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Reservoir Modeling and Prediction at Pleasant Bayou Geopressured-Geothermal Reservoir

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ABSTRACT

Modeling and prediction of geopressured-geothermal reservoirs is an excellent example of an engineering problem that can be solved through many different means. The problem may be approached from a purely numerical viewpoint, where a successful history match "demonstrates" the validity of the reservoir model, or from an analytical point of view. Each method has its own inherent limitations and weaknesses. Such limitations can be minimized by using some combination of both numerical and analytical methods, taking advantage of the strengths of each without the attendant weaknesses.

This paper describes a combined numerical/analytical approach to reservoir engineering at the Pleasant Bayou geopressured-geothermal reservoir. A reservoir description had previously been developed, through which a successful history match was performed. Certain details of the reservoir can also be obtained through analysis of pressure and flow transients; these can then be used to constrain the numerical model. Methods for extracting such reservoir data are discussed, and the manner in which they can be used as constraints in the numerical models are presented.

INTRODUCTION

Reservoir engineering is a branch of engineering that seeks to quantify the relationships between a given fluid reservoir in the subsurface and that reservoir's response to exploitation. The most important step in this process is development of an accurate reservoir description. It is interesting to note that reservoir engineering is among the few branches of science that relies almost exclusively on indirect measurements to develop a working model. Historically, the reservoir engineer has relied on core analysis, electric logs, and pressure transient testing for the reservoir model.

In the last decade more and more reservoir engineers have come to the realization that additional data is, in general, available. Geologic maps can be incorporated in the engineering work, as can seismic information. Simulation studies are also useful in developing a reasonable reservior description. Thus, the successful reservoir engineer has evolved into one that incorporates data from a variety of sources in developing his reservoir model.

In geopressured reservoirs, this incorporation of data is not just useful, it is crucial. The lack of well data (usually one per reservoir) means that little or no core or log data can be obtained areally. The only avenue open to the engineer is to incorporate reservoir information from geologic work and seismic profiles, and data from single well pressure transient tests. Failure to incorporate any available data places excessive limitation on the engineer's ability to develop a realistic reservoir model. The goal of the reservoir engineer is to predict future reservoir response to exploitation; an incorrect model will ultimately lead to incorrect predictions.

This paper is intended to describe the approach taken to develop a reservoir model for the Pleasant Bayou geopressured reservoir. This approach takes advantage of a numerical model of the reservoir developed previously, and incorporates transient test analysis to constrain and improve upon the numerical model.

A NUMERICAL MODEL

A numerical model of the Pleasant Bayou reservoir was developed at INEL in FY 91. This numerical model incorporated data from a variety of sources: reservoir geometry based on geologic interpretation by U. Texas Bureau of Economic Geology (UT-BEG) (Hamlin and Tyler, 1988), production data (rates and pressures) and fluid composition from Eaton Operating Co. and

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IGT (EOC, 1990), and estimates of permeability (based on transient analysis) from S[3] (Riney, 1991). Fluid properties based on composition were taken from a various sources in the literature. These properties are detailed in INEL's 1991 annual geopressure-geothermal report, and are summarized in Table 1.

After incorporating realistic geometry and geology in the Pleasant Bayou reservoir model, a history match of 1988-1990 production was attempted. This effort was also presented in the FY91 report, and is shown graphically in Figure 1. It can be summarized by noting that a successful history match for the complete period required a pressure-dependent flow boundary southwest of the test well. This boundary is proposed to be a geopressured compartment boundary. It is a no flow boundary as long as the pressure drop across the boundary remains small; for a sufficiently large pressure drop, the integrety of the boundary fails, and fluid can flow. There is no well control data southwest of the test well, nor has seismic work been performed in this area. While this lack of evidence certainly does not support a presence of a leaky compartment boundary, it does not preclude its presence either. The final working model developed in this earlier study is shown in Figure 2.

Despite the good production history match obtained, there is no guarantee that the reservoir description used in the model was accurate. This type of a problem is known as under-constrained — that is, the data is so sparse that many different reservoir descriptions could conceivably lead to similarly successful history matches. It would seem, then, that additional work is required before concluding that an accurate reservoir description has been developed.

TRANSIENT TESTING

Fortunately, a great deal of data is available from pressure transient tests performed since 1980. This data is in the form of downhole pressures and rates versus time. Some analysis of these data have been done; in fact, transient analysis (Garg et al., 1981) yielded the value for permeability used in the numerical model, and further suggested the presence of a flow boundary near the well. While this analysis has been extremely useful, additional data may be gleaned from these tests. In particular, one may extract reservoir size and shape from late time behavior of the reservoir during these tests. These data can then be used to further enhance the numerical model, and to test certain details of the model. Examples of the analyses are summarized below. Details of the techniques that are used are given in (eg) Earlougher (1977).

Drawdown Testing

Testing that is performed while the reservoir is flowing is known as drawdown testing. In its simplest form, a well is produced at a constant rate, and downhole pressures are measured through time. After accounting for wellbore storage, the plot of bottomhole pressure versus log time becomes linear. From the slope of this line one may extract reservoir permeability. The well skin can be obtained from the intercept of the pressure-time plot. This period is known as the "infinite acting period", in that the reservoir acts as though it were alone in an infinite reservoir.

If the well flow rate is not held constant, as is often the case, a similar, though more complicated, relationship holds for permeability (Earlougher, 1977). Care must be taken in the application of these techniques, since the method most often used is applicable for infinite acting periods of time only (Dake, 1978). Multi-rate analysis can still be done; however, more complex methods of superposition must be used.

If a drawdown test is conducted for sufficiently long a period of time, the reservoir is said to enter "pseudo steady state", wherein the pressure everywhere in the reservoir declines at a constant rate. When this occurs, a plot of pressure vs time is linear. From the slope of this line, and the intercept, one can extract the reservoir size and approximate shape.

Finally, a flow barrier, such as a fault, is indicated by the doubling of the slope in the infinite acting period. It should be noted, however, that many other causes can appear to double the slope. For example, a permeability transition away from the well, or neglecting to account for wellbore storage can also "look" like a fault.

Buildup Testing

Shutting a well in causes another pressure pulse in the reservoir. Measurements of pressure vs shutin time can again lead to estimates of permeability and well skin. Fault detection is another feature of pressure buildup testing. If the well is shut in for a sufficient period, additional analyses can also be performed to estimate reservoir size and shape. Methods of analysis are extremely dependent on the rate history of the well (Earlougher, 1977; Dake, 1978). Various methods of superposition are required when well rates vary appreciably, or when shutin times are the same order of magnitude as production times.

It should be obvious that an appreciable amount of information may be gleaned from transient test analysis. Furthermore, these techniques may be applied to periods of "normal" production (that is, periods when a test was not planned). An example of this is given in a following section.

STATUS OF THE COMBINED ANALYSIS

To date, seven periods of time have been identified that are amenable to transient testing, including the 1980 reservoir limits test, the1988 multi-rate test, and three pressure buildup tests when the well was shut in. Other possible time periods exist. For example, Oct 1989 - May 1990 consitutes a period of time in which the flow rate was held essentially constant. This period of flow was preceeded by over 1000 hours of pressure buildup, so the reservoir can be assumed to be essentially static. The flow period was followed by a 60 day buildup, and therefore we can also do a buildup analysis. Because this was not a designed test, appreciable pressure data was not collected; however, daily production rates and pressures were reported. Because of the difficulty in predicting wellbore storage effects without early time pressure data, care must be exercised in analysing the data.

Pressure-time plots are given in Figures 1 and 2. Times over which these plots were made were selected such that relevent analyses could be made from the available data. In particular, pseudo-steady state behavior was considered, and a buildup analysis was performed.

Some reservoir information is required to perform the relevent tests. In particular, the static reservoir pressure must be known. This can be estimated through material balance:

$$QB/V_p = c(P_I - P)$$

where Q is the cummulative production to data, B is the fluid volume factor, c is the reservoir pore compressibility, and PI is the initial pressure. From the reported data, the reservoir pressure at the beginning of this flow period is estimated to be 10,136 psia.

This estimate of reservoir pressure involved the use of the reservoir pore volume, Vp. Vp was found from the drawdown analysis, from the relationship:

$$Vp = 0.23395qB/(m^*c_t)$$

where m* is the slope of the pressure-time curve and c_t is the total compressibility. The total connected pore volume from this test was found to be 2.31 x 10^{10} ft^3. It should be noted that this is approximately half of the pore volume reported by Hamlin and Tyler (1988).

From the buildup portion of this analysis, a reservoir permeability is found to be 181 md, consistent with the values published by Garg et al. (1981). The well skin from this data is 3.8 larger than suggested by Garg et al., but smaller than other reported values for skin (Riney, 1991). More importantly from the context of this paper, an apparent fault is identified, at a distance 5740 feet from the well.

When interpreting these test results, and applying the results to the numerical model, several features are interesting. First, the pressure-dependent flow boundary to the southwest of the test well extends from the fault mapped by Hamlin and Tyler (1988) to the southern boundary of the reservoir. This boundary does not begin to leak in the model until later in 1990; therefore this would act as a linear flow boundary. This boundary (and the mapped fault) are at a distance of approximately 6000 feet from the well. The similarity between this value and the transient result is startling. Furthermore, this boundary effectively seals off the reservoir to the southwest. If this portion of the reservoir is not in communication with the well, the total communicating pore volume is approximately 55% that of the volume suggested by Hamlin and Tyler. Again, the similarity between this fraction and that from the transient test is extremely good. While these comparisons do not "prove" our numerical model, good agreement between these analyses tends to support the numerical model as feasible.

Reservoir properties estimated from these two approaches are summarized in Table 2.

CONCLUSIONS

A study in underway that incorporates analysis of transient pressure tests in an existing numerical model. From analysis of several different time periods, covering over ten years of production at Pleasant Bayou, reservoir properties, including reservoir size and shape, will be extracted. These estimates will be used to enhance and improve the numerical model. Analyses over time will allow us to comment on the "appropriateness" of the current leaky fault model proposed in the INEL reservoir description of Pleasant Bayou. Analysis done to date shows that the numerical model developed is a reasonable model of the correct reservoir description.

REFERENCES

Dake, L.P., Fundamentals of Reservoir Engineering, Elsevier Scientific Publishing Co, Amsterdam, 1978.

Garg, S.K., T.D. Riney, and J.M. Fwu, "Analysis of Phase I Flow Data from Pleasant Bayou No. 2 Geopressured Well," Proc. 5th Geopressured-Geothermal Energy Conference, Louisiana State University, 1981.

Earlougher, R.C., Advances in Well Test Analysis, SPE Monograph 5, SPE, Dallas, Texas, 1977.

Eaton Operating Company, Inc., "Final Contract Report", prepared for the U.S. Department of Energy under Contract No. DE-AC07-85ID12578, 1990.

Hamlin, H.S. and Noel Tyler, "Consolidation of Geologic Studies of Geopressured-Geothermal Resources in Texas", The University of Texas at Austin, Bureau of Economic Geology, report prepared for the U.S. DOE, Advanced Technologies Division, Contract No. DE-FC07-85NV10412, 1988.

Riney, T.D., "Pleasant Bayou Geopressured-Geothermal Reservoir Analysis January 1991", Topical Report, prepared under U.S. DOE Cooperative Agreement No. DE-FC07-85NV10412, January, 1991.

Table 1. Summary of Parameters Used in Pleasant Bayou Reservoir Model

Rock Properties	
Pore Volume (ft^3)	4.2×10^{10}
Pore compressibility (psi^{-1})	3.2×10^{-6}
Porosity	0.09 top, bottom layers (distal) 0.18 middle (proximal volume)
Permeability (md)	25. distal volume 172. proximal volume
Fluid Properties	
Bubble point pressure at T_R (psia)	6500.
Viscosity (cp)	0.27
Standard density (lb/ft^3)	69.
Formation Volume factor	1.045
Initial Conditions	
Pressure (psia) at 14,000 ft SS	10,708.
Temperature (°F)	306.

Table 2. Summary of Reservoir Parameters from Well Test Analysis and Numerical Studies.

Property	Transient Analysis	Numerical Model
Connected Pore Volume (ft^3)	2.31×10^{10}	2.2×10^{10}
Permeability	181	172
Distance to fault (ft)	5740	5900

Figure 1. History Match of 1988-1991 Production.

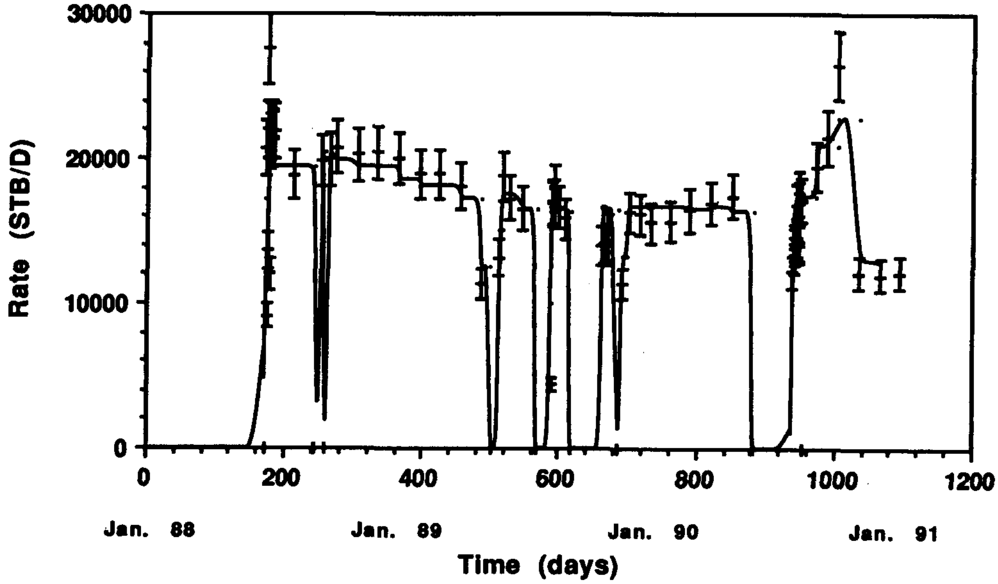
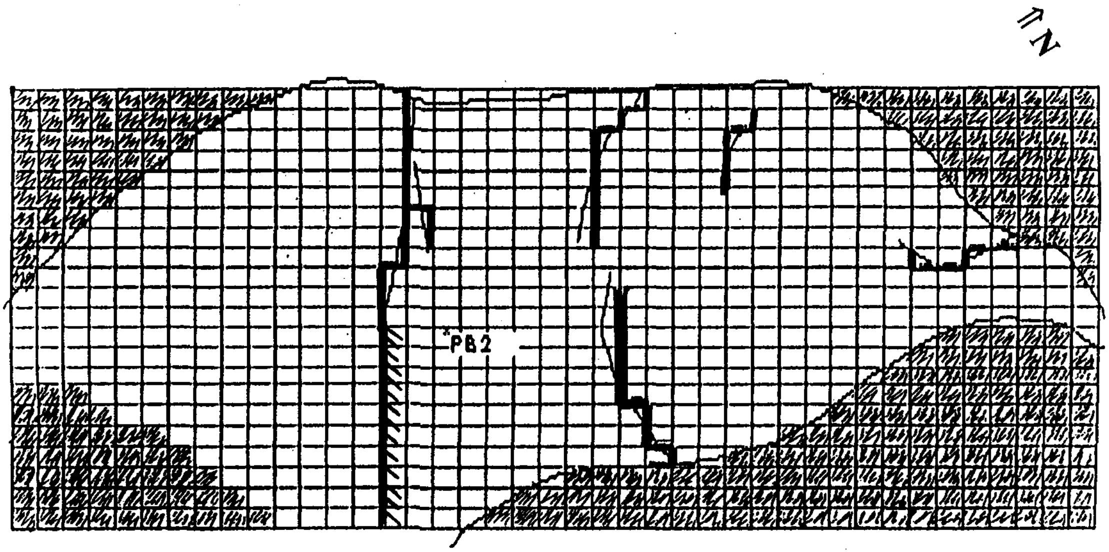


Figure 2. Working Map of Pleasant Bayou, Plan View.



LEGEND:

Internal Faults per BEG

Pressure-Dependent Fault Added

Inactive Blocks