SGP-TR-91

- Reservoir Technology -
Geothermal Reservoir Engineering Research at Stanford

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Stanford Geothermal Program
Interdisciplinary Research in
Engineering and Earth Sciences
STANFORD UNIVERSITY
Stanford, California

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PREFACE

The Stanford Geothermal Program conducts interdisciplinary research and training in engineering and earth sciences. The central objective of the Program is to carry out research on geothermal reservoir engineering techniques useful to the geothermal industry. A parallel objective is the training of geothermal engineers and scientists for employment in the industry. The research is focused toward accelerated development of hydrothermal resources through the evaluation of fluid reserves, and the forecasting of field behavior with time. Injection technology is a research area receiving special attention. The Program is geared to maintain a balance between theoretical, laboratory, and matching field applications.

Technology transfer is an integral part of the Stanford Geothermal Program. Major activities include a Geothermal Reservoir Engineering Workshop held annually, and weekly Seminars held throughout the academic year. The Workshop has produced a series of Proceedings that are a prominent literature source on geothermal energy. The Program publishes technical reports on all of its research projects. Research findings are also presented at conferences and published in the literature.

Geothermal reservoir engineering research at Stanford has gained considerable breadth through the Program's international cooperative projects. There are research agreements with Italy, Mexico, New Zealand, and Turkey. These international projects provide a wide spectrum of field experience far Stanford researchers, and produce field data with which to develop and test new geothermal reservoir engineering techniques.

The Stanford Geothermal Program was initiated under grants from the National Science Foundation in 1972 and continued under contracts from the

Energy Research and Development Administration and, since 1977, the Department of Energy. This publication is the Fifth Annual Report to the Department of Energy under contract DE-AS03-80SF11459 (previously DE-ATO3-80SF11459) which was initiated in fiscal year 1981. The report covers the period from October 1, 1984 through September 30, 1985. The Injection Technology activities are now separate from the Reservoir Technology activities and are presented in the First Annual Report to the Department of Energy under contract DE-AS07-84ID12529.

The successful completion of the Stanford Geothermal Program's objectives depends on significant help and support by members of federal agencies, the geothermal industry, national laboratories, and university programs. These are too many to acknowledge by name. The major financial contribution to the Program is the Department of Energy through its San Francisco and Idaho offices. We are most grateful for this support and for the continued cooperation and help we receive from the agency staff.

Henry J. Ramey, Jr.
Paul Kruger
Roland N. Home
Frank G. Miller
William E. Brigham

1. INTRODUCTION

The Stanford Geothermal Program in fiscal year 1985 was divided into several task areas, as defined in Department of Energy contract DE-AS03-80SF11459. Three of the task areas were carried out within the Petroleum Engineering Department, and one within the Civil Engineering Department.

Reservoir definition research at Stanford consists of well test analysis and bench-scale experiments. Well test analysis offers a rapid way to perform an initial assessment of geothermal systems. Well testing includes both single-well pressure drawdown and buildup testing, and multiple-well interference testing. The development of new well testing methods continued to receive major emphasis during the year. A balance between theoretical and experimental studies is sought. The goal is to develop new methods for observing reservoir behavior and to test these in the field. Bench-scale experiments are performed to determine fundamental flow characteristics of fluids and to provide a balanced university based research.

Heat extraction from rock will determine the long-term response of geothermal reservoirs to development. The work in this task area involved a combination of physical and mathematical modeling of heat extraction from fractured geothermal reservoirs. Experiments have been carried out in a rechargeable laboratory reservoir with comparative testing of alternative modes of heat and fluid production. The results are leading to a useful mathematical method for early evaluation of the potential for heat extraction in newly developing geothermal resources.

International cooperative research at Stanford has field applications as its focus. Several formal and informal cooperative projects were active during the year. The main objective of Stanford's cooperative research is the application and testing of new and proven reservoir engineering technology using nonproprietary field data and geothermal wells made available by steam field operators world-wide. Stanford has two formal cooperative agreements with foreign agencies. These are the DOE-ENEL cooperation with Italy, and **IIE-SGP** cooperation with Mexico. **Informal** agreements exist with colleagues in New Zealand, Turkey, and elsewhere. The interaction between academic research and field applications has proved valuable to the research **and** training program.

An **annual** Workshop of Geothermal Reservoir Engineering has been held at Stanford since **1975.** It is attended by 120-140 geothermal engineers, scientists, and developers from around the world. Weekly seminars on geothermal energy matters are held at Stanford throughout the academic year.

2. RESERVOIR DEFINITION

The major emphasis in this task is development of new pressure transient interpretation methods.

2.1 Multiphase and Multicomponent Compressibility

Luis Macias-Chapa and H.J. Ramey, Jr.

A detailed report on this project was given in the Fourth Annual Report dated September 1984. A report, SGP-TR-88 was completed and preparation of a publication manuscript is in progress. Plans are to extend this work with a more complete phase equilibrium equation of state to permit study of non-condensible gas composition with continued exploitation of a field.

2.2 Multiple Well Interference Testing in the Ohaaki Geothermal Field

J.D. Leaver, A. Sageev, and H.J. Ramey, Jr.

Multiple interference tests were carried out in the Ohaaki geothermal field between 1979 and 1983. Data were collected for periods of up to 200 days per test using both wellhead mounted water level recorders and quartz crystal pressure gauges, each with a resolution of about 100 Pa.

Data were analyzed using conventional log-log type curve matching techniques, followed by application of recently developed semilog type curve matching techniques which allow linear boundary detection without the necessity of developing two semilog straight lines. One type curve exists for each of the drawdown and buildup data which are produced by mathematically collapsing the family of curves produced in the solution for a system containing a line source and linear boundary. The type curve for the buildup data has not been previously published. The method allows the inference ellipse for a linear boundary to be determined without requiring knowledge of reservoir parameters.

The data in some tests show the presence of a no-flow boundary far which inference ellipses have been located. Four interference tests performed on the same doublet show that vastly different reservoir parameters can be found unless careful interpretation is made. Work on this problem should be completed during the coming year and a report issued.

2.3 Pressure Transient Analysis for Wells with Horizontal Drainholes

Michael D. Clonts and H.J. Ramey, Jr.

Drainholes have been drilled in several areas of the world and there is a need to understand these drainage systems for accurate well test analysis. A drainhole pressure transient solution could also aid in the evaluation of production induced drainholes. Although pressure transient analyses have considered many reservoir systems, there has been no publication to date of pressure transient analysis for horizontal drainholes.

This study presents an analytical solution for the transient pressure response of a uniform flux horizontal drainhole in an anisotropic reservoir of finite thickness. Thd solution also applies for a reservoir with multiple drainholes in a vertical array. The analytical solution is developed using instantaneous source functions, Green's functions and the Newman product method. The solution shows that there are two possible types of transient pressure behavior depending on the length of the drainhole relative to the height of the reservoir. If the drainhole is short, flow is characterized by three flow periods: an initial radial flow perpendicular to the drainhole axis, a transition flow period, and a pseudo-radial flow period. If the drainhole length is long relative to the reservoir height, the initial radial flow period ends instantaneously for all practical purposes. The transient pressure behavior here is identical to that of a uniform flux vertical fracture and is characterized by early time linear flow followed by a transition period and late time pseudo-radial flow.

It is demonstrated that the pressure transient response for multiple drainholes is identical to the single drainhole solution if dimensionless variables are defined relative to the number of drainholes. Consequently, the pressure response of a uniform flux vertical fracture can also be approximated by several short drainholes. The solution for infinite conductivity drainholes is also suggested by analogy to the infinite conductivity vertical fracture solution.

Log-log type curves were prepared for various drainhole radii and can be used in the conventional manner to determine reservoir characteristics including directional permeability or drainhole half length. Short and long time approximatians were determined with appropriate time limits. Finally, conditions for greater productivity than with vertical wells or hydraulic fractures were studied.

This project was completed and a report draft prepared. Both the report and a publication manuscript should be completed in the coming year. No further work on this problem is planned,

2.4 Slug Test and Drillstem Test Flow Phenomena including Wellbore Inertial and Frictional Effects

Miguel A. Saldana-C. and H.J. Ramey, Jr.

This project was conducted and reported in previous years. During the current year the work was reviewed and a manuscript for publication by the Society of Petroleum Engineers of AIME prepared. For convenience, a review of the nature of this problem follows.

During the flow period of a drillstem test from deep and highly-productive wells, the liquid column inside the wellbore can experience rapid acceleration changes. Also, flow velocities in the pipe can become extremely large. Therefore, inertial and frictional forces can be expected to be important in a dynamical relationship between flow rate and bottomhole pressure.

A mathematical formulation including the effects of inertia and friction on the wellbore liquid column during a drillstem test was prepared. Solutions for this formulation were obtained by assuming a large initial cushion and laminar flow during the test. This leads to a linear mathematical problem that was solved in the transformed Laplace-space. Solutions, in terms of the dimensionless groups of physical parameters that govern the response of practical wellbore-reservoir systems were calculated by applying the Stehfest algorithm for numerical inversion of Laplace transformations.

The results provide criteria useful to evaluate the magnitude of inertial and frictional effects from rough estimates of the properties of a wellbore-reservoir system. These criteria can be utilized to minimize undesired inertial and frictional effects through design of a drillstem test. Results also indicate practical conditions under which inertial and frictional effects are significant. The solution method can be used to estimate reservoir properties by matching bottomhole pressure data measured during the flow period of a drillstem test. Also, the flow rate solutions can be considered in pressure buildup data analysis of a subsequent shut-in period during a drillstem test. Work on this problem is complete, but several additional manuscripts for publication will be prepared in the coming year.

2.5 Interference Testing Near a Steam Cap

A. Sageev

An interpretation method was developed for analyzing interference tests in the presence of a steam cap or a local compressible two-phase region. A conventional early time log-log analysis of interference pressure data may yield high values of reservoir parameters such as transmissibility and storativity. The method presented uses these high values of reservoir parameters for detecting the presence of a steam cap and establishing its probable location.

The early time log-log pressure response of an interference well is similar to the line source solution, yet is displaced in the dimensionless pressure-time domain. This displacement yields an over estimation of the values of kh and ϕc_t using an early time log-log match. Figure 2-1 shows a log-log match of the pressure response of an interference well located at 180 degrees to the line source curve. All interference pressure responses approach a steady state condition at late time. A high interference estimate of the storativity, ϕc_t, may indicate the presence of a steam cap or a compressible subregion. A single well interference test yielding an over estimation of ϕc_t produces qualitative information about the location of the steam cap. The larger the deviation of the storativity from the expected liquid dominated storativity, the closer the steam cap to the line between the active well and the interference well. Two interference tests provide possible locations for the steam cap. This is based on the difference between the storativities of the two interference wells, and the deviation of these storativities from the expected storativity of the liquid dominated portion of the reservoir. Interference wells close to the production well with respect to their distance to the steam cap yield storativities ϕc_t, and transmissibilities, kh, of the liquid dominated portion of the reservoir.

2.6 Interference Between Constant Rate and Constant Pressure Wells

A. Sageev and R. N. Home

A pressure transient analysis method is developed for interference between wells producing at constant rate and wells producing at constant pressure. The wells are modeled as two line source wells in an infinite reservoir. The first well produces at a constant rate, and the second well remains at a constant pressure. Dimensionless semilog pressure type curves are presented together with instantaneous rates and cumulative dimensionless injection for the constant pressure well. The effects of the relative size of the two wells on the pressure response of the constant rate well and on the rate of injection at the constant pressure well are discussed. The rate-pressure model may

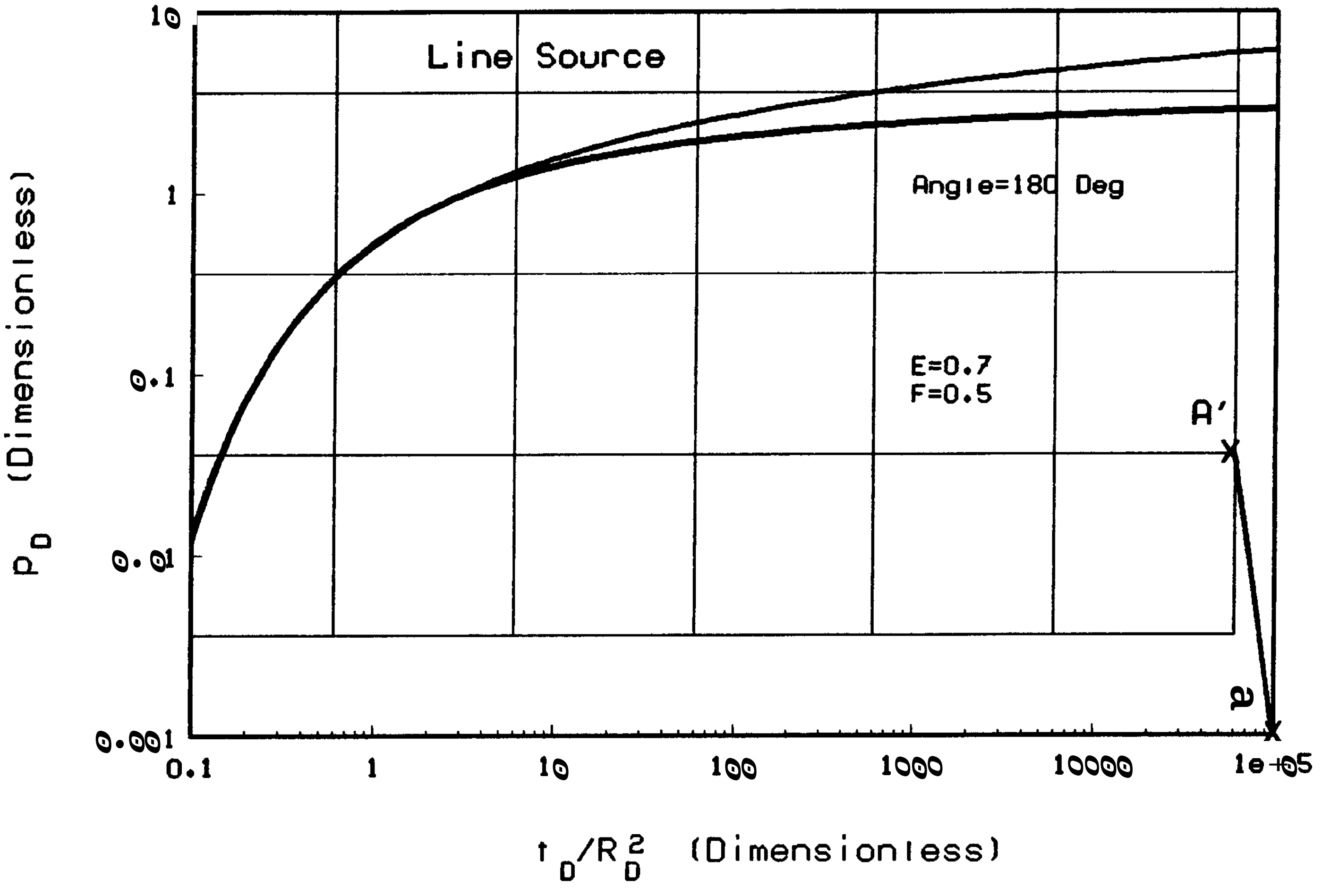

Figure 2-1. A log-log match of the pressure response of the interference well located at θ = 180 Deg to the line source curve.

also be applied in analyzing pressure interference between communicating geothermal reservoirs. The distance between the reservoirs may be estimated if the reservoirs are approximated as two line sources.

A semilog type curve method is presented that allows the interpretation or the design of a rate-pressure test. Three time dependent parameters are considered: the pressure response of the constant rate well, the instantaneous rate and the cumulative injection at the constant pressure well. Large differences in the diameters of the wells significantly affect the pressure and rate responses. A configuration of a constant pressure well and a constant rate well may not be assembled using the superposition theorem, and is solved as a special case of a constant rate line source producing near a constant pressure finite radius source. Figure 2-2 shows a semi log type curve for the rate-pressure model.

2.7 Application of Closed Chamber Testing

To Backsurge Completion Testing

J. Simmons and A. Sageev

A transient pressure analysis method for the closed chamber well test is summarized below. The method allows determination of reservoir transmissibility and well bore skin using log-log type curve matching. The method is believed applicable to analysis of perforation cleaning backsurge data.

Solution is obtained by superposition of the cumulative influx, constant pressure solution of the radial diffusivity equation. Superposition avoids many of the limitations of direct solution, and facilitates consideration of non-ideal chamber gas behavior and complex well bore geometry.

A sensitivity study of tool and reservoir parameters is presented. The results indicate that unlike the slug test, tool geometry greatly influences the dimensionless pres

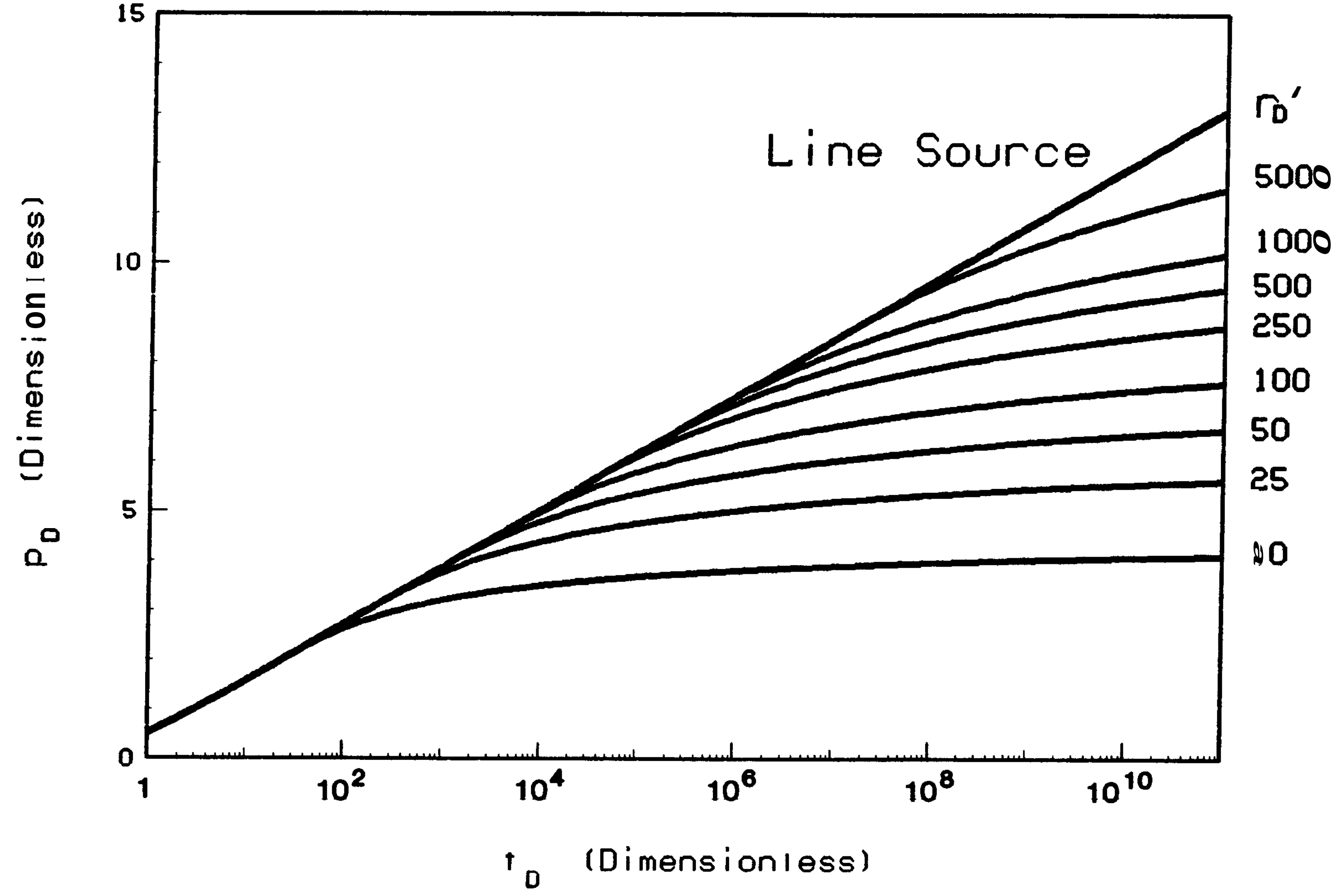

Figure 2-2. Semilog type curve for the rate-pressure model.

sure response of the closed chamber test. Tool design guidelines are presented for extending the period during which the closed chamber test behaves as a slug test, and is suitable for analysis by type curve matching with published slug test results. The superposition results also indicate that assuming ideal chamber gas behavior does not significantly alter the bottomhole pressure response.

A computer model was developed to simulate the pressure response of a closed chamber well test. Superposition of the constant pressure, cumulative influx solution to the radial diffusivity equation was used in the model. Although real gas compressibility effects were included in the model, the effects of friction and momentum were not. Chamber gas compression was assumed isothermal in the development of the mathematical model.

The superposition model was then tested for the ability to reproduce the results of *Ramey et al* [4] for the slug test, which is a special case of the general closed chamber test. A tool and reservoir parameter sensitivity study was conducted to formulate guidelines for design and analysis of the closed chamber test. The following conclusions are supported by the results of modeling of the closed chamber test by superposition of the constant pressure cumulative influx solution: The superposition model is capable of reproducing the slug test results of *Ramey* et *al* [4] which also neglected' momentum and friction effects. Deviation of the closed chamber test from the slug' test was illustrated. The shift on logarithmic coordinates of the late time dimension. less closed chamber pressure response is proportional to the ratio of the initial to final well bore storage. For moderate reservoir pressure (5000 psig), non-ideal chamber gas behavior does not affect the bottom hole pressure response of the closed chamber test. As a result, chamber gas composition is insignificant. Over a range of 100 to *500* (F), the temperature at which the isothermal compression of the chamber gas occurs does not influence the bottom hole pressure response of the closed chamber test. A greater portion of the closed chamber test response will be equivalent to a slug test, and thus suitable for slug test type curve analysis, if the effect of the chamber gas compression is minimized during the test. The sensitivity study indicates that increasing the chamber length, increasing the chamber diameter, and decreasing the initial fluid column length will decrease the effect of chamber gas compression. An initial chamber gas pressure near atmospheric is required to avoid deviation from the equivalent early time slug test response. Based on the late time dimensionless closed chamber type curves, generated by the superposition model, it is evident that pressure measurement within the first 60 seconds of the flow period will be required to evaluate skin effect for wells with capacities approaching 1000 md-ft. Figure 2-3 shows the effect of skin on the late time response of the closed chamber test. Since the initial chamber pressure affects the pressure response of the closed chamber test, it is recommended that chamber pressure be recorded during the test.

2.8 Pressure Distribution Around a Well Producing at Constant Pressure in a Double-Porosity Reservoir

A. Sageev

This study developed the characteristics of the pressure response of observation wells during a constant pressure test in a double-porosity bounded system. Wellbore skin in the constant pressure active well is considered negligible. The interacting effects of the exterior radius, r_{eD}, and the interporosity flow parameter, λ, are examined in pressure-radius and pressure-time responses. For pseudo steady state interporosity flow, the pressure-radius semilog responses are semilog straight in the region around the well. This indicates a constant rate in space. The shape of the fracture interference pressure response of the observation well is similar to the pressure response during constant rate tests in double-porosity systems. The dimensionless pressure response has a transition period where, for the pseudo steady state interporosity flow model, the

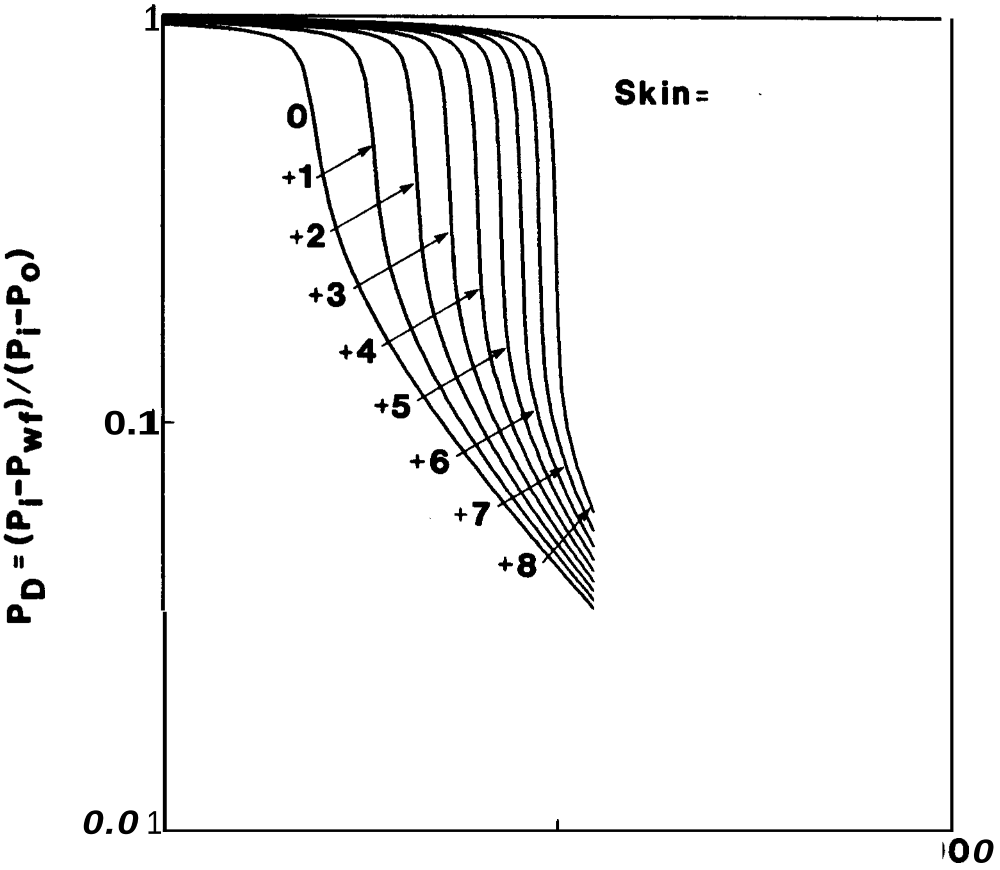

Figure 2-3. The effect of skin on the late time response of the closed

pressure is constant. Interference fracture pressure responses for the pseudo steady state and the transient interporosity flow models are compared.

The fracture pressure profiles in the region around the active constant pressure well are semi-log straight, indicating constant rate in space. The slope of the fracture pressure profiles is nearly constant during the constant rate flow period at the active well. The fracture pressure response at observation wells has a constant pressure period (pseudo steady state interporosity flow model) similar to the constant rate tests. For a double-porosity reservoir with a small value of the interporosity flow parameter, λ, the double-porosity effects occur late into the test, and may be detected only if $(1-p_D)$ is used instead of p_D. The magnitude of the interference pressure change at an observation well increases as the distance between the observation well and the active well decreases. For a given reservoir, the interference matrix pressure converges to the interference fracture pressure at the same time, and the double-porosity effects occur at the same time for all interference locations. Transient interporosity matrix flow reduces the pressure difference between the matrix and the fractures, and reduces the flattening of the interference pressure response. The fracture interference pressure responses for double-porosity reservoirs with slab shaped or spherically shaped matrix' blocks are similar. Figure 2-4 shows interference responses for finite double-porosity systems.

2.9 Decline Curve Analysis for Double-Porosity Systems

A. Sageev, G. DaPrat, and H. J. Ramey, Jr.

A type curve matching method for analyzing constant pressure testing in a double-porosity system is presented. Both infinite systems and closed outer boundary systems are considered. Rate responses of constant pressure wells with and without wellbore skin are described.

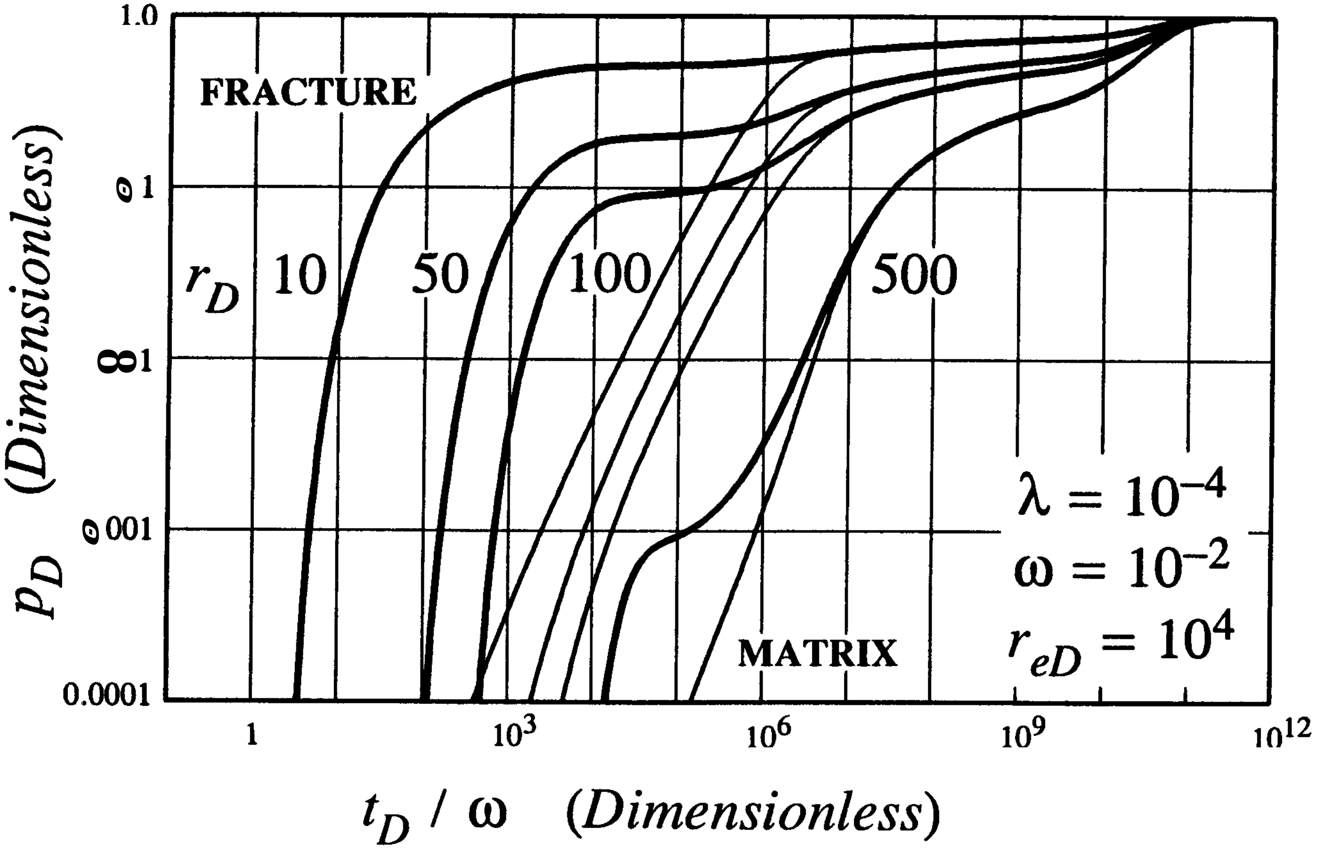

Figure 2-4. Interference responses for a finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-4}$, $r_D = 10, 50, 100, 500$, and $r_{eD} = 10^4$.

Five type curves are presented for the rate response of the constant pressure active well. The first four curves describe: (1) An infinite system without wellbore skin, (2) a closed outer boundary system without wellbore skin, (3) an infinite system with wellbore skin, and (4) a closed outer boundary system with wellbore skin. In the fifth type curve, the first four type curves are assembled into one. Figure 2-5 shows the log-log type curve for finite and infinite double-porosity systems with and without wellbore skin. A log-log type curve matching method is presented, where the parameters X, ω, r_{eD}, and S are estimated. The parameters λ and ω describe interporosity flow and relative fracture storativity respectively, and r_{eD} and S are the dimensionless size of the system and the wellbore skin respectively. This paper considers only the estimation of these four parameters. The estimations of permeabilities and storativities have been described in the past, hence, are not described in this report. It is observed that the presence of wellbore skin has an important effect on the rate response of the double-porosity system. It is essential for the success of the analysis, especially in the determination of X and r_{eD}, to include wellbore skin. The presented analysis method is valid for transient interporosity flow with fracture skin greater than 0.33, with slab-shaped matrix. Three type curve matching examples are presented along with a discussion of the applicability and practicality of the analysis method.

This discussion is centered on the four parameters considered in this report: ω, λ, r_{eD}, and S. In infinite systems, the first parameter to be determined is X, since it only requires rate support from the matrix without an extensive depletion of the matrix. If the test is long enough, the rate response represents the total system, fractures and matrix, and then, w may be determined. In closed outer boundary systems, there is an added effect of the boundary. This yields three classes of tests. In the first case, the effects of the matrix occur prior to the boundary effects. In the second case, the effects of the boundary occur prior to the matrix effects. The third case is between the first two cases. It is expected that in large finite systems, the effects of the matrix will be

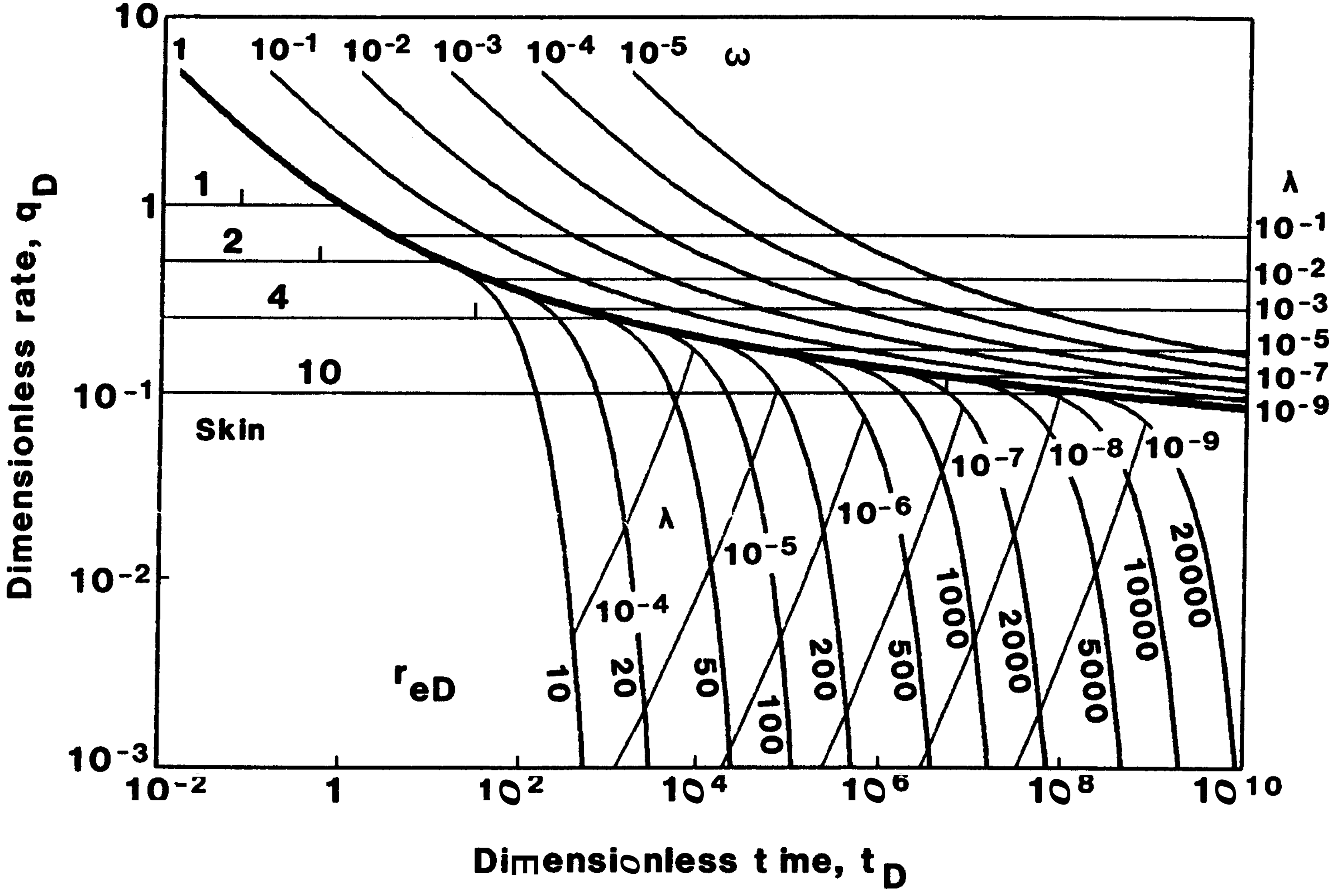

Figure 2-5. Log-log type curve for finite and infinite double porosity systems with and without wellbore skin (pss).

detected first, while in small finite systems, the effects of the boundary may take place first. However, it is important to consider the tests carefully. If the early time rate response is not available, the second exponential decline may be mistaken for the first decline, and yield errors in the permeability and storativity evaluations. The introduction of skin complicates the analysis. The log-log type curve method presented here is not the best method for determining skin. Early time rate data may be masked by other near wellbore effects. The presence of skin bears a significant effect on the rate response. The initial rate is upperbounded by the 'film coefficient' phenomenon. The rate response joins the infinite acting response. If the early time data are not available, there might not be an indication of the presence of skin. The knowledge of skin is essential for the log-log analysis in finite systems. Here, in order to find the dimensionless size of the system, the data must be shifted from the original log-log match. If the skin is unknown, the value of r_{eD} might be erroneously large. The constant rate flow period is indicative of either pseudo steady state interporosity flow, or, transient interporosity flow with fracture skin, $S_F > 0.33$, for a slab-shaped matrix.

2.10 Importance of Adsorption in Geothermal Systems

Jeralyn Leutkehans, Paul Pettit, Frank G. Miller, and H.J. Ramey, Jr.

Measurements of water adsorbed on porous media under geothermal system conditions were studied by Hsieh and Ramey (1983) and Herkelrath, Moench, and O'Neal (1983). The important results were that (1) the mass adsorbed was much larger than the mass of steam contained in the pore space, and (2) that it was not possible to match transient flow of steam in pore space with expressions that did not contain an adsorption term. The apparatus constructed by Hsieh was rebuilt during the year and trial runs performed on adsorption of steam on sandstones. Cores from various geothermal fields were solicited. Cores were received from The Geysers, California, Los Azufres, Mexico, and Larderello, Italy. During the coming year, it is planned to continue modification of the apparatus to permit fully automatic operation. The experiments are slow and tedious. Computer operation should permit more reliable operation of the equipment. It is also planned to repeat and extend the transient flow experiments of Herkelrath, Moench, and O'Neal (1983).

3. HEAT EXTRACTION

During the current year, the heat extraction project resulted in advances in four task areas: (1) completion of the SGP-LBL joint analysis of the SGP physical reservoir model experiments with the LBL reservoir simulator; (2) improvements in the one-dimensional Linear Heat Sweep model for analysis of recharge heat extraction in fractured hydrothermal reservoirs; (3) analysis of recharge heat sweep problems at the Cerro Prieto and Los Azufres geothermal fields in Mexico in cooperation with the Comision Federal de Electricidad (CFE); and (4) completion of the design phase of the experimental study on thermal property changes in fractured hydrothermal reservoirs under recharge thermal stressing.

3.1 SGP-LBL Joint Study

S. Lam, A. Hunsbedt, and P. Kruger

The results of this study showed that the LBL reservoir simulator is an excellent tool for evaluating the physical processes in the SGP physical reservoir model experiments, which have greater thermal gradients and more complex boundary conditions than actual geothermal reservoirs. The successful matching of the experimental cool-down data from the three experiments, which varied the number of heat transfer units, by the LBL reservoir simulator followed a period of detailed evaluations of both the physical properties of the experimental system and the numerical model. Parametric studies were made with more than 40 computer runs to examine the sensitivity of rock thermal conductivity, wall thermal conduction path length, heat loss from the reservoir, and model mesh size and time step. The heat loss characteristics were redefined by a controlled cool-down experiment in the physical model. Measurements of the rock thermal conductivity were made at the U.S. Geological Survey. With these experimental data and with improvements in the numerical codes, successful matches were achieved with rock matrix inlet temperatures specified from the experimental data. The details of the three-stage cooperative project were issued as a SGP technical report

[SGP-TR-85, April 1985] and is currently being prepared for publication in a refereed journal.

3.2 One-Dimensional Linear Heat Sweep Model

S. Lam and P. Kruger

A preliminary User's Manual for the one-dimensional Linear Heat Sweep model was released as SGP-TR-75 in FY85 to initiate external applications. Since then several improvements have been added to the model to make it easier to use and to expand its applicability. The model, including a subroutine for the Stehfest algorithm for inversion of the Laplace equation solution, has been compiled for microcomputer use. An external data format, shown in Table 3-1, allows for rapid changes in input data without need for recompiling the program each time. Part of the output for Ramey Test 1 is shown in Table 3-2. Dimensionless time (TS) is given at the production wells (dimensionless distance, XS = 1.0) for 24 time steps of half the mean fluid residence time. The fluid temperature (T, C) and reservoir rock temperature (TR, C) are given as a function of production time (TY, years).

Improvements were made to the model to increase its use for more general recharge heat sweep problems. Vertical recharge (as distributed percolation) was added to the sweep geometry to estimate fluid mixing characteristics of sweep, percolation, and hot water components. Radial flow as one-dimensional flow was added to allow for analysis of larger recharge heat sweep problems. Evaluation of the accuracy of the Stehfest algorithm for the Laplace inversion was made by comparison with two other published algorithms. In the application of the model to the cooldown study at the western boundary of the Cerro Prieto I reservoir, the results showed that the three algorithms yielded essentially identical solutions. These improvements will be incorporated into a revised User's Manual which is planned for release in the Spring Quarter of 1986.

Table 3-1

SGP 1-D Linear Heat Sweep Model

LSWEEP.DAT Input Data
formatted data file

1. Problem Name/No. ______________________________ (A20)

2. Init. Res. Temp. __________ °C Recharge Water Temp. __________ °C (2f10.2)

3. Mean Frac. Spac. __________ m Flowrate ______________________ t/h (2f 10.2)

4. Porosity ______________ m^3/m^3 (f10.2)

5. Res. Length ______________ m Width ________ m Height ________ m (3f 10.2)

6. Rock Density ________ kg/m^3 Water Density ______________ kg/m^3 (2f10.2)

7. Rock Ht. Cap,, ________ kJ/kg Water Ht. Cap. ______________ kJ/kg (2f10.2)

8. Rock Th. Cond. ______ kJ/hCm Ht. Xfer Coeff. __________ kJ/hCm^2 (2f10.2)

Table 3-2

1-D HEAT SWEEP MODEL ANALYSIS

```
Analysis of Problem:   Ramey Test 1

Parameters for this problem are:

    Initial Res Temp   =  240.0   C            Recharge Temp    =  120.0    C
    Res Length         =  900.0   m            Res Width        =  500.0    m
    Mean Frac Spacing  =   50.0   m            Res Height       =  300.0    m
    Flowrate           =  320.0   t/h          Porosity         =     .050
    Rock density       = 2720.0   kg/m^3       Rock Heat Cap    =    1.16   kJ/kg-C
    Fluid density      =  920.0   kg/m^3       Fluid Heat Cap
    Heat Conductivity  =    6.43  kJ/hCm       Heat Xfer Coeff  = 61304.67  kJ/kg-C
                                                                            kJ/hCm^2

      Mean Fluid Residence Time             2.21  yrs
      Rock Mass Time Constant               2.48  yrs
      Number of Heat Transfer Units          .89

      No. Coeffs = 10

 Output of Temperature History


                   XS        TS        TY        T         TR
                  ____      ____      ____      ____      ____

                  1.00        .5       1.1     240.0     240.0
                  1.00       1.0       2.2     240.0     240.0
                  1.00       1.5       3.3     240.0     240.0
                  1.00       2.0       4.4     239.9     240.0
                  1.00       2.5       5.5     239.8     239.9
                  1.00       3.0       6.6     239.6     239.8
                  1.00       3.5       7.7     239.4     239.7
                  1.00       4.0       8.9     239.0     239.5
                  1.00       4.5      10.0     238.6     239.3
                  1.00       5.0      11.1     238.0     239.0
                  1.00       5.5      12.2     237.2     238.6
                  1.00       6.0      13.3     236.0     238.0
                  1.00       6.5      14.4     234.5     237.2
                  1.00       7.0      15.5     232.6     236.0
                  1.00       7.5      16.6     230.2     234.4
                  1.00       8.0      17.7     227.4     232.4
                  1.00       8.5      18.8     224.2     229.9
                  1.00       9.0      19.9     220.6     227.1
                  1.00       9.5      21.0     216.8     223.9
                  1.00      10.0      22.1     212.6     220.4
                  1.00      10.5      23.2     208.3     216.6
                  1.00      11.0      24.4     203.9     212.5
                  1.00      11.5      25.5     199.4     208.3
                  1.00      12.0      26.6     194.8     204.0
```

3.3 Applications of the One-Dimensional Linear Heat Sweep Model

S. Lam and P. Kruger

The first application of the one-dimensional Linear Heat Sweep model was the evaluation of cold-water recharge behavior along the western boundary of the Cerro Prieto I reservoir near Mexicali, B.C. In a cooperative project with CFE staff, mean temperature cooldown histories were calculated from annual averaging of the chemical Na-K-Ca and SiO_2 geothermometers. The results, reported at the 10th Annual SGP Workshop, showed that the observed cooldown could be matched by mixing of sweep water from the west, percolating water from above, and reservoir hot water from the east at its calculated geothermometer temperature, cooling at a much slawer rate compared to the western line of wells. In continuation of the cooperative project, a more general analysis of the cooldown history of the Cerro Prieto I reservoir is underway. A series of three concentric rings of wells around the central well, shown by CFE to be the center of piezometric drawdown of the reservoir, was selected for analysis. Variations in cooldown gradient and initial reservoir temperature have been observed in the data as a function of radius. Efforts are underway to interpret the temperature cooldown data by mixing models as functions of radius from the piezometric drawdown center and recharge flow direction. The one-dimensional radial flow model is being adapted for this application.

A second effort is underway at Cerro Prieto to explore the recharge characteristics at the western boundary of CPI. Chloride dilution data have been compiled in relation to the observed enthalpy decline data for evaluating the mixing model already reported. The data derived during the current year are summarized in Table 3-3.

The data in Table 3-3 indicates that chloride dilution has been the same for the two lines of wells but that the linear decline rate of enthalpy for the border wells has been about twice as fast compared to the inner line of wells. The data suggest that the cold-water recharge from the west contains the same chloride concentration as the ori-

Table 3-3

Summary of Chloride Dilution and Enthalpy Decline Data at CPI

	Chloride			Enthalpy		
	$[Cl]_o$ (g/kg)	LDR (g/kg-yr)	r^2	H_o (kJ/kg)	LDR (kJ/kg-yr)	r^2
Border Wells	11.9	−0.315	0.95	1388	−20.2	0.90
Inner Wells	11.9	−0.312	0.95	1273	−10.6	0.61

ginal water and that the percolating water accounts for the observed linear deline rate. The final evaluation is expected to result in a second joint publication with the CFE Staff.

A second series of applications of the one-dimensional Linear Heat Sweep model is underway as a SGP-CFE cooperative project at the Los Azufres geothermal field, The cooperation joint project was initiated as a study of the startup history of the production wells for the five 5 MWe wellhead units in the south and north zones of the field. The analysis of the chemical and production data as seni-annual means were reported in two stages. The first, covering the first two years, is given in the Proceedings of the 1985 SGP Workshop. The second, covering additional data and a quality analysis, is given in the Proceedings of the 1985 Geothermal Resources Council Conference. As a result of this cooperation, a series of four recharge heat sweep analyses were undertaken with CFE staff members to evaluate the potential for cold-water breakthrough from existing and planned recharge and production wells. The abandonment temperature for the 5 MWe wellhead units is 170 C, corresponding to a minimum inlet pressure to the turbines. The results of the analyses are expected to assist in decisions on reinjection management under future field development.

The four reservoir study areas are:

1) Az31 - Az26 in the eastern part of the south zone,

2) Az8 - Az2 in the western part of the south zone,

3) Az15 injection past a line of future production wells in the north zone,

4) 55 MWe power-plant system of 15 production wells and 4 injection wells in the south zone.

A major accomplishment, to-date, has been the compilation with the CFE staff of a set of estimated input data for the four problems. Ranges of reasonable values were determined for:

1) geologic stucture and geometry of the reservoir sweep zones,

2) flow characteristics in the zones,

3) initial reservoir temperatures,

4) proposed recharge temperatures,

5) thermal properties of the reservoir rock types.

A large number of heat sweep runs have been completed with the microcomputer version of the model using the external formatted data file, for which a wide variety of data scenarios; were easy to evaluate. Results have been obtained for these problems for variable initial reservoir temperature, recharge fluid temperature, flow geometries, effective porosity, and mean fracture spacing. A summary of these initial results was prepared for the 7th New Zealand Geothermal Workshop, Novenber,1985. The next phase of the cooperative project will be the incorporation of the results into mixing models to estimate anticipated cooldowns under reservoir operating conditions.

3.4 Thermal Stress Effects on Thermal Conductivity

S. Lam and D. Nelson

During the year, the design of a definitive experiment for determining thermal conductivity change with thermal stress was completed. It was noted in prior reports that thermal conductivity is a critical parameter that effects thermal capacity and heat extraction rates from fractured hydrothermal reservoirs. Thermal conductivity measurements have been obtained for granite specimens by a steady-state, divided-bar method at the U. S. Geological Survey laboratories in Menlo Park. This data was used in the joint study with LBL on modeling the heat extraction experiments in the physical model. The conductivity measurements indicated significant decrease in dry rock specimens after cold water sweep and little decrease with thermal stress in saturated granite specimens. The present experiment emphasizes a large reduction in experimental uncertainty by direct measurement of thermal conductivity in long cylindrical blocks, before and after stressing the same blocks, over a range of geothermal reservoir temperatures. The blocks are stressed in the SGP physical reservoir model with adequate instrumentation and embedded thermocouples. Axial core heaters at controlled power are used to generate measureable radial temperature gradients in the blocks. The temperature transients are analyzed with a heat conduction model prepared by Stephen Lam as part of his PhD dissertation to estimate the magnitude of change in thermal conductivity with cold-water sweep stresses. The experimental results and analysis are expected to confirm the extent of change in thermal conductivity possible with long-term heat extraction behavior in fractured hydrothermal reservoirs under cold-water reinjection practices.

4. FIELD APPLICATIONS

4.1 Cooperative Agreements

F.G. Miller

The spirit of international cooperation that exists in the Stanford Geothermal Program provides a framework within which the talent and expertise that exists can be joined together with the international experience in the development and operation of geothermal reservoirs.

Stanford participates with two countries by international agreement. With Italy, the first five year agreement on cooperative research with ENEL took place in 1975. The agreement was extended in 1980 and in 1985 for additional five year terms. The DOE-ENEL agreement has provided the opportunity to acquire reservoir core samples from the Larderello Steam Field. These core samples will be used in the steam adsorption experiments described in section 2.10.

With Mexico, Stanford participates in a) a DOE-CFE formal bi-national agreement with Comision Federal de Electricidad and b) a SGP-IIE memorandum of understanding with Instituto de Investigaciones Electricas and supported by DOE. The SGP-IIE agreement has led to the acquisition of reservoir core samples from the Los Azufres Field. These core samples will be used in the steam adsorption experiments described in section 2.10. Additional work has involved two-phase well bore modelling as described in section 4.3 and the heat extraction modelling describad in section 3.3.

Stanford has a "cooperative effort" relationship with two countries. A number of well test studies were conducted using data from the Ohaaki Field, New Zealand. In Turkey, there is a cooperative research effort regarding reinjection. A number of representatives from other countries maintain a close tie to the Stanford Geothermal Program.

4.2 Optimum Field Development Strategy

J.A. Marcou and J.S. Gudmundsson

The development of geothermal resources is characterized by complex and uncertain decisions, both technical and economic. A development model was constructed ta integrate the main factors that affect the overall cost of geothermal field development. The model includes the elements of reservoir, production wells, surface facilities, power plant, and injection facilities, as shown in Figure 4-1. The primary objective of this project was to investigate the effect of reservoir deliverability on the cost of geothermal field developments.

Reservoir performance was modeled by the material balance/water influx method of Hurst (1958) as used by Olsen (1984). In this method the reservoir is taken as a lumped element of uniform properties in pressure communication with surrounding aquifers. Field data from the Wairakei reservoir in New Zealand and the Ahuachapan reservoir in El Salvador were matched assuming a radial configuration. The match parameters for these reservoirs were then used in the development model. Both reservoirs are liquid-dominated and have steam zones near the top - similar to the Svartsengi reservoir previously modeled by Gudmundsson and Olsen (1985).

Inflow performance was modeled assuming linear productivity index behavior in single-phase flow, and Vogel's (1968) inflow performance relationship in two-phase steam/water flow. The inflow performance of well 14-2 in the Roosevelt Hot Springs reservoir in Utah is matched in Figure 4-2, where two-phase flow occurs below the saturation pressure.

Casing performance was that of a 9-38" well producing a 250 C 1100 kJ/kg fluid from a depth of 900 m to a wellhead pressure of 100 psia. The casing performance data were taken from Butz and Plooster (1979) and are shown in Figure 4-3. Also shown is the casing performace of a 13-3/8" casing for the same feedzone and wellhead conditions.

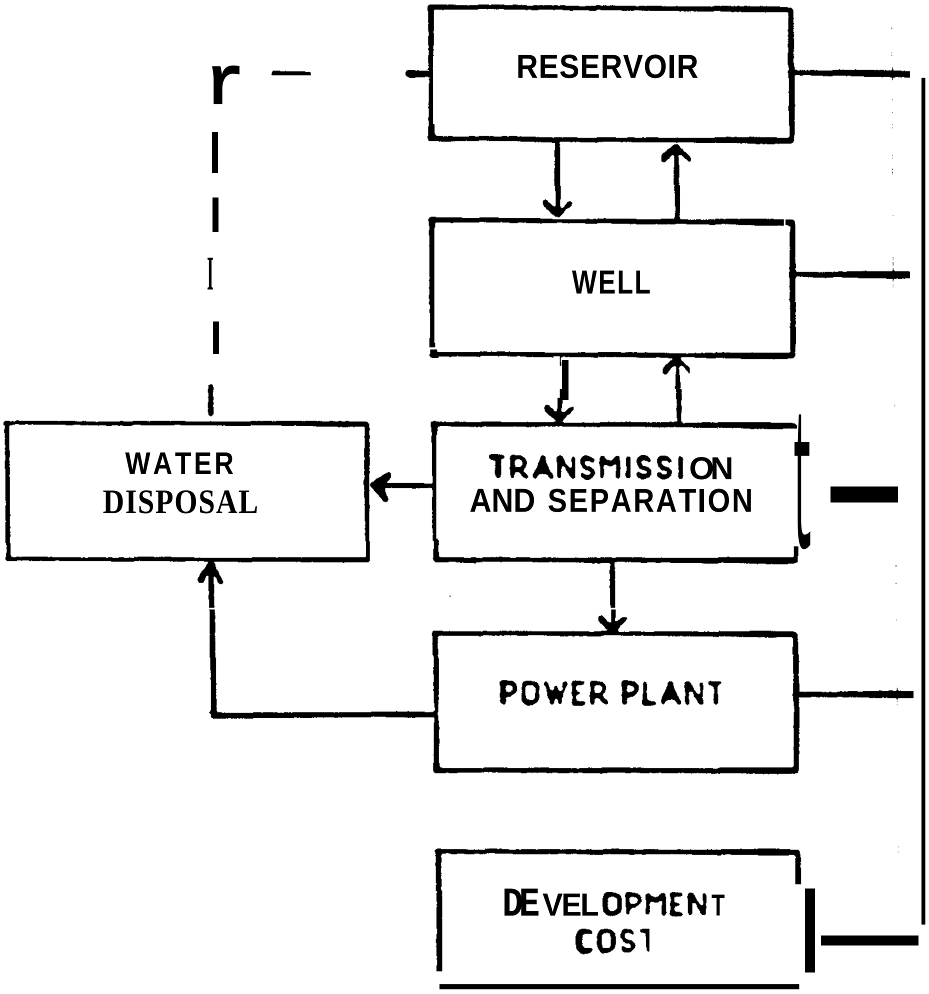

Figure **4-1. Elements of geothermal development model.**

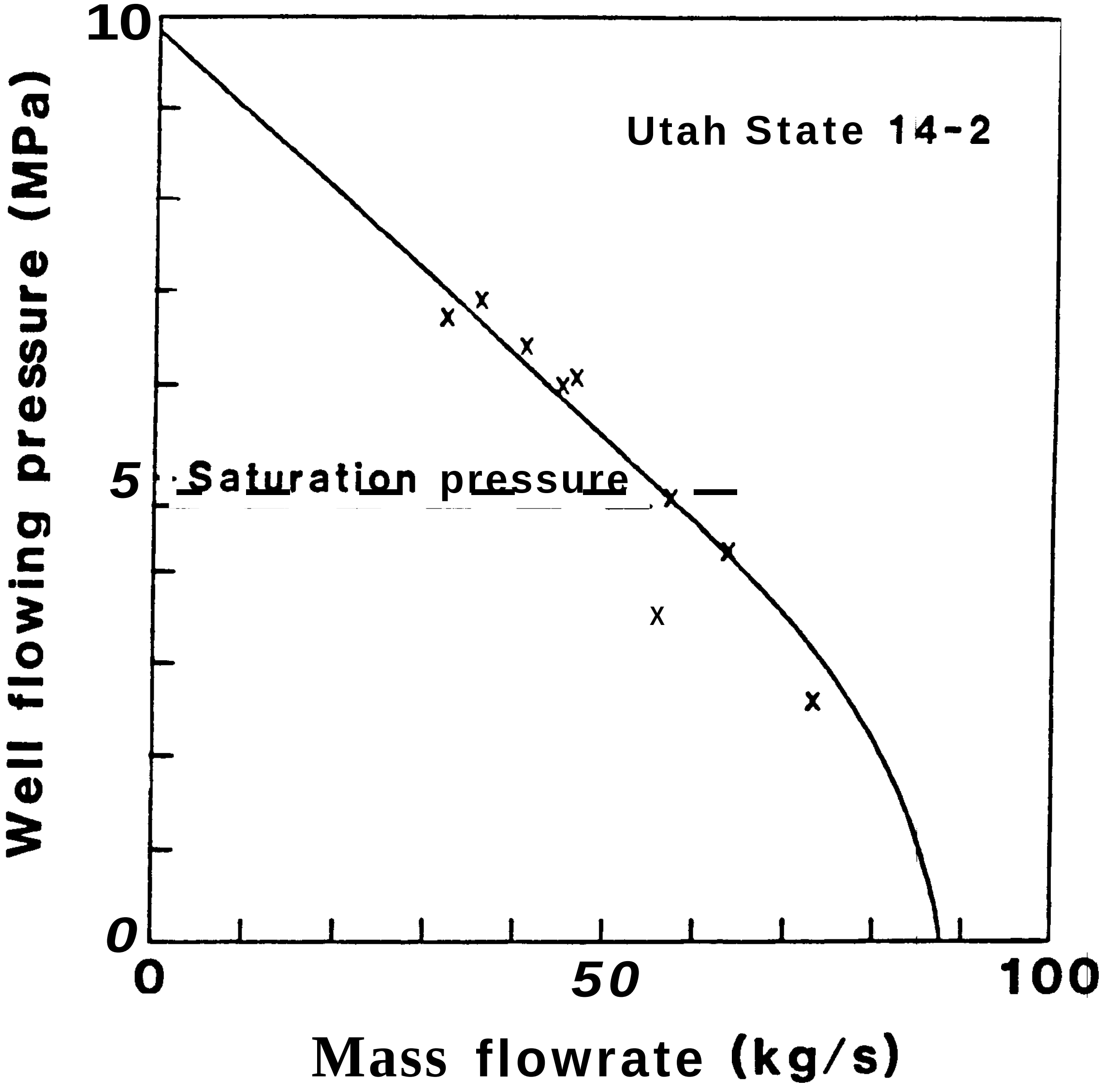

Figure 4-2. Inflow performance of well Utah State 14-2.

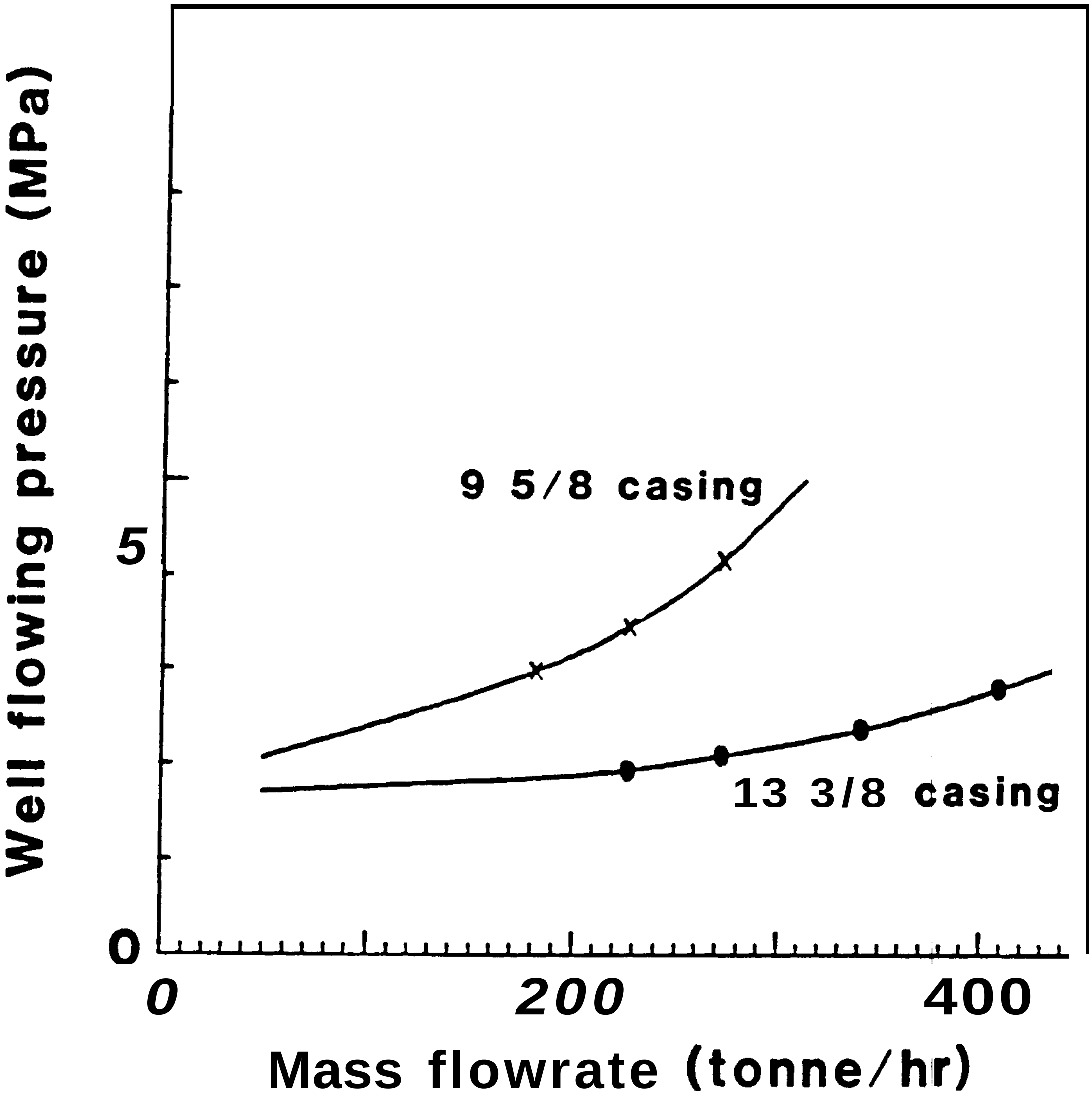

Figure 4-3. Wellbore performance of 9-5/8" and 13-3/8" wells.

The overall system performance or deliverability is obtained by arranging the individual performances in series. With falling reservoir pressure the flowrate of individual wells decreases for the same wellhead pressure. To maintain constant fluid production to a power plant, therefore, new wells have to be drilled.

Cost data for steam production and power plants from several countries were reviewed for this study. They were found to vary greatly so typical values had to be selected. Steam production costs were arrived at by specifying the total cost associated with each production well, including drilling and wellhead equipment, pipelines, injection and other facilities. This capital cost was taken as 2.2 M$ per production well. Operating the steam field and maintenance was taken as 0.3 M$ per production well. The capital cost for central power plants was taken as 1300 $/kW; condenser wellhead units 700 $/kW; backpressure wellhead units 500 $/kW. The annual operating and maintenace costs for these plants were taken as 30 $/kW, 60 $/kW, and 30 $/kW, respectively. A project lifetime of 25 years and a 10 percent discount rate were used throughout. Condensing plants were assumed to have a steam to electrical energy conversion of 8 kg/kWh and backpressure units 15 kg/kWh.

The development model was used to calculate the total cost of power projects of different sizes in terms of net present value. This was done assuming different power plant schemes and reservoir parameters. The many results obtained provided insight into the effect of reservoir deliverability on the cost of geothermal electric power. The results were presented in a manner shown in Figure 4-4. The figure shows the cost of power plants up to about 150 MW. The gradient of this line gives the marginal cost of electrical energy from plants of different sizes. The overall cost is the gradient of a line from a point on the line and through the origin. The line in Figure 4-4 is of the same general shape as obtained for the many scenarios calculated. It shows that the marginal cost of geothermal electric energy increases with plant size. Expressed differently, the results demonstrate the opposite of economy of scale commonly found

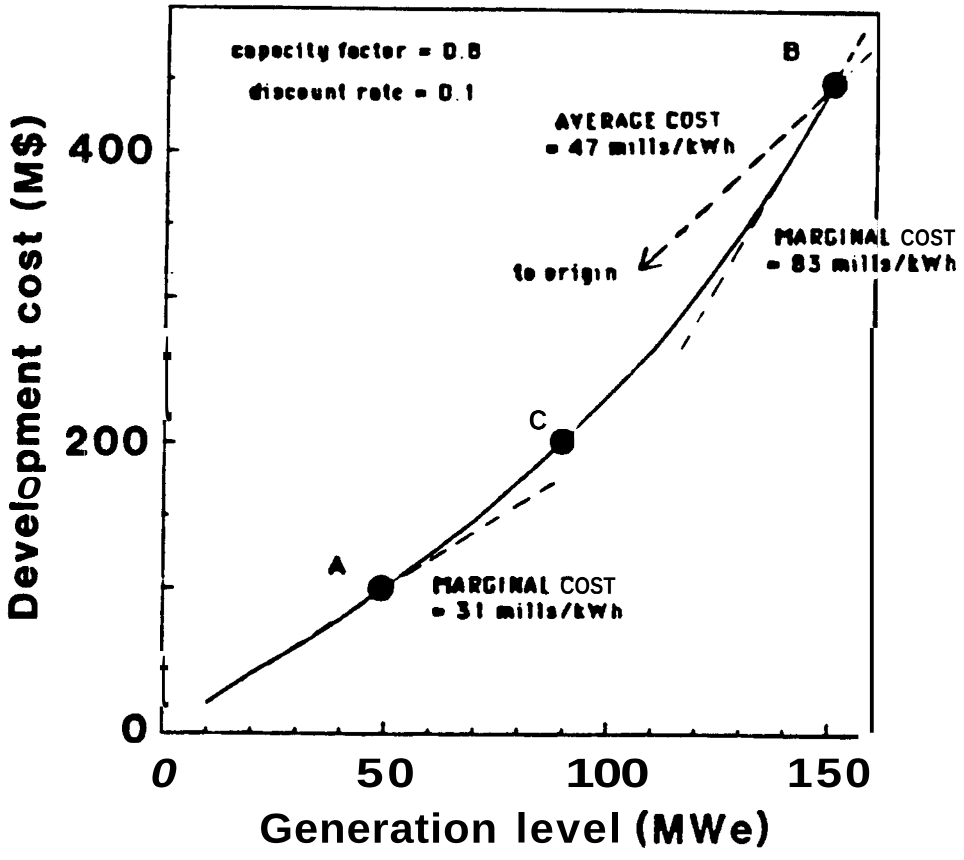

Figure 4-4. General form of results from development model.

in engineering systems; that is, the results demonstrate a dis-economy of scale for geothermal power developments.

A specific result from the development model is shown in Figure **4-5.** It shows the cost of portable condenser plants constructed in liquid-dominated geothermal fields behaving as either Wairakei in New Zealand or Ahuachapan in El Salvador. The Ahuachapan-type development is seen to be more expensive. The **reason** for this is that the Ahuachapan field is smaller than the Wairakei field so the same fluid production results in greater pressure loss at Ahuachapan. In turn this means **that** a greater number of new wells have to be **drilled** to maintain the specified power generation level. The difference in cost is greater for large power schemes. An important conclusion from the lack of economy of scale in geothermal developments, is that while small-scale developments can be economical, large-scale development may not. The marginal cost increases with size so there comes a point where it becomes more economical to develop another field or an alternative form of power generation.

4.3 TWO-PHASE WELLBORE FLOW

A.K. Ambastha and J.S. Gudmundsson

Increased confidence in the predictive power of two-phase correlations is a vital part of wellbore deliverability and deposition studies for geothermal wells. Previously, the Orkiszewski (1967) set of correlations has been recommended by many investigators to analyze geothermal wellbore performance. In this study, we use measured flowing pressure profile **data** from ten geothermal wells around the world, covering a wide range of flowrate, fluid enthalpy, wellhead pressure and well depth. The wells are in 6 countries: the **United States,** Mexico, New Zealand, the Philippines, Iceland, and Italy. The total flowrate ranges from 12.9 kg/s to 68.6 kg/s; the mixture enthalpy from 965 kJ/kg to 1966 kJ/kg ; wellhead pressure from 2.3 bar-g to ***56.5*** bar-g (245 kPa to 6027 kPa); well depth from 913 m to 2600 m. The nominal casing size near

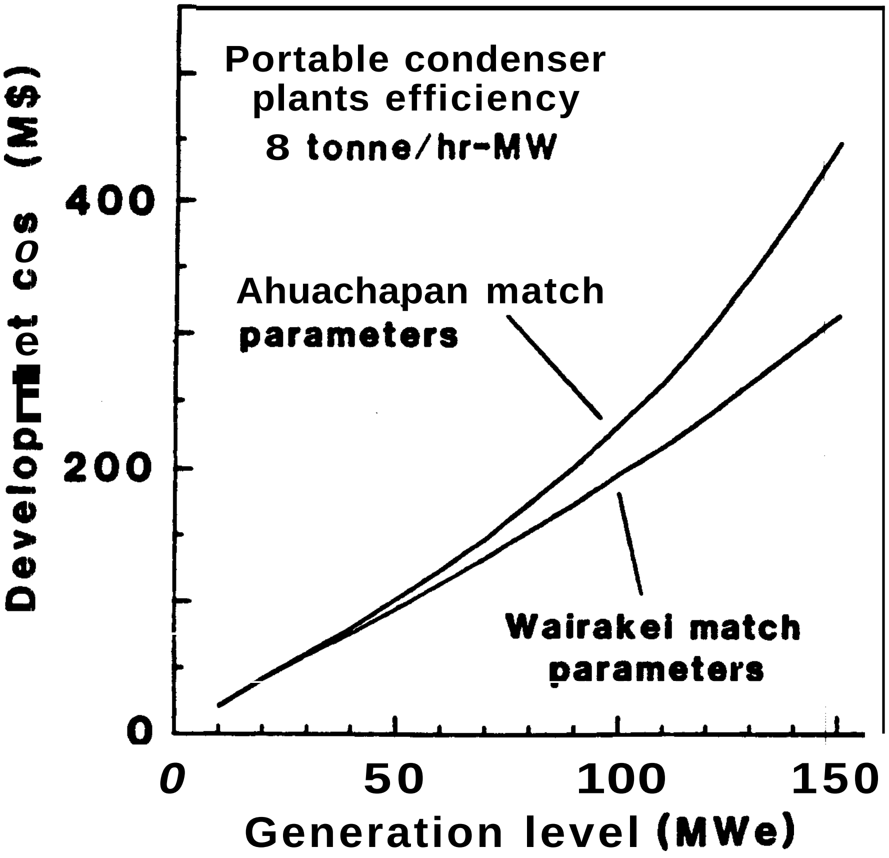

Figure 4-5. Effect of reservoir/wellbore deliverability on development cost for wellhead condensed plants.

the surface ranges from 7-98" to 9-98". We were not able to compile the chemical data (dissolved solids and non-condensible gas content) for the wells.

The pressure profiles for the 10 wells are shown in Figure 4-6. We used the Orkiszewski-based simulator to calculate the flowing profiles. This wellbore simulator was developed in the Stanford Geothermal Program and has been used for a number of projects in the past. All calculations were done from the surface to well bottom. The matches we obtained with the measured profiles ranged from good to fair.

The quality of match was characterized by estimating the mean and standard deviation of error and percent error, as follows:

$$e_i = p_{calc} - p_{meas} \qquad (1)$$

$$d_i = \frac{p_{calc} - p_{meas}}{p_{meas}} \times 100 \qquad (2)$$

where p_{calc} and p_{meas} are calculated and measured pressures at any point respectively.

$$\bar{e} = \frac{\sum_{i=1}^{n} e_i}{n} \qquad (3)$$

$$\sigma_e = \left[\frac{\sum_{i=1}^{n}(e_i - \bar{e})^2}{n-1}\right]^{1/2} \qquad (4)$$

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \qquad (5)$$

$$\sigma_d = \left[\frac{\sum_{i=1}^{n}(d_i - \bar{d})^2}{n-1}\right]^{1/2} \qquad (6)$$

where e_i is the error, $\bar{e}$ is arithmetic mean error, σ_e is the standard deviation about $\bar{e}$, and n is the number of data points. Similarly, d_i is the percent error, $\bar{d}$ is mean percent error, and σ_d is the standard deviation about $\bar{d}$. Such statistical parameters have been

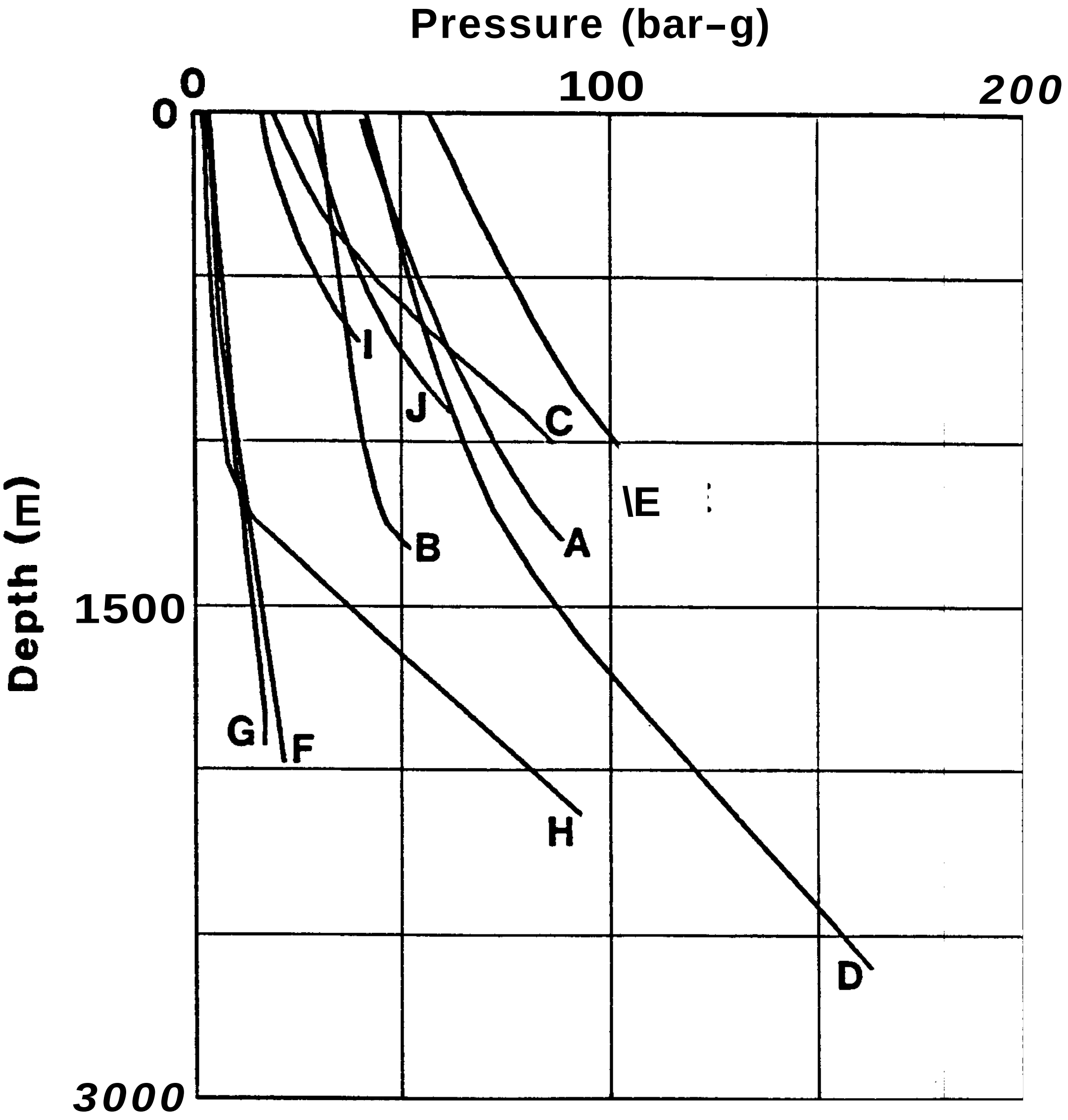

Figure 4-6. Measured pressure profiles for all wells.

used before to evaluate the accuracies of two-phase correlations (Vohra et *al.*, 1975). Results of our calculations are summarized in Table 4-1. For a good match, we should have a low mean and standard deviation. Looking at the mean and standard deviation of error, we find that Ngawha 11, Okoy 7, East Mesa 6-1, Krafla 9 and Utah State 14-2 fall in the category of fair matches. A similar conclusion is drawn by looking at the columns of mean percent error and standard deviation of percent error, except that now it appears that Mofete 2 and HGP-A are also fair matches. But these two wells are low pressure wells and hence a small deviation in calculated pressure gets magnified when percent error is calculated. So mean and standard deviation of percent error are not necessarily good ways to determine the quality of match for low pressure cases.

The Cerro Prieto 90 , Ngawha 11 , and Krafla 9 pressure profiles are shown in Figures 4-7, 4-8, and 4-9, respectively. They demonstrate the range of retults obtained in our work. All the wellbore calculations reported here were done assuming no heat transfer to/from the formation; the absolute casing roughness used throughout was 0.0006 feet; the wellbore was divided into about 50 segments in most cases. The effects of noncondensible gases and dissolved solids were not considered.

The Orkiszewski (1967) method performs well for geothermal wellbore flow; that is, the method seems to have general applicability. The details of this work are reported in Ambastha and Gudmundsson (1986).

4.4 Use of the Hurst Simplified Method to History Match Field Perfdrmance

D. Brock and J.S. Gudmundsson

The Hurst Simplified model, linear and radial geometries, was derived for use in geothermal systems. The model is being used to computer history match data from five fields that range from totally liquid (Ellidaar, Iceland) to highly two-phase (Broadlands, New Zealand). The matches yield compressibilities and permeability-thickness

Table 4-1. Comparison of measured and calculated pressure profiles.

Well	Data Points	Measured Pressure Range, bar-g	Mean Error bar-g	Standard Deviation of Error, bar-g	Mean Percent Error	Standard Deviation of Percent Error
A--Cerro Prieto 90	16	40.9-88.5	-0.3	0.8	-0.6	1.1
B--Los Azufres 18	18	30.0-52.1	-1.1	1.2	-2.65	2.2
C--Ngawha 11	14	19.0-86.3	10.8	5.1	22.8	10.4
D--Okoy 7	14	41.7-162.9	5.3	4.1	5.1	3.9
E--Cerro Prieto 91	13	56.5-117.0	-0.15	2.6	-0.66	2.9
F--Mofete 2	5	3.5-21.5	0.4	0.4	4.9	5.7
G--HGP-A	17	3.2-16.7	0.6	0.4	6.1	2.7
H--East Mesa 6-1	15	2.3-92.9	11.0	9.4	59.5	53.2
I--Krafla 9	8	16.3-40.0	-5.5	5.4	-17.5	13.8
J--Utah State 14-2	30	27.0-61.6	-6.7	4.6	-13.6	6.9

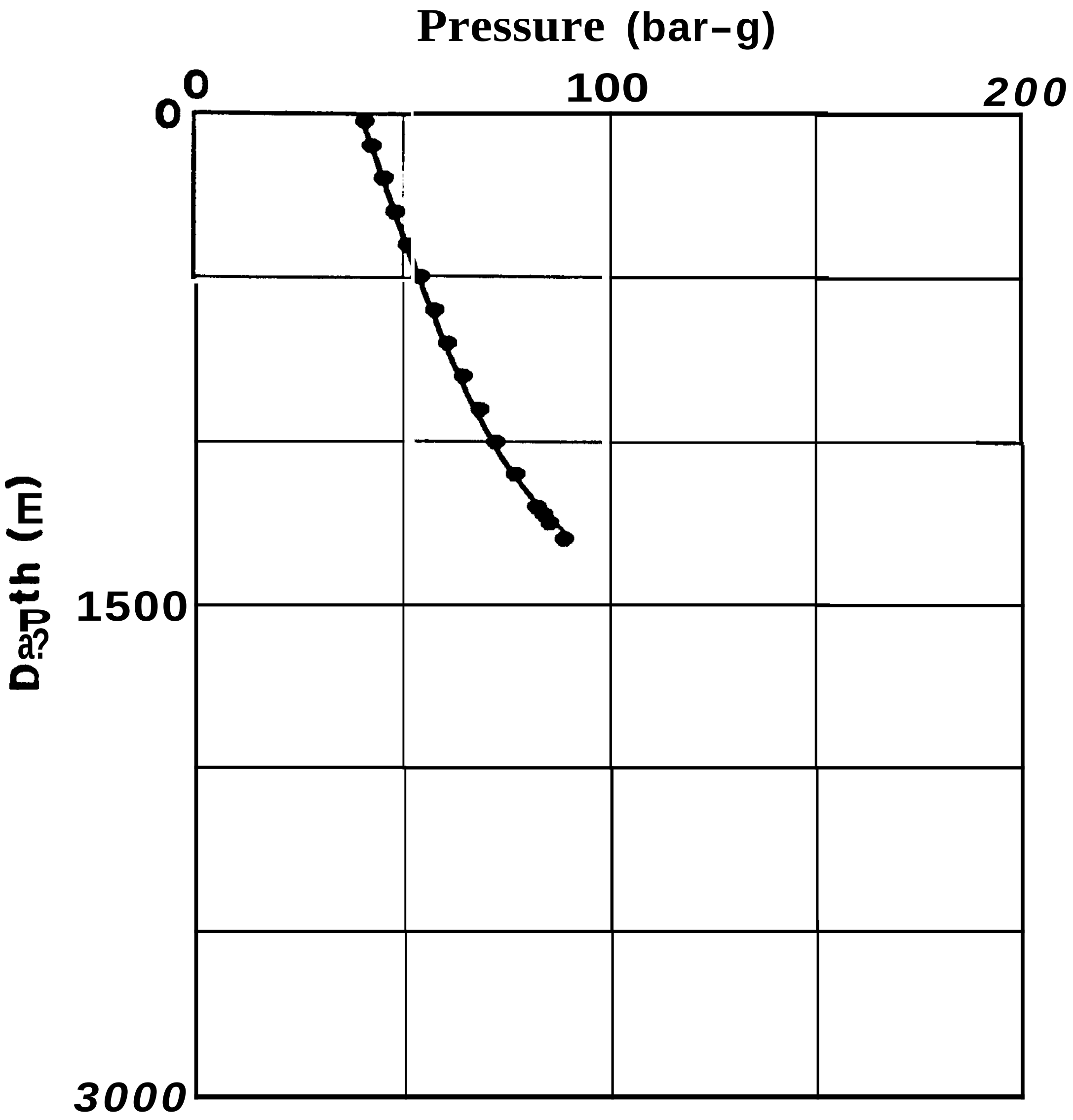

Figure 4-7. Pressure profile match for well Cerro Prieto 90.

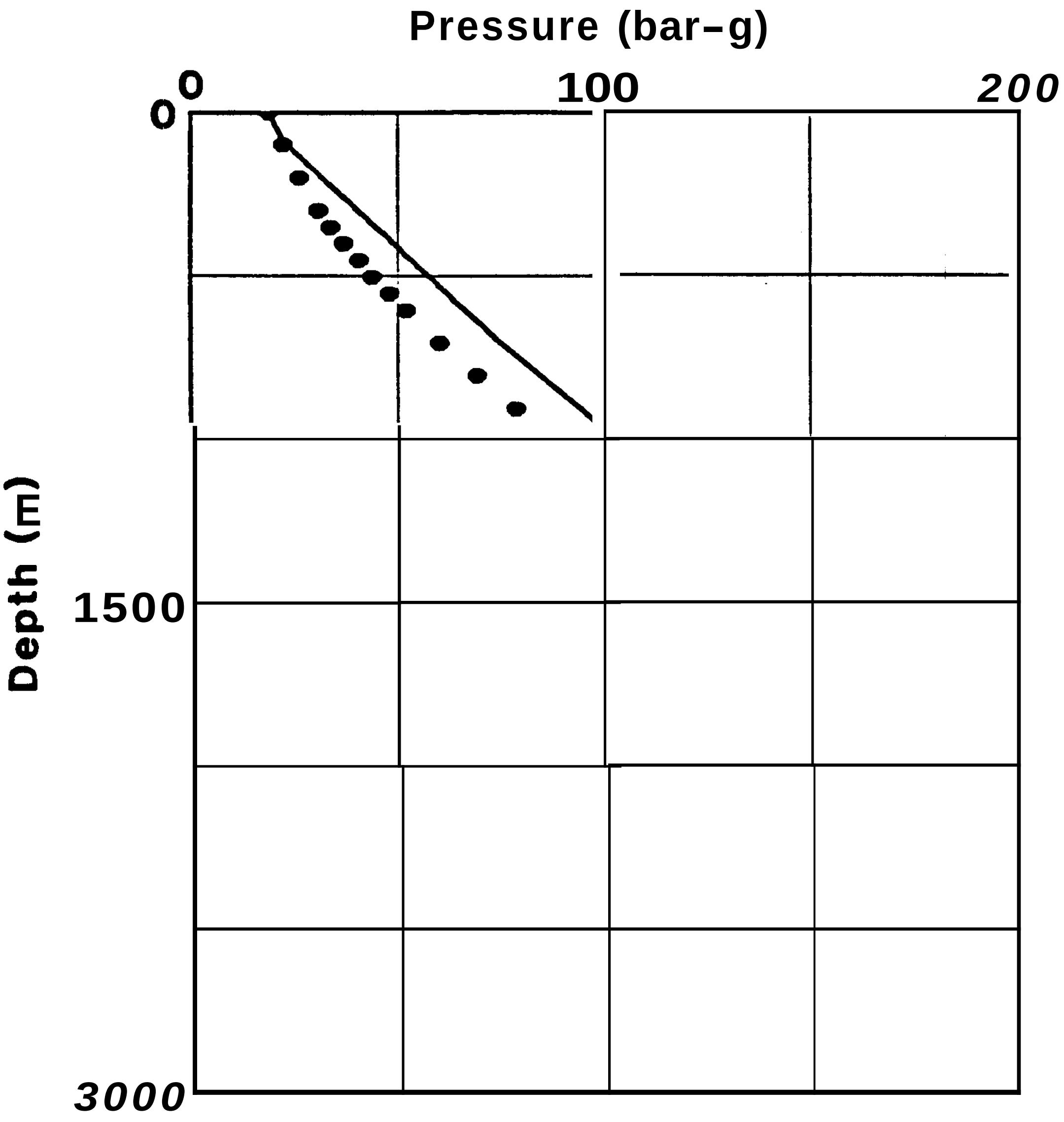

Figure 4-8. Pressure profile match for well Ngawha 11.

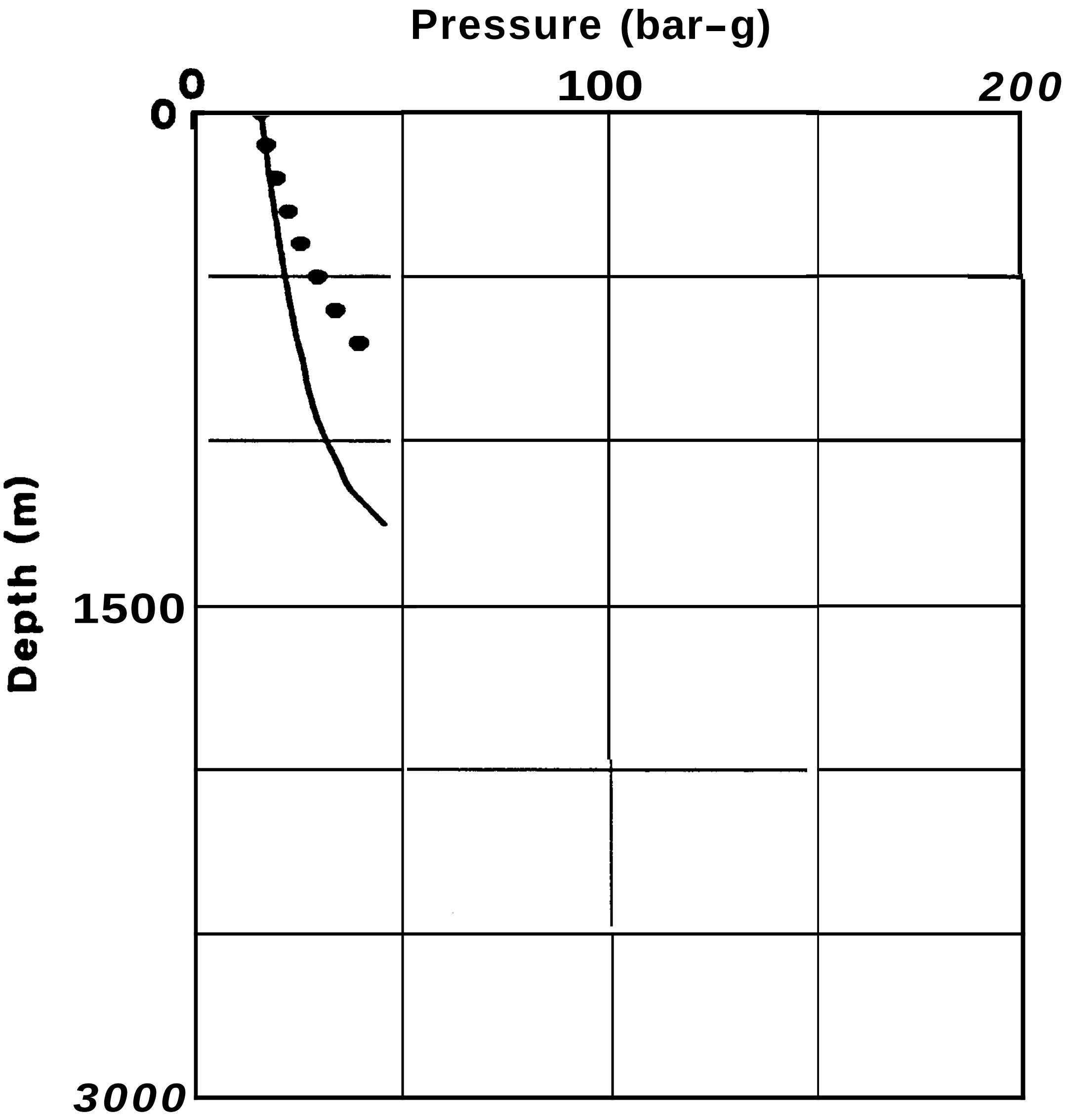

Figure 4-9. Pressure profile match for well Krafla 9.

products for most of the reservoirs. As expected, compressibilities are greatest in the field with a large two-phase zone (Broadlands, c = 0.000006/Pa).

The five fields being modeled include Ahuachapan (El Salvador), Baoadlands (New Zealand), Ellidaar (Iceland), Svartsengi (Iceland), and Wairakei (New Zealand). Based on standard deviation, it can be determined whether the system is behaving more like a radial or a linear system. Reservoir compressibility is often not easy to estimate initially and is therefore determined from the history match. Reasonable compressibility values cover a wide range, thus the history match value is useful for estimating the extent or existence of a two phase zone. This work will be completed in 1986.

5. TECHNOLOGY TRANSFER

The Tenth Workshop on Geothermal Reservoir Engineering was held at Stanford University on January 22-24, 1985. The attendance was up from previous years with about 140 registered participants. This was the first time the Workshop was held in January. Seven foreign countries were represented: France, Iceland, Indonesia, Italy, Japan, Mexico, and New Zealand.

The purposes of the Workshop are to bring together researchers, engineers, and managers involved in geothermal reservoir studies and development, and to provide for prompt and open reporting of progress and the exchange of ideas. There were 41 technical presentations at the Workshop. All of these were published in the Workshop Proceedings. Five technical papers not presented were also published.

Weekly Seminars were held during the academic year on geothermal energy topics. In autumn quarter the seminars were given by Stanford faculty, in winter quarter by representatives of industry, and spring quarter by student research assistants working of geothermal projects. These Seminars are attended by Stanford researchers and personnel of the U.S. Geological Survey and geothermal companies in the San Francisco area. The Seminars are also attended by representatives of geothermal companies in Santa Rosa.

The results of geothermal research at Stanford University were presented at several professional meetings during the year and published in the literature. Several technical reports were issued. Information on these technology transfers activities are given in appendices. The contents of the Proceedings of the Tenth Workshop on Geothermal Reservoir Engineering, and the Seminar Schedules for the 1984-1985 academic yeau, are also shown in appendices.

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Vohra, I.R., Hernandez, F., Marcano, N. and Brill, J.P.:"Comparison of Liquid-Holdup and Friction-Factor Correlations for Gas-Liquid Flow," J. Pet. Tech. (May 1975) 564-568.

APPENDIX A: Seminar Schedules

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

Jon S. Gudmundsson
Petroleum Eng. Dept.
Mitchell Building, Rm. 360
(415) 197-1218 or 497-4744

SEMINAR SCHEDULE

Autumn Quarter 1984 | Room i24. Noble Building | Thursdays, 1:15-2:30 p.m.

Date	Title	Speaker
Sept. 21	Organizational Meeting	SGP Faculty
Oct. 4	Discharge Analysis of Well 9 in Reykjanes Field: The World's Largest Well?	**Jon Gudmundsson** **Pet. Eng. Dept.**
11	Preliminary Heat Sweep Analysis at the Western Boundary of Cerro Prieto	Paul Kruger civil Eng. Dept.
18	**Alteration Mineralogy and** Isotope Studies of Los Azufres	Pat Dobson Geology Dept.
25	Formation of Natural Fracture Systems in Geothermal Reservoirs	Dave Pollard AES Dept.
Nov. 1	Multiphase Compressibility in Geothermal Reservoirs	**Luis Macias-Chapa** **Pet. Eng. Dept.**
8	Self Potential in Geothermal Exploration	**Dale** Morgan Geophysics Dept.
15	Monitoring the Hydrothermal System in Long Valley Caldera	Mike Sorey USCS
22	**No** Meeting (Thanksgiving)	
29	**Mineralogical** Record of mother-mal Fluid Circulation at the Skaergaard Intrusion	Dennis Bird Geology Dept.
Dec. 6	No Meeting (Dead Week)	

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

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Petroleum Eng. Dept.
Mitchell Bldg., Room 360
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SEMINAR SCHEDULE

Winter Quarter 1985 | Room 124, Roble Building | Thursday, 1:15-2:30 p.m.

Date	Title	Speaker
Jan. 31	Practical Aspects of Well Testing Using Quartz Crystal Transducers	Roger Harrison BCI
Feb. 7	Modeling the Olkaria Geothermal Field, Kenya	Bo Bodvarsson LBL
Feb. 14	Development Strategy at Coso Geothermal Field	Jim Moor CEC
Feb. 21	Temperature-Pressure Spinner Survey in Well at The Geysers	Andy Drenick GEO
Feb. 28	Origin of Reservoir Fluids at Baca Geothermal Field	Al Truesdell USCS
Mar. 7	Permits for Exploration and Development of Geothermal Power in California	Doug Stockton CDOG

STANFORD GEOTHERMAL PROGRAM
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SEMINAR SCHEDULE

Spring Quarter 1985	Room 124, Noble Building	Thursday, 1:15-2:30 p.m.
Date	**Title**	**Speaker**
April 11	Completion Testing and Discharge Measurements of Mokai 6 in New Zealand	Jonathan Leaver Petroleum Engineering
April 18	No Seminar (Affiliates Meeting)	
April 25	Direct Uses of Geothermal Energy Worldwide	Jon Gudmundsson Petroleum Engineering
May 2	Evolution and Natural State of Vapor-Dominated Systems	Steve Ingebritsen Applied Earth Sciences
May 9	Interpretation of Injection-backflow Tracer Tests	Ibrahim Kocabas Petroleum Engineering
May 16	Thermal Stability of Dye Tracers	Yathrib Al-Riyami Petroleum Engineering
May 23	Optimizing Field Development Strategy	John Marcou Petroleum Engineering
May 30	Discharge Analysis of Two-Phase Geothermal Wells	Carlos Tavares Petroleum Engineering
June 6	Dead Week	

APPENDIX B: Table of Contents Proceedings Tenth Workshop

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Reservoir Engineering Research

Field Development

Vapor-Dominated Systems

The Geysers Thermal Area

Well Test Analysis

Production Engineering

Reservoir Evaluation

Geochemistry and Injection

Numerical Simulation

Reservoir Physics

APPENDIX C: Participants in the Stanford Geothermal Program

Faculty	Reservoir Technology Research Assistants (and others)
Henry J. Ramey, Jr.	Dave Brock
Paul Kruger	Jonathan Leaver
Roland N. Home	James W. Lovekin
Frank G. Miller	Jeralyn Luetkehans
William E. Brigham	Tom Lyons
Abraham Sageev	Priscilla McLeroy
Jon S. Gudmundsson	Brenna Surritt
	Carlos Tavares
	Steve Lam
	Steve Ingebritsen
	Mary Eipper
	Luis Macias-Chapa
	Jeff Simmons
	Lew Semprini

APPENDIX D: Papers Presented and Published October 1,1984 through September 30,1985

Barua, J., Home, R.N., Greenstadt, J.L. and Lopez, L.: "Improved Estimation Algorithms for Automated Type Curve Analysis of Well Tests," paper SPE 14255, Proceedings, 1985 **SPE** Annual Conference and Exhibition, Las Vegas, NV, Sept. 23-25, 1985.

Dee, J.F. and Brigham, W.E.: "A Reservoir Engineering Analysis of a Vapor-Dominated Field," Proceedings, Tenth Workshop on Geothermal Reservoir Engineering, **Stanford** University, Stanford, CA, January 22-24, 1985, 45-51.

Dee, J.F. and Brigham, W.E.: "A Reservoir Engineering Analysis of a Vapor-Dominated Geothermal Field," Trans., 1985 International Symposium on Geothermal Energy, Geothermal Resources Council, Hilo, HA, August 26-30, 1985, 299-306.

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