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Long-term performance and sustainability of geothermal doublets

by Thomas Mégel[1] & Ladislaus Rybach [2]

[1] Mtgel GeoWatt, Sihlfeldstr. 81, 8004 Ziirich, Switzerland
e-mail: thmegel@swissonline.ch

[2] Institute of Geophysics, ETH Honggerberg, 8093 Ziirich, Switzerland
e-mail rybach@geo.phys.ethz.ch

ABSTRACT

The reinjection of the cooled water in geothermal doublet operation causes thermal drawdown in an expanding volume which propagates to the production well, where the temperature will decrease after the breakthrough time. Corresponding long-term calculations for the doublet operation in Riehen near Basel, Switzerland show that only a moderate temperature drop is to be expected even for decades of production. The maximum value will be about -0.7 K in one decade.

After produchon stop the heat production capacity of the reservoir will recover. Corresponding calculations show a recovery of the heat production capacity of the Riehen reservoir by 35%-40% after a **40** year production and a subsequent similar recovery hme. The thermal drawdown as well as the recovery occurs in an asymptotic manner. Shorter production-recovery cycles produce more thermal **energy.**

KEYWORDS

Geothermal doublet, thermal drawdown, recovery, sustainability

Introduction

The heat content of a deep aquifer can be utilised by producing the aquifer's fluid. The fluids heat is transferred through a heat exchanger to a district heating network, whereas the cooled water is reinjected into the aquifer by a second borehole at a sufficient distance to the production borehole (doublet operation). **Due** to this geothermal circuit the produced hot fluid is continuously replaced by cooled injected water. This leads to an increasing volume of thermal drawdown propagating from the injection to the production well. After the thermal breakthrough time the temperature **of** the produced fluid will decrease with a rate depending on the production rate, the distance between the boreholes as well as on the physical and geometric properties of the reservoir. The increasing thermal gradients in the reservoir cause a correspondingly increasing conductive thermal recovery. Hence a thermal steady state will be reached after a sufficient circulation time which yields a constant production temperature.

A central question often concerns the sustainability of a geothermal operation in general. Principally geothermal resources are renewable in consequence of the heat flux from the earth's interior. However, due to economic constraints the heat production of a geothermal operation exceeds the natural thermal resupply considerably. Therefore considerations about the sustainability of a geothermal operation includes also the recovery effect after the production has stopped.

The geothermal operation in Riehen

In the community of Riehen near the city of Basel a heating network has been installed in 1994, which supplies about 160 users. About 50% of the needed energy are covered by a geothermal doublet operation (production well 1547 m, reinjection well 1247 m in a distance of 1.0 km). The fluid is produced from a fractured aquifer (Triassic "Oberer Muschelkalk). The geothermal doublet operates with variable circulation rates. The extraction/reinjection flow rate depends on the seasonally changing demand. The annual average flowate is 10 **l/s.** Reinjection temperature is **25°C** which yield a useable temperature drop of 37 K.

It is essential to provide the heat exchanger with a production temperature of 62°C without a considerable drawdown **for** about **30** years. It has been demonstrated by numerical simulations in (MEGEL 1996) that these boundary conditions are fulfilled by the geothermal circuit even **for** a distance of 100 m between the fracture zones. Results of these numerical calculations for porous and fractured reservoir types **are** presented in this paper shortly.

Additional attention is focussed on the recovery effect of the geothermal doublet operation in Riehen. Results of numerical (finite element) calculations for porous and fractured reservoir models are presented.

Reservoir model

The geothermal operation Riehen utilises hot water from the "Oberer Muschelkalk" aquifer at the border of the Rheingraben rift structure. Three different FE-models have been used for the calculations of the production temperature and thermal recovery:

1. homogeneous porous aquifer
2. fractured aquifer with a distance between the fracture **zones** of 50 m
3. fractured aquifer with a distance between the fracture zones of 100 m.

Corresponding to the hydraulic interpretation of the production tests the aquifer bas two opposite impermeable boundaries (figure 1) and the hydraulic conductivity of the fracture zones must be about 10^5 times higher than that of the matrix.

The larger the spacing between the fractures, the smaller is the totally available beat exchange surface.

The numerical simulations have been performed with the FRACTure code (KOHL 1992; details *see* in MEGEL 1996).

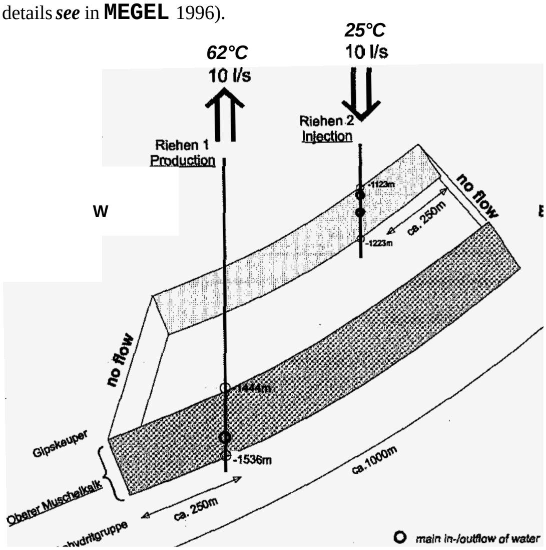

Figure 1: Conceptual model of the aquifer of the doublet operation in Riehen.

Results

Temperature development in the reservoir

The development of the temperature in the aquifer is shown in figure 2 for the porous model and for the model with a regular network of fracture zones with spacings of 100 m.

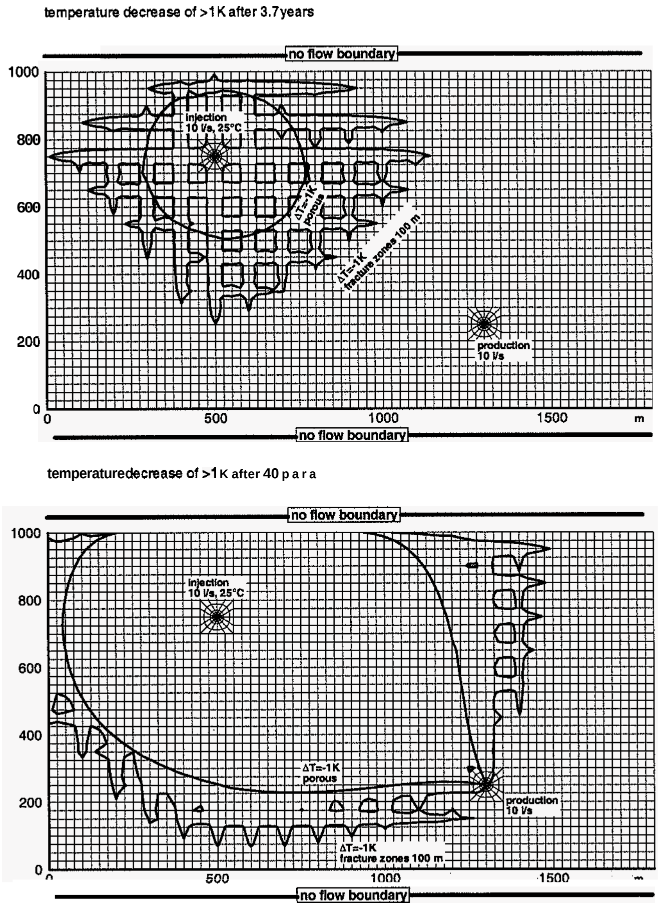

Figure 2: Propagation of the contour line of a temperature drop of 1 K for the porous and the 100 m fracture zone model in a horizontal plane. Indicated is also the 25 m FE-grid.

Constant long-term production

For the Riehen doublet operation a long-term calculation has been carried out with the aquifer model consisting of a network of fracture zones with 100 m spacing from each other. It is shown in figure **3** that the steady state production temperature is not reached even after 300 years. The temperature change can be characterised by considering the temperature change AT over a given time period, e.g. 10 years. This curve indicates the asymptotic behaviour of the production temperature. The maximum value of -0.7 K/10years is obtained after 20 years, afterwards the temperature drop decreases down to a value of -0.15 K/10 years after 300 years production.

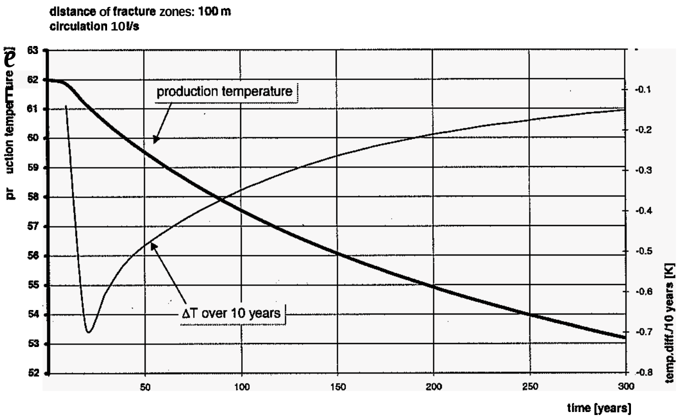

Figure 3: Development of the production temperature for a 100 m fracture zone model

Recovery of heat production capacity

The calculated drop of the production temperature for the doublet operation Riehen is very moderate for all reservoir models. **As** figure **4** illustrates the development of the production temperature depends strongly on the reservoir model type. For the model of a 100 m spaced fracture zone network the production temperature decreases by less than 2 K within 40 years. For a fracture zone network with 50 m spacing the corresponding value is less than 1K, due to the larger heat exchange area available in the reservoir. The most favourable case is the porous aquifer with a drop of 0.3K in **40** years **(see** figure **4).**

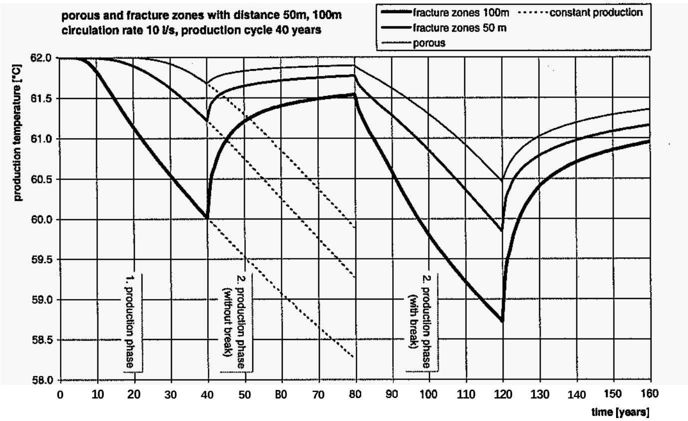

Figure 4: Calculated production temperatures for reservoir models of a porous, a 50 m and 100 m spaced fracture zone network type, two production phases of 40 years with and without a production break of 40 years.

The ability of the reservoir to recover thermally can be expressed by the comparison of the extracted energy decrease between the first and the second production phase with and without a production break between the two phases ("relative recovery", PRITCHETT **1998). As** shown in Table **1** the relative recovery of the reservoir due to a production break of 40 years between the first and the second production phases of **40** years each is between 35% and 40%. The tendency of a higher recovery value from the 50 m to the 100 m spaced fracture **zone** network model can be explained by the higher production provoked temperature gradients in the reservoir which leads to a stronger temperature compensating heat influx. The unexpected higher relative recovery in the porous model may come from the relatively late thermal breakthrough time in the first production phase.

A comparison between the production temperature of production-recovery cycles of 10, 20 and **40** years shows that the temperature will remain on a level which is the higher the shorter the cycle period is (figure 5). Relating the energy production of the most ideal case **of** no thermal drawdown to the energy output of a constant-rate production with a continuous temperature drop, the thermal recovery for an operating scheme with 10 year production-recovery cycles over **160** years amounts to **48.7%** (table **2). For** cycles of **20** years the corresponding value is 36.5%, for **40** years **20.8%** respectively. Consequently, short production-recovery cycles are more favourable with regard to the geothermal energy production.

Table 1: Relative reservoir recovery due to a 40 years production break between the first and second production phases of 40 years each

Reservoir model	break between phase 1 and 2	1. phase energy [MWh]	2. phase energy [MWh]	relative recovery [%]
porous	0	223'362	216'398	0
	40	223'362	218'938	36.5
fracture zones 50 m	0	222'368	212'884	0
	40	222'368	216'257	35.6
fracture zones 100 m	0	218341	205'836	0
	40	218'341	210698	38.9

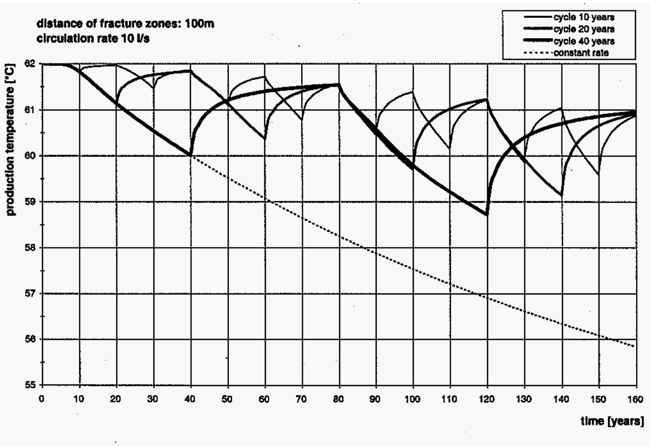

Figure 5: Production temperature for production-recovery cycles of different duration

operation type	total operation time [years]	energy production [MWh]	energy production [%]	reservoir recovery [%]
no production breaks, no thermal drawdown	80	447'552	105.5	100
8x10 year prod.-rec. cycles	160	435'565	102.7	48.7
4x20 year prod.-rec. cycles	160	432'702	102.0	36.5
2x40 year prod.-rec. cycles	160	429039	101.1	20.8
no production breaks	80	424'177	100	0

Conclusions

- The geothermal doublet Riehen will operate in a sustainable manner over decades without economically significant production temperature drop
- Production from doublets induces thermal recovery in the reservoir which is stronger than the natural recharge by terrestrial beat flow
- The thermal drawdown as well as the recovery occurs in an asymptotic manner
- Shorter production-recovery cycles produce more thermal energy

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