BEFORE THE INDUSTRIAL COMMISSION

OF THE STATE OF NORTH DAKOTA

IN THE MATTER OF A HEARING CALLED ON A MOTION OF THE COMMISSION TO CONSIDER HAVING THE OPERATORS IN THE FOLLOWING FIELDS SHOW CAUSE THAT FIELD RULES SHOULD NOT BE AMENDED TO PROVIDE FOR SURFACE CASING BEING SET NOT LESS THAN FIFTY (50) FEET BELOW THE BASE OF THE FOXHILLS FORMATION AND CEMENTED TO THE SURFACE: ELKHORN RANCH, FRANKS CREEK, FRYBURG, LITTLE KNIFE, MEDORA, AND ROCKY RIDGE, ALL IN BILLINGS COUNTY, NORTH DAKOTA; AMOR, ASH, CEDAR CREEK, COLD TURKEY CREEK, COYOTE CREEK, GRAND RIVER, HALEY, HORSE CREEK, LITTLE MISSOURI, MEDICINE POLE HILLS, AND STATE LINE, ALL IN BOWMAN COUNTY, NORTH DAKOTA; HALLIDAY, HAYSTACK BUTTE, KILLDEER, LITTLE KNIFE, LOST BRIDGE, OAKDALE, RATTLESNAKE POINT, RUSSIAN CREEK, ALL IN DUNN COUNTY, NORTH DAKOTA; RIDER AND SQUARE BUTTE IN GOLDEN VALLEY COUNTY, NORTH DAKOTA; ANTELOPE, BEAR DEN, BICENTENNIAL, BLUE BUTTE, BOXCAR BUTTE, CAMEL BUTTE, CHARLSON, CLEAR CREEK, CROFF, DIMMICK LAKE, EARL, HAWKEYE, KEENE, LITTLE KNIFE, MONDAK, NORTH FORK, PERSHING, POKER JIM, RED WING CREEK, ROUGH RIDER, UNION CENTER, AND YELLOWSTONE, ALL IN MCKENZIE COUNTY, NORTH DAKOTA; AMIDON, ELEVEN BAR, AND ROCKY RIDGE ALL IN SLOPE COUNTY, NORTH DAKOTA; BUFFALO CREEK, DICKINSON, GREEN RIVER, ROCKY RIDGE, SOUTH HEART AND ZENITH, ALL IN STARK COUNTY, NORTH DAKOTA.

CASE NO. 1563
ORDER NO. 1712

ORDER OF THE COMMISSION

BY THE COMMISSION:

Pursuant to legal notice this cause came on for hearing at 9:00 a.m. on the 20th day of June, 1978, in Bismarck, North Dakota, before the Industrial Commission of North Dakota, hereinafter referred to as the "Commission."

NOW, on this 25th day of July, 1978, the Commission, a quorum being present, having considered the testimony adduced and the exhibits received at said hearing, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That in southwestern North Dakota, the Foxhills Formation contains water of sufficient purity for domestic and livestock use.

(3) That oil and gas drilling operations might contaminate waters in the Foxhills Formation, and procedures should be adopted in the drilling of all wells, development and wildcat, to protect said waters.

IT IS THEREFORE ORDERED:

(1) That Commission orders establishing special field rules in the following fields are hereby amended to provide for the setting of surface casing not less than fifty (50) feet below the base of the Foxhills Formation:

Elkhorn Ranch, Franks Creek, Fryburg, Little Knife, Medora and Rocky Ridge, all in Billings County, North Dakota; Amor, Ash, Cedar Creek, Cold Turkey Creek, Coyote Creek, Grand River, Haley, Horse Creek, Little Missouri, Medicine Pole Hills and State Line, all in Bowman County, North Dakota; Halliday, Haystack Butte, Killdeer, Little Knife, Lost Bridge, Oakdale, Rattlesnake Point, Russian Creek, all in Dunn County, North Dakota; Rider and Square Butte in Golden Valley County, North Dakota; Antelope, Bear Den, Bicentennial, Blue Butte, Boxcar Butte, Camel Butte, Charlson, Clear Creek, Croff, Dimmick Lake, Earl, Hawkeye, Keene, Little Knife, MonDak, North Fork, Pershing, Poker Jim, Red Wing Creek, Rough Rider, Union Center and Yellowstone, all in McKenzie County, North Dakota; Amidon, Eleven Bar and Rocky Ridge all in Slope County, North Dakota; Buffalo Creek, Dickinson, Green River, Rocky Ridge, South Heart and Zenith, all in Stark County, North Dakota. The State Geologist is hereby authorized to waive this requirement if deemed necessary.

(2) That all wildcat wells drilled in southwestern North Dakota shall set surface casing not less than fifty (50) feet below the base of the Foxhills Formation.

(3) That this order shall continue in full force and effect until further order of the Commission.

DONE, in Bismarck, North Dakota, this 25th day of July, 1978.

THE NORTH DAKOTA INDUSTRIAL COMMISSION

Arthur A. Link
Arthur A. Link, Governor

Allen I. Olson
Allen I. Olson, Attorney General

Myron Just
Myron Just, Commissioner of Agriculture

Telegram western union

JUN 1978
RECEIVED
N. Dak. Geological Survey

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ICS IPMBNGZ CSP
7139324700 TDBN HOUSTON TX 40 06-19 0414P EST
PMS GOVERNOR ARTHUR LINK, DLR
CHAIRMAN, NORTH DAKOTA STATE INDUSTRIAL COMMISSION STATE CAPITOL
BISMARCK ND 58505
IN REFERENCE TO CASE NUMBER 1563, SETTING OF SURFACE CASING THROUGH THE FOXHILLS FORMATION. BELCO PETROLEUM CORPORATION FAVORS SUCH ACTION BUT FEELS THAT FOR OPERATIONS IN REMOTE AREAS COMMISSION SHOULD RESERVE THE RIGHT TO GRANT EXCEPTIONS. VERY TRULY YOURS
GEORGE E NUGENT, VICE PRESIDENT
DRILLING AND PRODUCTIONS
NNNN

Amoco Production Company

CASE #1563

June 1, 1978

JUN 1978
RECEIVED
N. Dak. Geological Survey

Jack G. Swenson
Executive Vice President &
General Manager
Rocky Mountain Oil &
Gas Association
345 Petroleum Club Bldg.
Denver, Colorado 80202

Dear Mr. Swenson:

RMOGA Study of Surface Pipe Requirements
To Protect Fox Hills Aquifer in
Western North Dakota

You received my May 3, 1978 letter polling an Ad Hoc Committee on the captioned question.

The preponderance of replies calls for the position I recommend RMOGA's Executive Committee approve:

> "Advocate at North Dakota Industrial Commission hearing that in the following nine counties of western North Dakota operators be required by the North Dakota Geological Survey, as a condition for drilling permit approval, to set surface pipe to a depth 50' below the Fox Hills aquifer and cement pipe to surface:
>
> McKenzie — Dunn
> Golden Valley — Stark
> Billings — Hettinger
> Slope — Bowman."

This position, if approved by the Industrial Commission, would not be a statewide rule change because it only concerns nine counties; instead, it would be a written policy position from the North Dakota Geological Survey to all operators involving just these nine counties.

Mr. Jack G. Swenson
Page 2
June 1, 1978

The municipality of Beach in Golden Valley County is the deepest user of Fox Hills water (2200'). For the most part, the Fox Hills exists at 1200' to 1700' in depth. Operators usually do not mud up until 4000-5000', well below the Fox Hills. It is cheaper and faster to drill with salt water to 4500'.

Four of the nine counties (McKenzie, Golden Valley, Billings, and Slope) have groundwater studies. Even if there are no existing water wells close by, it would be wise for an operator to set through the Fox Hills and protect that aquifer with cement because someone later on may desire to develop the Fox Hills water and an operator would not want the liability of having to clean up contaminated Fox Hills water in that area.

Upon Executive Committee approval, I intend to front RMOGA's position at the Industrial Commission hearing in Bismarck on June 20, 1978. I will need to receive Executive Committee approval by Friday, June 16, before I leave, or on Monday afternoon at the Kirkwood Inn.

Very truly yours,

RB Giles

R. B. Giles
Chairman, RMOGA Regional
Exploration and Production Committee

RBG:bp

cc: George S. Dibble
Darwin Van DeGraaff
Jess Cooper
David O. Cordell
Members of North Dakota Ad Hoc Committee

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CASE #1563

May 3, 1978

Members of a North Dakota
Ad Hoc Committee
(Attached Mailing List)

RMOGA Study of Surface Pipe
Requirements to Protect Fox Hills
Aquifer in Western North Dakota

The North Dakota Geological Survey this date has requested that RMOGA recommend its solution to a problem that has arisen in the western sector of North Dakota.

The Fox Hills formation is an aquifer ranging in depth from 1,200' to 2,500'. On Federal lands or Burlington Northern lands, the mineral rights are severed. The USGS or Burlington Northern owns the minerals. Surface owners usually are ranchers, some of whom drill water wells to the Fox Hills to water their livestock. Also, certain municipalities use the Fox Hills for domestic purposes.

Attorneys representing these surface owners have complained to Governor Arthur Link that operators drilling through the Fox Hills to deeper oil or gas prospects are not setting surface pipe through the Fox Hills and cement protecting that aquifer. Operators generally set only 600' of surface pipe on their hydrocarbon prospects. The complaints have arisen mainly within McKenzie County but the problem exists throughout the southwestern and west-central sector of North Dakota. The North Dakota Geological Survey has been following the practice of only requiring that operators set surface pipe through the Fox Hills and cement to surface where the operator is drilling within a mile of a known Fox Hills water well.

Q: Should operators without exception be required to set surface pipe through the Fox Hills in western North Dakota and cement to surface?

or

Q: Should operators only be required to set through if a certain distance away from known Fox Hills water wells? If so, how far away, i.e., one mile, two miles, or what?

Give reasons for your choice because eventually there will be a public hearing scheduled by the Industrial Commission on this matter. If you believe there is a better alternative, please provide it, also with reasons.

In summary, please discuss this problem within your firm and let me have your written solution by June 1. If the responses are quite diversified, we may decide upon a meeting in Denver to develop a consensus recommendation for RMOGA's Executive Committee to consider and approve in June.

RBGiles

R. B. Giles
Chairman, RMOGA Regional
Exploration and Production
Committee

RBG/slf

Enclosure

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CASE ...

Given: Ø = 40%, thickness = 50 feet.

Area	Volume
1 acre	155,155 barrels
10 acres	1,551,550 barrels
40 acres	6,206,200 barrels
80 acres	12,412,400 barrels
160 acres	24,824,800 barrels
350 acres	54,304,250 barrels

Lost Circulation–A Major Problem in Exploration and Development†

J. M. BUGBEE*

ABSTRACT

It is the thesis of this paper that the major drilling problem of lost circulation can be avoided or minimized by the study of possible losses and the programming of treating procedures in advance of drilling. Not only must there be openings in the formation of sufficient size to accept and store the lost mud, but excessive pressures must act to force it away. The nature of loss zones, their formation-fluid pressures, and the hydrostatic and mechanical pressures that can be imposed are discussed. The hypothesis is presented that many serious losses are to naturally occurring fractures which are normally impermeable, but which open and accept whole mud when a critical hydrostatic pressure is exceeded. The field procedures and materials for combating lost circulation are then critically examined.

It is concluded that when a well is planned, the possibility of lost circulation should be considered and the behavior of similar wells in the vicinity studied so that a program to properly handle lost-circulation occurrences can be prepared. Important considerations are the use of the minimum safe mud weight; the handling of the rig to avoid all pressure surges; the taking of full advantage of waiting periods; the proper choice of treatments; and, finally, the change from one type of treatment to another as indicated by results in the well.

INTRODUCTION

Lost circulation is a problem as old as rotary drilling. In the interior United States and Canada it is the major factor in most high drilling-cost wells. Where the average well may have a mud cost of $4,000, the lost-circulation well will have one of $8,000 to $50,000. To the cost of lost mud materials must be added that of the rig time consumed and the cost of the occasionally accompanying stuck drill pipe, lost hole, blowout, or abandonment. There are also cases of missed production chargeable to lost circulation, from failure to secure production tests and samples; and of decreased productivity from the plugging of productive zones. The problem is presently highlighted by the search for production from fracture reservoirs, i.e., from lost-circulation zones.

Lost circulation as a problem has not received the consideration it merits because its study has fallen between the fields of geological, reservoir, and drilling engineering. The literature, therefore, until very recently[1] has not contained a well-reasoned general discussion of the subject. The past three years have, however, seen what can be called an industry-wide attack develop on the problem.

The purpose of this paper is to review and extend the thinking that is being carried on and to recommend the institution of certain procedures that are helpful with lost-circulation problems.

CAUSES OF LOST CIRCULATION

Lost circulation is defined as the loss of whole mud, in quantity, to exposed formations. This plainly requires the presence of permeable zones with openings of sufficient size to permit the entrance and storage of lost mud. Consideration indicates that another equally important factor is that a certain hydrostatic pressure must be exceeded before the formations will accept the lost mud. Knowledge of the type of loss zone, its formation-fluid pressure, and the hydrostatic and mechanical pressures to be imposed are essential to consideration of the problem.

Seepage losses of mud are not included in the foregoing. In many parts of the interior United States, particularly in West Texas, low-solids muds, even dirty water, having very poor wall-building properties are used to considerable depths. The seepage loss of such muds to permeable beds can amount to several barrels per hour. The addition to the circulating fluid of such materials as flake mica, leather fiber, and cellophane fragments can effectively reduce these losses.

PROCEDURES FOR LOST CIRCULATION

The available procedures for dealing with lost circulation can be summarized as follows:

1. Avoidance or correction by the correction of drilling practices or mud properties. A long list of

* Shell Oil Company, Houston, Texas.

† Presented at the spring meeting of the Southwestern District, Division of Production, Fort Worth, Texas, March 1953.

[1] References are at the end of the paper.

procedures and considerations can be made, but all are directed at lowering the pressures on the formations.

2. Adoption of a drilling method such as drilling blind, with or without a floating mud cap; drilling under pressure with the well flowing; or drilling with air.

3. Correction by use of waiting periods—the pulling of the drill pipe into the casing and allowing the well to stand while the formations, or the formation blocks, adjust themselves to withstand the new pressure conditions.

4. Placement of a soft plug, batches of mud thickened with fiber and flake materials, in the loss zone. There is a decided trend away from circulating these materials and to the practice of spotting them in batches as plugs.

5. Placement of a bridging-particle plug, batches of mud loaded with gravel, expanded perlite, ground plastic, walnut shells, or formation cuttings, in the loss zone. If possible, some squeeze pressure is applied. This can sometimes be accomplished by blind drilling where the cuttings are carried into and bridge in the loss zone.

6. Placement of a plug that hardens or stiffens in the loss zone. Such plugs include gel cement, gypsum cement, oil-base mud, oil-bentonite, and time-setting clay. All may have admixtures of thickeners or bridging particles. If possible, moderate squeeze pressure is applied to the plug.

As a broad statement, it can be said that *watering back to lower the mud weight is the universal treatment for lost circulation.*

DISCUSSION OF CAUSES

This section includes discussions of the formations that can take whole mud, their formation-fluid pressures, and the hydrostatic and mechanical pressures that are or can be imposed on them.

The Formations

The formation types which can take whole mud can be summarized under three headings: *1*, cavernous and open-fissured formations; *2*, coarsely permeable formations; and *3*, faulted, jointed, and fissured formations. Cavernous and vugular beds, reefs, gravels, and other coarsely permeable formations are generally single sedimentary units and the geologic correlations of circulation losses in wells to such zones within a field, or even within a province, should be quite exact. Old, weathered surfaces, such as that of the Devonian in the northern Canadian plains, also provide correlatable loss zones. Faulted and fissured zones are, however, structural in origin and can extend across several stratigraphic units. In those fields where the loss zones in wells have no pattern and are scattered both areally and in section, mud loss to fissures can be assumed.

A range of formation permeabilities exists from those at one extreme, with formation openings large enough to be practically unpluggable, to the other extreme where the formation face can be readily sealed with a cake of mud and fiber and flake lost-circulation material. The nature of a loss zone is rarely known with certainty, but study of lost-circulation occurrences in an area can narrow the range of possibilities.

Coarsely Permeable Formations

The order-of-magnitude permeability of a granular formation of sufficient permeability to accept whole mud can be calculated. An appreciable portion of the solids present in natural muds have diameters of 70 microns or larger. A formation with openings which would permit such muds to pass would probably have pore diameters three times greater than the mud-particle size, or 210 microns. It can be shown that the average pore diameter *d*, in microns, is related to the permeability *k*, in darcys, and porosity *f*, in fractional percent (percent÷100) by the following equation:

$$d = 5.63\left[\frac{l}{l_c}\right]\sqrt{\frac{k}{f}}$$

wherein: l is the distance a fluid moves in traversing a length l_c of the porous medium. The ratio l/l_c is always greater than unity but, in general, approaches one as permeability increases and grain size becomes more uniform. For the present calculation, the value of 1.3 for this ratio can be used. If a 40-percent porosity is assumed for a rock with 210-micron diameter pore openings, the limiting permeability is found to be 325 darcys. Muds generally have an appreciable sand and fine-cuttings content and such particles will bridge on a coarser, more permeable formation than this. It is recalled that extremely few formation-permeability values are as great as 3 darcys.

The circulation of the conventional fiber and flake lost-circulation materials as a treatment very frequently gives disappointing or no results. One answer is that gravels and similar coarsely permeable loss zones are rare in the subsurface and that serious losses are generally to formations with openings of relatively large size.

Faulted, Jointed, and Fissured Formations

There are innumerable wells in which lost circulation is experienced, where no cavernous or coarsely permeable formations are exposed in the open hole and the losses are obviously to fissures. Fissure systems occur in all formations—sands, shales, limes, dolomites—and are not generally confined to single beds but can extend across several. Spinner and other surveys have established, in the Gulf Coast, that losses to fissured shales are as frequent as losses to fissured sands. Fissure systems are structural in origin rather than sedimentary. Fields are known where fissure loss zones are related to axial faulting and flank wells have little trouble; but, in general, correlation with known faulting is not evident.

The writer's consideration of lost circulation and the related phenomena of pressure fracturing, squeeze cementing, and pressure break-through in water flooding has suggested the hypothesis[2,3,4] that the crust of the earth in many fields and prospects is faulted, jointed, and fissured; and that such fissures are impermeable (will not take mud) at certain pressures, but will open and take whole mud, i. e., the formation blocks will shift slightly, when a critical hydrostatic pressure is exceeded. For the present subject, the question can be considered academic whether the fissures occur naturally or are actual ruptures induced by increases in hydrostatic pressure. This, however, can be important and the growing literature on pressure fracturing should be reviewed; see, for example, references 4, 5, and 6.

The question is often asked about losses to non-cavernous formations: "Where does the mud go?" A linear fissure ⅛ in. in width and with a circular area of 1 acre centering about a well has a volume of 81 bbl and the radius is only 118 ft.

Losses to fissures vary greatly in occurrence. Sometimes a half pit (50 to 150 bbl) of mud is lost rather suddenly, but drilling can continue with no further loss. In Gulf Coast wells, using high gel-strength muds, losses of mud to formation have been noted as circulation was started after trips. After two or three circulations which reduced pressure on the formation by breaking the gel of the mud, the lost mud had returned to the system. Such squeeze losses are not uncommon. There are many fields where loss of circulation with a 9.7 lb per gal (72.5 lb per cu ft) mud is complete but where, if a 9.5 lb per gal (71 lb per cu ft) mud is used, a well can be drilled as if the lost-circulation problem did not exist. Some fissure systems can be sealed by one or a series of lost-circulation plugs; others are best handled by a special drilling method.

Shallow Losses

In many fields circulation losses are discussed in two groups, viz., shallow and deeper losses. In most discussions of shallow losses, they are attributed to the "unconsolidated" nature of the near-surface formations. The writer believes that "uncemented" is a better descriptive term because ordinary sands are never unconsolidated, inasmuch as the normal deposition of sand grains results in an assemblage that is practically in its final state with insignificant later compaction effects. Further, unconsolidated is an unsuitable descriptive for clays and shales. It appears, however, that there is a valid point here, viz., that near-surface formations are generally checked and jointed, and lost circulation can be incurred with only slightly excessive pressures. Frequently, when the shallow formations are broken down, i.e., the joints and fissures are opened, the losses are extreme enough so that the largest concentrations of lost-circulation materials will not plug them and recourse is made to such a plug as oil-bentonite. In general, these losses can be avoided by watering the mud to hold low weight, and by the control of drilling practices to prevent balling-up or packing-off of the drill stem so that full pump pressure is not applied to the formations. The shallow formations are drilled in big hole with generally high drilling rates, and the mud velocities in the annulus are low. It is possible to pack off the bit in a soft formation because the circulation does not properly clear the cuttings. In fields where these losses occur, a warning regarding them should be posted on the bulletin board of drilling wells.

An example of this type of loss is recalled in the North Port Neches Field, in the upper Texas Gulf Coast. The contractor's water well went off production, but the drilling crew did not suspend drilling and drilled ahead in uncemented sands. The mud weight built up rapidly, the last measurement was 11.8 lb per gal (88 lb per cu ft), and returns were lost. Something over 24 hours' rig time and about $1,000 worth of purchased clays were required to regain circulation in this unnecessary occurrence.

Formation-fluid Pressures

Reservoir engineers, geologists working with problems of migration and accumulation of oil, and drilling engineers find that charts showing depths from surface to oil-water contact vs. initial reservoir pressure (psig) for various geological provinces or areas are of great interest. See, for example, Fig. 1 of reference 7. Not enough such displays of regional formation-fluid pressure gradients are available. Frequently, such charts show only the subsea depths and pressures; and they are, of course, an abstraction to the drilling engineer who works with the pressure from the surface, both for formation-fluid and hydrostatic pressures.

A normal-pressure reservoir is defined as one with a pressure, measured or calculated at the oil-water or gas-water interface, which is equal to the pressure of a water column to the surface. Most Gulf Coast reservoirs are under a normal salt-water column pressure and have a depth-pressure gradient of 0.465 psi per ft. Many West Texas fields and those in the foothills belt of Canada are also generally normal. It is also known that the Spraberry fields of West Texas, many Mid-Continent fields and those of the Canadian plains have subnormal pressures with gradients ranging from 0.24 to 0.38 psi per ft of depth. On a world-wide basis, abnormally high formation-fluid pressures are very uncommon.

Generally, when the fluid level is not at the surface the drilling crew will record the fluid level whenever drill pipe is pulled by noting the wetting level. This will not always be accurate and can be confusing. Running through the drill pipe of a float or short piece of spinning chain attached to the measuring line will accurately locate a fluid level.

Hydrostatic Pressures

In a very broad way, the commonly used muds have densities ranging between 9.5 and 10.5 lb per gal (71 to 78.5 lb per cu ft) with pressure gradients from 0.494 to 0.546 psi per ft of depth. Clay-water muds are three-part systems having gel and inert fractions and the fluid phase. Generally, the balance between these fractions is most easily maintained in the 9.5 to 10.5 lb per gal weight range. Muds of lesser weight need attention to maintain a fair gel fraction with constant watering, and muds above 10.5 lb per gal need attention because of high solids-to-water ratio.

Because a primary function of drilling muds is to confine formation fluids to their native strata, it is axiomatic that the hydrostatic pressure of the mud must always be greater than the formation-fluid pressure. Additionally, there is the pressure reduction in the withdrawal of drill pipe, or swabbing effect, which must be overbalanced. The necessary overbalance is provided by an increase in mud weight and this can cause loss of circulation. The amount of swabbed pressure reduction is governed chiefly by the gel strength of the mud and clearance between hole and drill pipe. Ordinary tool joints and rubber casing protectors increase swabbing effect by contributing decreased clearances. Little attention is paid to swabbing effect with the low-solids, inherently low gel-strength muds of the interior United States and Canada; but in the high-solids mud territory of the Gulf Coast and California low gel strength is an essential mud property. As to the effect of hole clearance when low gel-strength mud is in use, it is known that 200 to 500 psi overbalance is adequate with 4½-in. drill pipe in 8½-in. hole and that 800 to 1,200 psi is required with 3½-in. drill pipe in 6-in. hole.

In the planning of a well in the Gulf Coast and California, the provision of low gel-strength mud, as large diameter protective casing as possible, external-flush drill pipe for the lower portion of the string, and the omission of rubber casing protectors on the lower part of the drill pipe are important considerations with lost-circulation problems in high-pressure territory.

A normal-pressure sand at 10,000 ft in the Gulf Coast will have a pressure of about 4,650 psi. If a low-gel mud is in use and there are sufficient drilling clearances, e.g., 4½-in. drill pipe in 9⅞-in. hole, an overbalance of 300 to 400 psi is adequate. Thus, a 9.7 lb per gal (72.5 lb per cu ft) mud can be safely used. If there is no lost-circulation problem, however, the mud weight will be allowed to range between 10 and 10.5 lb per gal (75 to 78.5 lb per cu ft). In southern Oklahoma, some reservoirs have pressures with a subnormal gradient of approximately 0.37 psi per ft. Thus, to use approximate round numbers, the reservoir pressure is 3,700 psi at 10,000 ft. The commonly used mud weighs 9.5 lb per gal (71 lb per cu ft); its pressure is 4,940 psi at 10,000 ft; and the ordinary well drills the deeper zones with an overbalance up to 1,240 psi. Because there is frequently a lost-circulation problem, lower mud weights could be used, inasmuch as it is evident that a weight of only 7.9 lb per gal (59 lb per cu ft) would provide a 400-psi overbalance.

In lost-circulation territory the mud weight should, of necessity, be constantly checked and controlled by watering at the lowest value a study of the area has shown to be suitable. When a mud system is loaded with lost-circulation material, drilling proceeds with the shale screen bypassed and rapid weight increases can result from the re-circulation of cuttings, and control of the weight is much more difficult. In many cases holding the weight down is disregarded because of faith in the efficacy of the lost-circulation materials. Occurrences such as the following are not infrequent: A lost-circulation zone is encountered and after considerable mud is lost one of the lost-circulation plugs is displaced into the loss zone. A fresh bit is then run and, using newly made light-weight mud, drilling proceeds with full returns; but after further drilling circulation is again lost. The drillers generally assume that a new loss zone was encountered when actually it was the build-up in mud weight while drilling that broke down the original zone to cause the second loss.

A new tool to combat lost circulation is available, viz., the very low-weight drilling fluids made possible by the development of oil-emulsion muds. A 7.8 lb per gal (58 lb per cu ft) emulsion mud or an 8.2 lb per gal (61 lb per cu ft) saturated salt-emulsion mud can be built. The minimum weight of an oil-base mud is close to 7.5 lb per gal (56 lb per cu ft).

It continues to be said that oil-emulsion muds are expensive; that it is cheaper to use a 9.5 lb per gal (71 lb per cu ft) bentonite and chemical mud and accept the costs of lost circulation than it is to use a 9.0 or 8.5 lb per gal (67.5 or 63.5 lb per cu ft) emulsion mud. There is strong opinion, however, that the emulsion muds will prove to be cheaper because of faster drilling rate and longer bit life. Data are accumulating that the low-solids emulsion muds are even faster drilling fluids than water. Also, inasmuch as they do not take up solids as do clay-water muds, oil-emulsion muds are probably cheaper to maintain than the comparable, but higher weight, clay-water muds.

Mechanically Imposed Pressures

In March 1951, W. C. Goins and associates presented a paper, "Down-the-Hole Pressure Surges and Their Effect on Loss of Circulation"[8] (see also references 9, 10, 11, and 12). The work reported is widely recognized as a notable contribution to the drilling art. By means of pressure recorders mounted in the drill stem, measurement was made of the magnitudes of pressure surges developed while running drill pipe at different rates, from opening the pumps quickly or gradually, and from spudding with the pumps running. It also was evident that running in with a plugged bit or with a float in the drill stem increased the pressure surges and that pumping with a balled-up bit and drill collar threw the full pump pressure on the formation. Consideration also indicates that the clearance between drill pipe and casing or hole is important. Larger clearances minimize both the pressure reductions in withdrawing the drill pipe (swabbing) and the pressure increases (surges) in running and handling the drill pipe. The extent of the measured pressure surges is best realized in terms of increased mud density. Rapid running in of the drill pipe gave surges equivalent to an increase in mud weight of 1.3 lb per gal (10 lb per cu ft). Spudding with the pump running gave surges equivalent to an increase in mud density of 2.3 lb per gal (17 lb per cu ft). When the pump was kicked open to start circulation, surges equivalent to an increase of 0.36 lb per gal (3 lb per cu ft) in mud density were noted, as compared with the pressure when the pump was opened gradually. It is also evident that reduction of pump pressure to decrease the annular velocity will lower the pressure on the formations.

After this study was made, its teachings were applied to a new well in the Texas Gulf Coast. Oil-emulsion mud was used to eliminate balling-up and to secure a low-gel, stable mud. Increased clearances were secured by use of streamlined drill pipe and the elimination of the rubber casing protectors. A no-spudding rule was enforced, as was a requirement for gradual opening of the pump after the kelly was lowered to near bottom. No drill-pipe float was used and the stands were lowered at about 40 sec per stand rather than the common 11 to 15 sec per stand. The well was completed without a single circulation loss, as compared with 79 losses in the three prior wells in the same field.

Many wells can be recalled where circulation has been continuous until a certain round trip when, with the fresh bit on bottom, returns could not be secured. Such losses are probably caused by the effect of the pressure surges while running in or in starting the pumps.

As stated, a difficulty in studying lost circulation is that in many fields there is no pattern to the location of the loss wells; they are simply scattered over the field. Many of these losses can be attributed to mechanically imposed pressures, and educational programs with the drilling crews will correct them. In the past two years, very encouraging understanding and cooperation from company and contract crews have developed along these lines.

Location of Loss Zone

It is evident from the foregoing that it is often of prime importance to locate the loss zone in a well. An upper zone drilled with full circulation can be later broken down or a successfully treated zone can later fail. The location can be made[10] with temperature, spinner, or resistivity-temperature (hot-wire) surveys. These surveys are not entirely satisfactory because mud must be pumped into the loss zone while running them, and their interpretation is frequently inconclusive; nevertheless, their successful application must be considered.

DISCUSSION OF PROCEDURES

When the analysis of the lost-circulation problem at a well location has proceeded through the review of the nature of the zone and the pressure conditions, a procedure or sequence of procedures best suited to the problem should be selected.

Special Drilling Methods

There is no way to successfully plug a highly cavernous or open-fissured zone to permit conventional rotary drilling. Examples of this would be drilling into a cavern such as the Carlsbad in New Mexico or an abandoned coal mine, as has happened in Illinois. The method of blind drilling, where water is pumped down the drill pipe to cool the bit and carry the cuttings into the loss zone and no returns are secured at the surface, has been developed for these conditions. An important variation is the use of a floating mud cap when drilling blind. Generally, each such loss zone is cased off after penetration. A recent paper[13] describes these drilling procedures in Saudi Arabia, and states that their adoption was the chief cause for the reduction in average drilling time from 120 days to 40 days. As much as 20,000 bbl per day of water are pumped down the drill pipe to cool the bit and carry the cuttings into the loss zone. It is noted that the floating mud cap method requires careful balancing of formation-fluid pressures with drilling and hydrostatic pressures.

Recently, blind drilling in several wells in the Denton Field, New Mexico, has successfully penetrated an apparently unpluggable zone occurring below 9,500 ft. In one case, the cuttings rather quickly bridged in the loss zone to give partial returns. After some additional drilling, a gel-cement plug was squeezed into the loss zone, and full returns were then secured during the further drilling to some 12,000 ft.

One objection to blind drilling in prospect wells is the absence of formation samples. This can be partially alleviated by the securing of occasional conventional cores.

A related drilling method is to drill under pressure, pumping water or oil down the drill pipe, and permitting the formation fluids to flow from the annulus.

Floating mud-cap drilling has been used in only one field in the United States, viz., Sunniland, Florida. Seven or eight wells were so drilled and then the use of a low-pressure drilling head with the well flowing was adopted. This latter method has been used where artesian flows have been encountered in shallow beds. The balance between mud densities which cause loss or permit flow can be very close at shallow depths.

Where serious lost circulation occurs in formations located above the water table, air drilling[14] has proved very successful for drilling the surface hole.

Waiting Periods

In many areas merely allowing a well to stand without pumping seems to permit the formations to adjust themselves to new pressure conditions and to allow full returns after the waiting period. One operator, in a Gulf Coast well, made the following tests[12] of this time factor:

Waiting period, hours	0	1	2	4	8
Casing pressure at which formation took mud, psi	350	275	150	150	525

The effect of waiting is probably most notable in the Gulf Coast, but it is also taken advantage of in North Texas and other areas.

The formations frequently strengthen, as regards mud losses, on exposure to mud and the drilling operation. For example, in a well in coastal Louisiana which was drilling with a 15 lb per gal (112.5 lb per cu ft) mud below a protective string, a pressure test was made to see whether a 17 lb per gal (12.5 lb per cu ft) mud could be circulated; the formation took mud at the imposed pressure. Drilling was then continued with the 15 lb per gal mud for some 200 ft, at which time the mud was slowly weighted up to 17 lb per gal. This was accomplished and drilling continued without loss. The practice of "pressure conditioning," i.e., the imposition of pump pressures to determine whether higher weight muds can be circulated, is not generally deemed helpful because it disregards this increase of strength with exposure.

In a recent well in a coastal Louisiana field, there were five losses while drilling with a 17 lb per gal (127.5 lb per cu ft) mud below a protective string. The first three were cured by pulling into the shoe and letting the well stand 8 hours. The fourth loss did not clear up after a waiting period and a "soft plug," a batch of mud equal to twice the volume of the open hole and loaded with about 15 lb per bbl of fiber and flake material, was equalized on bottom. Drill pipe was pulled into the casing, the well allowed to stand 8 hours, and complete circulation was then secured. The lost-circulation material was not screened out but was circulated and a fifth loss occurred, probably the result of excessive pressure caused by the circulation of this material. A waiting period cured this final loss.

The mechanism by which a waiting period or exposure to the drilling operation strengthens loss zones is obscure. Sometimes a balled-up bit and drill collar are pulled and the cause is, therefore, removed. Generally, however, it is believed that the liquid mud entering fissures becomes dehydrated or thickens with time and serves as a gasket to strengthen the zone. This latter explanation also serves as an explanation of the success of "soft plugs," batches of mud loaded with fiber and flake material, when displaced into fissures.

Lost-circulation Plugs

Neat cement has no place as a lost-circulation plug because its density is high, above 16 lb per gal (120 lb per cu ft); it is very fluid and lacks gelling or angle-of-repose properties. A long column of such a fluid in the drill pipe in a well which has lost returns with a light-weight mud, drops with high velocity and is likely to do nothing but make the loss zone more open.

Gel-cement plugs have been used for over 20 years in attempts to plug loss zones. Their main application is where the loss zone is at bottom, as with the Devonian losses in the Canadian plains. There are a number of reasons why gel cement is an unsatisfactory plugging agent. The density is relatively high, about 14 lb per gal (105 lb per cu ft) is the minimum. It contaminates, both in placement and while drilling out, all drilling fluids except the lime muds. In placement there is always the possibility of sticking the drill pipe and the plugs are, therefore, rarely squeezed. In drilling out there is always the possibility of losing the hole by sidetracking the plug. Another unsatisfactory plug is the sodium silicate—clay plug which is expensive and difficult to place and has never been widely used.

The effect of mud contamination from drilling cement should be further considered. When a gel-cement plug has been displaced to a loss zone and a good fill-up secured, the upper part of the plug will be drilled out with full returns. Often, however, as the bit nears bottom returns are lost and it is usually assumed that the zone was not fully sealed. In many instances, however, the second loss should be attributed to the increased pressure resulting from pumping out a long column of thickened, cement-contaminated mud. Oil-bentonite or time-setting clay plugs do not have this disadvantage.

It should not be concluded, however, that a gel-cement squeeze is not sometimes an important lost-circulation corrective. Cannon[15] has described such an application in a 16,255-ft East Texas well having more than 11,000 ft of open hole, a high-pressure sand "kicking" from bottom, and lost returns. Some successes with "burlap" plugs have recently been reported in the Rocky Mountains. Squares of burlap or canvas, one or two feet on a side, are rolled up and lubricated into a gel-cement plug through a lubricator located between the well head and cementing truck. The cloth can be considered to be reinforcing material and to increase the angle-of-repose property.

In the past two years, three new types of plugs have been developed. These have low densities, will not stick drill pipe, and do not contaminate drilling fluids. Oil-base mud of certain types will thicken immensely when contaminated with water or drilling mud. Displacement of about 5 bbl into a loss zone, where it thickens on mixing with mud and formation water, is a useful lost-circulation corrective. Diesel-oil spacers ahead of and behind the oil-base mud could be used, but in most applications are omitted. The diesel or crude oil—bentonite (approximately 300 lb of bentonite suspended in each barrel of oil) plug[10,11] is a similar one. The mixture is very fluid when being displaced; but when formation water and drilling mud contaminate and mix with it, the material thickens to resemble modeling clay. Diesel-oil spacers are generally used with these plugs. The time-setting clay plug is also a recent development and is well described in reference 16. This plug has rather quickly come into wide use and many successful applications have been reported.

Just how strong such plugs are or what strength is required of a lost-circulation plug is not known. Some preference for gel cement because of higher strength will continue, but this should not be a controlling factor in the selection of a plug.

Soft Plugs and Bridging-particle Plugs

The commercial lost-circulation materials are generally well known and may be classified in two groups, viz.:

1. Fibers and flakes
   a. Plant, wood and bark, and synthetic fibers
   b. Animal fibers such as wool linters or leather fibers
   c. Cellophane and cork flakes
   d. Mica
2. Bridging particles (some are sized)
   a. Expanded perlite[17] and coated coke fragments
   b. Fragmented set plastic and walnut shells
   c. Gravel pebbles

Howard and Scott,[5] in a recent paper, present experimental work with a simulated fissure apparatus connecting the concentration in mud of the two types of lost-circulation material with the width of fissures at which seals across the face of the fissure (not within the fissure) can be accomplished.* Their work indicates that a concentration of about 14 lb of flake or fibrous material per barrel of mud will bridge over fissures with widths up to 0.10 to 0.12 in. Increased concentrations will not bridge on fissures of greater width and simply pass through. The critical concentration with a bridging-particle material was about 20 lb per bbl, and the critical width of fissure was between 0.18 and 0.20 in. When a serious loss is encountered, a good practice would be to mix 50 to 150 bbl of mud near the pump suction to a concentration of 14 lb per bbl of a mixture of three of the fibrous and flake materials or to a concentration of 20 lb per bbl of walnut shells, and then displace it to the loss zone as a plug. Such treatments can be repeated several times to insure that the batch of loaded mud has been displaced into the loss zone. If circulation is not established, recourse must then be made to a plug of the type that stiffens in the loss zone. If circulation is regained, the shale screen should be used to remove

*For convenience, the chart of these results is included as Fig. 1 herein.

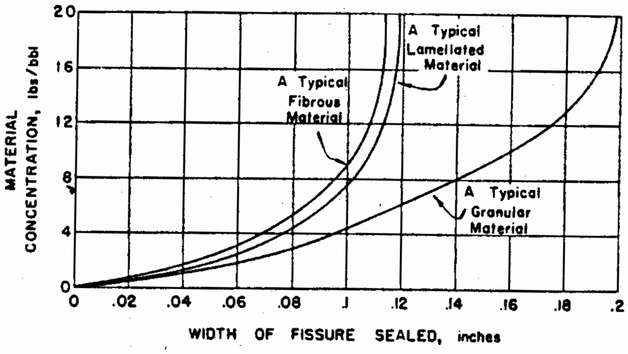

Fig. 1—Performance of Lost-circulation Materials in Sealing Fissures (After Howard and Scott[5])

any of the lost-circulation material which has joined the circulating mud.

Change of Method—Plugs to Blind Drilling

In a recent well in the Denton Field, New Mexico, a loss zone occurring near 10,000 ft was fought for 53 days without success. A great number of plugs of many types, utilizing a total of 9,000 sacks of cement and large quantities of other materials, were placed without effect. The fluid level stayed at 1,000 to 1,400 ft throughout. Blind drilling was then resorted to and, after drilling a few hundred feet, 7-in. casing was cemented.

In a more recent well in Denton, a complete loss occurred at 9,750 ft which was cured with 5 gel-cement and oil-bentonite plugs after pumping away 20 tons of bulk fiber and flake material had no effect. Drilling continued and another loss zone was encountered at 10,494 ft. Twenty-one varied plugs were placed and some drilling was done to 10,550 ft, but circulation was never regained. Blind drilling with water was then commenced, and within 12 hours partial returns were secured. Drilling continued to 11,300 ft with seepage losses of 10 to 20 bbl per hour, which the circulating of fiber and flake material did not decrease. A combination oil-bentonite and gel-cement plug was then squeezed into the loss zone, whereas previous plugs had gone away under vacuum. The plug was then drilled out and drilling continued to 12,100 ft with full returns.

It seems clear that the cuttings rising from the bit and carried into the loss zone bridged and closed the loss zone nearly completely. This occurrence raises the question whether a more practical procedure than long-continued blind drilling would be to drill blind through the zone(in the foregoing example to, say, 10,550 ft) and then displace through open-ended drill pipe in a thick gel-mud vehicle a quantity of a selected particle-size range of pea gravel, fragmented plastic, and walnut shells. Of course a great many such plugs have been used, but their record of success is not great and two suggestions are therefore made: *1*, that they be displaced from below the loss zone so that velocities are decreased in traveling up the annulus and out into the loss zone; and *2*, that larger quantities of bridging particles contained in the larger amounts of mud be used than in older treatments.

A conclusion as to change of method can be drawn from the foregoing well history:

1. Soft plugs (large quantities of bulk fiber material) had no success; because this is true generally in this field, such plugs should not be tried.
2. Hard plugs (five oil-bentonite and gel-cement) successfully sealed the zone at 9,750 ft. Therefore, a reasonable number of such plugs should be used as a first effort.
3. If these plugs are not successful, blind drilling should be tried. It would seem that engineered, bridging-particle plugs should be tried after only a short interval of blind drilling.

Circulation of Lost-circulation Materials, or Pretreatment

Howard and Scott[5] report tests in shallow simulated wells indicating that pretreatment, the addition to the circulating system in advance of loss of quantities of bridging materials, permits the imposition of considerably higher pressures on the formation before a breakdown or fracture occurs. This appears to be a dubious procedure with both low-solids and high-solids muds. Circulating lost-circulation materials requires that the mud bypass the shale screen. With the low-solids light-weight muds of the interior United States, bypassing the screen permits quick build-up of solids to increase weight and cannot, therefore, be tolerated. Certainly, any increased mud weight will contribute to losses. With high-solids muds, the addition of lost-circulation material will increase pressure against the formation because of thickened mud cake, increased-viscosity gels, and increased balling tendencies. Fine wood fiber or fine mica in concentrations of 1 to 5 lb per bbl of mud are recommended for pretreatment because they will pass through shale screens. It is difficult, however, to believe that such fine materials at such low concentrations can have any beneficial effects.

More recent work[6] by the same research group on multiple-pressure fracturing shows that an induced fracture may often be readily sealed by the displacement to it of a batch of mud thickened with bridging particles. Thus the use of bridging-particle plugs provides a way of "eating the cake and having it too." The circulation of heavy concentrations of lost-circulation material, with its attendant bad effects, can be omitted; and, if a fracture is induced, it can be remedied by the spotting of a batch of loaded mud.

Proper Use of Lost-circulation Materials

From the preceding two sections the suggestion is plain that a completely new evaluation should be made by the drilling industry of the use of these materials for combating lost circulation. For example, the citing of successful applications of these materials in wells drilled without any control of the drilling practices which cause large surge pressures with muds having a density to give, for example, 1,250-psi overbalance on the loss zone, would seem to be purely defensive. What is needed is to collect new experience with these materials in wells using the minimum proper mud weight and controlled drilling practices. It seems when the facts are developed that the use of these materials will be much restricted as compared with the present.

Lost Circulation in the Leduc Field, Canadian Plains

This great field is practically drilled up, but some observations there may have application in other fields. In wells located in the east flank, the drilling fluid was generally pretreated with sawdust before entering the vugular Devonian formation. In general, this was successful and less than 24 hours rig time was consumed with mud losses. Wells drilled in the central portion of the field frequently lost about 48 hours rig time in displacing mud loaded with sawdust and other lost-circulation materials into the loss zone. Wells situated along the west face of the reef frequently had real lost-circulation difficulties which required much more than 48 hours to clear up. In these wells the dropping of gel-cement plugs was resorted to; this procedure is detailed in reference 1, p. 78. The common mud weight in the field was 10.5 lb per gal (78.5 lb per cu ft), the Devonian was under a subnormal pressure gradient of about 0.37 psi per ft, and the overbalance was of the order of 800 psi. Inasmuch as an 8.5 lb per gal (63.5 lb per cu ft) mud would give about 325 psi overbalance, it would appear that decreased mud weights might have nullified or minimized the more difficult lost-circulation occurrences.

Drilling with Water

Much West Texas drilling is done with water because it is the cheapest and fastest drilling fluid. It is understandable that losses to the formation can be continuous and, for example, a loss of 15 bbl per hour is not considered serious. When losses increase, a leather fiber[18] circulated in the drilling fluid has an outstanding record of success. An older treatment is to suspend scrap cellophane in the fluid. Also, the oil-base, oil-bentonite, and time-setting clay plugs have been used with success in seepage-loss zones.

Casing Cementation

A most annoying type of loss is one where it is discovered, after much rig time has been consumed, that the lost mud is traveling back of surface or protective casing because of a channeled cementation. In any lost-circulation territory the use of the scratcher-centralizer-reciprocation technique for cementing both surface and protective casings seems justified.

A special type of lost circulation is the failure to secure proper fill-up in cementing casing because the cement goes out into the formation rather than rising in the annulus. The universal solution is to use lighter-weight cement slurries. A good neat cement slurry will weigh at least 16 lb per gal (120 lb per cu ft); one with a high bentonite concentration about 13 lb per gal (97.5 lb per cu ft); and current work is being carried on with expanded perlite and pozzolans as additives to gel cement to yield a density measured at atmospheric pressure as low as 10.5 lb per gal (78.5 lb per cu ft). Pressure increases the density of perlite-gel cements and they are generally used, therefore, only for surface-string cementation.

Simultaneous Lost Circulation and Blowout

Occasionally a well drills into a high-pressure zone with an insufficient mud weight and returns are lost while weighting-up the mud. Generally, the only satisfactory procedure is to plug off the high-pressure sand and then a string of casing can be set to exclude the loss zones. The placing of a barite or cement plug may be required to shut off the high-pressure zone and the procedures and considerations for this are set out in reference 1, p. 61. Barite plugs have been chiefly used in the Gulf Coast, but they should be kept in mind as a useful tool in any area.

Losses in the Gulf Coast

It is commonly accepted that the deeper a surface or protective casing string is set, the higher will be the mud weight that can be circulated without loss. Generally, no heavier than a 14.5 lb per gal (108 lb per cu ft) mud can be circulated in a deep well which has only 1,500 to 3,000 ft of surface pipe. Losses at lower weights than this are encountered often enough. No very successful way has been found to strengthen these long sections of open hole so that higher mud weights can be carried. Fortunately, normal-pressure zones can be safely drilled with mud weights from 9.7 to 10.2 lb per gal (73 to 76 lb per cu ft). If circulation is lost with a higher-weight mud, one procedure is to lower the mud weight to that which will circulate and to drill ahead to just above the first abnormal-pressure sand

and cement protective casing. The setting of protective casing at 9,000 ft or deeper generally permits the circulation of 16 to 18 lb per gal (120 to 135 lb per cu ft) muds.

If a generalization must be made as to the location of loss zones in Gulf Coast wells, it can be said that they are never, or rarely, at bottom; and, in general, are close to the last casing shoe.

When circulation is lost while drilling below a protective string with high-weight muds, the fluid level generally remains at the surface and the pressure in the annulus required for circulation, therefore, causes the loss. This pressure depends upon the clearances, the viscosity of the mud, and the rate of circulation. Where high-weight muds are to be used, as large clearances as possible should be provided, the mud should be a lime-emulsion mud for low viscosity and gel strength, and should have the minimum safe weight. If losses occur, circulation should be at reduced rates even though the drilling rate is slowed. The rig should be handled to avoid all pressure surges. Waiting periods should be used as a first treatment. Then displacement of one of the lost-circulation plugs should be undertaken. Lost-circulation materials should not be circulated in the mud.

Losses in Clam Lake Field, Upper Texas Gulf Coast

This field is located on a medium-depth salt dome and the normal fault pattern common to such structures is prominent. A recent well with surface casing at about 1,000 ft drilled with a lightly treated 9.8 lb per gal (73.5 lb per cu ft) mud to about 4,100 ft, which was at or near the intersection of two prominent faults, when circulation was lost and the fluid level dropped some hundreds of feet. Apparently, the drop in fluid caused some uncemented sand near the casing shoe to fall in and freeze the drill pipe. Another well indicated that this occurrence could recur and additional wells in the faulted area have, therefore, been drilled below the surface string with light concentration, 4 to 6 lb per bbl, of fiber and flake material in the 9.8 lb per gal mud. Such treatments can be considered as insurance and, being of low concentrations, are inexpensive and do not interfere with drilling.

CONCLUSION

When a well is being planned, the possibilities of lost circulation should be considered and the circumstances of the loss or losses and procedures used in similar wells in the vicinity should be studied. A program to properly handle the lost-circulation occurrences can then be prepared. Important considerations in preparing such a program are the use of *minimum* safe mud weight; the handling of the rig to avoid all pressure surges; any possible benefits should be taken from waiting periods; lost-circulation material should not be circulated except with well-understood conditions; lost-circulation plugs of the type most likely to succeed under the indicated conditions should be selected; and, finally, special drilling methods should be instituted after other procedures have been given a reasonable number of applications.

ACKNOWLEDGMENT

This paper was written after some three years' association in the work of the API Southwestern District Study Committee on Drilling Fluids, and acknowledgment is made of the stimulation from discussion and the published work of other committee members on the subject. Although the study committee has sponsored the presentation, the paper is the responsibility of the author alone.

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DISCUSSION

Orien Van Dyke (Magnet Cove Barium Corp., Houston) (written): Mr. Bugbee has presented a very thorough discussion of the lost-circulation problem, and I should like to compliment him for describing the various formation conditions which cause its occurrence. He has also called attention to the importance of educating the personnel on the drilling rig in regard to lost circulation so that both the drilling fluid and the mechanical phases of the drilling operation can be controlled in order to prevent needless cases of lost circulation.

As pointed out, surveys that have been run to accurately determine the point of loss have in most cases shown the loss point to be above bottom. The occurrence of such losses is baffling, because it is obvious that formation openings did not exist at the time such zones were drilled. There is the possibility that sometimes such losses may be caused by pressure surges or changes in the weight of the drilling fluid, as suggested by the author. However, in my opinion, such losses often occur with no changes in pressure conditions opposite such zones. In some areas, the frequency of lost circulation has been greatly reduced by drilling all of the hole below surface casing with a mud having reasonably good properties. It appears that the simple precaution of treating out the cement and conditioning the mud prior to drilling below surface casing will retard water soaking of soft-shale formations so that zones of weakness, which are potential points of loss, will not develop. The cost of such treating is very little, and it is something I should like to suggest as a protective measure to supplement those recommended by Mr. Bugbee.

Mr. Bugbee was quite critical of the fibrous and flake materials which are commonly used as a lost-circulation corrective. I do not believe he went so far as to say they were of no value, but there were numerous references to cases where they had proved ineffective. I certainly agree that fibrous and flake materials have limitations, but the fact remains that most cases of lost circulation are currently corrected with such additives, and it is the few exceptions that are widely discussed. Fine-size mica which will pass through an ordinary shaker screen is proving to be an easy-to-use protective measure against lost circulation, and there are indications that its use will allow the carrying of higher mud weights without formation rupture. Many cases of lost circulation have been very quickly corrected with a relatively small slug of fibrous material. In dealing with a lost-circulation problem, time is an important factor; and I would like to suggest that, along with the educational program which Mr. Bugbee has suggested, consideration be given to the maintenance of a small supply of a suitable fibrous material at all rigs so that, should lost circulation occur, a small treatment could be spotted in the hole immediately instead of the formation opening being enlarged by continued attempts to circulate while deciding what action should be taken and getting the necessary materials on the job.

The very fine work done by Howard and Scott certainly shows the limitations of fibrous, flake, and granular additives. Their laboratory work would indicate that a fissure having a width of 0.2 in. is the maximum size that could be sealed. Mr. Bugbee pointed out that it is probable that many of our severe cases of lost circulation are into relatively large openings. Additives to mud have a limitation as to pumpability, and it is not logical to expect bridging agents which can be circulated through a 4½-in. drill pipe and, in some cases, through 1-in. bit nozzles to effectively bridge openings that are larger, just because they are in the formation. This would certainly indicate that there is a limit to what can be expected of materials that can be added to the drilling fluid and circulated through the drill pipe to the point of loss. In view of the obvious limitations of mud-additive bridging agents, our only recourse appears to be the consideration of materials which change in physical properties after being spotted in the loss zone. Mr. Bugbee has discussed a number of these materials, which he describes as "plugs that harden or stiffen in the loss zone." For the past year our company has been doing work with the time-setting clay cement he mentions, which is mixed up as a viscous fluid and gradually changes to a very stiff gel after being squeezed into the loss zone. A recent study of slightly more than 100 applications of time-setting clay cement showed that approximately 64 percent were successful. These results are encouraging because most of the applications were in wells in which various other methods for correcting the loss had previously been tried without results. It appears that materials that change state after being placed in the formation offer the most interesting prospects for the correction of severe types of lost circulation.

H. W. Perkins (Sun Oil Company, Beaumont, Texas) written): Mr. Bugbee is to be complimented for his excellent and complete summary of the current thinking on this serious problem in our drilling operations. In addition, numerous references are included to expand the discussions in the paper which could not be covered completely without making it too lengthy. The paper should be especially helpful to those of us instructing company men in work on drilling fluids, because it can be used as a text in discussing our present approaches to combating lost circulation.

Our most troublesome cases of lost circulation in the Gulf Coast area of Texas and Louisiana have been those that occurred after setting protection strings, and mud weights of 15 lb per gal or higher have been required to prevent intrusion of formation fluids. In these cases, a delicate balance of 0.2 or 0.3 lb per gal in weight is often necessary to contain the formation fluids and yet not lose mud to the formation. Such losses are believed to be to the faulted, jointed, or fissured formations discussed by Mr. Bugbee. To explain the reason for this delicate balance and to make the literature references still more complete, I believe that two additional papers should be included in the list of references. One is "Abnormal Pressures and Lost Circulation," by P. E. Chaney.[1] This paper proposes a theory for abnormal pressures by which the formation-fluid pressures could be equivalent to the strength of the formation. Therefore, when such a reservoir is drilled, the mud weight to prevent the intrusion of fluid must be as high as the strength of the formation. Any excess mud weight would result in mud loss by breakdown of the formation. The other paper is "Mechanical Basis for Certain Familiar Geologic Structures," by M. King Hubbert.[2] Dr. Hubbert in his paper shows that the state of stress which results in normal faulting is one in which the horizontal stress is less than the vertical stress. Under these conditions, which are believed to exist in the Gulf Coast area, it is necessary that only the minimum or horizontal stress be exceeded to induce fracturing. Mud weights required to exert pressures exceeding the minimum-stress could therefore be considerably lower than those required to exceed the vertical stress, which is the weight of the overburden. The teachings of these two papers would explain the reason that only 0.2 or 0.3 lb per gal over a wide range of mud weights may mean the difference between mud loss and formation-fluid intrusion.

Of the recent advances in techniques for combating lost circulation, I believe we have had better results with the waiting period and careful control of both the drilling operations and mud properties. These methods have been used successfully in fields in the vicinity of Winnie, Texas, and Crowley, Louisiana. The mud losses with high-weight muds in these fields were believed to be caused by the breakdown of the formation. The mud weight could not be lowered because of abnormal pressures. A study of the factors involved in such losses indicated that methods which lessened the pressure surges on the formation would give the best chance of reaching total depth with minimum mud costs. Experiences in these fields thus far have supported these conclusions.

I should like to thank Mr. Bugbee on behalf of the API Southwestern District Study Committee on Drilling Fluids for his acknowledgment to our committee and for permitting the presentation of the paper to be sponsored by the committee.

W. C. Goins, Jr. (Gulf Oil Corp., Houston): This is a very fine paper, and I should like to compliment the author on it. He has covered the field very thoroughly as regards loss of circulation.

I should like to comment on this matter of engineered particle-size distribution of sealing materials which Mr. Bugbee mentioned. We frequently hear the statement on the Gulf Coast that sealing materials are not of any use at all, which is not quite true, because they do seal quite a few losses. However, it might be profitable to inquire just why they frequently fail. Mr. Van Dyke has already touched on that in part.

The work of Howard and Scott (reference 5 of the paper) indicates that the largest opening one can hope to seal with fibrous material is about 0.14 in. Soft materials can shear down and blow out of a plugged opening of a larger size when there is a pressure surge or if a large pressure differential has been built up. This explains the smallness of openings sealed. If a good hard granular material is used, an opening up to about 0.20 in. can be sealed. The reason for this limitation is that a minus 4-mesh hard particle (about 0.22 in.) is about the largest that can be circulated with rig pumps. In any event, the use of circulatable sealing mate-

[1] References are at the end of the discussion.

rials can be expected to seal what would be classed as only very small openings.

Then, too, with granular materials the matter of engineering for particle-size distribution is very important. If mud were pumped through a container filled with small marbles of equal size, it would pass through without difficulty. However, if the proper gradation of marble sizes were present, the openings between marbles would be closed and a seal would be obtained. Most of our sealing materials have been run into the well without consideration of the fact that there must be successively smaller particles to bridge the openings between large particles.

In summary, the use of circulatable sealing materials, even where proper particle-size distribution and mechanical strength are present, would not be expected to cure lost circulation except to very small openings. If these fail, other techniques must be used. It is hoped that these concepts of the performance of sealing materials help to explain the limitations on the usefulness of the materials and further emphasize Mr. Bugbee's statements about the use of properly engineered sealing agents.

D. E. Ramsey (Dowell, Inc., Midland, Texas) (written): There are a number of points which the author of this excellent paper brought up which I should like to discuss briefly; or, better still, on which I should like to encourage some more thought and action along some of the lines he mentioned.

Mr. Bugbee points out the tremendous expense that lost circulation adds to any major exploration or development program. Large mud bills, special lost-circulation materials, lost holes, blowouts, and lost rig time are some of the items of expense that are always associated with major lost circulation. The oil industry as a whole, and service companies in particular, have probably fallen far short of the merited research and development of new products and techniques for combating lost circulation.

There have been, as the author indicates, several recent developments such as improved drilling practices that have lessened the frequency of lost circulation. These developments are a result of better understanding of the factors that provoke lost circulation. There have also been some new and improved materials developed and tested to combat lost circulation once it occurs. These include time-setting clay cements, new soft plugs, and new bridging-particle plugs. Better techniques for placing these plugs have been developed. All of these developments came from planning and study of the problems and conditions involved. The individuals and groups, such as the API study committee, responsible for these developments have performed a worthy service to the industry as a whole.

The erratic occurrence of lost circulation was pointed out by Mr. Bugbee. In formations where weathered, vugular, or fracture porosity and permeability are present, lost circulation is an ever-present hazard. Inasmuch as lost circulation might occur at any point in such exposed sections, the problem of shutting off these losses is increased. In deep wells there is the danger of contaminating large volumes of mud, sticking drill pipe, and deviating from the hole while drilling long unnecessary cement plugs, if the control efforts are not directed at the thief zone. In 1951 and 1952 some 60-odd hot-wire surveys and about 20 spinner surveys were run to determine which part of the hole was thiefing the circulation fluid. These surveys revealed the fact that in about 65 percent of the wells surveyed the fluid was being lost to some zone above the current total depth of the hole. After the operator knew which zone was taking fluid, his efforts to shut off the thief zone were more efficient. It is impossible to definitely evaluate such surveys on a dollar-wise basis, but drilling could be resumed quicker, and the shut-off was effected after spotting fewer plugs in all of the difficult lost-circulation areas in West Texas that have been studied. Although this is not a large number of surveys, these surveys are becoming more popular, indicating that there is interest in this type of work. Repeat surveys speak for their advantage.

A recent development in locating zones of permeability which might have application in locating zones of lost circulation involves spotting a small volume of fluid containing a short-lived radioactive material in the well bore. After pumping a few barrels of mud into the well, the displacement of this spot of radioactive material could be determined with a Geiger counter or a gamma-ray tool. This method has not, to my knowledge, been used to determine zones of lost circulation although it would have several advantages over some of the other methods. About 30 of these surveys have been run on water-injection wells and producing wells, and have checked very favorably with the spinner surveys in the same wells.

Some recent developments in the equipment used in mixing and spotting plugs to combat zones of lost circulation are regular squeeze trucks equipped with ball-type valves for pumping mixtures containing large solid particles, and 72-bbl transports equipped with power-driven paddles to mix and disperse lost-circulation plugs. Anyone who has tried to mix a small plug with a jet hopper can appreciate the value of this equipment.

In closing, I should like to urge those who are in the management group to appreciate the fact that the engineer, foreman, or superintendent who is sitting on a well with lost circulation has the problems of the United Nations and an unsubsidized cotton farmer. Your cooperation with these unfortunate individuals will certainly be appreciated if not blessed.

Again, I should like to compliment Mr. Bugbee on his excellent paper, and to express appreciation for the fine job he and his committee have done.

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JUN 23 1978

Purchasing & Printing Division

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No. 1897

AFFIDAVIT OF PUBLICATION

STATE OF NORTH DAKOTA)
)ss.
County of Hettinger)

THE SLOPE MESSENGER

Duane F. Clark, of said State and County, being duly sworn on his oath says: That he is the Publisher of the SLOPE MESSENGER, a weekly newspaper of general circulation in Slope County, North Dakota, printed in the City of New England in Hettinger County, N. Da... legal newspaper for the county of Slo... the time hereinafter mentioned, ... numbered 1897 and headed ... printed copy of which is hereunto a... regular and entire issue of said new... time of publication, and that the noti... paper proper, and not in a supplemen... successive weeks, to-wit:

Thursday, 6-7 1978 Th...
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FEE $ 16.50

Duane...

Sworn and subscribed to bef...

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My commission expires ...

No...
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LEGAL NOTICE

NOTICE OF PUBLICATION
N. D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

The State of North Dakota by its Industrial Commission hereby gives notice pursuant to law and the rules and regulations of said Commission promulgated thereunder of the following public hearing to be held at 9:00 a.m. on June 20, 1978, in the Large Hearing Room, Capitol Building, Bismarck, North Dakota, before the Industrial Commission or an Examiner appointed by the Commission for that purpose.

STATE OF NORTH DAKOTA TO:

All named parties and persons having any right, title, interest, or claim in the following case and notice to the public. CASE NO. 1563: On a motion of the Commission to consider having the operators in the following fields show cause that field rules should not be amended to provide for surface casing being set not less than fifty (50) feet below the base of the Foxhills Formation and cemented to the surface: Elkhorn Ranch, Franks Creek, Fryburg, Little Knife, Medora, ...

... lings, County, North Dakota; Amor, Ash, Cedar Creek, Cold Turkey Creek, Coyote Creek, Grand River, Haley, horse Creek, Little Missouri, Medicine Pole Hills, and State Line, all in Bowman County, North Dakota; Halliday, Haystack Butte, Killdeer, Little Knife, Lost Bridge, Oakdale, Rattlesnake Point, and Russian Creek, all in Dunn County, North Dakota; Rider and Square Butte in Golden Valley County, North Dakota; Antelope, Bear Den, Bicentennial, Blue Butte, Boxcar Butte, Camel Butte, Charlson, Clear Creek, Croff, Dimmick Lake, Earl Hawkeye, Keene, Little Knife, MonDak, North Fork, Pershing, Poker Jim, Red Wing Creek, Rough Rider, Union Center, and Yellowstone, all in McKenzie County, North Dakota; Amidon, Eleven Bar, and Rocky Ridge, all in Slope County, North Dakota; Buffalo Creek, Dickinson, Green River, Rocky Ridge, South Heart, and Zenith, all in Stark County, North Dakota.

M June 7, 1978

Date 6-29-78

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State Printer

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6/21/78

Date
HAROLD NELSON
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AFFIDAVIT OF PUBLICATION

GOLDEN VALLEY NEWS
OFFICIAL NEWSPAPER FOR BEACH AND GOLDEN VALLEY COUNTY

Purchasing & Printing Division
RECEIVED
JUN 20 1978
STATE CAPITOL
Bismarck, North Dakota

STATE OF NORTH DAKOTA,
County of Golden Valley — ss

Leona Oderman being duly sworn, deposes and says, that the annexed printed copy of notice of publication

was taken from the Golden Valley News, a newspaper which during the whole time of publication of said notice hereinafter stated, has been and is printed and published in the City of Beach, County of Golden Valley, and State of North Dakota. That the said notice was published in said newspaper on the following dates:

June 8 19 78 ______19____ ______19____

______19____ ______19____ ______19____

in each and every issue of the full number thereof, upon which days or times of publication aforesaid newspaper was regularly published, and that during the whole time of said publication __he was one of the employees or publishers of said newspaper.

Leona Oderman

Subscribed and sworn to before me this 15th day of June 19 78

Sharon Brengle
Notary Public, Golden Valley, North Dakota.

My Commission expires ______

SHARON BRENGLE
Notary Public, GOLDEN VALLEY CO., N. D.
My Commission Expires NOV. 9, 1982

NOTICE OF PUBLICATION
N. D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

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(June 8)
(B&M)

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Date ......
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AFFIDAVIT OF PUBLICATION

BILLINGS COUNTY PIONEER

OFFICIAL NEWSPAPER FOR BILLINGS COUNTY

Purchasing & Printing Division
RECEIVED
JUN 20 1978
STATE CAPITOL
Bismarck, North Dakota

STATE OF NORTH DAKOTA.
County of Billings — ss

Leona Odermann being duly sworn, deposes and says, that the annexed printed copy of notice of publication

was taken from the Billings County Pioneer, a newspaper which during the whole time of publication of said notice hereinafter stated, has been and is printed and published in the Town of Medora, County of Billings, and State of North Dakota. That the said notice was published in said newspaper on the following dates:

June 8 1978 ...... 19 ...... 19 ......

...... 19 ...... 19 ...... 19 ......

in each and every issue of the full number thereof, upon which days or times of publication aforesaid newspaper was regularly published, and that during the whole time of said publication ....he was one of the employees or publishers of said newspaper.

Leona Odermann

Subscribed and sworn to before me this 15th day of June 1978

Sharon Brengle
Notary Public, Billings County, North Dakota.

My Commission expires ......

SHARON BRENGLE
Notary Public, GOLDEN VALLEY CO., N.D.
My Commission Expires NOV. 9, 1982

NOTICE OF PUBLICATION
N. D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

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(June 8)
(B&M)

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BOWMAN COUNTY PIONEER

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Affidavit of Publication

Date 6-16-78

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... is now the official newspaper for the County of
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Publication

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Patterson .... SECRETARY

9 ..... day of June ....

Ervin Schneider
ERVIN SCHNEIDER
Notary Public, Bowman County, N. D.
My Commission Expires Oct. 4, 1982

51

NOTICE OF PUBLICATION
N. D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

The State of North Dakota by its Industrial Commission hereby gives notice pursuant to law and the rules and regulations of said Commission promulgated thereunder of the following public hearing to be held at 9:00 a.m. on June 20, 1978, in the Large Hearing Room, Capitol Building, Bismarck, North Dakota, before the Industrial Commission or an Examiner appointed by the Commission for that purpose.

STATE OF NORTH DAKOTA TO:

All named parties and persons having any right, title, interest or claim in the following case and notice to the public.

CASE NO. 1563: On a motion of the Commission to consider having the operators in the following fields show cause that field rules should not be amended to provide for surface casing being set not less than fifty (50) feet below the base of the Foxhills Formation and cemented to the surface: Elkhorn Ranch, Franks Creek, Fryburg, Little Knife, Medora, and Rocky Ridge, all in Billings County, North Dakota; Amor, Ash, Cedar Creek, Cold Turkey Creek, Coyote Creek, Grand River, Haley, Horse Creek, Little Missouri, Medicine Pole Hills, and State Line, all in Bowman County, North Dakota; Halliday, Haystack Butte, Killdeer, Little Knife, Lost Bridge, Oakdale, Rattlesnake Point, and Russian Creek, all in Dunn County, North Dakota; Rider and Square Butte in Golden Valley County, North Dakota; Antelope, Bear Den, Bicentennial, Blue Butte, Boxcar Butte, Camel Butte, Charlson, Clear Creek, Croff, Dimmick Lake, Earl, Hawkeye, Keene, Little Knife, MonDak, North Fork, Pershing, Poker Jim, Red Wing Creek, Rough Rider, Union Center, and Yellowstone, all in McKenzie County, North Dakota; Amidon, Eleven Bar, and Rocky Ridge, all in Slope County, North Dakota; Buffalo Creek, Dickinson, Green River, Rocky Ridge, South Heart, and Zenith, all in Stark County, North Dakota.
(Published June 8, 1978)

CERTIFICATE OF PUBLICATION

THE DICKINSON PRESS
Dickinson, North Dakota

R
JUN 12 1978

STATE OF NORTH DAKOTA,
County of Stark.

Gloria Foster, of said state and county, being first duly sworn, on oath says: That she is the Bookkeeper of the Dickinson Press, Inc., publisher of THE DICKINSON PRESS, a daily newspaper of general circulation, printed and published at Dickinson, in said county and state, and has been such during the time hereinafter mentioned; and that advertisement headed Notice Of Publication

a printed copy of which is hereunto annexed, was printed and published in THE DICKINSON PRESS, and in the regular and entire issue of each and every number 1 consecutive weeks, commencing on the 8 day of June A. D. 1978, and ending on the 8 day of June A. D., 1978, both inclusive.

Gloria Foster

Sworn to and subscribed to before me this 8 day of June A. D. 1978.

Ed J. Hauck

$ 21.42
Date 6-12-78
HN
HAROLD NELSON
State Printer

ED J. HAUCK
Notary Public, STARK COUNTY, N. DAK.
My Commission Expires JUNE 7, 1979

BEFORE THE INDUSTRIAL COMMISSION

OF THE STATE OF NORTH DAKOTA

IN THE MATTER OF A HEARING CALLED ON A MOTION OF THE COMMISSION TO CONSIDER HAVING THE OPERATORS IN THE FOLLOWING FIELDS SHOW CAUSE THAT FIELD RULES SHOULD NOT BE AMENDED TO PROVIDE FOR SURFACE CASING BEING SET NOT LESS THAN FIFTY (50) FEET BELOW THE BASE OF THE FOXHILLS FORMATION AND CEMENTED TO THE SURFACE: ELKHORN RANCH, FRANKS CREEK, FRYBURG, LITTLE KNIFE, MEDORA, AND ROCKY RIDGE, ALL IN BILLINGS COUNTY, NORTH DAKOTA; AMOR, ASH, CEDAR CREEK, COLD TURKEY CREEK, COYOTE CREEK, GRAND RIVER, HALEY, HORSE CREEK, LITTLE MISSOURI, MEDICINE POLE HILLS, AND STATE LINE, ALL IN BOWMAN COUNTY, NORTH DAKOTA; HALLIDAY, HAYSTACK BUTTE, KILLDEER, LITTLE KNIFE, LOST BRIDGE, OAKDALE, RATTLESNAKE POINT, RUSSIAN CREEK, ALL IN DUNN COUNTY, NORTH DAKOTA; RIDER AND SQUARE BUTTE IN GOLDEN VALLEY COUNTY, NORTH DAKOTA; ANTELOPE, BEAR DEN, BICENTENNIAL, BLUE BUTTE, BOXCAR BUTTE, CAMEL BUTTE, CHARLSON, CLEAR CREEK, CROFF, DIMMICK LAKE, EARL, HAWKEYE, KEENE, LITTLE KNIFE, MONDAK, NORTH FORK, PERSHING, POKER JIM, RED WING CREEK, ROUGH RIDER, UNION CENTER, AND YELLOWSTONE, ALL IN MCKENZIE COUNTY, NORTH DAKOTA; AMIDON, ELEVEN BAR, AND ROCKY RIDGE ALL IN SLOPE COUNTY, NORTH DAKOTA; BUFFALO CREEK, DICKINSON, GREEN RIVER, ROCKY RIDGE, SOUTH HEART AND ZENITH, ALL IN STARK COUNTY, NORTH DAKOTA.

CASE NO. 1563
ORDER NO. 1712

ORDER OF THE COMMISSION

BY THE COMMISSION:

Pursuant to legal notice this cause came on for hearing at 9:00 a.m. on the 20th day of June, 1978, in Bismarck, North Dakota, before the Industrial Commission of North Dakota, hereinafter referred to as the "Commission."

NOW, on this 25th day of July, 1978, the Commission, a quorum being present, having considered the testimony adduced and the exhibits received at said hearing, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That in southwestern North Dakota, the Foxhills Formation contains water of sufficient purity for domestic and livestock use.

(3) That oil and gas drilling operations might contaminate waters in the Foxhills Formation, and procedures should be adopted in the drilling of all wells, development and wildcat, to protect said waters.

IT IS THEREFORE ORDERED:

(1) That Commission orders establishing special field rules in the following fields are hereby amended to provide for the setting of surface casing not less than fifty (50) feet below the base of the Foxhills Formation:

Elkhorn Ranch, Franks Creek, Fryburg, Little Knife, Medora and Rocky Ridge, all in Billings County, North Dakota; Amor, Ash, Cedar Creek, Cold Turkey Creek, Coyote Creek, Grand River, Haley, Horse Creek, Little Missouri, Medicine Pole Hills and State Line, all in Bowman County, North Dakota; Halliday, Haystack Butte, Killdeer, Little Knife, Lost Bridge, Oakdale, Rattlesnake Point, Russian Creek, all in Dunn County, North Dakota; Rider and Square Butte in Golden Valley County, North Dakota; Antelope, Bear Den, Bicentennial, Blue Butte, Boxcar Butte, Camel Butte, Charlson, Clear Creek, Croff, Dimmick Lake, Earl, Hawkeye, Keene, Little Knife, MonDak, North Fork, Pershing, Poker Jim, Red Wing Creek, Rough Rider, Union Center and Yellowstone, all in McKenzie County, North Dakota; Amidon, Eleven Bar and Rocky Ridge all in Slope County, North Dakota; Buffalo Creek, Dickinson, Green River, Rocky Ridge, South Heart and Zenith, all in Stark County, North Dakota. The State Geologist is hereby authorized to waive this requirement if deemed necessary.

(2) That all wildcat wells drilled in southwestern North Dakota shall set surface casing not less than fifty (50) feet below the base of the Foxhills Formation.

(3) That this order shall continue in full force and effect until further order of the Commission.

DONE, in Bismarck, North Dakota, this 25th day of July, 1978.

THE NORTH DAKOTA INDUSTRIAL COMMISSION

Arthur A. Link

Arthur A. Link, Governor

Allen I. Olson

Allen I. Olson, Attorney General

Myron Just

Myron Just, Commissioner of Agriculture

Telegram western union Telegram

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PMS GOVERNOR ARTHUR LINK, DLR
CHAIRMAN, NORTH DAKOTA STATE INDUSTRIAL COMMISSION STATE CAPITOL
BISMARCK ND 58505
IN REFERENCE TO CASE NUMBER 1563, SETTING OF SURFACE CASING THROUGH THE FOXHILLS FORMATION. BELCO PETROLEUM CORPORATION FAVORS SUCH ACTION BUT FEELS THAT FOR OPERATIONS IN REMOTE AREAS COMMISSION SHOULD RESERVE THE RIGHT TO GRANT EXCEPTIONS. VERY TRULY YOURS
GEORGE E NUGENT, VICE PRESIDENT
DRILLING AND PRODUCTIONS
NNNN

Amoco Production Company

CASE # 1563

June 1, 1978

JUN 1978
RECEIVED
N. Dak. Geological Survey

Jack G. Swenson
Executive Vice President &
General Manager
Rocky Mountain Oil &
Gas Association
345 Petroleum Club Bldg.
Denver, Colorado 80202

Dear Mr. Swenson:

RMOGA Study of Surface Pipe Requirements
To Protect Fox Hills Aquifer in
Western North Dakota

You received my May 3, 1978 letter polling an Ad Hoc Committee on the captioned question.

The preponderance of replies calls for the position I recommend RMOGA's Executive Committee approve:

> "Advocate at North Dakota Industrial Commission hearing that in the following nine counties of western North Dakota operators be required by the North Dakota Geological Survey, as a condition for drilling permit approval, to set surface pipe to a depth 50' below the Fox Hills aquifer and cement pipe to surface:
>
> | | |
> |---|---|
> | McKenzie | Dunn |
> | Golden Valley | Stark |
> | Billings | Hettinger |
> | Slope | Bowman." |

This position, if approved by the Industrial Commission, would not be a statewide rule change because it only concerns nine counties; instead, it would be a written policy position from the North Dakota Geological Survey to all operators involving just these nine counties.

The municipality of Beach in Golden Valley County is the deepest user of Fox Hills water (2200'). For the most part, the Fox Hills exists at 1200' to 1700' in depth. Operators usually do not mud up until 4000-5000', well below the Fox Hills. It is cheaper and faster to drill with salt water to 4500'.

Four of the nine counties (McKenzie, Golden Valley, Billings, and Slope) have groundwater studies. Even if there are no existing water wells close by, it would be wise for an operator to set through the Fox Hills and protect that aquifer with cement because someone later on may desire to develop the Fox Hills water and an operator would not want the liability of having to clean up contaminated Fox Hills water in that area.

Upon Executive Committee approval, I intend to front RMOGA's position at the Industrial Commission hearing in Bismarck on June 20, 1978. I will need to receive Executive Committee approval by Friday, June 16, before I leave, or on Monday afternoon at the Kirkwood Inn.

Very truly yours,

RB Giles

R. B. Giles
Chairman, RMOGA Regional
Exploration and Production Committee

RBG:bp

cc: George S. Dibble
Darwin Van DeGraaff
Jess Cooper
David O. Cordell
Members of North Dakota Ad Hoc Committee

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CASE #1563

May 3, 1978

Members of a North Dakota
Ad Hoc Committee
(Attached Mailing List)

RMOGA Study of Surface Pipe
Requirements to Protect Fox Hills
Aquifer in Western North Dakota

The North Dakota Geological Survey this date has requested that RMOGA recommend its solution to a problem that has arisen in the western sector of North Dakota.

The Fox Hills formation is an aquifer ranging in depth from 1,200' to 2,500'. On Federal lands or Burlington Northern lands, the mineral rights are severed. The USGS or Burlington Northern owns the minerals. Surface owners usually are ranchers, some of whom drill water wells to the Fox Hills to water their livestock. Also, certain municipalities use the Fox Hills for domestic purposes.

Attorneys representing these surface owners have complained to Governor Arthur Link that operators drilling through the Fox Hills to deeper oil or gas prospects are not setting surface pipe through the Fox Hills and cement protecting that aquifer. Operators generally set only 600' of surface pipe on their hydrocarbon prospects. The complaints have arisen mainly within McKenzie County but the problem exists throughout the southwestern and west-central sector of North Dakota. The North Dakota Geological Survey has been following the practice of only requiring that operators set surface pipe through the Fox Hills and cement to surface where the operator is drilling within a mile of a known Fox Hills water well.

Q: Should operators without exception be required to set surface pipe through the Fox Hills in western North Dakota and cement to surface?

or

Q: Should operators only be required to set through if a certain distance away from known Fox Hills water wells? If so, how far away, i.e., one mile, two miles, or what?

Give reasons for your choice because eventually there will be a public hearing scheduled by the Industrial Commission on this matter. If you believe there is a better alternative, please provide it, also with reasons.

In summary, please discuss this problem within your firm and let me have your written solution by June 1. If the responses are quite diversified, we may decide upon a meeting in Denver to develop a consensus recommendation for RMOGA's Executive Committee to consider and approve in June.

RBGiles

R. B. Giles
Chairman, RMOGA Regional
Exploration and Production
Committee

RBG/slf

Enclosure

cc:
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Given: Ø = 40%, thickness = 50 feet.

Area	Volume
1 acre	155,155 barrels
10 acres	1,551,550 barrels
40 acres	6,206,200 barrels
80 acres	12,412,400 barrels
160 acres	24,824,800 barrels
350 acres	54,304,250 barrels

Lost Circulation–A Major Problem in Exploration and Development†

J. M. BUGBEE*

ABSTRACT

It is the thesis of this paper that the major drilling problem of lost circulation can be avoided or minimized by the study of possible losses and the programming of treating procedures in advance of drilling. Not only must there be openings in the formation of sufficient size to accept and store the lost mud, but excessive pressures must act to force it away. The nature of loss zones, their formation-fluid pressures, and the hydrostatic and mechanical pressures that can be imposed are discussed. The hypothesis is presented that many serious losses are to naturally occurring fractures which are normally impermeable, but which open and accept whole mud when a critical hydrostatic pressure is exceeded. The field procedures and materials for combating lost circulation are then critically examined.

It is concluded that when a well is planned, the possibility of lost circulation should be considered and the behavior of similar wells in the vicinity studied so that a program to properly handle lost-circulation occurrences can be prepared. Important considerations are the use of the minimum safe mud weight; the handling of the rig to avoid all pressure surges; the taking of full advantage of waiting periods; the proper choice of treatments; and, finally, the change from one type of treatment to another as indicated by results in the well.

INTRODUCTION

Lost circulation is a problem as old as rotary drilling. In the interior United States and Canada it is the major factor in most high drilling-cost wells. Where the average well may have a mud cost of $4,000, the lost-circulation well will have one of $8,000 to $50,000. To the cost of lost mud materials must be added that of the rig time consumed and the cost of the occasionally accompanying stuck drill pipe, lost hole, blowout, or abandonment. There are also cases of missed production chargeable to lost circulation, from failure to secure production tests and samples; and of decreased productivity from the plugging of productive zones. The problem is presently highlighted by the search for production from fracture reservoirs, i.e., from lost-circulation zones.

Lost circulation as a problem has not received the consideration it merits because its study has fallen between the fields of geological, reservoir, and drilling engineering. The literature, therefore, until very recently[1] has not contained a well-reasoned general discussion of the subject. The past three years have, however, seen what can be called an industry-wide attack develop on the problem.

The purpose of this paper is to review and extend the thinking that is being carried on and to recommend the institution of certain procedures that are helpful with lost-circulation problems.

CAUSES OF LOST CIRCULATION

Lost circulation is defined as the loss of whole mud, in quantity, to exposed formations. This plainly requires the presence of permeable zones with openings of sufficient size to permit the entrance and storage of lost mud. Consideration indicates that another equally important factor is that a certain hydrostatic pressure must be exceeded before the formations will accept the lost mud. Knowledge of the type of loss zone, its formation-fluid pressure, and the hydrostatic and mechanical pressures to be imposed are essential to consideration of the problem.

Seepage losses of mud are not included in the foregoing. In many parts of the interior United States, particularly in West Texas, low-solids muds, even dirty water, having very poor wall-building properties are used to considerable depths. The seepage loss of such muds to permeable beds can amount to several barrels per hour. The addition to the circulating fluid of such materials as flake mica, leather fiber, and cellophane fragments can effectively reduce these losses.

PROCEDURES FOR LOST CIRCULATION

The available procedures for dealing with lost circulation can be summarized as follows:

1. Avoidance or correction by the correction of drilling practices or mud properties. A long list of

* Shell Oil Company, Houston, Texas.

† Presented at the spring meeting of the Southwestern District, Division of Production, Fort Worth, Texas, March 1953.

[1] References are at the end of the paper.

procedures and considerations can be made, but all are directed at lowering the pressures on the formations.

2. Adoption of a drilling method such as drilling blind, with or without a floating mud cap; drilling under pressure with the well flowing; or drilling with air.

3. Correction by use of waiting periods—the pulling of the drill pipe into the casing and allowing the well to stand while the formations, or the formation blocks, adjust themselves to withstand the new pressure conditions.

4. Placement of a soft plug, batches of mud thickened with fiber and flake materials, in the loss zone. There is a decided trend away from circulating these materials and to the practice of spotting them in batches as plugs.

5. Placement of a bridging-particle plug, batches of mud loaded with gravel, expanded perlite, ground plastic, walnut shells, or formation cuttings, in the loss zone. If possible, some squeeze pressure is applied. This can sometimes be accomplished by blind drilling where the cuttings are carried into and bridge in the loss zone.

6. Placement of a plug that hardens or stiffens in the loss zone. Such plugs include gel cement, gypsum cement, oil-base mud, oil-bentonite, and time-setting clay. All may have admixtures of thickeners or bridging particles. If possible, moderate squeeze pressure is applied to the plug.

As a broad statement, it can be said that *watering back to lower the mud weight is the universal treatment for lost circulation.*

DISCUSSION OF CAUSES

This section includes discussions of the formations that can take whole mud, their formation-fluid pressures, and the hydrostatic and mechanical pressures that are or can be imposed on them.

The Formations

The formation types which can take whole mud can be summarized under three headings: *1*, cavernous and open-fissured formations; *2*, coarsely permeable formations; and *3*, faulted, jointed, and fissured formations. Cavernous and vugular beds, reefs, gravels, and other coarsely permeable formations are generally single sedimentary units and the geologic correlations of circulation losses in wells to such zones within a field, or even within a province, should be quite exact. Old, weathered surfaces, such as that of the Devonian in the northern Canadian plains, also provide correlatable loss zones. Faulted and fissured zones are, however, structural in origin and can extend across several stratigraphic units. In those fields where the loss zones in wells have no pattern and are scattered both areally and in section, mud loss to fissures can be assumed.

A range of formation permeabilities exists from those at one extreme, with formation openings large enough to be practically unpluggable, to the other extreme where the formation face can be readily sealed with a cake of mud and fiber and flake lost-circulation material. The nature of a loss zone is rarely known with certainty, but study of lost-circulation occurrences in an area can narrow the range of possibilities.

Coarsely Permeable Formations

The order-of-magnitude permeability of a granular formation of sufficient permeability to accept whole mud can be calculated. An appreciable portion of the solids present in natural muds have diameters of 70 microns or larger. A formation with openings which would permit such muds to pass would probably have pore diameters three times greater than the mud-particle size, or 210 microns. It can be shown that the average pore diameter d, in microns, is related to the permeability k, in darcys, and porosity f, in fractional percent (percent÷100) by the following equation:

$$d = 5.63\left[\frac{l}{l_c}\right]\sqrt{\frac{k}{f}}$$

wherein: l is the distance a fluid moves in traversing a length l_c of the porous medium. The ratio l/l_c is always greater than unity but, in general, approaches one as permeability increases and grain size becomes more uniform. For the present calculation, the value of 1.3 for this ratio can be used. If a 40-percent porosity is assumed for a rock with 210-micron diameter pore openings, the limiting permeability is found to be 325 darcys. Muds generally have an appreciable sand and fine-cuttings content and such particles will bridge on a coarser, more permeable formation than this. It is recalled that extremely few formation-permeability values are as great as 3 darcys.

The circulation of the conventional fiber and flake lost-circulation materials as a treatment very frequently gives disappointing or no results. One answer is that gravels and similar coarsely permeable loss zones are rare in the subsurface and that serious losses are generally to formations with openings of relatively large size.

Faulted, Jointed, and Fissured Formations

There are innumerable wells in which lost circulation is experienced, where no cavernous or coarsely permeable formations are exposed in the open hole and the losses are obviously to fissures. Fissure systems occur in all formations—sands, shales, limes, dolomites—and are not generally confined to single beds but can extend across several. Spinner and other surveys have established, in the Gulf Coast, that losses to fissured shales are as frequent as losses to fissured sands. Fissure systems are structural in origin rather than sedimentary. Fields are known where fissure loss zones are related to axial faulting and flank wells have little trouble; but, in general, correlation with known faulting is not evident.

The writer's consideration of lost circulation and the related phenomena of pressure fracturing, squeeze cementing, and pressure break-through in water flooding has suggested the hypothesis[2,3,4] that the crust of the earth in many fields and prospects is faulted, jointed, and fissured; and that such fissures are impermeable (will not take mud) at certain pressures, but will open and take whole mud, i. e., the formation blocks will shift slightly, when a critical hydrostatic pressure is exceeded. For the present subject, the question can be considered academic whether the fissures occur naturally or are actual ruptures induced by increases in hydrostatic pressure. This, however, can be important and the growing literature on pressure fracturing should be reviewed; see, for example, references 4, 5, and 6.

The question is often asked about losses to noncavernous formations: "Where does the mud go?" A linear fissure ⅛ in. in width and with a circular area of 1 acre centering about a well has a volume of 81 bbl and the radius is only 118 ft.

Losses to fissures vary greatly in occurrence. Sometimes a half pit (50 to 150 bbl) of mud is lost rather suddenly, but drilling can continue with no further loss. In Gulf Coast wells, using high gel-strength muds, losses of mud to formation have been noted as circulation was started after trips. After two or three circulations which reduced pressure on the formation by breaking the gel of the mud, the lost mud had returned to the system. Such squeeze losses are not uncommon. There are many fields where loss of circulation with a 9.7 lb per gal (72.5 lb per cu ft) mud is complete but where, if a 9.5 lb per gal (71 lb per cu ft) mud is used, a well can be drilled as if the lost-circulation problem did not exist. Some fissure systems can be sealed by one or a series of lost-circulation plugs; others are best handled by a special drilling method.

Shallow Losses

In many fields circulation losses are discussed in two groups, viz., shallow and deeper losses. In most discussions of shallow losses, they are attributed to the "unconsolidated" nature of the near-surface formations. The writer believes that "uncemented" is a better descriptive term because ordinary sands are never unconsolidated, inasmuch as the normal deposition of sand grains results in an assemblage that is practically in its final state with insignificant later compaction effects. Further, unconsolidated is an unsuitable descriptive for clays and shales. It appears, however, that there is a valid point here, viz., that near-surface formations are generally checked and jointed, and lost circulation can be incurred with only slightly excessive pressures. Frequently, when the shallow formations are broken down, i.e., the joints and fissures are opened, the losses are extreme enough so that the largest concentrations of lost-circulation materials will not plug them and recourse is made to such a plug as oil-bentonite. In general, these losses can be avoided by watering the mud to hold low weight, and by the control of drilling practices to prevent balling-up or packing-off of the drill stem so that full pump pressure is not applied to the formations. The shallow formations are drilled in big hole with generally high drilling rates, and the mud velocities in the annulus are low. It is possible to pack off the bit in a soft formation because the circulation does not properly clear the cuttings. In fields where these losses occur, a warning regarding them should be posted on the bulletin board of drilling wells.

An example of this type of loss is recalled in the North Port Neches Field, in the upper Texas Gulf Coast. The contractor's water well went off production, but the drilling crew did not suspend drilling and drilled ahead in uncemented sands. The mud weight built up rapidly, the last measurement was 11.8 lb per gal (88 lb per cu ft), and returns were lost. Something over 24 hours' rig time and about $1,000 worth of purchased clays were required to regain circulation in this unnecessary occurrence.

Formation-fluid Pressures

Reservoir engineers, geologists working with problems of migration and accumulation of oil, and drilling engineers find that charts showing depths from surface to oil-water contact vs. initial reservoir pressure (psig) for various geological provinces or areas are of great interest. See, for example, Fig. 1 of reference 7. Not enough such displays of regional formation-fluid pressure gradients are available. Frequently, such charts show only the subsea depths and pressures; and they are, of course, an abstraction to the drilling engineer who works with the pressure from the surface, both for formation-fluid and hydrostatic pressures.

A normal-pressure reservoir is defined as one with a pressure, measured or calculated at the oil-water or gas-water interface, which is equal to the pressure of a water column to the surface. Most Gulf Coast reservoirs are under a normal salt-water column pressure and have a depth-pressure gradient of 0.465 psi per ft. Many West Texas fields and those in the foothills belt of Canada are also generally normal. It is also known that the Spraberry fields of West Texas, many Mid-Continent fields and those of the Canadian plains have subnormal pressures with gradients ranging from 0.24 to 0.38 psi per ft of depth. On a world-wide basis, abnormally high formation-fluid pressures are very uncommon.

Generally, when the fluid level is not at the surface the drilling crew will record the fluid level whenever drill pipe is pulled by noting the wetting level. This will not always be accurate and can be confusing. Running through the drill pipe of a float or short piece of spinning chain attached to the measuring line will accurately locate a fluid level.

Hydrostatic Pressures

In a very broad way, the commonly used muds have densities ranging between 9.5 and 10.5 lb per gal (71 to 78.5 lb per cu ft) with pressure gradients from 0.494 to 0.546 psi per ft of depth. Clay-water muds are three-part systems having gel and inert fractions and the fluid phase. Generally, the balance between these fractions is most easily maintained in the 9.5 to 10.5 lb per gal weight range. Muds of lesser weight need attention to maintain a fair gel fraction with constant watering, and muds above 10.5 lb per gal need attention because of high solids-to-water ratio.

Because a primary function of drilling muds is to confine formation fluids to their native strata, it is axiomatic that the hydrostatic pressure of the mud must always be greater than the formation-fluid pressure. Additionally, there is the pressure reduction in the withdrawal of drill pipe, or swabbing effect, which must be overbalanced. The necessary overbalance is provided by an increase in mud weight and this can cause loss of circulation. The amount of swabbed pressure reduction is governed chiefly by the gel strength of the mud and clearance between hole and drill pipe. Ordinary tool joints and rubber casing protectors increase swabbing effect by contributing decreased clearances. Little attention is paid to swabbing effect with the low-solids, inherently low gel-strength muds of the interior United States and Canada; but in the high-solids mud territory of the Gulf Coast and California low gel strength is an essential mud property. As to the effect of hole clearance when low gel-strength mud is in use, it is known that 200 to 500 psi overbalance is adequate with 4½-in. drill pipe in 8½-in. hole and that 800 to 1,200 psi is required with 3½-in. drill pipe in 6-in. hole.

In the planning of a well in the Gulf Coast and California, the provision of low gel-strength mud, as large diameter protective casing as possible, external-flush drill pipe for the lower portion of the string, and the omission of rubber casing protectors on the lower part of the drill pipe are important considerations with lost-circulation problems in high-pressure territory.

A normal-pressure sand at 10,000 ft in the Gulf Coast will have a pressure of about 4,650 psi. If a low-gel mud is in use and there are sufficient drilling clearances, e.g., 4½-in. drill pipe in 9⅞-in. hole, an overbalance of 300 to 400 psi is adequate. Thus, a 9.7 lb per gal (72.5 lb per cu ft) mud can be safely used. If there is no lost-circulation problem, however, the mud weight will be allowed to range between 10 and 10.5 lb per gal (75 to 78.5 lb per cu ft). In southern Oklahoma, some reservoirs have pressures with a subnormal gradient of approximately 0.37 psi per ft. Thus, to use approximate round numbers, the reservoir pressure is 3,700 psi at 10,000 ft. The commonly used mud weighs 9.5 lb per gal (71 lb per cu ft); its pressure is 4,940 psi at 10,000 ft; and the ordinary well drills the deeper zones with an overbalance up to 1,240 psi. Because there is frequently a lost-circulation problem, lower mud weights could be used, inasmuch as it is evident that a weight of only 7.9 lb per gal (59 lb per cu ft) would provide a 400-psi overbalance.

In lost-circulation territory the mud weight should, of necessity, be constantly checked and controlled by watering at the lowest value a study of the area has shown to be suitable. When a mud system is loaded with lost-circulation material, drilling proceeds with the shale screen bypassed and rapid weight increases can result from the re-circulation of cuttings, and control of the weight is much more difficult. In many cases holding the weight down is disregarded because of faith in the efficacy of the lost-circulation materials. Occurrences such as the following are not infrequent: A lost-circulation zone is encountered and after considerable mud is lost one of the lost-circulation plugs is displaced into the loss zone. A fresh bit is then run and, using newly made light-weight mud, drilling proceeds with full returns; but after further drilling circulation is again lost. The drillers generally assume that a new loss zone was encountered when actually it was the build-up in mud weight while drilling that broke down the original zone to cause the second loss.

A new tool to combat lost circulation is available, viz., the very low-weight drilling fluids made possible by the development of oil-emulsion muds. A 7.8 lb per gal (58 lb per cu ft) emulsion mud or an 8.2 lb per gal (61 lb per cu ft) saturated salt-emulsion mud can be built. The minimum weight of an oil-base mud is close to 7.5 lb per gal (56 lb per cu ft).

It continues to be said that oil-emulsion muds are expensive; that it is cheaper to use a 9.5 lb per gal (71 lb per cu ft) bentonite and chemical mud and accept the costs of lost circulation than it is to use a 9.0 or 8.5 lb per gal (67.5 or 63.5 lb per cu ft) emulsion mud. There is strong opinion, however, that the emulsion muds will prove to be cheaper because of faster drilling rate and longer bit life. Data are accumulating that the low-solids emulsion muds are even faster drilling fluids than water. Also, inasmuch as they do not take up solids as do clay-water muds, oil-emulsion muds are probably cheaper to maintain than the comparable, but higher weight, clay-water muds.

Mechanically Imposed Pressures

In March 1951, W. C. Goins and associates presented a paper, "Down-the-Hole Pressure Surges and Their Effect on Loss of Circulation"[8] (see also references 9, 10, 11, and 12). The work reported is widely recognized as a notable contribution to the drilling art. By means of pressure recorders mounted in the drill stem, measurement was made of the magnitudes of pressure surges developed while running drill pipe at different rates, from opening the pumps quickly or gradually, and from spudding with the pumps running. It also was evident that running in with a plugged bit or with a float in the drill stem increased the pressure surges and that pumping with a balled-up bit and drill collar threw the full pump pressure on the formation. Consideration also indicates that the clearance between drill pipe and casing or hole is important. Larger clearances minimize both the pressure reductions in withdrawing the drill pipe (swabbing) and the pressure increases (surges) in running and handling the drill pipe. The extent of the measured pressure surges is best realized in terms of increased mud density. Rapid running in of the drill pipe gave surges equivalent to an increase in mud weight of 1.3 lb per gal (10 lb per cu ft). Spudding with the pump running gave surges equivalent to an increase in mud density of 2.3 lb per gal (17 lb per cu ft). When the pump was kicked open to start circulation, surges equivalent to an increase of 0.36 lb per gal (3 lb per cu ft) in mud density were noted, as compared with the pressure when the pump was opened gradually. It is also evident that reduction of pump pressure to decrease the annular velocity will lower the pressure on the formations.

After this study was made, its teachings were applied to a new well in the Texas Gulf Coast. Oil-emulsion mud was used to eliminate balling-up and to secure a low-gel, stable mud. Increased clearances were secured by use of streamlined drill pipe and the elimination of the rubber casing protectors. A no-spudding rule was enforced, as was a requirement for gradual opening of the pump after the kelly was lowered to near bottom. No drill-pipe float was used and the stands were lowered at about 40 sec per stand rather than the common 11 to 15 sec per stand. The well was completed without a single circulation loss, as compared with 79 losses in the three prior wells in the same field.

Many wells can be recalled where circulation has been continuous until a certain round trip when, with the fresh bit on bottom, returns could not be secured. Such losses are probably caused by the effect of the pressure surges while running in or in starting the pumps.

As stated, a difficulty in studying lost circulation is that in many fields there is no pattern to the location of the loss wells; they are simply scattered over the field. Many of these losses can be attributed to mechanically imposed pressures, and educational programs with the drilling crews will correct them. In the past two years, very encouraging understanding and cooperation from company and contract crews have developed along these lines.

Location of Loss Zone

It is evident from the foregoing that it is often of prime importance to locate the loss zone in a well. An upper zone drilled with full circulation can be later broken down or a successfully treated zone can later fail. The location can be made[10] with temperature, spinner, or resistivity-temperature(hot-wire) surveys. These surveys are not entirely satisfactory because mud must be pumped into the loss zone while running them, and their interpretation is frequently inconclusive; nevertheless, their successful application must be considered.

DISCUSSION OF PROCEDURES

When the analysis of the lost-circulation problem at a well location has proceeded through the review of the nature of the zone and the pressure conditions, a procedure or sequence of procedures best suited to the problem should be selected.

Special Drilling Methods

There is no way to successfully plug a highly cavernous or open-fissured zone to permit conventional rotary drilling. Examples of this would be drilling into a cavern such as the Carlsbad in New Mexico or an abandoned coal mine, as has happened in Illinois. The method of blind drilling, where water is pumped down the drill pipe to cool the bit and carry the cuttings into the loss zone and no returns are secured at the surface, has been developed for these conditions. An important variation is the use of a floating mud cap when drilling blind. Generally, each such loss zone is cased off after penetration. A recent paper[13] describes these drilling procedures in Saudi Arabia, and states that their adoption was the chief cause for the reduction in average drilling time from 120 days to 40 days. As much as 20,000 bbl per day of water are pumped down the drill pipe to cool the bit and carry the cuttings into the loss zone. It is noted that the floating mud cap method requires careful balancing of formation-fluid pressures with drilling and hydrostatic pressures.

Recently, blind drilling in several wells in the Denton Field, New Mexico, has successfully penetrated an apparently unpluggable zone occurring below 9,500 ft. In one case, the cuttings rather quickly bridged in the loss zone to give partial returns. After some additional drilling, a gel-cement plug was squeezed into the loss zone, and full returns were then secured during the further drilling to some 12,000 ft.

One objection to blind drilling in prospect wells is the absence of formation samples. This can be partially alleviated by the securing of occasional conventional cores.

A related drilling method is to drill under pressure, pumping water or oil down the drill pipe, and permitting the formation fluids to flow from the annulus.

Floating mud-cap drilling has been used in only one field in the United States, viz., Sunniland, Florida. Seven or eight wells were so drilled and then the use of a low-pressure drilling head with the well flowing was adopted. This latter method has been used where artesian flows have been encountered in shallow beds. The balance between mud densities which cause loss or permit flow can be very close at shallow depths.

Where serious lost circulation occurs in formations located above the water table, air drilling[14] has proved very successful for drilling the surface hole.

Waiting Periods

In many areas merely allowing a well to stand without pumping seems to permit the formations to adjust themselves to new pressure conditions and to allow full returns after the waiting period. One operator, in a Gulf Coast well, made the following tests[12] of this time factor:

Waiting period, hours	0	1	2	4	8
Casing pressure at which formation took mud, psi	350	275	150	150	525

The effect of waiting is probably most notable in the Gulf Coast, but it is also taken advantage of in North Texas and other areas.

The formations frequently strengthen, as regards mud losses, on exposure to mud and the drilling operation. For example, in a well in coastal Louisiana which was drilling with a 15 lb per gal (112.5 lb per cu ft) mud below a protective string, a pressure test was made to see whether a 17 lb per gal (12.5 lb per cu ft) mud could be circulated; the formation took mud at the imposed pressure. Drilling was then continued with the 15 lb per gal mud for some 200 ft, at which time the mud was slowly weighted up to 17 lb per gal. This was accomplished and drilling continued without loss. The practice of "pressure conditioning," i.e., the imposition of pump pressures to determine whether higher weight muds can be circulated, is not generally deemed helpful because it disregards this increase of strength with exposure.

In a recent well in a coastal Louisiana field, there were five losses while drilling with a 17 lb per gal (127.5 lb per cu ft) mud below a protective string. The first three were cured by pulling into the shoe and letting the well stand 8 hours. The fourth loss did not clear up after a waiting period and a "soft plug," a batch of mud equal to twice the volume of the open hole and loaded with about 15 lb per bbl of fiber and flake material, was equalized on bottom. Drill pipe was pulled into the casing, the well allowed to stand 8 hours, and complete circulation was then secured. The lost-circulation material was not screened out but was circulated and a fifth loss occurred, probably the result of excessive pressure caused by the circulation of this material. A waiting period cured this final loss.

The mechanism by which a waiting period or exposure to the drilling operation strengthens loss zones is obscure. Sometimes a balled-up bit and drill collar are pulled and the cause is, therefore, removed. Generally, however, it is believed that the liquid mud entering fissures becomes dehydrated or thickens with time and serves as a gasket to strengthen the zone. This latter explanation also serves as an explanation of the success of "soft plugs," batches of mud loaded with fiber and flake material, when displaced into fissures.

Lost-circulation Plugs

Neat cement has no place as a lost-circulation plug because its density is high, above 16 lb per gal (120 lb per cu ft); it is very fluid and lacks gelling or angle-of-repose properties. A long column of such a fluid in the drill pipe in a well which has lost returns with a light-weight mud, drops with high velocity and is likely to do nothing but make the loss zone more open.

Gel-cement plugs have been used for over 20 years in attempts to plug loss zones. Their main application is where the loss zone is at bottom, as with the Devonian losses in the Canadian plains. There are a number of reasons why gel cement is an unsatisfactory plugging agent. The density is relatively high, about 14 lb per gal (105 lb per cu ft) is the minimum. It contaminates, both in placement and while drilling out, all drilling fluids except the lime muds. In placement there is always the possibility of sticking the drill pipe and the plugs are, therefore, rarely squeezed. In drilling out there is always the possibility of losing the hole by sidetracking the plug. Another unsatisfactory plug is the sodium silicate–clay plug which is expensive and difficult to place and has never been widely used.

The effect of mud contamination from drilling cement should be further considered. When a gel-cement plug has been displaced to a loss zone and a good fill-up secured, the upper part of the plug will be drilled out with full returns. Often, however, as the bit nears bottom returns are lost and it is usually assumed that the zone was not fully sealed. In many instances, however, the second loss should be attributed to the increased pressure resulting from pumping out a long column of thickened, cement-contaminated mud. Oil-bentonite or time-setting clay plugs do not have this disadvantage.

It should not be concluded, however, that a gel-cement squeeze is not sometimes an important lost-circulation corrective. Cannon[15] has described such an application in a 16,255-ft East Texas well having more than 11,000 ft of open hole, a high-pressure sand "kicking" from bottom, and lost returns. Some successes with "burlap" plugs have recently been reported in the Rocky Mountains. Squares of burlap or canvas, one or two feet on a side, are rolled up and lubricated into a gel-cement plug through a lubricator located between the well head and cementing truck. The cloth can be considered to be reinforcing material and to increase the angle-of-repose property.

In the past two years, three new types of plugs have been developed. These have low densities, will not stick drill pipe, and do not contaminate drilling fluids. Oil-base mud of certain types will thicken immensely when contaminated with water or drilling mud. Displacement of about 5 bbl into a loss zone, where it thickens on mixing with mud and formation water, is a useful lost-circulation corrective. Diesel-oil spacers ahead of and behind the oil-base mud could be used, but in most applications are omitted. The diesel or crude oil–bentonite (approximately 300 lb of bentonite suspended in each barrel of oil) plug[10,11] is a similar one. The mixture is very fluid when being displaced; but when formation water and drilling mud contaminate and mix with it, the material thickens to resemble modeling clay. Diesel-oil spacers are generally used with these plugs. The time-setting clay plug is also a recent development and is well described in reference 16. This plug has rather quickly come into wide use and many successful applications have been reported.

Just how strong such plugs are or what strength is required of a lost-circulation plug is not known. Some preference for gel cement because of higher strength will continue, but this should not be a controlling factor in the selection of a plug.

Soft Plugs and Bridging-particle Plugs

The commercial lost-circulation materials are generally well known and may be classified in two groups, viz.:

1. Fibers and flakes
   a. Plant, wood and bark, and synthetic fibers
   b. Animal fibers such as wool linters or leather fibers
   c. Cellophane and cork flakes
   d. Mica
2. Bridging particles (some are sized)
   a. Expanded perlite[17] and coated coke fragments
   b. Fragmented set plastic and walnut shells
   c. Gravel pebbles

Howard and Scott,[5] in a recent paper, present experimental work with a simulated fissure apparatus connecting the concentration in mud of the two types of lost-circulation material with the width of fissures at which seals across the face of the fissure (not within the fissure) can be accomplished.* Their work indicates that a concentration of about 14 lb of flake or fibrous material per barrel of mud will bridge over fissures with widths up to 0.10 to 0.12 in. Increased concentrations will not bridge on fissures of greater width and simply pass through. The critical concentration with a bridging-particle material was about 20 lb per bbl, and the critical width of fissure was between 0.18 and 0.20 in. When a serious loss is encountered, a good practice would be to mix 50 to 150 bbl of mud near the pump suction to a concentration of 14 lb per bbl of a mixture of three of the fibrous and flake materials or to a concentration of 20 lb per bbl of walnut shells, and then displace it to the loss zone as a plug. Such treatments can be repeated several times to insure that the batch of loaded mud has been displaced into the loss zone. If circulation is not established, recourse must then be made to a plug of the type that stiffens in the loss zone. If circulation is regained, the shale screen should be used to remove

*For convenience, the chart of these results is included as Fig. 1 herein.

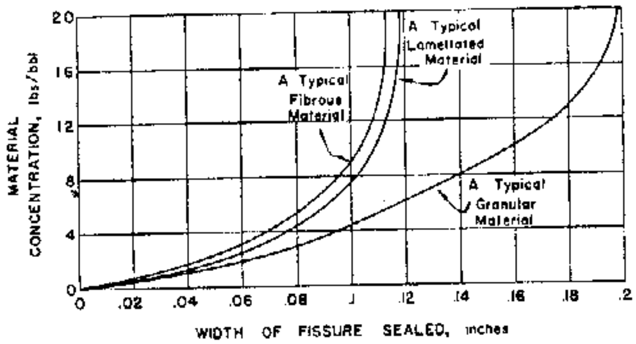

Fig. 1—Performance of Lost-circulation Materials in Sealing Fissures (After Howard and Scott[5])

any of the lost-circulation material which has joined the circulating mud.

Change of Method—Plugs to Blind Drilling

In a recent well in the Denton Field, New Mexico, a loss zone occurring near 10,000 ft was fought for 53 days without success. A great number of plugs of many types, utilizing a total of 9,000 sacks of cement and large quantities of other materials, were placed without effect. The fluid level stayed at 1,000 to 1,400 ft throughout. Blind drilling was then resorted to and, after drilling a few hundred feet, 7-in. casing was cemented.

In a more recent well in Denton, a complete loss occurred at 9,750 ft which was cured with 5 gel-cement and oil-bentonite plugs after pumping away 20 tons of bulk fiber and flake material had no effect. Drilling continued and another loss zone was encountered at 10,494 ft. Twenty-one varied plugs were placed and some drilling was done to 10,550 ft, but circulation was never regained. Blind drilling with water was then commenced, and within 12 hours partial returns were secured. Drilling continued to 11,300 ft with seepage losses of 10 to 20 bbl per hour, which the circulating of fiber and flake material did not decrease. A combination oil-bentonite and gel-cement plug was then squeezed into the loss zone, whereas previous plugs had gone away under vacuum. The plug was then drilled out and drilling continued to 12,100 ft with full returns.

It seems clear that the cuttings rising from the bit and carried into the loss zone bridged and closed the loss zone nearly completely. This occurrence raises the question whether a more practical procedure than long-continued blind drilling would be to drill blind through the zone (in the foregoing example to, say, 10,550 ft) and then displace through open-ended drill pipe in a thick gel-mud vehicle a quantity of a selected particle-size range of pea gravel, fragmented plastic, and walnut shells. Of course a great many such plugs have been used, but their record of success is not great and two suggestions are therefore made: *1*, that they be displaced from below the loss zone so that velocities are decreased in traveling up the annulus and out into the loss zone; and *2*, that larger quantities of bridging particles contained in the larger amounts of mud be used than in older treatments.

A conclusion as to change of method can be drawn from the foregoing well history:

1. Soft plugs (large quantities of bulk fiber material) had no success; because this is true generally in this field, such plugs should not be tried.
2. Hard plugs (five oil-bentonite and gel-cement) successfully sealed the zone at 9,750 ft. Therefore, a reasonable number of such plugs should be used as a first effort.
3. If these plugs are not successful, blind drilling should be tried. It would seem that engineered, bridging-particle plugs should be tried after only a short interval of blind drilling.

Circulation of Lost-circulation Materials, or Pretreatment

Howard and Scott[5] report tests in shallow simulated wells indicating that pretreatment, the addition to the circulating system in advance of loss of quantities of bridging materials, permits the imposition of considerably higher pressures on the formation before a breakdown or fracture occurs. This appears to be a dubious procedure with both low-solids and high-solids muds. Circulating lost-circulation materials requires that the mud bypass the shale screen. With the low-solids light-weight muds of the interior United States, bypassing the screen permits quick build-up of solids to increase weight and cannot, therefore, be tolerated. Certainly, any increased mud weight will contribute to losses. With high-solids muds, the addition of lost-circulation material will increase pressure against the formation because of thickened mud cake, increased-viscosity gels, and increased balling tendencies. Fine wood fiber or fine mica in concentrations of 1 to 5 lb per bbl of mud are recommended for pretreatment because they will pass through shale screens. It is difficult, however, to believe that such fine materials at such low concentrations can have any beneficial effects.

More recent work[6] by the same research group on multiple-pressure fracturing shows that an induced fracture may often be readily sealed by the displacement to it of a batch of mud thickened with bridging particles. Thus the use of bridging-particle plugs provides a way of "eating the cake and having it too." The circulation of heavy concentrations of lost-circulation material, with its attendant bad effects, can be omitted; and, if a fracture is induced, it can be remedied by the spotting of a batch of loaded mud.

Proper Use of Lost-circulation Materials

From the preceding two sections the suggestion is plain that a completely new evaluation should be made by the drilling industry of the use of these materials for combating lost circulation. For example, the citing of successful applications of these materials in wells drilled without any control of the drilling practices which cause large surge pressures with muds having a density to give, for example, 1,250-psi overbalance on the loss zone, would seem to be purely defensive. What is needed is to collect new experience with these materials in wells using the minimum proper mud weight and controlled drilling practices. It seems when the facts are developed that the use of these materials will be much restricted as compared with the present.

Lost Circulation in the Leduc Field, Canadian Plains

This great field is practically drilled up, but some observations there may have application in other fields. In wells located in the east flank, the drilling fluid was generally pretreated with sawdust before entering the vugular Devonian formation. In general, this was successful and less than 24 hours rig time was consumed with mud losses. Wells drilled in the central portion of the field frequently lost about 48 hours rig time in displacing mud loaded with sawdust and other lost-circulation materials into the loss zone. Wells situated along the west face of the reef frequently had real lost-circulation difficulties which required much more than 48 hours to clear up. In these wells the dropping of gel-cement plugs was resorted to; this procedure is detailed in reference 1, p. 78. The common mud weight in the field was 10.5 lb per gal (78.5 lb per cu ft), the Devonian was under a subnormal pressure gradient of about 0.37 psi per ft, and the overbalance was of the order of 800 psi. Inasmuch as an 8.5 lb per gal (63.5 lb per cu ft) mud would give about 325 psi overbalance, it would appear that decreased mud weights might have nullified or minimized the more difficult lost-circulation occurrences.

Drilling with Water

Much West Texas drilling is done with water because it is the cheapest and fastest drilling fluid. It is understandable that losses to the formation can be continuous and, for example, a loss of 15 bbl per hour is not considered serious. When losses increase, a leather fiber[18] circulated in the drilling fluid has an outstanding record of success. An older treatment is to suspend scrap cellophane in the fluid. Also, the oil-base, oil-bentonite, and time-setting clay plugs have been used with success in seepage-loss zones.

Casing Cementation

A most annoying type of loss is one where it is discovered, after much rig time has been consumed, that the lost mud is traveling back of surface or protective casing because of a channeled cementation. In any lost-circulation territory the use of the scratcher-centralizer-reciprocation technique for cementing both surface and protective casings seems justified.

A special type of lost circulation is the failure to secure proper fill-up in cementing casing because the cement goes out into the formation rather than rising in the annulus. The universal solution is to use lighter-weight cement slurries. A good neat cement slurry will weigh at least 16 lb per gal (120 lb per cu ft); one with a high bentonite concentration about 13 lb per gal (97.5 lb per cu ft); and current work is being carried on with expanded perlite and pozzolans as additives to gel cement to yield a density measured at atmospheric pressure as low as 10.5 lb per gal (78.5 lb per cu ft). Pressure increases the density of perlite-gel cements and they are generally used, therefore, only for surface-string cementation.

Simultaneous Lost Circulation and Blowout

Occasionally a well drills into a high-pressure zone with an insufficient mud weight and returns are lost while weighting-up the mud. Generally, the only satisfactory procedure is to plug off the high-pressure sand and then a string of casing can be set to exclude the loss zones. The placing of a barite or cement plug may be required to shut off the high-pressure zone and the procedures and considerations for this are set out in reference 1, p. 61. Barite plugs have been chiefly used in the Gulf Coast, but they should be kept in mind as a useful tool in any area.

Losses in the Gulf Coast

It is commonly accepted that the deeper a surface or protective casing string is set, the higher will be the mud weight that can be circulated without loss. Generally, no heavier than a 14.5 lb per gal (108 lb per cu ft) mud can be circulated in a deep well which has only 1,500 to 3,000 ft of surface pipe. Losses at lower weights than this are encountered often enough. No very successful way has been found to strengthen these long sections of open hole so that higher mud weights can be carried. Fortunately, normal-pressure zones can be safely drilled with mud weights from 9.7 to 10.2 lb per gal (73 to 76 lb per cu ft). If circulation is lost with a higher-weight mud, one procedure is to lower the mud weight to that which will circulate and to drill ahead to just above the first abnormal-pressure sand

and cement protective casing. The setting of protective casing at 9,000 ft or deeper generally permits the circulation of 16 to 18 lb per gal (120 to 135 lb per cu ft) muds.

If a generalization must be made as to the location of loss zones in Gulf Coast wells, it can be said that they are never, or rarely, at bottom; and, in general, are close to the last casing shoe.

When circulation is lost while drilling below a protective string with high-weight muds, the fluid level generally remains at the surface and the pressure in the annulus required for circulation, therefore, causes the loss. This pressure depends upon the clearances, the viscosity of the mud, and the rate of circulation. Where high-weight muds are to be used, as large clearances as possible should be provided, the mud should be a lime-emulsion mud for low viscosity and gel strength, and should have the minimum safe weight. If losses occur, circulation should be at reduced rates even though the drilling rate is slowed. The rig should be handled to avoid all pressure surges. Waiting periods should be used as a first treatment. Then displacement of one of the lost-circulation plugs should be undertaken. Lost-circulation materials should not be circulated in the mud.

Losses in Clam Lake Field, Upper Texas Gulf Coast

This field is located on a medium-depth salt dome and the normal fault pattern common to such structures is prominent. A recent well with surface casing at about 1,000 ft drilled with a lightly treated 9.8 lb per gal (73.5 lb per cu ft) mud to about 4,100 ft, which was at or near the intersection of two prominent faults, when circulation was lost and the fluid level dropped some hundreds of feet. Apparently, the drop in fluid caused some uncemented sand near the casing shoe to fall in and freeze the drill pipe. Another well indicated that this occurrence could recur and additional wells in the faulted area have, therefore, been drilled below the surface string with light concentration, 4 to 6 lb per bbl, of fiber and flake material in the 9.8 lb per gal mud. Such treatments can be considered as insurance and, being of low concentrations, are inexpensive and do not interfere with drilling.

CONCLUSION

When a well is being planned, the possibilities of lost circulation should be considered and the circumstances of the loss or losses and procedures used in similar wells in the vicinity should be studied. A program to properly handle the lost-circulation occurrences can then be prepared. Important considerations in preparing such a program are the use of *minimum* safe mud weight; the handling of the rig to avoid all pressure surges; any possible benefits should be taken from waiting periods; lost-circulation material should not be circulated except with well-understood conditions; lost-circulation plugs of the type most likely to succeed under the indicated conditions should be selected; and, finally, special drilling methods should be instituted after other procedures have been given a reasonable number of applications.

ACKNOWLEDGMENT

This paper was written after some three years' association in the work of the API Southwestern District Study Committee on Drilling Fluids, and acknowledgment is made of the stimulation from discussion and the published work of other committee members on the subject. Although the study committee has sponsored the presentation, the paper is the responsibility of the author alone.

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DISCUSSION

Orien Van Dyke (Magnet Cove Barium Corp., Houston) (written): Mr. Bugbee has presented a very thorough discussion of the lost-circulation problem, and I should like to compliment him for describing the various formation conditions which cause its occurrence. He has also called attention to the importance of educating the personnel on the drilling rig in regard to lost circulation so that both the drilling fluid and the mechanical phases of the drilling operation can be controlled in order to prevent needless cases of lost circulation.

As pointed out, surveys that have been run to accurately determine the point of loss have in most cases shown the loss point to be above bottom. The occurrence of such losses is baffling, because it is obvious that formation openings did not exist at the time such zones were drilled. There is the possibility that sometimes such losses may be caused by pressure surges or changes in the weight of the drilling fluid, as suggested by the author. However, in my opinion, such losses often occur with no changes in pressure conditions opposite such zones. In some areas, the frequency of lost circulation has been greatly reduced by drilling all of the hole below surface casing with a mud having reasonably good properties. It appears that the simple precaution of treating out the cement and conditioning the mud prior to drilling below surface casing will retard water soaking of soft-shale formations so that zones of weakness, which are potential points of loss, will not develop. The cost of such treating is very little, and it is something I should like to suggest as a protective measure to supplement those recommended by Mr. Bugbee.

Mr. Bugbee was quite critical of the fibrous and flake materials which are commonly used as a lost-circulation corrective. I do not believe he went so far as to say they were of no value, but there were numerous references to cases where they had proved ineffective. I certainly agree that fibrous and flake materials have limitations, but the fact remains that most cases of lost circulation are currently corrected with such additives, and it is the few exceptions that are widely discussed. Fine-size mica which will pass through an ordinary shaker screen is proving to be an easy-to-use protective measure against lost circulation, and there are indications that its use will allow the carrying of higher mud weights without formation rupture. Many cases of lost circulation have been very quickly corrected with a relatively small slug of fibrous material. In dealing with a lost-circulation problem, time is an important factor; and I would like to suggest that, along with the educational program which Mr. Bugbee has suggested, consideration be given to the maintenance of a small supply of a suitable fibrous material at all rigs so that, should lost circulation occur, a small treatment could be spotted in the hole immediately instead of the formation opening being enlarged by continued attempts to circulate while deciding what action should be taken and getting the necessary materials on the job.

The very fine work done by Howard and Scott certainly shows the limitations of fibrous, flake, and granular additives. Their laboratory work would indicate that a fissure having a width of 0.2 in. is the maximum size that could be sealed. Mr. Bugbee pointed out that it is probable that many of our severe cases of lost circulation are into relatively large openings. Additives to mud have a limitation as to pumpability, and it is not logical to expect bridging agents which can be circulated through a 4½-in. drill pipe and, in some cases, through 1-in. bit nozzles to effectively bridge openings that are larger, just because they are in the formation. This would certainly indicate that there is a limit to what can be expected of materials that can be added to the drilling fluid and circulated through the drill pipe to the point of loss. In view of the obvious limitations of mud-additive bridging agents, our only recourse appears to be the consideration of materials which change in physical properties after being spotted in the loss zone. Mr. Bugbee has discussed a number of these materials, which he describes as "plugs that harden or stiffen in the loss zone." For the past year our company has been doing work with the time-setting clay cement he mentions, which is mixed up as a viscous fluid and gradually changes to a very stiff gel after being squeezed into the loss zone. A recent study of slightly more than 100 applications of time-setting clay cement showed that approximately 64 percent were successful. These results are encouraging because most of the applications were in wells in which various other methods for correcting the loss had previously been tried without results. It appears that materials that change state after being placed in the formation offer the most interesting prospects for the correction of severe types of lost circulation.

H. W. Perkins (Sun Oil Company, Beaumont, Texas) written): Mr. Bugbee is to be complimented for his excellent and complete summary of the current thinking on this serious problem in our drilling operations. In addition, numerous references are included to expand the discussions in the paper which could not be covered completely without making it too lengthy. The paper should be especially helpful to those of us instructing company men in work on drilling fluids, because it can be used as a text in discussing our present approaches to combating lost circulation.

Our most troublesome cases of lost circulation in the Gulf Coast area of Texas and Louisiana have been those that occurred after setting protection strings, and mud weights of 15 lb per gal or higher have been required to prevent intrusion of formation fluids. In these cases, a delicate balance of 0.2 or 0.3 lb per gal in weight is often necessary to contain the formation fluids and yet not lose mud to the formation. Such losses are believed to be to the faulted, jointed, or fissured formations discussed by Mr. Bugbee. To explain the reason for this delicate balance and to make the literature references still more complete, I believe that two additional papers should be included in the list of references. One is "Abnormal Pressures and Lost Circulation," by P. E. Chaney.[1] This paper proposes a theory for abnormal pressures by which the formation-fluid pressures could be equivalent to the strength of the formation. Therefore, when such a reservoir is drilled, the mud weight to prevent the intrusion of fluid must be as high as the strength of the formation. Any excess mud weight would result in mud loss by breakdown of the formation. The other paper is "Mechanical Basis for Certain Familiar Geologic Structures," by M. King Hubbert.[2] Dr. Hubbert in his paper shows that the state of stress which results in normal faulting is one in which the horizontal stress is less than the vertical stress. Under these conditions, which are believed to exist in the Gulf Coast area, it is necessary that only the minimum or horizontal stress be exceeded to induce fracturing. Mud weights required to exert pressures exceeding the minimum stress could therefore be considerably lower than those required to exceed the vertical stress, which is the weight of the overburden. The teachings of these two papers would explain the reason that only 0.2 or 0.3 lb per gal over a wide range of mud weights may mean the difference between mud loss and formation-fluid intrusion.

Of the recent advances in techniques for combating lost circulation, I believe we have had better results with the waiting period and careful control of both the drilling operations and mud properties. These methods have been used successfully in fields in the vicinity of Winnie, Texas, and Crowley, Louisiana. The mud losses with high-weight muds in these fields were believed to be caused by the breakdown of the formation. The mud weight could not be lowered because of abnormal pressures. A study of the factors involved in such losses indicated that methods which lessened the pressure surges on the formation would give the best chance of reaching total depth with minimum mud costs. Experiences in these fields thus far have supported these conclusions.

I should like to thank Mr. Bugbee on behalf of the API Southwestern District Study Committee on Drilling Fluids for his acknowledgment to our committee and for permitting the presentation of the paper to be sponsored by the committee.

W. C. Goins, Jr. (Gulf Oil Corp., Houston): This is a very fine paper, and I should like to compliment the author on it. He has covered the field very thoroughly as regards loss of circulation.

I should like to comment on this matter of engineered particle-size distribution of sealing materials which Mr. Bugbee mentioned. We frequently hear the statement on the Gulf Coast that sealing materials are not of any use at all, which is not quite true, because they do seal quite a few losses. However, it might be profitable to inquire just why they frequently fail. Mr. Van Dyke has already touched on that in part.

The work of Howard and Scott (reference 5 of the paper) indicates that the largest opening one can hope to seal with fibrous material is about 0.14 in. Soft materials can shear down and blow out of a plugged opening of a larger size when there is a pressure surge or if a large pressure differential has been built up. This explains the smallness of openings sealed. If a good hard granular material is used, an opening up to about 0.20 in. can be sealed. The reason for this limitation is that a minus 4-mesh hard particle (about 0.22 in.) is about the largest that can be circulated with rig pumps. In any event, the use of circulatable sealing mate-

[1] References are at the end of the discussion.

rials can be expected to seal what would be classed as only very small openings.

Then, too, with granular materials the matter of engineering for particle-size distribution is very important. If mud were pumped through a container filled with small marbles of equal size, it would pass through without difficulty. However, if the proper gradation of marble sizes were present, the openings between marbles would be closed and a seal would be obtained. Most of our sealing materials have been run into the well without consideration of the fact that there must be successively smaller particles to bridge the openings between large particles.

In summary, the use of circulatable sealing materials, even where proper particle-size distribution and mechanical strength are present, would not be expected to cure lost circulation except to very small openings. If these fail, other techniques must be used. It is hoped that these concepts of the performance of sealing materials help to explain the limitations on the usefulness of the materials and further emphasize Mr. Bugbee's statements about the use of properly engineered sealing agents.

D. E. Ramsey (Dowell, Inc., Midland, Texas) (written): There are a number of points which the author of this excellent paper brought up which I should like to discuss briefly; or, better still, on which I should like to encourage some more thought and action along some of the lines he mentioned.

Mr. Bugbee points out the tremendous expense that lost circulation adds to any major exploration or development program. Large mud bills, special lost-circulation materials, lost holes, blowouts, and lost rig time are some of the items of expense that are always associated with major lost circulation. The oil industry as a whole, and service companies in particular, have probably fallen far short of the merited research and development of new products and techniques for combating lost circulation.

There have been, as the author indicates, several recent developments such as improved drilling practices that have lessened the frequency of lost circulation. These developments are a result of better understanding of the factors that provoke lost circulation. There have also been some new and improved materials developed and tested to combat lost circulation once it occurs. These include time-setting clay cements, new soft plugs, and new bridging-particle plugs. Better techniques for placing these plugs have been developed. All of these developments came from planning and study of the problems and conditions involved. The individuals and groups, such as the API study committee, responsible for these developments have performed a worthy service to the industry as a whole.

The erratic occurrence of lost circulation was pointed out by Mr. Bugbee. In formations where weathered, vugular, or fracture porosity and permeability are present, lost circulation is an ever-present hazard. Inasmuch as lost circulation might occur at any point in such exposed sections, the problem of shutting off these losses is increased. In deep wells there is the danger of contaminating large volumes of mud, sticking drill pipe, and deviating from the hole while drilling long unnecessary cement plugs, if the control efforts are not directed at the thief zone. In 1951 and 1952 some 60-odd hot-wire surveys and about 20 spinner surveys were run to determine which part of the hole was thiefing the circulation fluid. These surveys revealed the fact that in about 65 percent of the wells surveyed the fluid was being lost to some zone above the current total depth of the hole. After the operator knew which zone was taking fluid, his efforts to shut off the thief zone were more efficient. It is impossible to definitely evaluate such surveys on a dollar-wise basis, but drilling could be resumed quicker, and the shut-off was effected after spotting fewer plugs in all of the difficult lost-circulation areas in West Texas that have been studied. Although this is not a large number of surveys, these surveys are becoming more popular, indicating that there is interest in this type of work. Repeat surveys speak for their advantage.

A recent development in locating zones of permeability which might have application in locating zones of lost circulation involves spotting a small volume of fluid containing a short-lived radioactive material in the well bore. After pumping a few barrels of mud into the well, the displacement of this spot of radioactive material could be determined with a Geiger counter or a gamma-ray tool. This method has not, to my knowledge, been used to determine zones of lost circulation although it would have several advantages over some of the other methods. About 30 of these surveys have been run on water-injection wells and producing wells, and have checked very favorably with the spinner surveys in the same wells.

Some recent developments in the equipment used in mixing and spotting plugs to combat zones of lost circulation are regular squeeze trucks equipped with ball-type valves for pumping mixtures containing large solid particles, and 72-bbl transports equipped with power-driven paddles to mix and disperse lost-circulation plugs. Anyone who has tried to mix a small plug with a jet hopper can appreciate the value of this equipment.

In closing, I should like to urge those who are in the management group to appreciate the fact that the engineer, foreman, or superintendent who is sitting on a well with lost circulation has the problems of the United Nations and an unsubsidized cotton farmer. Your cooperation with these unfortunate individuals will certainly be appreciated if not blessed.

Again, I should like to compliment Mr. Bugbee on his excellent paper, and to express appreciation for the fine job he and his committee have done.

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Purchasing & Printing Division
R
JUN 23 1978

No. 1897

AFFIDAVIT OF PUBLICATION

STATE OF NORTH DAKOTA)
)ss.
County of Hettinger)

THE SLOPE MESSENGER

Duane F. Clark ..., of said State and County, being duly sworn on his oath says: That he is the Publisher of the SLOPE MESSENGER, a weekly newspaper of general circulation in Slope County, North Dakota, printed in the City of New England in Hettinger County, N. Da... legal newspaper for the county of Slo... the time hereinafter mentioned, a... numbered 1897 and headed ... printed copy of which is hereunto a... regular and entire issue of said new... time of publication, and that the noti... paper proper, and not in a supplemen... successive weeks, to-wit:

Thursday, 6-7 1978 Th...
Thursday, ... 19...... Th...
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FEE $ 16.50

Duane ...

Sworn and subscribed to bef...

My commission expires ...

LEGAL NOTICE

NOTICE OF PUBLICATION
N. D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

The State of North Dakota by its Industrial Commission hereby gives notice pursuant to law and the rules and regulations of said Commission promulgated thereunder of the following public hearing to be held at 9:00 a.m. on June 20, 1978, in the Large Hearing Room, Capitol Building, Bismarck, North Dakota, before the Industrial Commission or an Examiner appointed by the Commission for that purpose.

STATE OF NORTH DAKOTA TO:

All named parties and persons having any right, title, interest, or claim in the following case and notice to the public. CASE NO. 1563: On a motion of the Commission to consider having the operators in the following fields show cause that field rules should not be amended to provide for surface casing being set not less than fifty (50) feet below the base of the Foxhills Formation and cemented to the surface: Elkhorn Ranch, Franks Creek, Fryburg, Little Knife, Medora, and Rocky Ridge, all in Billings, County, North Dakota; Amor, Ash, Cedar Creek, Cold Turkey Creek, Coyote Creek, Grand River, Haley, horse Creek, Little Missouri, Medicine Pole Hills, and State Line, all in Bowman County, North Dakota; Halliday, Haystack Butte, Killdeer, Little Knife, Lost Bridge, Oakdale, Rattlesnake Point, and Russian Creek, all in Dunn County, North Dakota; Rider and Square Butte in Golden Valley County, North Dakota; Antelope, Bear Den, Bicentennial, Blue Butte, Boxcar Butte, Camel Butte, Charlson, Clear Creek, Croff, Dimmick Lake, Earl Hawkeye, Keene, Little Knife, MonDak, North Fork, Pershing, Poker Jim, Red Wing Creek, Rough Rider, Union Center, and Yellowstone, all in McKenzie County, North Dakota; Amidon, Eleven Bar, and Rocky Ridge, all in Slope County, North Dakota; Buffalo Creek, Dickinson, Green River, Rocky Ridge, South Heart, and Zenith, all in Stark County, North Dakota.

Date 6-1-78

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M June 7, 1978

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Date 6/21/78

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JUN 20 1978
STATE CAPITOL
Bismarck, North Dakota

AFFIDAVIT OF PUBLICATION

GOLDEN VALLEY NEWS
OFFICIAL NEWSPAPER FOR BEACH AND GOLDEN VALLEY COUNTY

STATE OF NORTH DAKOTA,
County of Golden Valley — ss

Leana Odermann being duly sworn, deposes and says, that the annexed printed copy of notice of publication

was taken from the Golden Valley News, a newspaper which during the whole time of publication of said notice hereinafter stated, has been and is printed and published in the City of Beach, County of Golden Valley, and State of North Dakota. That the said notice was published in said newspaper on the following dates:

June 8 19 78	19	19
19	19	19

in each and every issue of the full number thereof, upon which days or times of publication aforesaid newspaper was regularly published, and that during the whole time of said publication __he was one of the employees or publishers of said newspaper.

Leana Odermann

Subscribed and sworn to before me this 15th day of June 19 78

Sharon Brengle
Notary Public, Golden Valley, North Dakota.

My Commission expires
SHARON BRENGLE
Notary Public, GOLDEN VALLEY CO., N. D.
My Commission Expires NOV. 9, 1982

NOTARY PUBLIC

NOTICE OF PUBLICATION
N. D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

The State of North Dakota by its Industrial Commission hereby gives notice pursuant to law and the rules and regulations of said Commission promulgated thereunder of the following public hearing to be held at 9:00 a.m. on June 20, 1978, in the Large Hearing Room, Capitol Building, Bismarck, North Dakota, before the Industrial Commission or an Examiner appointed by the Commission for that purpose.

STATE OF NORTH DAKOTA TO:

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(June 8)
(B&M)

14^{30}

$ ______ Date 6/21/78

HAROLD NELSON State Printer

AFFIDAVIT OF PUBLICATION

BILLINGS COUNTY PIONEER

OFFICIAL NEWSPAPER FOR BILLINGS COUNTY

Purchasing & Printing Division RECEIVED JUN 20 1978 STATE CAPITOL Bismarck, North Dakota

STATE OF NORTH DAKOTA.
County of Billings — ss

Leona Odermann being duly sworn, deposes and says, that the annexed printed copy of notice of publication

was taken from the Billings County Pioneer, a newspaper which during the whole time of publication of said notice hereinafter stated, has been and is printed and published in the Town of Medora, County of Billings, and State of North Dakota. That the said notice was published in said newspaper on the following dates:

June 8 1978 .... 19 .... 19 ......

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in each and every issue of the full number thereof, upon which days or times of publication aforesaid newspaper was regularly published, and that during the whole time of said publication ....he was one of the employees or publishers of said newspaper.

Leona Odermann

Subscribed and sworn to before me this 15th day of June 1978

Sharon Brengle
Notary Public, Billings County, North Dakota.

My Commission expires ....

SHARON BRENGLE
Notary Public, GOLDEN VALLEY CO., N.D.
My Commission Expires NOV. 9, 1982

SHARON BRENGLE NOTARY PUBLIC NORTH DAKOTA

NOTICE OF PUBLICATION
N. D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

The State of North Dakota by its Industrial Commission hereby gives notice pursuant to law and the rules and regulations of said Commission promulgated thereunder of the following public hearing to be held at 9:00 a.m. on June 20, 1978, in the Large Hearing Room, Capitol Building, Bismarck, North Dakota, before the Industrial Commission or an Examiner appointed by the Commission for that purpose.

STATE OF NORTH DAKOTA TO:

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(June 8)
(B&M)

BOWMAN COUNTY PIONEER

ok

Affidavit of Publication

Date 6-16-78

HARVEY NELSON

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State Printer

...rson ... of said State and County
...s the SECRETARY of the BOWMAN COUNTY
...ation printed and published in the City of Bowman
... is now the official newspaper for the County of
...einafter mentioned, and headed

Publication

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Ervin Schneider

ERVIN SCHNEIDER
Notary Public, Bowman County, N. D.
My Commission Expires Oct. 4, 1982

NOTICE OF PUBLICATION
N.D. INDUSTRIAL COMMISSION
BISMARCK, NORTH DAKOTA

The State of North Dakota by its Industrial Commission hereby gives notice pursuant to law and the rules and regulations of said Commission promulgated thereunder of the following public hearing to be held at 9:00 a.m. on June 20, 1978, in the Large Hearing Room, Capitol Building, Bismarck, North Dakota, before the Industrial Commission or an Examiner appointed by the Commission for that purpose.

STATE OF NORTH DAKOTA

TO:

All named parties and persons having any right, title, interest or claim in the following case and notice to the public.

CASE NO. 1563: On a motion of the Commission to consider having the operators in the following fields show cause that field rules should not be amended to provide for surface casing being set not less than fifty (50) feet below the base of the Foxhills Formation and cemented to the surface: Elkhorn Ranch, Franks Creek, Fryburg, Little Knife, Medora, and Rocky Ridge, all in Billings County, North Dakota; Amor, Ash, Cedar Creek, Cold Turkey Creek, Coyote Creek, Grand River, Haley, Horse Creek, Little Missouri, Medicine Pole Hills, and State Line, all in Bowman County, North Dakota; Halliday, Haystack Butte, Killdeer, Little Knife, Lost Bridge, Oakdale, Rattlesnake Point, and Russian Creek, all in Dunn County, North Dakota; Rider and Square Butte in Golden Valley County, North Dakota; Antelope, Bear Den, Bicentennial, Blue Butte, Boxcar Butte, Camel Butte, Charlson, Clear Creek, Croff, Dimmick Lake, Earl, Hawkeye, Keene, Little Knife, MonDak, North Fork, Pershing, Poker Jim, Red Wing Creek, Rough Rider, Union Center, and Yellowstone, all in McKenzie County, North Dakota; Amidon, Eleven Bar, and Rocky Ridge, all in Slope County, North Dakota; Buffalo Creek, Dickinson, Green River, Rocky Ridge, South Heart, and Zenith, all in Stark County, North Dakota.

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(Published June 8, 1978)

CERTIFICATE OF PUBLICATION

THE DICKINSON PRESS
Dickinson, North Dakota

RECEIVED
JUN 12 1978
Bismarck, North Dakota

STATE OF NORTH DAKOTA,
County of Stark.

Gloria Foster, of said state and county, being first duly sworn, on oath says: That she is the Bookkeeper of the Dickinson Press, Inc., publisher of **THE DICKINSON PRESS**, a daily newspaper of general circulation, printed and published at Dickinson, in said county and state, and has been such during the time hereinafter mentioned; and that advertisement headed Notice Of Publication

a printed copy of which is hereunto annexed, was printed and published in **THE DICKINSON PRESS**, and in the regular and entire issue of each and every number 1 consecutive weeks, commencing on the 8 day of June A. D. 1978, and ending on the 8 day of June A. D., 1978, both inclusive.

Gloria Foster

Sworn to and subscribed to before me this 8 day of June A. D. 1978.

$ 21.42

Date 6-12-78

MP

HAROLD NELSON
State Printer

ED J. HAUCK
Notary Public, STARK COUNTY, N. DAK.
My Commission Expires JUNE 7, 1979