Centre for Geothermal Research

Geothermie Soultz

Centre of Hydrogeology
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Acid treatments on geothermal wells: first experiments and modelling at the Soultz EGS fractured reservoir.

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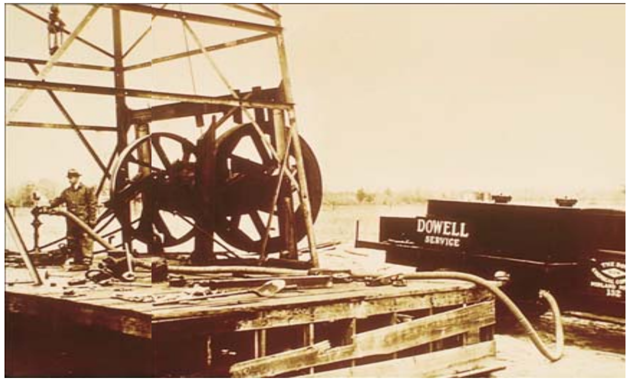
Acid treatments

- **Long and successful experience acquired from the oil industry**
  - ✓ Large number of methods and experiences set up for oil and gas wells.
  - ✓ Procedures partially adapted to the needs for geothermal reservoirs.

- **Aims**
  - ✓ enhancing well productivity;
  - ✓ reducing skin factor by removing near-wellbore damage;
  - ✓ dissolving the scales in fractures.

Acidizing operation, 1932



- **Reactants used**
  - ✓ Conventional acid systems
    - HCl acid and HCl-HF mud acid
    - Mixture containing organic acid and HF
  - ✓ Chelatants (EDTA family)
  - ✓ Retarded acid systems
    - Addition of retardants to prolong the effect of the reactive agent further in the fractures

- **Types of acidizing processes**
  - ✓ Matrix acidizing
  - ✓ Fracture acidizing

Acidizing processes

Types of acidizing processes	Matrix acidizing	Fracture acidizing
Process	performed below fracturing flow rate and pressure	performed above fracturing flow rate and pressure
Aims	enhancing well productivity; reducing skin factor by removing near-wellbore damage	cracking of the rock; farthest penetration of acid along the fracture
Procedure	3 steps : injecting 15% HCl, then an HCl-HF mixture, followed by a sufficient afterflush of water to clear all acid from well tubulars	acid is injected in natural/created fractures by fluid-loss control (use of packers, viscosity of acid, addition of solid particulates)
Injected fluid properties	chemical formulation of mud acid depends on the rock composition	injection of a viscous fluid
Treatment volumes	120 up to 6000 L/m of open hole	12 000 - 25 000 L/m of open hole
Additives	corrosion inhibitor to protect tubulars during exposure to acid	

Cleaning of geothermal wells (1)

- High temperature geothermal fields
  - ✓ Numerous wells in various geothermal fields have been chemically stimulated, mostly by strong acids (Philippines, El Salvador, USA, Italy, etc…).
  - ✓ Mineral deposits on casings and around the wells are treated successfully several times per year at Heber geothermal field (California, USA).
  - ✓ Corrosion damage can be mostly avoided by using adequate inhibitors.

Cleaning of geothermal wells (2)

Results of HCl-HF treatments for scaling removal and connectivity development

Geothermal Fields	Number of treated wells	Injectivity Index (kg/s/bar)	Improvement factor
Bacman (Philippines)	2	0.68 → 3.01	4.4
		0.99 → 1.4	1.4
Leyte (Philippines)	3	3.01 → 5.84	1.9
		0.68 → 1.77	2.6
		1.52 → 10.8	7.1
Salak (Indonesia)	1	4.7 → 12.1	2.6
Larderello (Italy)	5	11 → 54	5
		4 → 25	7
		1.5 → 18	12
		-	4
		11 → 54	5
Berlín (El Salvador)	5	1.6 → 7.6	4.8
		1.4 → 8.6	6.1
		0.2 → 1.98	9.9
		0.9 → 3.4	3.8
		1.65 → 4.67	2.8
Beowawe (USA)	1	-	2.2
Coso (USA)	30	24 wells	successful

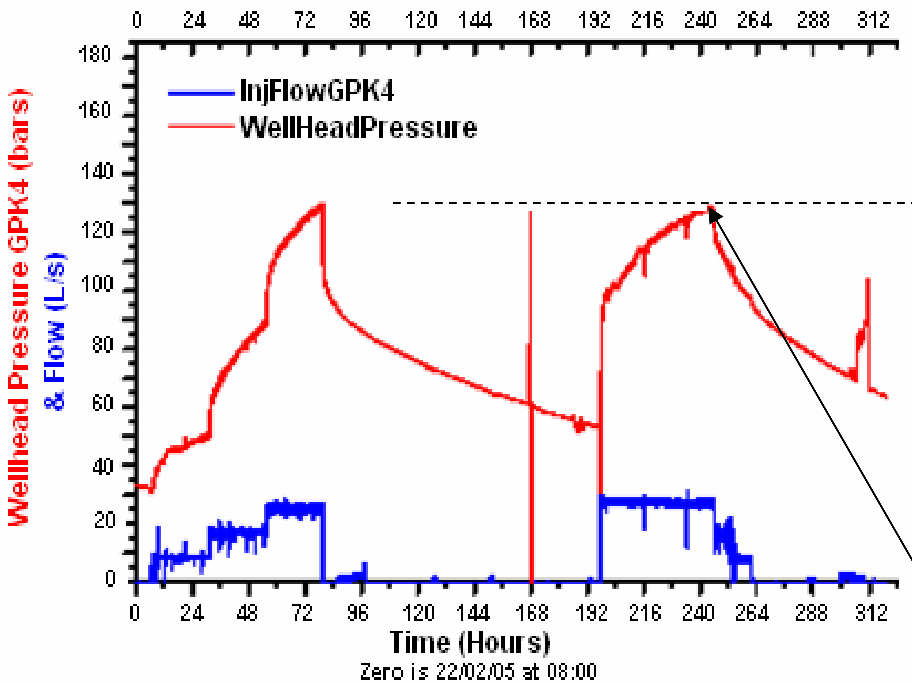
Cleaning of geothermal wells (3)

- **EGS reservoirs**
  - ✓ **Only two chemical stimulation were performed on past EGS reservoirs : Fenton Hill (USA) and Fjällbacka (S).**
  - ✓ **The Soultz EGS has probably the best experience on soft HCl / RMA stimulation.**

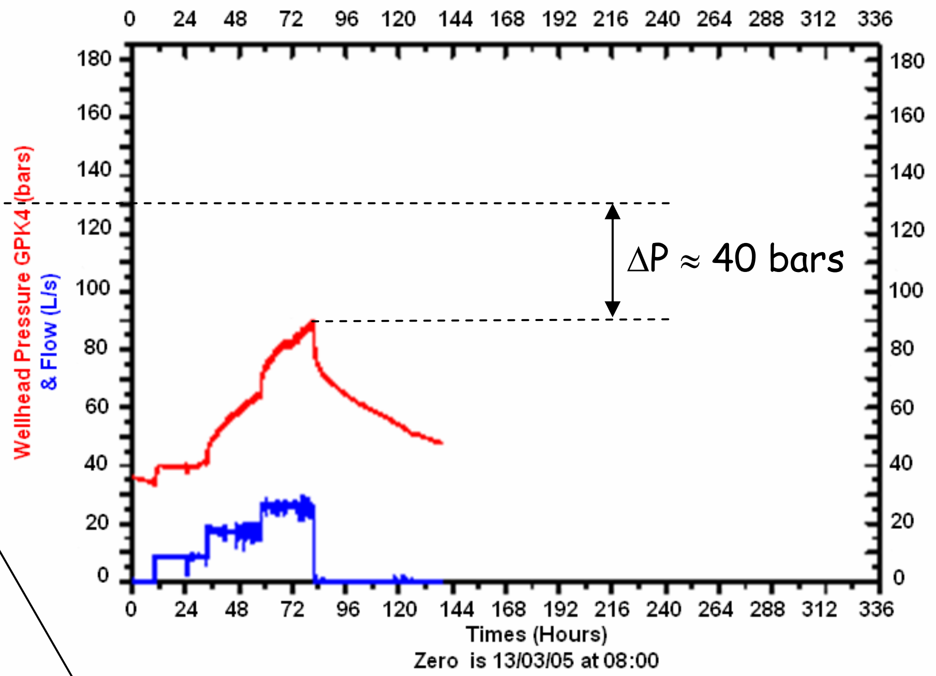
First acidification test at Soultz: GPK4 well

February 2005: 5200 m^3 of HCl acid solution at 2 g/L and a flow of 27 L/s.
A total of 11 tons of HCl were injected.

- **35% reduction of the wellhead pressure due to acidification**
- **Decrease of the reservoir impedance by a factor 1.5 (0.2 to 0.3 L/s/bar).**



Water injection test performed **before** acidification (February 22, 2005)



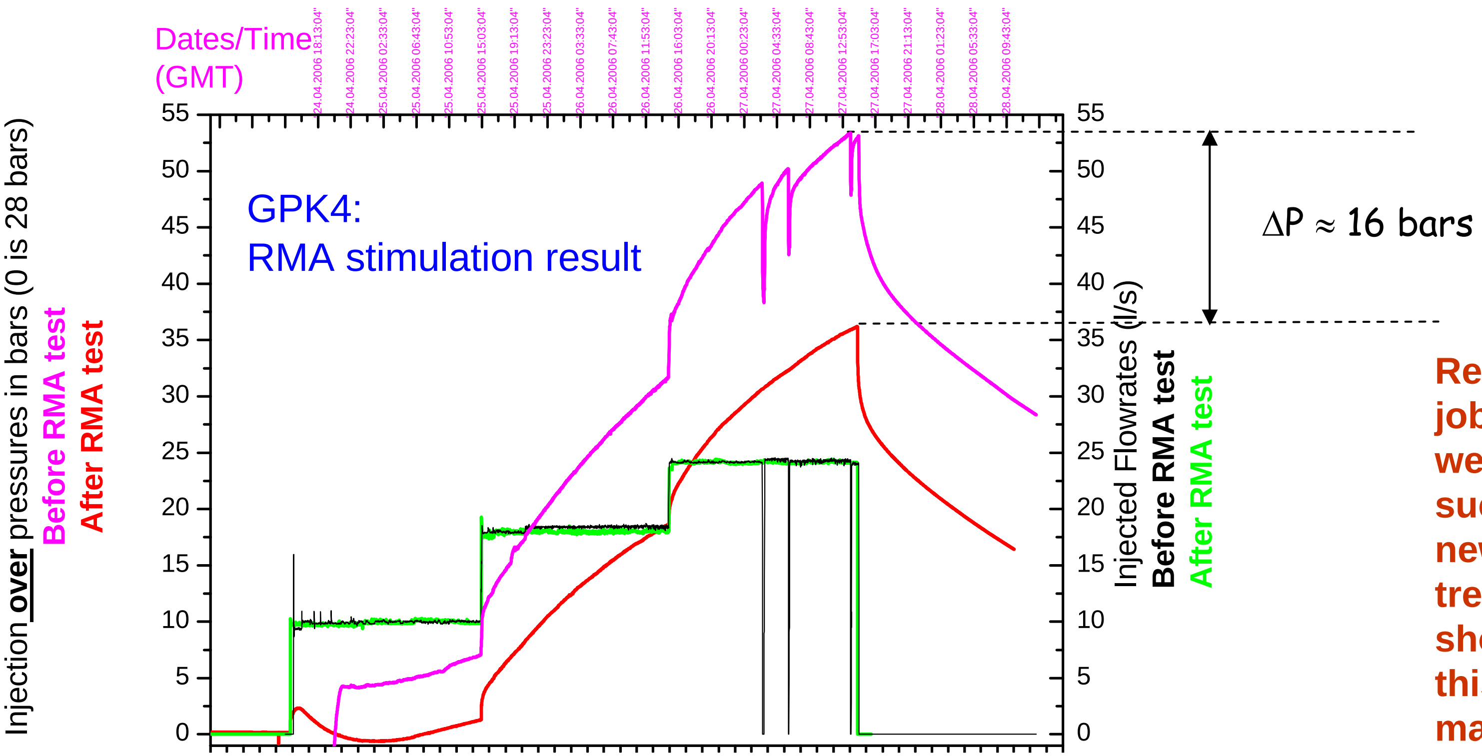
Water injection test performed **after** acidification (March 13, 2005)

Drop of the wellhead pressure : possibly due to minerals dissolution

(From Gérard et al., 2005)

RMA acid job at Soultz: GPK4 well

May 2006 : acid treatment performed in four stages.
Main flush : injection of 200 m^3 of Regular Mud Acid (RMA), (12 % HCl - 3 % HF acid mixture treatment), with addition of a corrosion inhibitor, at a flow rate of 22 l/s during 2,5 hours. During this test, 98 tons of HCl were injected. Estimation of the increase of GPK4 injectivity due to acidification : from 0.3 to 0.4 L/s/bar.



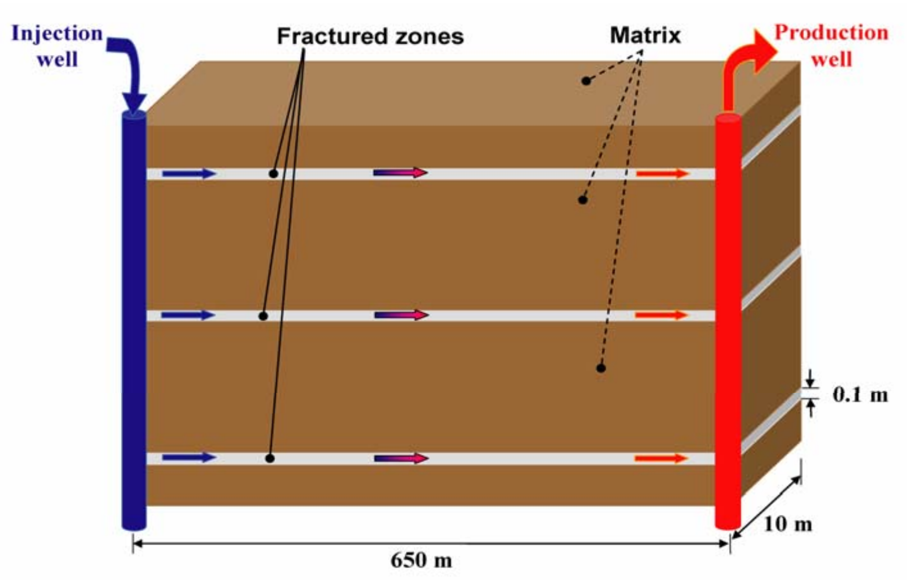
Recent acid jobs on GPK4 were rather successful, but new chemical treatments should connect this well to major fractures.

Impact of the **RMA acidification test** on the wellhead measured by comparison before and after the acidification test on GPK4 well (May 2006). (GEIE, 2006).

Simulation of acidification tests (1)

- Use of the thermo-hydraulic-chemical coupled code : FRACHEM
- Geometrical model is intended to represent Soultz site
- Well configuration and data for mineralogical composition were taken from the EGS at Soultz.

- 2-D simplified geometrical model
- 1250 fractured zones
- Matrix
  - $K_{matrix} = 10^{-15}$ m^2/Pa
  - $Porosity_{matrix} = 0$
- Fractured zones
  - $K_{frac} = 7.4\ 10^{-8}$ m^2/Pa
  - $Porosity_{frac} = 10$ %
- $Q_{frac} = 0.02$ L/s
- $T_{injection} = 65$ °C and $T_{initial} = 200$ °C
- $P_{injection} = 8$ MPa and $P_{production} = 0$ MPa



Simulation of acidification tests (2)

Characteristics of formation fluid

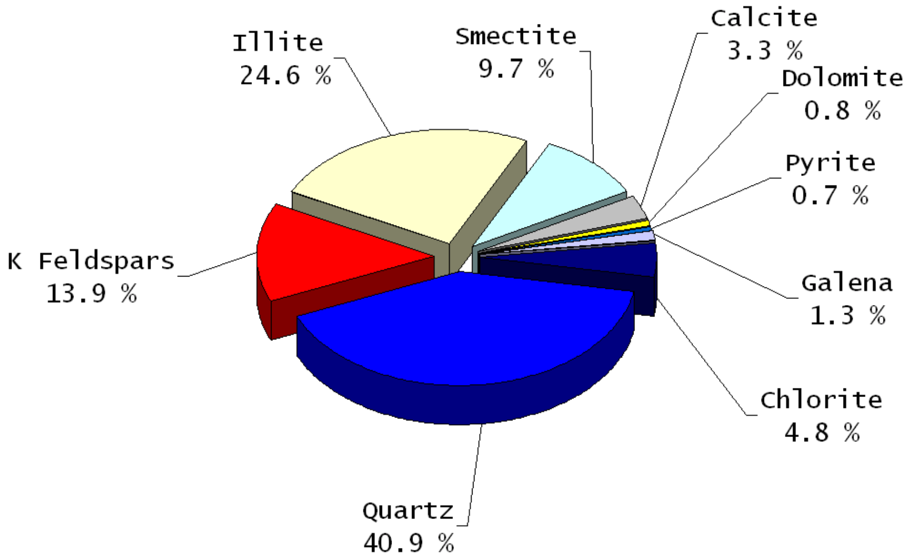
- NaCl brine, Temp. = 200°C, pH = 4.9
- TDS ~ 100 g/kg (ionic strength ~ 1.8 m)
- Chemical composition : analysis of GPK2 (1999)

Characteristics of injected fluids

- Injection of HCl acid solutions at two different concentrations
  - Soft acidification: 2 g/L during 60 hours
  - RMA treatment: 15 g/L during 70 hours
- Temp. injection = 65°C
- Total injection flow fixed at 25 L/s

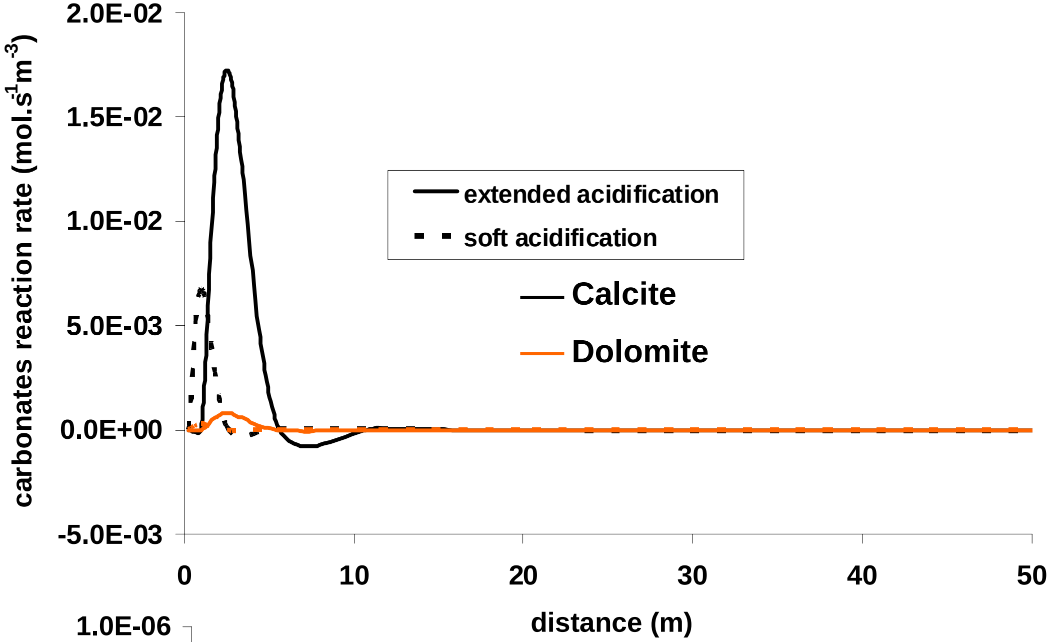
Assumptions on water-rock interactions

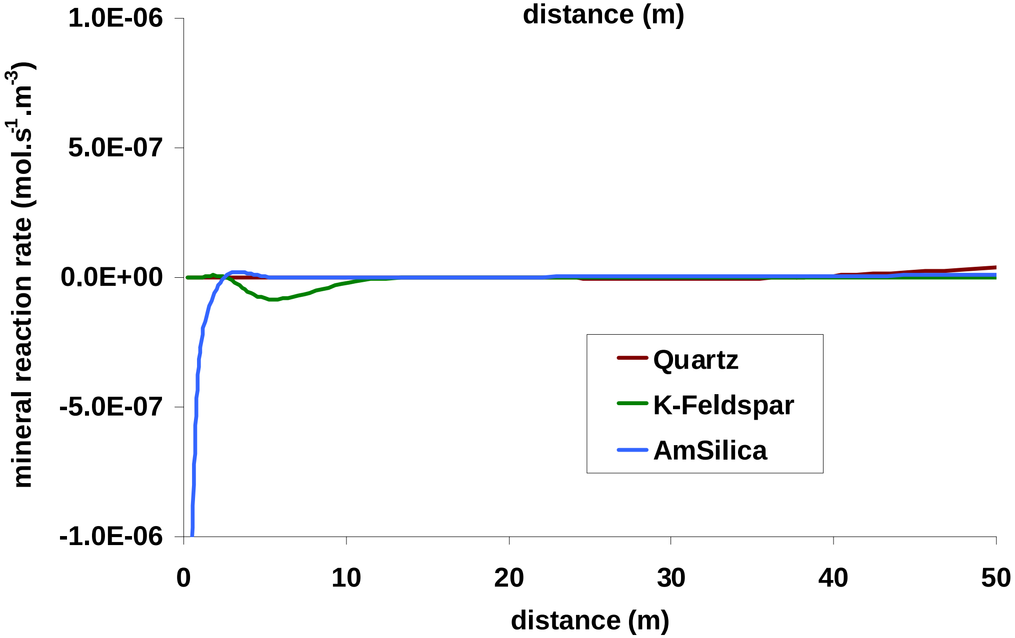
- Major circulation occurs in hydrothermally altered granite.
- Acid interacts with carbonates, quartz, K-feldspars, sulfides and clays.



Results : minerals behaviour

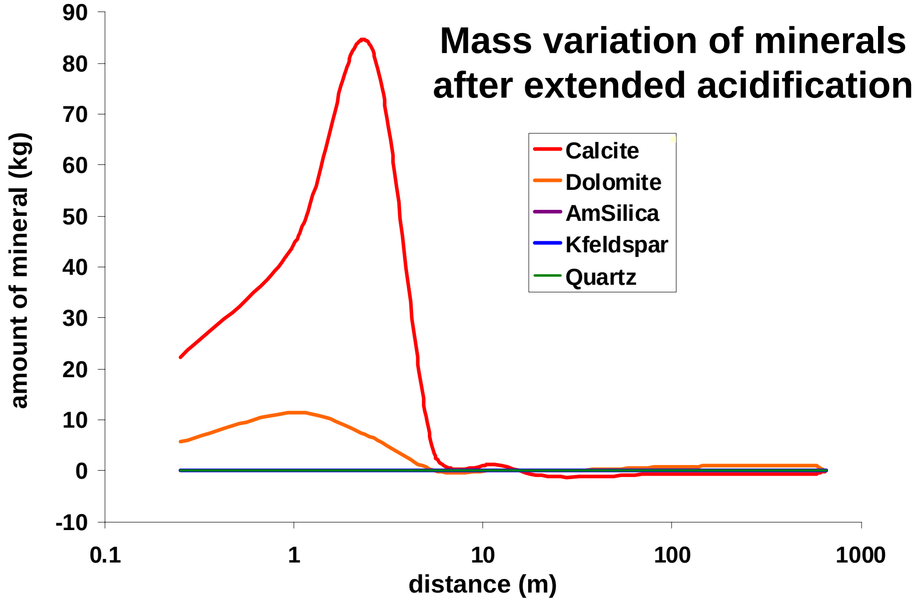
- High reactivity of carbonates and massive dissolution of these compounds near the injection well.
- The rapid reaction means the acid does not penetrate very far into the formation before it is spent.
- **Soft acidification: 11 tons of HCl**
  - ✓ 20 % of the carbonates are dissolved in in the first 3.5 m.
- **Extended acidification: 98 tons of HCl**
  - ✓ 70 % of the carbonates are dissolved in a radius of 7.5 m.
  - ✓ Weak impact on other minerals: low precipitation of K-feldspar and amorphous silica, quartz is not affected by the HCl acidification.

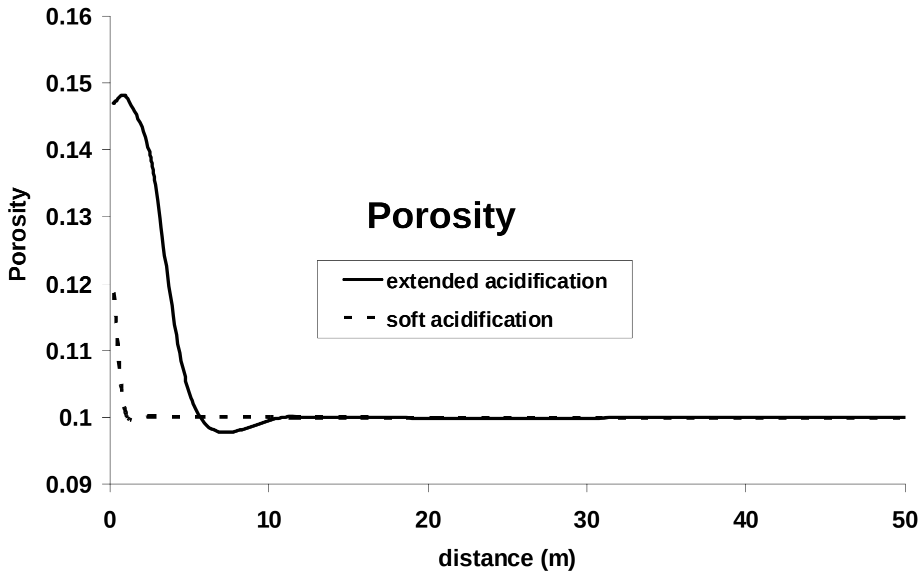


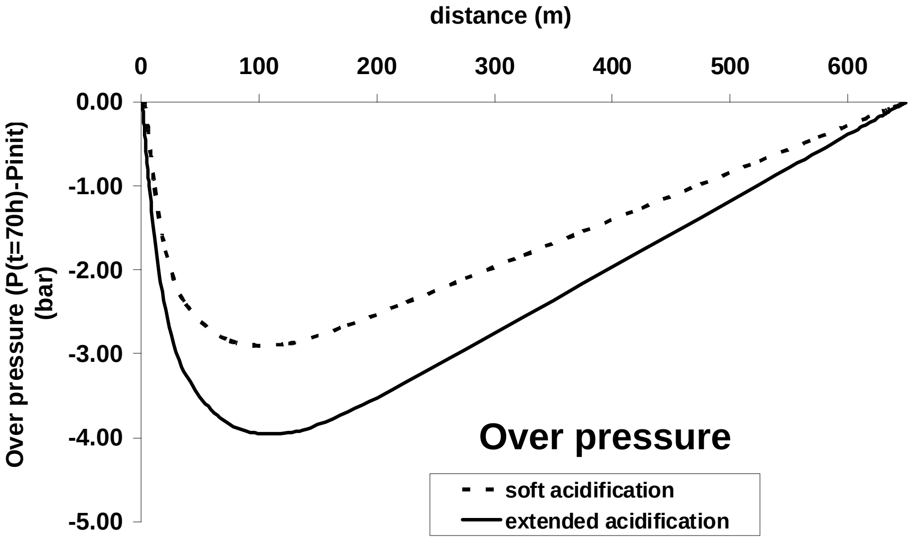


Results: consequences on reservoir porosity

- In FRACHEM code : double model of fracture and grain.
- Porosity increases near the injection well due to carbonates dissolution (calcite and dolomite).
- Porosity increase within the first 10 metres from injection well.
- Pressure decrease near the injection well.
- Impact on the reservoir injectivity.







Conclusion on modelling the impact of acid jobs

Modelling of acid stimulation experiments is carried out for the Soultz reservoir

- Expected increase of porosity due to the dissolution of calcite and dolomite present in the fractures.
- Mixing an acid solution with the formation brine instead of fresh water prevents a weak precipitation processes of pyrite, quartz and amorphous silica.
- Due to the high reactivity of HCl, all these simulated processes occur in a very limited zone around the injection well.

Improvement of the simulation of the acidification processes

- by increasing the injection times of low concentration solutions or by augmenting the acid concentration of the injected fluids;
- by increasing the injection flow to allow a farther acid transport trough the fractures;
- by increasing the acid injection pressure to simulate fracture acidizing.

Thank you for your attention