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HEAT SWEEP ANALYSIS OF THERMAL BREAKTHROUGH AT LOS HUMEROS AND LA PRIMAVERA FIELDS, MEXICO

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ABSTRACT

Early evaluation of the potential for thermal breakthrough of reinjected fluids in newly developed geothermal fields can be obtained with the SGP one-dimensional heat sweep model. The model was used to estimate fluid cooldown from wells selected for the first wellhead generating units to be installed at the Los Humeros and La Primavera geothermal fields in Mexico, based on staff-compiled geometric and geologic data, thermal properties of the reservoir rock, and expected production conditions. Geometric considerations were evaluated with respect to known and postulated fault zones and return flow angle of the reinjected fluid. The results show the range of parameter values that affect the rate of thermal breakthrough to an abandonment temperature of 170 °C corresponding to the minimum inlet pressure to the CFE 5-MW wellhead generator units.

INTRODUCTION

Los Humeros and La Primavera are geothermal fields in Mexico at which the Comision Federal de Electricidad (CFE) has announced installation of first 5-MW wellhead units for 1987-88. In management planning of field operation, one of the early decisions required for these first units is the choice of reinjection wells for the separated brines and condensates. An important aspect of such choices is the thermal behavior of the reinjected fluid from either surface-stored water bodies or directly from the liquid leg of the wellhead separators. The one-dimensional heat sweep model, described by Hunsbedt, Lam, and Kruger (1983), can be used as a tool for early estimate of the potential for thermal breakthrough of recharge fluids to geothermal wells under steady production. An advantage in the use of this simple, one-dimensional model, especially for newly developed geothermal fields, is in the selection of a practical range of values for the parameters of temperature distribution, reservoir flow geometry, formation structure, thermal properties of the formation composition, and planned production conditions. The model allows rapid evaluation of the estimated wellhead fluid temperature decline curve over a wide variety of assumed reservoir and production parameters.

The model is based on the equations for heat transfer from a distribution of fractured rock blocks to the pore fluid in a geothermal reservoir. The basic equations for heat transfer from a distribution of rock blocks described as lumped equivalent radius spheres were given by Kuo et al. (1977) and Hunsbedt et al. (1979). The one-dimensional heat sweep model, improved by Lam (1986), allows for five types of fluid flow geometry and fluid mixing near the production wells; linear and radial flow geometries between single and lines of injection and production wells either by heat sweep alone or by mixing flow with percolation recharge flow from above and/or hot water flow from the reservoir.

The model has been applied to a number of projects in Mexican geothermal fields, for example the Cerro Prieto field in Baja California (Kruger, 1985) and the Los Azufres field in Michoacan (Molinar, et al., 1986). The model has been applied at two new fields, Los Humeros in Puebla and La Primavera in Jalisco. This report describes the initial results of the studies carried out jointly between the Stanford Geothermal Program and the Comision Federal de Electricidad to evaluate the planned reinjection schemes for the first 5-MW wellhead units to be installed at the Los Humeros and La Primavera geothermal fields.

LOS HUMEROS UNIT 1 STUDY

The Los Humeros geothermal field is located in the State of Puebla, 200 km east of Mexico City, along the Mexican volcanic axis described by Alonso (1975). A description of the field and available pre-production data for the wells drilled to date are reported by the Residencia de Perforacion (1986). A map of the geothermal area is given in Figure 1. The structural geometry of the geothermal zone lies along a general NW-SE axis with three principal collapse areas, an outer ring mainfested primarily in the western border, an intermediate ring with characteristic walls noted in the south and east of the field, and a central collapse zone with subsidence walls noted in the north and east. The Los Humeros corridor is aligned primarily NW-SE bounded laterally by the regional tectonic structure.

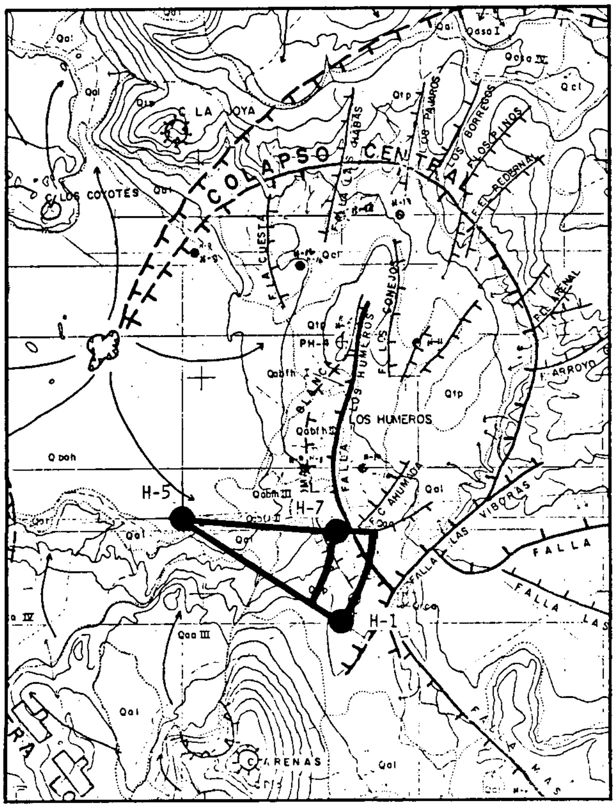

Fig. 1. Radial flow geometry from the proposed reinjection well H-5 to the two production wells H-7 and H-1 for the first 5-MW wellhead unit at Los Humeros.

The thermal manifestations of the field have been evaluated geochemically in five zones by noncondensable gas geothermometry as follows:

1. 290-320 °C
2. 307-324 °C = Zone A
3. 312-330 °C
4. 280-300 °C = Zone B
5. 310-330 °C = Zone C

with zones 2 and 3 being considered the more important areas. Fifteen wells have been drilled in the central collapse zone to delineate the production potential of the field. Data for the wells that have been evaluated are given in Table 1. The last three of these wells are being considered as candidate wells for reinjection recharge.

Planning is underway to initiate exploitation of the field with the installation of three or four 5-MW wellhead flash units of the type presently operating at the Los Azufres geothermal field in Michoacan. The first of these units is being considered for the pair of wells H-1 and H-7 with possible reinjection into well H-5. The heat sweep model was used to evaluate the potential for thermal breakthrough for this system of two production wells each at different flow rates. A

Table 1

PREPRODUCTION DATA FOR 12 LOS HUMEROS WELLS*

Well No	Depth (m)	P_{wh} (MPa)	Q_v** (t/h)	Q_w (t/h)	H (kJ/kg)
H-1	1458	1.5	44	114	1300
H-6	2543	1.5	26	17	1905
H-7	2340	1.5	35	2	2606
H-8	2388	1.5	23	9	2142
H-9	2500	1.5	89	5	2630
H-10	2158	1.14	10+	1	2612
H-11	2388	1.5	31	2.7	2562
H-12	3104	1.5	42	8	2305
H-16	2048	1.5	48	3.6	2606
H-2	2301	—	+	--	--
H-4	1880	—	+	--	--
H-5	1905	—	+	--	--

+ wells contemplated for stimulation or reinjection
** at separator pressure = 0.8 MPa.
• from Residencia de Perforacion (1986).

plan view of these wells is indicated in Figure 1, which shows the geometry for the radial flow heat sweep modeling study.

Figure 2 shows the data accumulated in conjunction with the technical staff at Los Humeros. Two recharge sweep temperatures were selected, 35 °C to reflect the ambient surface water temperature on storage of the separated brine, and 115 °C to reflect the brine temperature on direct reinjection from the wellhead separators. The injection and reservoir fluid flowrates for wells H-7 and H-1 were obtained from Table 1. Well H-7 which is closer to the proposed injection well H-5 would produce only 19 % of the total Unit flow, but 44 % of the steam supply. The fraction of reinjected fluid would be only 2 % of the well flowrate. Well H-1 essentially controls the rate of reinjected fluid return. A value of $-0.005\ y^{-1}$ was selected as the expected cooldown rate, based on experience at two other fields. Since the angle between the two production wells from the injection well is about 21 degrees, heat sweep for the two wells was considered as independent small-angle radial flows ranging from 2.5 degrees (essentially direct return flow) to 20 degrees (dispersed return flow).

The results of the heat sweep runs for recharge sweep flow from well H-5 to well H-7 are shown in Figure 3. The values for the number of heat sweep units parameter were 8.5 for 2.5 degree flow and 17.1 for 5 degree flow, indicating the relatively long residence time of the sweep fluid. The small sweep fluid fraction (5 %) coupled with the small reinjection flowrate results in sufficient heat transfer to sustain the sweep fluid at 280°C while the reservoir fluid temperature declines with the assumed cooldown rate of $-0.005\ y^{-1}$. In this example, reinjection heat sweep prolongs the thermal life of the well.

Figure 4 shows the results of the well pair H-5 to H-1. In this case, the larger sweep

Problem Name HSP5b Los Humeros Unit 1 A25

Date of Analysis (DD-Mmm-YY) 20-Oct-86 A9

Reservoir Data for Heat Sweep

T(initial) 280 (°C)	T(recharge) 115 (°C)	2F10.2
Porosity 0.08 (fraction)	Q(injection) 0.6 31.7 (kg/s)	2F10.2
Mean Frac. Spacing 50 (m)	Res. Thickness 665 (m)	2F10.2

Geometry for Linear Sweep

Length (m)	Width (m)	2F10.2

Geometry for Radial Sweep

Inner Radius 0.0889 (m)	Outer Radius H7 H1 1250, 1650 (m)	2F10.2
Flow Angle α (°)		F10.2

Reservoir Data for Fluid Mixing

T(perc) 0 (°C)	Q(perc) 0 (kg/s)	2F10.2
Res. Cooldown Rate -0.005 (y^{-1})	Q(res) 10.3 12.6 (kg/s)	2F10.2

Thermal Properties

Rock: Density 2700 (kg/m^3)	Spec. Ht. Cap. 1164 (J/kgK)	2F10.2
Fluid: Density 920 (kg/m^3)	Spec. Ht. Cap. 4870 (J/kgK)	2F10.2
Rock Thermal Cond. 1.90 (W/mK)	Heat Xfer Coeff. 1703 (W/m^2K)	2F10.2
Res. Heat Loss 0 (W/m)	BETA -1.0 d12 (1/sec)	2F10.2

Program Constants

IFLAG 4	ITERM 14	2I5
NTIME 60	KTIME 4	2I5
DELT 1.0		F10.2
NSPACE 100	NUMLOC (1-5) 1	2I5
ISPLOC (I) 100		5I3

Fig. 2. Input data sheet for the two radial flows to wells H-7 and H-1 at Los Humeros.

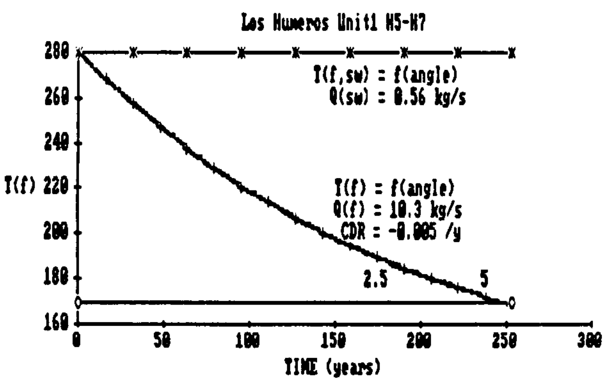

Fig. 3. Heat sweep results for recharge flow from well H-5 to H-7 at Los Humeros. Upper curve is for sweep fluid temperature for all angles; lower curve for mixed fluid temperature with reservoir fluid cooldown rate of $-0.005\ y^{-1}$.

flow fraction and injection flowrate results in a small number of heat sweep units and a more rapid sweep fluid temperature decline, which combined with the 72 % reservoir fluid flow at a cooldown rate of $-0.005\ y^{-1}$, accelerates the production fluid cooldown.

The parameter most useful to assess the results of these model runs is the time to fluid cooldown to the abandonment temperature of 170 °C corresponding to the minimum inlet pressure for the 5-MW wellhead generators.

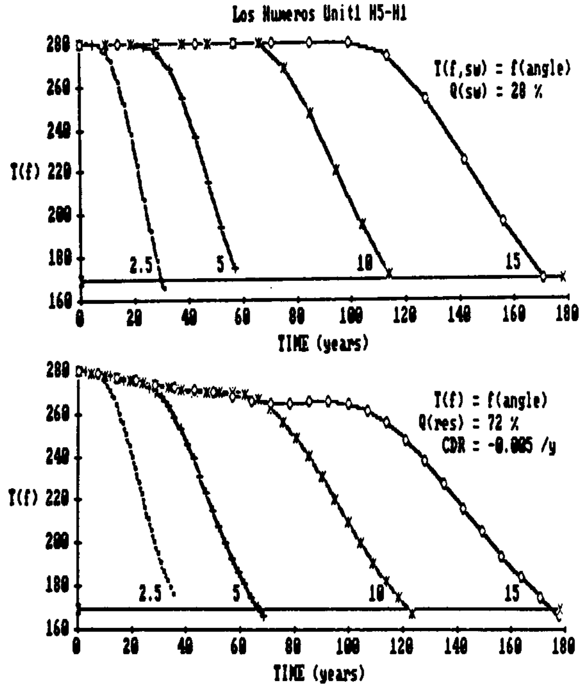

Fig. 4. Heat sweep results for recharge flow from well H-1 to H-7. Upper curves are for sweep fluid temperature as a function of recharge flow angle; lower curves for mixed fluid temperature with reservoir cooldown rate of $-0.005\ y^{-1}$.

The data for the two radial flows are summarized in Table 2, together with an estimate of the combined flow at the Unit based on the respective reinjection flowrates and the individual cooldown curves. The longer sustained temperature at well H-7 seems to add about 7 years to the time to abandonment based on well H-1 alone.

LA PRIMAVERA UNIT 1 STUDY

The La Primavera geothermal field is located in the State of Jalisco, near the city of Guadalajara. A description of the field and its geologic setting is given in the report of the first survey prepared by JICA (1986). A map of the area, showing the boundaries of the collapse zones and the location of existing production wells is given in Figure 5. From prior surveys, the general structure of the field is described as a set of fractures to a depth of about 1000 m along a NE-SW direction, with high-angle fractures below 1000 m in a NW-SE direction. To date, wells of 600 - 3000 m depth have been drilled and from the geologic studies, the zone of thermal upflow has been reasonably well identified. The earliest studied wells include PR-1, PR-5, PR-8, and PR-9. Available data for 5 la Primavera wells are given in Table 3, and a section through them with stabilized bottom-hole temperature contours is shown in Figure 6.

Table 2

LOS HUMEROS UNIT 1 THERMAL COOLDOWN TIMES

Injection Flow Dispersion Angle (degrees)	Time to T(f) = 170 °C Well H-7 (yrs)	Well H-1 (yrs)	Combined (yrs)
2.5	243	37	44
5	243	67	74
10	--	121	--
15	--	174	--

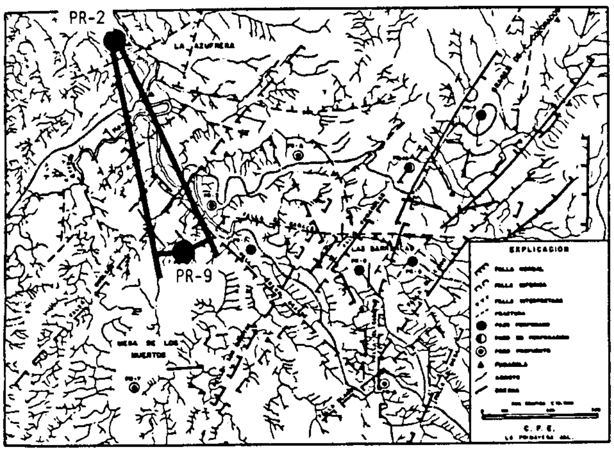

Fig. 5. Radial flow geometry from proposed reinjection well PR-2 to production well PR-9 for the first 5-MW wellhead unit at La Primavera.

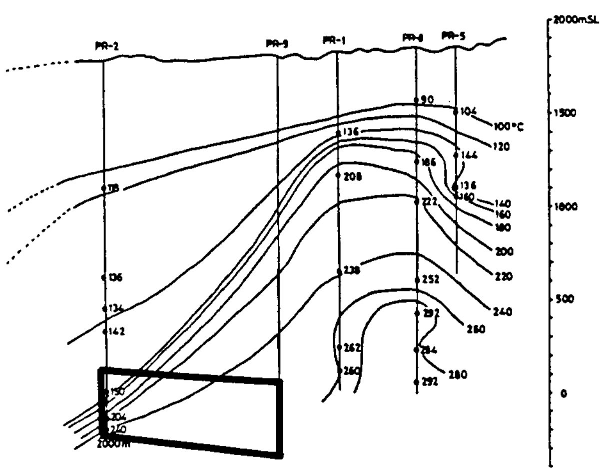

Fig. 6. Reservoir temperature distribution across the expected flow sweep zone from injection well PR-2 to production well PR-9.

Table 3

PREPRODUCTION DATA FOR 5 LA PRIMAVERA WELLS*

Well No	Depth (m)	T(bh) (C)	T(Na-K-Ca)[a] (C)	$T(SiO_2)$[b] (C)	$[Cl^-]$ (mg/l)	[NCG] (%)
PR-1	1820	260	297	295	1160	2.2
PR-2	1995	240	223	237	1120	0.21
PR-5	1213	220	250	242	780	--
PR-8	1860	292	295	280	929	3.5
PR-9	2986	250	290	293	870	0.2

[a]from Fournier and Truesdell (1973)
[b]from Fournier and Potter (1982)
*from JICA (1986)

The temperature contours suggest that the major thermal upflow zone is between wells PR-1 and PR-8. The development plan for La Primavera visualizes well PR-9 for the first 5-MW wellhead unit with well PR-2 possibly as an injection well for reinjection of the brine from the separator. Compililation of the data for recharge thermal breakthrough estimates were achieved with the technical staff at the field. The data set is shown in Figure 7. The initial reservoir temperature was estimated as the mean temperature from the contours in Figure 6. Recharge temperature was taken as 70 °C for surface-stored brine and 143 °C for direct reinjected brine from the wellhead separators. The flow rates are from production testing, and the reservoir flow, at an assumed cooldown rate of -0.005 y^{-1}, was assumed equal to the steam flow through the turbine.

Problem Name HSP6b La Primavera PR2-PR9 A25
Date of Analysis (DD-Mmm-YY) 24-Oct-86 A9

Reservoir Data for Heat Sweep

T(initial) 280 (°C) T(recharge) 70, 143 (°C) 2F10.2
Porosity 0.10 (fraction) Q(injection) 26.1 (kg/s) 2F10.2
Mean Frac. Spacing 90 (m) Res. Thickness 428 (m) 2F10.2

Geometry for Linear Sweep

Length ____ (m) Width ____ (m) 2F10.2

Geometry for Radial Sweep

Inner Radius 0.0889 (m) Outer Radius 965 (m) 2F10.2
Flow Angle 2.5, 5, 10, 20 (°) F10.2

Reservoir Data for Fluid Mixing

T(perc) 0 (°C) Q(perc) 0 (kg/s) 2F10.2
Res. Cooldown Rate -0.005 (y^{-1}) Q(res) 20.7 (kg/s) 2F10.2

Thermal Properties

Rock: Density 2450 (kg/m^3) Spec. Ht. Cap. 1164 (J/kgK) 2F10.2
Fluid: Density 920 (kg/m^3) Spec. Ht. Cap. 4870 (J/kgK) 2F10.2
Rock Thermal Cond. 1.786 (W/mK) Heat Xfer Coeff. 1703 (W/m^2K) 2F10.2
Res. Heat Loss 0 (W/m) BETA -1.0 d12 (1/sec) 2F10.2

Program Constants

IFLAG 4 ITERM 14 2I5
NTIME 60 KTIME 4 2I5
DELT 1.0 F10.2
NSPACE 100 NUMLOC (1-5) 1 2I5
ISPLOC (I) 100 ____ ____ ____ ____ 5I3

Fig. 7. Input data sheet for the radial flow at recharge temperatures of 70 °C for surface stored brines and 140 °C for direct brine reinjection from the separator.

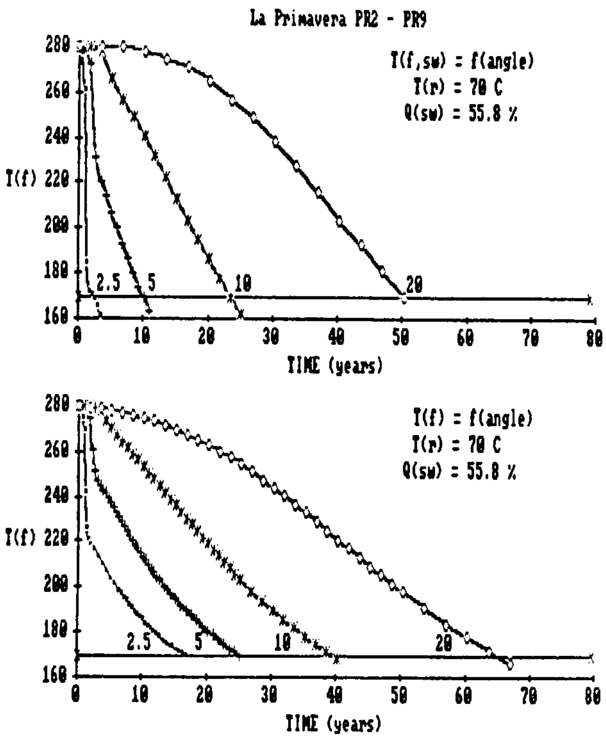

Fig. 8. Heat sweep results for recharge brine temperature of 70 °C. Upper curves are for sweep temperature cooldown as a function of return flow angle; lower curves mixed fluid temperature with reservoir cooldown rate of $-0.005\ y^{-1}$.

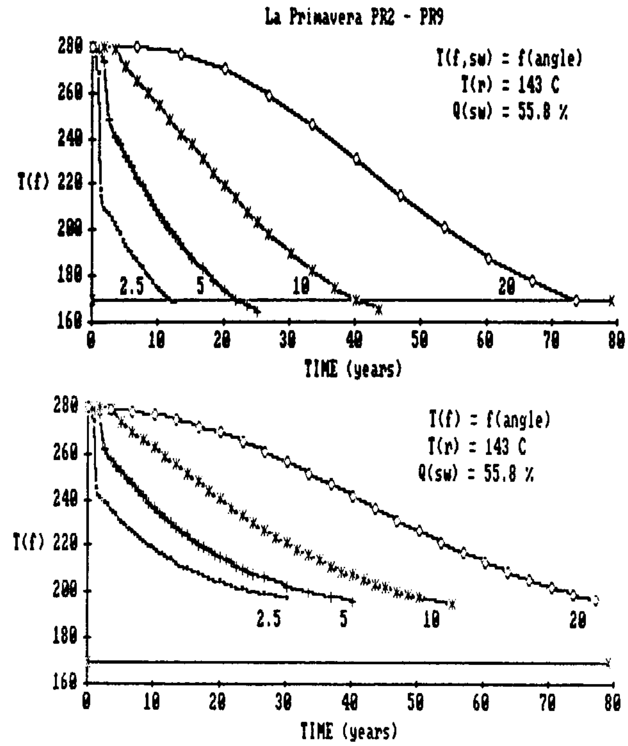

Fig. 9. Heat sweep results for recharge brine temperature of 143 °C. Upper curves are for sweep temperature cooldown as a function of return flow angle; lower curves mixed fluid temperature with reservoir cooldown rate of $-0.005\ y^{-1}$.

With no apparent geologic boundaries for containing the recharge flow, the estimates were obtained for radial flow with angles from 2.5 deg (essentially direct fracture flow) to 20 deg (more dispersed flow). The results for the reinjection temperature of 70 °C are shown in Figure 8 and of 143 °C in Figure 9. The upper part of each figure shows the temperature decline curve as it reaches the production interval and the lower part shows the mixed fluid temperatures in the well. The equilibrium mixed fluid temperature, without cooldown of the resource fluid, would be 163 °C for the 70 °C recharge sweep and 203 °C for the 143 °C recharge sweep. Figures 8 and 9 show the approach to cooldown with the assumed cooldown rate of $-0.005\ y^{-1}$. A summary of the cooldown times under this set of assumptions is given in Table 4.

ACKNOWLEDGMENT

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Table 4

LA PRIMAVERA UNIT 1 THERMAL COOLDOWN TIMES

Injection Flow Dispersion Angle (degrees)	Time to T(f) = 170 °C, T(r) = 70 °C, Q(sw) (yrs)	T(r) = 70 °C, Q(f) (yrs)	T(r) = 143 °C, Q(sw) (yrs)	T(r) = 143 °C, Q(f) (yrs)
2.5	2.3	16	12	160
5	10	25	22	160
10	23	40	40	160
20	50	65	73	160

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