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FACTORS CONTROLLING OIL-WELL COMPLETIONS IN THE ILLINOIS BASIN

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FACTORS CONTROLLING OIL-WELL COMPLETIONS IN THE ILLINOIS BASIN

By CARL A. BAYS

THE most vital period during the development of an oil well is the time between the decision that it is of commercial value and its actual completion on production through the tubing. In the Illinois basin the Tri-State area of Illinois, Indiana and Kentucky (Fig. 1), production is characterized by low pressure, low fluid levels, and relatively small but long-lived wells. Production is mainly from the Chester (upper Mississippian) sands and the Ste. Genevieve (lower Mississippian) oolitic lime horizons, although Pennsylvanian, other lower Mississippian, Devonian, and "Trenton" zones are productive in various fields.

The present discussion is concerned mainly with the stages in well completion as particularly applied in the Illinois basin. No attempt is made to acknowledge any sources of the procedure, techniques, or other matter as they are generally common knowledge or common field practice. The writer was formerly engaged in consulting practice, specializing in those stages of drilling and completion that involve the handling of drilling mud, coring, electric surveying, control of measurements, setting pipe, cementing, drilling plug or perforating, swabbing in, shooting, acidizing, and generally making a well ready for the actual connecting and production. The work was designed to bridge the gap between the normal service of the oil-field geologist and the service of average farm boss or pumper who handles wells for independent operators. During the past 2 years, work with the Illinois Geological Survey has given an opportunity to review practices in general use by all operators. The writer's experience has been concentrated in the Wabash Valley area, and the generalizations reached here may not be broadly applicable to some fields in other parts of the basin.

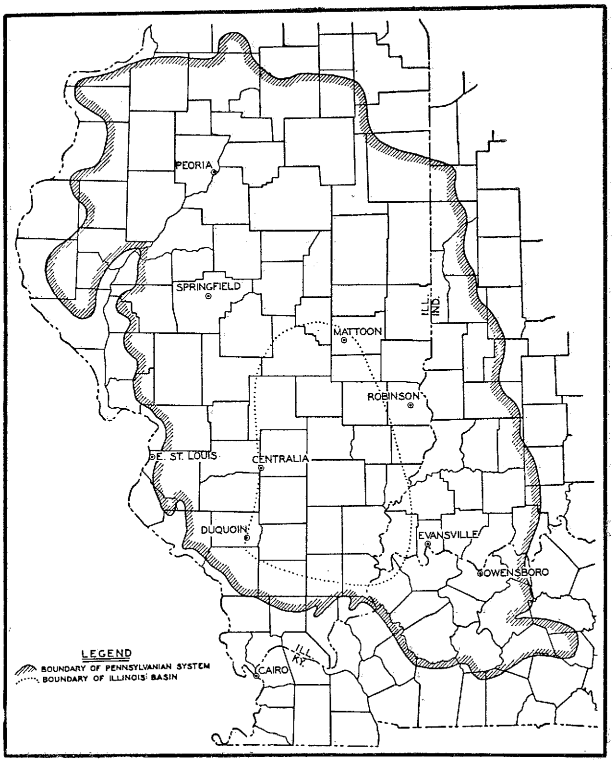

Fig. 1: Index map of the Illinois basin

Essential Geological Conditions

Pennsylvanian Strata.—The Pennsylvanian zones (see Fig. 2, columnar section) include a number of more or less lenticular sands. The cores are generally tight, somewhat streaked, and permeability is generally low. Oil from Pennsylvanian zones in many areas is of low viscosity and relatively low gravity. Small wells are typical and recoveries are low. Many of the Pennsylvanian horizons are commercial only because of their shallow depth or because operators use maximum economy in drilling, equipping, and operating. A number of different sands are included in this generalization, and locally a number of different names are applied to the different zones. In most of the sands in the lower portion of the Pennsylvanian system a good water drive is present, and where fair permeability prevails better wells are obtained.

Kinkaid, Clore-Degonia, and Palestine.—The highest Chester sands that yield commercial production are the Kinkaid, Clore-Degonia, and Palestine sands. They are not consistent producing horizons and pay off only locally, for the principal production comes from scattered wells in White and Gallatin counties, Illinois, and Posey County, Indiana. In most of the wells the sands are rather thin, erratically tight, with low permeability. In many wells there is no recognizable oil-water contact, but instead an intermixture of connate water and oil in the producing zone and apparently a lateral water drive, so that the transition from oil production to oil-and-water production to water production is rather gradual. In general

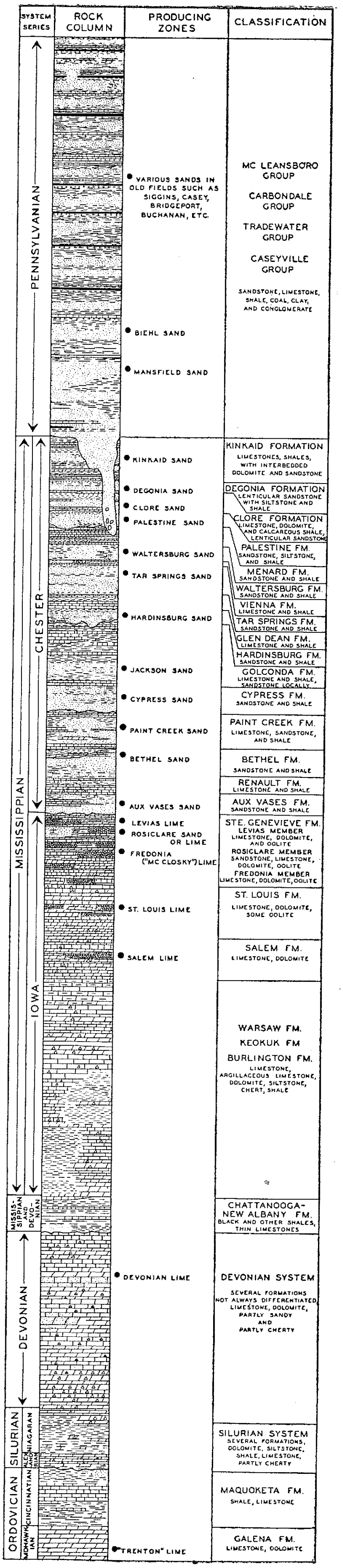

Fig. 2: Diagrammatic columnar section of the Illinois basin showing the producing zones. Lithologies and thicknesses are those typical of Wayne or White counties, Illinois, or Posey County, Indiana

small almost noncommercial wells are typical of the Clore-Degonia and Palestine as developed in the Illinois basin to date. In some of the Gallatin County area a rather thick and well-developed permeable sand is present in the Palestine and a strong water drive with the oil "floating" has been noted.

Waltersburg sand.—The next lower producing zone is the Waltersburg sand. The sand is typically lenticular but the lentils are fairly well developed and where the structure is favorable, big wells and high recoveries are not uncommon. Wells drilled near the edges of Waltersburg lentils show little thinning of the sand section, indicative of the proximity to shaling out. The edges of the lentils are rather abrupt so that the producing zone may disappear from one 10-acre location to the next. The typical Waltersburg sand in the Wabash Valley is a fairly to highly permeable sand with few shale breaks and a gradational oil-water contact that occupies about 5 ft. or more. Reservoir gas expansion and water drives are both common. To all of these generalizations the Storms field in White County, Illinois, is exceptional in having a consistent, but more erratically permeable, sand body with a well-developed gas sand overlying the oil sand. In the Storms pool the oil is poor and production has been handicapped by the large volumes of gas.

Tar Springs sand.—The next producing zone beneath the Waltersburg is the Tar Springs sand which is separated from it by the thin Vienna formation. This zone changes greatly in character from the Wabash Valley fields to the Franklin County area and to the west. At the west side of the basin the sand is a consistent crossbedded, fairly permeable sand; it has a thick saturated zone and both good gas-expansion drive and water drive. In the central portion of the basin a thick water-sand zone is typical with some interbedded calcareous sandy zones. In the eastern portion of the basin the Tar Springs generally consists of several sands with interbedded shales. The lower portion of the Tar Springs is normally a prolific water-producing zone and where the shaly interbeds are not developed the water generally drowns out oil production under normal open-hole conditions. To obtain commercial Tar Springs production in this area it is usually necessary to find saturation where there is a shale break above the oil-water contact. The lenticular character of such a shale break frequently means that wells at the same elevation and with essentially the same saturation conditions may not behave in the same manner on production, because one without a shale break will normally go to water readily. In the Wabash Valley such "floating" zones have been perforated in several wells in which there is production from a lower zone, and small production is received through these perforations that augments the regular production from the well, but the Tar Springs oil is produced at such a slow rate as to permit little water to come in. In these same areas similar wells in the Tar Springs alone have failed to make commercial producers.

Hardinsburg sand.—The Hardinsburg sandstone is irregularly developed and is not a significant producer in the Illinois basin. In the Iron pool, White County, where this sand is the principal productive zone, there are unusual reservoir conditions, first because the field apparently is a fault trap, and second because the locally thick Hardinsburg here cuts out the upper part of the underlying Golconda formation. In this field the Hardinsburg is fairly tight but is an excellent producer because of the constant rate of production and the thick sand body. Elsewhere locally in the Wabash Valley fields the Hardinsburg has been found to be saturated and has made commercial producers.

Golconda "Stray" sand. — Locally there is sand between the main Golconda limestone and the "Barlow" or lower Golconda limestone. This sand is known as the Jackson in Kentucky and is generally correlated as Cypress in Indiana. It is not a significant sand body in the Illinois basin fields, but in the eastern margin of the basin area at scattered places in Indiana and in western Kentucky it is locally an important producing horizon. This importance is primarily because of the shallow depth, for generally the sand is tight and irregular.

Cypress sandstone. — The Cypress sandstone is one of the most important producing sand formations in the Illinois basin. It usually has one to three sandstone zones. The upper one is locally a green sand and is commonly known as the "upper Weiler." In general, it is not important because it is tight and calcareous but in some fields it is a well-developed reservoir. The sand which has its top about 20 to 40 ft. under the Barlow limestone is the principal producing sand. In some wells this sand is divided by shale so as to make three Cypress sands in all. The sands range from fine to medium grained, well sorted to poorly sorted quartz sand with low to high permeability and porosity. Lateral variations in texture and porosity are common and thin shaly lenses are numerous. Although many of the fields have a definite water table, the oil-water contact is usually gradational so that even though the well cores show apparently good saturation the sand will produce water in some localities when tested.

Paint Creek sands. — The Paint Creek formation, which consists of interbedded sandstone, limestone, and shale, contains sand-producing zones. There is considerable difference of opinion as to which strata can be classed as Paint Creek and which are part of the underlying Bethel. In the opinion of many geologists much of the production which is classed as Bethel should be called Paint Creek. In the Roland field, White County, Illinois, for example, the producing zone next below the Cypress is called Bethel, Paint Creek, and "Paint Creek-Benoist." In the New Harmony field certain sands below the Cypress are called both Bethel and Paint Creek. The higher sands that are certainly Paint Creek in the Wabash Valley area are locally productive, particularly in White County, Illinois. The sands are good reservoir sands and are typically consistent locally in texture and character. The lower sands which may be referred either to the Bethel or Paint Creek are productive over a much wider area. They are more shaly, they vary laterally in position, thickness, porosity, and permeability, and in quantity of shale present.

Bethel sand. — The Bethel sandstone is an important producing zone in the fields on the west side of the basin, particularly Salem, Woodlawn, Centralia, and Louden. In these fields the sand is well developed and although it has local shaly lenses, it is commonly a good homogeneous reservoir with good permeability and porosity. The Bethel is one of the most productive zones in the basin because of the richness of saturation and because the sands are thick and continuous. Eastward in the center of the basin and on the east side the zones classed as Bethel are as described for the Paint Creek, although locally in the Wabash Valley, thick homogeneous and consistent sand bodies are present. The Bethel generally has a well-developed water table but the oil-water contact is commonly gradational through a few feet. On several of the Wabash Valley structures the entire sand is above the oil-water contact in most of the field so that the water drive is lateral in effect.

Aux Vases sand.—The Aux Vases sandstone is an important producing zone in the Illinois basin and is rather unusual in its characteristics. Normally it is a fine-grained and highly calcareous sand. Local tight spots are developed by its becoming more calcareous or by shaling out. Because of its fineness and general irregularities, under normal conditions the sand reacts to shooting with good increases in production. Electric logs usually show low resistivity, and the sand was called a water sand for a considerable period. Generally on the west side of the basin the Aux Vases sands are coarser and less calcareous. In rotary-drilled wells the key to whether the Aux Vases is productive is in core analysis and drill-stem testing. Because of the fineness of the sand it may be difficult to recognize a show in cuttings. As a general rule, in order to avoid missing commercial Aux Vases wells, a drilling-time break sufficient to suggest the presence of porosity should justify the cutting of a core, and a show of oil in an Aux Vases core should justify the running of a drill-stem test and careful core analysis.

Ste. Genevieve zones. — The Ste. Genevieve formation is commonly divided into three members, the Levias, Rosiclare, and Fredonia. In common usage the term McClosky applies to the porous oolitic strata of the Fredonia, although commonly any oolitic zone in the Ste. Genevieve has been called McClosky. An oolitic break occurs locally in the Levias limestone, and in a number of fields this zone is productive in a few wells. Occasionally oolitic limestones have developed in part of the Aux Vases formation, even above the main Aux Vases sandstone, and in some areas these zones are correlated as Levias and in others they are recognized as Aux Vases. In general they are not significant producing zones. The Rosiclare ranges in character from an oolitic limestone to a sandy oolite to a calcareous or siliceous sandstone, and is productive at one or more localities in all of these facies.

The oolitic zones of the Fredonia are the most important oil-producing zones in the Ste. Genevieve. These oolitic sections vary laterally in thickness, permeability, and degree of dolomitization from one location to another. Structure plays an important part in control of McClosky production where the oolitic strata are continuous, but there are a number of places where production occurs without regard to structure but is controlled by updip destructive dolomitization or pinchout of an oolitic zone. Apparently in any one area the oolitic zones may be continuous or discontinuous so that a zone present at one location on a structure may not be present at another. The McClosky zones are characteristically flashy producers, having high initial production, giving great increases from acidizing, and declining sharply. However, McClosky wells which do settle at a commercial rate of production after the flush is gone apparently are long lived and fairly consistent producers. Both gas-expansion and water-drive production are common in McClosky fields, although it seems probable that gas-expansion drive is more important, at least in the early stages.

Zones below Ste. Genevieve.—Except locally for the Carper (basal Osage) and the Hoing (Devonian) sands in the margins of the basin, the producing zones below the Ste. Genevieve in the Tri-State area are oolitic limestones or crystalline limestones or dolomites. These include zones in the St. Louis and Salem formations in the Mississippian and the Devonian and Trenton* which are productive on the west edge of the basin. The writer has not had enough first-hand experience with these zones to present a detailed picture of them.

Drilling Practices

In the Illinois basin careful and intelligent practice during drilling may obviate a number of the difficulties of completion. Care of the drilling mud used in the drilling, testing and completion of a well, attention to accurate measurements, careful sampling, coring, and keeping of logs and drilling-time records are very important to the ultimate productivity of a well. In spite of extreme care in all of these matters there are a number of wells in the Illinois basin in which pipe either should not have been set or an oil well should have been completed.

Drilling mud.—Common practice in the handling of drilling mud is to drill the Pennsylvanian strata or drill to the top of any expected pay before mixing mud. Some contractors drill until they are ready to run an electric log before mixing mud. An analysis of costs to contractors, considering total costs, including time lost on fishing jobs, reaming bridges, lost circulation, and trying to get an electric survey elec-

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*Description of Trenton production to 1941 is given in Cohee, George V., "Trenton Production in Illinois," Ill. Geol. Sur., Illinois Petroleum, No. 39, 1941.

trode to bottom, indicates that the least expensive method of operation is to drill the plug on the surface pipe with the drilling mud in condition and to maintain it that way by frequent jetting of pits and mixing of new mud all during the drilling of the well. Commercial gel muds and fresh water make the most suitable drilling mud for Illinois basin wells although in many circumstances other constituents may be used to maintain a low-water-loss mud. Sufficient calcareous material comes from the limestones to make the addition of lime unnecessary and frequently disastrous to the quality of the drilling mud. It is good practice to test salinity, water loss, and pH of the mud during drilling of all wells, and where mud difficulties have been encountered, to have a resistivity test run on the mud several days before running the electric log of the well so that conditions can be made suitable for the proper recording of the electric log. In general with the use of commercial gel muds, frequent jetting and gunning of pits to maintain clean and thoroughly equalized mud of 9.6 to 10 lb. per gal. in weight and 38 to 44 seconds viscosity A.P.I. will eliminate difficulty. Such muds will usually have low water loss and will give most satisfactory drilling conditions. Care should be taken in running drill-stem tests to see that no salty water or oil gets into the pits to flocculate the mud.

If the mud has become salty from some of the Pennsylvanian or deeper sands it is possible to avoid mixing new mud by the use of gels designed to stay in suspension in salt water, provided the salinity and resistivity are still within the range of suitable electric logging.

Another aid to mud is a box cellar if a flow nipple is not used. A cellar should be dug in any event so the bradenhead can be put below the ground, the casing head set low, and high pump bases made unnecessary. If a cellar without flow nipple is used, a trough to pits should be constructed to protect the mud, and the cellar should also be equipped with a jet so that frequent jetting is possible.

Measurements. — Accurate measurements are as necessary to completion as to drilling. Common practice is to take measurements from the top of the kelly bushing or the top of the rotary table. During drilling it is common practice to keep a pipe tally and run a steel line at frequent intervals, particularly at coring points. It has been found that steel-line measurements to the top of the float section in the drill pipe and the keeping of pipe tallies are both subject to error. A good check method is to strap the pipe in the derrick occasionally, particularly at coring points, as a verification of drill-pipe and steel-line measurements. It has been found that the use of a foot and tenths tape instead of the standard foot and inches tape eliminates considerable chance for error both in taking measurements for the pipe tally and for strapping drill pipe. An ideal set of measurements is one in which the pipe tally, steel-line drill pipe measurements, open-hole line measurements (if taken), casing tally, and steel-line casing measurements for any well all check to a foot. Unless such measurements are obtained there is some possibility of doubt which may ultimately affect the completion of a well. If there is any discrepancy in measurements a good practice is to check the tops of markers as picked from sample-study and 1-ft. drilling-time records against the electric-log record so as to locate the error exactly. It is helpful to record measurements in terms of footage of "zero," the rotary table or kelly bushing above the ground, but even better methods include an accurate measurement of the footage from the top of surface pipe or top of bradenhead, if pipe is set. It is easy to sight the bushing or table with a simple hand-level, and then by sighting at the same level to a nearby tree or other more or less permanent marker and by setting a nail, notch or stake for zero, there is a ready reference after the rig is torn down and during tailing in. In the writer's opinion no one or two of the various methods of measurement should be trusted by itself, where possible or where variations exist all should be used.

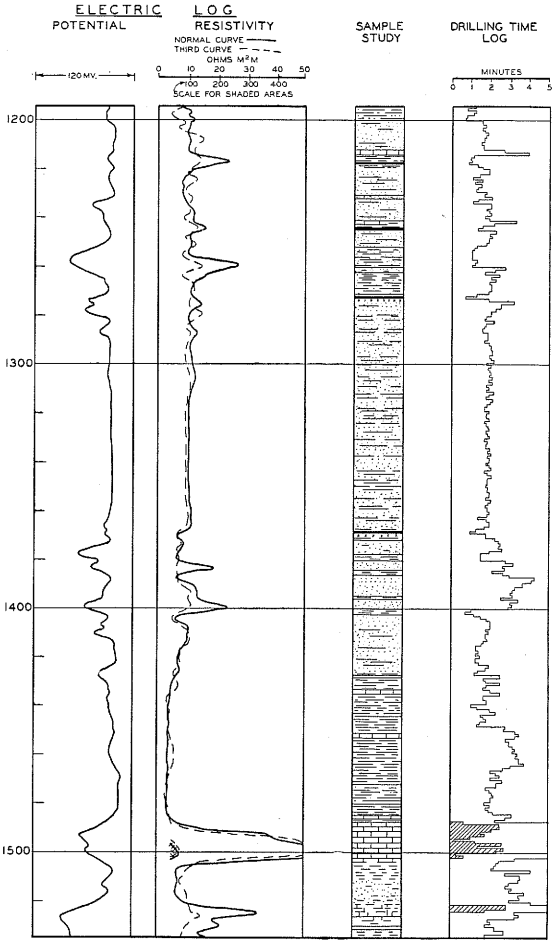

Fig. 3: Portion of a typical sample-drilling time-electric log

Sampling and logging.—In order to obtain a clear picture of the strata in a well, careful sampling is essential. The samples are caught in a properly constructed, easily cleaned sample box at either regular footage or regular time intervals during drilling. A record should be kept so as to indicate at what point in relation to the samples trips were made, and at what points there may have been circulation in the hole without drilling being in progress. To interpret the samples a drilling-time record is essential. The drilling-time record also affords an accurate check on measurements. A log based on samples and drilling time should be available for each well, and in the writer's opinion it is essential to the proper interpretation of many features in the electric log (Fig. 3). Careful logging will provide a knowledge of casing seats, caving characteristic of formations, cementing difficulties that may be encountered, and a number of other important facts not directly related to the pay zone but important in completing the well. Electric logging is common practice in almost all the rotary wells drilled and its merits are obvious, although most successful interpretations are based on close correlations with sample drilling-time logs.

Sample boxes in current use in Illinois are either obstructions in the return ditch or trough or are designed to sidetrack cuttings into a box from the main trough or ditch. A sample catcher that was devised by employes of Pure Oil Co. is being more widely used and offers many advantages (Fig. 4). A 2-in. elbow and nipple facing the surface pipe are welded into the flow nipple. A connecting pipe to a tee delivers cuttings to a bucket and excess mud to the ditch. Buckets are changed at the end of each sampling interval. Experimentation with position of the elbow in the flow nipple will give the most desirable sample size and eliminate much sample contamination.

Coring.—Coring is the most important means for obtaining information needed in the completion of a well. It is general practice to penetrate sands and circulate up samples to see whether the sand is saturated. This gives little information

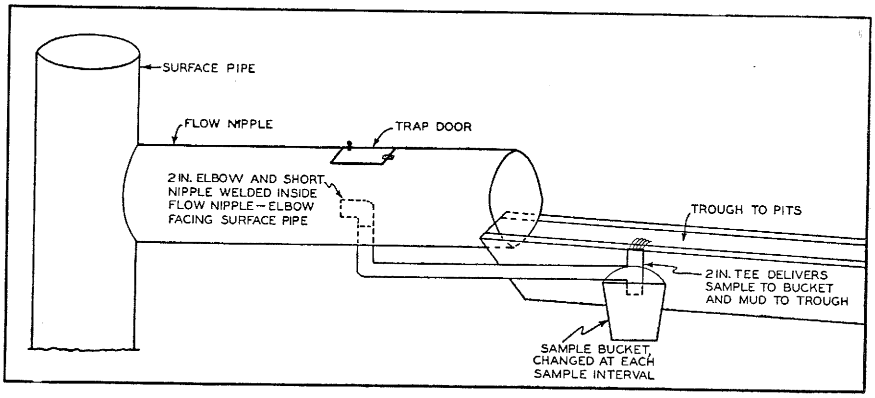

Fig. 4: Device for catching samples of rotary cuttings used by Pure Oil Co.

as to the top of the sands and the character of casing seats above them. On the other hand, economical operation does not normally permit the cutting of cores above the top of the various zones because of the erratic character of most of the sands in the Illinois basin.

During several hundred coring jobs, observations were made involving weight run, speed of rotary, pump pressure, and coring time. The writer has concluded that the average driller can obtain good recoveries under any number of variable conditions. The most important factors seem to be circulating cuttings and cavings from the well for a period that varies with the depth and return time prior to coring, and having the drilling mud in proper condition. Where cores are not recovered in spite of these precautions it is economical in many instances to run side-wall coring or sampling devices to obtain full information concerning a possible pay horizon.

Core analysis. — The cutting of cores loses much of its value if the cores are not examined by someone experienced in that type of work and if determinative core analyses are not run. The core analysis by itself cannot be considered as an index to productivity but it furnishes valuable aid when used with the electric log and other methods of study. The most frequent reason for undependable core analysis lies in the improper selection of samples and in careless handling of the samples before they reach the laboratory. The samples should be typical of the core and pay zone. Proper directions for selection of core samples and the wrapping and handling can usually be obtained from the engineers who run core analyses for the service companies. Because of demonstrated evaporation loss from cores, in the writer's opinion the porosity and permeability determinations are most indicative of the type of reservoir. All saturation data are also important but they are more difficult to evaluate.

Setting Pipe

After a decision has been made to attempt to complete a well as a producer, the setting of pipe is the next important stage. The decision to set pipe on wells without having collected sufficient data to indicate a commercial well has accounted for numerous failures in the Illinois basin, many of which are blamed on bad cement jobs and other poor completion techniques. However, there are a number of wells which are known by their later records to have been bad cement jobs. Most of these could be avoided by taking due precautions in the setting of pipe. Where they do occur it is the writer's opinion that they should not be blamed entirely on the cementing company that merely mixes the cement and pumps it down the pipe but rather on the procedure followed in the drilling, preparation of the hole, and actual running of the pipe.

Casing seat. — The picking of a

suitable "casing seat" is essential to a successful cementing job. Of course, in most rotary holes in the Illinois basin, the pipe is swung and not set on a seat, but the spotting of the shoe in terms of formation is of importance, and this point in the well is usually referred to as the casing seat. Most of the producing sands are overlain by shale and this in turn by a limestone. The shale interval varies from very thin to 30 or 40 ft. in some zones and in some wells. In some zones, but varying from one locality to another, the shales range from hard, firm, splintery, possibly calcareous shales to soft, rather rotten shales. Some shales are suitable for setting casing and others are not. The soft shales, in general, pump out so that the hole diameter is excessively large. With the constriction of the overlying limestone where the hole is probably near diameter, the cleaning of the bottom of the hole and proper even cementing is difficult. Some of the apparently hard shales are exceedingly brittle and pump out much the same as the softer shales. The limestones in general make excellent casing seats, but since in many wells they overlie shales which cave, they cannot often conveniently serve. If the oil sand is to be produced from pipe set above it, it is frequently necessary to spot the shoe right at the top of the sand, neither high enough to expose any shale nor low enough to cut off any essential portion of the producing zone. The importance of exact measurements in such cases is obvious. Experience has shown that where the selection of a casing seat is somewhat hazardous, series cementing is sometimes a help. Also where no evidence from samples or cores can be brought to bear on the character of a casing seat, a caliper survey is useful. It is also a guide in cementing, logging, and other matters related to the well.

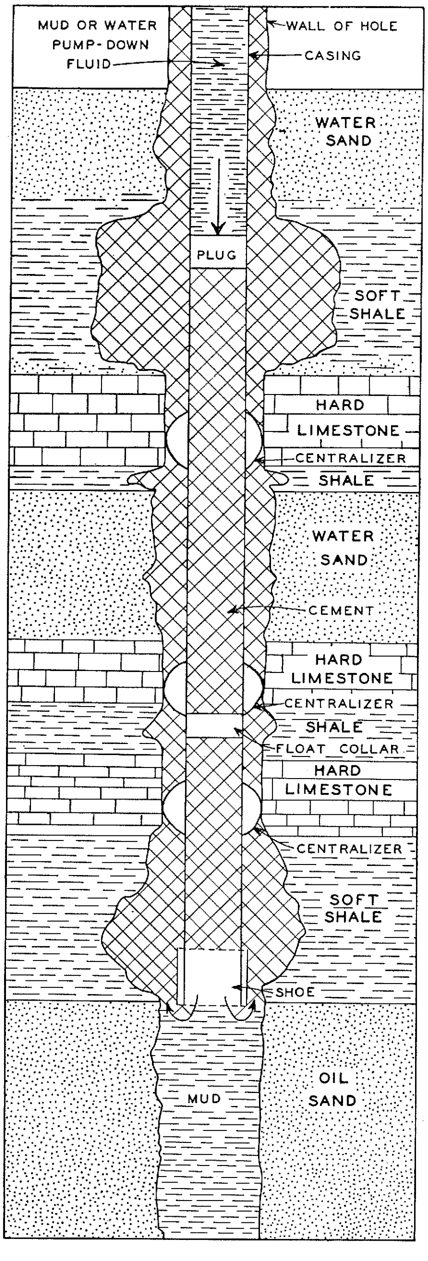

Fig. 5: Diagram showing typical conditions for cementing an oil string. The shoe is set exactly at the top of the sand and centralizers are set in the hard limestones

Conditioning the hole.—Prior to the setting of pipe it is usually necessary to condition the hole. Experience has shown that reaming down after coring and before setting pipe or running drill-stem test will generally allow a better cement job. In running a drill-stem test it is better to test a section which has been cored in larger hole with a wall packer than with a cone-type packer set on top of the rat-hole. A certain amount of caving sometimes takes place in holes that are properly mudded if many trips, much coring, drill-stem testing, etc., has taken place in the final drilling stages. Most wells have a waiting period between the completion of the electric logging and the actual commencement of pipe running. At the end of this period the well should be conditioned for pipe running. Equalized mud of proper weight and viscosity should be circulated until the hole is free from caving and cuttings. Zones where reaming has been done should be checked with the bit going into the hole to make certain that they are to diameter. During the waiting period the well should be kept full of mud. It is undesirable to thicken mud at this time if the mud has been carried at near the proper weight and viscosity because an increase in weight and viscosity, particularly the latter, frequently causes undesirable caving whereas equalized mud near the proper composition will usually serve to condition satisfactorily. A check of returns will usually indicate whether the hole is cleaned up.

The oil string.—The oil string in Illinois is normally equipped with a guide shoe, float collar at top of first joint, a combination float and guide shoe, or some wash-down or whirler variation of guide and float equipment. Various devices are used for centralizing the pipe in the hole. In the writer's opinion centralizing equipment is essential to successful cementing in the Illinois basin. It has been found that a careful study of the well log so as to spot centralizing equipment on the pipe string so that it is placed opposite hard limestones rather than shales or sands makes centralizers more effective. It has also been noted that in some cases the use of centralizing equipment at one place on the string may force the pipe against the wall above if the hole

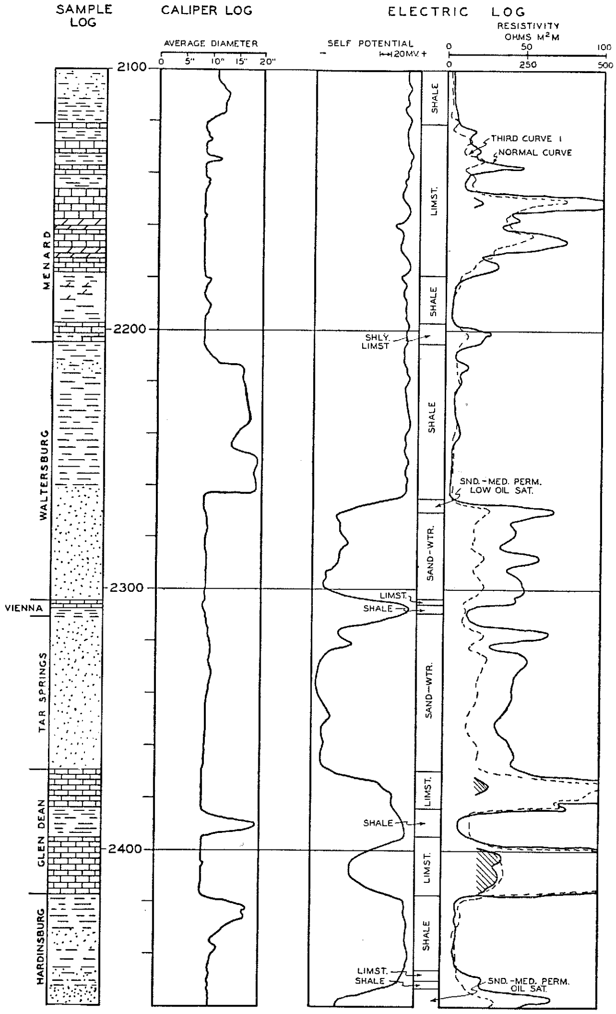

Fig. 6: Caliper log of a portion of the Chester series in an Illinois basin well with sample log and electric log to permit comparison. Note caving of soft shales

is slightly crooked. This is shown by temperature surveys indicating a lack of cement above the centralizing equipment; whereas if two or three centralizers, properly spotted, are used a more even distribution of cement normally results (Fig. 5). It is customary to spot-weld the lower several joints of pipe together so as to strengthen the string against the stresses of tailing in.

Amount of cement.—The amount of cement used is normally computed by assuming the theoretical fill per sack for the diameter of the hole and using a safety factor of several times the amount necessary to properly shut off fluids back of the pipe, cover high pays above the bottom of the pipe, serve as support for the pipe against the stresses and jars of tailing in and properly cushion the string in event the well is to be shot. The only safe method to determine the amount of cement is on the basis of a caliper survey (Fig. 6) or else to use greatly excessive amounts of cement to be on the safe side as experience has shown that shale zones make large cavities, as sometimes do the soft sandstones, that some horizons occasionally will take cement, and that frequently mud occlusions which may occur cannot be displaced with a small amount of cement slurry.

Casing measurements. — Casing run into a well should be carefully tallied. The casing should be set on bottom and picked back up to the casing seat sometime during or prior to the conditioning of the hole after pipe is run. Steel-line measurements should be run inside the casing string and checked against the pipe tally, casing tally, electric log, and other measurements.

Conditioning after casing is run.—After the casing is run into the hole, the hole should be further conditioned for cementing. Circulation through the casing with frequent movement of the casing and rotation where possible greatly aid in cleaning up. Returns should be carefully noted as to whether they indicate a clean hole. It has been found that where there are caving shales or mud occlusions, circulation of 5 to 10-minute "slugs" of clear water back of the pipe will tend to remove these undesirable conditions.

Cementing. — When the hole is conditioned after pipe is run in, the well is ready to cement. Several operators with very few cementing failures attribute their success to rotation or moving of the pipe during cementing. Careful measurements on top of plug are usually made. It is nearly always desirable to leave some cement in the pipe. In many wells the plug may coast a few feet after pump pressure is cut off so allowance should be made for this. Also in cases of faulty float equipment the leaving of some cement has saved recementing in several wells.

Observations during "waiting-on-cement" period.—During the waiting period while the cement is setting, it is usually desirable to run a temperature survey to check the cement job, particularly when it was desired to cement through pays some distance above the bottom of the pipe. Another check on the cement job is to run a steel line on top of the plug before drilling in so as to determine whether there has been any leakage or coasting of the plug. Such measurements are often a help in reconstructing the conditions in wells that are thought to need workover jobs.

DRILLING IN

DRILLING in may be accomplished with either cable tools or rotary. The greater part of this work in the Illinois basin has been done with cable tools, although rotary completions have been used with about the same degree of success by many operators. In most wells rotary pump pressure and heavy viscous muds have already been on the formation under pressure during coring, reaming, hole conditioning for and during pipe setting, and frequently also the cement slurry has been on the formation. Therefore drilling in with a rotary would seem to make little difference on a theoretical basis. A string of tubing is commonly used instead of drill pipe for drilling in. In practice it has been found that with good wells, results are about the same in drilling in with a rotary as with cable tools but the former is more rapid. In poorer wells it sometimes seems better to drill in with cable tools because of the pressure situation, but in most cases rotary tools will do as well.

Rotary drilling in. — Experience has shown that many of the difficulties attributed to drilling in with rotary tools are apparently not related to the system but to the choice of drilling-in fluid. When formations that were drilled with rotary mud are circulated with live oil for drilling-in fluid, a mud-oil gel may form that is probably forced back into the formation by pump pressure after the mud seal is broken. Drilling of the plug with rotary mud, on the other hand, should make little difference if the formation was properly mudded prior to setting pipe. The advisability of using clear water on Illinois basin formations is debatable. Some formations in some fields appear to react better to clear-water rotary drilling in than to any other method; they clean up in better shape and in less time. In other zones, particularly the limestones, clear-water drilling in and washing apparently forces considerable of the circulating fluid back into the formation and is generally unsatisfactory. The choice of rotary drilling-in fluid is thus a controlling factor in satisfactory results and the fluids used must be varied with the zone and field.

Cable-tool drilling in.—As stated cable-tool drilling in is the most common practice. This method is generally satisfactory in all of the pay zones in the basin. There are two drawbacks to this type of tailing in: (1) If it is desired to deepen below the existing bottom of the hole, the samples are less satisfactory for the determination of saturation and porosity conditions than rotary coring; (2) some cases of failure of cement thought to be due to jar of tools in drilling out the cement left in the pipe and drilling up the shoe are known. The first of these can be easily eliminated by the use of the cable-tool core barrel, cutting of short cores for analysis, and providing periods of testing during deepening. The second can be alleviated to some extent by leaving no more cement in the pipe than essential for safety, by spot-welding the lower joints of the casing string, and by using proper cementing techniques and equipment so that the cement sheath will be evenly distributed around centralized pipe.

Basis for tailing-in measurements.—Prior to tailing in it has been found a good practice to carefully determine for the tailing-in rig the zero point from which all the rotary measurements were taken. The writer has customarily done this by shooting with a hand level a temporary bench mark on a nearby tree or stake during drilling and also by recording footage of zero in relation to surface casinghead or bradenhead and then establishing the measurements for the drilling-in rig when moved in. When the shoe is drilled a further check with a steel line should be made to make certain that the pipe has been set as supposed. This can be done in rotary drilling in at any time but the exact position of the shoe can be determined by noting returns and drilling time during tailing in and measuring up inside the tailing-in string. Topping the shoe can usually be noted in the cable-tool rate of drilling as well, and fragments of the shoe are usually obvious in the cuttings. Several cases are known where the pipe-supporting device or tension-holding ring on the bradenhead has failed while cement was setting and prior to cutting off the pipe nipple above the head so that the pipe had slipped to a position across part or all of the pay section. The danger in not recognizing such a situation is obvious if accurate measurements are not taken; it can be easily corrected by pipe ripping or gun perforating where it has occurred.

Cleaning out to bottom.—After the plug is drilled, tools should be run to bottom with either rotary or cable tools. Careful check on the measurement should be kept so that no new formation is drilled unless desired but so the hole can be cleaned out to bottom. With rotary tools. washing down to bottom should take place immediately after drilling the shoe. It is preferable to attempt to wash in a well with a good gas drive by reversing circulation so that as soon as the hole is cleaned up circulation should be reversed. Experience has shown that wells which do not readily show a tendency to come in through the drill-pipe or tubing drill-in string should not be circulated unnecessarily but should be put on the swab at once. In cable-tool work, after the plug is drilled, cleaning out to bottom should be carefully done with a sand pump and tools.

Gun-perforating completions.—Another type of tailing-in and completion procedure which is common practice is the setting of pipe through the pay zone and gun perforating for completion. In the Illinois basin, considerable differences of opinion exist as to the merits of open-hole and gun-perforation completions. Since many of the sands do not readily produce oil without shooting, gun perforating is not possible in these cases. In a number of zones, such as those where it is necessary to squeeze the basal portion of an oil and water-bearing section, gun perforation is the only practical method of completion. In some of the Wabash Valley fields in certain sands, particularly the Waltersburg and Cypress where the reservoir energy is high, open-hole and gun-perforation completions apparently have equal merit where the sands are of such quality as to justify production natural (without shooting). In McClosky and Devonian zones with high reservoir energy it is the writer's opinion that gun-perforation completions are more successful because they permit the ready production of a number of thin zones and because, as is pointed out below, acidizing is more efficient in following channels set up by gun perforating directly into the pay. In multiple-zone wells gun perforation is apparently as efficient as any other method of completion except where shooting is necessary and sufficient thickness of sand permits the setting of alloy windows, their removal and the setting of a shot. Some producers contend that as high or higher ultimate recoveries and more efficient production are obtained even in zones normally shot with glycerine by production through gun perforations.

Completion by ripping or slotting.—There are methods of ripping and slotting the oil-string pipe which are suitable for the same methods of completion as gun perforating. Some of these are not as efficient as gun perforating because they do not penetrate the pipe, the cement sheath, the mud cake, and into the formation, while others apparently serve as well. These are not widely used in the Illinois basin.

Completion with alloy pipe.—Another type of completion commonly used, more normally in multiple-zone wells but also in single-zone sand wells, is the setting of alloy pipe across the pay and obtaining production by its removal after cement has set. The alloy is removed in several different ways. If a rotary completion is used, the well is normally brought in by removal of alloy with a rotary scraping or milling tool which reams alloy, cement, mud sheath and formation face to large diameter; after washing, circulation is normally reversed and the well washed in or the well is swabbed in if it will not flow. Where cable tools are used a standard ripper or reamer or variations thereof are commonly used to remove the alloy. In some wells the alloys may be largely removed or destroyed by use of special gun-perforating bullets or by use of bullets to partly open pipe followed by shooting so that shot caving and alloys are cleaned out together after shooting. In some wells alloys which can be removed by acid or shooting have been used with considerable success. In general such alloys, removable by acid or shooting, are not stable and are unsuited for leaving in the presence of salt water or on zones which it is not desired to produce immediately. Other alloys of a more stable character are available, and are commonly used to case off zones intended for production at a much later date. The use of alloys in the oil string necessitates more than normal care in handling and setting of pipe. Several cases are known where alloys may have failed under intensive casing swabbing, particularly in unloading pump-down fluid from the hole after cementing.

Many operators treat their regular seamless casing much as alloy pipe is used, ripping, setting shots, and cleaning out in sand zones. Of course, the seamless pipe is more difficult to clean out and less convenient than alloy pipe.

Swabbing.—Any well in the Illinois basin, with only a few possible exceptions where extreme caution is dictated by proximity to water-bearing strata, should be swabbed extensively before being put on production. In general, casing swabbing is much more satisfactory than tubing swabbing. As a normal rule, after the well is cleaned out to bottom, the casing swab and sand pump should be rigged up. The well should be alternately swabbed and sand pumped for several days so that all drilling mud materials are removed from the formation and as many flow channels as possible are opened up while the initial flush and gas energy are available to aid.

Accurate swabbing records should be kept because they guide decisions in later completion (Fig. 7). Where possible it is advisable to swab into the tanks. Where tanks are not yet built, pits should have been emptied by the mud pump after setting pipe. By swabbing into pits which have been measured and in which a marked stake is set to indicate depth of fluid, a fair estimate of swab recovery may be made, although differentiation of mud, oil, and water is not possible unless a tank thief is used. A record indicating time into hole, top of fluid, feet of fluid pulled, time out of hole, for each trip of the swab gives an accurate record of the fill up and yield of well during swabbing. Several days of swabbing on any well which does not have a strong gas drive will usually show benefit because fluid levels and rates of production normally show some increase as the well is cleaned up; however, in high gas-drive wells the decline in flush gas and reservoir energy frequently offsets this effect. As swabbing progresses in low-fluid-level wells, it may be advisable to shut down swabbing operations for short periods in order to allow periods of fill-up so as to give a more accurate gage. In other wells an effort should be made to have

SWAB RECORD

Date: **Oct. 12, 1940**

Operator: **Jones** Farm: **H. Fox** Well No.: **3**
Location: **SE SE SE** Sec. **3,** T. **15s,** R. **11e,** **Wayne** County, **Illinois**
Contractor: **Smith** Driller: **Doe** Tool Dresser: **Brown**
Formation: **McClosky** T.D.: **3,492** Casing Diameter: **7 in.**

Time into hole	Top of fluid	Ft. fluid pulled on trip	Time out of hole	Approx. per cent Oil	Approx. per cent Water	Remarks
10:16 a.m.	**2,650**	**400**	**10:37 a.m.**	**95**	**5**	**850 ft. fillup since plug drilled at 8:50 a.m.**
10:40 a.m.	**2,790**	**350**	**11:03 a.m.**	**98**	**2**	**About 1 bbl. b.s.**
11:04 a.m.	**2,810**	**400**	**11:21 a.m.**	**98**	**2**	**Net gage oil swabbed to tanks 1st hour 41.66 bbl.**
11:27 a.m.	**2,800**	**400**	**11:48 a.m.**	**99**	**1**	**2 bbl. b.s. to pits**

Shut down to fix valve on swab for hour and half. Well flowed two heads and gassed a lot.

Time into hole	Top of fluid	Ft. fluid pulled on trip	Time out of hole	Approx. per cent Oil	Approx. per cent Water	Remarks
1:20 p.m.	**2,430**	**400**	**1:45 p.m.**	**98**	**2**	
1:50 p.m.	**2,500**	**400**	**2:03 p.m.**	**98**	**2**	**Flowed small head after swab up.**

Fig. 7: Swab record form, partially filled out from records of one well in Illinois basin

swabbing continuous. All of these matters should appear on a carefully kept swab record; it is not usual practice to keep such a record but it has been found to be extremely helpful. The decision to shoot, acidize, use chemical treatments, etc., to increase production should be based on an analysis of the performance of a well natural on a swabbing test, and on the performance of wells in the same reservoir or in fields with similar situations as to porosity, permeability, oil and water conditions, gas or water drive, and other factors that govern well behavior under both natural and shot, acidized, chemically treated, etc., conditions.

Shooting

If it is desirable to shoot a sand, it is probably better to do so early in the life of the well while the flush energy can aid in establishing formation flow channels. In some wells it has been found that the tamping and cleaning out are as important as the actual shooting.

Normal shooting procedure.—In the Illinois basin the shot is usually set in a cylindrical cartridge with time bomb and covered with tamped sand, screened pea-gravel, or patented quick-set cement. After the shot goes off, the well is cleaned out to bottom, usually with tools and sand pump. Most wells are then swabbed and sand pumped till caving stops and are then put on production. Generally shots are of uniform intensity but some operators do selective shooting, use core-analyses or electric-log permeabilities to place heavier loads opposite less permeable zones.

Tamping material.—The choice of tamping material is varied with the conditions and the customs of the various operators. In some holes the patented cements have not set, while in others they have given the most satisfactory results in protecting pipe. They are also most readily cleaned out. Either sand or pea gravel should be washed into the hole with water until the shot is well covered. Washing should then be alternated with tamping. Care should be taken that the sand or gravel does not bridge up the hole above the shot. With either sand or gravel, a sufficient period of time after the shot has gone off should be allowed for settling before cleaning out is started.

Factors controlling effectiveness of shooting.—The size of shots must be based on experience. In spite of common opinion few cases of actual "burning" or fusing of the sand face by heavy shooting are known. Shooting does not always improve wells, however, due to the following conditions:

1. Lack of proper cleaning out prior to shooting so that rotary mud, suspended materials, etc., were driven back into the formation by the shot.

2. Shooting with too large a shot so that the formation was pulverized, the small particles making an effective seal of the producing face.

3. Lack of proper cleaning out after shooting, including lack of sufficient swabbing and sand pumping to withdraw all fine particles in suspension in the oil or water into the bottom of the hole where it can be removed.

4. Lack of sufficient swabbing after shooting to start fluid which was driven away from the hole back into the hole or to assist development of flow channels. It seems apparent from study of behavior in adjacent wells that when a shot is set off and relief is prevented upward in the hole by an effective seal of sand or gravel and fluid or cement that the gases and force of the concussion cause a surge of the fluids in the reservoir away from the hole. This is often noted in closely spaced offset wells. Then after a cleaning out, the fluids cannot be or are not drawn back toward the hole.

The first three of the above conditions may be eliminated by the obvious methods of sufficient cleaning out or adjusting the size of the shot.

Uncovered shooting.—A modification of the normal shooting technique has been found helpful in eliminating the last condition above.

This is the use of smaller shots and shooting in open hole without cover other than a hole full of fluid so that after a short settling time, swabbing and cleaning out may be started immediately. Where a surge of fluid away from the hole may be set up in the reservoir, it is established that there is probably a reversal of this surge at some time shortly after. When it is possible to take advantage of such a returning surge with the casing swab, the well gives higher recoveries. Thus it is often possible to use a 5 to 10-qt. open-hole shot with as good or better results than a 50 or 60-qt. tamped shot; the cost is also lower because it takes less rig time. A few comparative results have shown this method of shooting to be more efficient in low fluid level and smaller wells, but too few operators have used this technique to permit a conclusive comparison.

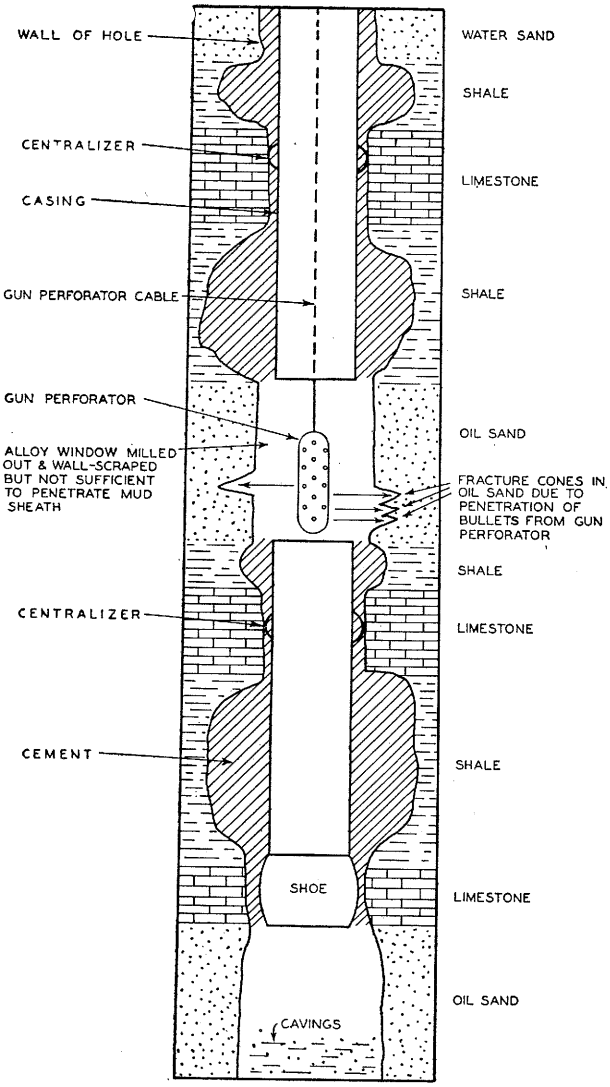

Fig. 8: Diagram showing operation of gun perforator in open hole. This well is to be a dual completion. Shooting the upper sand might damage pipe, so after wall scraping the alloy and wall, a gun perforator is used to develop the upper sand. The lower sand is shot in the regular way

Dump shots.— Dump shots are used in some zones and in some fields. The shots are usually of such size as to fill a cavity made by a previous shot. They are commonly covered with several yards of sand or gravel or with the special cement. Shots up to 700 qt. have been used successfully with this method In the Aux Vases sand in several fields where pipe has been set in local calcareous tight spots in the reservoir, noncommercial wells have been converted into good producers by use of large-size dump shots. In other wells greatly increased yields have been obtained by large-size dump shots. In others, no noticeable effect was obtained by large-size shots. There is a serious need in the Illinois basin for a careful study of the results of shooting with regard to costs, results in yields, and determination of proper technique for the varying reservoir conditions

Open formation shooting with gun perforator.—A practice which has been successful in some wells and not in others is open-hole gun perforating of the producing formation instead of shooting (Fig. 8). It has been substituted for shooting in a few wells where pipe might be damaged by glycerine shots, and it has been used when cleaning out a few wells after they were on production. Increases resulted but how much was due to cleaning out and how much to formation shooting with the gun perforator is problematical. However, higher fluid levels and considerable caving with each shot were noted. In a very few wells the gun perforator has been used to shoot a pay in open hole instead of glycerine shooting. An increase over the natural swab yields was noted in each case. Considering the results obtained in these few wells and the results obtained from producing wells through perforated casing in which the only openings for production in casing, cement sheath, and formation are those from gun-perforated bullets, this method should be given serious consideration as a completion technique and aid.

Acidizing

The calcareous and dolomite pay zones in the Illinois basin are usually acidized either during completion or after they have been on production a while. In most wells, acidization is highly successful. In some zones, in some wells, acidization has not been successful, or has even been detrimental to the wells; improper techniques or improper acid compounds might have been responsible. There are two usual techniques for acidizing, one through the tubing, with or without a packer on tubing, and the other, through the casing.

Acidized through tubing.—When a well is acidized through the tubing the open end of the tubing or a perforated nipple is spotted at the pay zone. The hole is filled with oil or water and the casing head is shut. The acid is pumped down the tubing and into whatever place of easiest relief there may be if pressure builds up, or into the zone of easiest reaction if no pressure is built up. The volume of acid is displaced from the tubing with an oil or water flush. After displacement of the acid, sometimes a short waiting period is observed or tubing swabbing is started immediately. After swabbing for sufficient time to recover most of the acid water, to start the well to flow, or to clean up the oil, the well is usually put on production. Most of the limestone wells in the Illinois basin are completed in this manner.

Acidizing through tubing with packer. — Another common procedure is to acidize through the tubing but with an anchor, ring-wall, or other packer set on the tubing just above the pay zone, or if it is a perforated zone in a multiple pay well, above and below the treated pay zone. This method has two advantages over the preceding in that there is somewhat better control of the direction of the acid, thereby giving a more efficient reaction in many wells, and because of the smaller volume drawn against it, makes tubing swabbing much more effective in creating suction on the formation.

Acidizing through casing. — The third normal acidizing procedure is to acidize through the casing. A short tubing nipple is run through the casing head. The acid, followed immediately by the flush to displace it from the casing, is pumped down the casing. After the acid has reached the formation and has been completely displaced from the pipe, the casing is swabbed until the acid water is recovered and the well is ready for production. This method has the obvious advantage of permitting casing swabbing instead of tubing swabbing with or without a packer.

Special conditions governing acidizing techniques.—Special modifications of these techniques are suitable for different limestone zones in different fields. For example, many of the producing zones have an insoluble residue content of clay and silt of considerable amount. When the limestone is dissolved, clays and silts and partly dissolved calcite or dolomite crystals are in suspension in the spent acid. If they remain static, a gel may form which has a sealing effect. This is particularly true where the paraffin content of the oil is rather high. In such circumstances it is desirable to remove all acid water from the hole and to start oil moving into the new flow channels as readily as possible after the acid is spent. This can be done efficiently only with a casing swab. In such conditions, the writer has had best results by beginning continuous casing swabbing within 2 hours after the acid reaches formation. The displacement of the oil in the formation apparently causes the movement of some fluid in the reservoir away from the hole. A natural surge back toward the hole from this displacement probably takes place, and if with this surge, active casing swabbing is in progress and the spent acid water is removed from the formation, a more efficient acidizing job will result.

Acidizing in perforated zones.—Where pay zones are thin, it has been found that completion by perforations is the most efficient way of controlling the acidizing. Acid has more tendency to react with the unsaturated zones than with saturated zones. Where there are thick inter-pay limestones with thin or separated pay zones in open hole the acidizing by any of the three normal techniques usually dissolves the inter-pay strata with little of the acid actually entering the pay zones. Where casing is set through such a section and each thin zone is perforated, the perforations form guide channels along which the acid enters the formation and a much more efficient acidizing job results. Statistical studies generally indicate that completion of McClosky limestone wells in the Illinois basin by perforating and acidizing may be expected to give the highest ultimate recoveries. Of course, there are exceptions to this generalization because of the many variables that must be considered.

Acidizing jet gun.—Another method for treating thin pays or treating in open hole where deepening has taken place is the use of the acid jet gun. In wells where there are thin pay zones, the position of which is exactly known and which are separated by larger thicknesses of unsaturated limestone or dolomite, where desired to produce in open hole, the jet gun directing acid into the producing zone has been found very effective. The jet gun is also used in such wells with a packer run on the tubing string above or below or both to separate the zone being treated from zones above or below. This practice is usual in wells where a sand and a lime pay are to be produced together and excellent results are frequently obtained. The widest use of the acid jet gun has been in treating zones opened by deeper drilling of existing wells. In the earlier development in the Illinois basin, few wells were carried much below the first limestone producing horizon. Many McClosky wells have since been deepened to lower McClosky, St. Louis, and Salem zones with cable tools, as commonly there are no water-producing zones between these pays. Wells with several limestone producing horizons and several hundred feet of open hole are not uncommon. These lower pays are usually treated with the jet gun

Some special acidizing techniques.—There are a number of other variations that may be used to fit particular conditions governing acid treatment. In some wells, partial treatments may be desirable, and commercial gels can be used to protect the portion of the formation not needing treatment. In others acid-soluble cement has been used in squeeze jobs with jet-gun treatment to remove the cement on the desired portions of the formation and to treat at the same time. Special acid treatments for sand formations or calcareous sandstones are desirable in some wells.

Factors controlling acidization.—As stated, most of the acid treatments in the Illinois basin are successful but many variables must be considered. An analysis of a core from the pay zone plus some knowledge of the character of the oil is helpful in deciding on the best acidizing technique. The physical properties of the reservoir, the permeability of the zone as determined from the electric log and core analysis, plus the carbonate and oil character of the pay all should be considered in deciding on the type of acid, its surface tension, and the inhibitor best suited for the particular acidization. As many of these things as possible should be known before setting pipe so that the type of completion may be determined at that time. It is thus evident that core-analysis, electric-logging, samples of oil from drill-stem testing, etc., all have important bearing on the completion of a limestone producer. The principle that has been least followed is that spent-acid water standing on a producing formation or occupying the pore spaces in it can do little good and its quick removal is desirable.

Multiple-Zone Completions

With the war the emphasis has been placed on higher recoveries and higher yields in relation to the amount of steel used. This is bringing about a greater number of deeper exploratory tests in the Illinois basin, wildcats designed to find all of the producing zones in an area and intended to be completed in more than one zone or designed to be used for the production of one pay after another is exhausted. Either method of production is consistent with the war effort. If sufficient work is done with the drill-stem tester, core analysis, electric log, etc., during drilling to prove the potentialities of all zones, it is more desirable to produce from a single zone at a time. This method proves the reserves for later needs and avoids the complexities of multizone completion and production.

Methods of multizone completions.—Nearly all of the methods of completing multiple-zone wells have been mentioned elsewhere in this paper. They include:

1. Use of alloy pipe opposite pay zones in the casing string and removal of that pipe for production by ripping, gun perforating, shooting, acidizing, milling, or combinations thereof.
2. Setting of seamless pipe and ripping with or without shooting, slotting, gun perforating, or milling this pipe.
3. Combinations of either of the above with setting pipe on top of the lowest pay so that it is produced in open hole.
4. A newer method, not previously discussed is setting the pipe sectionally and cementing with special tools so that open hole is left opposite the pay zones.

Any of these methods are satisfactory for use with certain pays but some of them are restricted in their usage depending on conditions in various pay zones and fields. The choice of method for setting pipe is governed by the production characteristics of the zones involved and by the necessity for shooting, acidizing, etc., that may be determined.

Some factors of importance in multizone completions.—Certain cautions are more necessary in multizone completions than elsewhere. Cement jobs are of great importance and the knowledge that cement has reached the desired point behind the pipe is imperative. This necessitates the careful control of drilling mud, caliper and temperature surveys to guide and check cementing, and accurately kept records and measurements during drilling and pipe setting. It is highly desirable to test the pays in multizone wells separately and this necessitates the use of tubing and packer, bridging plugs, or retainers to separate the pays while testing or treating is in progress. Accurate swabbing tests of each pay and the keeping of accurate swabbing records are desirable as a guide in the production characteristics of the multizone well. Some concessions in efficiency to separate zone or open-hole single-zone production are sometimes necessary, as for instance in wells where shooting is impossible although desirable. In such wells, special substitutes such as open-formation gun perforation are desirable. Careful observation of multizone wells on production is necessary to guide completions and to determine which horizons may be successfully produced together and which may not in any one field. Frequent observations of fluid levels during production are a great aid in determining the handling of a well and in modifying completion practices on future wells.

Producing aspects of multizone wells.—The producing aspects of wells producing from more than one horizon are many. "Thieving," the stealing of oil produced by one horizon by another, is common. Studies should be made of the movement of fluid in wells. These can be made with a modified current meter commonly used in stream gaging, and production methods should be changed to fit the circumstances. It should be determined in each well which pay produces best when above or below fluid level and where production packers may be used. The position of tubing perforations with respect to fluid levels and pay zones, the capacity of tubing and pump, back pressure on separator, and other factors controlling production must be changed during production because there is a decline in energy of gas or water drives. Careful observations of these matters, the fluid levels, production rate, and their interpretation in terms of the characteristics of the producing horizon and completion history are essential to the most efficient results from multizone completions.

Completion Failure and Workover Jobs

It is common that there are failures in completions or that wells are worked over to increase or modify production conditions. It is not intended to go into these matters in detail but a few of the factors governing these matters are pointed out.

Squeeze jobs.—Frequently it is desired to squeeze cement a well, either to shut off water coming from back of the pipe, or shut off a portion or all of a porous zone. As a general rule, cement will not set on the saturated portion of a producing horizon, but in the lower pressure formations of the Illinois basin, especially where water has been standing on the face of a pay zone, cement under pressure will set up. Where it is desired to produce a zone after the casing seat has been squeezed, it is better to plug the pay off effectively or to use acid-soluble cement for squeezing so that the pay may be readily uncovered. The most efficient plug-back found by this writer was to use sand to cover the formation and dump a sack or two of commercial or gypsum cement on top of the sand plug and allow it to set before squeezing (Fig. 9), or to use easily drilled gypsum cement for the entire plug. With the latter method care should be

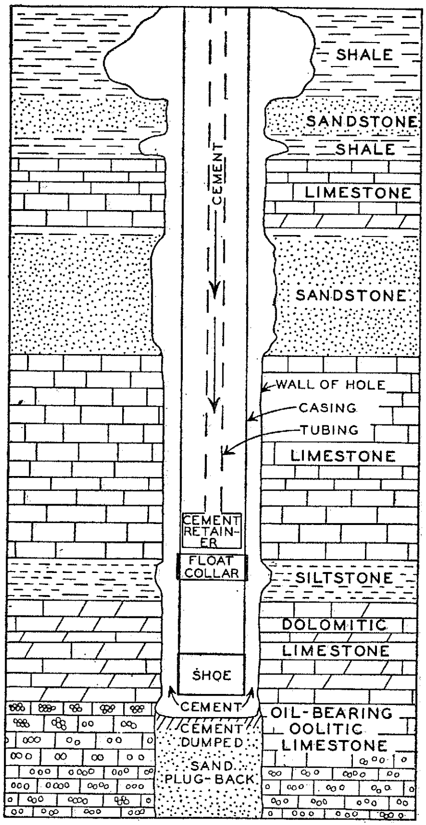

Fig. 9: Diagram showing method of using sand to plug back opposite the pay zone for squeeze job to shut off water coming from behind casing

taken that hole conditions are proper to allow this cement to set firmly.

Reshooting.—Frequently it is desired to reshoot a well on production in hopes of increasing the production rate. In some wells this is successful and in some the apparent yield increases are possible due to the cleaning out usually associated with reshooting. Careful observation of working over is essential to justify the expense of reshooting. As pointed out, some operators let their shooting go until a well has been on production for some time. This may be desirable in discovery or early wells in a new pool so as to furnish a basis for determining the aid received by shooting; however, more efficient results from shooting are usually obtained by shooting early in its history while reservoir energy is at its maximum. Reshooting can be of aid in cleaning out the well and cleaning up the face of the sand while being reworked. In some cases chemical treatments designed to do this may prove more effective.

Reacidizing.—It is frequently desired by many operators to acidize a well after it has been on production for some time or to reacidize or stage-treat a well. As in the case of shooting, acidization is more desirable early in a well's history when reservoir energy is at its maximum. Care should be taken that when a well is reacidized the volume of acid in the new treatment is followed not only by sufficient flush to displace it from the tubing or casing but also a volume of flush equal to the previous treatments so that it will reach untreated zones. Quick removal of spent acid water is even more desirable on wells in which the reservoir energy is reduced than on new wells as there is less drive to expel the fluids and more possibility of acid-paraffin gels or emulsions sealing the formations.

Factors meriting consideration before working over.—Most operators are familiar with wells where because of poor completion techniques, lack of sufficient information to justify setting pipe, lack of commercial pay, or because of poorly understood or accidental conditions large sums have been expended in attempting completions, reworking, squeezing, etc., where on more mature consideration the wells would have been better abandoned without such attempted completions or recompletions. When a water well is encountered, the conditions surrounding it should be carefully analyzed. A recheck of measurements, evidence justifying setting of pipe, records of the well's performance and behavior to that point, its geological position with respect to structure, etc., should be undertaken immediately. Analyses of the water should be made to determine whether its source may be recognized by its chemical character. Swabbing tests to determine whether water may not be exhausted as is common in some zones in some fields should be run. Electric-eye turbidity surveys or other studies can be run to determine, if possible, where water is entering hole. The possibilities of drilling deeper to find another pay zone should be evaluated. When these considerations are made, the advisability of reworking, squeezing, abandoning, or drilling deeper can be determined. The need of adequate records for such wells is obvious.

Conclusions

The factors governing well completion in the Illinois basin are variable with the field and producing zone or zones. A number of special techniques have been developed so that any particular conditions may be met. A number of tools and instruments are available for the determination of the conditions and for guidance or use in well completion.

Proper care in drilling, setting pipe, tailing in, acidizing, and shooting will normally result in successful completions. The making of adequate observations of a geological and engineering nature during drilling and completion and the keeping of adequate records and measurements on wells are as essential to their successful drilling and completion as to their production. Such records will form a sound basis for future secondary-recovery operations. Most of the observations and practices that are of aid to the geologist or should be followed by him are also of benefit to the engineer and the production man. There are a number of things that must be done by the geologist in order to assure adequate records, complete information, and satisfactory well conditions for completion just as there is considerable information concerning completion and production behavior of producing zones that should be available to and be understood by the geologist in order to make his recommendations valid.

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