ANALYSIS OF PRELIMINARY FLOW DATA FROM PLEASANT BAYOU NO. 2 GEOPRESSURED WELL

S. K. Garg, Systems, Science and Software,
P. O. Box 1620, La Jolla, CA 92038

I. INTRODUCTION

For the last several years, the University of Texas at Austin (UTA) and, more recently, Louisiana State University (LSU) have analyzed the geopressured tertiary sandstones along the Texas Gulf Coast and the Louisiana Gulf Coast with the objective of locating prospective reservoirs from which geothermal energy could be recovered. Of the "geothermal fairways" (areas with thick sandstone bodies and estimated temperatures in excess of 300°F) in Texas, the Brazoria Fairway in Brazoria County appears most promising and the Austin Bayou Prospect has been developed within this fairway. The first well drilled at the Austin Bayou Prospect (DOE Pleasant Bayou No. 1, drilled in 1978) is being used for reinjection since well completion problems precluded its use for geopressured reservoir testing. A second well (DOE Pleasant Bayou No. 2) was drilled in 1979 in the immediate vicinity of the first to obtain the transient flow data needed to evaluate the geopressured reservoir.

Preliminary short term production and buildup tests of the Pleasant Bayou No. 2 well were conducted during the second half of 1979. A series of five pressure drawdown (production times ranging from 13 minutes to 10.5 days) and buildup tests were performed with flow rates up to about 20,000 bbl/day in an effort to evaluate formation parameters for the geopressured sand perforated at 14,644 feet to 14,704 feet (net sand thickness 60 feet). The relevant flow and pressure data are given in a report by Clark [1].

The Pleasant Bayou No. 2 well has 7 inch casing set through the Frio sand at 14,644 feet to 14,704 feet (mean depth 14,674 feet). The well has 5-1/2 inch production tubing. Bottom-hole pressure was measured using the Hewlett-Packard quartz crystal surface recording element. A nickle-iron alloy sensor with solid state transmission was employed to measure the bottom-hole temperature (~ 301°F). Some pressure and temperature gradients at 1,000 feet intervals were also taken. Surface pressures were obtained using a dead weight tester and a Panex 1100 pressure transducer. Independent temperature sensing capability was also available. A turbine pulse meter was used to record flow rates.

Due to various problems with the bottom-hole pressure gauges and the instrument cable, bottom-hole pressures were measured at different depths (ranging from 14,500 feet to 14,750 feet) at different times during the drawdown/buildup tests. In order to use these data to evaluate formation properties, it is convenient to reduce the measured bottom-hole pressures to a common depth. Since the majority of buildup data were obtained at the 14,600 feet datum we have elected to refer all bottom-hole pressure data to this depth. The initial reservoir pressure at the 14,600 datum is estimated to be 11,206.3 psi. It is also worth noting here that a change in the instrument cable design after flow period 4 may have resulted in a systematic error in the measured bottom-hole pressures. Bottom-hole pressures for well shutdown period 4, flow period 5 and shutdown period 5 apparently need to be corrected by 20-40psi.

It was originally planned to measure the liquid and gas flow rates separately at the well head. However, due to problems with the separator, the entire flow stream had to be directly passed through the turbine meter. For purposes of analysis, it is necessary to estimate the liquid and gas flow rates separately. We describe elsewhere [2] the procedures employed to reduce the flow data to standard conditions.

Southern Petroleum Laboratory, Inc. reported a salinity of 175,435 ppm based on measurements on fluid samples obtained from the reservoir. The salinity may also be estimated from the static pressure gradient and the measured temperature. Based on a static pressure gradient of 0.4607 psi/feet and a temperature of 301°F, salinity at standard conditions is estimated to be 169,548 ppm. The latter value of salinity is in good agreement with the value reported by Southern Petroleum Laboratory, Inc., but is at considerable variance with the value of 130,000 ppm given by Kharaka et al [3]. In the absence of additional data, we will assume that the reservoir fluids have a salinity of 169,548 ppm. The latter value of salinity, together with the S^3 methane/brine equation-of-state data [4], yields a methane content of 22.47 SCF/STB at saturation. Although the GWR (Gas Water Ratio) was not measured for the greater part of the flow test, Clark [1] mentions that at the end of the first hour of the third flow period, the GWR averaged around 19.6 cu. ft./bbl at p $\sim$ 766.7 psia and T $\sim$ 172°F (separator pressure and mean temperature of flow stream). This implies that the reservoir fluids are most probably saturated with gas.

The main purpose of this study is to analyze pressure drawdown and buildup data to evaulate formation parameters. In this connection, we note that the flow periods 1 and 2 were too short (13 minutes and 184 minutes respectively) to give meaningful data for analysis purposes. Also, flow data for part of flow period 3 and pressure buildup data for practically all of buildup period 4 are missing. The complete flow and pressure drawdown/buildup data are, however, available for flow/shutin period 5 (flowing time $\sim$ 10.5 days, shutin time $\sim$ 20 days). For the aforementioned reasons, our analysis will be primarily concerned with the flow/shutin period 5.

II. ANALYSIS OF BUILDUP PERIOD 5 PRESSURE DATA

Pleasant Bayou No. 2 well was flowed at an average rate of approximately 12,746 STB/D from December 3, 1979 (19:31:50 hours) to December 14, 1979 (7:59 hours). Buildup pressures were measured from the shutin time on December 14, 1979 to January 3, 1980 (8:00 hours). The flow stream, at bottom-hole conditions, contained less than 1 percent by volume of free gas; it is, therefore, felt that classical single-phase analysis methods should be adequate to analyze the buildup data. In analyzing the buildup data for shutin period 5, the question arises as to how the production periods 1-4 influence the buildup pressures. One could, in principle, utilize superposition to account for the prior flow periods; in practice, this procedure is rather cumbersome. An alternate method is to assume a constant flow rate, and calculate an equivalent flow time. Since the prior flow periods mainly influence the late-time buildup data, the latter procedure should suffice for present purposes. Given a total production of 210,506 STB, and an average producing rate (q) of 12,746 STB/D, the equivalent producing time (t) is 396.37 hours.

The buildup data versus $(t + \Delta t)/\Delta t$ are shown in Figure 1. It can be seen from Figure 1 that the buildup data may be approximated by two straight lines with slopes (m) of 60 psi/cycle and 66 psi/cycle respectively. These slopes yield the following values for formation permeability:

(i) Near 'well bore' permeability, $k = 177.6$ md

(ii) Far field permeability, $k = 161.5$ md

The two straight-line segments on the Horner plot intersect at $(t + \Delta t)/\Delta t \sim 17.5$ (corresponding to $\Delta t \sim 24$ hours). The transition from near well permeability to far field permeability occurs approximately at (see e.g. Matthews and Russell [5]):

$$r_{trans} = \left(\frac{0.00105\ k\Delta t}{\phi\mu C_T}\right)^{1/2}$$

where Δt = Shutin time corresponding to the intersection of the straight lines on the Horner plot, hours; ϕ ~ Formation porosity; C_T ~ Total formation compressibility (= $[(1-\phi)/\phi]$ C_m + C_f), psi^{-1}; C_m ~ Uniaxial formation compressibility, psi^{-1}; and C_f ~ Pore fluid compressibility, psi^{-1}.

With $k = 177.6$ md, $\mu = 0.295$ Cp, $C_m \sim 10^{-6}$ psi^{-1}, $C_f \sim 3 \times 10^{-6}$ psi^{-1}, $\phi \sim 0.176$ and $\Delta t \sim 24$ hours, r_{trans} is approximately 3350 ft.

The skin factor s is given by the relation [5]:

$$s = 1.151 \left[\frac{P_{1hr} - P_f}{m} - \log \frac{k}{\phi \mu \; C_T \; r_w^{\;2}} + 3.23 \right] ,$$

where P_{1hr} ~ Shutin pressure at Δt ~ 1 hour extrapolated from the straight line on the Horner plot, psi; P_f ~ Last flowing pressure, psi; and r_w ~ Well radius, ft.

With P_{1hr} ~ 11,018 psi, P_f ~ 10,466 psi, and r_w ~ (3.5/12) ft, the skin factor s is 3.12.

The radius investigated by the buildup test is approximately given by r_{inv} [5]:

$$r_{inv} = \left(0.00105 \, \frac{k \Delta t}{\phi \mu \; C_T} \right)^{1/2}$$

where Δt = buildup time. With Δt = 480 hours (shutin period 5), the formation radius investigated during buildup is approximately 14,960 ft.

The preceding analysis indicates that no definite boundaries (permeability barriers) can be identified from the 20 day buildup test. This conclusion is, however, somewhat uncertain in so far as the MUSHRM history-match calculations, discussed in Section III, indicate that late-time buildup data can be better matched by assuming a closed boundary. It is also appropriate to mention here that the two-mobility interpretation of the buildup data was first suggested by MacDonald [6]; this interpretation is, however, at variance with the one given by Clark [1]. Clark attributes the upward shift in the slope on the Horner plot to a minor fault of less than the sand thickness that causes an area of flow constriction at the fault position.

III. HISTORY - MATCH CALCULATIONS

In this section, we will employ the formation properties derived in Section II in the reservoir simulator MUSHRM to history match the observed drawdown/buildup pressures and flow rates. For our initial simulation, the reservoir is assumed to be a right circular cylinder with radius R ~ 37, 200 feet (Note that this radius is approximately two and one-half times the maximum radius, 14,960 feet, explored during the 20 day buildup test, and should be adequate to simulate an infinite reservoir.) and height h=60 feet (depth 14,644 -14,674 feet). The details regarding the numerical grid, production history, initial fluid state and the formation properties utilized are given elsewhere [2].

Figures 2-4 compare the calculated bottom-hole pressures with observed drawdown/buildup pressures for flow/shutin periods 1-4. The calculated flowing pressure at t = 13 minutes (end of first drawdown period) is almost 200 psi more than the measured value; on the other hand, the calculated flowing pressure at the end of drawdown period 2 ($t \sim 229$ minutes) is approximately 200 psi less than the observed value. Due to the uncertainties in flow data for these short term drawdown tests, no inference can be drawn from this disagreement between the observed and calculated values. Calculated drawdown pressures for flow-periods 3 and 4 (Figures 3 and 4) generally follow the observed pressure response; the calculated values are, however, about 20 psi greater than the measured pressures. This suggests that the flow rates used in the simulation are somewhat lower than the actual flow rates for periods 3 and 4.

The calculated drawdown response for flow period 5 is compared with the relevant data in Figure 5. Note that 24 psi were added to all measured pressure values to match measured and calculated pressures at the start of flow period 5. In general, there is good agreement between the observed and simulated pressures. Figure 6 compares the observed buildup pressures with the calculated buildup pressures for shutin period 5; for Δt (Δt= shutin time) < 10^4 m, there is close agreement between the two sets of values. For $\Delta t > 10^4$ m, the calculated buildup pressures (shown by a broken line in Figure 6) lie above the actual pressures; this suggests the possible presence of a permeability barrier. A second simulation was therefore, run by assuming the reservoir to be bounded at $R \sim 16{,}700$ feet ($R \sim 16{,}700$ feet represents the radius at which the maximum pressure drop, in the initial simulation, was less than 1 percent of the maximum pressure drop at the sand face); all other parameters for this calculation were identical to those for the initial simulation. The finite reservoir simulation results are identical with those obtained for the infinite reservoir except for the late part of the fifth buildup period ($\Delta t > 10^4$ minutes). Figure 6 clearly shows that the bounded reservoir assumption leads to a closer agreement between the observed and calculated pressures. We, therefore, speculate that the geopressured reservoir in question may have a permeability barrier at a distance of about $R \sim 16{,}700$ feet.

The total calculated brine and methane production during the flow periods 1-5 are 210,487 STB and 4,672,469 SCF respectively. The calculated brine production is practically identical with the estimated actual production (210,506 STB). The calculated methane content of the produced brine is 22.2 SCF/STB.

IV. CONCLUDING REMARKS

Analysis of pressure buildup data from the preliminary 10 day flow/20 day buildup test indicates the presence of a mobility change at approximately 3500 feet (assuming a uniaxial compressibility of 10^{-6} psi^{-1}), and possibly a mobility barrier at approximately 17,000 feet. The formation parameters derived from the preceding analysis were employed in the MUSHRM reservoir simulator to successfully history-match the available drawdown/buildup data from the various short-term flow/buildup tests. Current DOE plans call for extensive long-term testing of the Pleasant Bayou No. 2 well. These tests will include separation of the gas and liquid fluid components. Long-term testing will determine reservoir limits (30 day producing at 20,000 bbl/day; 60 day buildup; test started September, 1980), and well productivity (six months producing up to 40,000 bbl/day). The data from these tests are required to confirm the presence of the mobility barrier at 17,000 feet.

REFERENCES

1. Clark, J. D., "Summary of Production Tests, Reservoir Engineering Interpretations of Pleasant Bayou Wells No. 1 and 2, Geopressured Geothermal Project, Brazoria County, Texas", Report Submitted to Department of Energy, January 29, 1980.

2. Garg, S. K., J. W. Pritchett, L. F. Rice and T. D. Riney, "Well Test Analysis and Reservoir Predictions for Geopressured Geothermal Systems (1979-1980)," Systems, Science and Software, La Jolla, CA, Report DOE/ET/27202-4, 1980.

3. Kharaka, Y. K., W. W. Carothers, and G. J. Yee, "Geochemistry of Formation Waters from Pleasant Bayou No. 2 Well and Adjacent areas in Coastal Texas", Proceedings Fourth United States Gulf Coast Geopressured - Geothermal Energy Conference: Research and Development, Austin, Texas, October 29-31, 1979.

4. Pritchett, J. W., S. K. Garg, M. H. Rice, and T. D. Riney, "Geopressured Reservoir Simulation", Systems, Science and Software, La Jolla, Ca, Report SSS-R-79-4022, 1979.

5. Matthews, C. S., and D. G. Russell, Pressure Buildup and Flow Tests in Wells, Monograph No. 1, Society of Petroleum Engineers of AIME, Dallas, Texas, 1967.

6. MacDonald, R. C., Personal Communication, 1980.

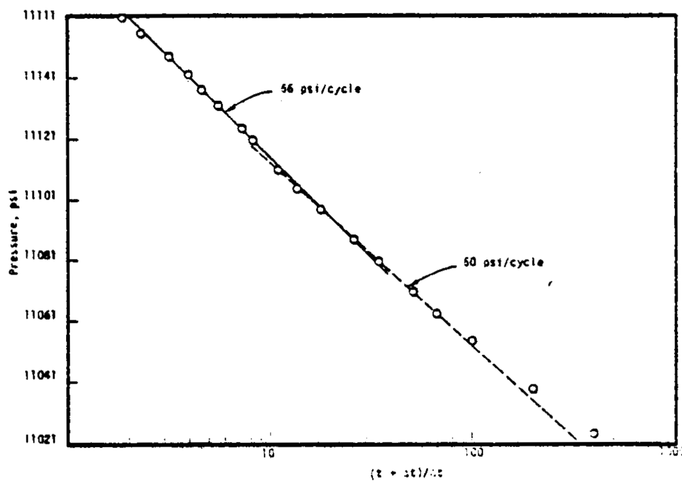

Figure 1. Horner plot for buildup period 5.

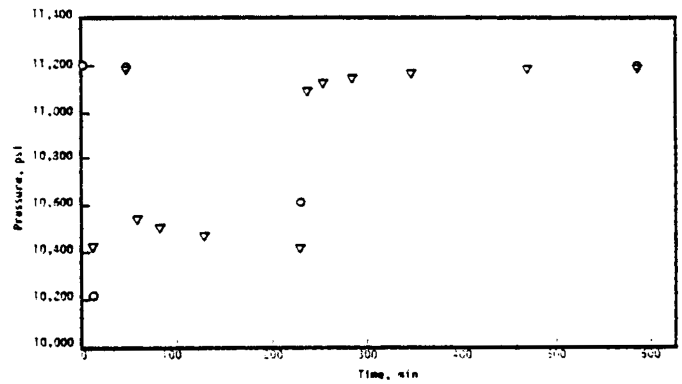

Figure 2. Comparison of calculated and measured bottom-hole pressures for drawdown/buildup periods 1 and 2. The abscissa denotes time from the start of drawdown test 1, O - measured values. ∇ - calculated values.

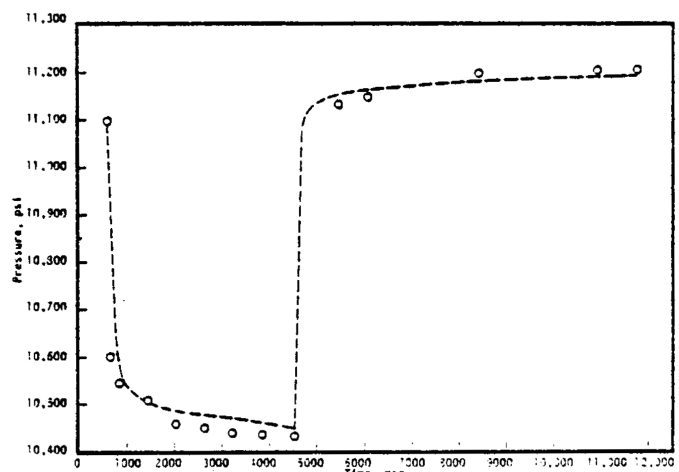

Figure 3. Comparison of calculated and measured bottom-hole pressures for drawdown/buildup period 3. The abscissa denotes time from the start of drawdown test 1. — calculated; O - measured.

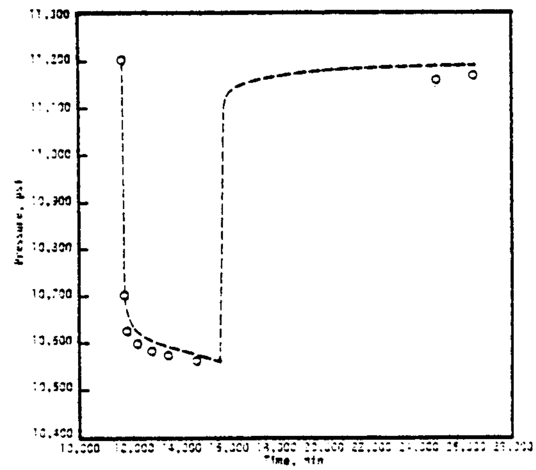

Figure 4. Comparison of calculated and measured bottom-hole pressures for drawdown/buildup period 4. The abscissa denotes time from the start of drawdown test 1. —— calculated; o - measured.

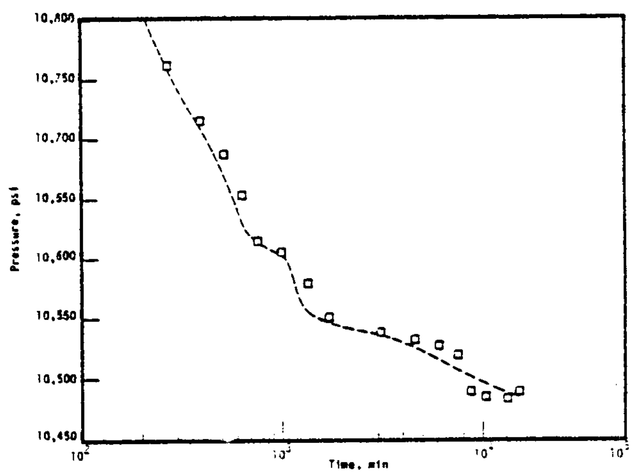

Figure 5. Calculated and measured pressure data for drawdown period 5. All measured pressure values were increased by 24 psi to match measured and calculated values at start of flow period 5. Abscissa denotes time from the start of flow period 5. ◻ - measurements; —— calculated.

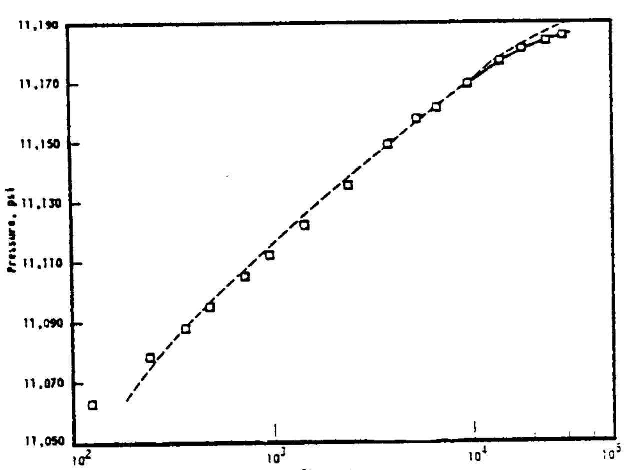

Figure 6. Calculated and measured pressure data for buildup period 5. All measured values were increased by 24 psi to match observed and calculated values at the start of flow period 5. Abscissa denotes time from the start of buildup period 5. ◻ - measurements: - - - calculations (infinite reservoir); —— calculations (finite reservoir).