MUD ENGINEERING

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MUD engineering, a comparatively new specialization, is of increasing significance as diminishing oil reserves emphasize the need for more drilling. Application of this particular technology is typical of many that are found in the nation's fourth industry, now of even greater importance in our present oil war. An understanding of how chemical engineering aids in the search for oil requires some explanation of the process of rotary drilling.

DRILLING OPERATIONS

Two principal methods have been used in drilling for oil and gas. In the older standard, cable-tool or churn-type method percussion tools are employed; however, for the most part this method has been superseded by the use of rotating bits. These bits are screwed on the ends of lengths of hollow pipe as needed. At the surface end of the assembly, torque is applied and rotation established through a bushing in which a special square, hexagonal, or octagonal member slides. In effect, the machine is a huge drill press driving a bit through a hollow shaft. Cutting force is applied to the bit by the weight of the string of pipe itself, although only a small fraction of this weight usually is needed. A lifting mechanism is required to control this force and to pull the pipe from the hole. Each time a bit becomes dull the entire length of pipe must be removed from the bore and stacked in the derrick in sections, the bit replaced, and then re-run back to the previous depth.

A large proportion of the time required to drill a well is consumed in making round trips into and out of the hole, at which time a dull bit is replaced by a sharp one. Shorter "round trip" time makes for economical operation and may be accomplished by more hoisting speed or higher derricks to accommodate greater lengths of the individual elements (usually three or four pipe lengths) of the racked drill pipe. Derrick height for deep drilling is limited by other considerations and standardized at 136 feet. Hoist flexibility requires several gear ratios to attain high speed with the pipe load of a few hundred to 200,000 pounds. Electric motors, steam or internal combustion engines are used to power the rotary and lifting mechanisms, as prime movers for pumps, and for other requirements.

Circulating fluid and pumps constitute one remaining major element of the rotary drilling process. The mud is forced via a hose and swivel into the rotating drill string, down to and through holes in the bit, where jetting helps drill soft formations, where it lubricates, flushes, and cleans and then returns to the surface. The mud carries the drilled cuttings up the annulus between drill pipe and hole wall to the top, where they are separated and discarded. Other functions of the mud depend on its constituents and treatment. Desiderata such as control of potential hazards from formation characteristics or content, proper removal of cuttings, helping to keep the hole free and minimizing the formation of cavities are some of the functions which have been attained with some success. Progress and improvement along these lines have required a great deal of time and research from simple beginnings.

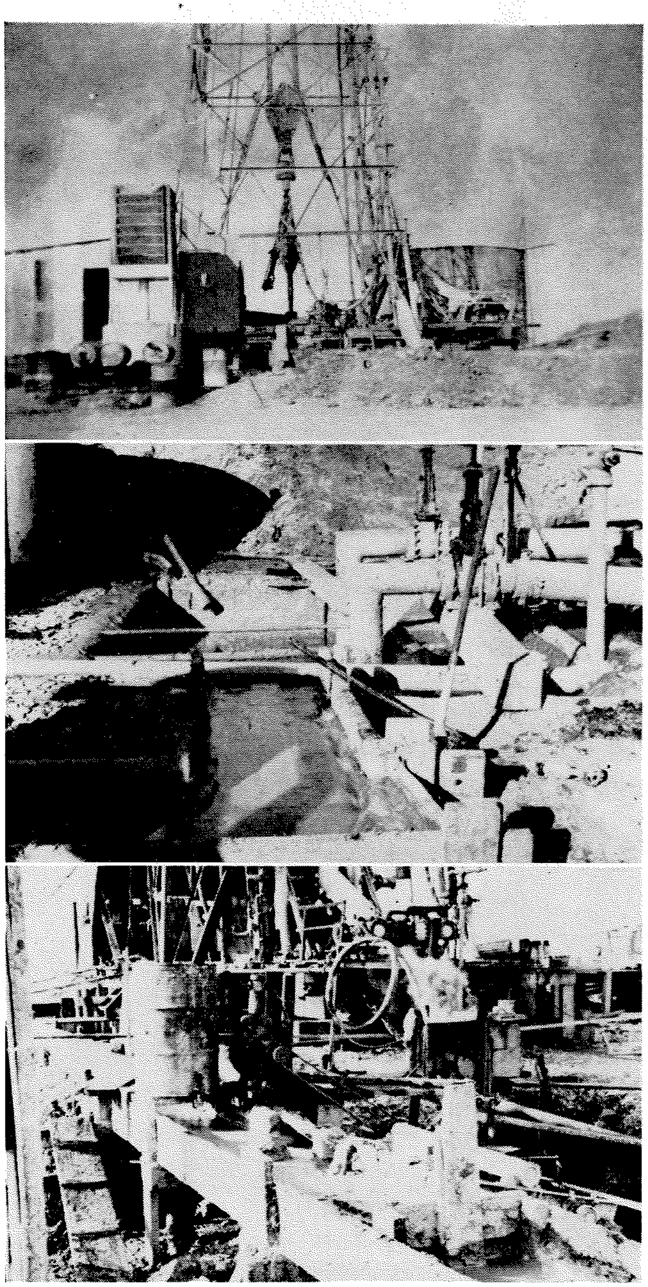
The percussion method of drilling uses water to facilitate bailing the cuttings out of the hole, but as there is no circulating fluid, mud problems are non-existent.

Drilling rig in the California woods.

Early rotary drilling crews used water as a circulating fluid; however, it was soon found that clay from upper strata produced muds and that better results followed. Thus, born of necessity, the development of mud technology was slow in its early stages, although progress has been accelerated by a realization of the role improved muds play in drilling operations. The oil industry has found that efficient drilling and profitable completions require muds made from carefully selected materials along with adequate field control. The importance of proper drilling fluid preparation and use cannot be overemphasized. Deep drilling has become increasingly successful almost in proportion as the mud engineer has increased his knowledge and experience.

MUD FORMULATION

Raw materials used for mud making are usually selected clays and are judged by properties of water mixtures of them. Their suitability is determined by various criteria, among which are the volumetric yield of a given clay, soluble impurities, abrasives content, and filtration characteristics. The last of these is a measure of the watery filtrate expressed from the mud when it is forced against porous media. The major physical properties desired and controlled when possible by the operator are as follows: density at a pumpable viscosity, *pH*, alkalinity, thixotropy, and filtration performance. Density is adjusted in an effort to keep formation fluids in place and at times to reduce harmful effects of formations sensitive to excessive filtration or improper *pH*. The



UPPER VIEW: Swivel and hose. CENTER VIEW: Mud ditch where chemical treatment is given. LOWER VIEW: Chemical treatment drum over mud ditch.

control of *pH* may be useful in viscosity reduction, thixotropy change and the tendency of some formations to contaminate the mud with inferior material. A certain degree of gelling is desired to hold cuttings in place when circulation is suspended; hence thixotropic properties of muds are altered by various means. Certain characteristics may be tailored in so far as it is possible to fulfill the requirements of particular jobs.

Mud is mixed in the field at the rig by simple means. Water is circulated through a jet mixer which creates a suction. Clay is shovelled or dumped into a cone above the jet and thus introduced into the water. Hydration and circulation help to make a more uniform mix. Some ready-mixed muds are available in areas of considerable activity, but the added cost of transporting water precludes universal use of this simple expedient. Chemical treatment usually is given by means of mixes added directly to the flowing mud during its passage from hole to pump through open ditches. A small tank or tanks, from oil drum size up, are spotted over the ditch and provided with water and steam or other heating means. Additions to the mud are proportioned from these tanks.

When high-pressure-formation fluids such as water, gas or oil are suspected or encountered, or when other less tangible factors lead to the use of increased density muds, special clays may be required, plus high-density fine-ground mineral additives. Among the latter, silica, limestone, barytes, hematite and gelena have been used. At times an excess of mud density over some critical value causes the hole to take fluid through various possible mechanisms. A combination of high-pressure-formation fluids plus critical density for fluid loss may occasion one of the most difficult of mud problems. Added complications may include a high-density mud requisite for pressure control and a few pounds per cubic foot density differential between backflow and lost mud. If the backflow is due to salt water under high pressure, too low density can cause contamination and ruining of the expensive weighted mud, whereas a slightly higher density may cause large fluid losses. Fortunately usual problems are less severe.

Chemical treatment is valuable in most applications and under certain conditions its use is imperative. Should it become necessary to control excessive viscosity when using high-density mixes or at other times, more clay extra additives or chemical viscosity reducing agents may be employed. Reagents are used to reduce viscosity, change *pH*, alter gel formation, improve filtration, deflocculate solids, and for other minor purposes. Complex phosphates, organic colloids like various tannins, sodium carbonate, bicarbonate, and hydroxide find frequent application. Often, tons of chemicals may be used on one job, the majority of which may be of a flexible ratio, tannin-phosphate treatment. Even larger quantities have been used on longer jobs necessitated by deeper drilling or special problem wells. Since the usual chemicals cost from three to 30 cents per pound, it can be seen why expenses often run into thousands of dollars.

Although there is no direct relationship, the consumption of a ton of chemicals may be accompanied by the use of 10 tons of clay and perhaps tons of additive high density minerals. These materials have, in some instances, run the cost of mud alone toward the hundred thousand dollar mark. At the other extreme, a shallow well may be drilled in an area where clays or shales are penetrated which make satisfactory muds merely by being mixed with adequate quantities of water. Little or no chemicals may be required and the cost can be less than a hundred dollars spent for mud to commence drilling or for minor treatments. Other factors influencing mud needs or treatment complexity depend on the well's location.

In lease drilling, where adjacent wells are progressively drilled, costs may be reduced by salvage and piping of muds from one to another, which reduces consumption materially. Drilling costs, especially mud expense, usually will be less in successive wells. Here the mud engineer, operator, and drilling crew can cooperate through experience and mutual effort to use chemicals and clays more efficiently. Often costs can be cut in half or further reduced in the course of several jobs.

Prospect or "wildcat" drilling is more expensive, for mud must be more carefully prepared and controlled, with a reasonable factor of safety, particularly with regard to its density, to reduce blowout hazard. Formations penetrated, apart and aside from their contained fluids, influence the mud problem.

Although most shales are hydratable and disintegrate somewhat when wet by water, drilling in some areas, notably along the coast of the Gulf of Mexico, is complicated by thick zones of extremely sensitive shale. Drilling these beds is sometimes virtually impossible, because the hole cannot be kept open and may even close in on the rotary tools during drilling. However, extraordinary mechanical techniques, large equipment and careful mud control contribute to successful penetration toward the lower objective horizons. Both special drilling fluids and extensive chemical treatments have been used. Although high density fluids seem to help, the most important factor is to avoid watery filtrate penetration into shale, which causes it to constrict the bore and freeze the drill pipe and bit, slowing up the job or forcing abandonment. Sodium silicate and common salt mixtures possess desirable properties for this type of drilling and have been used extensively. Drilling with this mixture often yields cuttings similar to turnings from a metal lathe. The formation chips show scoring and bit marks. There has been some application of salt-silicate fluids in similar formations encountered in the San Joaquin Valley of California. Other formation types require different mud technique.

It is often desirable to treat the mud and use an accompanying mechanical technique which will reduce the amount of drilled material incorporated in the mud. With salt-silicate mud, a proper choice of bits, rotary speeds and applied force will increase the size of cuttings and reduce tendency to form powder which would be left in the mud when passed through shaker screens normally used to separate cuttings, and thus eventually become part of the mud. Excess solids in the fluid require more makeup and treatment and will thus raise mud costs. Water-clay muds suffer the same type of contamination, which may cause complications if the formation drilled makes lower density mud with poorer qualities than that desired for the job. Control of *pH* and the use of special reagents have been used to counteract this tendency. Formations with large size pores give rise to another type of problem.

Part of all of the circulating mud stream may be diverted by a gravel, conglomerate, fractured zone, or other extra porous formation, or by gross fissures and caverns. Loss of mud through such causes, which may be expensive and time consuming to cure, is frequently encountered, especially in certain areas. Lost circulation is treated by various means, including thickeners, fibrous or flaky materials, addition of selected solids, special reagents, and cementing. Extreme cases require the use of protective piping. Besides problems arising from formation variables, others due to special auxiliary mechanical operations may necessitate different attacks by the engineer.

Viscosity usually is reduced and the mud stream made uniform by treatment and careful control preparatory to several phases in the average well's history. These steps are taken to improve results when casing (a protective pipe string) is run, when formations are tested or cored by special tools, and when logging by electrical devices is done. Extra precautions may be necessary for the above and for other operations before the well is finished.

Specialized mud preparation for certain stages has proceeded beyond the simpler mixtures which were used for every purpose only a few years ago. Now various phases in the drilling may call for diversified treatments and control. The period after the hole is finished, or, in known areas, from before the producing formations are penetrated until the final conclusion of work, constitutes a stage in the job known as completion. Current belief backed up by considerable supporting evidence suggests that the use of carefully-selected completion fluids may result in increased production. The possible deleterious effect of water loss, which may block production by reducing the permeability of the formation to oil flow, should be reduced and any mechanical impediment mud cakes may offer to oil flow should be minimized. These muds may be water-clay mixes with special treatments or they may have entirely different constituents. Among those finding current usage are oil base muds, which take several forms, all using some petroleum oil or cut as the major fluid constituent; organic colloid muds, which are heavily treated with starch or similar agents; and positive colloid muds, recently suggested, which are mixes of lower-than-normal hydrogen ion concentration containing dyes and special clay muds. Low-density muds with a relatively weak concentration of special clays containing preponderantly colloid-sized particles have been employed and special efforts to reduce water loss to the producing formation have been made when regular muds are used. Frequent contamination of muds with ground set cement just prior to completion has been countered with special treatments, dilution, flushing or replacement with fresh mud. A casing usually is provided to keep the hole open, and is sealed with cement before completing. Since cement has a deleterious effect on ordinary mud, in that it both gels and thickens it, muds not harmed by cement are desirable. Here, too, other special treatments or fluids have been applied, all in an effort to enhance completion muds, and with the ultimate aim of increasing production. Coupled with new and different type muds and treatments are improved testing apparatus and instruments, with many more envisaged for the future.

MUD CONTROL AND TESTING

Ordinary control testing employs fairly simple tools. Among these are hydrometer type or beam-balance density devices, capillary tube funnel-shape and Stoermer viscosimeters, compressed-air-operated filter press, simple immersion tube or Stoermer viscosimeter gel meters, colorimetric gelatin strip and vacuum tube voltmeter glass electrode *pH* meters, screen or elutriative abrasives content devices and titrimetric salt content apparatus. Other apparatus has been used but the kinds named above find most common field application. Laboratory and research instruments are more complicated and include improved viscosimeters, filter presses, and analytical procedures for other chemical constituents. X-ray crystallographic spectroscopy and ultracentrifuging have been used in clay analysis. Efforts have been made to develop instruments capable of more than spot measurement.

Both viscosity and density have been continually indicated and recorded by instruments. Density meters are difficult to design and apply because of the thixotropic character of the usual mud. Some success has been attained with direct displacement types, particularly with a rotating float which also measured viscosity in a manner similar to the Stoermer viscosimeter, modified for continuous operation. A successful gravimeter presents a novel approach; it is described in detail.

The instrument consists of an indicator dial, voltage regulator and vibrator cell. The principle of operation involves the dampening effect of a dense fluid medium on a vibrating reed which, in turn, is actuated by an exciter coil suitably located so as to produce vibrations in the reed with oscillations of alternating current. The lower end of the reed is connected directly to a paddle, or vane, which is immersed in the fluid tested; hence the vibrations of the reed are transmitted to the vane. The reed and vane assembly is supported within the cell by ribbon or torsion type bearings located just below the reed member of the assembly. The free or upper end of the reed carries a magnetic coil over a permanent magnet, thus inducing a current which is registered on the indicator dial and which varies with the amplitude of *the period of vibration of the reed. With* this arrangement it is apparent that increasing resistance to vibration in the vane will increase the amplitude of vibration in the reed (assuming constant voltage and frequency of the exciter current) and thus generate more current from the magnetic field, which is registered by the indicator. Resistance to vibration in the vane is provided by the inertia resulting from the density of the fluid in which the vane is immersed. Theoretically, and apparently in practice, viscosity of the fluid is a negligible factor because the period of vibration of the vane is too small to exert any appreciable shear.

THE FUTURE OF MUD ENGINEERING

Development of other instruments like the gravimeter has been held up for the duration, but their usefulness has manifold possibilities in the future. Mud preparation and its chemical control are comparatively new and offer a fertile field for future improvement. Not only are varied fluids needed for specific applications but new treatments may be found. A great deal of fundamental work is necessary, as demonstrated by the comparatively little known about the common clays and the mechanics of treatments of their water suspensions.

As time goes on, and as drilling goes deeper past the present record, which is 600 feet short of three miles, mud treatment and control will be more and more helpful. Drilling must continue at an accelerated pace, for although more fields are found, they are smaller in reserves. Thus since the targets are smaller the firing must be greater and more accurate.

The Engineer and Postwar Planning

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neutrality legislation and we were determined not to be provoked into war, but the isolationists would not foresee that the decision was not ultimately in our control. Actually even they were unwilling to accept the conditions Japan and Germany would have imposed upon us. They should have abandoned their isolationism after Pearl Harbor—and many did. Yet it appears that there are still enough of them left to make both major political parties afraid to take an unequivocal stand in favor of joint force to oppose aggression. The pattern of thought on postwar planning is not now significantly different from that following World War I. It does not appear, therefore, that the present war will be the last.

Reluctant though one may be to accept the implication of such action, it seems wise in our postwar planning to recognize that seriously destructive wars occur about once per generation and that as time goes on they become more extensive and more destructive. The action in starting now to prepare for World War III seems realistic and sensible. The disheartening effect of planning in the midst of one war for the one to follow in about 30 years is somewhat relieved by the knowledge that most postwar planning is for peace.

The engineer is amused by some of the imaginative predictions that some advertisers are making. He knows that extravagant claims cannot be fulfilled, that unfair advantage is being taken of the fact that non-technical people have recently heard more than usual about the usefulness of science. But the engineer knows also that the war has given tremendous acceleration to many developments such as jet and rocket propulsion, the combustion gas turbine, welding processes, electrical communication, electronic heating, X-ray inspection, plastics, and to almost every other scientific process and product.

Although winning the war is still the primary purpose of engineers, they know that the first day of peace will see most of them return to projects abandoned a few years ago and to planning new peacetime projects not believed necessary or economical before the war. Their efforts will be demanded by civilians almost as urgently as they are now needed by war and it will be difficult to explain to potential buyers why their postponed wants cannot be fulfilled immediately. Conversion of war production was remarkably rapid and complete but, very fortunately and in spite of the misguided isolationists, it started long before we were actually at war. Because it started so early many people do not realize how long the process of conversion actually required nor do they realize that the conversion was planned years before it was started.

Reconversion to peacetime production probably will not proceed as rapidly as did conversion to war goods production since reconversion will not be of such vital importance to survival and its costs will have to be borne to a larger extent by private capital. Because it will proceed more slowly, it should start earlier. The indefiniteness of V-Day makes it difficult to know just when reconversion should start but it is probable that those who have not already at least started to plan reconversion will find postwar competition extremely hard to meet.

The importance of starting reconversion as early as possible is attested by the recent agreement of the War Production Board, the War and Navy Departments, and of the War Manpower Commission to permit the manufacture of civilian goods hitherto prohibited or restricted in the plants of companies which have labor and machinery not needed in the war effort.

Sediment Transportation

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field measurements is still missing for large streams with fine bed material.

Often conditions are too complicated for analytical treatment. Irregular shaped cross sections or profiles, confluence of streams or temporary deposition of bed material are some of the complicating factors. In these cases the direct analytical method may be supported by model studies which can give quantitative results for transportation problems if they are based on the rules given by the laws of transportation (6). Model studies of such sediment problems have been performed using either sediment of the same or of different specific gravity in model and prototype.

The analytic determination of the transporting power of different stream sections gives the engineer a tool to predict the future development of streams with a movable bed. *Figs. 5a and 5b* show the canyons into which two small streams developed when their transporting power exceeded the available sediment supply. Thousands of acres of the most valuable valley lands are made unusable for agricultural purposes by similar developments. Hundreds of thousands of dollars are spent every year to prevent and repair damages to our communication systems due to channel cutting. But just