Geothermal Resources Council, TRANSACTIONS, Vol. 12, October 1988

PREPRODUCTION SIMULATION OF THERMAL DECLINE AT LA PRIMAVERA FIRST 5-MW WELLHEAD UNITS

P. Kruger*, A. Aragon**, R. Maciel***,
C. Lucio***, and J. Villa***

*SGP Stanford University, Stanford
**CFE Gerencia, Morelia
***CFE Residencia, Guadalajara

ABSTRACT

Thermal breakthrough of separator brine and turbine condensate reinjected into non-production wells at the La Primavera geothermal field in central Mexico has been estimated for the first two 5-MW portable generating units to be installed in 1989. The analyses are based on staff-compiled reservoir and preproduction flow data used with the SGP 1-D radial and doublet heat sweep models. The results are useful in selection of wells for recharge disposal of the waste fluids. The data were compiled under a single radial return flow geometry with mean reservoir characteristics for the two units. The simulations cover a range of reservoir and production parameter values that effect the cooldown rate of produced fluid from the three production wells to an abandonment temperature of 170°C, corresponding to the minimum inlet pressure to the CFE 5-MW generating unit turbines. The data show a range of thermal decline of 35 to 90 years over a range of return heat sweep angle from 25 to 65 degrees to the abandonment temperature for recharge of 68 % of the produced fluid and a cooldown rate of the reservoir fluid of -0.005 per year. The dependence on cooldown rate and mean fracture spacing is small. The doublet heat sweep model shows recharge fluid returning over a period of 450 years with thermal decline to 170°C in 300 years, compared to an estimated cooldown in 150 years without reinjection recharge.

INTRODUCTION

The La Primavera geothermal field is located in the State of Jalisco in the south-central part of Mexico, about 15 km west of the city of Guadalajara. The surroundings of the field are shown in Figure 1. The field currently contains 8 wells, of which seven have been evaluated as commercial production wells. Table 1 lists the characteristics of these wells. Three of them, PR-1, PR-8, and PR-9, have been designated as production wells for connection to the two portable 5-MW generating units to be installed during 1989.

The brines that will be collected from the separators at these wells during production are planned for disposal by reinjection into the formation, with consideration of non-productive well PR-2 as the injection well. Studies are underway to evaluate the potential for thermal breakthrough of the cooled reinjected brines at the production zone. This study using the SGP 1-D Heat Sweep Model with preproduction data currently available or estimated for steady-production conditions provides early analysis of the implications of reinjection on reservoir behavior.

Table 1
Preproduction Data for the La Primavera Wells+

Well No.	Total Depth (m)	Open Interval (m)	P(wh) (bar)	Q(v)* (t/h)	Q(w)* (t/h)	H(wh)* (kJ/kg)
PR-1	1822	1440-1818	10.7	39.7	55.4	1918
PR-2	2000	1567-1995	--	i	i	--
PR-8	1861	1423-1850	7.6	30.7	64.1	1783
PR-9	2986	1735-2161	9.3	60.7	17.5	1807
PR-10	2271	1799-2143	s	--	--	--
PR-11	2157	1800-2150	s	--	--	--
PR-12	2303	1705-2293	--	--	--	--
PR-13	2006	1800-2000	s	--	--	--

* estimated at P(wh) = 8 bar
i to be used as injection well
s under temperature stabilization
\+ data obtained from CFE Residencia, Guadalajara (April, 1988).

GEOLOGICAL CONDITIONS

The geothermal field La Primavera, Jalisco, is within a Quaternary volcanic complex, associated with a caldera and domes arranged in semi-circular form that encircles a zone of collapse. The collapse zone made room for a sedimentary basin, which has been named the Mexican Volcanic Belt (Venegas, et al., 1981;Gutierrez, 1984). The basement of this volcanic complex is associated with a series of flows consisting of basalts, ignimbrites, rhyolites, and andesites, outcropping to the large Santiago River. The observed lavas are characterized by their large alkalinity in comparison with the more recently erupted lavas to the south of the complex, which appeared after the pyroclastics called Toba Tala. The emplacement of the magma towards the southeast margin of the caldera resulted in the formation of new domes, consisting of largely aphiritic obsidian that marks the last volcanic event of this complex. Actually, it is considered that the magmatic chamber has begun the process of final solidification and cooling.

During the drilling of the existing wells in the field, detailed studies of recovered cores and cuttings have verified the subsurface lithology. The specific wells in this study, PR-1, PR-2, PR-8, and PR-9, are being geologically evaluated by Gutierrez (1981), Venegas (1984), and Sanchez (1985). The most complete stratigraphic column, that cut for well PR-9 reaching a depth of 2986 m, is described in Figure 2.

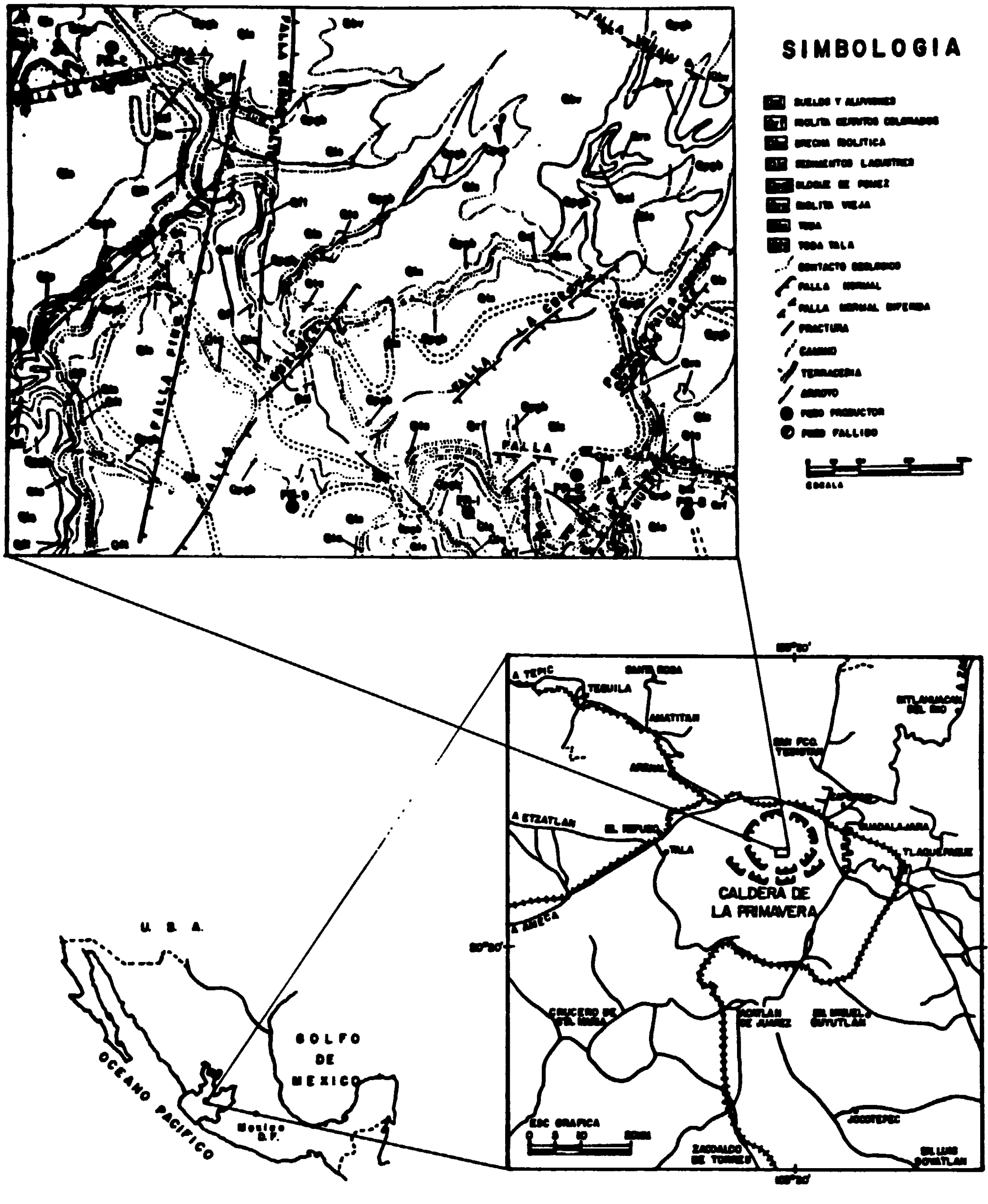

Fig. 1. Location of the La Primavera geothermal field showing the fault structure in the caldera zone.

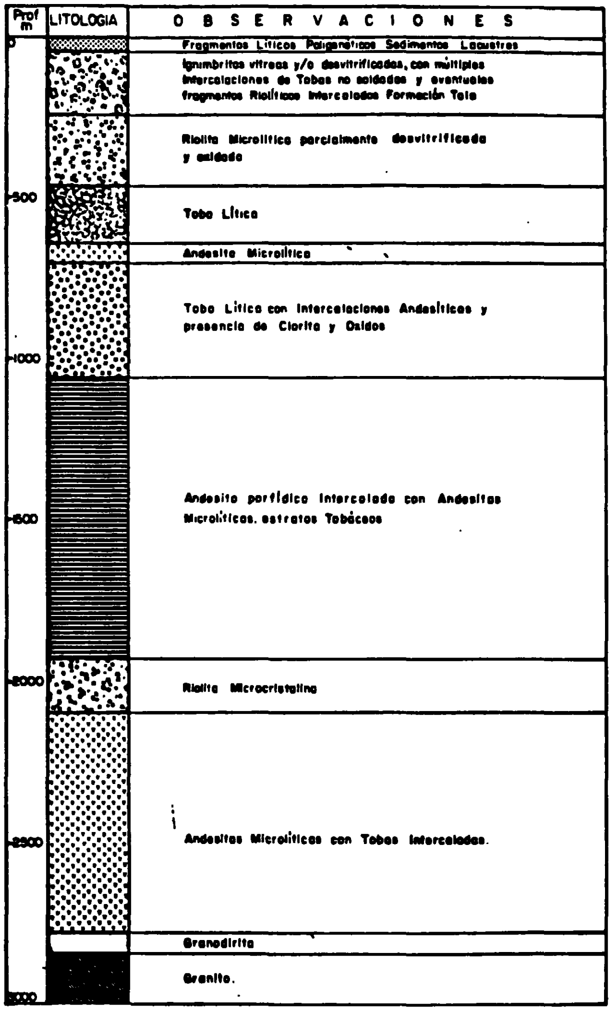

Fig. 2. Lithologic column for well PR-9.

The chemical aspects of the reservoir between the injection well PR-2 and the three production wells have been evaluated. From measurements of separated brines, the water from wells PR-1,PR-8, and PR-9 show a sodium-chloride character, whereas the water from injection well PR-2 has a mixed character, namely sodium-bicarbonate-chloride. Furthermore, the waters from the three production wells indicate that communication exists between the wells, and that the water from well PR-2 does not have the same source.

DATA COMPILATION

The data used in the present study were compiled by analysis of all available exploration, chemical, laboratory, and field data. Where measured data were not available, estimates were made based either on other similar studies or plans for operating conditions under sustained flow of the production wells. A summary of the data used for the HSWEEP.DAT input file to the SGP 1-D Heat Sweep Model is given in Table 2. A composite cross section of the reinjection recharge return flow is given in Figure 3.

The production data given in Table 1 are the most recent values measured by the CFE Residencia technical staff. The reinjection flowrate includes 1.9 kg/s of condensate from each turbine which will be added to the separator brine flow. The initial temperature estimated for the recharge flow zone was obtained from available mechanical logs, which indicated a mean reservoir temperature of approximately 280°C. The temperature of the reinjected fluid was selected as 70°C taking into account the brine and condensate temperatures and the time for surface storage before reinjection. A study has been initiated to evaluate the potential for thermal dispersion in various surface storage sites at the field to obtain data for future simulations.

The value for mean reservoir porosity was selected from those obtained by Iglesias et al . (1986) from analysis of cores obtained from the Los Azufres geothermal field in Michoacan. Values for the thermal conductivity were also obtained from the same source. In addition to the flow of the reinjection recharge with its thermal sweep properties, the total production rate is maintained by makeup flow from the geothermal fluid source cooling at a mean exponential rate of $-0.005\ y^{-1}$, a value observed at other geothermal fields. The effect of various rates of cold water intrusion to the geothermal fluid at the production well from percolation or groundwater seepage can be modeled by varying the cooldown rate parameter.

RESULTS

A description of the SGP 1-D Heat Sweep Model has been given in several reports. The original model for linear flow was reviewed in detail by Hunsbedt, Lam, and Kruger (1984). Improvements to the model by Lam (1986) to include radial flow and mixing injection recharge flow with reservoir makeup flow and areal percolation was described by Kruger et al (1985). The recent addition of doublet flow was summarized by Lam and Kruger(1987). The simulations for the La Primavera preproduction data given in Table 2 was run with the radial flow model for scenarios of individual flow from reinjection well PR-2 to each of the three production wells for small angle return flow in the event of direct return through large fracture connections, for combined flow through larger angles for dispersed flow in the preferred direction from recharge mound to production drawdown zones, and with the doublet flow model for the limiting case of isotropic dispersion along the doublet streamlines from the injection well to the center of the production zone.

A summary of the cooldown times to the abandonment temperature of $T_a = 170°C$ is given in Table 3 for the small angle return flow to the three production wells of Units 1 and 2. In Table 4, the data are summarized for the collective flow to the wells as functions of return flow angle for both the radial and doublet flow models, mean fracture spacing, and reservoir fluid cooldown rate. The results are shown in Figures 4 to 6.

Table 3
La Primavera Heat Sweep Simulations
Small Angle Individual Flows

Time (years) to $T_a = 170°C$

Return Flow Sweep Angle (o)	PR2-PR9		PR2-PR1		PR2-PR8	
	Sweep Fluid	Mixed Fluid	Sweep Fluid	Mixed Fluid	Sweep Fluid	Mixed Fluid
5	8.6	12.1	24.8	31.6	38.6	42.7
10	18.2	22.4	50.3	57.0	78.2	81.4
15	27.7	32.3	75.6	81.4	118	119

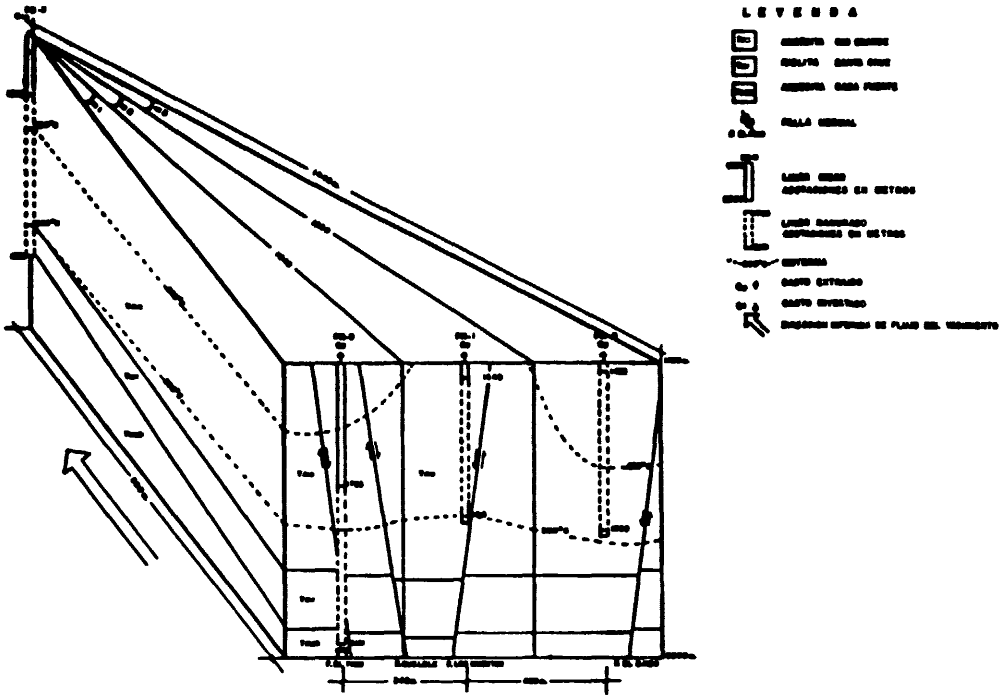

Fig. 3. Isometric view of the radial flow geometry selected for the simulations, showing structural details, major lithology, and temperature contours.

Table 2
Input Data for La Primavera Heat Sweep Analysis

	PR2-PR9	PR2-PR1	PR2-PR8	PR2-PR918
Init Res Temp (C)	280	280	270	277
Recharge Temp (C)	70	70	70	70
Inj Flowrate (kg/s)	34.6	16.4	18.8	69.8
Res Flowrate (kg/s)	14.8	10.1	7.6	32.5
Res Thickness (m)	426	378	427	410
Inner Radius (m)	0.089	0.057	0.089	0.078
Outer Radius (m)	950	1140	1440	1180

Constants

Porosity (%)	10
Res Cooldown Rate (y^{-1})	-0.005
Mean Fracture Spacing (m)	50
Rock Density (kg/m^3)	2450
Water Density (kg/m^3)	843
Rock Spec Heat Cap (J/kg C)	1164
Water Spec Heat Cap (J/kg C)	4870
Rock Thermal Cond (W/m C)	1.786
Heat Transfer Coeff (W/m^2 C)	1700

Parameters for Specific Simulations

Return Flow Angle		
Individual Production Wells	(deg)	5,10,15
Collective Flow	(deg)	25,45,65
Mean Fracture Spacing	(m)	25,50,100
Reservoir Fluid Cooldown Rate	(y^{-1})	-0.001,-0.005,-0.01

Table 4
La Primavera Heat Sweep Simulations
Units 1+2 Collective Flow

Time (years) to T_a = 170°C

	PR2 - PR9+PR1+PR8	
	Sweep Fluid	Mixed Fluid
I Heat Sweep Angle		
Radial Flow (o)		
25	33.9	38.9
45	61.6	66.3
65	89.2	92.8
Doublet Flow (o)		
360 (with sweep)	484	297
(w/o sweep)	--	146
II Mean Fracture Spacing		
MFS (m)		
25	62.0	65.3
50	61.6	66.3
100	59.0	67.7
III Res. Fluid Cooldown Rate		
CDR (y^{-1})		
-0.001	61.6	71.2
-0.005	61.6	66.3
-0.010	61.6	62.6

DISCUSSION

It is anticipated that reinjection of 68 % of the produced fluid will result in a return flow geometry somewhere between direct flow through specific unknown fractures and isotropic flow under the classical doublet flow model. The 1-D radial flow model for the small angle direct flow of 5 degrees yields a range of injection sweep fluid breakthrough times to abandonment temperature (Table 3) from 8.6 years for well PR-9 to 38.6 years for the more distant well PR8. The times are slightly longer for the bottom hole mixed fluid. These times would constitute a significant risk for premature thermal breakthrough if such direct fractures were indeed present. For a larger angle of 15 degrees for direct flow, the breakthrough times increase to 32 to 120 years, respectfully.

For the collective flow assumption (using ±20 deg from the geometric angle of 45 deg in the sector from recharge well PR2 to the mean arc of the three production wells), the corresponding range of thermal breakthrough times (Table 4) range from 40 to 93 years, entailing significantly less risk. For full doublet flow conditions, the time to abandonment temperature is about 300 years with injection recharge heat sweep and about 150 years without. Figure 6 shows the extent of secondary heat recovery (the area between the cooldown curves for the bottom hole mixed fluid) with and without injection recharge heat sweep.

Figure 5 shows the small effect of varying the reservoir fluid cooldown rate from -0.001 to -0.01 y^{-1} and Table 4 shows the small effect of varying the mean fracture spacing from 25 to 100 m as the controlling parameter for heat transfer from the formation rock blocks to the injection fluid. For the given key parameters, it appears that 68 % reinjection for the two units some 1150 m from the PR2 injection well should result in small risk from premature cooldown to abandonment temperature and significant benefit of secondary recovery of thermal energy by about a factor of two. Additional heat sweep analysis should be of interest following acquisition of initial production data from the first two 5-MW portable generating units at La Primavera.

REFERENCES

Venegas S., S., Geología de la Sierra de La Primavera,Estado de Jalisco. Informe 52/81. C.F.E. Inédito.,1981.

Gutiérrez Negrín, L., López Martínez, A. y Balcázar García, M.,"Application of dating for searching geothermic sources", Nuclear Tracks and Radiation-Measurements, vol. 8. núms. 1-4, pp. 380-385, 1984.

Gutiérrez N., L.C.A., Litología y Mineralogía secundaria del pozo PR-2 de La Primavera, Jal. Informe 19-81 C.F.E. Inédito, 1981.

Venegas S., S., Informe geológico del pozo Primavera No. 1. Reporte RPG - 6-84. C.F.E. Inédito, 1984.

Sánchez, R.S., Informe geológico del pozo Primavera No. 8 Reporte RPG - 1-85. C.F.E. Inédito, 1985.

E. Iglesias, E. Contreras, and A. Garcia, "Apoyo para Diagnosticosde Perforacion de Pozos Mediante la Determinacion de Propiedades Fisicas de Rocas en Medios Geotermico. Fase 1: Correlaciones entre Petrologia y Petrofisica en Campos del Eje Neovolcanico", Informe Final, IIE/11/2014/I, 1987.

A. Hunsbedt, S. Lam, and P. Kruger, User's Manual for the 1-D Linear Heat Sweep Model, Stanford University, SGP-TR-75,April , 1984.

S. Lam, Heat Extraction Modeling of Single-Phase Sweep Flows in Fractured Geothermal Reservoirs, Ph.D. Dissertation, Stanford University, Stanford, CA, December 1988.

P. Kruger, S. Lam, A. Hunsbedt, C. Esquer, R. Marquez, L. Hernandez, and J. Cobo, Analysis of Recharge Cooldown at the Western Boundary of Cerro Prieto I Geothermal Field, Proceedings, Tenth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, January, 1985.

S. Lam and P. Kruger , 1-D Doublet Heat Sweep Model, 9th New Zealand Geothermal Workshop, Auckland, NZ, 1988.

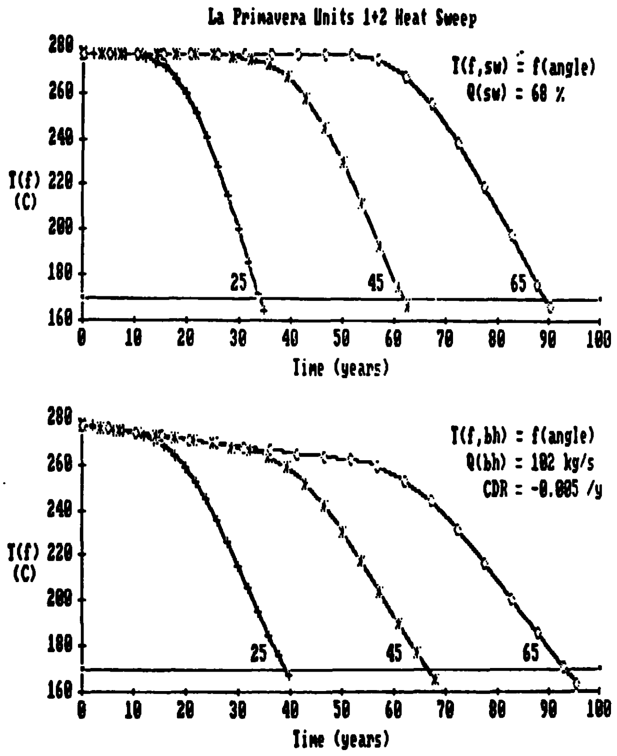

Fig. 4. Upper: Sweep fluid temperature at the production well as a function of return flow angle to the abandonment temperature of 170°C; Lower: mixed bottom hole temperature with reservoir fluid cooldown rate of ~0.005 y^{-1}.

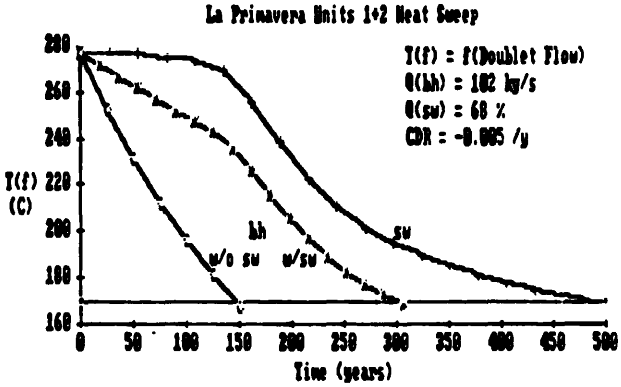

Fig. 5. Produced fluid temperature as a function of assumed reservoir fluid cooldown rates of -.0.001, -0.005, and -0.01 y^{-1}.

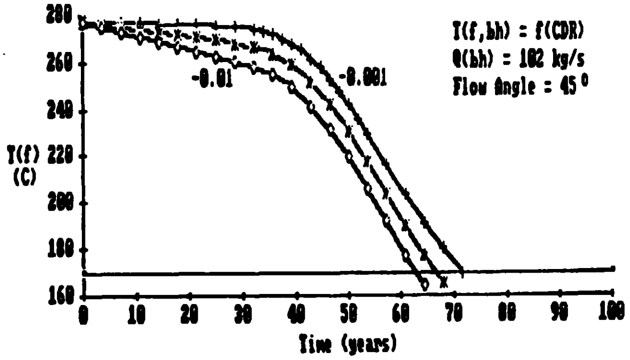

Fig. 6. Produced fluid temperature for doublet flow geometry, showing the relative heat extraction with and without reinjection recharge heat sweep.