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AN INTEGRATED APPROACH TO GEOTHERMAL WELL TESTING

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ABSTRACT

The testing of geothermal wells to measure reservoir and well potential is similar in some respects to oil and gas testing; however, a number of unique problems have arisen in the geothermal case. For example, when commonly accepted oil and gas procedures have been applied to geothermal well testing, many important parameters have been determined inaccurately or not at all. This paper presents an integrated approach to geothermal well testing which the authors believe will improve the reliability and usefulness of the data which is obtained. The objectives are to determine the key parameters in 5 major areas: (1) reservoir; (2) reservoir/wellbore interface; (3) wellbore; (4) surface equipment; and (5) reinjection ability. Some of the potential pitfalls in obtaining and interpreting this data are discussed. Finally, the paper presents several schematic diagrams of detailed field test facilities and test loops.

INTRODUCTION

Many problems encountered during geothermal well testing arise because of the thermodynamic instability of the reservoir fluids. Gases can break out, resulting in multiple phases, and solids can form at various locations within the flow system. Such reactions may produce misleading results, especially in the case of short-term tests. Conventional pressure analyses (e.g., build-up, multi-rate tests, etc.) cannot be accurately interpreted unless these reactions are eliminated or taken into account.

The lack of dependable high temperature downhole tools causes potentially valuable data to be lost and testing costs to increase. Tools which are currently available for measuring inflow profiles, flowing temperatures and downhole pressures frequently malfunction or yield inaccurate results. This results in either loss of data or costly re-runs. There is little that can be done about this until the tool manufacturers are able to improve their products.

Chemical investigations must be carried out on the well fluids while flow tests are going on. The chemical data are important for analyzing the well test and for evaluating future field development, fluid handling, and injection problems and their solution.

If the geothermal system is not accurately characterized in all five major areas listed above, a costly misunderstanding of the system may arise. This can lead to poor economic and technical decisions which in turn will adversely impact future development of the field.

GENERAL STRATEGY OF GEOTHERMAL WELL TESTING

Table 1 lists the major objectives to be accomplished during a comprehensive program of geothermal well testing. Ideally, the well test procedures should be designed so that all or most of these objectives are accomplished in a fairly short time and at a reasonable cost. Table 2 shows the various test methods normally used to obtain the reservoir, well, fluid, fluid utilization potential and injectivity information needed before proceeding with further development of the field.

A major shortcoming of past and present geothermal well tests has been the lack of an integrated approach. Flow tests are often run to obtain data for a specific purpose such as formation kh or productivity index. Later on, it is recognized that other data, such as chemical properties of the fluids, scaling tendencies, or environmental parameters must also be obtained. The result is a needless duplication of expensive production tests which, with proper planning, could have been combined.

This lack of an integrated approach is one of the major reasons for the high costs and long delays involved in developing a geothermal field. Table 3 lists some of the penalties which may result, each of which provides a strong incentive to utilize an integrated well test approach.

A GENERAL APPROACH TO WELL TESTING

Conditions encountered in testing in a geothermal reservoir are quite different from those in oil and gas field operations. Most of the differences are caused by: (a) the thermodynamic instability of geothermal fluids; (b) the type of fluid utilization (i.e., power generation) planned for geothermal operations; and (c) the substantially higher flow rates and temperatures encountered in a geothermal well.

The physical and chemical behavior of geothermal fluids should be determined in detail at an early stage of field development. For example, if the tendency for the geothermal fluid to scale in the wellbore is determined early on, it may be possible to prevent irrevocable damage to the well by taking appropriate precautions.

TABLE 1

OBJECTIVES FOR GEOTHERMAL WELL TESTING

1) RESERVOIR CHARACTERISTICS

- A) STATIC PRESSURE, TEMPERATURE, FLUID PROPERTIES IN RESERVOIR
- B) AVERAGE KH
- C) STORAGE CAPACITY IN RESERVOIR (ØHC)
- D) RESERVOIR DRIVE MECHANISM
- E) RESERVOIR TYPE
  - 1) Fractured
  - 2) Matrix (uniform or heterogeneities)
  - 3) Combination
- F) BOUNDARIES EFFECTS DUE TO:
  - 1) Faults
  - 2) Pinch-outs
  - 3) Lateral change of diffusivity
  - 4) Closed or leaky boundaries (influx and/or communication)
- G) VERTICAL TRANSMISSIBILITY
- H) FLOW EFFICIENCY (STEADY STATE PRODUCTIVITY)
- I) RESERVES
  - 1) Heat in place
  - 2) Heat recoverable
- J) COMPACTION

2) WELLBORE/RESERVOIR INTERFACE

- A) THEORETICAL WELL PRODUCTIVITY
- B) NEAR WELLBORE PRODUCTIVITY IMPAIRMENT DUE TO DRILLING AND COMPLETION
- C) NEAR WELLBORE IMPAIRMENT PRODUCTIVITY DUE TO PRODUCTION
  - 1) Damage due to flowing fluid properties (scale)
  - 2) Damage due to formation solids (sand, clays, etc.)
  - 3) Damage caused during stimulation
- D) WELLBORE STABILITY
  - 1) Sand influx
  - 2) Cave-in

3) WELLBORE

- A) PROBLEMS CAUSED BY PERFORATIONS AND/OR SLOTS
- B) HARDWARE INDUCED PROBLEMS
- C) FLUID INDUCED PROBLEMS
- D) TEMPERATURE INDUCED PROBLEMS
- E) FLOW INDUCED PROBLEMS
- F) WELLBORE STORAGE EFFECTS

4) FLUID UTILIZATION

- A) CHEMICAL AND PHYSICAL FLUID BEHAVIOR AS FUNCTION OF TEMP., PRESSURE, RATE AND TIME
- B) FLUID PHASE BEHAVIOR AS FUNCTION OF TEMP., PRESSURE, RATE & TIME
- C) FLOW DYNAMICS AND ASSOCIATED EFFECTS
- D) SUSPENDED PARTICLES AND THEIR BEHAVIOR
- E) ENVIRONMENTAL
- F) ADAPTABILITY OF FLUIDS FOR CHEMICAL AND PHYSICAL ALTERATION

5) PROBLEMS ASSOCIATED WITH REINJECTION AND INJECTION (DISPOSAL)

- A) WELLBORE
- B) WELLBORE/RESERVOIR INTERFACE
- C) RESERVOIR

TABLE 2

TEST METHODS IN GEOTHERMAL WELL TESTING

1) PRODUCTION RESERVOIR CHARACTERISTICS
- A) BUILD-UP
- B) DRAW-DOWN
- C) MULTI-RATE TEST (CONSTANT RATES)
- D) VARIABLE RATE TEST
- E) INTERFERENCE TEST
- F) PULSE TESTING
- G) FLUID SAMPLING AND CHEMICAL ANALYSES

2) WELLBORE/RESERVOIR INTERFACE CHARACTERISTICS
- A) SKIN EFFECTS THROUGH BUILD-UP, DRAW-DOWN, VARIABLE RATE TEST
- B) PRODUCTION TESTING (SPINNERS, RA TRACER, TEMP, & PRESSURE)
- C) FLUID SAMPLING AND CHEMICAL ANALYSES

3) WELLBORE CHARACTERISTICS
- A) PRODUCTION TESTING (SPINNERS, RA TRACERS, TEMP., PRESSURE, CALIPERS, IMPRESSION BLOCKS, GAUGE RINGS, ETC.)
- B) FLUID SAMPLING AND ANALYSES

4) FLUID UTILIZATION
- A) RATE MEASURING
- B) SAMPLING AND CHEMICAL ANALYSES
- C) INLINE INSTRUMENTATION FOR THERMODYNAMIC PROPERTIES (TEMP., PRESSURE, pH AND CONDUCTIVITY CELLS, ETC.)
- D) TEST LOOPS AND APPARATUSES (E.G., EXPERIMENTAL SIMULATION OF POWER PLANTS)

5) INJECTIVITY AND INJECTIBILITY
- A) FALL-OFF
- B) STEP RATE
- C) PRESSURE-RATE-TIME RELATIONS (INJECTIVITY DECLINE)
- D) SAMPLING AND ANALYSES
- E) FILTER AND CORE TESTING

TABLE 3

PENALTIES FOR NOT USING INTEGRATED APPROACH TO WELL TESTING

1) UNDUE TIME DELAYS IN FIELD DEVELOPMENT DUE TO:
   - A) NEED TO REPEAT TESTS
   - B) INCREASE OF CUMULATIVE TEST TIME
   - C) LONG TIME PERIODS BETWEEN INDIVIDUAL TESTS
   - D) EXCESSIVE TIME REQUIREMENTS FOR INDIVIDUAL TEST EVALUATION
2) TEST DATA INTERPRETATION PROBLEMS
3) GENERATING OF FALSE CONCEPTS BETWEEN INDIVIDUAL TESTS
4) DAMAGE TO WELL AND SURFACE EQUIPMENT BECAUSE OF INTERMITTENTLY FALSE CONCEPTS
5) COST PENALTIES BECAUSE OF THE ITEMS MENTIONED ABOVE

Figure 1 illustrates the general concept of an integrated well testing approach. The obvious advantage of this approach is the accumulation of high density data during a short period of time. The entire well test can usually be accomplished within a four- to six-week period. This can be achieved by concurrent production testing and injection with careful planning of interrelated objectives.

HARDWARE AND INSTRUMENT REQUIREMENTS FOR INTEGRATED WELL TESTING

In order to perform the various tests concurrently and without internal interferences, a set of special hardware and instrumentation is required. Test loops which are constructed or assembled at the well site are key elements. These loops provide the operator with the means for investigating fluid properties and flow rates while other test work (e.g., pressure transient and injectivity testing) is going on. Figures 2 and 3 show the basic flow diagram of two loops that have been used in the past. Figures 4 and 5 show the diagram of a new loop design which allows a large degree of freedom for performing more complex fluid investigations.

The physical and chemical behavior of the fluids including their critical phase and flow behavior under the entire range of operating conditions can be studied in detail. These data are not only pertinent for the interpretation of the other concurrent test work, but also for the future fluid utilization and injection processes. For example, these loops allow the determination of most, if not all, of the fluid characteristics critical for a future power plant design. They also yield important chemical information that may be useful in determining scaling problems or in designing future stimulation treatments.

The data obtained from the fluid investigations in the high and low pressure test loops can be recorded by using an automatic data acquisition system. The data from in-line instruments such as pressure, temperature, flow rate, conductivity and ion concentration can be collected, digitized and stored on tapes or cassettes. This provides a means for rapid data evaluation during the actual testing. For example, any necessary changes in the test procedures will be indicated almost immediately. The data on tape can be transferred to a disc and used as input information for presently available computer programs.

FIGURE 1

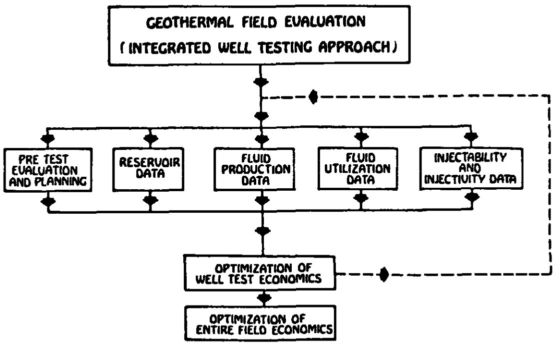

FIGURE 2

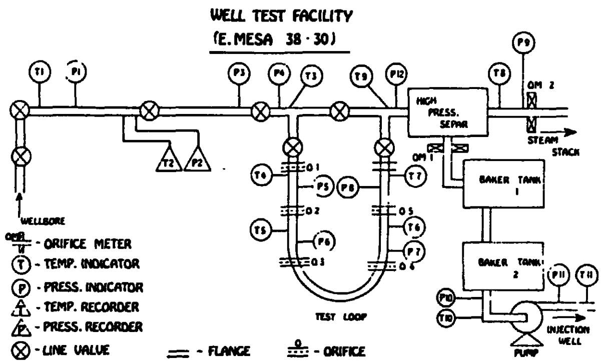

FIGURE 3

SCHEMATIC DIAGRAM OF TEST FACILITY

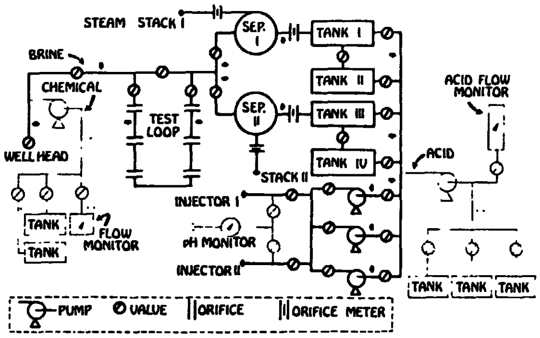

FIGURE 4

SCHEMATIC DIAGRAM OF LINES AND VALVES
(GEOTHERMAL TEST FACILITY)

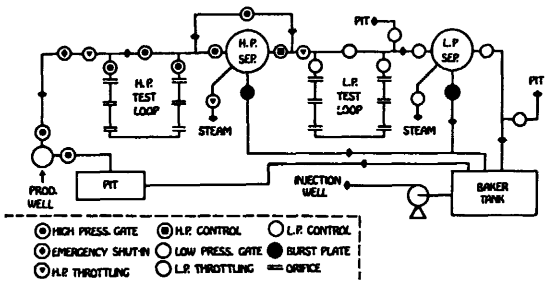

FIGURE 5

SCHEMATIC DIAGRAM OF MONITORING STATIONS
(GEOTHERMAL TEST FACILITY)