been able to accumulate a certain amount of information which I trust will be of interest to you. So, if you will bear with me, I would like to relate in my own words a few of my observations in shooting practice in those water-flood areas in which I have been employed.

First of all, it might be well to review a bit of history in regard to well shooting, which has been accepted oil field practice for many years. The results of shooting were first noticed in the early oil regions of Pennsylvania, and it was quite evident that the amount of increased production certainly warranted the procedure. It was further determined that the production rates from unshot wells suddenly declined to uneconomic limits, whereas the production rates from shot wells were sustained for a long period of years. All of this was evident prior to the introduction of water-flooding to the industry. As this specialized form of production gradually came into existence it was quite logical to assume that if the same results could be achieved by shooting water-injection wells as had been obtained by shooting producers, more water could be forced through the formation with a greater ultimate recovery of oil. As water-flooding techniques advanced it was necessary to modify or change what had formerly been accepted as routine practice. The operator became aware of

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electric logs, cores, and samples from his wells and used this information to govern his completions. Rather than shoot the entire formation from top to bottom, particular attention was paid to varying the diameter of the shells to fit the particular sand characteristics of the individual well, and consideration was likewise given the shale breaks or streaks of barren sand that frequently appeared. The location of the packer seat was determined and the top of the shot placed accordingly. This was termed "selective shooting" and resulted in unusual success. No longer did a field foreman or shooter place in a well the shot he thought best, but that responsibility was put in the hands of capable engineers who ordered shots based on the individual well formation characteristics.

Throughout the years numerous types of explosives have been developed and are available for use in the shooting of wells. Some of these feature shorter clean-out periods after the shot, and others are recommended because of their safety features. However, in order to achieve safety it is necessary to reduce the sensitivity of the explosive; and when that is accomplished the speed of the explosive is lessened to such an extent that difficulty frequently occurs in detonating the lower portions of such a charge. This is particularly true when shot is placed in the well in long sections of shell. Some of the speeds have been lowered as much as 65%. In my opinion, it is impossible for the operator to anticipate any results from a lower section of such a shot, as it either burns or does not explode. This results in tedious clean-out jobs at additional expense to the operator. In some instances, this type of explosive has been bailed from a hole after it failed to detonate; and in other cases, portions of the charge have been exploded with tools, endangering the lives of men on the rig and threatening the possible loss of the well.

The explosive that I have found to be most satisfactory in the different types of shots that we have today is LNG, or Liquid Nitro Glycerine. It sounds dangerous, but fewer accidents have resulted from the use of this explosive than from all our so-called "Safety Explosives." This statement can be checked by records in different fields taken over a period of years and reported by the Association of Well Shooting Torpedo Companies of America. LNG has a speed of 27,800 feet per second and is the most powerful explosive used today in oil well shooting. The results of shooting with LNG are just as apparent at the bottom as at the top of a shot, regardless of the length or size of shells. We use it today in shells ranging from 1½-inch diameter to 7-inch diameter. The effect of this explosive on a formation is that of rapid jolting, during the course of which is expended an explosive wave of a lateral or horizontal nature far out into the formation. This has been proved many times by checking line wells in different fields that have been shot with LNG, against those shot with other charges. It is the conclusion of most operators that those wells shot with LNG have definitely shown a much greater recovery and longer production life. A good example of the power and energy of LNG against the face of a formation is to be found in the following test of one pound of the explosive. It yielded 156.7 cubic feet of gas at a temperature of 6280° F. and developed an energy of 2,120,000 pounds with a pressure of 150,050 pounds per square inch. The period of application of such an explosive is brief, and dissipation is so great that the temperature rise in the wall of the hole or the casing is practically negligible.

The OWE, or Oil Well Explosive, is also a good explosive when used in the 100 percent grade. This type of explosive is used a great deal in gas fields and in window shooting or where a section of Securoloy has been set and removed by the usual method. OWE tends to have more of a slow pushing effect on a formation and has a speed varying from 24,300 feet per second to 8,000 feet per second. It is advisable, when using this explosive in long sections of shot, to utilize as large a shell as possible. Nothing less than a 3½-inch diameter shell should be used in a long column of shot, since OWE shows a considerable variation in speed because of the conditions under which it is exploded. A booster of sufficient nitroglycerine dynamite is necessary in such a charge to assure detonation throughout the column of shot.

Our liquid nitroglycerine 440E or Red Glycerine as it is commonly called today, has been developed in the past two or three years and is rapidly coming to the front as a leader in this type of explosive. In its development the company has been able to reduce pressure unit volume and at the same time maintain a good detonating velocity rate. This has given superior execution value in fracturing a formation. The speed of this explosive has been developed in excess of 22,000 feet per second, and it carries through to the bottom of a long charge at that speed, giving equal results the entire length of the shot. The successful use of this explosive is attributed to the fact that it has a true nitroglycerine base due to its high oxygen content. When examined through a microscope, it resembles a cell structure.

Along with the development of explosives, new and better ways of stemming or tamping a shot have also been devised. In years gone by, water tamping was about the only method known to the industry. It was necessary to set the pipe sufficiently high above the formation in order to prevent injury to the casing; and as a result, the hole would often be filled completely to the top with water. The procedure in some water-flood areas, and especially those producing from the shallow formations, has been to run electric wire and then pull the casing over the wire before detonating the shot. Shooters who used this method in conjunction with water tamping frequently encountered difficulties before better tamping methods were adopted. I have witnessed strings of pipe shot from wells and the ruination of some holes because of bad pipe. There is also the added danger of faulty wire which fails to detonate the shot and involves a very dangerous and lengthy clean-out period. The Time Bomb has been developed and perfected until now it is probably the most popular method of detonation in use in secondary-recovery operations. The use of a bomb enables the operator to cement his pipe close to the pay formation without damage from the shot. At first, sand and gravel were used as a tamp with considerable success, but these tamps have now been replaced in a great majority of the jobs by Cal-Seal. This product is a quick-setting cement which, when used in conjunction with Time Bombs, enables the operator to shoot a horizon within three or four feet of a string of casing. Very few bad jobs are encountered any more if a proper bridge of gravel is set under the pipe and followed up with Cal-Seal. These new methods of tamping have been of great benefit in water-injection wells, where the casing is set into the top of the formation that is being water-flooded.

As previously stated, the most popular method of detonating a shot today is accomplished with Time Bombs. Generally speaking, these are placed in the well with settings of not less than one hour and can be set as high as 114 hours. The chief advantage of the Time Bomb is that it allows sufficient time for the tamp to set up, whether it be sand, gravel, or Cal-Seal. Another prime advantage in the use of Time Bombs is safety. More positive and accurate firing of the shot is assured, and very few failures have been noted.

In some of the more shallow water-flood areas it is still common practice to detonate with Jack Squibs. This last mentioned method is used for the most part where a short string of casing is run in the well.

In most of the engineered water-flood operations, careful consideration is given the physical properties of a formation, which are determined from samples brought to the surface by conventional coring or cable-tool chipping methods. These samples are submitted to detailed analyses in a laboratory where porosity, permeability, and oil and water content are determined and where other tests are run to determine the floodability of the sand. Some operators use electric logs in place of cores to supply this information. By applying laboratory data of this nature the operator or engineer is able to determine the quarts of glycerine per foot of sand to be used in the shot. Different methods are used by most engineers in computing these shots; but their chief objective remains the same, and that is to obtain as nearly as possible a uniform water-injection rate. Past experience is also a good guide; so, on an expanding water-flood program the operator or engineer may govern his future shooting and recommendations for shooting by results already achieved on previously completed wells.

During the past 17 years I have been working with waterflood projects almost exclusively; and I have yet to see an unshot well completed as an input well with satisfactory injection rate. My reasoning on this subject may differ from that of the technical men, but I am of the opinion that sand will take water for a period of time until it has absorbed all it can possibly contain within itself. Then, after pressure starts building up, the rate of injection is still unsatisfactory and it is necessary to boost the pressure to maintain injection rates. This pressure increase endangers the project by a possible channeling occurrence, which is surely a nemesis of water-flooding. Why then should a risk like this be taken, when a shot and a little clean-out time will eliminate that danger? I have observed a great many successful water-floods while following my work from field to field. I have also been aware of several miserable failures caused primarily by cutting a few corners to eliminate or reduce costs.

Just a few months ago, for example, a new water-flood project was completed with unshot input wells. The daily production failed to exceed 44 barrels of oil, which was considered very low for this particular area. The reason for this failure was due to poor injection rates which could not be increased by additional pressure because of the fear of channeling. We have just completed shooting the last of the inputs in this project over a period of approximately seven months. The shots were run in 2-inch shells with LNG through 4-inch casing cemented in the top of the pay. Today, the flood yields as much as 250 barrels daily and has not reached the peak of its production climb.

On another project to which I have reference, a deeper formation was tried with unshot wells in the same manner and resulted in the same failure, except that in this flood the pressures were raised as high as 1,400 pounds in an effort to gain a satisfactory injection rate. The result was serious channeling on the development; and now that project is beyond recovery, as far as a water-flood is concerned. I have seen this happen repeatedly. Why this practice is still being tried I cannot understand, because water-flooding is a very expensive proposition and to me a shot is insurance against failure.

What actually happens when a producing formation is shot has been the subject of theory and technical discussions for many years. However, nearly everyone concurs that fractures are formed; and, as a result of these fractures, additional fluid conductivity is developed. Therefore, the prime purpose of shooting is to increase the rate at which a well can produce by creating a zone of fracturing in the reservoir rock around the well bore. The effective permeability of the formation is increased; and by shooting both the producing and injection wells of a water-flooding project, the oil recovery and economics of the operation are certain to be favorably affected.