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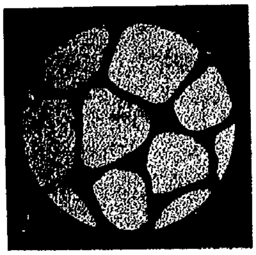

What is Reservoir Engineering?

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Abstract

Reservoir engineering involves more than applied reservoir mechanics. The objective of engineering is optimization. To obtain optimum profit from a field the engineer or the engineering team must identify and define all individual reservoirs and their physical properties, deduce each reservoir's performance, prevent drilling of unnecessary wells, initiate operating controls at the proper time, and consider all important economic factors, including income taxes. Early and accurate identification and definition of the reservoir system is essential to effective engineering. Conventional geologic techniques seldom provide sufficient data to identify and define each individual reservoir; the engineer must supplement the geologic study with engineering data and tests to provide the necessary information.

Reservoir engineering is difficult. The most successful practitioner is usually the engineer who, through extensive efforts to understand the reservoir, manages to acquire a few more facts and thus needs fewer assumptions.

Introduction

Reservoir engineering has advanced rapidly during the last decade. The industry is drilling wells on wider spacing, unitizing earlier, and recovering a greater percentage of the oil in place. Techniques are better, tools are better, and background knowledge of reservoir conditions has been greatly improved. In spite of these general advances, many reservoirs are being developed in an inefficient manner, vital engineering considerations often are neglected or ignored, and individual engineering efforts often are inferior to those of a decade ago. Reservoir engineers often disagree in their interpretation of a reservoir's performance. It is not uncommon for two engineers to take exactly opposite positions before a state commission. Such disagreements understandably confuse and bewilder management, lawyers, state commission members and laymen. Can they be blamed if they question the technical competence of a professional group whose members cannot agree among themselves?

There is considerable difference between the reservoir engineering practiced by different companies. The differences between good engineering and ineffective engineering generally involve only minor variations in fundamental knowledge but involve major differences in emphasis of what is important. Some companies or groups emphasize calculation procedures and reservoir mechanics, but pay little attention to reservoir geology. Others emphasize geology and make extensive efforts to identify individual reservoirs and deduce their performance during the development period or during the early operating period. They use reservoir engineering equations and calculation procedures primarily as tools to provide additional insight of a reservoir's performance. Those utilizing the latter approach generally are the most successful.

The differences in practice observed indicate that many individuals, including managers, field personnel, educators, scientists and reservoir engineers do not understand the full scope of reservoir engineering or how the reservoir engineer can be used most effectively. A better understanding of the basic purpose of reservoir engineering and how it can be utilized most effectively should result in improved engineering.

Reservoir Engineering — A Group Effort

The Purpose of Engineering

The goal of engineering is optimization. The purpose of reservoir engineering is to provide the facts, information and knowledge necessary to control operations to obtain the maximum possible recovery from a reservoir at the least possible cost. Since a maximum recovery generally is not obtained by a minimum expenditure, the engineer must seek some optimum combination of recovery, cost, and other pertinent factors. How one defines "optimum" will depend upon the policies of the various operators and is immaterial to the views presented in this paper.

From an operator's point of view any procedure or course of action that results in an optimum profit to the company is effective engineering, and any that doesn't is not. There are two reasons why a company may not receive effective engineering. Its engineers may be poorly trained and fail to perform properly. However, a company can employ competent engineers and receive good engineering work from them, but as a company, still do an ineffective job of engineering. For instance, an engineer might do an excellent job of water flooding a reservoir. However, if even greater profit could have been received by water flooding five years earlier, then obviously the reservoir was not effectively engineered by the operator. To provide optimum profits, all oper-

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ations must be initiated at the proper time. Effective reservoir engineering, therefore, must provide the necessary facts sufficiently early to allow most effective control of a reservoir.

The Engineering System

Calhoun[1] has described the engineering system of concern to the petroleum engineer as being composed of three principal subsystems: (1) the creation and operation of the wells; (2) the surface processing of the fluids; and (3) the fluids and their behavior within the reservoir. The first two subsystems are subordinate to the last. The nature of the reservoir(s) and the reservoir fluids determines how many wells are needed, where they should be drilled, how they should be completed and produced, and what processing equipment is necessary to obtain optimum profits. For effective engineering, the various subsystems cannot be isolated. They must be considered as interrelated portions of a unified system. Petroleum engineering applies to the entire engineering system whereas reservoir engineering applies only to one part of the system. However, the entire system is controlled so completely by the reservoir's performance that there is only minor distinction between petroleum engineering and reservoir engineering.

The reservoir engineer is concerned with reservoir fluids and their behavior, and with identifying the geological environment and character of each separate reservoir with which he must deal. For convenience the individual reservoirs and their fluids may be described as composing a reservoir system.

The Engineering Process

The reservoir engineer applies a general knowledge of reservoir behavior to a particular reservoir system to produce a desired result. The reservoir systems with which the reservoir engineer must deal are generally complex, involving multiple reservoirs, flow barriers, faults and irregular distribution of physical properties. Obtaining a desired result from such reservoir systems may be exceedingly difficult. It seems unnecessary to state that *we cannot engineer a particular reservoir system until we have obtained adequate knowledge of the particular system to identify its parts and otherwise describe it.* Yet we are prone to forget this vital phase of engineering. Too often we make broad, general assumptions regarding reservoir uniformity, continuity, thickness and other factors. We then apply general equations and obtain a general solution pertaining to an idealized reservoir. We delude ourselves when we call this engineering. If we are to truly practice engineering we must obtain particular solutions pertaining to particular reservoir systems.

Evaluation of the Reservoir System

The first consideration in reservoir engineering and the principal function of the reservoir engineer is to define and evaluate the reservoir system. To "define" means to determine the areal extent, thickness, inclination, producing limits and the geological environment of each separate reservoir within the reservoir system. To "evaluate" means to determine the physical properties of each separate reservoir and its fluids, the variation of the physical properties throughout the system, and the location of inhomogeneities, barriers, fractures, etc., that may affect flow. Only when the limits and properties of each separate reservoir are determined adequately will an engineer have sufficient knowledge of a reservoir system to accurately deduce its future performance.

Most engineers will agree to the necessity of defining and evaluating the reservoir system. Yet surprisingly few devote adequate effort to doing it. Generally they rely on a structural map and a few isopachous maps. An isopachous map of total net pay may prove valuable for estimating original oil in place, or as a political tool for unitizing a reservoir, but it offers little help in understanding reservoir performance if more than one reservoir is involved. Unfortunately, in the sand-shale series which comprise many or our so-called common sources of supply, we more often than not deal with multiple reservoirs. Fig. 1 shows a typical 1st Dakota, "D" sand log from a field in the Denver-Julesburg basin. Each sand zone in this field is separate, with unique initial fluid contacts and individual performance. The D-5 sand zone had the highest initial water-oil contact and had an active water drive. The D-4 reservoir is lenticular, covers only a portion of the field, and produces by a solution-gas drive. After five years of production the D-4 zone pressure was 800 psi less than in the underlying zone and 500 psi less than in the overlying zones. The D-2 and D-3 sand zones were connected through common completions and thus had similar pressures. Both reservoirs had initial gas caps, active water drives, and were being drained by wells on the south flank of the structure (by accident, wells on the north flank were completed in other zones). This caused a shift of the initial gas cap towards the south. Active water encroachment displaced most of the oil on the north flank of the reservoirs into the initial gas cap area. It is unnecessary to carry this story much further. A large portion of the recoverable oil from the D-2 and D-3 zones was lost. The operator assumed that this field was fully developed and was being efficiently drained. When considered as one reservoir, it appeared to be; when considered as five reservoirs, it obviously was not. If the nature of the multiple reservoirs had been determined sufficiently early, the procedures necessary to prevent loss of recoverable oil would have been clear.

This case is not atypical. Not far from this field an operator released approximately 1,000 acres of eventually productive, highly profitable leases, located downdip from three producing wells. In this case, the engineers interpreted water production from a lower sand zone as indicating the position of the water-oil contact in the productive sand zone. Failure to define the reservoir was costly.

In both of these cases numerous clues were available for early interpretation. Even when obvious clues do not exist, a competent engineer or superintendent interested in defining and evaluating the reservoir system should be capable of obtaining the necessary data. Modern engineering techniques provide the engineer with numerous tools and test procedures to study the reservoir system. Used wisely in conjunction with geologic

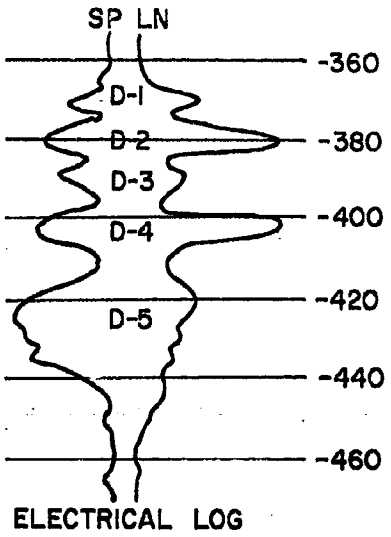

Fig. 1—Electrical log.

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[1] References given at end of paper.

data and production data these tools can impart worthwhile insight into reservoir conditions.

The Coordinated Reservoir Evaluation Program

When the production superintendent, geologist, and engineer cooperate during development of a field to evaluate the reservoir system, it is often possible to deduce reservoir performance quite early. A coordinated reservoir evaluation program not only provides information for better engineering, it generally costs less than a haphazard program. A few drill stem tests, judiciously placed to test individual zones at selected depths, often can give more reservoir information than more numerous tests of multiple zones indiscriminately placed. An extra log, or an additional hour's time on a drill stem test, may provide more usable information than can be obtained from much more costly coring and core analyses.

Occasionally an early reservoir evaluation program will present reasonable proof or reservoir communication and drainage over wide areas. This information may be the evidence necessary to obtain wide spacing. Such use of engineering to reduce costs is becoming more common. A few companies devote considerable effort to this phase of reservoir engineering. In a recent case early proof of reservoir drainage by wide spacing allowed an operator to save $1,600,000 in unnecessary drilling costs during development of a relatively small reservoir. Early evaluation also provides data for early unitization and optimum timing of pressure maintenance operations.

Early definition and evaluation of the reservoir system is the basic requirement for effective engineering. The engineer must be allowed to obtain the data necessary to evaluate the reservoir system and should participate in operating decisions with regard to the reservoir. It should be the engineer's job to *obtain*, as well as interpret, the facts necessary to evaluate the reservoir system. It is his responsibility to know what data are required and to devise a plan to obtain them at the minimum cost.

The Geological Study

To define and evaluate the reservoir system, the engineer must consider the depositional environment, continuity, lithology and limits of the reservoir rock. The depositional environment provides clues concerning both the larger geological units, which may cause different sand zones to behave as separate reservoirs, and the smaller nonuniformities present within the larger units, which may significantly affect flow and reservoir performance. Hutchinson has discussed nonuniformities present in reservoir systems.[2,3] Such reservoir inhomogeneities may provide the key to interpreting reservoir performance or the success of an injection project. Shale or silt streaks, or laminations, which restrict or prevent fluid flow, may or may not be continuous over a wide area. Such nonuniformities are often too thin to appear on logs and are seldom noted in core analyses but may be observed in outcrops and are often described in the geologist's description of the cores.

Elkins has commented on the effect of such inhomogeneities on reducing vertical permeability in apparently clean sands.[4] He has described calculations indicating that these minute barriers may cause the ratio of horizontal to vertical permeability to be as high as 10,000:1. Such barriers effectively prevent water and gas coning and may prevent gravity drainage or gravity underrunning. However, identification of inhomogeneities in cores, or deducing their effect from well tests, does not indicate that such barriers are continuous. Several reservoirs are known where thin impermeable streaks, randomly located within a large sand body, prevent coning but have little effect in preventing vertical segregation of reservoir fluids.

Knowledge of the extent and kind of nonuniformities present may help the engineer interpret reservoir data or design special reservoir tests to evaluate reservoir performance. Yet the effect of nonuniformities on the performance of a reservoir system is usually ignored by engineers.

In reservoir engineering the geologic study must precede the engineering study. However, conventional geological techniques rarely provide sufficient data to define the reservoir system. The engineer must supplement the geology with engineering data and tests to provide the necessary information. Production data, formation pressure, pressure gradients, interference tests, and build-up tests may be used to prove communication between wells or zones, prove the existence of faults or other barriers, and otherwise define the reservoir. In practice, this interrelationship between geology and engineering is seldom obtained. Only rarely do we find an extensive geologic study of a reservoir. Even less often do we find a systematic engineering effort to prove geological interpretation and further define the reservoir system. Yet *such studies provide the base upon which we must build our engineering.* The ability to communicate and work closely with geologists, or to perform the functions of the geologist, is vital to reservoir engineering.

Application of Reservoir Mechanics

Reservoir mechanics generally receives the most attention from reservoir engineers. In fact, many engineers specialize in this apparently worthy endeavor and limit their practice (either by their own decision or by that of others) to evaluating reservoir performance curves and predicting future performance. Superficially, such practice appears to be a valid engineering specialty. Actually, it is not. Given sufficient time the nature of a reservoir's performance will generally become apparent. Hindsight is wonderfully accurate but is difficult to optimize. Those who specialize in reservoir mechanics may be competent reservoir theorists and may provide many valuable services, yet their work rarely produces the maximum possible profit from a reservoir. A simple case history will illustrate why.

An operator owns most of a small reservoir, which produces from a typical Pennsylvanian sand-shale series. Two offset wells were producing from Zone A. The operator met these offset wells by completing two wells in Zone B of the sand-shale series. Detailed mapping indicated that Zone B was lenticular and existed only under the operator's lease. Zone A was continuous throughout the entire field. A reservoir specialist may someday note that Zones A and B have different pressures and will conclude that the operator's lease is being drained in Zone A without benefit of compensating drainage in Zone B. He will be doing a good job, but the company has not received good engineering. All facts necessary to deduce performance were available at the time the wells were completed. Maximum profits were possible only by completing the wells properly in the first place.

There is a distinct difference between reservoir engineering and the application of reservoir mechanics. The determination of a reservoir's producing mechanism and prediction of its future performance is not in itself engineering. Effective engineering requires deducing a reservoir's probable performance under all possible methods of operation and then controlling its performance to obtain optimum profits. This usually requires operating decisions before the behavior of the reservoir is apparent. Engineers, geologists, and superintendents are not infallible. They will make mistakes. However, if operating decisions are preceded by a systematic attempt to define and evaluate the reservoir system, the chances of successfully deducing a reservoir's future performance and controlling operations to obtain an optimum profit will be greatly improved. Calhoun has pointed to the analogy between effective engineering and preventive medicine.[1] It is not sufficient for the engineer to determine the state of a reservoir's health and then attempt to improve it. To be most effective, the engineer must maintain the reservoir's health from the start.

The Importance of Timing

Optimization requires consideration of the time element. Often, *when* to do something may be nearly as important a consideration as *what* to do. Most engineers are becoming increasingly aware that proper timing is a vital consideration in engineering. Generalizations as to the proper time to initiate a particular oil field operation are not possible. However, one generalization concerning engineering is valid: the best time to apply reservoir engineering principles and study a reservoir system is as early as possible.

Economic Considerations

Optimization requires comparison. For logical comparison, things which are distinctly different must be reduced to a common basis. Thus, the engineer must become acquainted with certain techniques of the economist and the banker. The details of economic calculations are important to the engineer but will not be discussed here.

In such economic calculations all important cost items must be considered. It is somewhat ironic that income tax, which may represent the largest single cost item in an evaluation, is often ignored. The rate of return calculated after income taxes are considered may be higher than when calculated before taxes. Economic comparisons may not be valid unless income taxes are considered. Tax consequences may occasionally represent the major consideration in an operating decision. An apparently sound secondary recovery plan may result in several million dollars' greater tax liability than would an equally attractive alternate plan. In one large Oklahoma water flood the increased tax liability amounted to more than a few million. In a relatively small Illinois water flood, the operating practice increased tax liability by approximately $500,000. In both cases development drilling in stages resulted in loss of depletion allowance for several years. In both cases alternate plans could have been devised to reduce the tax liability. Several years ago a well-known water flood engineer outlined a stage development program for living with prorated water floods. The program he outlined could result in a loss in depletion allowance and increased taxes.

The reservoir engineer should consult with a tax attorney on any development program involving large expenditures for development drilling, or for injection of propane, butane or other materials. The engineer cannot justify ignoring an item that may have such serious economic consequences.

Responsibility of the Group Effort

From a company point of view successful engineering requires optimizing an entire system. This generally requires a group effort. A company's engineering may be ineffective due to its failure to recognize the almost total dependence of the group effort upon accurately defining and evaluating the reservoir system and correctly deducing future performance.

Reservoir engineering does not start at some time after a field is developed. For maximum effectiveness it must start simultaneously with discovery. Well locations, drill stem tests, selection of logging tools, and determination of completion intervals are all reservoir engineering problems. *All development and operating decisions should be made by an individual who recognizes the dependence of the entire system upon the nature and behavior of the reservoir.* It is not necessary that such an individual be a "reservoir engineer". Any manager, superintendent or foreman who considers the entire reservoir system during operations, and not just the individual well, and who develops and operates the field as a system in a manner which can obtain the maximum amount of reservoir information, is practicing one of the most important phases of reservoir engineering. It helps if the individual has a background knowledge of reservoir mechanics and geology. However, many nontechnical personnel develop an intuitive feel for the reservoir system and know when to seek and accept technical advice with regard to individual components of the system. On the other hand, many technical personnel, with extensive training and background knowledge in certain disciplines, are so obsessed with their calculation procedures and balances that they often forget they are dealing with a particular system which cannot be engineered until it is defined.

Reservoir Engineering — Individual Practice

An Art, or a Science?

Reservoir engineering is more of an art than an exact science, although it has a broad scientific base. Most observed reservoir facts, phenomena, or "symptoms" are subject to more than one logical interpretation. Wyllie discussed this peculiarity of reservoir engineering with regard to interpreting pilot field tests, but extended his remarks to cover all of reservoir engineering.[3] It is analogous to the mathematical condition of having more unknowns than equations and obtaining multiple solutions. Elkins has also emphasized the necessity of investigating all possible interpretations of reservoir performance.[4] When the complexities of reservoir geometry, multiphase fluid flow, potential gradients and reservoir mechanics are considered, multiple interpretations should not prove startling to any reservoir engineer. Yet too often we are prone to accept the first interpretation that appears to fit most of the data. That some pieces of information don't fit into place never seem to bother us or cause us to question our interpretation.

The most obvious interpretation of data often is incorrect. An example of this is illustrated by the reservoir performance curves shown as Fig. 2. Generally an increase in reservoir pressure following a reduction in the reservoir withdrawal rate suggests water encroachment. However, no water was being produced and the reservoir was apparently sealed at the water-oil contact by a low gravity, tar-like oil. The data were questioned but were proven to be reliable. The engineering committee concluded that the pressure increase could not reflect a true reservoir condition and was caused by the method used to obtain a weighted average field pressure. Actually, pressure increases were observed in individual wells in all parts of the reservoir and in later pressure surveys, confirming a field-wide pressure increase. The present interpretation, and the only one that satisfies all known facts, is that the apparently anomalous pressure increase was due to a redistribution of fluids within the reservoir, resulting from gravity segregation. The anomalous pressure effect is similar to the one discussed by Matthews and Stegemeier.[8] At high producing rates most of the gas released from solution in the reservoir was produced at nearby wells. Following the drastic allowable cut, gas-oil ratios decreased, and the high-pressure downdip gas migrated upstructure to the low-pressure gas cap. Theoretical calculations were made to determine the effect of the fluid redistribution on the field pressure and indicated a good agreement with actual field performance. The results are shown on Fig. 2.

Gas injection was started in this reservoir shortly after the pressure peaked (67 million bbl cumulative production). For several years prior to gas injection considerable fluids were being withdrawn from the reservoir; yet the reservoir pressure was increasing. For several years after the start of gas injection reservoir withdrawals were replaced, but the average field pressure declined. An extensive geological and engineering study revealed that the field consisted of a large number of individual reservoirs, resulting from lenticular zones and extensive faulting. The apparently anomalous pressure decline was due to the fact that many wells were producing from reservoirs other than the ones receiving the injected gas.

This example illustrates the difficulty of interpreting field performance curves and the complexity of some reservoir engineering problems. Theoretical calculations in this field have little meaning except as clues to aid interpretation of observed phenomena. Due to the complexity of the field, large volumes of oil could easily be trapped and not be drained. Reservoir engineering in this field consists almost entirely of identifying and defining the numerous reservoirs. Engineering tests are being conducted to confirm or disprove the geological interpretation, to locate flow barriers and determine communicating zones. It will not be an easy task. Nature hides her secrets well.

In theory, reservoir engineering is based on broad scientific principles. In practice, however, it is not rigorously scientific. To start with, we deal with a system which may be unbelievable complex and impossible to define completely. To arrive at a diagnosis of our system we generally rely on: (1) a few physical facts; (2) production statistics (often of doubtful reliability); (3) samples representing approximately one billionth of the reservoir; (4) statistical averaging techniques (often misapplied); and (5) stylized mathematical equations derived from assumptions which may only remotely represent reservoir conditions.

Is it any wonder, then, that the reservoir engineer has been described as "an individual who takes a limited number of facts, adds numerous assumptions and arrives at an unlimited number of conclusions"? Such a statement may have been made in jest; nevertheless, it provides an intrinsic description of reservoir engineering as it is often practiced. Unfortunately, due to the complexity of the reservoir system, reservoir engineering will always remain this way.

The fact that we must rely on insufficient facts, data of poor quality, and an imperfect knowledge of the reservoir does not mean that we cannot do a good job of engineering. It does mean that we cannot expect perfection and that we should continually strive to obtain better data and learn more about the reservoir. Occasional failures are inevitable. What we must strive for is the highest possible batting average. The most successful practitioner of the art is usually the engineer who, through extensive studies to define and evaluate the reservoir system, manages to obtain more facts and thus requires fewer assumptions. Additional facts can be obtained only by hard work and imaginative thinking. Assumptions are easily conceived. This no doubt explains our innate tendency to substitute assumptions for facts when the facts are not readily obtainable.

The Hypnotic Effect of the Calculated Solution

As a profession grows it logically tries to reduce concepts to mathematical expressions. Reservoir engineering is no exception, even though due to the complexity of reservoir systems it is ill-suited for exact mathematical solutions. As a consequence we have a generation of engineers schooled in the mechanics of the mathematical solution. A few apparently believe that engineering involves no more than obtaining solutions with equations and balances. While such engineers are a small minority, their fanaticism illustrates the hypnotic effect which a calculated solution occasionally has on all engineers. This siren's call has lured many an engineer to a rocky conclusion in the past and no doubt will continue to do so in the future.

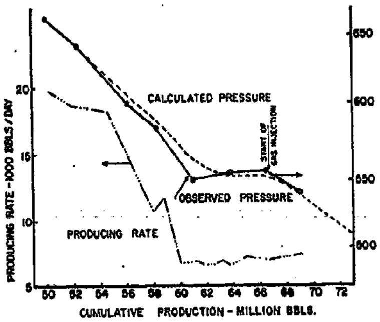

Fig. 2—Production history and calculated and observed pressure.

A classic example was given recently by an engineering committee report and later testimony of the chairman of the committee before a state commission. Pressure data in the reservoir in question were sparse but clearly indicated a several-thousand psi gradient towards the center of the reservoir. The committee extrapolated the pressure gradient across a distance of approximately 1 mile to obtain the pressure at the water-oil contact. The extrapolated pressure at the contact at different times varied from several hundred to nearly 1,000 psi greater than the highest measured pressures. The committee used this information in a van Everdingen and Hurst type equation to directly calculate water influx.[7] They determined from their calculations that a stable influx rate of 1,500 B/D would eventually be obtained. Since this was less than 1/10 of the rate of reservoir withdrawals, they concluded that the limited water influx would not materially alter the solution gas drive performance. The water influx calculation was the crux of their analysis. All of their conclusions and recommendations were dependent on it. Yet they made no effort to confirm their answer by other methods. The fact that water had invaded an appreciable portion of the reservoir, that numerous wells had watered out, and that actual water production exceeded 1,500 B/D didn't seem to bother them. They were so hypnotized by their calculations that the chairman later testified under oath that only a minor volume of water had moved into the reservoir. Instead of questioning their own results, they went to considerable trouble to concoct a theory to make the apparently anomalous facts fit the results indicated by their calculation.

All equations we use as reservoir engineers are based on certain assumed conditions, which may or may not represent the conditions in a particular reservoir. An equation which is valid in one situation may not apply in another. Often our equations must be modified to fit particular reservoir conditions. Used wisely and *cautiously* our equations are valuable engineering tools. However, they are by no means our only tools and on occasions may be our least important ones.

The Use of Models

Due to the complexity of most reservoirs, it is impossible to duplicate a reservoir or build a true prototype model. All models with which we deal are greatly simplified systems. Such models provide valuable information concerning the general nature of reservoir systems and the nature of fluid flow in such systems. Indeed, it is from the study of such models that we obtain much of our knowledge concerning reservoir mechanics.

The advent of the high-speed digital computer has allowed construction of mathematical models for the study of multiphase, multidimensional fluid flow. These models come close to duplicating simple reservoir systems and provide additional insight concerning reservoir behavior. As a scientific tool, they are superb. However, in our exuberance with our new toy, let us not forget two significant facts: the mathematical reservoir models are still greatly simplified compared to many reservoirs, and until we can define a reservoir system, it is impossible to duplicate it in a model. No model, however rigorous, can provide an exact answer if the input information is wrong.

My remarks concerning the calculated solution also apply to the mathematical model. With the glamour of the computer and the intriguing sophistication of the mathematical model it will be doubly difficult to treat such calculated solutions objectively. These remarks are not intended to discourage use of such models. Rather, they are intended as words of caution to the engineers who would use these scientific tools to obtain engineering solutions. Used wisely, they will provide valuable clues about a reservoir's performance. Used unwisely, they can lead one blindly astray.

Two-Dimensional Representation of Data

It surprises most engineers to learn that we use two-dimensional techniques less today than our predecessors did 20 years ago. Any map or cross section is a graphical two-dimensional representation of information. Data plotted on such maps and cross sections will indicate reservoir performance trends far more quickly and accurately than a field performance curve. Yet we are relying increasingly on field performance curves and less on two-dimensional plots of the data and individual well performance curves. This is a step backward, as a field performance curve cannot show variation of data throughout the reservoir. Variation provides the key to early interpretation of reservoir performance.

Field performance curves have little value for early assessment of reservoir performance. They have led many engineers astray. The technique of plotting, or visualizing, all data in two dimensions, used extensively by our predecessors, will allow much earlier evaluation of reservoir performance. The technique is simple, quick and effective. It should be used more widely.

The Difficulty of Reservoir Engineering

Reservoir engineers deal with systems which cannot be examined physically. A complete knowledge of the reservoir system is not possible. The engineer's job is further complicated by the lack of exactness of most data. Water and gas production data are often unreliable, measured pressures may not represent stabilized pressures, and results obtained from fluid samples may not represent the reservoir fluids. Consequently, we should not expect exact solutions from our calculations even on the rare occasions when we use rigorous equations. This does not mean that our equations are worthless. It merely means that we should regard our calculations as providing clues to reservoir behavior and not as exact indicators of reservoir behavior. Further, we should always question the results of our calculations. If we are to obtain the right answer, we must continually seek answers to the following questions: (1) what does the answer mean; (2) does the answer fit all the facts; (3) why doesn't it; (4) are there other possible interpretations of the data; (5) were the assumptions correct; (6) are the data reliable; (7) are additional data necessary; (8) has there been an adequate geological study; and (9) has the reservoir been adequately defined?

To be successful we must be innately curious and scientifically honest. We must continually question our own results and search for additional facts. Elkins stated this quite aptly: "Since nearly all basic features of reservoir performance must be inferred, periodic re-evaluation of specific cases is imperative".[4]

From an individual engineer's point of view, successful engineering is limited to optimizing a system from the time he first becomes acquainted with it. Even from this more limited viewpoint effective engineering is dependent upon recognizing the nature of the reservoir and its performance. Most examples of poor individual engineering result from an unwarranted reliance upon field performance curves and calculation procedures as tools to evaluate reservoir performance. An increased effort to define and evaluate the reservoir system and greater use of two-dimensional plots of data should improve individual engineering efforts.

The Background Required for Reservoir Engineering

The diversity of the functions the reservoir engineer is expected to perform also compounds the difficulty of his job. He may be required to plan a reservoir evaluation program during drilling and development, determine proper well spacing, evaluate logs, calculate reserves, evaluate open flow tests or drawdown and build-up tests, investigate the economics of the proposed expenditures (including income taxes in the evaluation), participate in engineering committee studies and unitization meetings, recommend procedures for pressure maintenance, dig through accounting data to determine costs or to determine the past production of depleted reservoirs, evaluate pilot floods and plan secondary recovery projects, explain why a particular project failed, or undertake any number of other duties.

To succeed, the engineer must develop the geologist's knowledge of sediments and environmental conditions; the physical chemist's knowledge of reservoir fluid properties, phase behavior, electrical conductivity, and fluid flow in porous systems; and the mathematician's knowledge of numerical analysis and the use of high-speed digital computers. In addition, he must be completely familiar with past production and completion practices in the reservoir, including a knowledge of which zones are perforated in every well and each well's performance. He also must be an economist, an accountant of sorts, an expert negotiator, and have a working knowledge of proration law, unitization law and taxes. Few engineers develop a background in depth that is this extensive. However, the engineer must develop a working knowledge in each area and know when to consult with specialists for additional information. The experienced reservoir engineer is a generalist, not a specialist.

Summary

The purpose of reservoir engineering is to control each separate reservoir's performance to obtain an optimum profit. To accomplish this purpose generally requires operating decisions before the performance of each reservoir can be determined. To correctly deduce the performance of each reservoir requires that the reservoir system be identified and defined by geologic techniques and special engineering tests to provide a basis for deduction. *Effective engineering requires that the reservoir engineer, or someone familiar with reservoir engineering principles, participate in development and operating decisions.* Companies which do not consider the development and operation of an oil field as parts of an engineering system, and do not utilize reservoir engineering principles as a basis for development and operating decisions, generally do not obtain optimum profits from their operations. They may employ numerous engineers but their engineering is "too little and too late," and is usually inadequate. In such cases company policies greatly handicap the efforts of the individual engineers. They have difficulty obtaining necessary data, and generally must attempt to salvage lost profits rather than to create new profits.

Reservoir engineers often disagree in interpreting a field's performance. Generally incorrect interpretations result from ignoring signicant facts or from a failure to dig deep enough to uncover all the facts. Incorrect interpretations also result from an unwarranted reliance on field performance curves and calculation procedures as tools for interpreting reservoir performance. Reservoir engineering is difficult. The most successful engineer is usually the one who makes the greatest effort to define and evaluate the reservoir system, and uncovers the most facts.

In examining several hundred engineering reports and observing engineering practice for a number of years, I have concluded that relatively few individuals truly understand reservoir engineering. As a result, reservoir engineering is not as effective as it should be. Too often the maximum possible profit is not obtained from a reservoir. To improve engineering I offer a simple suggestion: Put the reservoir back into reservoir engineering.

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