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Petroleum exploration and production research

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Research problems in the petroleum industry are concerned with a great many subjects. The exploration division of an oil company is charged with locating new petroleum reservoirs. The producing division has the task of "producing" the content of existing reservoirs, that is, of bringing to the surface the deposits of crude oil and of hydrocarbon gases. There the materials are temporarily stored in tanks from where they are moved to the refinery by various means such as pipe lines, tank cars and barges. The refinery department has as its object the conversion of the raw materials into final products such as gasoline, oils, waxes, asphalts, and related chemical products. In the following a number of the research problems are discussed which are related to the operation of the exploration and producing divisions.

The most important project related to the activities of exploration consists in the improvement of existing and the development of new methods for locating oil deposits. At this time, there does not exist a method which directly indicates from the surface the existence of oil pools. Present day exploration methods endeavor to give information of the subsurface geology by taking measurements at the surface of the ground. Such data help the petroleum geologist in deciding on the likelihood of the existence of an oil reservoir. In the last ten to fifteen years the seismograph method has yielded the greatest success. In seismic exploration, an explosive is detonated at the surface or in a shallow hole in the ground which may be from 10 to 300 feet deep. A shock wave is generated which travels through the ground. At its origin, this wave contains a wide spectrum of frequencies. As the wave travels through the ground, energy is lost at a rate which increases sharply with the frequency. After the wave has traveled through a considerable path length of the order of 10000 to 20000 feet, the amplitudes of the higher frequencies has been strongly attenuated and for practical purposes only the lower frequency part of the spectrum contains enough energy to be detectable. The detrecting means are, therefore, constructed in such a way that they are sensitive in a frequency range from approximately 20 to 100 cycles per second. In a homogeneous medium, the energy in the progressing wave is spherically symmetrical with respect to the shot point. One is mostly interested in the energy which travels in nearly a vertical direction into the ground. The wave velocity depends on the physical characteristics of the earth's formation through which the beam is traveling. Velocities range from 6000 to 20000 feet per second. When the beam passes from one formation with its velocity to another formation with a different velocity, reflection and refraction occur. The reflected wave travels back to the surface and can there be detected by suitable means. Customarily, the detector output is fed through an amplifier to a recorder where it is written down as a function of time. By observing the time interval between the shot and the arrival of the reflected energy and knowing the velocity, one can calculate the depth of the reflecting horizon.

Another part of the original wave passes under refraction into the lower medium (formation) in the ground. Further down it may encounter a second discontinuity where the velocity changes. Some of the energy will be reflected toward the surface and affect the seismograph detector. From the time interval and the knowledge of the two velocities one can calculate the depth at which the second reflection occurred. Such events may occur many times until the original wave has been attenuated to such an extent that the reflected energy is below the measureable amount. A record of this kind may, therefore, have several reflection events.

This procedure of "shooting" is repeated continuously along a gridwork which has been laid out at the surface. By computing the depths of the reflecting horizons for the various shot points, one can finally draw a profile which depicts their position. It is more customary to use this information for the drawing of contour maps. Here points are connected below which the reflection occurred at a given depth. Contour maps and profiles are of great help to the geologist in piecing together the knowledge of the subsurface.

Generally, the technical realization of such measurements is not as simple as it was described above. A time record of the output of a detector shows a continuously moving trace with many humps and valleys. It is very difficult to decide which wavelet should be assigned to a given reflecting horizon. It is, therefore, customary to record simultaneously the reflected energy at various distances from the shot point. For example, 24 to 36 detectors might be located on a straight line radiating from the shot point. The output of each detector is recorded and the traces are usually contained on one recording strip which shows one line for each detector. Characteristic reflections can thereby be separated since corresponding wavelets will be lined up across the various traces. In certain areas this procedure gives excellent results, whereas in others, the records are utterly confused and no distinct reflections can be "picked". Considerable research effort is being made to improve the situation. Sometimes the difficulty arises from strictly local disturbances. For example, the detectors are affected by "wind noise" which produces small disturbances at the surface. In such cases, a number of detectors are set out at each measuring point in relatively close vicinity (several feet) and their combined output is recorded as one trace. By this procedure statistical fluctuations can be averaged out. In other cases, improvement is obtained by recording the sum or the difference of the outputs of two detectors which are at neighboring measuring stations.

Considerable effort has been spent in developing highly sensitive detectors and suitable amplifiers. The energy received from shallow reflection horizons is much larger than those from deep horizons, a fact which makes the recording rather difficult. Early (shallow) reflections produce large amplitudes and the late amplitudes are very small. In order to produce a record which shows all reflections with reasonable size, many of the amplifiers are equipped with automatic volume control. A great deal of controversy has arisen concerning the question of the frequency for which the amplifiers should be built. Certain companies believe in the use of a rather wide band amplifier whereas other companies prefer narrow band amplifiers in which the frequency response can be changed. In the latter case, the best frequency response is established by experimenting with various frequencies in a given area.

Refraction shooting is another version of seismic exploration. In this case, one follows the energy of the primary wave which has been refracted into a second formation, travels along the boundary between the two formations and eventually is refracted back to the surface, where it is measured. In this case, the distance between the shot point and the detector is much larger than in the reflection method, namely of the order of 5000 to 40000 feet. Again the depths of the refracted horizon can be calculated from the knowledge of time and velocities.

Wherever possible, one tries to measure the characteristic velocities for the various formations in a given area. This can easily be done after a well has been drilled. Seismograph detectors are lowered into the well and a shot is fired nearby at the surface. The travel time from the surface to the depth of the detector can be recorded and therefrom the velocity is computed. Velocities do not only change because of a complete change in the geological formations, but they also change because of the increasing compaction of a formation with depth. Average laws for the change of velocity with depth have been experimentally established in many areas.

Of much less importance in exploration is the gravimetric method. Here the value of the earth's gravitational acceleration is measured with high accuracy at various points along the surface of the ground. The value of the gravimetric constant changes when the density of the formations below the measuring point varies. Again, the results are usually expressed by a contour map in which points of equal gravity values are connected. Unfortunately, there is no unique solution to the explanation of a change in gravity. A small body of a given density contrast buried in the ground at a shallow depth produces the same change as does a larger body with the same density at a greater depth. Therefore, the results of gravimetric measurements must be closely scrutinized and interpreted in a way which is compatible with other geological knowledge of the area.

Similar difficulties are encountered with the magnetic method in which the strength of the earth's magnetic field is mapped. Great progress has been achieved during the war years in the construction of magnetometers. An airborne magnetometer has been developed which is flown over the area and which automatically records the magnetic field strength.

While a well is being drilled, a "drilling fluid or mud" is circulated in the bore hole. It serves as cooling agent for the drill bit. The mud, furthermore, has to have adequate viscosity to carry with it to the surface the small pieces of rock which are ground off by the drill. The mud is pumped down through the drill system which carries the bit and it returns in the annulus between it and the well bore. The mud, furthermore, has to have proper qualities to plaster the wall of the hole with an almost impermeable layer. This is necessary in order to prevent the drilling fluid from passing from the hole into the formation and thereby being lost. The fluid also has to have proper density so that the hydrostatic head from the column of mud exceeds the pressure of the fluids or gases in any formation and thereby prevents a "blow-out" of the well. Considerable studies on the behavior of clays and mixtures of various chemicals are constantly being undertaken in order to produce drilling muds with more desirable properties.

After a well bore has been completed, it is of utmost importance to learn as much of the subsurface layers or formations as possible. This information helps the geologist to confirm or correct the picture which he has drawn of the subsurface based on general geological information and on the previous surface exploration. On the other hand, it furnishes to the petroleum engineer data on which he bases the best means of producing a crude or gas reservoir into which the bore has penetrated. Such measurements are partly made in situ by "well logging" tools. They are instruments which are lowered into the bore hole and which measure certain physical characteristics of the surrounding formations. In a second method, samples or cores are taken from the subsurface and brought up for investigation in core laboratories.

The most widespread method of well logging consists in measuring the electrical resistivity of the formations. In the simplest case, an electrode is lowered into the well with a cable and a second electrode is buried at the surface. A voltage is applied between the two and the current which flows is recorded while the one electrode is moved through the hole. Thereby, a measure is obtained of the total resistance between the moving and the stationary electrode. More complicated arrangements are sometimes used where several electrodes are lowered into the hole to supply the current and to measure the voltage. The rock formations themselves have high electrical resistivity. When the rock is porous and the pores contain a conducting fluid such as salt water the resistivity is low, whereas it is high when the pores contain hydrocarbons. It is important to arrange these tools in such a way that sufficient detail for thin strata can be obtained and that, at the same time, the measurements represent the average resistivity of the formation sufficiently far removed from the bore hole. The immediate neighborhood of the bore hole is changed during the drilling. Some of the drilling fluid passes into it and thereby changes the electrical characteristics.

In a recent development, electrical induction is used for resistivity measurements. A coil which is lowered into the hole produces an alternating magnetic field, and creates induction currents which flow in the fluids of the formations. The intensity of these currents is measured by their inductive reaction on a second or measuring coil which is at some distance from the primary coil.

In another arrangement, the spontaneous electrical potential is measured in the bore hole with respect to a fixed point which might be at the surface. These "self-potentials" are a result of potentials between two different adjoining formations with their fluid content and the fluid in the well bore. Based on a large amount of experience, resisitivty and self-potential curves yield considerable information with respect to the subsurface.

It has been found that all formations contain a certain amount of radioactive contaminations which is due to radium, thorium and potassium. These substances emit gamma rays. They are measured with detectors which are passed through the bore hole. Either ionization chambers or counters are used. In general, it has been found that shales show high radioactive content whereas sands and limestones have low radioactivity.

In another arrangement, a source of neutrons, usually a mixture of beryllium and radium, is lowered into the hole toegther with a detector for gamma rays. The detector is shielded from the direct action of the gamma rays which are emitted from the source. The neutrons travel into the formation and are slowed down by collisions with hydrogen atoms. Eventually, the neutrons are captured by hydrogen atoms and high energy gamma rays are emitted. Some of the gamma rays return to the bore hole and are there measured with the gamma ray detector. Thereby, a measurement of the hydrogen concentration in the formations is obtained. Such a neutron-gamma ray log is of great value in evaluating the amount of fluid in the formation.

The cores which are brought to the surface are carefully analyzed for their fluid content. However, the results obtained are not too reliable since the fluid content in the immediate neighborhood of the bore hole has mostly been changed by invasion of the drilling fluid. The total pore space available for fluid content can easily be determined in the laboratory, and thereby, a value for "porosity" is obtained. Furthermore, the "permeability" or the ease with which fluids can pass through the cores can be measured. Both porosity and permeability are of great importance in evaluating a reservoir for possible oil productivity. Porous rocks are mostly water wet, that is, the surface of the pores are first of all covered with a thin film of water. If there is any oil present in addition to the water, its droplets are surrounded by the water film. The relative amounts of water and oil present in a reservoir depend on the difference in density between the two fluids, on their position in the formation above a free water level (surface), on the pore size distribution in the rock, and on the interfacial tension between the two fluids. A process entitled "restored state" technique has been developed in which the core is resaturated in the laboratory under conditions which are equivalent to those at the particular depth from which the core was taken. In this way, the original proportions of oil and water in the reservoir rock can be determined.

Since most formations contain both oil and water to varying degrees, investigations are undertaken to learn the laws of simultaneous flow of such fluids through porous media. The effective permeability for one fluid depends on the amount of saturation which exists with respect to the other fluid. Such flow studies will eventually yield information which will make it possible to produce more effectively the hydrocarbons which are contained in the pores.

Since the oils and gases in the underground reservoirs are made up of very complex mixtures of hydrocarbons and other organic materials, the calculation of their physical properties is at the present time impossible. It is, however, of great importance to know certain facts concerning the volumetric and phase behavior of the mixtures at the temperatures and pressures existing in the reservoir. In this way estimates of marketable reserves can be made, and the most desirable producing techniques can be chosen. Thus, it is necessary that the naturally occurring fluids be studied in the laboratory to determine the desired properties. It is hoped that by study of such information correlations can be found which will lead to the possibility of calculating many of the properties which must now be established experimentally.

The production of oil has always been accompanied by the difficulty of corrosion of the metal equipment used in field operations. This corrosion is a troublesome and extremely costly item of expense so that naturally the research organizations are called upon to study the problem and find means of eliminating the difficulty. Much research effort has been directed toward a better understanding of the corrosion process, and these studies are leading to many successful techniques which may be employed.

This description indicates some of the great number of research problems in the field of physics, chemistry, and physical chemistry which are pursued by the research laboratories of the oil industry and which are designed to make more efficient use of the natural resources.