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CORRELATION OF RIG TESTS AND JAMES TUBE TESTS IN THE COSO GEOTHERMAL FIELD

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ABSTRACT

Rig test results are correlated with longer term flow rates for wells in the Coso Geothermal Field. This work is based on analysis of 55 selected rig tests and subsequent James Tube tests. The correlations can provide preliminary estimates of well productivity for Coso and similar water-dominated, fracture-controlled, geothermal fields.

INTRODUCTION

The Coso Geothermal Field is located approximately 200 miles north of Los Angeles in Inyo County, California (Fig. 1). California Energy Company has drilled 98 production-sized wellbores in the field since 1981, 86 of these in the past three years (Fig. 2). Sixty-one of these wells have proved productive, 14 are being used as injectors, and 23 are considered uneconomic.

Testing for the productive wells has typically included at least one "rig test" (i.e., a brief flow through an orifice in the blooie line with the rig in place), followed by an "initial test," during which the well is flowed to atmosphere for several weeks through a succession of James tubes.

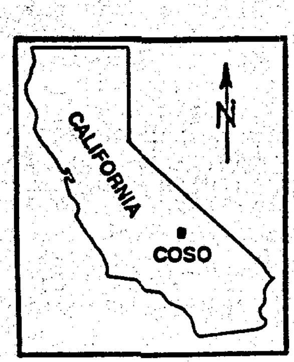

Figure 1. Location map of the Coso Geothermal Field.

The purpose of this paper is to describe the correlation between the results of rig tests and initial tests (i.e., James Tube tests) at Coso. This will provide an empirical basis for improving estimates of well productivity based on rig tests, both at Coso and at similar water-dominated geothermal fields.

DESCRIPTION OF COSO RESOURCE

The Coso field produces from fractured crystalline rock at depths ranging from 1,329 feet to 10,455 feet. Core analysis has shown that the reservoir rock matrix has low porosity (0.4 to 1.4%) and low permeability (less than 0.1 microdarcy), indicating that production is entirely controlled by fractures. Table 1 lists properties of the bulk reservoir and of the produced fluids.

The production wells at Coso are artesian and usually produce a two-phase mixture at the surface. In certain areas, the high enthalpy of produced fluids reflects excess steam production due to boiling in the reservoir.

TYPICAL WELL COMPLETION

Production wells at Coso are usually completed with a 13-3/8" string of

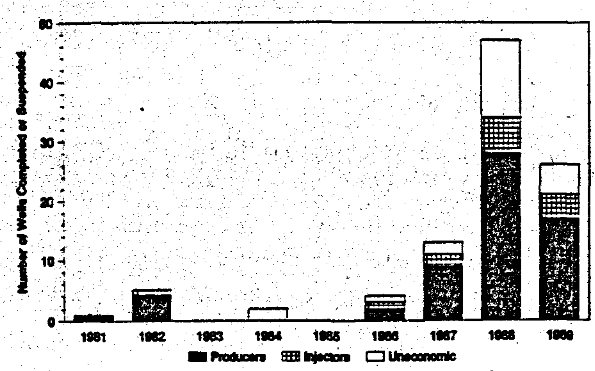

Figure 2. Drilling activity in the Coso Geothermal Field.

Table 1.
Coso Reservoir Properties

Temperature	400-650 deg F
Pressure (at 2000 ft. above sea level)	575-650 psig
Permeability-Thickness Product (kh)	50,000-250,000 md-ft
Enthalpy of Produced Fluids	400-1,150 BTU/lbm
Total Dissolved Solids (Pre-Flash)	3,700-8,000 mg/kg
Non-Condensible Gas (Pre-Flash)	0.5-2.5 %

casing cemented at 1,500 to 2,500 feet, depending on the expected total depth of the hole. A 9-5/8" slotted liner is hung in 12-1/4" hole from just above the 13-3/8" shoe to total depth. (Some older wells were drilled with an 8-3/4" wellbore and were completed with 7" or 7-5/8" liners.) Occasionally, wells have been completed without liners if their productivity is marginal and their wellbores appear to be in good condition.

DESCRIPTION OF RIG TEST PROCEDURE

When a drilling well has encountered enough lost circulation zones or fluid entries to warrant testing, the wellbore is displaced with a mist of air and soap. The drill pipe is pulled from the hole, and the well is flowed fully open for several hours through the blooie line to clean up. Then the well is shut in to build up pressure and to allow an orifice plate to be installed in the blooie line.

The orifice plate may range in size from 5 to 8 inches. It is installed downstream of two 13-3/8" wear spools and the blooie line valve (12", 400 series), about 15 feet from the banjo box on the wellhead. The flowing pressure and temperature are recorded at taps three to four feet upstream of the orifice. Downstream of the orifice, the blooie line expands to 20" pipe, which discharges into an atmospheric separator.

A rig test usually lasts from three to seven hours, ideally until the flowing pressure and temperature stabilize. A given well may be rig tested several times at different drilling depths, or it may be tested both before and after setting a liner.

DESCRIPTION OF JAMES TUBE TESTING

The James Tube testing on a productive well at Coso typically begins several weeks after the rig moves off. The testing lasts approximately 30 days, on a sequence of three James Tube sizes chosen to define a deliverability curve over a range of flowing wellhead pressures.

The metering equipment consists of a horizontal meter run with flanges for an orifice, followed by a James Tube which discharges to an atmospheric separator. Steam is vented through the top of the separator, and the water discharge from the separator is measured across a weir. The meter run is 30 feet long and 12 inches in diameter, with the orifice flanges 20 feet from the upstream end. The James Tubes range in size from 4 to 9 inches and are chosen so that the flowing wellhead pressure on the largest James Tube remains above 100 psig. Generally, the James Tube and the orifice are close to the same size.

The total mass flow rate and the mixture enthalpy of the produced fluid are calculated from the lip pressure of the James Tube and the water rate across the weir, using the method described by James (1962) and Ramey (1978). The orifice in the meter run provides an independent method of checking the mass rate and the enthalpy based on the orifice equation of James (1965-66) and is used for quality control on the weir calculations. The steam rate is calculated as a fraction of the total mass rate based on the measured enthalpy. At Coso, a separation pressure of 82 psia has been assumed for calculating steam rates from initial tests.

DESCRIPTION OF RIG TEST CORRELATIONS

A total of 114 rig tests have been performed at Coso through the end of 1989, including multiple tests on many of the wells. For the purposes of this paper, 55 representative rig tests were selected, allowing just one rig test per completion or workover. In general, the rig test selected was the last performed prior to moving the rig off, so that the wellbore conditions would be as close as possible to those that existed during the subsequent James Tube testing. The breakdown of orifice sizes for the 55 selected rig tests was as follows: 21 on 8", 13 on 7", 15 on 6", and 6 on 5".

From each James Tube test, a single total mass rate was selected (with its associated steam rate) as the well's initial potential (IP). This was the stabilized mass rate on the largest James Tube for which the flowing wellhead pressure remained above 100 psig.

This study investigated the correlation between the last flowing pressure from each selected rig test and the IP mass and steam rates. In general, the rig test orifice and the IP James Tube were close to being the same size. However, the stabilized pressures on the James Tube test were usually subsantially higher than the ending rig test pressures. This appears to be because wells on a James Tube test had had more time to recover from the effects of cooler fluids lost to the formation during drilling operations.

It should be noted that the correlations presented here do not establish a well's total mass and steam rate at the time of the rig test. Rather, they attempt to use the rig test results (which are still affected by recent drilling operations) to predict the performance of a well once it has recovered from those operations. One would expect, then, that the correlations would be approximate, but hopefully accurate enough to be useful for preliminary estimates.

Four parameters were investigated for their impact on the rig test correlations: (1) the size of the rig test orifice; (2) the enthalpy of the produced fluid as measured during the James Tube test; (3) the presence or absence of a liner; and (4) the depth of the well.

The correlations of rig test pressure and total mass rate are presented in Figures 3-9. The first three figures (3-5) show results for the 8" orifice for wells with enthalpies in three ranges: low (less than 450 BTU/lbm), intermediate (450 to 600 BTU/lbm), and high (above 600 BTU/lbm). The figures show that there is a fairly good correlation between rig test pressure and total mass rate, but that the correlation is sensitive to the produced fluid enthalpy. The correlation for high enthalpy wells is the least clear, due to the small number of data points. However, it is clear that the impact of higher enthalpies is to shift to lower mass rates for the same rig test pressure, which is consistent with what one would expect.

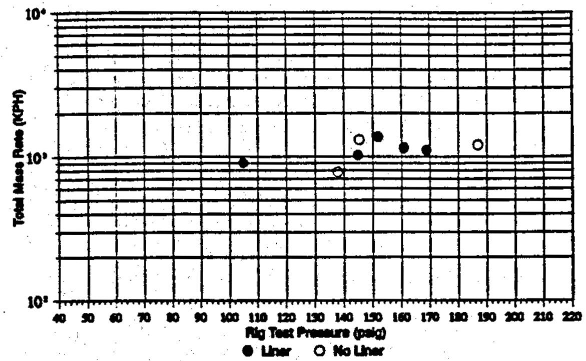

Figure 3. Rig test pressures vs. total mass rate, Coso Geothermal Field, 8" orifice, enthalpy 450 BTU/lbm or less.

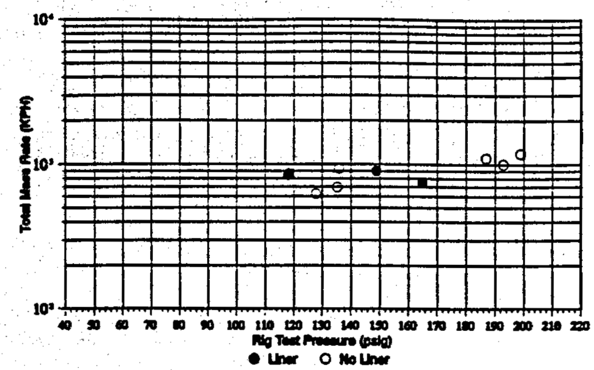

Figure 4. Rig test pressures vs. total mass rate, Coso Geothermal Field, 8" orifice, enthalpy 450-600 BTU/lbm.

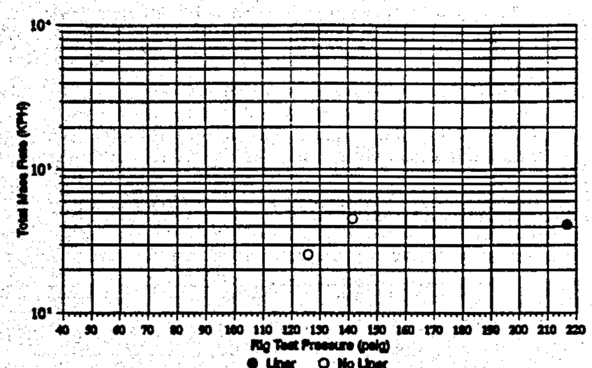

Figure 5. Rig test pressures vs. total mass rate, Coso Geothermal Field, 8" orifice, enthalpy above 600 BTU/lbm.

Figures 3-5 also illustrate that the correlations appear to be insensitive to the presence or absence of a liner at the time the rig test was performed. (Note that in several cases wells were rig tested before liners were installed, but the James Tube test was performed after the wells were lined.) The wells which were tested without liners fall on the same trend lines as those with liners. Similar results were obtained in correlations for other orifice sizes.

Figure 6 shows that the impact of well depth on the rig test correlation was also surprisingly slight. The figure presents the 8" orifice results for all enthalpy ranges, and it distinguishes between shallow wells (less than 4000 feet) and deep wells (greater than 4000 feet). The shallow wells appear to plot at slightly higher mass rates for a given rig test pressure, but there is substantial overlap between the two ranges. The three lowest mass rates on the plot appear to be more a function of high enthalpy than well depth (compare Figure 5).

Figures 7-9 present the correlations for the other orifice sizes (7", 6", and 5"). Because there were fewer data points for these orifice sizes, the results for the three enthalpy ranges were combined on each graph. All but two of the wells with 7" orifice tests were in the intermediate enthalpy range (Figure 7). The 7" data show somewhat more scatter than the 8" data, but there is still a recognizable correlation. For the 6" data (Figure 8), there is a remarkably good (and perhaps fortuitous) correlation for wells with high enthalpy, while wells in the lower enthalpy ranges have too few data points to draw much of a conclusion. Similarly, the data for the 5" orifice (Figure 9) are too sparse to establish any correlation. However, the plots for these three orifice sizes confirm the impression that high enthalpy wells plot at lower mass rates for a given rig test pressure.

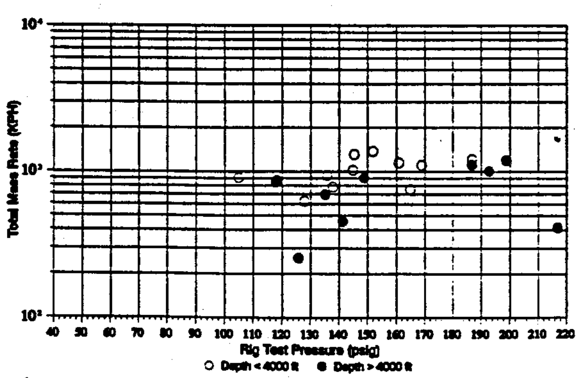

Figure 6. Rig test pressures vs. total mass rate, Coso Geothermal Field, 8" orifice, all enthalpy ranges, distinguishing wells based on depth.

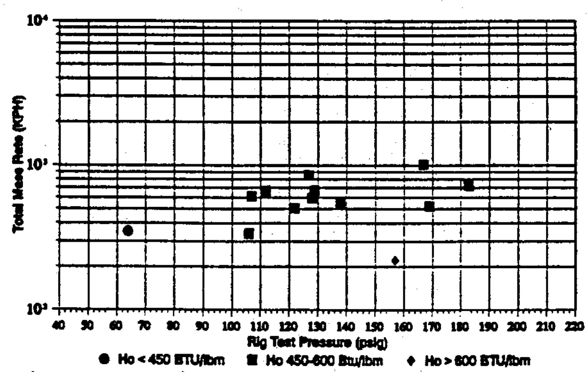

Figure 7. Rig test pressures vs. total mass rate, Coso Geothermal Field, 7" orifice, all enthalpy ranges.

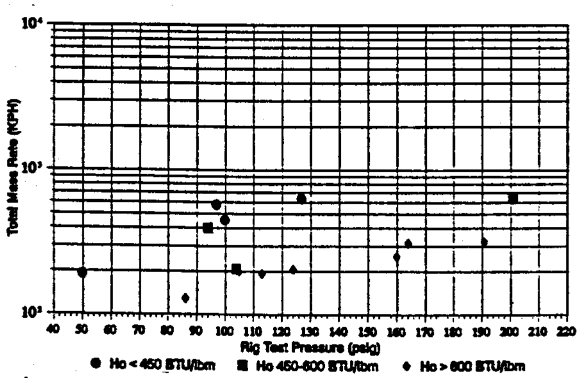

Figure 8. Rig test pressures vs. total mass rate, Coso Geothermal Field, 6" orifice, all enthalpy ranges.

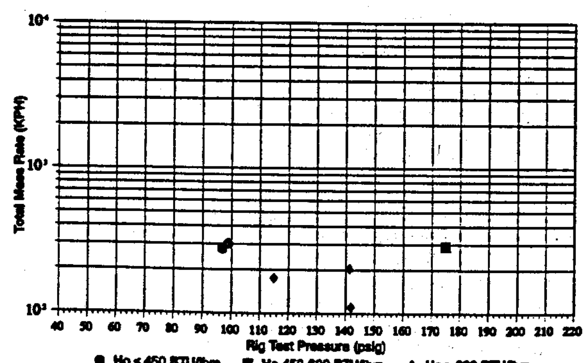

Figure 9. Rig test pressures vs. total mass rate, Coso Geothermal Field, 5" orifice, all enthalpy ranges.

Figures 10-14 present the correlations between rig test pressures and steam rates. These figures show that, for the 8", 7", and 6" orifice sizes, the correlation is fairly good for all enthalpy ranges combined. (The 5" data are again too sparse to show much of a trend.) In other words, plotting rig test pressures against steam rates rather than total mass rates appears to cause the separate correlations for different enthalpy ranges to collapse to a single trend. Once again, the correlations appear to be insensitive to the presence of a liner during the rig test. Further, the figures suggest that, as a predictor of steam rates, the rig test is fairly insensitive even to the size of the orifice used. Figure 14 combines the results from all four orifice sizes and illustrates that the 7" and the 8" data plot essentially on top of each other. The 6" and the 5" data show progressively greater offsets but still overlap considerably.

CONCLUSIONS

(1) Rig tests can be useful in providing a preliminary estimate of well productivity for a two-phase, fracture-controlled, geothermal reservoir.

(2) The correlation between final rig test pressures and total mass rate is sensitive to the orifice size used in the rig test and to the enthalpy of the produced fluids. The correlation is relatively insensitive to the depth of the well and to the presence or absence of a liner in the well at the time of the rig test.

(3) The correlation between final rig test pressures and steam rate is insensitive to the enthalpy of the produced fluids and is only slightly sensitive to the size of the orifice used.

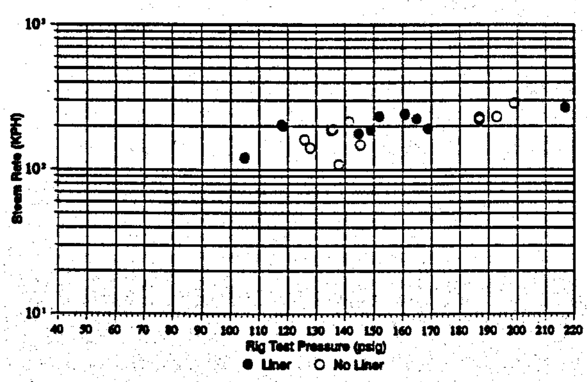

Figure 10. Rig test pressures vs steam rate, Coso Geothermal Field, 8" orifice, all enthalpy ranges.

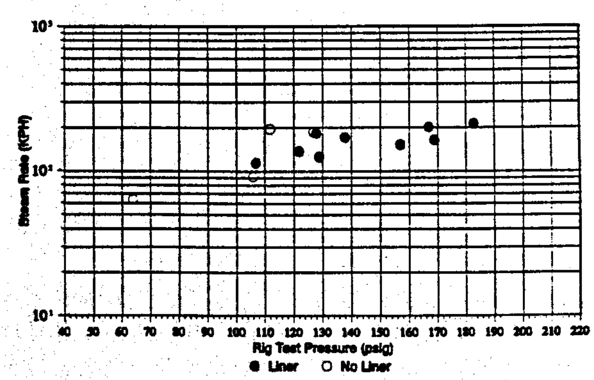

Figure 11. Rig test pressures vs steam rate, Coso Geothermal Field, 7" orifice, all enthalpy ranges.

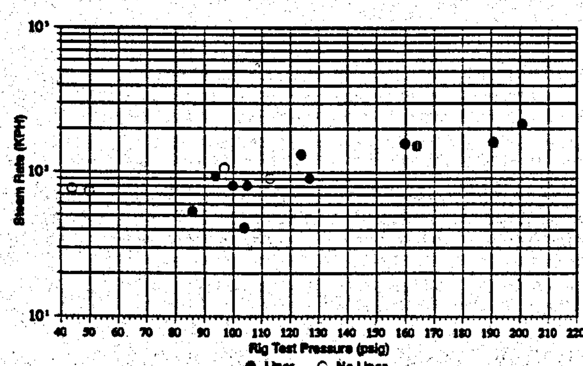

Figure 12. Rig test pressures vs steam rate, Coso Geothermal Field, 6" orifice, all enthalpy ranges.

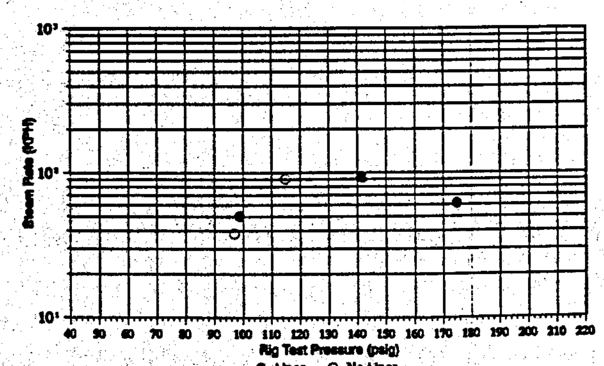

Figure 13. Rig test pressures vs steam rate, Coso Geothermal Field, 5" orifice, all enthalpy ranges.

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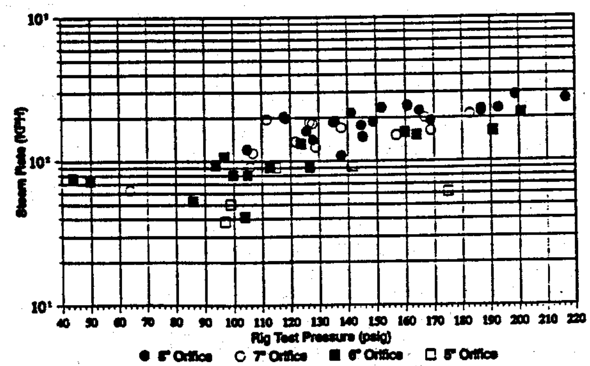

Figure 14. Rig test pressures vs steam rate, Coso Geothermal Field, all orifice sizes, all enthalpy ranges.