Injection Strategies Design and Implementation in Fractured Carbonates

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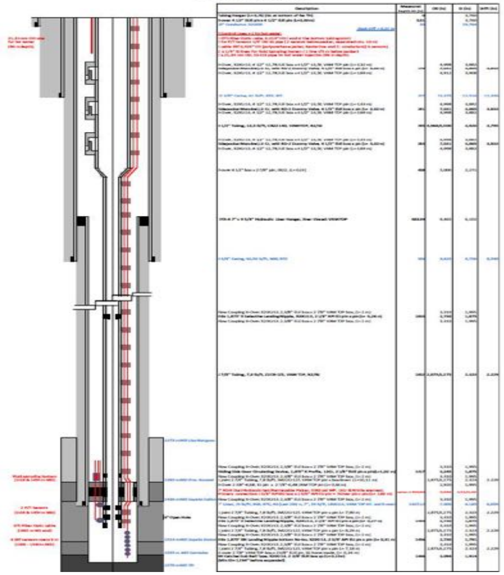
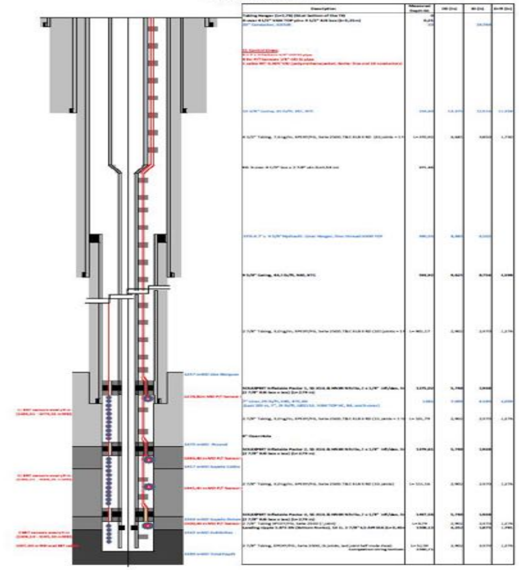
Hontomin TDP

COMPLETION AND INSTRUMENTATION OF HI & HA WELLS

H-I Well Completion



H-A Well Completion



Hydraulic characterization. Goal and methodology

Goal

The hydraulic characterization of the geological storage involves the different tests to be developed to "laboratory and real" scale at the exploration phase, in order to model the reservoir dynamic behavior and design safe and efficient injection strategies for the whole of the project life.

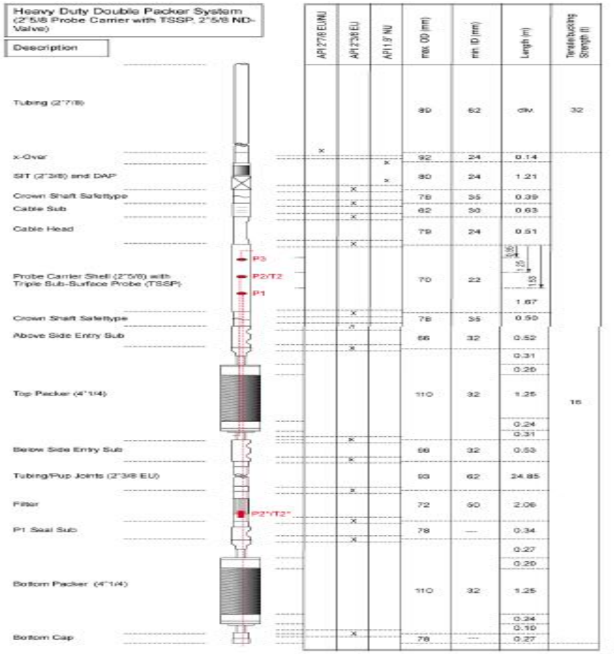
Methodology in fractured carbonates

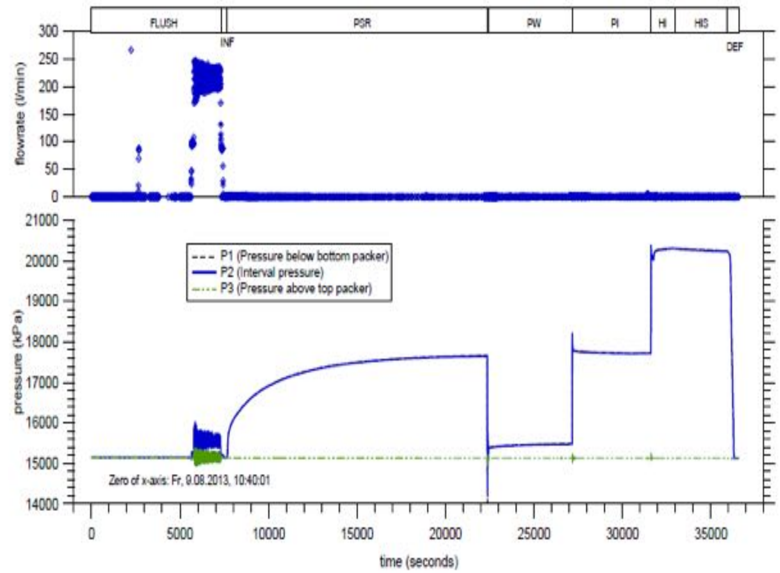
Boundary Conditions: Low porosity (permeability by fractures), high anysotropy and high chemical reactivity level

- Identify pressure and temperature distribution at the cap and reservoir formations during the injection and fall off period.
- Analyze geomechanical, thermal and chemical effects in the rock massif.
- Establish the operational pressure range. Injection threshold, fracking pressure and the binomial "injection pressure-seismic response".
- Quantifying the level of entrapment.
- Design the injectivity abacous for each stage of the operational phase.
- Refine the "radial composite" and 3D dynamic models
- Data for the risk prevention model.

Using brine and carbon dioxide for analyzing the injection parameters effects of both (fluid density, viscosity, compressibility, presence of impurities, etc)

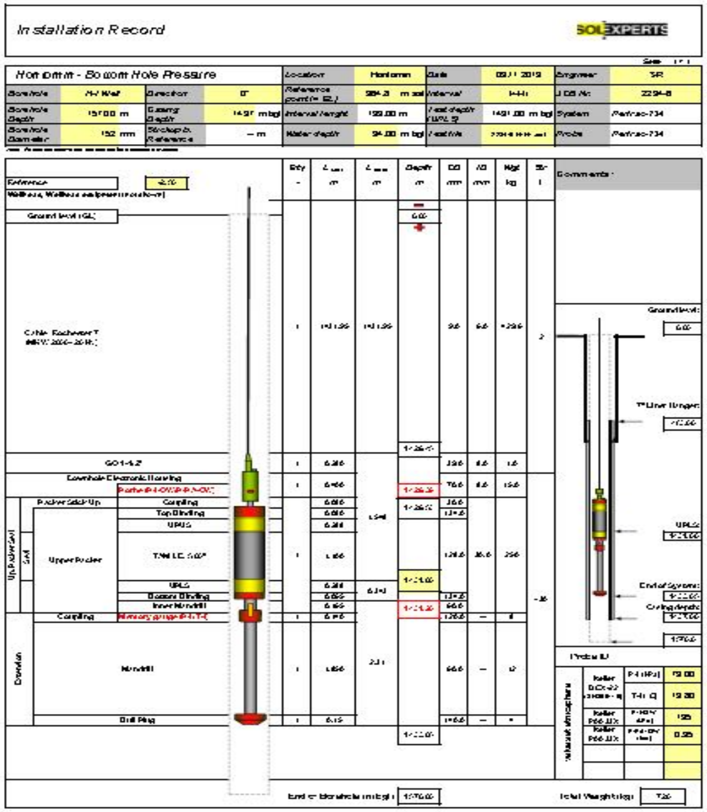
Preliminary tests during the drilling phase. Permeability tests

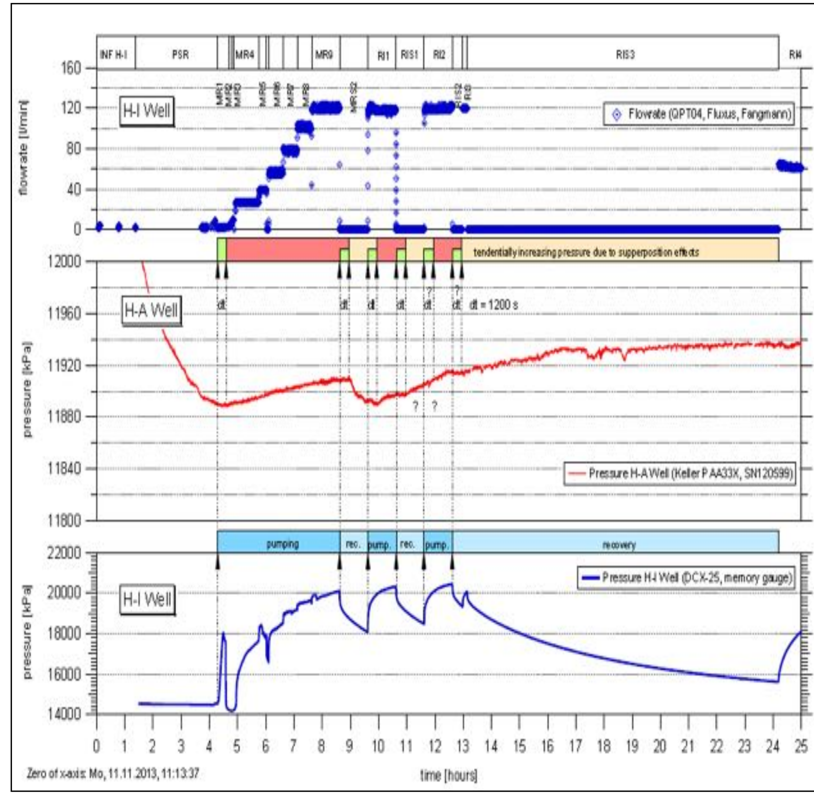




Test	Model	Remarks	DP WH	Rate l/hr	Dt hr	K.h mD.m	K mD	S	K outside zone for radial comp model
Production #1		Rate drops down to 1/4 within 24hr	50 ?	200	> 24				
Injection #1		unconclusive tests	23	-	-	-	-	-	
Injection #2	Possible Double F (weak)	Inj with N2 at WH	53	17,34	0,52	0,18	0,0225	-1	
Injection #3	Possible Double F (weak)	Inj with N2 at WH	48	47,8	1,03	1,43	0,286	-0,4	
Injection #4	Possible Double F (weak)	Inj with N2 at WH	41,6	9,42	1,09	0,95	0,063192	9,8	
Injection #5	Radial comp	Inj with Solexpert small pump	12,5	90	4,00	8,83	0,316	2,11	# 3 mD @ 12m ?
Injection #5B	Radial comp	Inj with Rig pump	42	600	2,00	24,23042	0,866	1	# 3-5mD @ 20m ?

Preliminary tests during the drilling phase. Connectivity tests

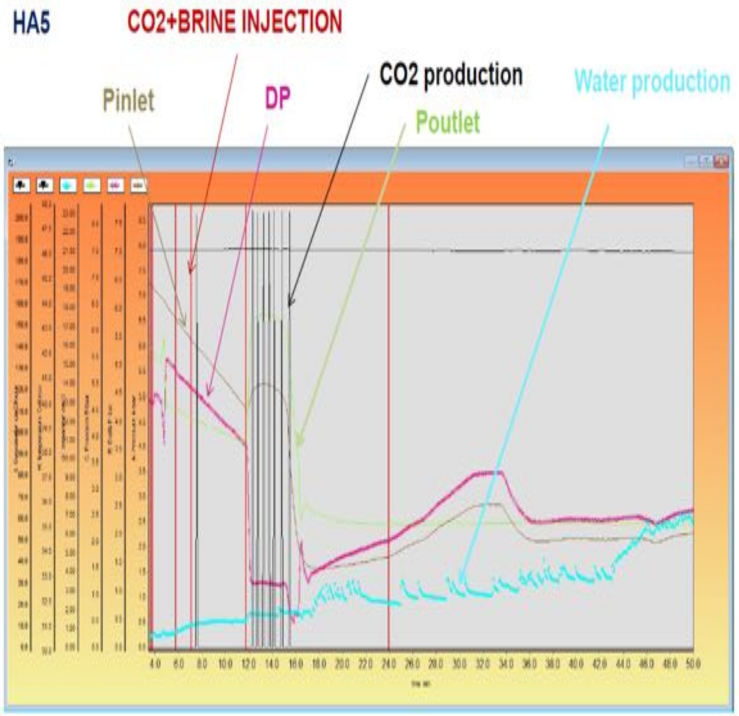




Leak off test (LoT) results from the reservoir level are needed

Petrophysical laboratory works

Main Goals: To determine the injection threshold in reservoir conditions analyzing the preliminary chemical effects between the brine, carbon dioxide and the rock massifs



ATAP Equipment *Universidad Politécnica de Madrid*

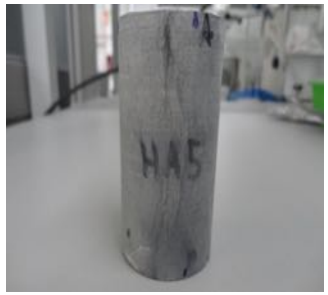
Test Conditions Sopeña Formation (reservoir) Limestone Lias

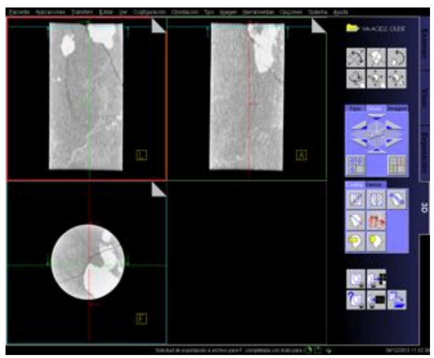
Injection Pressure	**75 bar (supercrital phase at the wellhead)**
Temperature	**45º C (according well logging tests)**
Confining pressure	**133-141 bar (according well logging tests)**
Mixture CO_2-brine	**several**
Flow rate	**0,5 cm^3/min**
Plug sample	**Reservoir. Low porosity and permeability**

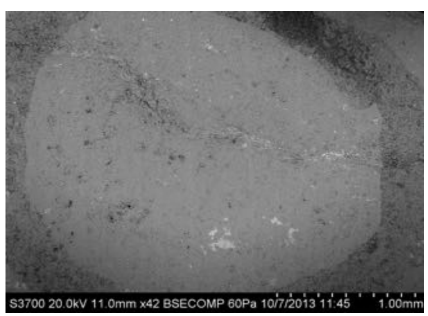
Laura Valle Ph.D Mining Engineer IPf

Petrophysical laboratory works. CT Scanner and SEM

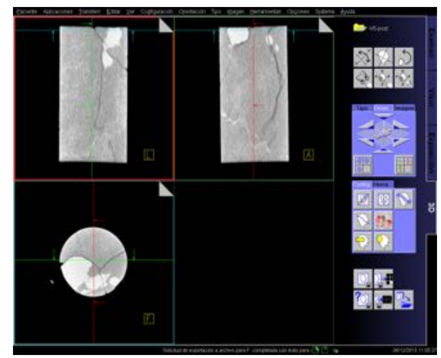
Pre-Injection

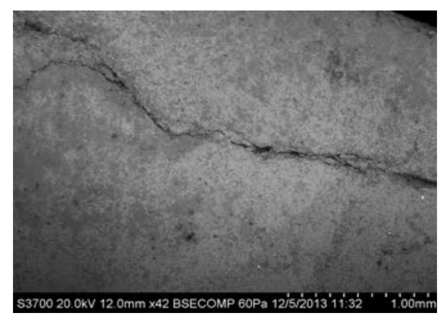






Post-injection



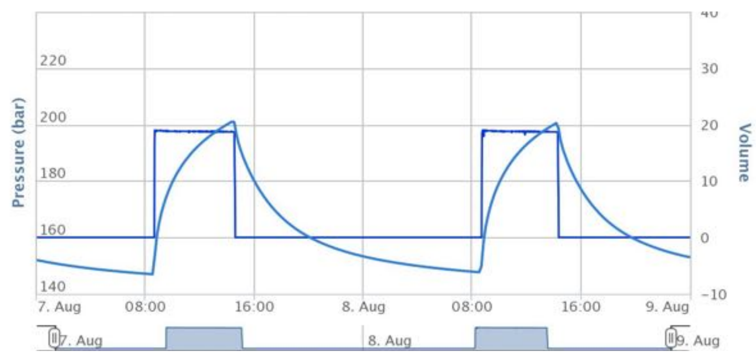


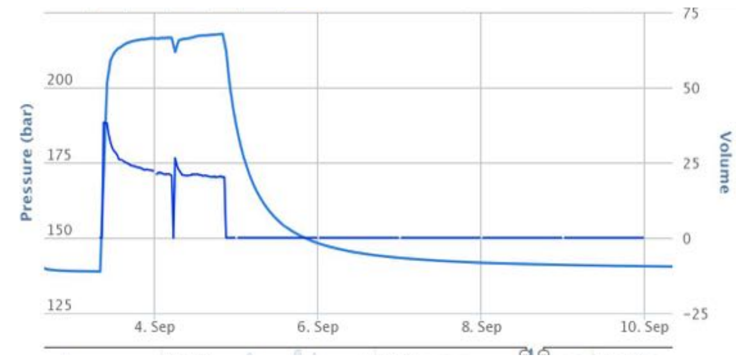
Fundación Instituto Petrofísico (IPf)

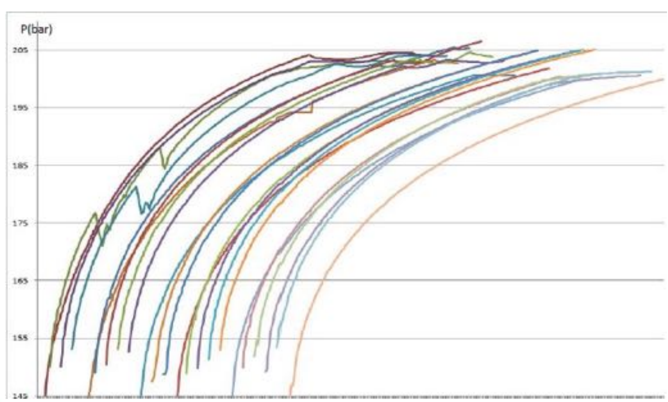
Hydraulic characterization campaigns. Tests with brine

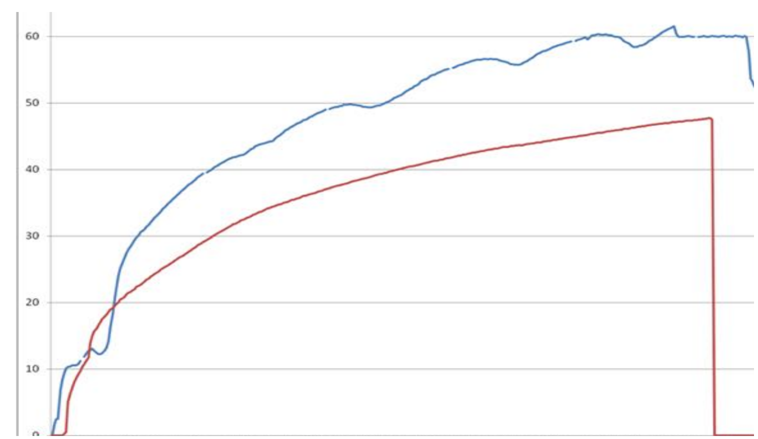
Methodology: More than 10.000 m^3 of brine have been injected in the reservoir following the modes: “pressure control”, “flow control” and “injection-production” according with the goals described.

Tests in the mode “Pressure Control” (Well HI)





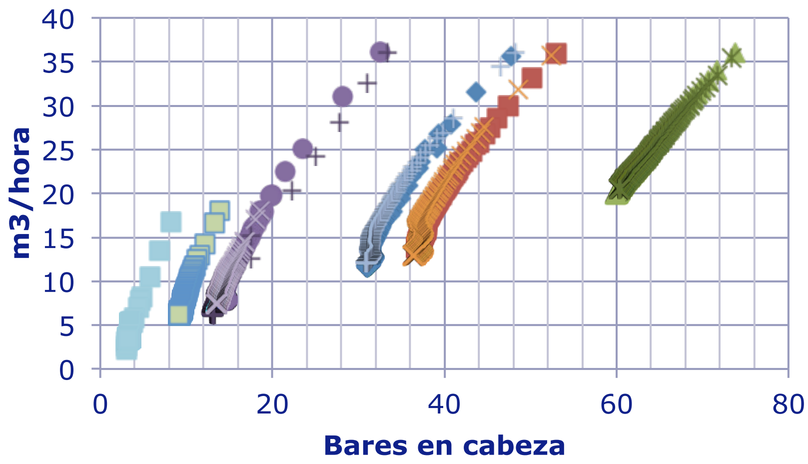


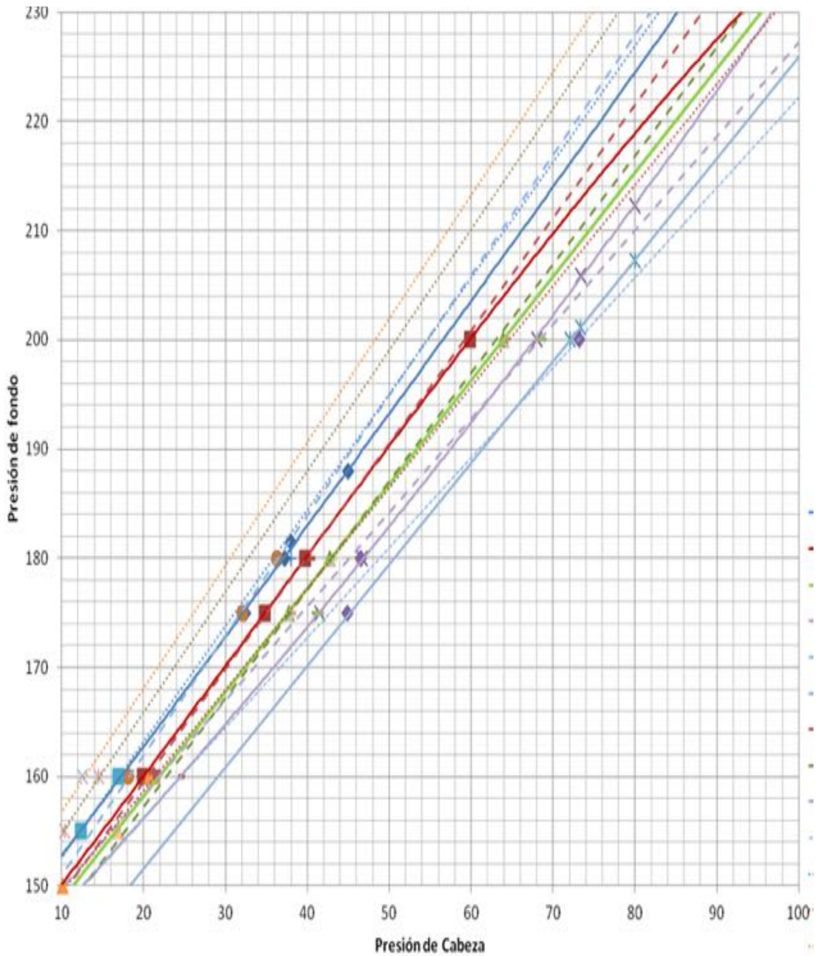


Preliminary conclusion.-The hydrodinamic effect has a high influence in the reservoir behaviour, changing the permeability and the transmissivity.

Hydraulic characterization campaigns. Tests with brine

Tests in the mode “Flow Control” (Well HI)





The injectivity abacous correlates the WHP with the WBP and the injection flow per **<u>each reservoir operational stage</u>**, this means the correlated parameters could change during the different phases of the project.

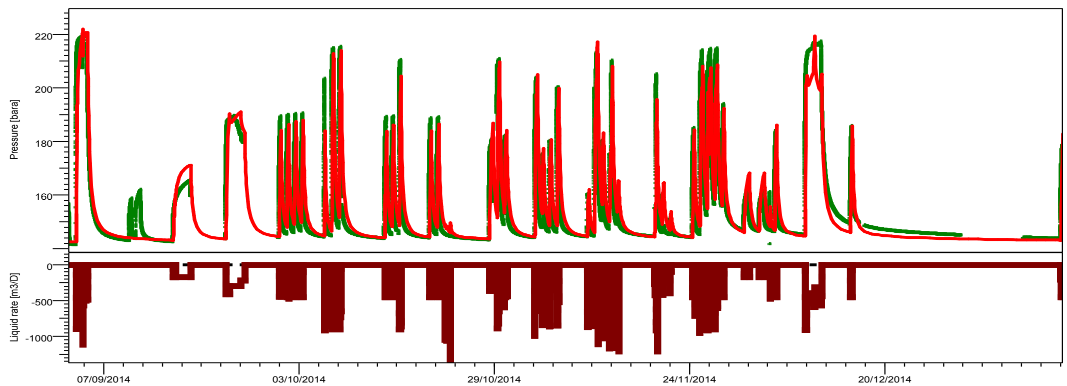
The fractured carbonates dynamic behaviour involves changes in the operation conditions which should be predicted

Hydraulic tests interpretation with brine

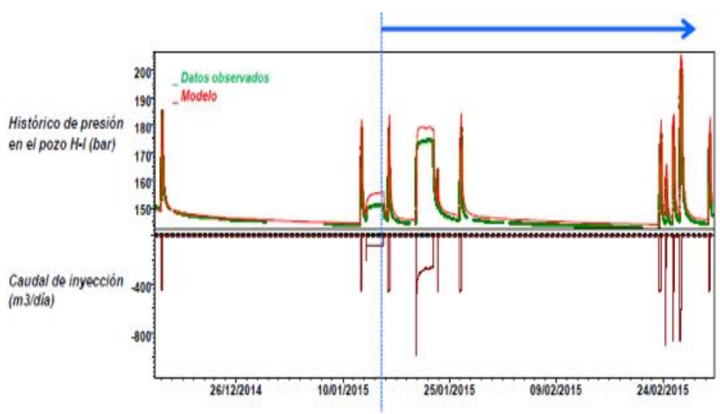
Software Shaphir "Radial composite"

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right)=\frac{\emptyset\mu c}{k}\frac{\partial p}{\partial t}$$

Difussivity ecuation



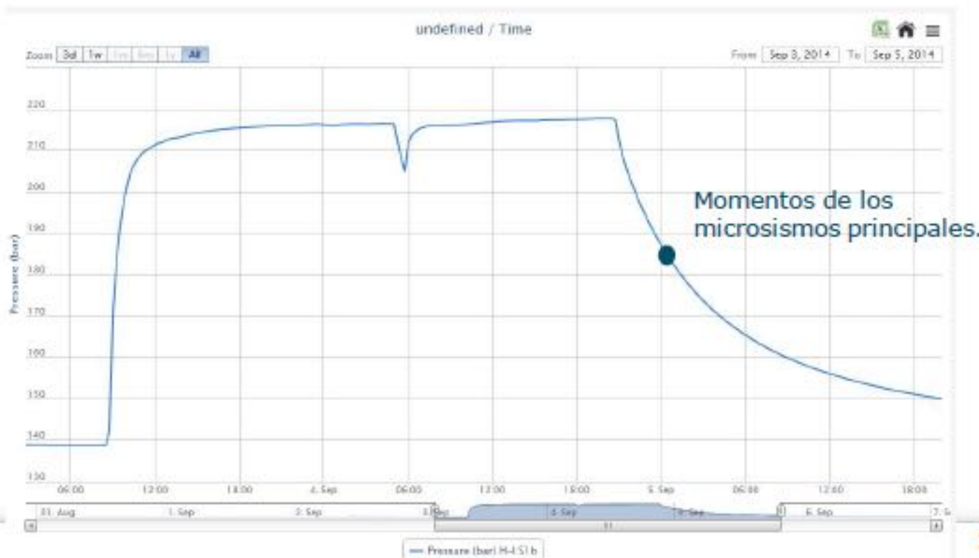
After 14.000 m^3 of brine injected and 1.000 t of CO_2 mixtured with brine at the injection facility commissioning the results are the following (January 2015):



Permeability test (HA Aug 2013)= 24,23 mD.m
Hydraulic campaign (HI Jan 2015)= 247 mD.m

Seismic Response. The event

Facility control in pressure mode 80 bar

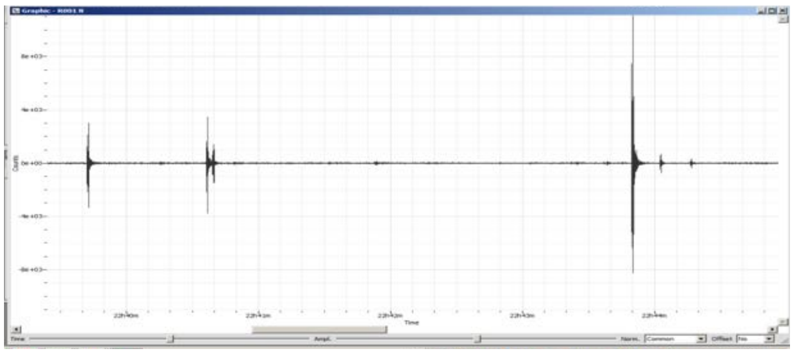


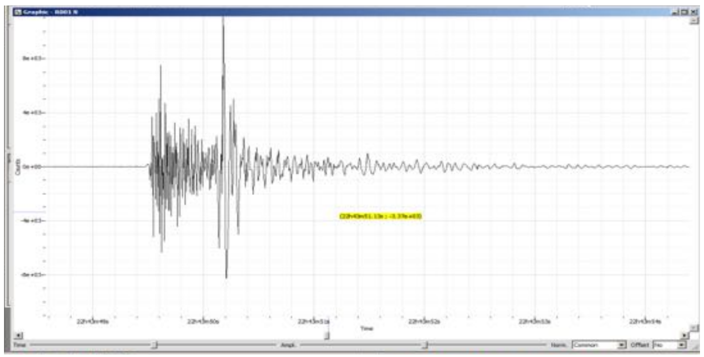
Questions:

1.- Fault activation?

2.- Pressure for fracture?

3.-Stress distribution reallocation?





Seismic response threshold 80 bar

Seismic Response. The solution

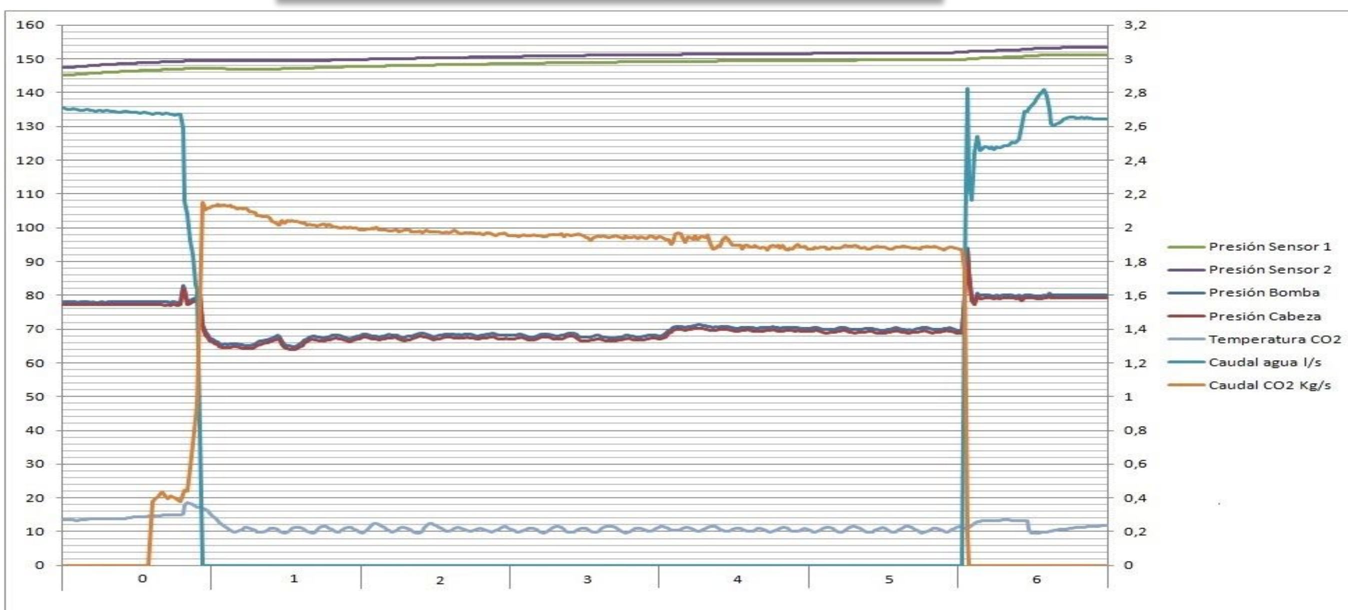
Specific choke for CO_2 injection

Darcy-Weisbach Equation

$$\Delta p = f \cdot \frac{L}{d0} \cdot \frac{v_f^2}{2}$$

Δp: Pressure drop (Pa)
f: Friction Coef. Darcy – Weisbach
L: Choke lenght (mm)
d0: Inner diameter (mm)
vf: Fluid speed (m/s)

Low pressure CO_2 Injection



Modelling

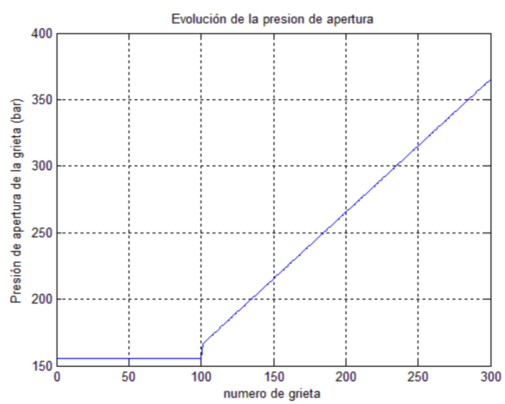
- Specific software for fractured carbonates.
- Transport code: multiphase flow, several specimens and reactive. Impurities considered
- Equation of state for transport:

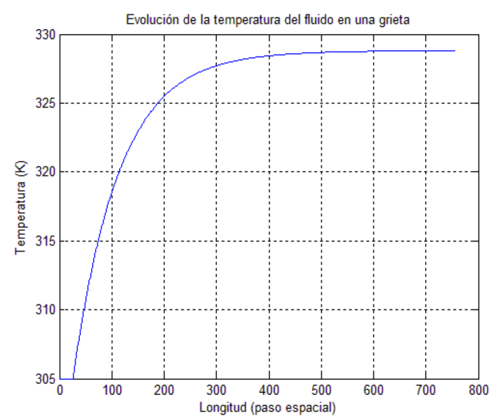
$$\frac{\partial(\rho\cdot m_k)}{\partial t}+\frac{\partial}{\partial x_i}(\rho\cdot\bar{v}_i\cdot m_k)=\frac{\partial}{\partial x_j}\left[\left(\rho\cdot D_k+\frac{\mu_t}{Sc_t}\right)\frac{\partial m_k}{\partial x_j}\right]+R_k$$

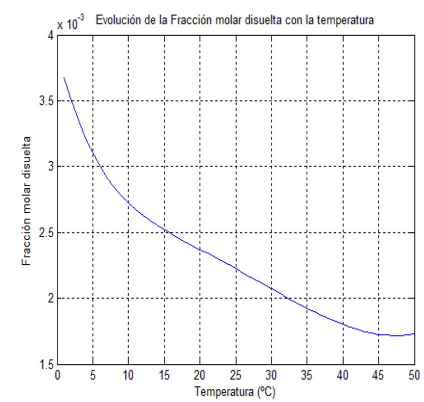
- Calculus method for chemical reactivity (finite-rate based in Arrhenius Principles):

$$R_k = M_k\cdot\sum_{r=1}^{N_R}\widehat{R}_k^{(r)} \qquad \sum_{k=1}^{N} c_k'^{(r)}\cdot S_k \underset{K_f^{(r)},K_b^{(r)}}{\longleftrightarrow}\sum_{k=1}^{N} c_k''^{(r)}\cdot S_k$$

- The code uses the “finite volume method” to solve the different equations of the state.
- The Navier-Stokes equations should be solved for each carbon dioxide secuestration phase, regarding the following CO_2 tramping mechanisms:
  - Residual
  - Dissolution
  - Mineralization
- Radial composite, modelling the fractures considering two types (faults and joints)







Conclusions

- The fractured carbonates, to become in reservoirs for carbon dioxide storage, exhibit a behaviour with low porosity (permeability by fractures), high anysotropy and high chemical reactivity level.

- It is needed to analyze the hydraulic, geomechanical, chemical and thermal effects through de different hydraulic characterization phases (with brine and CO_2).

- The firts step for the injection strategies design is to set the pressure range: preliminar injectivity, fracture pressure and seismic response threshold. Information from laboratory tests and well logging works (leak off test) is necessary.

- The dynamic behaviour of the reservoir involves changes in the permeability and transmissivity for the whole of the project life, which means it would be needed to determine the operational conditions for each stage(injectivity abacous).

- The seismic response and its relationship with the injection pressure range are one of the most important concerns for the site operator. Specific tools for its interpretation and prediction are needed to define mitigation procedures.

- These facts could condition the decission making process about the number of wells to be drilled, the works schedule, maximum flow to be injected, etc.

- The use of specific well completions (chokes) could be the solution regarding the permeability changes and seismic response from the reservoir.

- New and adapted models for simulating the fractured carbonates behaviour, for the CO_2 geological storage cicle, are key issue in the decission making process.

Thank you for your attention

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