PREPARED TESTIMONY

by

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INTRODUCTION

For a number of years (since 1955), I have been involved in the evaluation of wells, well testing, reservoir engineering and reservoir modeling. The objective of all studies in these areas is to predict the performance of individual wells, petroleum reservoirs, aquifers, and ground-water basins under production or injection of liquids.

Throughout the years several techniques have been used to make these studies. Originally only analytical techniques were used to solve simpler problems. Statistical techniques were used when only production histories were available (decline curves), next material balance calculations were made when entire reservoirs were studied with available pressure histories in addition to the production histories. In the latter instance, the effects of aquifers (water drives) on the pressure volume behavior were incorporated. These water drives were included in the calculations as analytical solutions, RC networks or analog computers and during the last ten years reservoir models were used to simulate such behavior.

These techniques are described in somewhat more detail in the next paragraphs.

Decline curves are plots of rate of withdrawal versus time or cumulative withdrawal on a variety of coordinate scales. Usually a straight line is drawn through these observations and extrapolated to give ultimate recovery and rates of recovery. Decline curves only use rates of withdrawal and pay relatively little attention to reservoir or flowing pressures.

In material balance studies, the pressure-volume behavior of the entire field is studied assuming an infinite permeability for the reservoir. By assuming an initial oil-in-place from volumetric calculations, the pressure is allowed to decline following fluid withdrawal. This decline is matched against the observed pressure behavior and, if necessary, the original

oil-in-place figure is modified until a match is obtained. In the presence of a water drive, additional variables are included by allowing water influx. Water influx is governed by mathematical relationships which are simple solutions of the diffusivity equation.

Another attempt to calculate the water influx into the reservoir during material balance calculations has been by RC networks; the R standing for resistance and C standing for capacitance. This RC network simulates the flow of fluids through the aquifer under transient conditions; by changing values for both R and C, eventually a match between observed and calculated reservoir performance may be obtained.

Similarly, analog computers have been used to simulate the transient aquifer behavior.

For the purpose of displacement studies, various models and techniques have been used. They include mathematical front tracking. When employing unit mobility ratios, electrolytic models have been used. Similarly, Hele-Shaw models have been used to study displacement in the laboratory. The Buckley-Leverett relationships allow for varying mobility ratios due to saturation changes and relative permeability effects. Short cuts have been offered for more complicated systems using the Higgins-Leighton models.

During the last ten years numerical reservoir modeling has been used to study reservoir behavior and individual well performance.

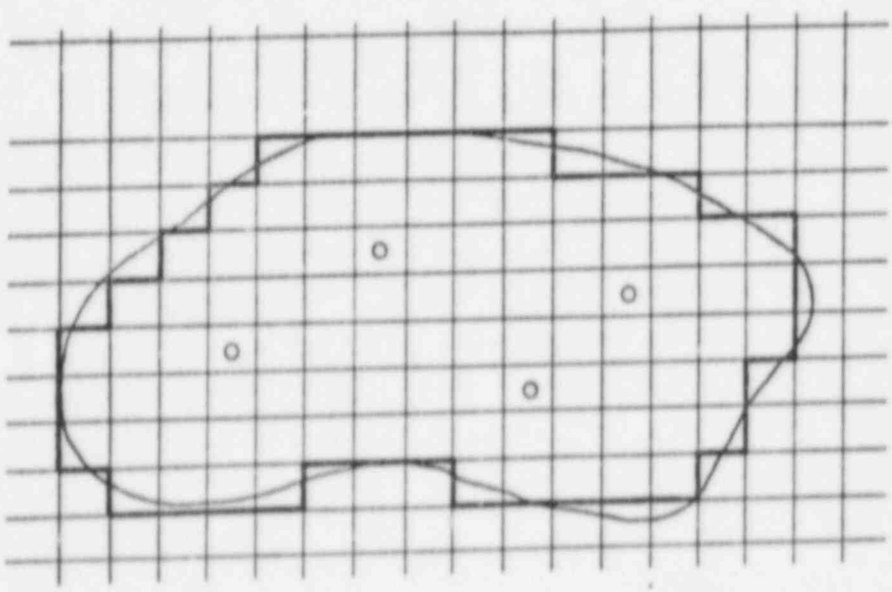
What is Numerical Reservoir Modeling?

In numerical reservoir modeling one first writes the fundamental fluid flow equations in partial differential form for each of the phases present. These partial differential equations are obtained by writing the conventional equations such as the continuity equation, equation of flow, and the equation of state. These three are then combined into a single partial differential equation. The continuity equation expresses the conservation

of mass. For most fluid flow through porous media situation, the equation of flow is Darcy's law. The equation of state consists of a description of the pressure-volume or pressure-density relationship of the various fluids present. Next, the partial differential equation, possibly following combination, is written in finite differences form, both in space and time.

A finite differences grid is laid over the field as shown below. Each grid point or node is assigned a value for permeability, thickness, porosity, fluid content, elevation, and pressure. The fluids are assigned with values for viscosity, formation volume factor,* solution gas-oil ratio, and density. The rock is assigned a value for compressiblity. Rates for one of these produced fluid phases are assigned to the well. Then, for a finite time difference (time step), new pressures and rates for all producing phases are calculated. The rates for the wells are calculated from the saturations existing at each point in the grid system. This process is repeated for a number of time steps, and in this manner both rate and pressure histories are calculated for each well in the system.

*The formation volume factor is reservoir volume per surface volume accounting for fluid compressibility, temperature and solution gas.



Input Data

For each node in the grid system, a value for the following parameters is required:

Permeability
Porosity
Thickness
Elevation
Grid dimensions
Initial saturation for each phase
Initial pressure
Rock compressibility

Fluid characteristics are assigned by the following relationships:

Oil formation volume factor vs. pressure
Water formation volume factor vs. pressure
Gas formation volume factor vs. pressure
Oil viscosity vs. pressure
Water viscosity vs. pressure
Gas viscosity vs. pressure
Solution gas-oil ratio vs. pressure
Solution gas-water ratio vs. pressure
Liquid to gas ratio vs. pressure
Oil density
Water density
Gas density

The interaction of forces between rock and fluids are given by the following saturation dependent functions:

Relative permeability for each phase
Capillary pressure between oil and water
Capillary pressure between gas and oil

Additional data may come from wells and include:

Producing interval
Oil production rate vs. time
Water production rate vs. time
Gas production rate vs. time
Observed pressures vs. time

PRACTICAL APPLICATIONS

Probably the best known application of numerical reservoir modeling is that of matching and prediction of oil field behavior. In matching, one uses the best data available for all those listed in the previous paragraph. Then the wells are allowed to produce at the observed rate for one of the phases. Next, pressure behavior for all wells and the production rate of the remaining phases are calculated. Calculated plots are compared with observed pressures and rates. Comparison between these two will indicate how good an initial guess was made at the input data. Next, it may be necessary to modify some of the input data until all observed and calculated data compare sufficiently favorably. In this manner, a rather sophisticated black box has been obtained, and it can be used to predict the future behavior of the field.

In this manner, various exploitation schemes may be evaluated, economics may be applied to the results, and the "optimum" exploitation scheme may be selected.

Although reservoir modeling was initiated to study overall field performance and to predict that performance following matching, it has many other applications. Reservoir models are used to study well problems such as pressure buildup and drawdown behavior, gas-oil behavior, and water-oil ratio histories. It has the advantage over other techniques that it can handle more complex systems.

THEORY

One, two and three-dimensional single-phase flow equations for slightly compressible fluids have been used for studying various aspects of reservoir fluid flow. Among others, these models are used to study single well problems (simulating pressure buildup and drawdown behavior with cylindrical or cartesian coordinate systems).

The three-dimensional flow equation for a slightly compressible fluid, neglecting gravity and assuming tnat the pressure gradients in the x, y and z directions are small, reads:

$$\frac{\partial}{\partial x}\left(\frac{k_x}{\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{k_y}{\mu}\frac{\partial p}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{k_z}{\mu}\frac{\partial p}{\partial z}\right)=\phi c\frac{\partial p}{\partial t}$$

where

p = pressure of the fluid
ρ = density
k_x = x direction permeability
k_y = y direction permeability
k_z = z direction permeability
μ = viscosity
ϕ = porosity
x,y,z = distances and
t = time.

In one-dimensional flow only one of the terms on the left remains and the other two are zero. And for two-dimensional flow only two terms remain.

The equation for two-dimensional flow for constant thickness, permeability and viscosity becomes

$$\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}=\frac{\phi\mu c}{k}\frac{\partial p}{\partial t}$$

in cartesian cordinates and

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right)=\frac{\phi\mu c}{k}\frac{\partial p}{\partial t}$$

in one-dimensional radial coordinates.

This equation for the radial flow of fluid of small and constant compressibility is one of the most often used in petroleum engineering. It forms the basis for most of the transient pressure analysis techniques used today. Analytical solutions to this equation has been obtained for a well located in an infinite media, for a well located at the center of a closed

circular reservoir, for a well located at the center of a circular reservoir having a constant pressure at its outer boundary, for a well located at the center of a radial discontinuity, and for a well located near a linear discontinuity, to name a few examples only.

However, many of these analytical solutions contain complicated mathematical terms which necessitate the use of a digital computer for their evaluation. Also the permeability has to be uniform. In these cases one might prefer the use of finite-difference techniques over analytical techniques.

To incorporate varying formation thickness, the two-dimensional flow equation may be rewritten as

$$\frac{\partial}{\partial x}\left(\frac{k_x h}{\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{k_y h}{\mu}\frac{\partial p}{\partial y}\right)=\phi c h\frac{\partial p}{\partial t}$$

To solve this equation when k_x, k_y, μ, or h is not constant, one must resort to finite-difference methods. This equation can be written in finite-difference form as:

$$\frac{1}{\Delta x_j}\left[\left(\frac{k_x h}{\mu}\right)_{i,j+1/2}\frac{(p_{i,j+1}-p_{i,j})}{\Delta x_{j+1/2}}-\left(\frac{k_x h}{\mu}\right)_{i,j-1/2}\frac{(p_{i,j}-p_{i,j-1})}{\Delta x_{j-1/2}}\right]+\frac{1}{\Delta y_i}\left[\left(\frac{k_y h}{\mu}\right)_{i+1/2,j}\frac{(p_{i+1,j}-p_{i,j})}{\Delta y_{i+1/2}}-\left(\frac{k_y h}{\mu}\right)_{i-1/2,j}\frac{(p_{i,j}-p_{i-1,j})}{\Delta y_{i-1/2}}\right]-q_{i,j}$$

$$=(\phi c h)_{i,j}\frac{(p_{i,j,n+1}-p_{i,j,n})}{\Delta t}$$

The pressures on the left-hand side of the above equation may be taken at time level n + 1 so that an implicit finite-difference scheme is used, and q is a source or sink term that represents a production or injection well.

A system of N simultaneous equations will be formed by writing the above equation about each node in the system and including the appropriate boundary conditions.

This system of equations may then be solved by several methods some of which are Gaussian elimination, alternating direction implicit, or successive over relaxation.

The flow equations can be written in a cylindrical-coordinate system--especially useful when studying single well problems. This gives the following equation:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{k_r}{\mu}\frac{\partial p}{\partial r}\right)+\frac{\partial}{\partial z}\left(\frac{k_z}{\mu}\frac{\partial p}{\partial z}\right)=\phi c\frac{\partial p}{\partial t}$$

This equation assumes angular symmetry about the well.

This equation can be written in finite-difference form as it stands. In setting up the finite-difference grid the best results would be obtained using small increments of r around the well and letting the increment size increase logarithmically with the distance from the well. This effect can be accomplished by making a logarithmic transformation to the space dimension, r.

Let

$$u = \ln(r/r_w)$$

or

$$e^u = \frac{r}{r_w}$$

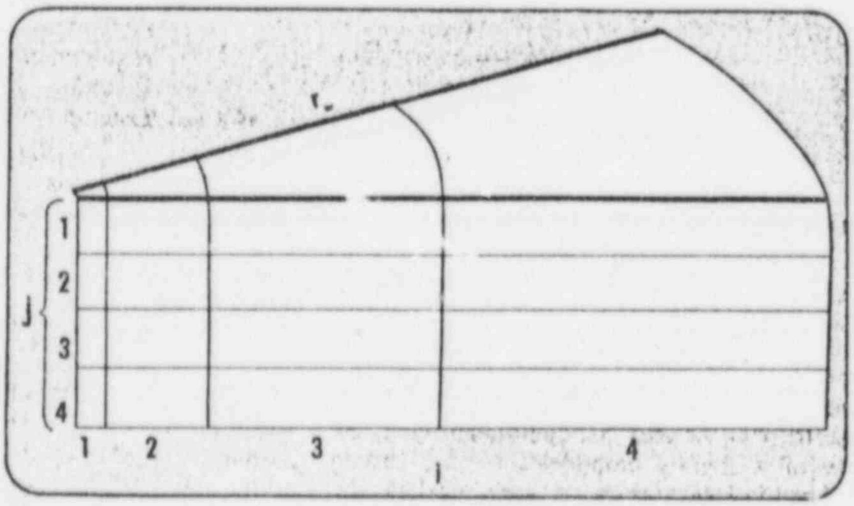
then

$$\frac{\partial p}{\partial r}=\frac{\partial p}{\partial u}\frac{\partial u}{\partial r}=\frac{\partial p}{\partial u}\frac{1}{e^u r_w}=\frac{1}{r}\frac{\partial p}{\partial u}$$

making this substitution

$$\frac{\partial}{\partial u}\left(\frac{k_r}{\mu}\frac{\partial p}{\partial u}\right) + e^{2u} r_w^{\,2} \frac{\partial}{\partial z}\left(\frac{k_z}{\mu}\frac{\partial p}{\partial z}\right) = e^{2u} r_w^{\,2}\, \phi c \frac{\partial p}{\partial t}$$

This equation can be expanded in finite-difference form. The following figure shows a graphical layout of the finite-difference grid.



In finite-differences form, the above equation becomes

$$\frac{1}{\Delta u_j}\left[\left(\frac{k_r}{\mu}\right)_{i+1/2,j}\frac{(p_{i+1,j}-p_{i,j})}{\Delta u_{i+1/2}}-\left(\frac{k_r}{\mu}\right)_{i-1/2,j}\frac{(p_{i,j}-p_{i-1,j})}{\Delta u_{i-1/2}}\right]+\frac{1}{\Delta z_j}(e^{2i\Delta u}r^2_w)\left[\left(\frac{k_z}{\mu}\right)_{i,j+1/2}\frac{(p_{i,j+1}-p_{i,j})}{\Delta z_{j+1/2}}\right.$$

$$\left.-\left(\frac{k_z}{\mu}\right)_{i,j-1/2}\frac{(p_{i,j-1}-p_{i,j})}{\Delta z_{j-1/2}}\right]-q_{i,j}=e^{2i\Delta u}r^2_w(\phi c)_{i,j}\frac{(p_{i,j,n+1}-p_{i,j,n})}{\Delta t}$$

The logarithmic transformation allows for a logarithmic variation in increment size in the radial direction if Δu is chosen as constant. That is, the increments are small around the well bore where the changes in the pressure surface are the greatest and they are large at large distances from the well where the pressure changes are small.

STATE-OF-THE-ART

The previous discussions briefly outlined how reservoir modeling works. The fact that it is a standard tool in our industry and in others such as groundwater may be borne out by the frequency of its use. All major oil companies use the models for both individual well behavior and overall reservoir behavior. The USGS recently purchased a complete suite of models to make groundwater studies. Various consultants and software firms have models.

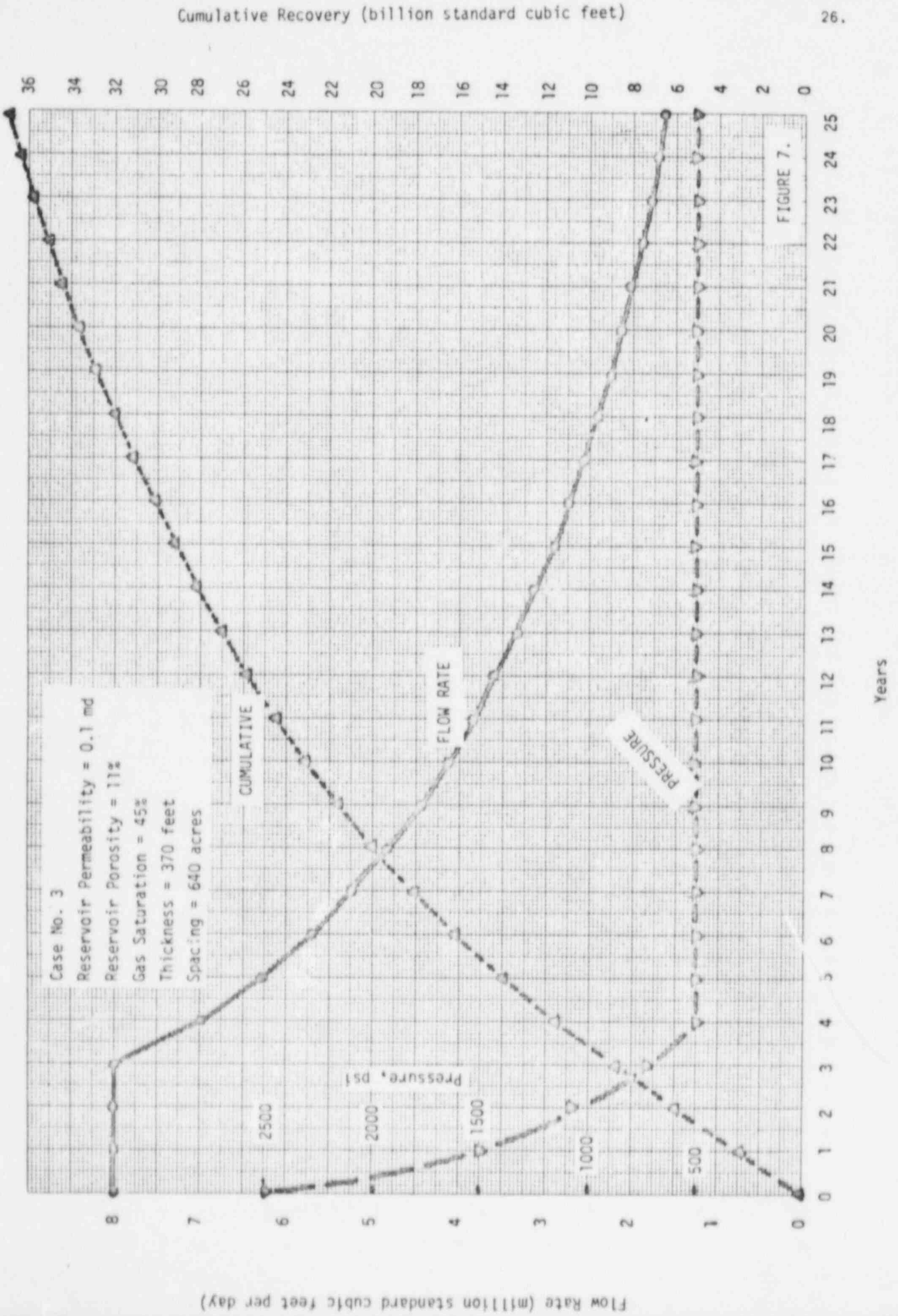
I myself have been deeply involved in the construction and use of these models. Presently I am using these models commercially for clients in many parts of the world.

Figure 7 (shown on the next page and from a report described below) is an example of the results of a report prepared by me for the Atomic Energy Commission entitled, "Projected Reservoir Performance - Rio Blanco Project, March 1973" (Open File Report NVO-38-33, PNE-RB-26). All methods used in that report are similar to those used by Gruy in his evaluation of the Sequoyah project.

EVALUATION OF THE SEQUOYAH WELL

A review of all available data and reports was made. The electric logs, together with core analyses, radioactive tracer logs and the pressure fall-off data, were used to determine formation permeability, porosity and relative injectivity into each zone. Values obtained from this evaluation are in agreement with those reported by Gruy. Comparison between the initial hydrostatic pressure obtained on 6/25/71 and the extrapolated reservoir fall off of 7/9/71 - 7/12/71 indicates an apparent increase of 5.5 psi following the cumulative water injection of 836,000 gallons. This increase could be explained by the finite character of the reservoir. Assuming a pore space of 860,000 bbls, a total rock plus water compressibility of 6.8×10^{-6} psi^{-1}, the calculated increase would have been 3.4 psi compared to the measured 5.5 psi. However, one should consider the possibility that the apparent increase of 5.5 psi is in the range of measurement error.

The May 1, 1972, original report (Attachment A) by Gruy was reviewed in detail. I concur with the method of attack; i.e., to use a finite difference numerical model and to match the production and pressure history observed during the fall-off period. Matching both items renders an excellent degree of reliability. Evaluation of the fall-off curve and its changes in slope when pressure is plotted versus a rate-time function supports the existence of sealing barriers. It is realized that the duration


Cumulative Recovery (billion standard cubic feet)
Case No. 3
Reservoir Permeability = 0.1 md
Reservoir Porosity = 11%
Gas Saturation = 45%
Thickness = 370 feet
Spacing = 640 acres
CUMULATIVE
FLOW RATE
PRESSURE
Pressure, psi
2500
2000
1500
1000
500
FIGURE 7.
Years
Flow Rate (million standard cubic feet per day)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36

of the tests was such that not all of the boundaries of the reservoir could be conclusively determined. However, the above-mentioned pressure increase of 5.5 psi supports the confined pore space.

It is recommended that the finite character of the formation be determined more precisely during early injection of waste fluids (see Monitoring).

I approve of the methods used by Gruy, and I support the conclusions obtained.

MONITORING

The process of underground liquid waste disposal should be duly monitored. In the case of the Sequoyah well, the main problem is that of maintaining a sealed reservoir system. The best way to observe such behavior is by carefully measuring the injection rate, cumulative injection and pressure behavior of the injection well To facilitate calculations, the fluid should be injected at a constant rate for a period of from 5 to 10 days, whereafter the well should be shut in preferably at the well head (not the plant) for a period at least equal to the previous injection period and preferably twice that time. This cycle should be repeated a number of times. Pressures should be observed during each shut-in period. Extrapolation of the resulting fall-off data will result in calculated static reservoir pressures which allow for material balance calculations.

The fall-off data could also be matched with the model. However, it should be realized that certain chemical reactions could alter the permeability in the vicinity of the well. It is, therefore, advised that the initial quantity up to 3,300,000 gallons be rendered substantially inert to the Arbuckle Formation. This precaution is only required to allow detailed simulation but not for the purpose of material balance.

I see no reason why additional observation wells are required to determine the sealed character of the formation. I realize that proposals have been made to drill observation wells to determine the existence f faults, cross flow and reservoir pressures.

The barrier could be either a fault or a permeability pinchout. The sealing character of the barrier was demonstrated following the injection of fluids in 1971. More than likely the barrier is a sealing fault. However, whether it is a fault or a pinchout is academic.

With the very low permeability of the overlying formations, cross flow should not occur. Certainly it will not be a measurable quantity in the Simpson Formation. Therefore, an observation well in that formation is impractical.

Pressure observation in the existing well should give at least as reliable a measurement of the existing reservoir pressure as could possibly be determined by means of an additional observation well.

January 1973

BIOGRAPHICAL INFORMATION

Dr. H. K. van Poollen

Dr. H. K. van Poollen is president of H. K. van Poollen and Associates, Inc., a petroleum consulting firm in Littleton, Colorado.

He was born in the Netherlands on May 10, 1927. In 1948 he received his Bachelor's degree in Mining Engineering from the University of Delft, in the Netherlands. He then studied at the Colorado School of Mines, Golden, Colorado, and received a Master's degree in Mining Engineering in 1950.

In 1950 he returned to the Netherlands to serve in the Dutch Army until 1951. Then he joined the Standard Vacuum Petroleum Maatschappij in Sumatra, Indonesia, as a reservoir engineer. In 1954 he returned to the Colorado School of Mines to receive his DSc in Mining Engineering in 1955.

In 1955 he joined the Halliburton Company in Duncan, Oklahoma, to be in charge of the Reservoir Engineering Section. There he was responsible for core analyses, stimulation recommendations, and drill stem test interpretations.

In 1958 van Poollen joined Marathon Oil Company as a Research Scientist at the Denver Research Center in Littleton, Colorado. His function was to further develop well testing methods and techniques and to keep abreast of well stimulation. He was involved in the writing of mathematical reservoir fluid flow models. He rendered technical consultation and services to field personnel in the areas of well testing and stimulation in particular, and reservoir engineering in general. He left Marathon in 1969 when he formed the above-mentioned world-wide petroleum consulting firm headquartered in Littleton, Colorado.

Starting in the fall of 1960, Dr. van Poollen became a special lecturer in Advanced Reservoir Engineering at the Colorado School of Mines, teaching the subjects of well testing, water flooding, primary depletion, well stimulation, and reservoir models. In the summer of 1965 he taught in a summer course at Princeton University on the subject of ground water movement. He is currently an Adjunct Professor at the Colorado School of Mines.

In 19[illegible] he served on the Corps of Engineers Panel of Consultants who studied the Denver earthquakes. Subsequently he served on a Presidential Panel to study this problem on a long-term scale. In 1968 he was again called on as a consultant by the U. S. Corps of Engineers.

H. K. van Poollen is a member of various professional societies which include Koninklijk Instituut van Ingenieurs, Koninklijk Nederland Mijnbouwkundig en Geologisch Genootschap, American Institute of Mining, Metallurgical and Petroleum Engineers, American Petroleum Institute, Denver Well Logging, and Society of Petroleum Evaluation Engineers. In these organizations he has held various offices ranging from Study Group Chairman (AIME, API) through Program Chairman (DWS, AIME) (Section Chairman AIME) to Regional Meeting Chairman (AIME).

He was chosen as an SPE Distinguished Lecturer for the period of September 1967 through May 1968.

In 1969 he was selected to be a member of the Water Pollution Control Commission of Colorado.

He is a registered professional engineer.

The attached sheets list Dr. van Poollen's published papers and also his patents.

External Publications

In the Dutch Language:

1. "A Short History of Oil," Boortoren en Schachtwiel, March 1956.

2. "The Application of Heat in Secondary Recovery," Boortoren en Schachtwiel, June 1956.

In the English Language:

1. "Horizontal Support of Mine Openings," First Symposium on Rock Mechanics, Quarterly of the Colorado School of Mines, vol. 51, no. 3, pp. 101-122.

2. "Theories of Hydraulic Fracturing," Second Annual Symposium on Rock Mechanics, Quarterly of the Colorado School of Mines, vol. 52, no. 3, pp. 113-128.

3. "Do Fracture Fluids Damage Productivity," The Oil and Gas Journal, vol. 55, no. 21, May 27, 1957, pp. 120-124.

4. "Damage Ratio Determined by Drill Stem Test Data," World Oil, November 1957, pp. 138-139.

5. "Productivity vs. Permeability Damage in Hydraulically Produced Fractures," Drilling and Production Practice, 1957.

6. "Application of DST to Hydrodynamic Studies," co-author S. J. Bateman, World Oil, July 1958.

7. "Hydraulic Fracturing: Fracture Flow Capacity vs. Well Productivity," co-authors John M. Tinsley and Calvin D. Saunders, Journal of Petroleum Technology, vol. 213, 1958, p. 91.

8. Formal Discussion of Paper by B. Gilbert. "The FI Process - Theory and Practice," which was presented at the Fourth Annual Joint Meeting of the Rocky Mountain Section of AIME, Denver, March 1959.

9. "A Stimulation-Sand Control Method," co-author W. T. Malone. Paper No. 1321-G presented at AIME meeting in Dallas, October 4-7, 1959, and Pasadena, California, October 22-23, 1959.

10. "Particle Tilting - A Physical Form of Well Bore Damage," The Mines Magazine, December 1959, p. 7.

11. A Formal Discussion of Paper by J. L. Huitt, et al. "The Propping of Fractures in Formations in Which Propping Sand Crushes." API, Drilling and Production Practices, 1959, pp. 120-130.

12. A Formal Discussion of Paper by R. E. Hurst. "An Engineered Method for the Evaluation and Control of Fracturing Treatments." API, Drilling and Production Practices, 1959, pp. 168-170.

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14. A Formal Discussion of Paper by F. L. Maier. "Recent Developments and Field Applications of Drill Stem Test Interpretation." Journal of Petroleum Technology, vol. 14, no. 11, November 1962, pp. 1213-1222.

15. Thesis advice to S. W. Roberdeau (Colorado School of Mines). "An Electric-Analog Model and Its Application to the Study of the Effect of Hydrodynamics on the Entrapment of Petroleum," 1962.

16. Thesis advice to Mehta Ramesh (Colorado School of Mines). "Application of an Electrolytic Model in the Hydrodynamic Analysis of Stratigraphic Traps," May 20, 1963.

17. "Effect of Linear Discontinuities on Pressure Build-Up and Drawdown Behavior," co-authors H. C. Bixel and B. K. Larkin, Journal of Petroleum Technology, August 1963, p. 885.

18. "Effect of Fluid Influx on Drawdown Behavior," co-author W. J. Kunzman, SPE Paper 835, May 1964.

19. "Radius-of-Drainage and Stabilization-Time Equations," The Oil and Gas Journal, 138, September 14, 1964.

20. "Transient Tests Find Fire Front in an In Situ Combustion Project," The Oil and Gas Journal, February 1, 1965.

21. "For Sure Payout Select Well and Treatment with Care," The Oil and Gas Journal, July 12, 1965.

22. "Let Well Tests Help Solve Stimulation Problems," The Oil and Gas Journal, August 30, 1965.

23. "Unit Response Function from Varying Rate Data," co-author J. R. Jargon, Journal of Petroleum Technology, August 1965.

24. "Find Permeability with Drawdown and Buildup Curves," Part I, The Oil and Gas Journal, October 18, 1965; Part II, November 1, 1965.

25. "Drawdown Curves Give Angle Between Intersecting Faults," The Oil and Gas Journal, December 20, 1965.

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29. "How Acids Work in Stimulating Production and Injection Wells," The Oil and Gas Journal, September 11, 1967.

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32. "Immiscible Fluid Flow Simulator," SPE 2019, 1968.

33. "The Fluid Flow Simulation Equations," SPE 2020, 1968.

34. "How Conditions Affect Reaction Rate of Well-Treating Acids," The Oil and Gas Journal, October 21, 1968.

35. "Treatment of Individual Wells and Grids in Reservoir Modeling," co-authors E. A. Breitenbach and D. H. Thurnau, Society of Petroleum Engineers Journal, December 1968, pp. 341-346.

36. "What Those Trade Names Mean," The Oil and Gas Journal, January 27, 1969.

37. "How to Engineer Those Acid Jobs for Better Well Stimulation," The Oil and Gas Journal, March 3, 1969.

38. "Unsteady State Flow of Non-Newtonian Fluids Through Porous Media," co-author J. R. Jargon, Society of Petroleum Engineers Journal, March 1969, pp. 80-88.

39. "Solution of the Immiscible Fluid Flow Simulation Equations," co-authors E. A. Breitenbach and D. H. Thurnau, Society of Petroleum Engineers Journal, June 1969, pp. 155-169.

40. "Reservoir Modeling - What It Is, What It Does," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, July 28, 1969.

41. "Single-phase Fluid-Flow Equations," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, August 18, 1969.

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43. "Explicit Finite-Difference Technique," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, November 3, 1969.

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45. "General Form of Finite Difference Approximations," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, January 19, 1970.

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47. "Single-Phase Gas Flow," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, March 30, 1970.

48. "Here Are Fundamental Equations for Multiphase Fluid Flow," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, May 11, 1970.

49. "Applications of Multiphase Immiscible Fluid-Flow Simulator," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, June 29, 1970.

50. "Comparison of Multiphase Models," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, July 27, 1970.

51. "Waste Disposal and Earthquakes at the Rocky Mountain Arsenal - Derby, Colorado," co-author D. B. Hoover, Journal of Petroleum Technology, August 1970.

52. "Individual Well Pressures in Reservoir Modeling," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, October 26, 1970.

53. "Data Analysis for High Influx Wells," co-author J. B. Weber, SPE 3017, 1970.

54. "A Review--And A Look Ahead," co-authors H. C. Bixel and J. R. Jargon, The Oil and Gas Journal, March 1, 1971.

55. "The Wise Use of Reservoir Models," Australian Petroleum Exploration Association Journal, vol. 11, Part I, 1971, pp. 131-134.

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Patents

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2. U. S. Patent #3,072,192. Method of Inhibiting Corrosion in Oil Production.
3. U. S. Patent #3,194,314. Process of Inhibiting Corrosion in Oil Production.
4. U. S. Patent #3,196,947. Method for Facilitating the Production of Viscous Petroleum Through a Well.
5. U. S. Patent #3,247,902. Prevention of Emulsion Formation in Crude Oil Production.
6. U. S. Patent #3,329,206. Process for Storing Natural Gas.
7. U. S. Patent #3,362,476. Process and Device for Restoring Lost Circulation.
8. U. S. Patent #3,384,170. Well-Bore Sampling Device & Process for Its Use.
9. U. S. Patent #3,417,824. Lost Circulation Restoring Devices.