STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

SGP-TR-61

GEOTHERMAL RESERVOIR ENGINEERING RESEARCH

AT STANFORD UNIVERSITY

SECOND ANNUAL REPORT

DOE CONTRACT NO. DE-AT03-80SF11459

FOR THE PERIOD

OCTOBER 1, 1981 THROUGH SEPTEMBER 30, 1982

Principal Investigators:
H. J. Ramey, Jr., P. Kruger, R. N. Horne, W. E. Brigham, F. G. Miller

September 1982

TABLE OF CONTENTS

PREFACE

This publication is the second annual progress report to the Department of Energy under contract number DE-AT03-80SF11459. It covers the period from October 1, 1981 through September 30, 1982.

The Stanford Geothermal Program conducts interdisciplinary research and training in engineering and earth sciences. The Program was initiated under grants from the National Science Foundation in 1972 and has continued under contracts from the Energy Research and Development Administration and the subsequent Department of Energy since 1977.

The central objective of the Stanford Geothermal Program is to carry out research in geothermal reservoir engineering techniques that will be useful to the geothermal industry. The research is focused toward accelerated development of hydrothermal resources through the evaluation of fluid reserves and forecasting the behavior of geothermal fields. The Program is geared to maintain a balance between laboratory studies and matching field applications.

A parallel objective of the Program is the training of engineers and scientists for employment in the geothermal industry. In the first 10 years of the Program about 50 graduates have been trained in geothermal engineering.

The dissemination of technical information is also important in the Stanford Geothermal Program. Major activities include a Geothermal Reservoir Engineering Workshop held annually in December and weekly seminars held throughout the academic year. The Workshop has produced a series of Proceedings that stand as one of the prominent literature sources in the field of geothermal energy.

The geothermal reservoir engineering research at Stanford has gained considerable depth from its ties with industry and through international cooperative projects. There are two specific research projects with Italy and Mexico. Cooperation of this nature and several colleague-to-colleague research projects are an important element of the Stanford Geothermal Program. They provide a wider spectrum of field experience and augment data with which to test new ideas, theory and experiment.

The successful completion of the objectives of the Program depends on significant help and continuing support by members of the industry, various federal agencies, national laboratories and university programs. Their names are acknowledged in the preface of the Workshop Proceedings and in the Appendices to this progress report.

The major financial contribution to the Stanford Geothermal Program is the Department of Energy through this contract. 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. Horne
William E. Brigham
Frank G. Miller
Jon S. Gudmundsson

INTRODUCTION

The Stanford Geothermal Program in fiscal year 1982 was divided into six task areas as defined in the Department of Energy contract. Tasks 1–2 were carried out within the Civil Engineering Department and Tasks 3–6 within the Petroleum Engineering Department.

Task 1. Heat Extraction from Hydrothermal Reservoirs The long-term commercial development of geothermal resources for power production will depend on optimum heat extraction from hydrothermal resources. The work in this task has 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.

Task 2. Noncondensable Gas Reservoir Engineering Radon and other noncondensable gases in geothermal fluids can be used as natural in-situ tracers for assessing thermodynamic conditions and structural features of geothermal reservoirs. Measurements of radon mass transients have been shown to be a complementary method to pressure transient analysis in single- and two-phase geothermal reservoirs. Current work in this task aims at relating radon measurements to two-phase conditions in reservoirs through analysis of noncondensable gas partitioning during two-phase flow to the wellhead. The results should be useful for assessing the potential for thermodynamic changes during production and the effect of recharge and structural features of the reservoir on future production.

Task 3. 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 at Stanford during the year. Work in this task included projects on the effect of slotted liners on well testing, and the relationship between thermal and hydraulic transients in fractured systems. Such systems and reservoirs that produce from two-phase conditions are of great interest at Stanford and were investigated by considering flashing two-phase flow in fractures.

Improving understanding of the physical processes occurring in geothermal reservoirs has always been an important objective of this Program. A balance between theoretical and experimental studies has been sought. The goal has been to develop new methods for observing reservoir behavior and to test these in the field. Bench-scale experiments are carried out to determine fundamental flow characteristics of fluids and to provide a balanced university-based research. Three main pieces of equipment are involved: a large core and a small core permeameter, and BET adsorption apparatus. Work on this task included further studies of relative permeability functions which are needed for simulation of geothermal reservoirs.

Tasks 4 and 5. Cooperative Agreements The Stanford Geothermal Program takes part in several cooperative projects through both formal and informal agreements. The main objective of these agreements is the application and testing of new and proven reservoir engineering technology using nonproprietory field data and geothermal wells made available by cooperating field developers. Stanford has two formal cooperative agreements with foreign agencies. These are the DOE-ENEL cooperation with Italy, and Stanford-IIE cooperation with Mexico. The interaction between academic research and field applications has proved valuable in both of these tasks.

Task 6. Workshop and Seminars Technology transfer is the main purpose of this task. As more people become involved in the exploration, development and production of geothermal energy, the need for dissemination of reservoir engineering knowledge and information becomes greater. The annual Workshop on Geothermal Reservoir Engineering has been held at Stanford University since 1975. The Workshop is attended by more than 100 scientists and engineeers actively involved in geothermal energy developments in the U.S. and worldwide. Weekly geothermal energy Seminars are held at Stanford throughout the academic year. The Seminars are open and are attended by Stanford faculty and students, and individuals from geothermal companies and institutions in the San Francisco area.

The appendices to this annual report describe some of the activities of the Stanford Geothermal Program that result in interactions with the geothernal community. These occur in the form of technical reports, presentations at technical meetings, and publications in the open literature. The following presents more detailed accomplishments of the program from October 1981 through September 1982.

TASK 1. HEAT EXTRACTION FROM HYDROTHERMAL RESERVOIRS

The Stanford Geothermal Program since its inception in 1972 has had as one of its major tasks the development of a simple means to estimate the heat extraction potential from fractured hydrothermal systems. It is evident that long-term commercial development of geothermal resources will depend on adequate heat extraction. The ability to estimate heat extraction potential from geologic information and rock thermal properties is especially important in the early reservoir definition of a prospective new field. The effort in the Stanford Geothermal Program has been a combination of physical and mathematical modeling of heat extraction from fractured geothermal reservoirs. Experiments have involved several rock loadings in the SGP physical model of a rechargeable hydrothermal reservoir with comparative testing of alternate modes of heat and fluid production. The results are leading to a useful mathematical means to evaluate the heat/fluid extractability in full-size geothermal resources.

During the recent preceding years, several advances have been achieved, such as the development of a simple, lumped-parameter heat extraction model to evaluate the potential for recharge-sweep production of geothermal reservoirs. This model built on the studies of Hunsbedt et al. (1975) in developing the original model, Kuo et al. (1976) in correlating shape factors for single, irregular-shaped rocks, and Iregui et al. (1978) in extending the concept of a single, equivalent radius sphere for an assembly of reservoir-shaped rocks. These efforts resulted in the 1-D sweep model reported by Hunsbedt et al. (1979) which examines a hydrothermal rock system with cold water reinjection using the single spherical-rock concept of "effective radius" as the heat source and "number of heat transfer units" (NHTU) as the heat extraction parameter.

Current efforts in the program are focused on improving the one-dimensional heat extraction model and to perform a more detailed study of the physical model using a numerical reservoir simulator with a rock loading of known geometric shape. During the current year, progress was achieved in two directions: (1) completion of three heat extraction experiments with the regular-shaped rock loading and completion of a no-production cool-down run to model the steel reservoir heat loss, and

(2) application of the l-D model and the LBL numerical model to analyze the experimental data.

(a) Heat Extraction Experiments

The SGP physical model of a fractured hydrothermal reservoir has been described previously, e.g. Hunsbedt, Kruger, and London (1977, 1978). The main component is a 5 ft high by 2 ft diameter insulated pressure vessel rated at 800 psig at 500°F. The rock loading matrix consists of 30 granite rock blocks of 7.5-inch x 7.5-inch rectangular cross section and 24 triangular blocks in the vessel, as shown in Figure 1-1. The blocks are 10.4 inches in height. The average porosity of the rock matrix is 17.5 percent. Vertical channels between blocks are spaced at 0.25 inch and horizontal channels between layers are spaced at 0.15 inch. The water and rock center temperatures are measured at several locations. The distribution of thermocouples in the bottom (B) plane, middle (M) plane, and top (T) plane is shown in Figure 1-1.

Cold water is injected at the bottom of the vessel by a high pressure pump through a flow-distribution baffle at the bottom. During the experiment, system pressure is maintained above saturation by a flow control valve downsteam of the outlet. Most of the system pressure drop is in this valve. Thus the rock matrix can be considered to have essentially infinite permeability. Significant vertical flow can also occur in the relatively large edge channels between the outer rock blocks and the pressure vessel.

Four experiments have been run with the regular-shaped rock loading: three heat extraction experiments at various production times to cover a range of the number of heat transfer units parameter and one with no production to calibrate the cool-down rate of the system with the current rock loading. In each of the three heat extraction experiments, the rock-water-vessel system was heated to the uniform initial temperatures by electric strap heaters wrapped outside the vessel. The experiments were initiated by starting the injection pump and opening the flow control valve. The injection rate was constant during the experiments. A summary of the data for the experimental conditions and parameter values for the three experiments is given in Table 1-1. Experimental Run 5-2 is noted to be for a flowrate about three times

Symbol	Description	Quantity
o	Water	24
a	Rock	6
▽	Water inlet/outlet	2
O	Metal	6

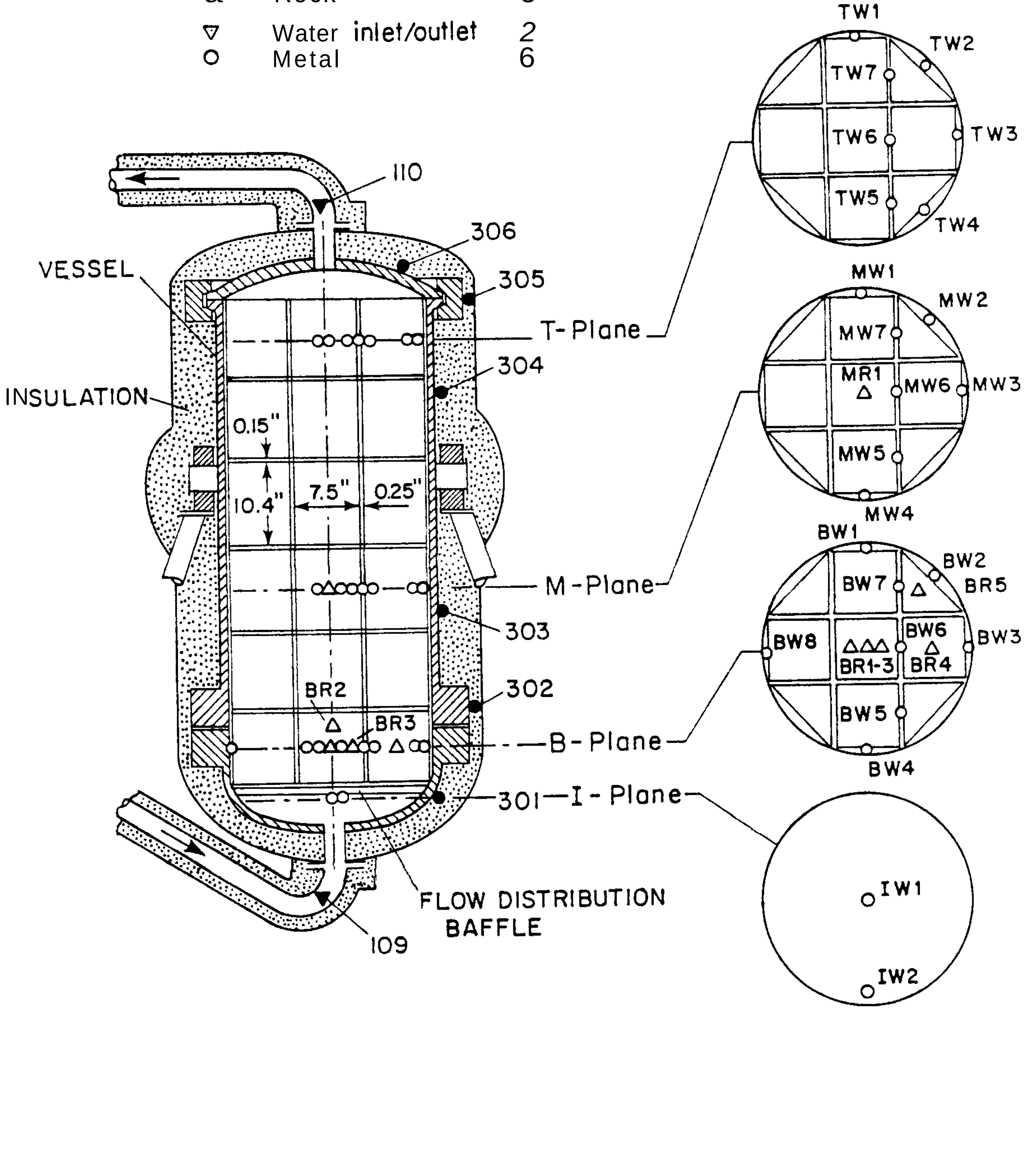

FIG. **1–1:** EXPERIMENTAL ROCK MATRIX CONFIGURATION **AND** THERMOCOUPLE LOCATIONS that for Run 5–1 while the water flow of Run 5–3 was for about one-half that of Run 5–1.

Table 1–1

EXPERIMENTAL DATA AND PARAMETERS

	Heat Extraction Experiment		
	5–1	5–2	5–3
Average Reservoir Pressure (MPa)	3.8	3.8	3.8
Initial Reservoir Temperature ("C)	239	220	220
Final Water Temperature at Top ("C)	156	125	141
Final Water Temperature at Bottom (°C)	19	20	28
Injection Water Temperature ("C)	15	15.6	18.3
Injected Water Mass (kg)	340	341	330
Water Injection Rate (kg/hr)	68	227	31.4
Production Time (hr)	5	1.5	10.5
NHTU Parameter (dim. less)	7	2	15

For the calibration experiment, the system was heated to a uniform temperature of about 242°C *(468°F)*. Temperature and pressure data were recorded as the system cooled down as a result of heat loss through the vessel insulation and through metal objects protruding from the vessel. The vessel isolation valves in the inlet and outlet lines of the vessel were closed during this experiment.

(b) Experimental Results

Measured water and rock temperature data for the three heat extraction experiments are given in Figures 1–2 to 1–4. The locations of the measurement planes are indicated in Figure 1–1. The temperature of the water entering from the distribution baffle below the rock matrix, indicated by thermocouples IW1 and IW2, decreases approximately exponentially from temperature levels near the initial matrix temperature to the injection water temperature indicated by thermocouple 109. The inlet water temperature appears to be relatively uniform in all experiments except for experiment 5–2 (Figure 1–3). The maximum temperature difference between water entering the rock matrix at the bottom is about 38°C (100°F). This large nonuniformity in entering water temperature is

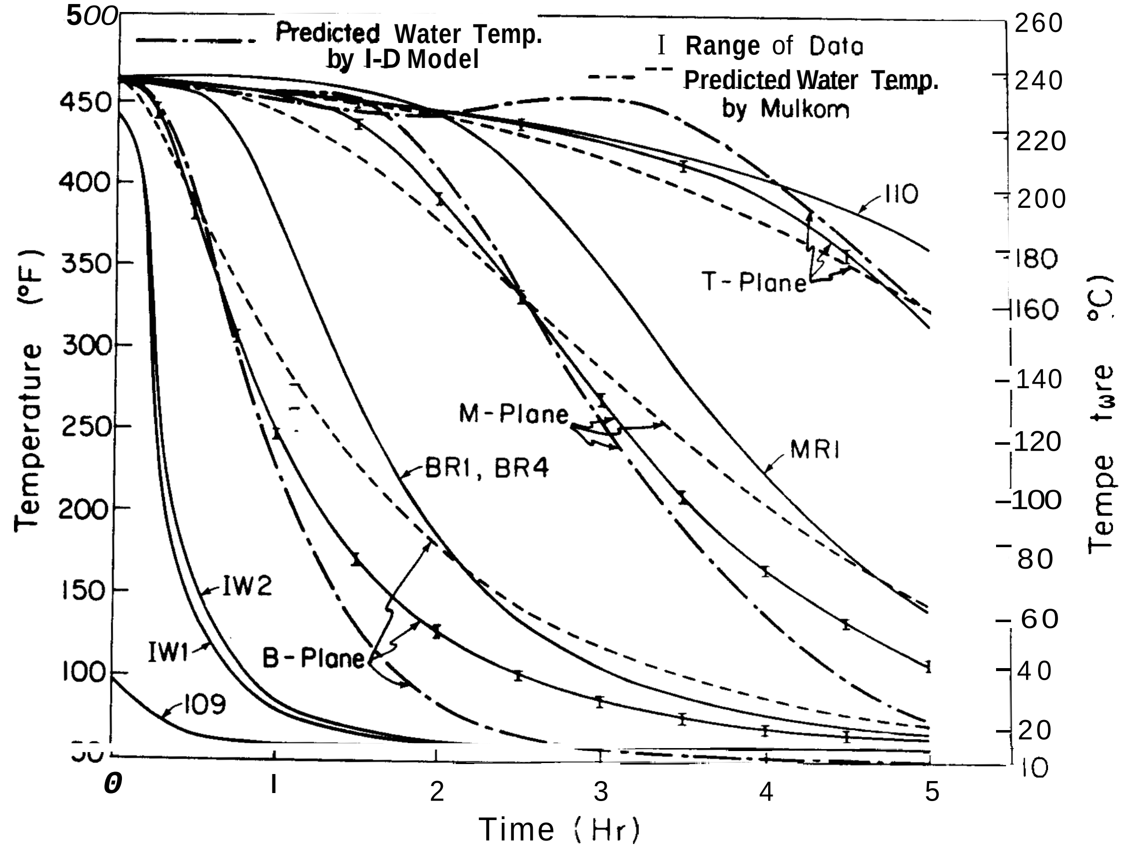

FIG. 1-2: WATER AND ROCK TEMPERATURES TRANSIENTS FOR EXPERIMENT 5-1

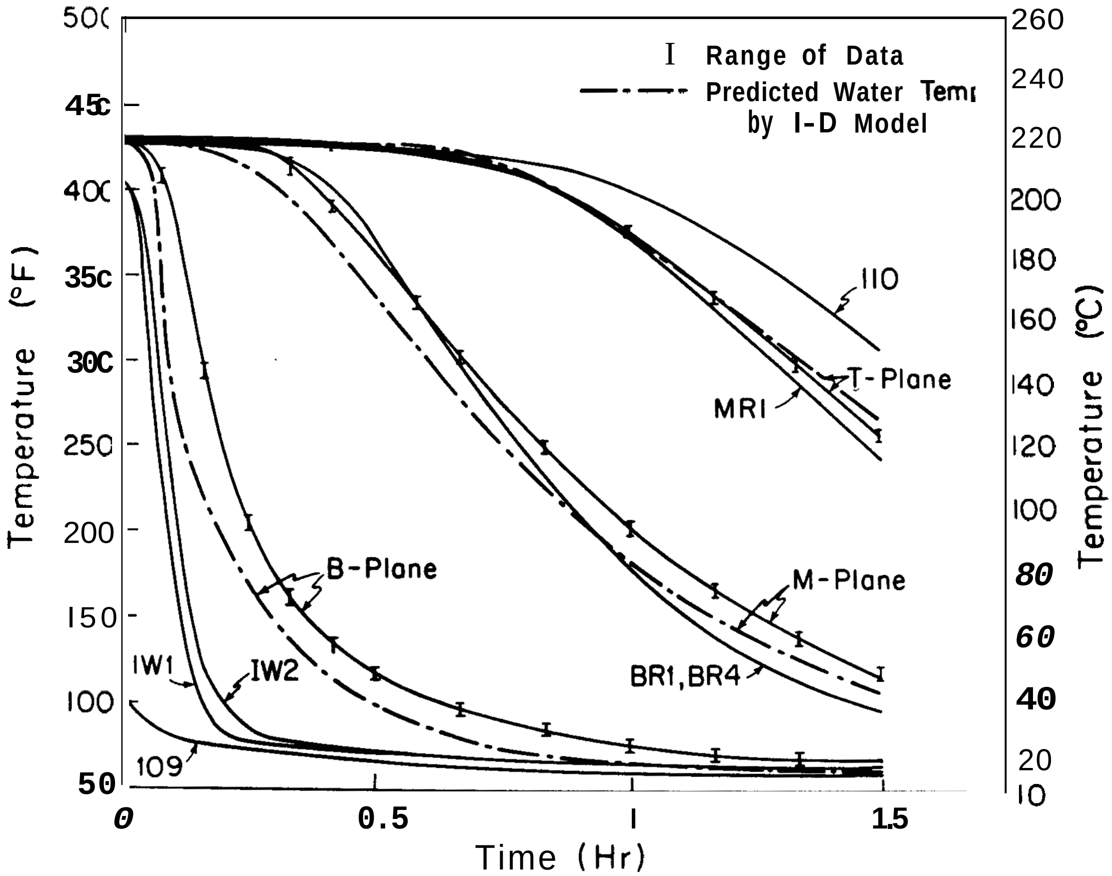

FIG. 1-3: WATER AND ROCK TEMPERATURE TRANSIENTS FOR EXPERIMENT 5-2

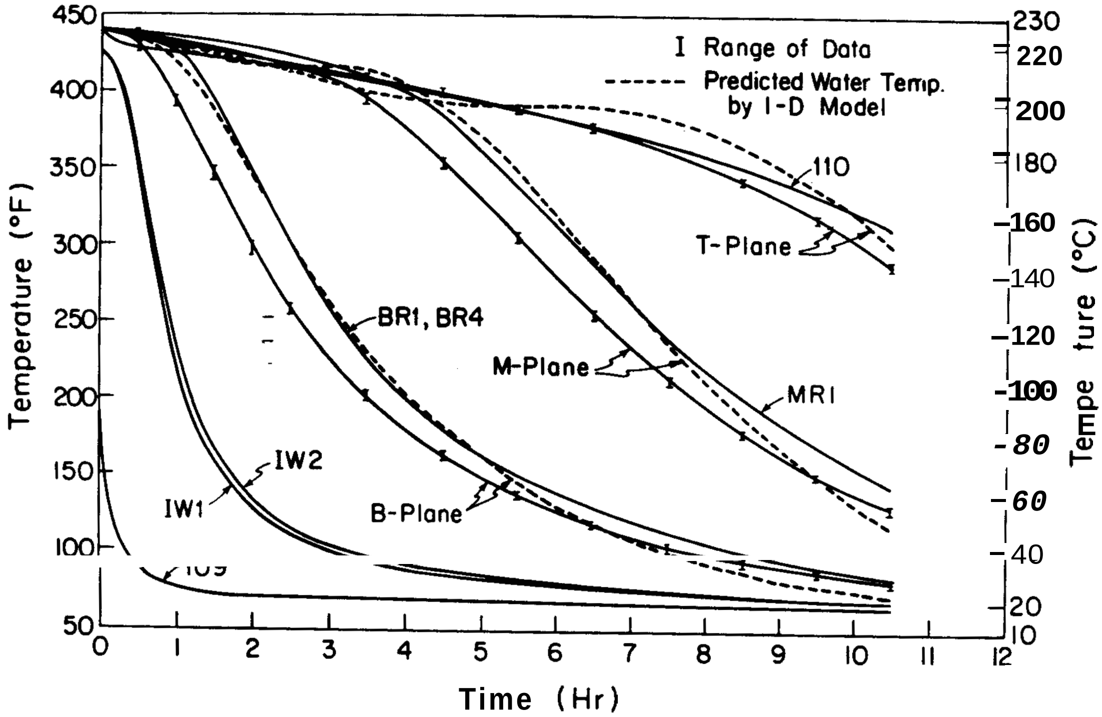

FIG. 1-4: WATER AND ROCK TEMPERATURE TRANSIENTS FOR EXPERIMENT 5-3

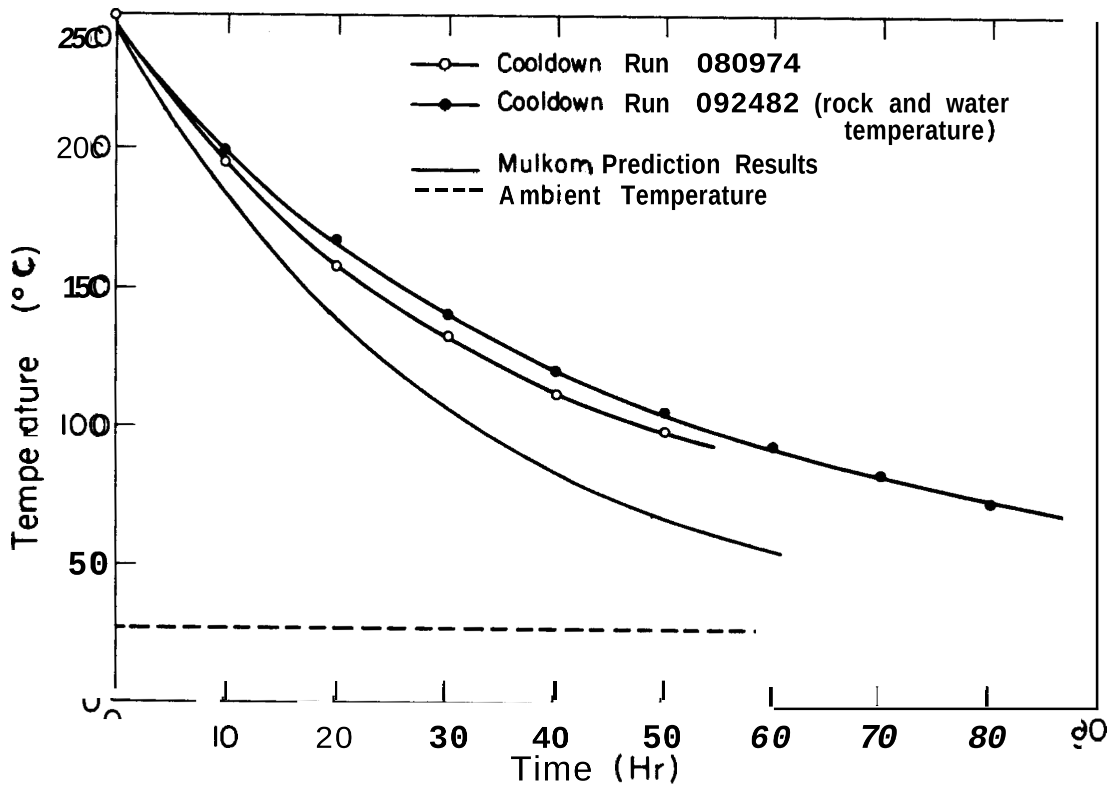

FIG.1-5: AVERAGE VESSEL TEMPERATURE TRANSIENTS FOR CALIBRATION EXPERIMENT

probably caused by the higher heating rate from the steel vessel lower head and flanges when cooled more rapidly by the higher water flowrate.

The water temperature distribution in the other three measurement planes were observed to be quite uniform. The maximum temperature difference or range of water temperature data was usually less than 5°C (9°F). The water temperatures given in the figures for the B-, M-, and T-planes are the averages of all thermocouples in each plane. Since the uncertainty interval of the temperature measurements is estimated to be 3°C (5°F), it is concluded that water temperatures in the various flow channels appears to be virtually uniform, indicating good cross mixing between flow channels.

The effect of water flowrate on rock-to-water temperature differences is also indicated in Figures 1-2 through 1-4. The maximum temperature difference developed was about 150°C (270°F) for experiment 5-2 with the highest water flowrate to 28°C (50°F) for experiment 5-3 with the lowest flowrate. The maximum temperature difference occurred in the bottom plane that experiences the highest cooldown.

Although high rock-to-water temperature differences result in higher rates of heat extraction from the rock, insufficient heating of the water may result in premature drop in produced water temperatures for high water flowrates. In that case much of the energy stored in the rock is not utilized. The premature drop in produced water temperature as a function of water flowrate is not clearly illustrated in the experimental results because of the effects of total heat losses from the vessel which are much larger for experiment 5-3, lasting for about 10.5 hr as compared to experiment 5-2, lasting only 1.5 hr. The steady drop in produced water temperature in Figure 1-4 is caused by greater vessel insulation heat losses to the environment because of the longer time period involved.

Mathematical modeling of the experimental system requires accurate data of this heat loss term as a function of production time. The low flowrate experiments last for longer time periods, and the heat loss term becomes a more important factor in the heat balance equation relative to the rock heat extraction term. Data from the calibration cooldown experiments are expected to reduce the uncertainty in the net heat extraction from the rock matrix. Average water and rock temperatures inside the vessel for the calibration experiment are given in Figure 1-5. The data are compared to the average water temperature data obtained from an earlier experiment. The agreement between these two experiments is very good, and the difference is probably due to the difference in volumetric heat capacity of the steel/rock loading in the two tests.

(c) Numerical Modeling

The results of these heat extraction experiments are being examined with a distributed parameter model (Pruess and Schroeder, 1980). All important processes involved in the thermal sweep model are represented: (1) upflow of water through the void spaces in the vessel, (2) heat conduction in the rocks, *(3)* heat transfer from the rock blocks to the water, *(4)* heat transfer between water and the walls of the vessel, (5) heat conduction in the walls, and (6) heat transfer between the walls and the surroundings.

The basic computational mesh is shown in Figure 1-6, which also indicates the major subdomains to be treated in the modeling effort. The main portion of the mesh is a two-dimensional r-z system, with additional irregularly shaped grid blocks employed to represent the zones at the top and bottom of the vessel, respectively. The interior of the vessel (rock loading and water in the voids) is represented by a one-dimensional column of 30 disk-shaped elements (5 per layer). This column is surrounded by two columns of concentric rings, which represent the vessel wall and the (ambient) boundary conditions, respectively. Each interior element is further sub-partitioned into a one-dimensional string of 4-8 elements, so that heat conduction from the interior of the rock blocks to the surfaces, and subsequent heat transfer to the invading cold water, can be modeled in quantitative detail. The sub-partitioning is based on the method of "multiple interacting continua", or MINC, as developed by Pruess and Narasimhan (1982). Specific details on the mesh generation methodology are described by Pruess and Karasaki (1982).

Calculations were carried out with Lawrence Berkeley Laboratory's geothermal simulators SHAFT79 and MULKOM (Pruess and Schroeder, 1980).

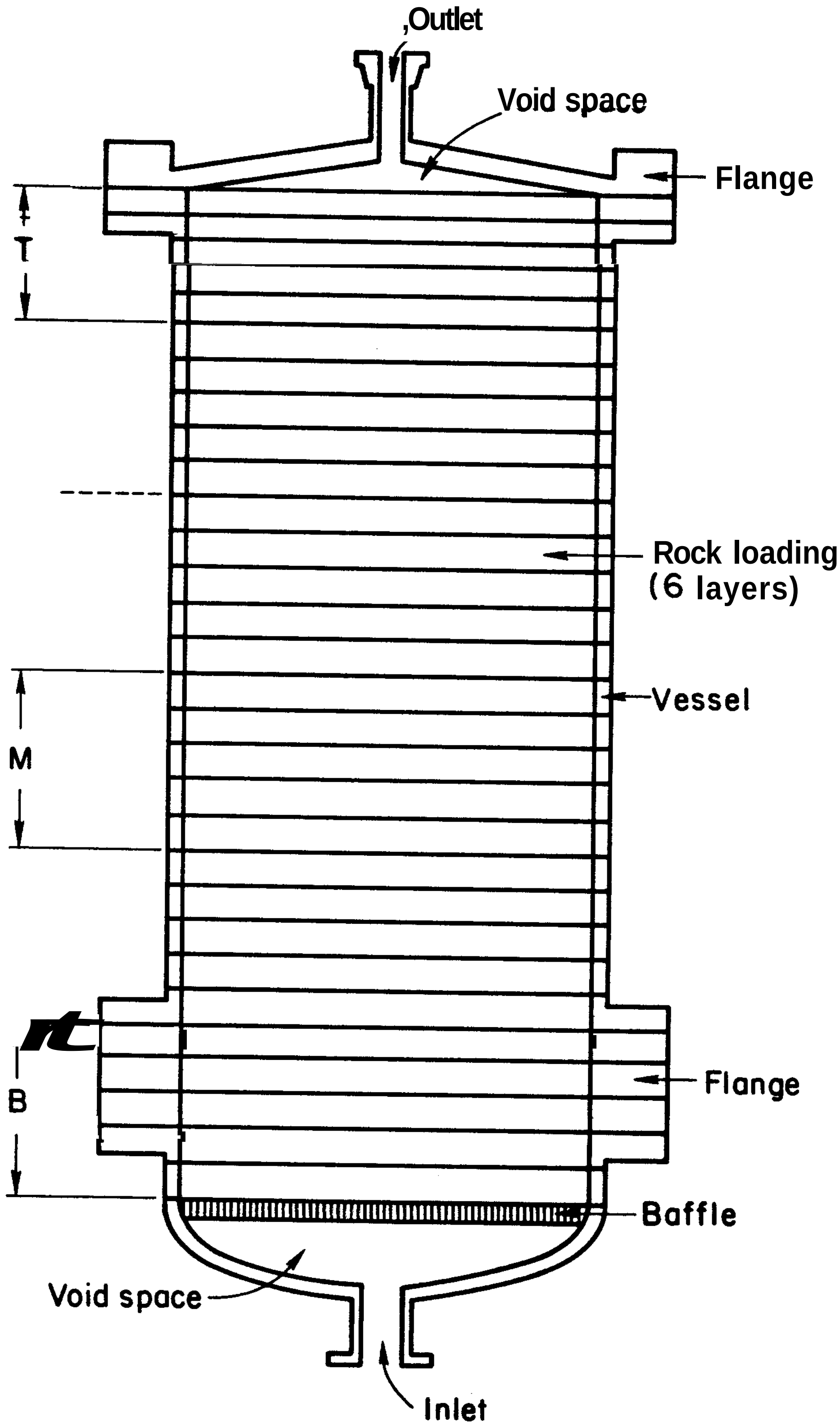

FIG. 1-6: BASIC COMPUTATIONAL MESH OF THE EXPERIMENTAL SYSTEM

These simulators feature an accurate representation of the thermophysical properties of water substance (International Formulation Committee, 1967). Handbook values were used for the thermal parameters of the steel vessel and the rock loading. Figure 1-2 shows the comparison of the simulated temperature transients with the experimental measurements for run 5-1. The overall agreement is rather good, considering that no adjustments were made in the parameters employed in the simulation. The largest discrepancies occur for the bottom layer (B-plane in Figure 1-2), and are probably due to too coarse discretization near the cold water inlet. Temperatures in the M-plane agree better, with the simulation predicting a somewhat too broad distribution. The best comparison is obtained near the top (T-plane).

These results are certainly encouraging, and improvements in various details of the model to obtain a better match of the experiments are in progress. These efforts focus on: (1) improving the computational mesh to more faithfully represent the physical model, and (2) checking on the thermal parameters of the system components. The simulation shows that heat transfer from the steel vessel to the injected water is of the same order of magnitude as heat transfer from the rocks. Therefore, heat conduction in the vessel walls and heat loss to the surroundings must be modeled with a high degree of accuracy. Work is in progress to adjust the heat loss term in the numerical model. It is evident from the predictions given in Figure 1-5 for the cooldown experiment using the present numerical model that model heat losses are greater than actual physical system heat losses. Once the heat loss term has been adjusted the calculations should be sufficiently sensitive to the rock-water heat transfer to allow quantitative testing of the approximations made in the MINC-method.

The heat extraction experiments were also modeled using the one-dimensional cold-water sweep model. The rock geometry in this model is represented by uniform size spheres with an equivalent diameter resulting in heat transfer characteristics that are similar to those of the actual rock configurations (Iregui et al. 1978).

The predicted water temperatures in the three planes are compared to measured temperatures in Figures 1-2 through 1-4 for experiments 5-1 through 5–3, respectively. The comparisons show that the predicted temperatures are generally higher than the experimental temperatures during early times but tend to drop more rapidly at later times. However the prediction for experiment 5-2 with the highest injection rate is generally in better agreement with the experimental data, the predictions being generally lower than the experiment. This difference is being evaluated and is believed to be associated with the lumping of the vessel steel with the rock.

TASK 2. NONCONDENSABLE GAS RESERVOIR ENGINEERING

The projects underway in the current year were (1) emanation studies from graywacke rock, (2) analysis of the Serrazzano, Italy radon transects, and (3) analysis of the Cerro Prieto radon transects. The first two of these projects were completed during the current year and resulted in the following publications: "Radon Emanation Mechanism from Finely Ground Rocks", issued as SGP TR-63, by Kazuichi Satomi and Paul Kruger and "Interpretation of Radon Concentration in the Serrazzano Zone of the Larderello Geothermal Field", prepared by Lewis Semprini and Paul Kruger in cooperation with Franco D'Amore of CNR - Istituto Internazionale per le Ricerche Geotermiche, Pisa, Italy, for presentation at the Eighth Annual Stanford Geothermal Program Workshop on Geothermal Keservoir Engineering. Progress in the third project is proceeding satisfactorily, the current work on the time changes in noncondensable gas contours across the field were reported as "Relationship of Radon Concentration to Spatial and Temporal Variations of Reservoir Thermodynamic Conditions in the Cerro Prieto Geothermal Field" by Lewis Semprini and Paul Kruger at the Fourth Symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico. This paper was revised for publication in Geothermics.

(a) Emanation Studies

Kadon emanation from porous graywacke sandstone rock particles was measured under various reservoir conditions. Experiments were carried out to observe the dependence of emanation power on effects of annealing, rock size, and moisture content. The data were analyzed to determine the relative importance of recoil and diffusion processes for radon emanation from porous rock particles.

The annealing effect, associated with curing of crystal imperfections in a rock matrix, was quite small for the graywacke sandstone. The moisture effect, associated with water adsorbed on the rock pore surface, was much more pronounced. The magnitude of the effect was calculated from the results of emanation measurements under wet and dry conditions in the test reservoirs.

The effect of rock size was quite pronounced for small particle sizes. Emanation power from particles of diameters less than 300 µm showed steep increases with decreasing diameter. The dependence was inversely proportional, a function of $d^{1.5}$ for water and $d^{1.0}$ for nitrogen. Radon emanation from particle sizes larger than 300 µm in diameter showed less dependence on rock size. The effect is attributed to increases in surface area between particle and grain sizes created during crushing. The data are not sufficiently clear to show a specific relationship based on grain size.

The data from the moisture tests indicated that water adsorbed on the rock pore surface could account for much of the radon emanation. Emanation power increased rapidly with increased addition of water vapor to the rock samples to a vapor pressure of 40% of the saturation vapor pressure. This value may correspond to the minimum thickness of a water layer on the rock surface which can absorb the kinetic energy of recoil radon atoms and stop them in the pore space. In the absence of adsorbed pore water, recoil radon atoms can penetrate into neighboring grains without contributing to the emanation power.

Diffusion coefficients for radon gas were calculated from the experimental data and from a mathematical model. The agreement was satisfactory. Calculated values were of the order of 10^{-10} to 10^{-11} cm2/sec for dry samples. The effects of moisture on diffusion could not be accounted for, and the diffusion coefficients calculated under wet conditions were about ten times larger, ranging from 10^{-9} to 10^{-10} to cm^2/sec.

A conceptual model of the emanation power in porous rock particles, where the granular pore surface is large compared to the particle surface area indicates that direct recoil to the pore space should be the most important process.

(b) Serrazzano Transect Data Analysis

Wellhead concentrations of radon were made at 22 wells in the south-west region of the Larderello geothermal fields by two analytical methods, a field measurement as reported by D'Amore (1975) and laboratory measurement as reported by Semprini and Kruger (1981). Agreement between the two methods was satisfactory.

The radon concentrations were correlated with average specific volume of superheated steam for each well estimated from available thermodynamic parameters of the reservoir. The correlation was improved by adjusting the specific volume of steam by a mass steam saturation value calculated at the boiling front from chemical fluid composition for each well by a method developed by D'Amore and Celati (1983). A compressible flow model for radon transport developed by Sakakura et al. (1959) was also tested.

The results confirm that radon behavior in geothermal systems is characterized by thermodynamic conditions in the reservoir. In the Serrazzano zone, abnormally high values of radon concentration with respect to estimated specific volume in four of the 22 wells were observed an area of proposed low permeability. The high values may also result from higher emanating power or lower porosity in this zone. A cross-section normal to the zone of low permeability between the two basins shows a similar radon profile as noted in a Geysers production zone.

A comparison of these data with the set obtained in 1976 by D'Amore (1975) shows relatively constant radon concentration despite several wells having large variations in gas/steam ratios.

(c) Cerro Prieto Transect Data Analysis

Measurements of radon concentration in geothermal fluids at Cerro Prieto were evaluated with respect to spatial and temporal variations in reservoir thermodynamic conditions and the rock to fluid mass ratio for radon emanation. Higher concentration of radon observed at wells with higher fluid enthalpy can be attributed to the higher steam fraction in the reservoir fluid. Regression analysis of radon concentration with specific volume of pore fluid shows a significant degree of correlation, resulting from the dependence of specific volume on both two-phase conditions and reservoir temperature. Temporal variations in radon concentration reflect changing phase conditions in the reservoir. Observations over a two-year interval show significant changes in the producing zones. The constant, low concentration along the western edge of the field indicates a fluid of low steam saturation. In the eastern area, radon concentrations have increased significantly suggesting an increase in the steam saturation in this part of the reservoir due to exploitation. Other areas, e.g., the southeast area, show decreased radon concentration, indicating a decrease in steam saturation. Concurrent measurements of ammonia, a soluble component of the noncondensable gases, support the observations of partitioning of gas components, with wellhead concentration dependent on spatial variations in steam saturation over the field.

TASK 3. WELL TEST ANALYSIS AND BENCH-SCALE EXPERIMENTS

3.1 Well Test Analvsis

(a) Inertia and Friction in the Flow Period of a Drill-Stem Test, by Miguel Saldana-Cortez, research assistant, and Professor Henry J. Ramey, Jr.

For a long tine, drill-stem testing (DST) has been used as an early source of important information on well productivity. However, a comprehensive description of all the physical effects that are expected to be involved in a drill-stem test (DST) has not been presented yet.

Usually, only part of the pressure data recorded during a DST is considered for interpretation purposes. These pressure data correspond to the shut-in period and are basically analyzed with pressure buildup theory. This theory requires a knowledge of the flowrate behavior prior to the shut-in. There are two simplified techniques currently used for estimating flowrate behavior for DST shut-in pressure buildup analysis: (1) divide the total volume of oil recovered in the drill string by the duration of the flow period, or (2) read pressure behavior recorded during the flow period and evaluate fluid level change in the wellbore by using hydrostatic column calculations. Although the second technique is superior and is often used, it involves the assumption of hydrostatic equilibrium between fluid column and bottomhole pressure at all times and, therefore, dynamic effects, such as inertia and friction, are neglected during the flow period. Improved interpretation of pressure buildup data from a shut-in period of a DST should result if the effects of inertia and friction in the wellbore are included, and evaluated in the description of the corresonding flow period.

On the other hand, since the characteristics of the wellbore-reservoir system affect the response of the flow of fluid from the reservoir into the wellbore, the possibility of designing a test and performing an appropriate analysis of the pressure data from the flow period in a DST deserves study because quantitative information on reservoir properties and on wellbore condition may be obtained from these data.

Therefore, understanding the dynamic phenomena during the flow period of a DST can: (1) improve the application of pressure buildup analysis methods to the shut-in period of a DST, and (2) perhaps permit interpretation of DST flow period pressure data to estimate reservoir properties and well conditions.

In this study, a mathematical description of the physical phenomena during the flow period in a DST has been formulated. This formulation includes inertial and frictional effects in a realistic wellbore geometry. A solution method for the resulting mathematical problem has been developed to calculate the behavior of pressure, flowrate, and level, velocity and acceleration of the liquid column in a wellbore.

Figure 3-1 is an example of pressure and liquid level solutions for a typical case with dimensionless wellbore storage constant (C_D) of one thousand, wellbore damage (s) of zero, and a value of one thousand for the dimensionless group of parameters (a) that Shinohara and Ramey (1979) found to control the inertial effects in the wellbore. In the same figure, the combined effect of inertia and friction is illustrated for several values of the dimensionless group of parameters (8) that the present study proposes to be responsible for the magnitude of frictional losses during the flow period of a DST.

Analysis of the results obtained in this study has indicated that the magnitude of inertial and frictional effects can vary from negligible to completely dominant during the flow period of a DST, depending on the wellbore-reservoir characteristics. Moreover, since the flow phenomena is being analyzed in terms of dimensionless parameters, the actual reservoir properties and wellbore characteristics that have an effect on inertia and friction have been identified from the definition of the parameters a and β.

Figure 3-2 shows a correlation of $C_D \dot{z}_{Dmax}$ vs $a2/C_D^2$ for s = 0, 20, and 100 and C_D = 1 and 10^{10}. In this correlation $\dot{z}_{Dmax}$ is the maximum value of dimensionless liquid velocity, which is directly related to flowrate. Since friction losses are expected to depend on velocity, correlations of this type are being developed to obtain criteria for estimating practical conditions under which inertial and frictional effects are negligible, moderate, or dominant on the flow response of any particular flow period of a DST.

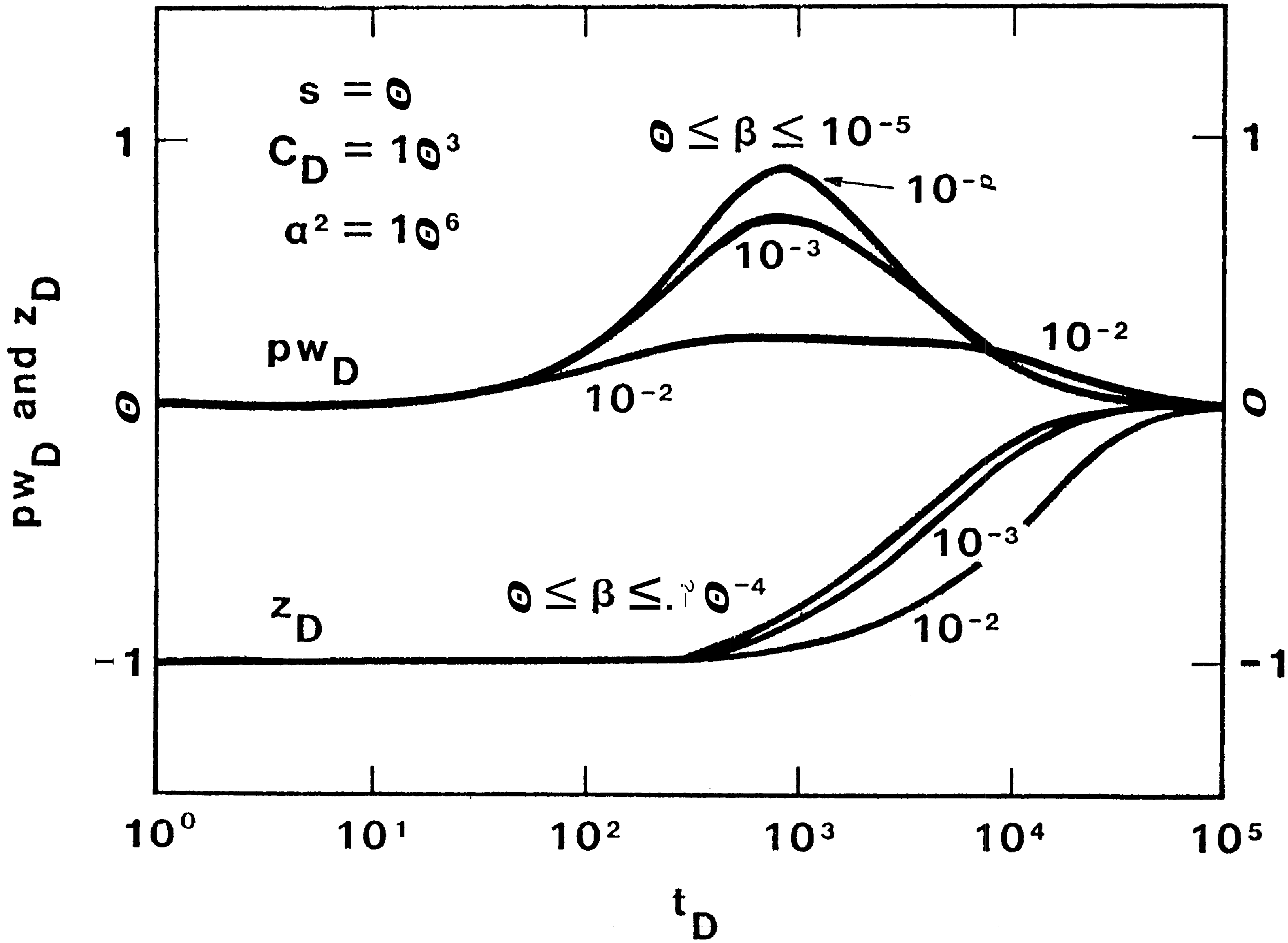

FIG 3-1: COMBINED EFFECT OF INERTIA AND FRICTION ON PRESSURE AND LIQUID LEVEL IN WELLBORE

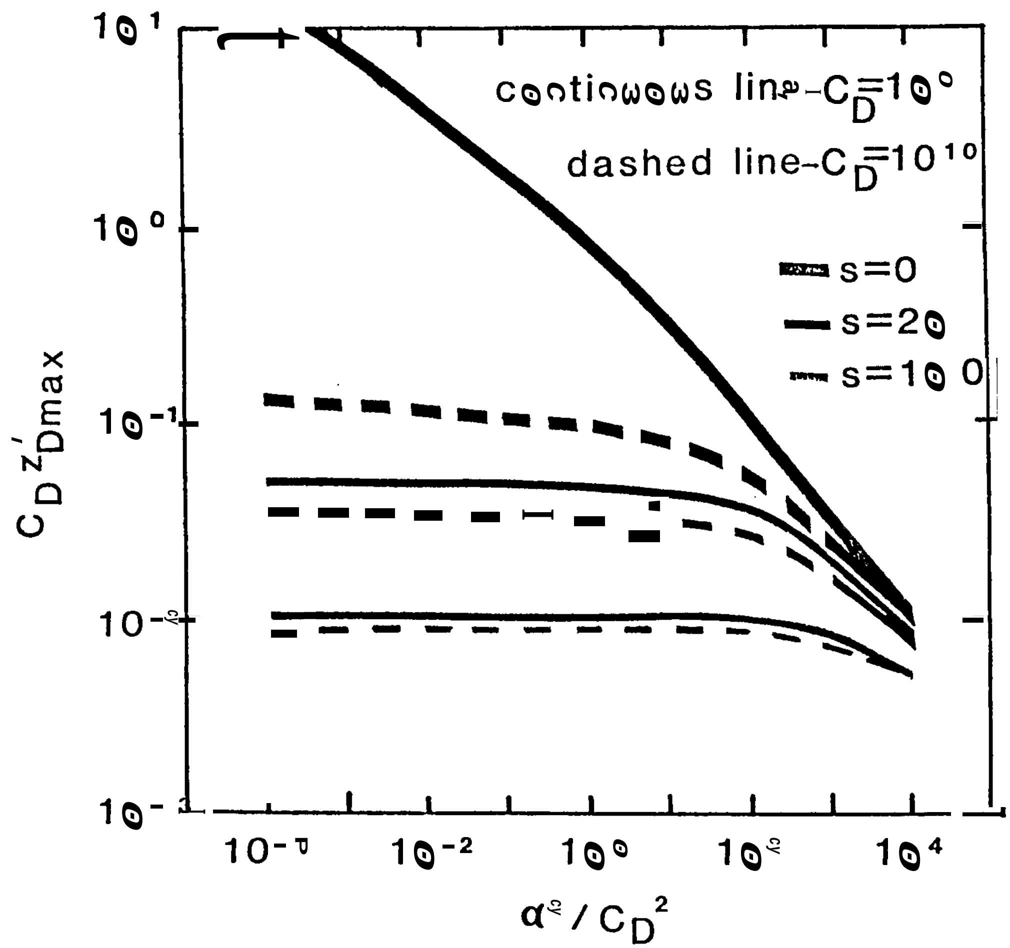

FIG 3-2: EFFECT OF INERTIA ON MAXIMUM DIMENSIONLESS LIQUID VELOCITY IN WELLBORE

(b) Effect of a Slotted Liner on Pressure Transients, by David Spivak, research assistant, and Professor Roland N. Horne.

Geothermal wells are usually completed with a slotted liner to prevent formation collapse. Despite the widespread use of this completion method, well test analysis techniques used for geothermal well tests assume that the well is a line source or cylindrical source. The object of this project was to evaluate the impact of this assumption when flow into the well is into several separate slots rather than a uniform cylindrical body.

The transient behavior of production from a well with a slotted liner has been solved analytically by the source function method. The unsteady-state pressure response was examined as a function of slot frequency, slot length and penetration ratio of 0.5. Slots were represented as line slots of zero width. The results indicate that due to limited entry into the well, pseudo skin effects appear. However, the effects become negligible when the number of slots distributed around the circumference of the liner is six or more. For more than six slots, the well behaves effectively like a continuous surface cylindrical source (or a line source well, depending on time and location). This is shown in Figure 3-3.

This work concludes that there is likely to be little reduction in flow efficiency in an ideal slotted liner completion, unless some slots are clogged. In addition the effect of the length of the slots was examined and found to have little effect.

This work was presented at the 1982 California Regional Meeting of the Society of Petroleum Engineers (Spivak and Horne, 1982), and has been accepted for publication in Journal of Petroleum Technology. It has also been issued as a technical report SGP-TR-52.

(c) Heat Transfer in Naturally-Fractured Systems by John D. G. Moody, research assistant, and Professor Roland N. Horne.

This study considered the heat and fluid flow characteristics of an infinite, naturally fractured geothermal reservoir in which forced convection is the only form of heat transfer. For simplicity, it was assumed that there was only one injector well and no producer wells in

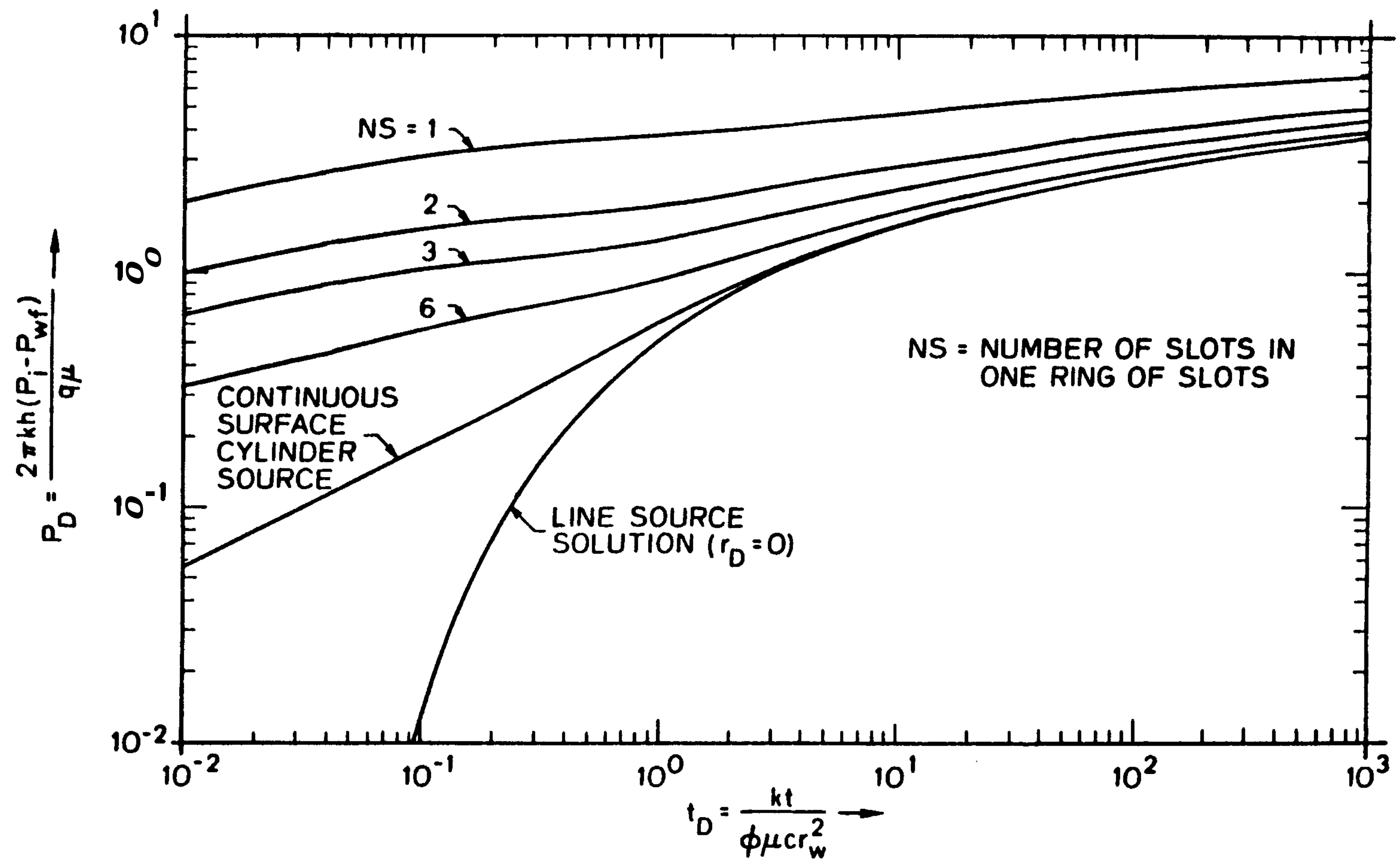

FIG. 3-3: DIMENSIONLESS PRESSURE DROP VS. DIMENSIONLESS TIME FOR A SLOTTED LINER WITH VARIOUS NUMBERS OF STAGGERED VERTICAL ROWS

the system. Further, primary porosity was neglected and the fracture porosity was assumed to be constant throughout the reservoir.

With these specifications, the governing equations were derived from an energy balance, and solved using dimensionless parameters and the Laplace transform. Both numerical inversion and analytical inversion were then used, though only the latter appeared to give a reliable solution. Typical results are plotted as dimensionless temperature versus dimensionless volume swept (called dimensionless radius) in Figure 3-4, and the velocity of the thermal front in the rock and water determined.

Assuming one injector well in an infinite, naturally-fractured geothermal reservoir, the results of this study apply for those times during which convection is the dominant form of heat transfer and fluid flow is steady state. The period therefore excludes very long and very short times.

Upon injection of water into the system, a thermal front quickly develops, and moves through the reservoir at a constant average rate. The thermal front velocity is less than that of the injected fluid for early times. Although at first the front spreads at an increasing rate, spreading gradually slows and eventually reverses itself. The rock and water temperature fronts approach each other at a dimensionless time of about 1000 and move at the same rate thereafter. For times much greater than this, the front moves with the fluid, and there is step-like displacement of heat in the reservoir. As there is no conduction, the radial velocity of the thermal front decreases with the radial velocity of the fluid, and in the limit approaches zero.

The problem presented in this report can be solved in a straightforward way using the Laplace transform. While numerical inversion routines are often of great value, analytical inversion appears to be the most reliable approach to a solution of this problem.

(d) Flashing Flow in Fractures by Anthony J. Menzies, research assistant, Professor Jon S. Gudmundsson, and Professor Roland N. Horne.

In fractured geothermal reservoirs, flashing can occur as the water flows toward the wellbore. The fluid entering the wellbore will then be

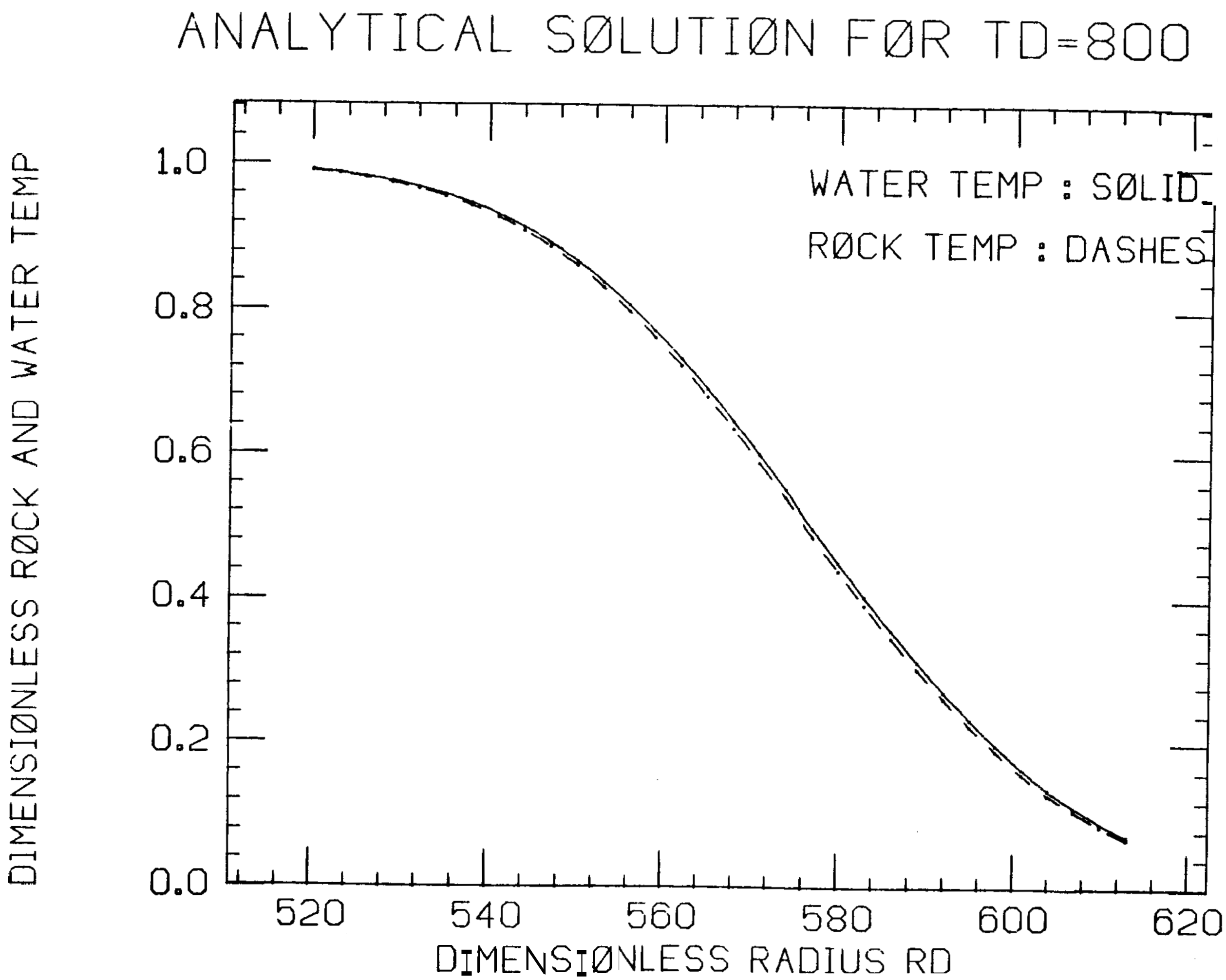

FIG. 3-4: TEMPERATURE DISTRIBUTION IN RADIAL FLOW IN A NATURALLY FRACTURED SYSTEM

a two-phase mixture. This mixture will in most geothermal wells enter through a major feedzone or fracture. Wells with flashing in the resevoir have flow characteristics (massflow and enthalpy vs. wellhead pressure) that indicate that some heat transfer takes place from the formation rock to the two-phase fluid. Well *403* in the Tongonan field in the Philippines shows typical characteristics of wells with two-phase feedzones (see Figure *3-5)*. The figure shows that the flowrate does not increase much when the wellhead pressure is lowered. This indicates that the well flow has reached some maximum value which depends on the nature of the reservoir-well system. The well flow is choked because lower wellhead pressure does not result in larger mass flow.

The two-phase flow streamtube model of Wallis and Richter (1978) which has been found to be valid for critical flow in pipes and nozzles, was modified and applied to flashing flow in fractures with heat transfer. Typical results from this modified steamtube model are illustrated in Figure *3-6*. The two-phase mass flux in the fracture increases with increasing pressure drop (difference between reservoir and feedzone pressure) as more liquid flashes and the mixture velocity becomes greater. Figure *3-6* also shows the total two-phase mixture enthalpy. The enthalpy depends on the degree of heat transfer from the formation rock to the two-phase mixture. The maximum mass flux (choked flow) decreases with increasing heat transfer.

The streamtube model has been used to calculate the flow characteristics of well *403* in the Tongonan field. Using the two available downhole (feedzone) pressures and the associated mass flow and enthalpy, the model calculations were matched with the field data by assuming that the two-phase mixture flashed with some heat transfer (isentropic efficiency 0.987) from the formation rock to the mixture. The calculated results are shown in Table *3-1* and in Figure 3-7. Model calculations have also been compared with field data from Koosevelt Hot Springs in Utah and the Krafla field in Iceland. The results have been encouraging.

By using the modified streamtube model, it was possible to study the flashing process in fractured geothermal reservoirs. The results indicate that flashing in two-phase feedzone wells may be in general

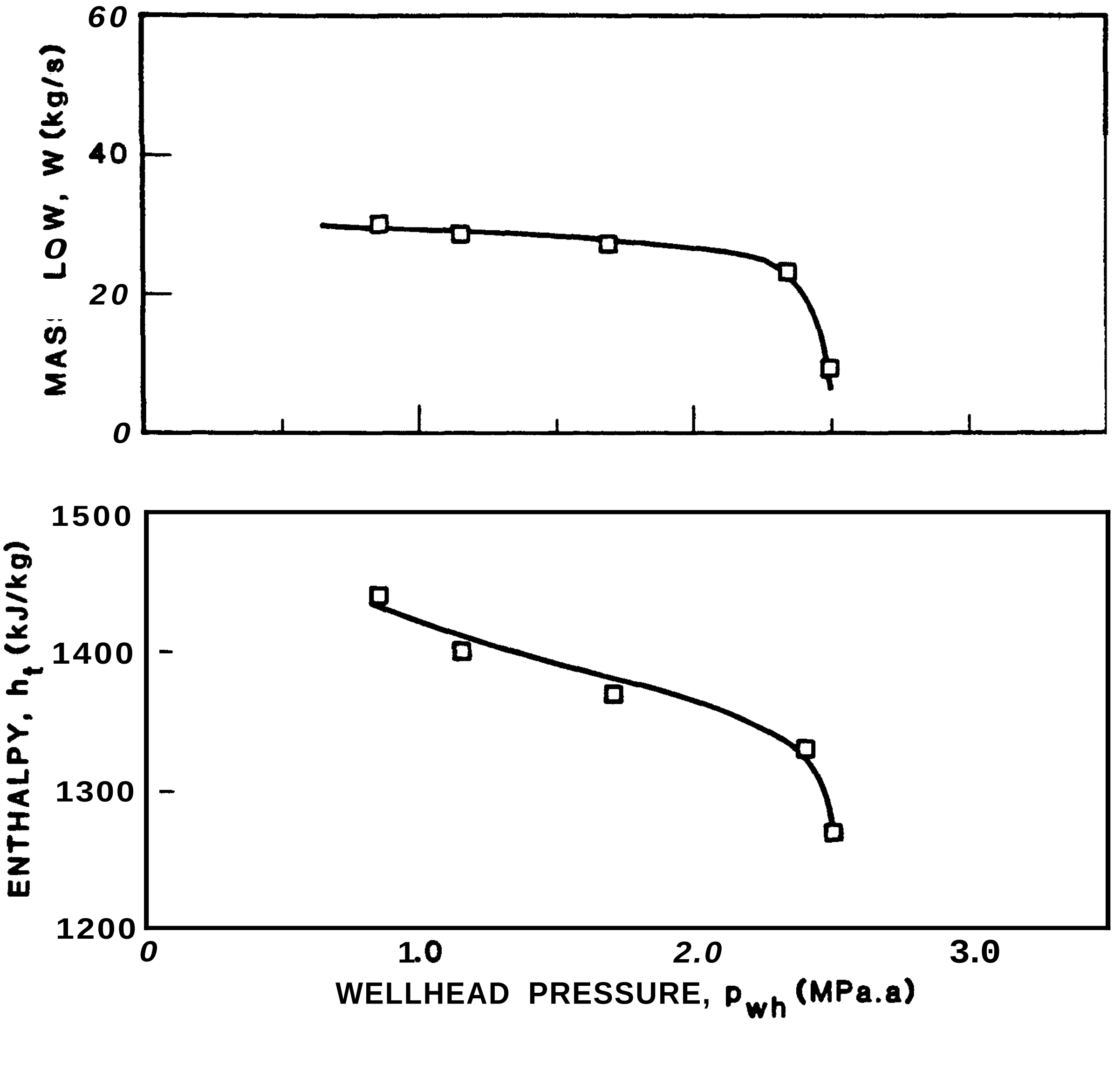

FIG. 3-5: MEASURED FLOWRATE AND ENTHALPY OF WELL 403 IN TONGONAN, THE PHILIPPINES

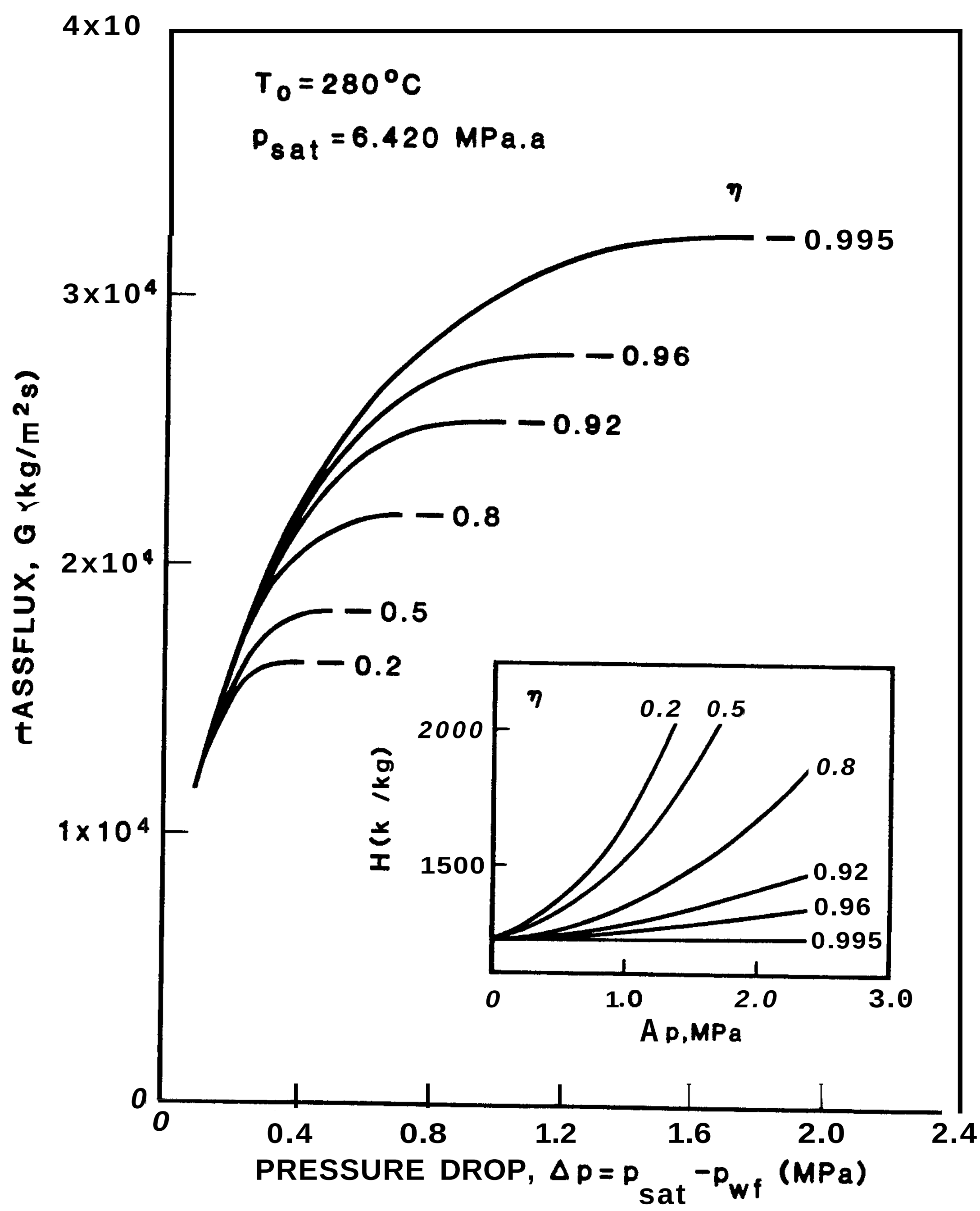

FIG. **3-6:** TYPICAL RESULTS FROM THE MODIFIED STREAMTUBE MODEL

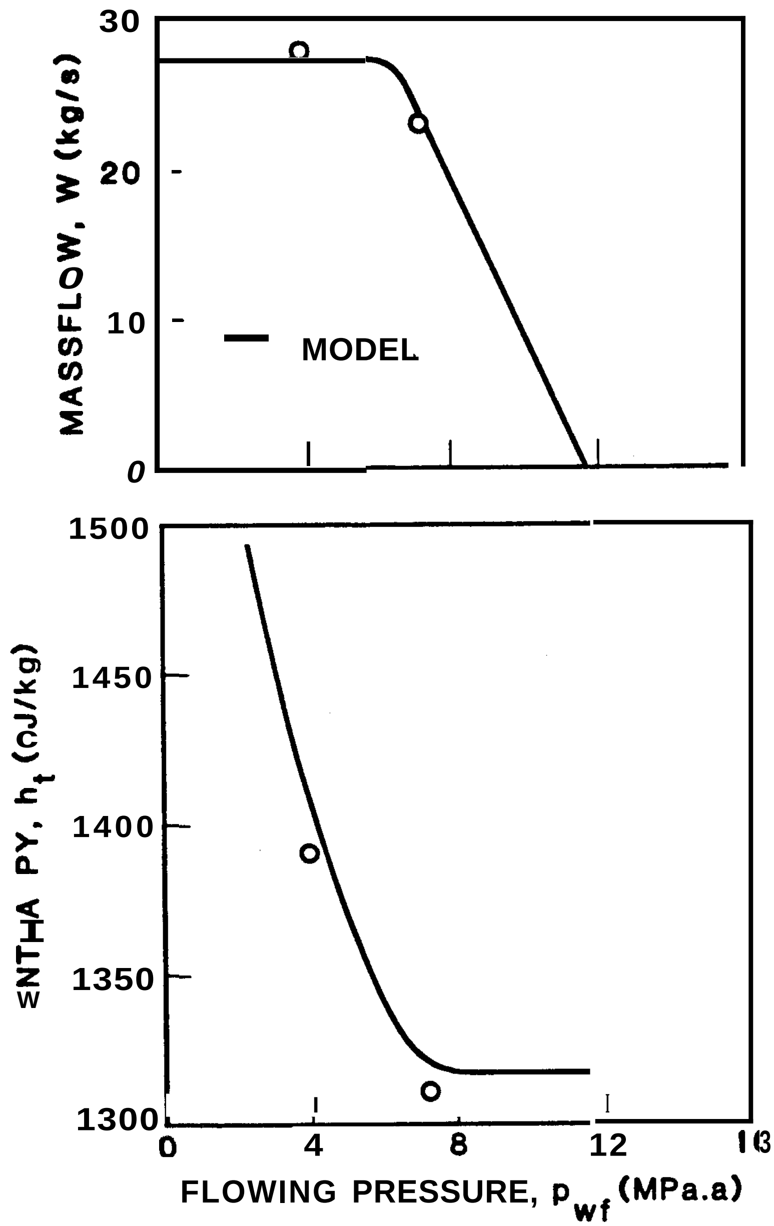

FIG. 3-7: CALCULATED MASSFLOW AND ENTHALPY OF WELL 403 IN TONGONAN, THE PHILIPPINES

occur close to the wellbore. The flashing mixture seems to approach the reservoir rock temperature only to a limited extent. The work has shown that critical two-phase flow can occur in fractures in geothermal reservoir-well systems. The choking behavior of some two-phase feedzone wells may be due to critical flow in fractures near the wellbore.

Table 3-1

STEAMTUBE MODEL CALCULATIONS FOR WELL 403

IN THE TONGONAN FIELD

Wellhead pressure (MPa.a)	1.26	2.46
Feedzone pressure (MPa.a)	3.73	7.20
Two-phase flowrate (kg/s)	28.8	22.8
Mixture enthalpy (kJ/kg)	1,400	1,330
Fracture massflux (kg/m2s)	34,088	29,063
Effective flow area (cm^2)	8.4	7.8

(e) Testing of Composite Reservoirs by Abraham Sageev, research assistant and Professor Roland N. Horne.

This project is a part of an effort to test reservoirs composed of two differing regions. Such composite reservoirs may exist when injecting water into a steam-dominated reservoir, or while producing a steam zone around a production well in a liquid-dominated reservoir. Other similar conditions may exist in oil and gas reservoirs mainly under secondary or tertiary recovery.

So far, the study has been limited to circular boundary regions. The approach is to test for the size of the "hole" using a well exterior to the hole (see Figure 3-8).

Partial differential equations describing two cases have been considered: constant pressure, and no flow boundaries. These are the extreme cases of a two region composite system. The analytical solutions were obtained using the Laplace transform technique.

Currently, a computer program that will produce graphical descriptions of the pressure-time behavior of these composite systems is being

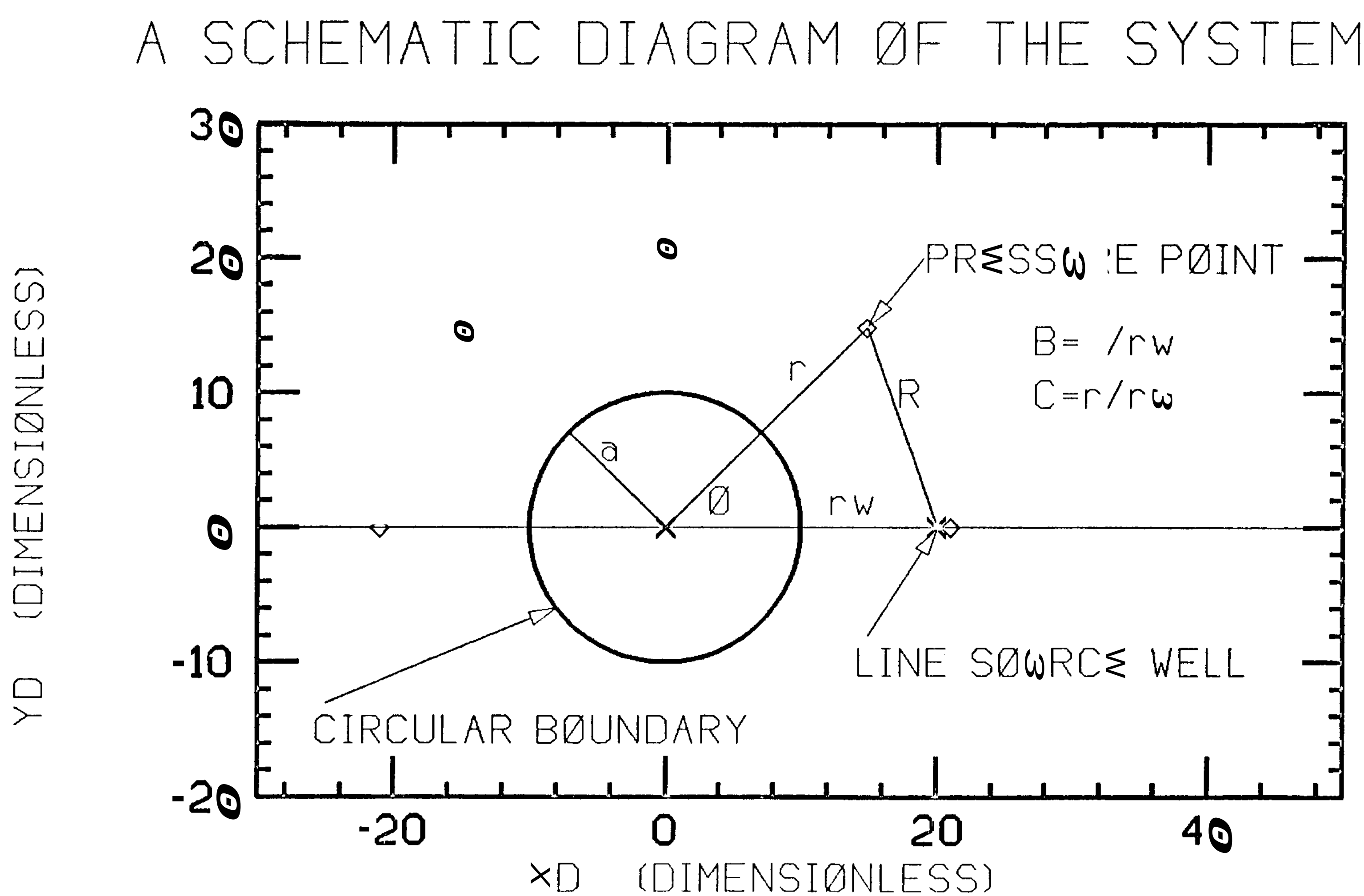

FIG. 3-8: A SCHEMATIC DIAGRAM OF A RESERVOIR WITH A HOLE

developed. The Laplace form of the solution is used and inverted numerically to real time.

Figure 3-9 presents pressure-time curves for one well-hole configuration, including four interference wells at various angles. Since the boundary is at a constant pressure, the curves tend to a constant, steady-state pressure at long times. The line source curve is presented for comparison.

The analysis of systems with these two types of boundaries will be completed and systems with different region configurations and types of boundaries will be considered.

3.2: Bench Scale Experiments by Mark A. Miller, research assistant and Professor Henry J. Ramey, Jr.

Work on the bench scale relative permeability project has been directed to a fundamental investigation of flow through porous media--specifically at the question of mechanism(s) causing temperature effects on relative permeabilities. Because of conflicting experimental results, and the lack of physical explanation for observed changes with temperature, it was deemed necessary to ascertain whether the observed phenomena was confined to the laboratory (because of physical size, experimental problems, etc.) or not.

The work thus far has concentrated on immiscible systems. The advantages of immiscible fluids in relative permeability experiments include: (a) in-situ saturations and relative flow rates are easily determined, and (b) dynamic displacement relative permeability measurements can be made, which are faster and easier than steady-state type experiments. In order to eliminate as many extraneous variables as possible, pure systems were initially selected. The porous media is an unconsolidated silica sand. Fluids are distilled water and refined white mineral oil.

The apparatus has been designed and modified several times in order to make the results as accurate and repeatable as possible. The concept of the apparatus has been on getting direct measurements of the necessary variables. A working apparatus has now been achieved that gives

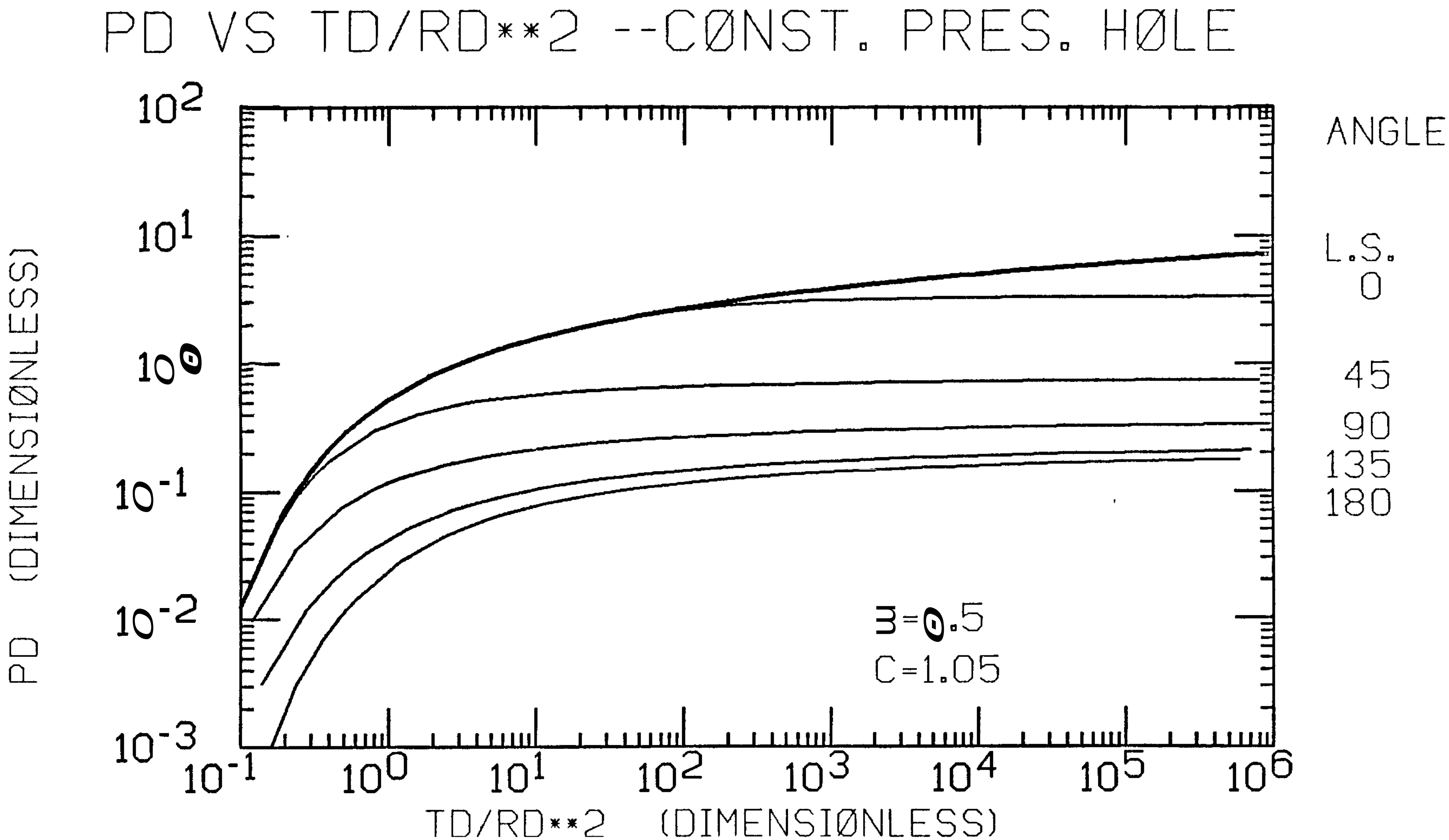

FIG 3-9: DIMENSIONLESS PRESSURE VS. NORMALIZED DIMENSIONLESS TIME. CONSTANT PRESSURE BOUNDARY HOLE

extremely repeatable measurements (especially of material balance) even after over 50 pore volumes of alternate oil and water injection through a given core.

Thus far, only a few runs have been made with the above system, however the results have been encouraging. Figures 3-10 and 3-11 show successive runs on a given core at 197°F and 74°F. Although the curves are slightly different, the magnitude and direction of the changes with temperature is different from previous studies. The most important aspect of these results was the lack of change in irreducible water saturation. Irreducible water saturation was 8.5% at 74°F decreasing to 7.6% at 197°F. This small change is believed to be within experimental error. Previous researchers had reported significant increases in irreducible water saturation with temperature. At this time, the relative permeability curves are believed to be essentially identical.

Additional runs are planned in the near future to: (a) determine whether the lack of temperature effects is repeatable and evident to at least 300°F and (b) test for temperature effects on consolidated materials such as Berea sandstone to determine if such effects exist in more realistic reservoir materials.

Some work was also done last year on formulating a mathematical network model of porous media to use as a tool for attempting to explain changes in flow behavior from a microscopic viewpoint. A computer program was completed which modelled both imbibition and drainage capillary pressure phenomena. Work on formulation of a dynamic model was halted until more definitive results were achieved in the laboratory experiments. If the laboratory experiments continue to show no temperature effects, further work on the network model may be postponed for later studies.

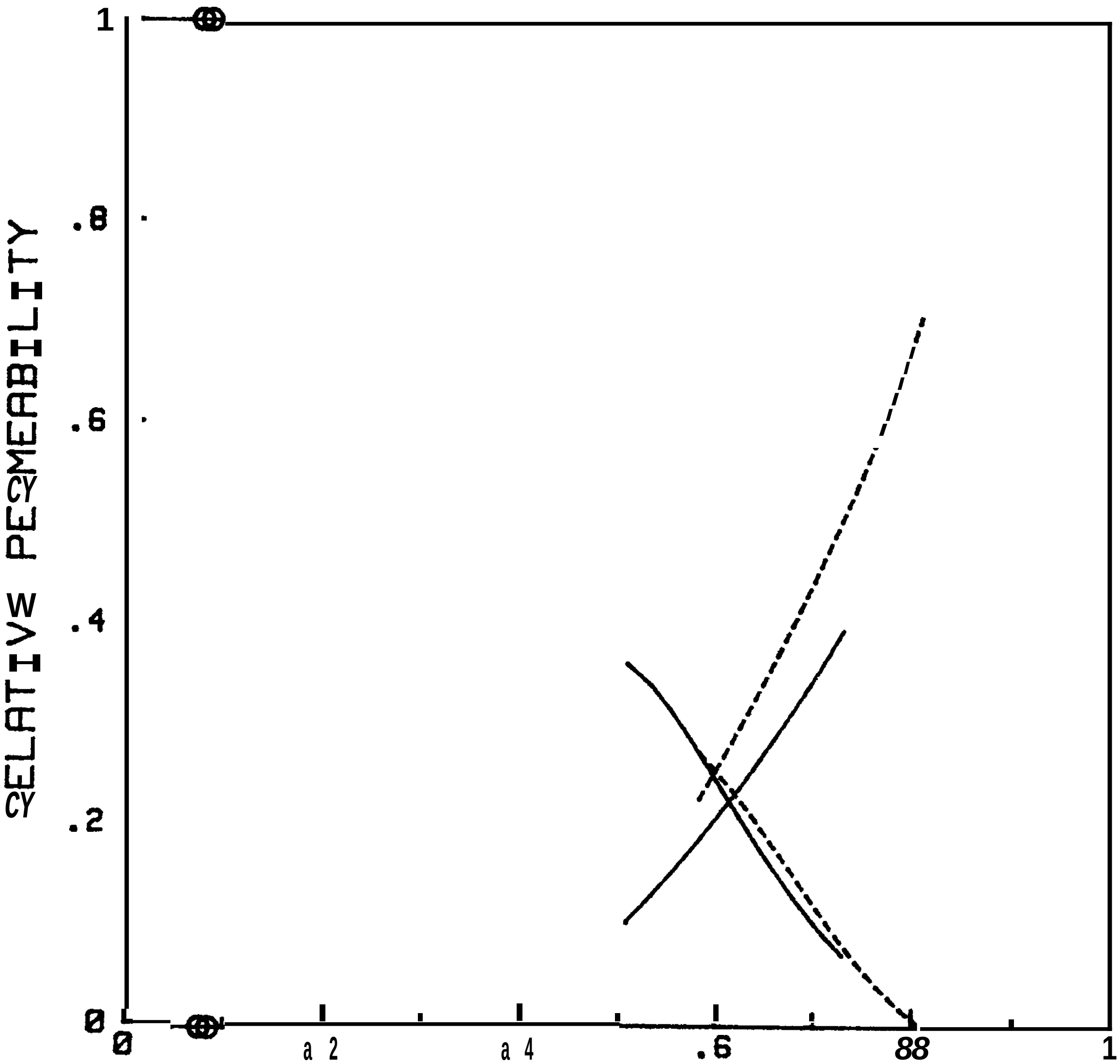

FIG. 3-10: COMPARISON OF RELATIVE PERMEABILITIES FOR CORE #2 AT 74°F AND 197°F

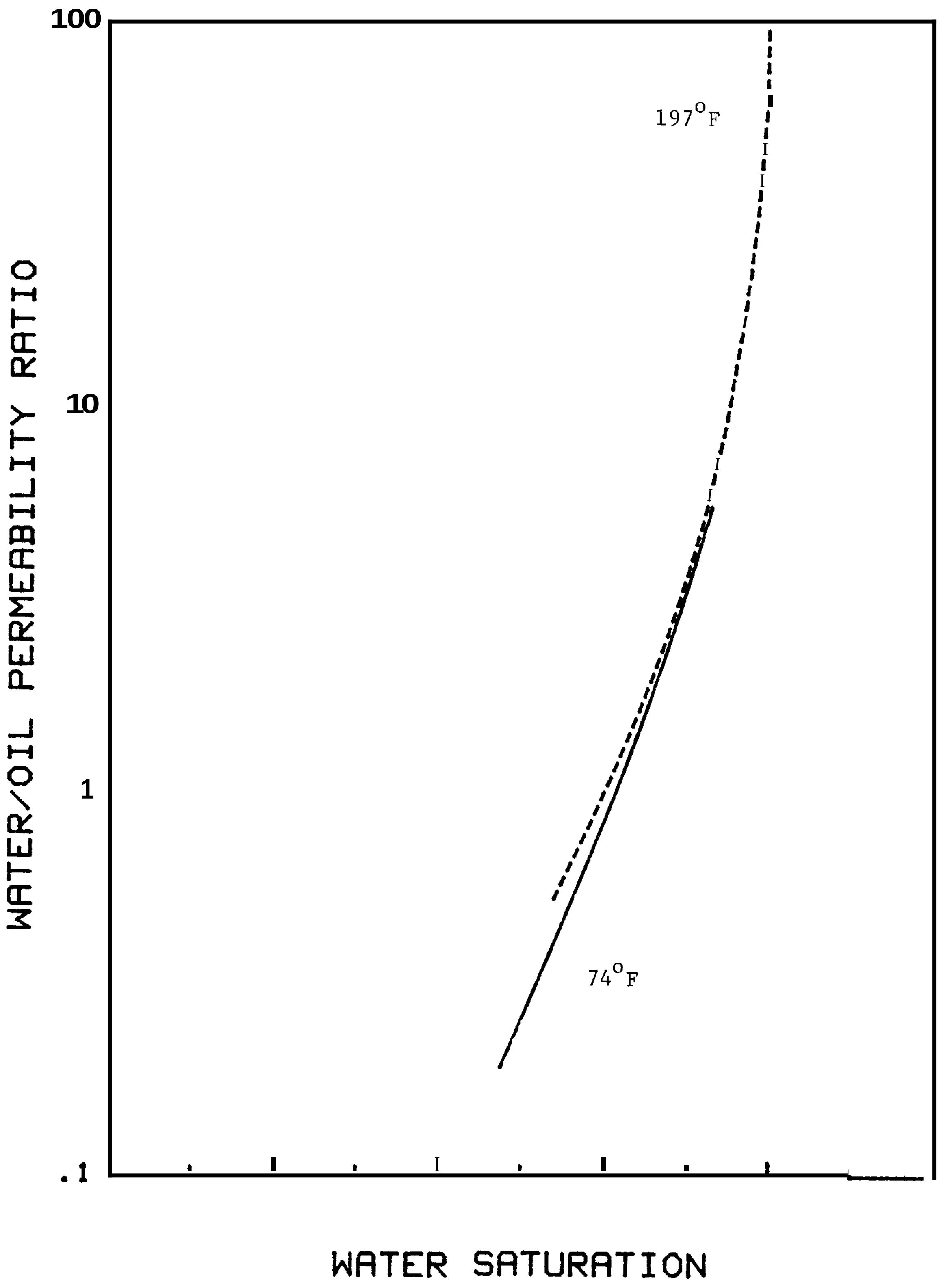

FIG. 3-11: COMPARISON OF RELATIVE PERMEABILITY RATIOS FOR CORE 82 AT 74°F AND 197°F

TASK 4: DOE-ENEL COOPERATIVE RESEARCH

This program was initiated in conformance with Project 3 of the DOE - ENEL Cooperative Agreement on geothermal energy, first signed by representatives of the U.S.A. and Italy in 1975. The first contract involving Stanford and ENEL, pursuing the objectives of this Project became effective on October 1, 1976. Prior to that time, for a period exceeding two years, ENEL engineers became acquainted with reservoir engineering concepts through efforts made by faculty and staff members of Stanford's Petroleum Engineering Department. Also, before the contract became effective, possible joint research was discussed by Stanford representatives and their Italian counterparts, ENEL research engineers and scientists.

Enthusiasm ran high during the years from 1976 to 1980. In 1980 the Agreement was renewed for a second five years. The Italians were eager to learn reservoir engineering technology as developed in the petroleum industry and in groundwater management operations. The goal of the Italians was to adapt this technology to their geothermal reservoirs with the hope that they could increase economic recoveries of energy. The Americans were anxious to gain access to long-term field data mainly on reservoir pressures, temperatures, production and fluid composition. They also wanted to gain information on reservoir geology, structure and chemistry. Both teams planned to examine field performance histories and to make reservoir engineering analyses where the prospects for success in forecasting future behavior looked best. Aside from this, both teams wanted to plan, design and implement field tests that would yield data for estimating reservoir size, reserves and future rates of production. The success of the program during its first five years is evident from the publications it generated.

Progress on the program began to slow in 1981, although not significantly at the outset. This deceleration in activity was not due to any change of the enthusiasm or interest on the part of researchers. Moreover, a Stanford visit to ENEL in Pisa in April 1981 indicated that the feelings and enthusiastic outlook of those Italians who worked directly on the program had undergone no change. However, the number of Italians assigned to work on the program had been reduced. This probably was due to a pressing need to complete other work and to a shortage of professional help.

During this visit to Pisa, members of the Stanford team conferred with their Italian technical colleagues on several matters of mutual concern. Two important subjects were:

(a) Formulation of plans to coordinate joint research through an informal agreement between Stanford and ENEL, acceptable to both countries. It was proposed by Stanford that this agreement be in the form of a gentlemen's agreement, letter of intent, or memorandum of understanding. Basically, a document prepared on this basis would apply to each research task and would indicate guidelines to be followed by both Stanford and ENEL. This kind of document had been suggested to Stanford by the Division of Geothermal Energy in Washington, D.C. The purpose was to simplify the more formal procedure followed when the "Stanford - Italian" research was administered by the DOE through Lawrence Berkeley Laboratory. The Italians eventually decided against the simplifed procedure and prepared a new formal procedure bearing the title "Procedures for the Implementation of the 'Agreement Between the U.S. DOE and ENEL on Cooperation in the Field of Geothermal Energy Research and Development"'. It was accepted by DOE.

(b) Discussion of possible research subjects for FY '82, selection of those to be worked on, and preparation of descriptions of the proposed work. About seven topics were considered as prospects, but only two could be accepted owing to limited funding and technical help. The two agreed upon were: (1) forecasting of performance of fields similar to the Piancastagnio Field and, (2) analysis of well test results on liquid-dominated fractured reservoirs. The first of these involved the use of tracer studies to forecast reservoir performance. The second involved the effects of pressure buildup and drawdown on the total compressibilities of reservoirs. Brief preliminary descriptions of these two projects were prepared for ENEL management. Stanford did not learn until July 1981 that these proposals had not been not approved.

As a result, further conferences were held in July and a new project was agreed upon by the Stanford team and their technical colleagues in ENEL. The subject was "Tracer Experiments in the Latera Field."

ENEL management did not approve this proposal either, but Stanford did not learn this until 1982.

The reasons for ENEL's failure to approve the new research proposed in 1981 were never made clear to Stanford. The Italians mentioned informally four influencing factors, however, which they considered to be important. First, ENEL was undergoing a reorganization. Apparently there was general uncertainty about the job assignments that would be made in the new organization. This must have created some insecurity and dampened progress on plans being made for future research. Second, it seemed that the geosciences and reservoir engineering were not being held in the same high esteem as they had been a few years earlier. No attempt was ever made by the Stanford team to promote these fields of endeavor as cure-alls. On the contrary, care was taken to point out their weaknesses as well as their strengths. A determined effort was made in this respect to demonstrate through analyses of field data and tests that reservoir engineering could lead to a more advanced level of understanding of reservoir behavior than was possible without it and that forecasts of field performance could be made with a degree of confidence that would not be possible otherwise.

Third, the financial climate in Italy was far from robust. Conversations with the Italians led Stanford to believe that research funding had become much more dificult to obtain. This also must have had a bearing on the reactions of ENEL management to research proposals. Emphasis in ENEL evidently was being placed mainly on energy production, with decreased attention on research.

Fourth, and probably most important, ENEL by 1981 had begun to consider its field data as proprietary information. This of course was a difficult reason to combat when at the same time important geothermal field data in the U.S.A. were proprietary. However, there is the distinction to be considered between government and private industry. It is easy to understand why field data generated by an American corporaion can be proprietary and some government field data cannot. In the first instance the corporation is owned by a relatively few people. Within the confines of public law and interest these people, the stockholders, can determine what directions their company will take and what production practices it will adopt. In the second instance, government energy-development projects as well as other government projects are owned in effect by the public at large because the public through taxes pays for them. So, one might argue that every taxpayer is entitled within limits to whatever information is developed. In Italy the situation with ENEL is different. Stanford was informed that ENEL was not in competition with other Italian companies during its first five years of cooperative research with Stanford. No problems arose in connection with the release of field data for research under joint DOE-ENEL proposals. Field tests such as well tests could be planned, approved, implemented and analyzed with publication of results, including pressure, production, and composition data and whatever other data were collected. By 1981 there were a number of other organizations competing with ENEL in the search for and development and production of geothermal energy in Italy. Thus ENEL became wary about releasing field data, perhaps even adamant in its position on the matter.

To avoid the problem of exposing ENEL data, Stanford members proposed in their most recent conferences with their Italian counterparts, in May 1982, that field data when released to non-ENEL personnel be disguised; for example, data could reveal no field, reservoir or well designations. A reservoir could be referred to merely as reservoir "A" and its wells as a, b, c, etc. Care would have to be exercised to use data from reservoirs that are not too well known and to use only data necessary for analysis of the problem at hand. Petroleum publications contain many papers in which field data have been successfully disguised in this manner. ENEL did not approve of this method however.

Unquestionably, both the U.S.A. and Italy can gain from a continuation of Stanford-ENEL joint research under Project 3, now effective until 1985. It would be most difficult to do really meaningful joint work, however, without Italian field data. A lack of data has already crippled the cooperation and would continue to do so.

To resolve the current impasse, it is recommended that (1) the DOE - ENEL Cooperative Agreement be studied to determine whether it contains any provisions which apply to the present problem, and (2) a meeting of DOE and ENEL representatives be convoked to discuss possible solutions with the hope that one can be found which is mutually acceptable to both countries. If this is not possible, continuation of Stanford - ENEL reservoir engineering research should be discontinued. This should be done, if possible, on the basis of a final formal letter or statement signed by personnel at appropriate levels of authority in both countries. If such a statement becomes necessary it certainly should be executed with the spirit of good will and friendship that has been a hallmark of the Stanford - ENEL program since the early years of its existence.

Although Stanford has had little opportunity to contribute to DOE-ENEL cooperative research during FY '81 because of no new Italian field data and because new joint proposals have not been approved by ENEL, some progress has been made.

A paper entitled "Geothermal Reservoir Engineering Development through International Cooperation" by F. G. Miller and H. J. Ramey, Jr. (1981) was presented at Stanford's Seventh Workshop on Geothermal Reservoir Engineering. The paper dealt mainly with international cooperative studies and research, the problems that arise in the execution of international agreements and the advances that have been made in the development of geothermal reservoir engineering.

A paper entitled "Implications of Adsorption and Formation Fluid Composition on Geothermal Reservoir Evaluation" by Economides, M. J., Ostermann, K., and Miller, F. G. (1982) was presented at an International Conference on Geothermal Energy in Florence, Italy. Much of this work was based on M. J. Economides' Ph.D. thesis research done as a part of the Stanford - ENEL program.

A paper entitled "Geothermal Well Testing: State of the Art" by Economides, M. J., Ogbe, D., and Miller, F. G. (1982) had been presented at a Society of Petroleum Engineers meeting prior to its publication. As its title implies the paper reviewed well testing technology, describing well testing theory and practice.

Work progressed on M. J. Economides' thesis which bears the title of the above paper presented in Florence. A first draft of the thesis was submitted in 1982 for review to Professor F. G. Miller, Economides' thesis adviser in the Petroleum Engineering Department at Stanford. Economides plans to complete his work in 1983.

While in Italy in May 1982, Professors F. G. Miller and R. N. Horne attended the Florence conference. Many ENEL personnel were present. As a starting point for possible joint Stanford - ENEL research on reinjection, Professor Horne presented his paper entitled "Geothermal Reinjection Experience in Japan." This gave the Italians a better idea of recent Stanford research on reinjection.

At a meeting held in Washington, D.C. in September 1982, Professors F. G. Miller, W. E. Brigham, and R. N. Horne discussed Stanford's geothermal program with members of DOE's technical staff on geothermal energy. Professor Miller reviewed the origin and history of Stanford - ENEL cooperative research on reservoir engineering. He pointed out its purposes, the kinds of studies made, accomplishments to date, research plans for the future, and the status of the cooperative effort. Procedural and administrative problems facing both the U.S.A. and Italy were discussed. Much of what was said appears in the forepart of the present report.

TASK 5. STANFORD-IIE COOPERATIVE RESEARCH

At the completion of the second year of this task (the cooperative project was initiated in October 1982), the early progress from the first year of activity reached fruition with the completion of several projects. One of the highlights of the year's program was to have been the implementation of the planned tracer test at Los Azufres geothermal field. This test was postponed due to economic conditions at C.F.E. and in Mexico in general, however the research performed in support of this work is sufficiently general that it will be easily transferred to tracer tests in other fields. In fact, the tracer selection and analysis techniques developed in this task during the year are being used directly in the Roosevelt Hot Springs geothermal field tracer test to be performed in early 1983.

(a) Interpretation of Tracer Tests in Fractured Systems by Martin P. Fossum and Fernando J. Rodriguez, research assistants and Professor R. N. Horne.

Following the initial proposition of an interpretation technique, based mainly on the methods developed at Los Alamos (Tester, Bivins, and Potter, 1982), a fracture flow dispersion model was developed. This model considered the relative importance of molecular, convective and Taylor dispersion in tracer flow through linear fractures, and formed the basis of the transfer function used in interpretation. This work was presented at the 1981 Stanford Workshop (Horne and Rodriguez, 1981) and has also been submitted for publication in Geophysical Research Letters.

Having analyzed the physical processes, a computer program was developed to fit field data to the proposed transfer function. This program was successfully tested on data from radioactive tracer tests at Wairakei (McCabe, Manning and Barry, 1980), and yields the mean transit time and Peclet numbers for the transit paths. Each of the tracer profiles showed acceptable matches with a 2-flow path model. Based on the dispersion work, it was possible to infer effective fracture apertures from these results. The values estimated are given in Table 5-1, and a typical match to the field data are shown in Figure 5-1. Fracture apertures estimated in this way are of the order 1 - 2 cm, and are

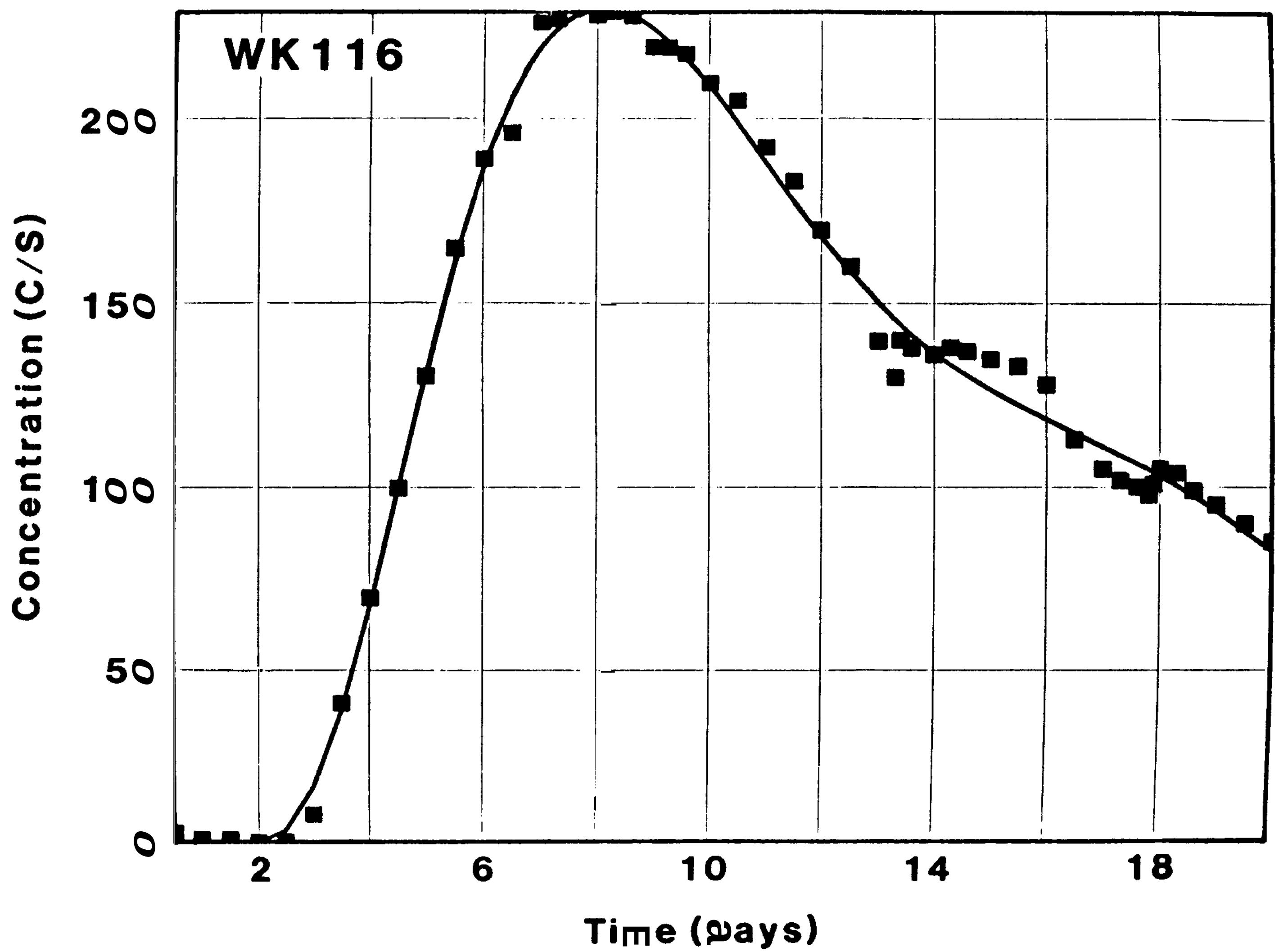

FIG. 5-1: TRACER BREAKTHROUGH CONCENTRATION IN WK116 (WAIRAKEI) FROM INJECTION INTO WK10a

likely to be an overestimate since the model is only one-dimensional and does not include the retention of the tracer. This work was reported in a technical report SGP-TR-56 (Fossum, 1982) published as a paper in the Geothermal Resources Council Transactions (Fossum and Horne, 1982) and will be presented at the Geothermal Resources Council Annual Meeting in October 1982.

Table 5-1

CALCULATED PARAMETERS OF TKACER
ANALYSIS MODEL FOR TWO FIELD TESTS

Wairakei Well	Flow Fraction	Peak Arrival Time (Days)	Peclet Number
WK 116	0.87	8.5	9.3
	0.13	18.9	41.6
WK 76	0.42	21.5	15.80
	0.58	8.6	13.5

(b) Tracer Retention Experiments, by Kenneth A. Breitenbach, research assistant, and Professor Roland N. Horne.

This work examined the loss of potassium iodide (KI) and sodium bromide (NaBr) when isolated in a reservoir rock at high temperature and pressure. The rock used was a Los Azufres andesite sample provided by IIE. Experiments were performed in an apparatus modified from earlier absolute permeability experiments (Sageev, 1980). The core was saturated with tracer and isolated from the rest of the pipework which was then flushed clean with water through a core bypass loop, see Figure 5-2. The core was heated to 150°C for up to 3 days, after which the tracer was flushed with water and detected using an ion-specific electrode. Approximately 60% of KI was retained in the 3-day residence tests, irrespective of tracer input concentration (within experimental error), see Figure 5-3. The retention was found to increase as a function of time, Figure 5-4, but levelled off at around 60%.

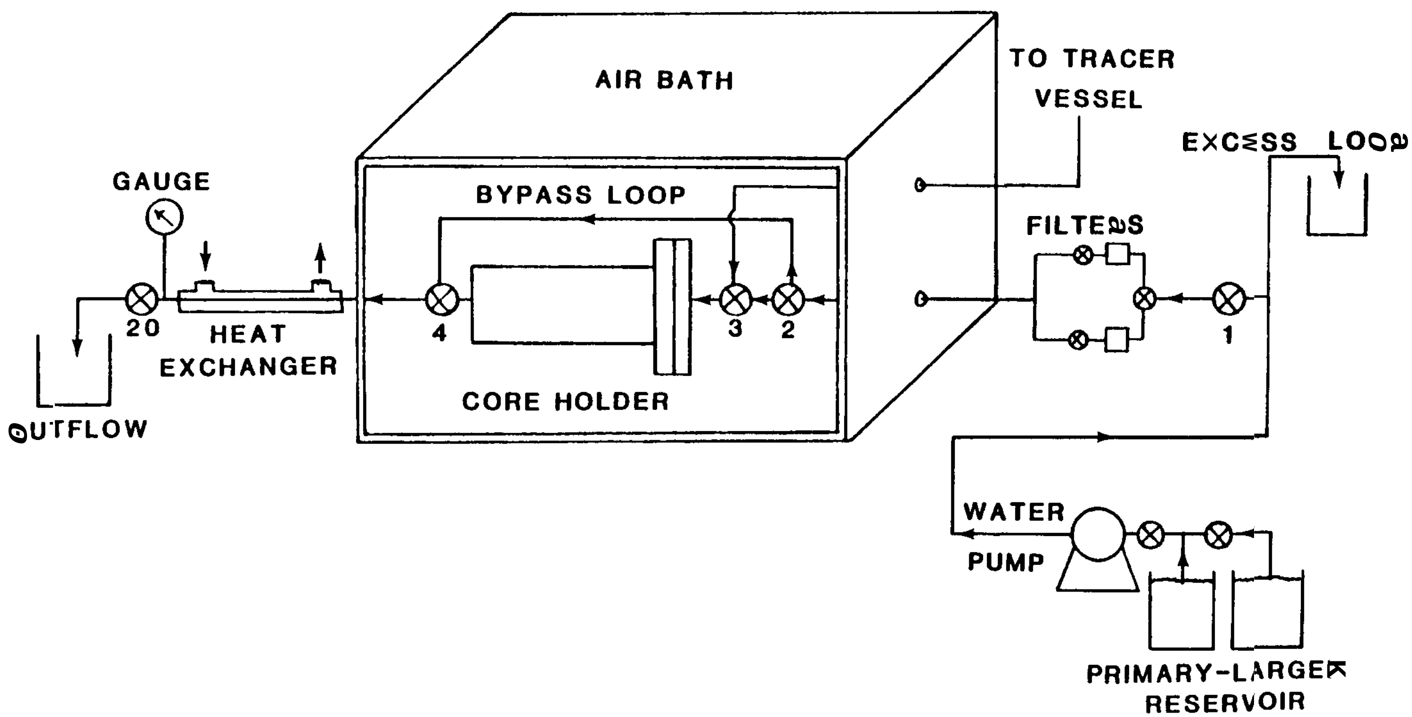

FIG. 5-2: A SCHEMATIC OF THE WATER FLOW SYSTEMS

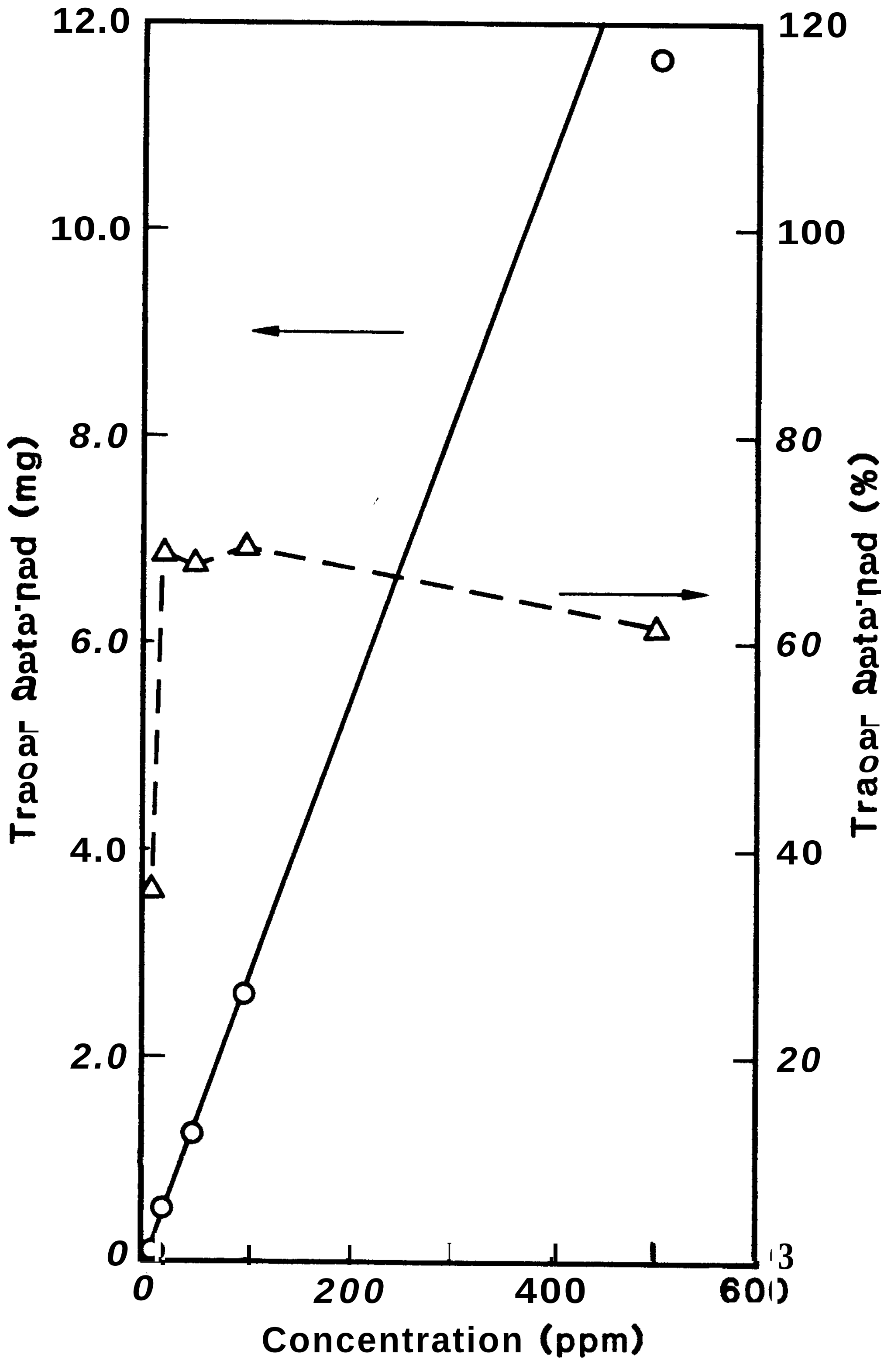

FIG. 5-3: POTASSIUM IODIDE, 3 DAY RESIDENCE, 300°F

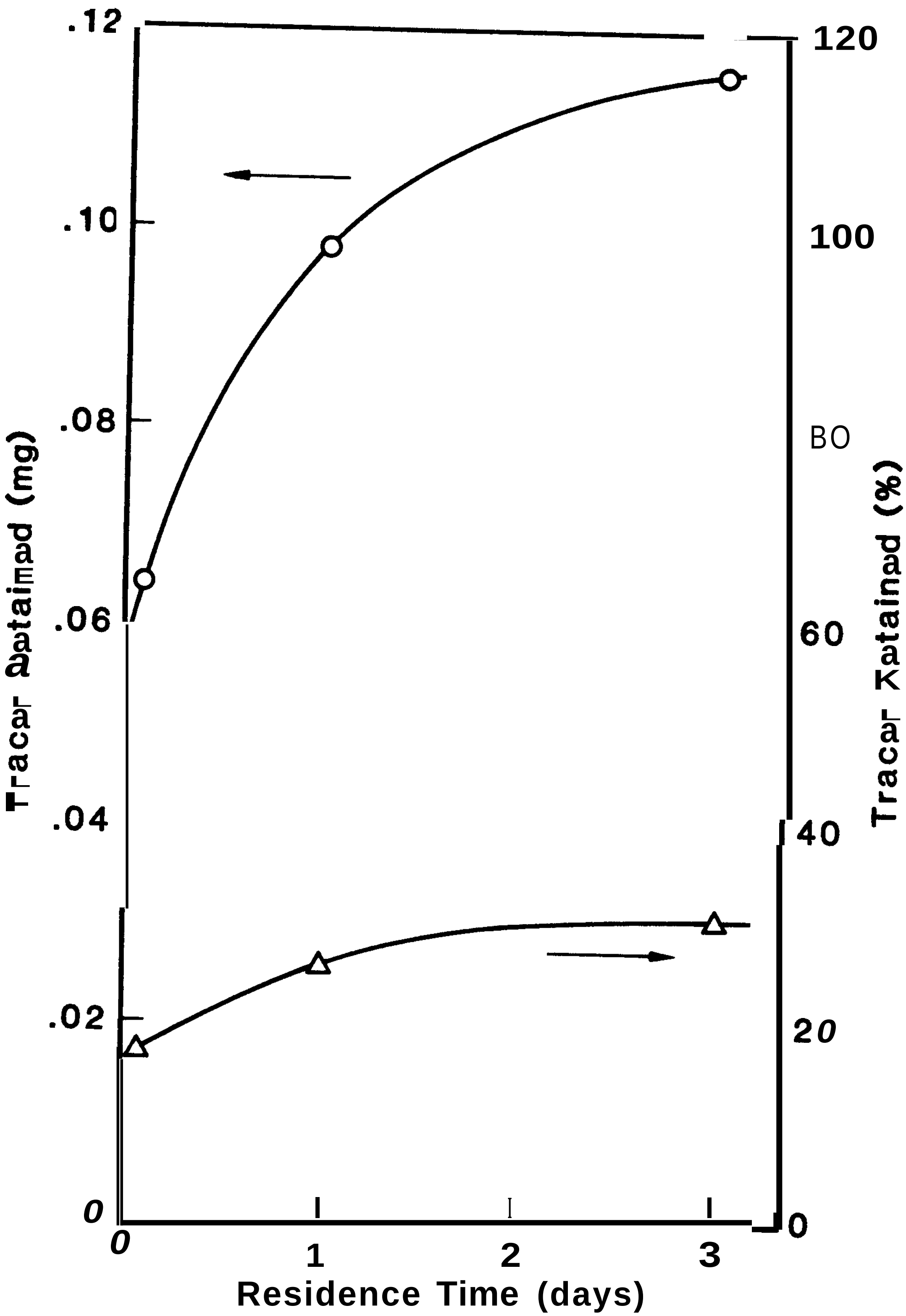

FIG. *5-4:* **POTASSIUM IODIDE, 10** PPM, 300°F

Subsequent saturation with lower concentration tracer showed some of the "retained" tracer to be released, suggesting that a retention-and-release mechanism is important in tracer transport through geothermal reservoir formations. Such a mechanism tends to compensate for the overly wide fractures inferred in Table 5-1, since the holdup mechanism provides a larger dispersion than is possible with simple conservative flow through a fracture.

A technical report SGP-TR-53 (Breitenbach, 1982) on this work was issued in June 1982, and a paper will be presented at the Pacific Geothermal Conference in Auckland, New Zealand in November 1982 (Breitenbach and Horne, 1982). As a preliminary look at this problem, this study so far suggests several future directions for this research. Quantifying the mechanism for the tracer holdup has a potential for estimating the surface area of rock in contact with tracer, which is an important parameter in determining the thermal breakthrough due to reinjection. In the coming year, the approaches will be further modified to replace the viton rubber sleeve with stainless steel to remove the possibility of tracer holdup in the organic material. Full water chemistry will also be analysed, and the cooperation of a geochemist enlisted to help quantify the rock/water chemical reactions.

TASK 6: WORKSHOP AND SEMINARS

The Seventh Workshop on Geothermal Reservoir Engineering was held at Stanford University 15-18 December 1981. A total of 33 papers were presented and published in the Proceedings under the categories of Developments in Geothermal Reservoir Engineering, Field Development, General, Reservoir Chemistry and Physics, and Modeling. In addition to the technical paper presentations, there was a one-half day panel discussion on Future Directions of Geothermal Reservoir Engineering Development.

The attendance at the Workshop was 104 and foreign participation was evident as before with 16 visitors from 5 countries. The excellent results of the 1981 Workshop confirmed its major objective of bringing together active researchers and engineers on the development of geothermal energy as a viable resource and on providing a forum for prompt reporting of progress and the exchange of ideas.

During the academic year, weekly Seminars were held on geothermal energy topics. During the autumn quarter, the Seminars covered some of the work carried out at Stanford as has been the tradition in past years. This provides a way to introduce to new students current geothermal reservoir engineering research of the Program. In the winter and spring quarters, the Seminars were mainly given by scientists and engineers outside Stanford University. The Stanford Geothermal Program faculty and students are most grateful to the speakers and their organizations for their support and time.

The contents of the Proceedings of the Seventh Workshop on Geothermal Reservoir Engineering and the Seminar Schedules for 1981/1982 academic year are shown in the following.

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY

STANFORD, CALIFORNIA 94305

SGP-TR-55

PROCEEDINGS OF THE SEVENTH WORKSHOP ON GEOTHERMAL RESERVOIR ENGINEERING

Editors

Paul Kruger

Henry J. Ramey, Jr.

Frank G. Miller

Roland N. Horne

William E. Brigham

Ian G. Donaldson

Jon S. Gudmundsson

December 15-17, 1981

SPONSORED BY

THE GEOTHERMAL AND HYDROPOWER TECHNOLOGIES DIVISION

OF THE DEPARTMENT OF ENERGY

STANFORD-DOE CONTRACT NO. DE-AT03-80SF11459

Page

General

Reservoir Chemistry and Physics

Modeling

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

Inquiries:
Dr. J. Gudmundsson
Petr. Engr. Dept.
Mitchell #360

STANFORD GEOTHERMAL PROGRAM

SEMINAR SCHEDULE

Autumn Quarter, 1981-82 — Room B67, Mitchell Building — Thursdays, 1:15-2:30 p.m.

Date		Speaker
Oct 15	The Stanford Geothermal Program	P. Kruger, C.E. Dept., S.G.P.
22	Looking to the Future--Some Geothermal Reservoir Problems for Which We Will Require Solutions	I.G. Donaldson, Visiting Prof., P.E., S.G.P.
29	Tracer Flows in Fractures	F.J. Rodriguez and R.N. Horne, P.E. Dept., S.G.P.
Nov 5	Geothermal Studies in Iceland	J. Gudmundsson, Visiting Prof., P.E. Dept.
12	Geophysical Monitoring of Geothermal Fields under Exploitation in New Zealand	Trevor Hunt, D.S. I.R., New Zealand
19	Relative Permeability Studies at Stanford	Mark A. Miller, P.E. Dept., S.G.P.
26	(No meeting)	
Dec. 3	The Stanford Geothermal Program Heat Project	Lyle Swenson and Anstein Hunsbedt, C.E. Dept., S.G.P.

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD, CALIFORNIA *94305*

Inquiries:
Jon Steinar Gudmundsson
Petroleum Engr. Dept.
Mitchell Building, Rm. 360
(415) 497-1218 or 497-4744

STANFORD GEOTHERMAL PROGRAM

SEMINAR SCHEDULE

Winter Quarter, 1981-82 Room 134, McCullough Building Thursdays, 1:15-2:30 p.m.

Date	Topic	Speaker
Jan 14	The Momotombo Field in Nicaragua	Herman Dykstra, Consultant
21	Geothermal Activity in Alaska	Michael Economides, Univ. of Alaska
28	Tongonan and Other Fields in the Philippines	Tony Menzies, KRTA Consultants
Feb 4	Commercial Operations in the Imperial Valley	Philip Messer, Union Geothermal
11	Geothermal Well-Test Analysis in Horizontally Stratified Formations	Allen Moench, U.S.G.S.
18	Occidental's Power Plant in The Geysers	Robert Ward, Occidental Geothermal
25	Reinjection Experience in Japan	Roland Horne, Stanford University
Mar 4	'Mathematical Models of Geothermal Systems	Gudmundur Bodvarsson, LBL

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD. CALIFORNIA 94305

Inquiries:
Jon Steinar Gudmundsson
Petroleum Engr. Dept.
Mitchell Building, Rm. 360
(415) 497-1218 or 297-4744

STANFORD GEOTHERMAL PROGRAM

SEMINAR SCHEDULE

Spring Quarter 1981-82 102, Terman Engineering Ctr. Thursdays, 1:15-2:30 p.m.

Date	Topic	Speaker
Apr 8	Geothermal Reinjection: The Department of Energy Program	Martin W. Molloy Department of Energy
15	World Survey of Low-Temperature Geothermal Energy Utilization	Jon S. Gudmundsson Stanford Geothermal Program
22	Geology and Geothermal Systems of the Cascade Range	Charles R. Bacon and L. J. Patrick Muffler U.S. Geological Survey
29	Characteristics of Wells in the Tongonan and Palimpinon Geothermal Fields, the Philippines	Anthony J. Menzies KRTA Consultants
May 6	Geochemical Characteristics of the Reservoir Conditions at the Coso Geothermal Prospect	Robert O. Fournier U.S. Geological Survey
13	Regulating Geothermal Resource Development: The Need for Earth Scientists	William F. Isherwood U.S. Minerals Management Service
20	Geology and Reservoir Engineering of the Beowawe Geothermal Area, Nevada	Robert W. Butler and I. Jerry Epperson Chevron Resources Company
May 27	"Mini-Symposium on Geothermal Activities at the Institute of Electrical Investigations in Mexico (Note time: 1:15-4:15 p.m.)	Eduardo R. Iglesias Sergio Mercado David Nieva IIE, Mexico

REFERENCES

Breitenbach, K. A., "Chemical Tracer Retention in Porous Media," SGP-TR-53, Stanford University, Stanford, CA, June 1982.

Breitenbach, K. A. and Horne, R. N., "Evaluation of Chemical Tracers for Geothermal Use," Proceedings, Pacific Geothermal Conference, Auckland, New Zealand, Nov. 1982, p. 229-234.

D'Amore, F., "Radon-222 Survey in Larderello Geothermal Field," Italy, Geothermics, 4, 1975, 96-108.

D'Amore, F. and R. Celati, "Methodology for Calculating Steam Quality in Geothermal Reservoirs," Geothermics, (in press, 1983).

Economides, M. J., Ostermann, R., and Miller, F. G., "Implications of Adsorption and Formation Fluid Composition on Geothermal Reservoir Evaluation," Paper C1, pp. 149-162, Vol. 1 of the Papers Presented at the International Conference on Geothermal Energy, Florence, Italy. Published by BHRA Fluid Engineering, Cranfield, Bedford, England. (May 11-14, 1982).

Economides, M. J., Ogbe, D., and Miller, F. G., "Geothermal Well Testing: State of the Art," Jour. Petrol. Technol., V. 34, pp. 976-988, May 1982.

Fossum, M. P., "Tracer Analysis in a Fractured Geothermal Reservoir: Field Results from Wairakei, New Zealand," SGP-TR-56, Stanford University, Stanford, CA, June 1982.

Fossum, M. P. and Horne, R. N., "Interpretation of Tracer Return Profiles at Wairakei Geothermal Field Using Fracture Analysis," Geothermal Resources Council Transactions, 6, 1982.

Horne, R. N., "Geothermal Reinjection Experience in Japan," J. Petroleum Technology, Vol. 34, 1982, 495-503.

Horne, R. N. and Rodriguez, F., "Dispersion in Tracer Flow in Fractured Geothermal Systems," Proceedings, 7th Annual Stanford University Geothermal Workshop, December 1981.

International Formulation Committee, "A Formulation of the Thermodynamic Properties of Ordinary Water Substance," IFC Secretariat, Dusseldorf, Germany, 1967.

Iregui, R., Hunsbedt, A., Kruger, P., London, A. L., "Analysis of Heat Transfer and Energy Recovery in Fractured Geothermal Reservoirs," Stanford Geothermal Report SGP-TR-31, June 1978.

McCabe, W. J., Manning, M. R., and Barry, B. J., "Tracer Tests - Wairakei," Institute of Nuclear Sciences Report INS-R-275, Department of Scientific and Industrial Research, Lower Hutt, New Zealand, July 1980. Geothermal Circular WJMcC 2.

Miller, F. G. and Ramey, H. J., Jr., "Geothermal Reservoir Engineering Development through International Cooperation," Proc., Stanford Univ. Seventh Workshop on Geothermal Reservoir Engineering, Dec., 1981.

Pruess, K. and Karasaki, K., "Proximity Functions for Modeling Fluid and Heat Flow in Reservoirs with Stochastic Fracture Distributions," Proceedings, Eighth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, December 1982.

Pruess, K. and Narasimhan, T. N., "A Practical Method for Modeling Fluid and Heat Flow in Fractured Porous Media," Proc. Sixth SPE-Symposium on Reservoir Simulation (paper SPE-10509), New Orleans, 1982.

Pruess, K. and Schroeder, R. D., SHAFT79 User's Manual Manual, LBL-10861, Lawrence Berkeley Laboratory, Berkeley, 1980.

Sageev, A., "Design and Construction of an Absolute Permeameter to Measure the Effect of Elevated Temperature on the Absolute Permeability to Distilled Water of Unconsolidated Sand Cover," SGP-TR-43, Stanford University, Stanford, CA, December 1980.

Sakakura, A. Y., Lindberg, C, and Faul, H., "Equation of Continuity in Geology with Applications to the Transport of Radioactive Gas," U.S. Geological Survey Bulletin 1052-1, 1959.

Semprini, L. and Kruger, P., "Radon and Ammonia Transects in Geothermal Reservoirs," SGP-TR-46, Stanford University, 1981.

Shinohara, K. and Ramey, H. J., Jr., "Slug Test Data Analysis, Including the Inertia Effect of the Fluid in the Wellbore," SPE 8208, 54th Annual Fall Technical Conference, SPE of AIME, Las Vegas, Nevada, September 23-26, 1979.

Spivak, D. and Horne, R. N., "Unsteady State Pressure Response Due to Production with a Slotted Liner Completion," Proc., SPE Calif. Regional Meeting, San Francisco, March 1982, 745-754.

Tester, J. N., Bivins, R. L., and Potter, R. M., (1982) "Inter-well Tracer Analysis of a Hydraulically Fractured Granite Geothermal Reservoir," Society of Petroleum Engineers Journal, 22, p. 537-554.

Wallis, G. B. and Richter, H. J., (1978), "An Isentropic Steantube Model for Flashing Two-Phase Vapor-Liquid Flow," J. Heat Transfer, 100, 595-600.

APPENDIX At PARTICIPANTS IN THE STANFORD GEOTHERMAL PROGRAM 1981/1982

PRINCIPAL INVESTIGATORS

Henry J Ramey, Jr.	Petroleum Engineering
Paul Kruger	Civil Engineering
Roland N. Horne	Petroleum Engineering
William E. Brigham	Petroleum Engineering
Frank G. Miller	Petroleum Engineering

ASSOCIATED FACULTY

Jon S. Gudmundsson	Petroleum Engineering
Anstein Hunsbedt	Civil Engineering
Drew V. Nelson	Mechanical Engineering

STUDENT RESEARCH ASSISTANTS

Petroleum Engineering

Kenneth A. Breitenbach
Michael J. Economides
Martin P. Fossum
Luis Macias-Chapa
Anthony J. Menzies
Mark A. Miller
John D. G. Moody
Jaime Ortiz-Ramirez
Fernando J. Rodriguez
Abraham Sageev
Miguel Saldana-Cortez
David Spivak
John Westwood

Civil Engineering

Kazuichi Satomi
Lewis Semprini

Mechanical Engineering

Stephen T. Lam

APPENDIX B: PAPERS PRESENTED AND PUBLISHED OCTOBER 1, 1981 THROUGH SEPTEMBER 30, 1982.

Seventh Workshop on Geothermal Reservoir Engineering, Stanford University. December 15-17. 1981.

University Research in Geothermal Reservoir Engineering--R. N. Horne

Geothermal Reservoir Engineering Development through International Cooperation--F. G. Miller and H. J. Ramey, Jr.

Application of a Lumped Parameter Model to the Cerro Prieto Geothermal Field--J. D. Westwood and L. M. Castanier

The Reykjanes Geothermal Field in Iceland: Subsurface Exploration and Well Discharge Characteristics--J. S. Gudmundsson, T. Hauksson, and J. Tomasson

Dispersion in Tracer Flow in Fractured Geothermal Systems--R. N. Horne and F. J. Rodriguez

Experimental and Finite Element Analyses of the Stanford Hydrothermal Reservoir Model--L. W. Swenson, Jr. and A. Hunsbedt

Stanford Geothermal Workshops: The First Six Years--1. G. Donaldson and P. Kruger

Third New Zealand Geothermal Workshop, Auckland, New Zealand, November 9-11, 1981

Location of Production Zones with Pressure Gradient Logging--R. N. Horne and M. Castaneda

Heat Extraction from Fractured Hydrothermal Reservoirs--1. G. Donaldson, A. Hunsbedt, P. Kruger

Geothermal Resources Council Annual Meeting, Houston, Texas, October 25-29. 1981

Location of Production Zones in the Pressure Gradient Logging--M. Castaneda and R. N. Horne

Tracer Analysis of Fractured Geothermal Systems--R. N. Horne

Society of Petroleum Engineers Annual Technical Conference and Exhibition. San Antonio. Texas. October 4-7, 1981

Pressure Response of a Reservoir with Spherically Discontinuous Properties--M. D. Onyekonwu and R. N. Horne

International Conference on Geotherm Energy, orence Italy May 11-14 1982

Implication of Adsorption and Formation Fluid Composition on Geothermal Reservoir Evaluation--M. J. Economides, R. Osterman, and F. G. Miller

Society of Petroleum Engineers California Regional Meeting, San Francisco. CA. March 24-26. 1982

Unsteady State Pressure Response Due to Production with a Slotted Liner Completion--D. Spivak and R. N. Horne

Electric Power Research Institute Sixth Annual Geothermal Conference and Workshop, Snowbird, Utah, June 28 - July 1, 1982

New Zealand: *An* Update on Reinjection Experience--R. N. Horne and M. A. Grant

Small-scale Geothermal Electric Power Units in Iceland--J. S. Gudmundsson

Geothermal Resources Council Workshop on Fractures in Geothermal Reservoirs, Honolulu, Hawaii, August 27-28, 1982

Well Tests in Fractured Reservoirs--H. J. Ramey, Jr. and A. C Gringarten

Effect of Water Injection into Fractured Geothermal Reservoirs: A Summary of Worldwide Experience--R, N. Horne

Fourth Symposium on the Cerro Prieto Field. Baia California. Mexico. August, 1982

Relationship of Radon Concentration to Spatial and Temporal Variations of Reservoir Thermodynamic Conditions in the Cerro Prieto Geothermal Field--L. Semprini and P. Kruger

Society of Petroleum Engineers Annual Technical Conference and Exhibition. New Orleans. Louisiana. September 26-29. 1982

Interpretation of Interference Tests in Reservoirs with Double Porosity Behavior--Theory and Field Expertiments--B. G. Deruyck, D. P. Bourdet, G. DaPrat, and H. J. Ramey, Jr.

Effects of External Boundaries on the Recognition and Procedure for Location of Reservoir Pinchout Boundaries by Pressure Transient Analysis--M. G. Gerard and R. N. Horne

Pressure Distribution in Eccentric Circular Systems--K. O. Temeng and R. N. Horne

Society of Petroleum Engineers Journal (February 1982), 108-116

Effects of Vaporization and Temperature in Gas/Liquid Relative Permeability Experiments--J. R. Counsil and H. J. Ramey, Jr.

Recent Trends in Hydrogeology, Geol. Soc. Am. Special Paper 189 (1982), 265-272

Well Loss Function and the Skin Effect: A Review--H. J. Ramey, Jr.

Journal of Petroleum Technology, (May 1982), 976-988

Geothermal Steam Well Testing: State of the Art--M. J. Economides, D. O. Ogbe, F. G. Miller, and H. J. Ramey, Jr.

Geothermics. Vol. 11. (1982). 59-68

Low-temperature Geothermal Energy Use in Iceland--J. S. Gudmundsson

Geothermal Resources Council Bulletin. 11. (May 82)

Utility Industry Estimates of Geothermal Electricity--V. W. Roberts and P. Kruger

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY

STANFORD. CALIFORNIA 94305

'APPENDIX C: TECHNICAL REPORTS

SGP-TR-1* Paul Kruger and Henry J. Ramey, Jr., "Stimulation and Reservoir Engineering of Geothermal Resources," Progress Report No. 3, June, 1974.

SGP-TR-2* Norio Arihara, "A Study of Non-isothermal and Two-phase Flow Through Consolidated Sandstones," November, 1974.

SGP-TR-3* Francis J. Casse, "The Effect of Temperature and Confining Pressure on Fluid Flow Properties of Consolidated Rocks," November, 1974.

SGP-TR-4* Alan K. Stoker and Paul Kruger, "Radon Measurements in Geothermal Systems," January, 1975.

SGP-TR-5* Paul Kruger and Henry J. Ramey, Jr., "Stimulation of Geothermal Aquifers," Progress Report No. 1, March, 1973.

SGP-TR-6* Henry J. Ramey, Jr., William E. Brigham, Hsiu-Kuo Chen, Paul G. Atkinson, and Norio Arihara, "Thermodynamic and Hydrodynamic Properties of Hydrothermal Systems," April, 1974.

SGP-TR-7* Anstein Hunsbedt, Paul Kruger, and Alexander L. London, "A Laboratory Model of Stimulated Geothermal Reservoirs," February, 1975.

SGP-TR-8* Henry J. Ramey, Jr., and A. Louis London, "Stimulation and Reservoir Engineering of Geothermal Resources," Progress Report No. 4, August, 1975.

SGP-TR-9* Paul Kruger, "Geothermal Energy Development," November, 1975.

SGP-TR-10* Ming-Ching Tom Kuo, Paul Kruger, and William E. Brigham, "Heat and Mass Transfer in Porous Rock Fragments," December 1975.

SGP-TR-11* Anstein Hunsbedt, Paul Kruger, and A. L. London, Laboratory Studies of Stimulated Geothermal Reservoirs," December, 1975.

SGP-TR-12* Paul Kruger and Henry J. Ramey, Jr., editors, "Geothermal Reservoir Engineering," Proceedings, Workshop on Geothermal Reservoir Engineering, Stanford University, December, 1975.

SGP-TR-13* Muhammadu Aruna, "The Effects of Temperature and Pressure on Absolute Permeability of Sandstones," May, 1976.

SGP-TR-14* Paul G. Atkinson, "Mathematical Modelling of Single-Phase Nonisothermal Fluid Flow through Porous Media," May, 1976.

* Out of print

SGP-TR-15 Hsiu-Kuo Chen, "Measurement of Water Content of Porous Media Under Geothermal System Conditions," August, 1976.

SGP-TR-16 Ming-Ching Tom Kuo, Paul Kruger, and William E. Brigham, "Shape Factor Correlations for Transient Heat Conduction from Irregular Shaped Rock Fragments to Surrounding Fluid," August, 1976.

SGP-TR-17 Stephen D. Chicoine, "A Physical Model of a Geothermal System — Its Design and Construction and Its Application to Reservoir Engineering," June, 1975.

SGP-TR-18 Paul G. Atkinson, "Numerical Simulation of Two-phase Boiling Flow in a Linear Horizontal Porous Medium," December, 1975.

SGP-TR-19 Roger P. Denlinger, "An Evaluation of the Capacitance Probe As a Technique for Determining Liquid Saturations In Laboratory Flow Experiments," June 4, 1975.

SGP-TR-20* Summaries: Second Workshop on Geothermal Reservoir Engineering, December 1-3, 1976.

SGP-TR-21* Paul Kruger and Henry J. Ramey, Jr., "Final Report to National Science Foundation."

SGP-TR-22 Gary Warren, "Radon in Vapor-Dominated Geothermal Reservoirs," December, 1978.

SGP-TR-23 Chih-Hang Hsieh, "Progress Report on Experiments on Water Vapor Pressure Lowering Relating to Capillarity and Adsorption-Desorption," November, 1977.

SGP-TR-24 Syed M. Tariz, "A Study of the Behavior of Layered Reservoir with Wellbore Storage and Skin Effect," December, 1977.

SGP-TR-25* Proceedings: Third Workshop on Geothermal Reservoir Engineering, December 14-16, 1977.

SGP-TR-26* Leslie S. Mannon and Paul G. Atkinson, "The Real Gas ~- Pseudo-Pressure for Geothermal Steam," September, 1977.

SGP-TR-27 Paul Kruger and Lewis Semprini, "Radon Data--Phase I Test, Los Alamos Scientific Laboratory, LASL Hot Dry Rock Project, January 27-April 12, 1978."

SGP-TR-28 Paul Kruger and Henry J. Ramey, Jr., "Stimulation and Reservoir Engineering of Geothermal Resources," First Annual Report to U.S. Department of Energy, April 1978.

SGP-TR-29 Kiyoshi Shinohara, "Calculation and Use of Steam/Water Relative Permeabilities in Geothermal Reservoirs," June 1978.

* Out of print

SGP-TR-30* Proceedings: Fourth Workshop on Geothermal Reservoir Engineering, December 13-15, 1978.

SGP-TR-31 Roberto Iregui, Anstein Hunsbedt, Paul Ktuger, and Alexander L. London, "Analysis of the Heat Transfer Limitations on the Energy Recovery from Geothermal Reservoirs," June 1978.

SGP-TR-32 Paul Rruger and Henry J. Ramey, Jr., Stanford Geothermal Program Progress Report No. 7 to the U.S. Department of Energy for the Period October 1, 1978 to December 31, 1978.

SGP-TR-33 Paul Kruger, Lewis Semprini, Gail Cederberg, and Luis Macias, "Recent Radon Transient Experiments," December, 1978.

SGP-TR-34 Patricia Arditty, "The Earth Tide Effects on Petroleum Reservoirs; Preliminary Study," May, 1978.

SGP-TR-35 Paul Kruger and Henry J. Ramey, Jr., "Stimulation and Reservoir Engineering of Geothermal Resources," Second Annual Report to U.S. Department of Energy/LBL. DOE-LBL #1673500, September 1979.

SGP-TR-36 Christine A. Ehlig-Economides, "Well Test Analysis €or Wells Produced at a Constant Pressure," June 1979.

SGP-TR-37 John R. Counsil, "Steam-Water Relative Permeability," May 1979.

SGP-TR-38 Chih-Hang Hsieh, "Vapor Pressure Lowering in Porous Media," August 1980, Ph.D. Dissertation.

SGP-TR-39 Kiyoshi Shinohara, "A Study of Inertial Effect in the Wellbore in Pressure Transient Well Testing," April 1980.

SGP-TR-40* "Proceedings: Fifth Workshop on Geothermal Reservoir Engineering," December 12-14, 1979. (Henry J. Ramey, Jr., and Paul Kruger, Editors)

SGP-TR-41 Kern H. Guppy, "Non-Darcy Flow in Wells with a Finite Conductivity Vertical Fracture," Spring 1980.

SGP-TR-42 Proceedings, Special Panel on Geothermal Model Intercomparison Study, at the Sixth Workshop on Geothermal Reservoir Engineering, Dec. 17, 1980.

SGP-TR-43 Abraham Sageev, "The Design and Construction of an Absolute Permeameter to Measure the Effect of Elevated Temperature on the Absolute Permeability to Distilled Water of Unconsolidated Sand Cores," December 1980 (M.S. Report).

SGP-TR-44 Hasan Y. Al-Yousef "Limitations of the p/a Approximation in the Analysis of Pressure Drawdown Interference with Variable Flow Rate," June 1979 (M.S. Report).

* Out of print

SGP-TR-45 Henry J. Ramey, Jr., and Paul Kruger, "Stimulation and Reservoir Engineering of Geothermal Resources," Third Annual Report to U.S. Dept. of Energy, September, 1980.

SGP-TR-46 Lewis Semprini and Paul Kruger, "Radon and Ammonia Transects in Geothermal Reservoirs," September, 1981.

SGP-TR-47 Mario Castaneda, "Feed Zones in Geothermal Wellbores," March, 1981 (M.S. Report).

SGP-TR-48 John D. Westwood and Louis M. Castanier, "The Application of Lumped Parameter Modeling *to* Cerro Prieto Geothermal Field," June, 1981.

SGP-TR-49 Giovanni Da Prat, "Well Test Analysis for Naturally-Fractured Reservoirs," July, 1981 (Ph.D. Dissertation).

SGP-TR-50* Henry J. Ramey, Jr., and Paul Kruger, Editors, "Proceedings, Sixth Workshop on Geothermal Reservoir Engineering," Dec. 16-18, 1980.

SGP-TR-51 Henry J. Ramey, Jr., and Paul Kruger, "Geothermal Reservoir Engineering Research at Stanford University," First Annual Report, DOE Contract No. DE-AT-03-80SF11459, September, 1981. (Period: 10-1-80 - 9-30-81).

SGP-TR-52 David Spivak, "Unsteady-State Pressure Response in a Slotted Liner," October, 1981 (M.S. Report).

SGP-TR-53 Kenneth A. Breitenbach, "Chemical Tracer Retention in Porous Media," June, 1982 (M.S. Report).

SGP-TR-54 Rajiv Rana and Drew Nelson, "Exploratory Study of the Effect of Thermal Stressing on Granite Strength and Porosity," December, 1981.

SGP-TR-55* Paul Kruger, Henry J. Ramey, Jr., Frank G. Miller, Roland N. Horne, William E. Brigham, Ian G. Donaldson, and Jon S. Gudmundsson, Editors, "Proceedings Seventh Workshop Geothermal Reservoir Engineering," December 15-17, 1981.

SGP-TR-56 Martin P. Fossum, "Tracer Analysis in a Fractured Geothermal Reservoir: Field Results from Wairakei, New Zealand," June, 1982 (M.S. Report).

SGP-TR-57 Roland N. Horne, "Effects of Water Injection into Fractured Geothermal Reservoirs: A Summary of Experience Worldwide," June, 1982.

SGP-TR-58 Paul Kruger, "Experimental Studies on Heat Extraction from Fractured Geothermal Reservoirs," November, 1982.

* out of print