THE BIRTH OF GEOTHERMAL RESERVOIR ENGINEERING

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The term "reservoir engineering" arose within the field of study of the development of gas and oil reservoirs. One definition of reservoir engineering is the application of scientific principles to the drainage problems arising during development and production of oil and gas reservoirs. Although many important physical laws concerning reservoir mechanics were established during the first half of this century, reservoir engineering has flourished mainly since the end of World War II. The Combination of the recognition of increasing energy requirements in a rapidly industrializing world and the release of trained manpower following World War II abetted the development of the field of reservoir engineering. In the 1940's and 1950's oil recovery processes such as underground combustion of oil and oil recovery by steam and hot water injection received great attention. The modern development of geothermal reservoirs also began to accelerate about that time. The pioneering geothermal development in Larderello, Italy, began the massive job of rebuilding the devastation of World War II. New Zealand began the important development of geothermal power in the Wairakei steam field, and the Magma-Thermal Power Company development of the Geysers in California, USA, followed thereafter.

Nevertheless, it was not until the early 1960's that petroleum reservoir engineering principles were first applied to geothermal reservoir problems. It appears that the first such study was conducted by Whiting and Ramey in the mid 960's (Whiting and Ramey, 1969). As a result of this work, Cady began an experimental study of the importance of capillary pressure on boiling w thin porous media in 1967 (Cady, 1969), a line of study which continues to this date, A second reservoir engineering study of a geothermal field was presented by Ramey in 1968 concerning the Geysers Geothermal Field in California.

Although reservoir engineering principles were widely known for 20 years prior to application to geothermal reservoirs, the birth of geothermal reservoir engineering appears to date to the early 1960's. This is not to say that geothermal reservoirs were not subject to scientific study closely related to modern reservoir engineering. It appears that the types of investigation were more closely aligned to the fields of geology, geophysics, hydrology, and geochemistry.

The reason for this situation appears to lie in a misunderstanding concerning petroleum reservoirs. In one state publication concerning geothermal resources, it was remarked that because petroleum reservoirs were always closed pools and geothermal systems were always active hydrothermal systems, there was nothing applicable within the field of petroleum reservoir engineering. The conclusion that geothermal systems were large hydrothermal systems subject to natural "recharge" also had an effect. It had been theorized that geothermal systems could be self-regenerating if developed properly. It was only necessary to discover the natural recharge rate (both heat and fluid) and produce at that rate to have a steady-state system which would never deplete. It now appears that few if any natural systems can recharge at the phenomenal rates required for electric power generation.

The remark that petroleum reservoirs were always closed pools is incorrect as well. The first study of oil reservoir performance subject to water recharge (influx) was published in 1930. The word "reservoir" is now used in the same sense as a "thermodynamic system." It is possible to have transport into and out of the system, of course. Let us then turn to geothermal reservoir engineering as a new field of study.

Although many of the principles of reservoir physics involved in non-isothermal oil production by fluid injection (oil production by underground combustion and steam injection) are reasonably well understood, it is not surprising that some problems appear to remain for geothermal reservoir physics. For this reason, Cady (1969) studied geothermal system behavior with the physical model prior to 1969. A speculation that capillary pressure might reduce the vapor pressure of liquid water to a substantial degree was responsible for the Cady study. Although vapor pressure suppression was not noticed in Cady's work with an unconsolidated sand core, he did make the surprising observation that an isothermal dry steam zone could develop within a few inches above a two-phase boiling zone which followed the vapor pressure curve for water as pressure declined. A search for capillary pressure effects upon boiling continues at Stanford.

Unfortunately, it is difficult to scale all important physical parameters between the field and the laboratory. Many important physical phenomena have been discovered by thorough analysis of field performance data. However, field data for geothermal systems are not readily available. In reservoir engineering it appears that there is no hope of ever physically examining the reservoir directly. It is not likely that we shall mine or exhume many reservoirs. Thus, the responsibility of the reservoir engineer usually involves a two-step process: (1) to make and interpret indirect measurements of the quantitative characteristics of the reservoir, and (2) to employ this information and basic physical principles to forecast the behavior of the reservoir under any potentially useful production scheme. The second step assumes that <u>all</u> basic physical principles are known. Herein lies the need for much field and laboratory experimental work. Even in the much older field of petroleum reservoir engineering, it is clear that much remains to be discovered concerning basic physical principles. See recent discussions of reservoir engineering by Wyllie (1962) and Ramey (1971).

Ramey pointed out that such important information as can be determined by direct measurement on reservoir samples (cores) often leaves much to be desired. The difficulty with core analysis information lies in relating it to the reservoir. Indeed, as Wyllie has pointed out, why should we assume that the reservoir is like the minuscule volume of rock samples taken out *of* the reservoir and discarded? Many important computations and decisions are reached, nevertheless, upon the basis of quantitative information derived from core samples.

By now, interpretation of information derived from cores should be well established and standardized. It is not! There is no consensus of proper methods of handling core data. Wyllie made an eloquent plea that the approach to reservoir engineering be holistic (that the determinations be made in wholes, not in parts--for example, that "what matters is the rock unit and not samples of arbitrary size that may have been taken from it"). He cited pressure buildup and drawdown testing. Determining the characteristics of the reservoir by in-situ measurements using wells as the input and output flow faces of the reservoir "core" makes a great deal of sense. Reservoir simulation by digital computer is another highly popular technique that embodies the holistic approach. We attempt to generate a detailed'description of a reservoir to match all known performance data. If the matching is successful, we assume that a reasonably accurate model of the actual reservoir system is available and employ it to forecast behavior under various operational schemes. To restate this situation, performance matching consists of developing an n-dimensional mathematical reservoir model that responds to model fluid production as the prototype responds to actual fluid production. The "response" involved usually means pressure response. In the case of geothermal systems, we generalize production to include both fluid and energy, and response to include pressure, temperature, enthalpy, quality, and composition. The birth of geothermal reservoir engineering is accomplished, and we await the development of the child.

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