Optimization survey of Gas CO2 sequestration in the TAGS Algerian reservoirs

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Abstract

This work is devoted to present the experience of Gas CO2 Storage in Algeria. The study was done to optimise the best reservoir for Gas CO2 Storage. The risks name for the two Fields considered Field I & Field II, they are : Permeable Zone in Seal, Earthquake Induced Fracturing, Leakage –Undetected Fault, NW Fractures corridors (that linear features are connected fracture corridors and, with current injection plan, could propagate through seal allowing CO_2 into potable aquifer), Injection Well Leakage (With increasing pressure an inadequate barrier in wellbore material provides a leakage path to potable aquifer or surface), Old Well Leakage (Inadequate completion or chemical alteration of wellbore material provides a leakage path to potable aquifer or surface), Exceeding Spill-Point (Restricted access to pore space within structure causes CO2 flow below spill point, leaking up-dip to unknown resource potential) and Migration Direction.

1- The main results of the study of the CO2 sequestration of Field I are summarised as below:

- if we stop the production of gas and we inject the CO2 only in the top of Tags, the final average pressure reached by the reservoir will increase no more than 10 or 20bars, what will raise no problem mechanical geography such as, the deformation of the rock or the break of waterproofness.
-In the case of the following of the production of gas, the final recovery ratio will be doubled (until 90%). With an adequate arrangement of the producing wells and the injectors and in particular if the CO2 is injected in the aquifer, no breakthrough of CO2 in the producing wells will be observed, at least during the first 10 years.
- If the CO2 is partially injected in the bottom of Tags, the production of oil of this zone could be increased and the clay separating both zones will improve the process of detention of the CO2, delaying advantage or even avoiding totally the breakthrough during all the life of the field.
- With the aim of maximizing the profit of the storage of the CO2 in this reservoir and to prevent any incident, certain precautions must be taken of among are:
· A campaign of collection of data must be led with the aim of determining the current thermodynamics properties of the fluids as well as the study of distribution and convection to remedy the uncertainties concerning the heterogeneousness of the reservoir and with the

aim of establishing a schedule of the operations, a study of detailed characterization must be led.
· A particular attention must be given to the installations of surface and to the completion of wells.
· A program of monitoring must be set up on the basis of the conditions of the reservoir to counter in any unforeseen.
2- For the FieldI which offers certain number of advantages are summarized as below:

The FieldI is enough situated far from the base of life and the processing center of FieldII. The aspect HSE is thus better insured. The topography of the zone presents no difficulty of access. The structure is simple and known well. Not divided, she so confers a better waterproofness compared with FieldI Tags's reservoir. There is no ring of oil in this reservoir and only the reservoir Tags produces gas. The reservoir Tags petrophysics of good characteristics (15 % f and K of 100 mD) so good as those of Field II, so allowing the injection of the CO2 a considerable flow rate. The pressure of the reservoir is low and presents no inconvenience to the injectivity of the CO2.

a. Background

This work is devoted to present the experience of Gas CO2 Storage in Algeria. The study was done to optimise the best reservoir for Gas CO2 Storage. The URS RISQUE method was used to identify and quantify technique that characterises storage of risks. It is supported by calculation these steps : Establish the context, identify risks, analyse risks, than deduce likelihood and consequences to estimate level, evaluate risks against targets and finally plan the operating strategy to treat risks.

b. Introduction

With the application of the Kyoto protocol from 2008, several projects were introduced. Three (03) projects pioneers of storage of industrial-wide CO2 were realized:

b.1- Statoil (1996) with the injection of 1 million Tons / year in the deep aquifer of the field of Sleipner (offshore).

b.2- Encana (2000) with the injection of 1.8 million Tons / year in the oil reservoir of (Onshore) Weyburn to improve the recovery ratio.

b.3- BP In Salah Gas (2004) with the injection of 1 million Tons / year in the aquifer of the reservoir of Khrechba. In front of the complexity of the concept, several oil companies created consortiums grouping including renowned institutes (IFP, BRGM, IMPERIAL, Stuttgart University...).

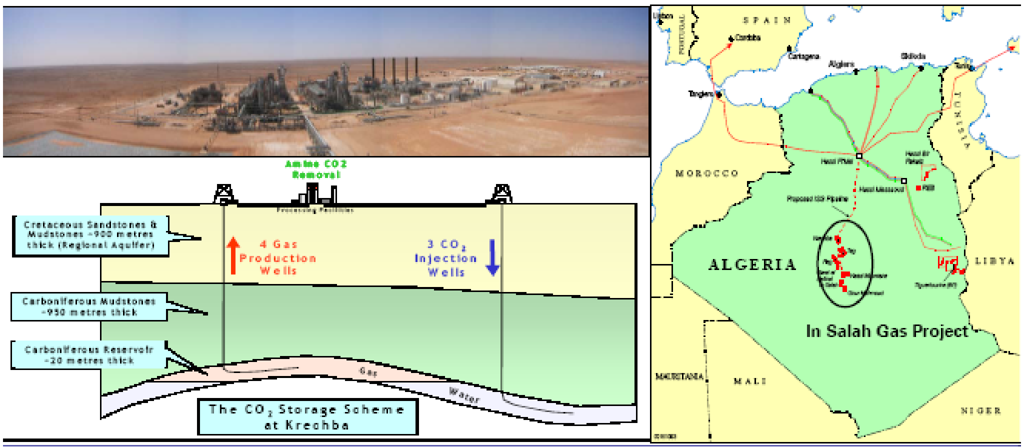


Fig. 1: Industrial Scale Demonstration of CO2 Geological Storage (Conventional Capture).

The Storage Formation is common in Europe, USA & China. The started storage was in August 2004, Fig.1. Three Projects at In Salah have been introduced :

-In Salah Gas Development
-In Salah CO2 Storage.
-In Salah CO2 Assurance JIP.

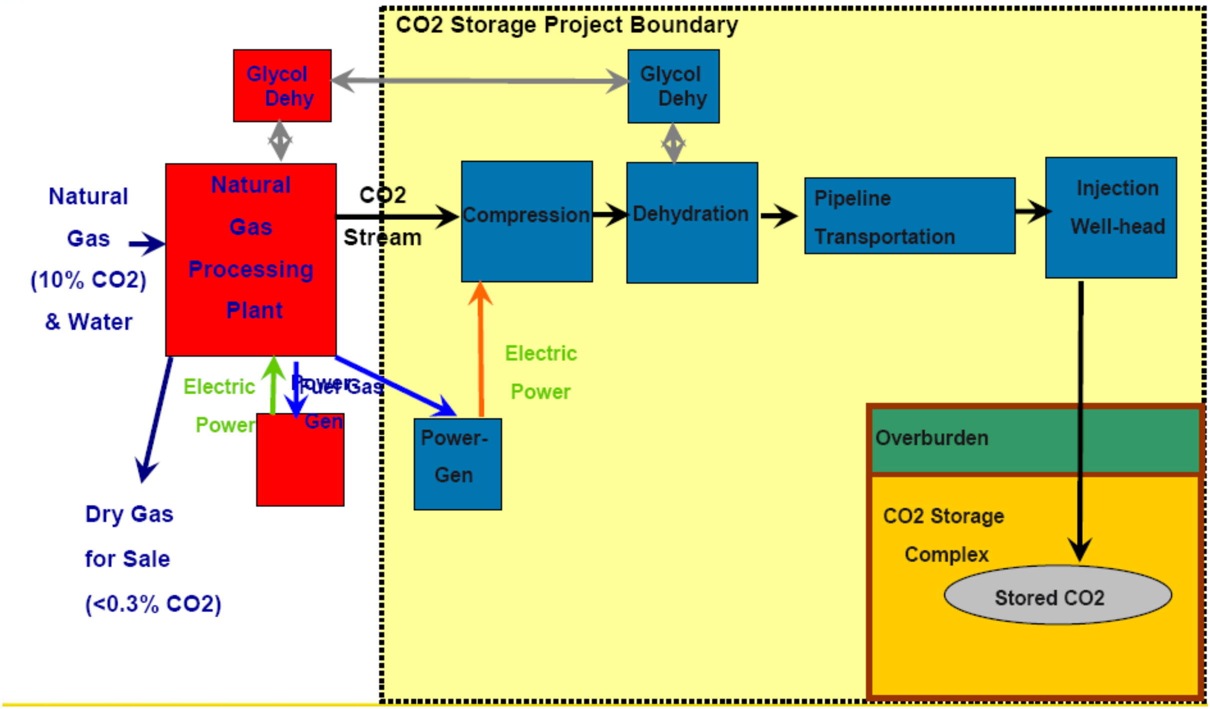


Fig.2 : Additional CCS Infrastructure

The objectives of In Salah CO2 Joint Industry Project (JIP) are listed above (Fig.2):

To provide assurance that secure geological storage of CO2 can be cost-effectively verified and that long-term assurance can be provided by short-term monitoring. To demonstrate to stakeholders that industrial-scale geological storage of CO_2 is a viable GHG mitigation option. To set precedents for the regulation and verification of the geological storage of CO_2, allowing eligibility for GHG credits.

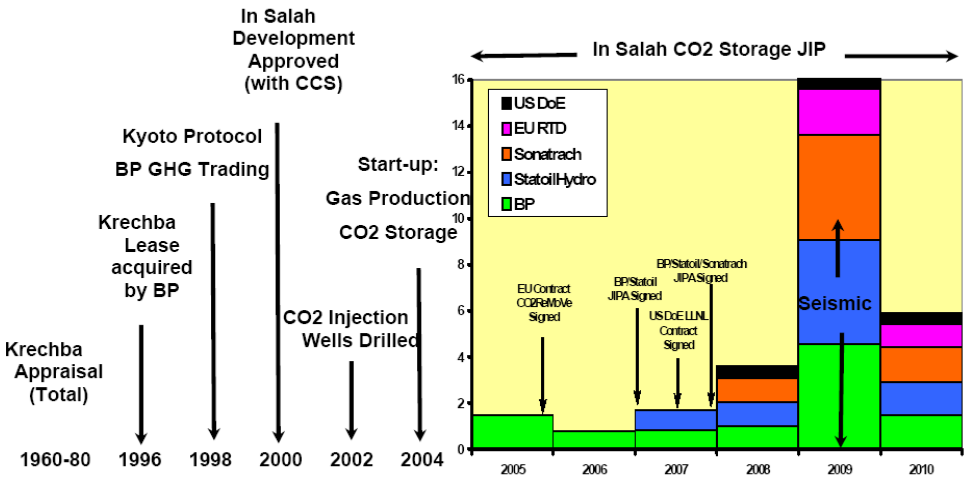


Fig.3 : In Salah CCS Project : Timeline

b.3.1-The CO2 Storage at Krechba

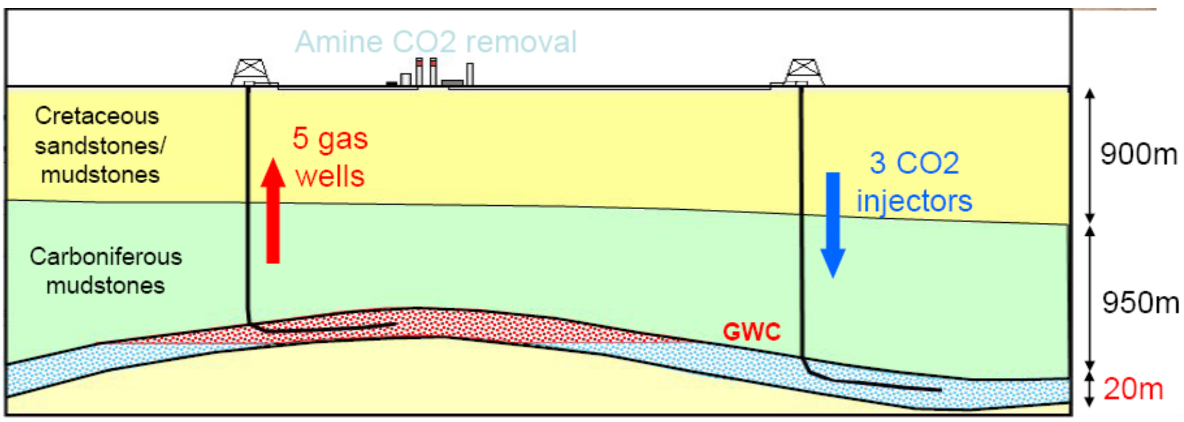
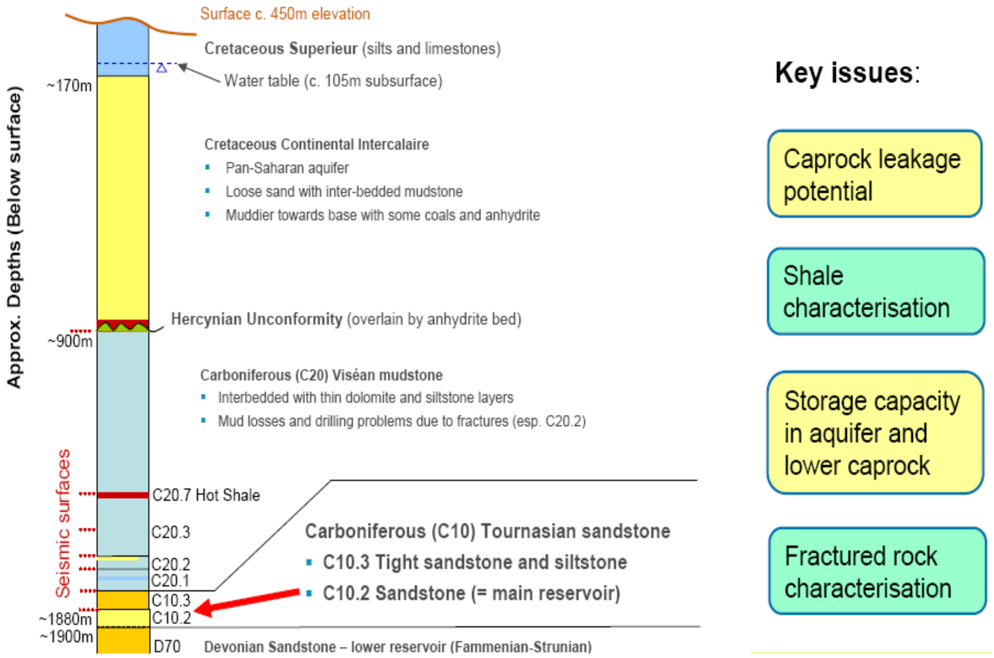
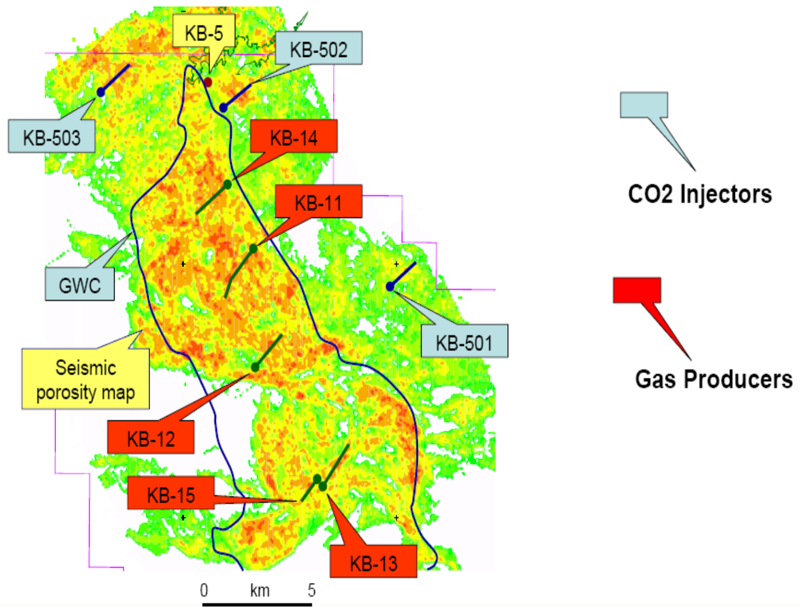


Fig.4 : Well CO2 injectors at Krechba

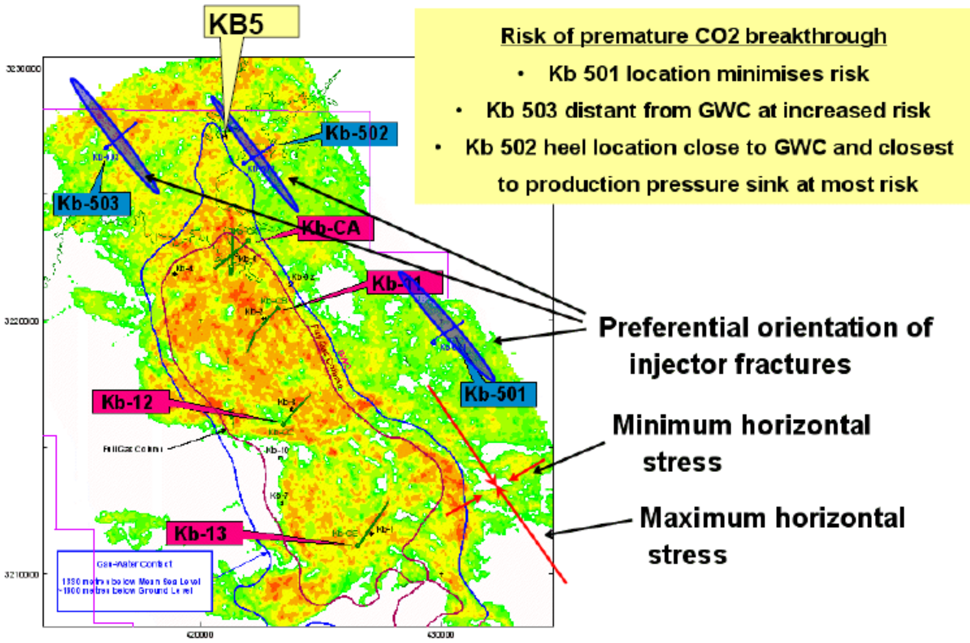
b.3.2- Krechba Stratigraphic Summary



b.3.3- Krechba Field Lyaout



b.3.4- Krechba Key Risk Location



b.3.5- Summury of Key Technologies

Monitoring technology	Risk to Monitor	Action/Status
3D seismic	Plume migration Subsurface characterisation	▪Initial survey in 1997 ▪ High resolution repeat 3D survey acquired in mid 2009. ▪ May show some time lapse (4D) effect
Microseismic	Caprock integrity	▪Test well drilled and recording information to 500m beside KB502 – no results to date
InSAR monitoring	Plume migration Caprock integrity Pressure Development	▪ Images captured using X-band (8 days) and C- Band (28 days)
Tiltmeters/GPS	Plume migration Caprock integrity Pressure Development	▪ Currently being installed ▪ Use to calibrate satellite data
Shallow aquifer wells	Caprock Integrity Potable aquifer contamination	▪ 5 wells drilled to 350m -one beside each injector, one remote and one between KB5 and KB502.
Wellhead/annulus sampling	Wellbore integrity Plume migration	▪ 2 monthly sampling since 2005
Tracers	Plume migration	▪ Implemented 2006
Surface Flux/Soil Gas	Surface seepage	▪Initial survey pre-injection ▪Two surveys in 2009 around key risk wells
Microbiology	Surface seepage	▪ First samples to be collected in 2010
Wireline Logging/sampling	Subsurface characterization	▪ Overburden samples and logs collected in new development wells

CO_2 breakthrough occurred at KB-
between inspection intervals
(August 2006 to June 2007)

Detected by leak from valve (shoul
have been pressure on a gauge)

Approx. 0.1 tonne CO_2 escaped
(3.2 million tonnes stored)

Flange and gauge fitted

CO_2 injection at Kb-502 stopped
during KB-5 decommissioning

b.3.6- Completion Diagrams

Before (1981) **After (2009)**

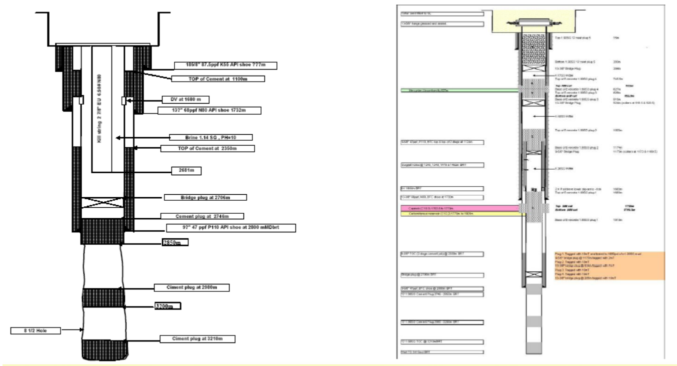
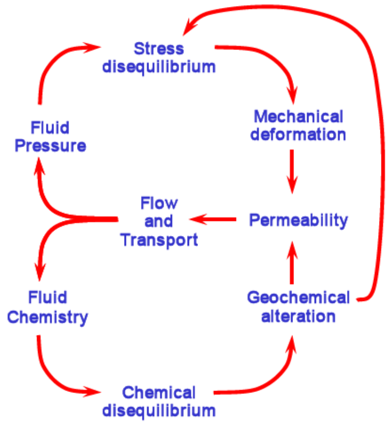


Fig.5 : Well completions

b.3.6- Predicting the fate of CO2 requires understanding of coupled processes



- Multiple processes are either directly or indirectly coupled
  - Relative significance of these couplings is both *site and injection scenario specific*
- Coupling is potentially exaggerated by fracture networks, e.g.:
  - Small changes in aperture
    → Large change in permeability
  - Creation of new fractures
    → new flow paths
  - Healing of fractures through precipitation
    → Potential for drastic reduction in permeability

Fig.5 : Geomechanical Analysis

b.3.7-Fracture/fault mechanics:

A performed a series of investigations of progressively more sophisticated analyses, a Mohr-Coulomb analysis of single fractures:

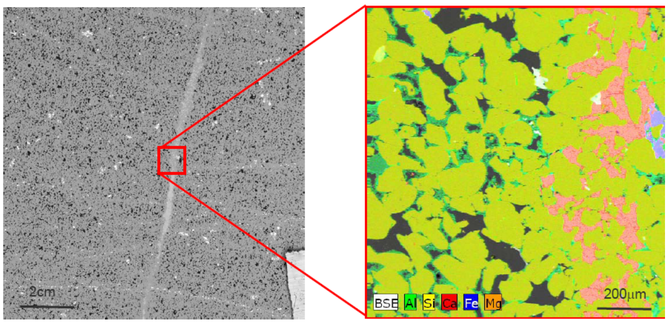
- Frac-HMC analysis of single fractures/fracture network
- Mohr-Coulomb analysis of fault network
- LDEC analysis of combined fracture network/faults

and overburden response and surface deformation :

- Preliminary Stochastic Inversion
- Geomechanical model in concert with reservoir forward model
- Future work: Induced microseismicity.

b.3.8-Pore-space Characterisation

The Chlorite grain coatings are in green color, and quartz sandstone grains are in yellow color. The Cemented fractures filled with Fe-carbonate cements are in pink color.



Implications of pore-space characterisation have been studied, two important findings have emerged from this work:
•The chlorite grain coatings, which are important in preserving the pore space in the first place, are also important incontrolling the mobility of CO2and the chemical reactions between the CO2 and the brine.
•The Fe-carbonate cement (Ankerite), which is observed filling naturally occurring fractures, is similar to the main mineral phases precipitated by reactions of injected CO2with the formation brine in the presence of chlorite grain coatings. The second observation supports the hypothesis that CO2injection may in fact be a self-sealing process at long-term timescales at this site.
The results are listed as follows :
-Cement carbonation, Portlandite and CaSiO3 are replaced by calcite and amorphous SiO2.

Class G cement hydrated in synthetic Krechba brine

Sandstone surface reacted with cement + CO_2

Shale surface reacted with cement + CO_2; carbonate precipitate juxtaposed against chlorite/illite

Fig.6: Pore-space Characterisation

Some changes in formation mineralogy have been observed like a partial replacement of chlorite (and possibly illite) with other silicate phases (kaolinite, smectite).
- Consistent results between observed solid phases and changes in brine.
The results provide key insights, the net volume changes in cement mineralogy resulting from carbonation will create a zone of reduced porosity (via diffusion) near the formation interface. The porosity will decrease within a fractured/damaged zone at the cement-formation interface in the downstream direction (via advection), implying some degree of self-healing to a possible pre-existing CO2conduit. The challenging technical issues remain:
•Compositions of unknown precipitates in some experiments
•Lack of a complete thermodynamic data set •Incomplete set of reaction kinetic models for all relevant mineral phases under reservoir conditions
•No formal geochemical-geomechanical coupling.

Other projects are implemented in Europe, we distinguish:

CO2STORE Project (2003-2006)

The purpose of the project is the study of the long-term behaviour of the CO2 injected in the reservoir of Sleipner.

CASTOR Project (2004-2008)

The project aims at the cost cutting of capture of the CO2 and at the detailed study of the future sites of storage in Europe (Spain, Norway, Austria and the Netherlands).

INCACO2 Project (2004-2007).

The project aims at strengthening the European and world cooperation for the improvement of the technical competitiveness.

c. Case studies

More than 10 millions of m^3/ j of gas loaded in CO2 will be produced by reservoirs Quartzite's de Hamra within the framework of the integrated Project of FieldII.
The raw gas has content in CO2 between 8 and 10 % according to reservoirs. The specifications of the treated gas impose the extraction of the CO2 to assure a maximum content of 2 % before its expedition in the transport network, the quantity is 660 000 m3 /j of the CO2 to reinsert.
The injection of the extracted CO2 is, besides, a contractual obligation. The contractor and the Contracting party will determine, the reservoir suited for the reinjection of the CO2, in accordance with the current safety standards in the world.
It is specified, besides that the CO2 must be reinjected in a reservoir other than soft water reservoirs, of surface or of Continental Intercalary.

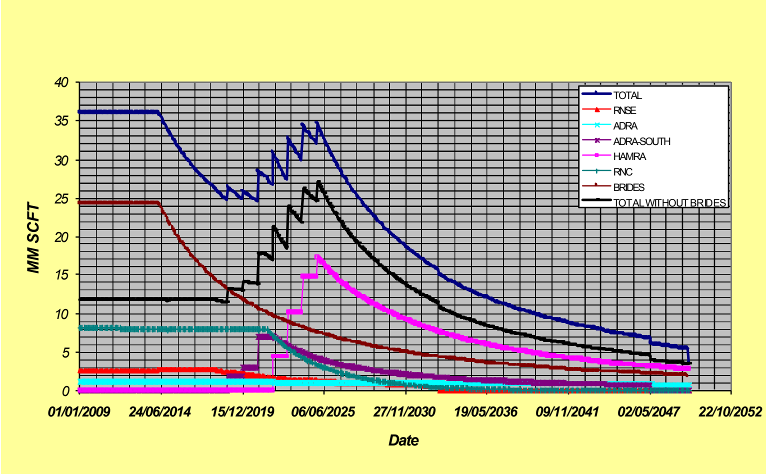


Fig. 7: Production profile of CO_2 for some Algerian fields

The partner considers Field I Tags' reservoir as being the best choice among the various alternatives which counts the region, because of its storage capacity and of its current state. According to the preliminary results, the following observations were made:
If we stop the production of gas and we inject the CO_2 only in the top of Tags, the final pressure reached by the reservoir will raise no geomechanical problem such as deformation (distortion) of the rock or the break of waterproof ness.In the case of the continuation of the production of gas the final recovery ratio will be doubled (until 90 %).With an adequate arrangement (measure) of the producing wells and the injectors and in particular if the CO_2 is injected in the aquifer, no breakthrough of CO_2 in the producing wells will be observed, at least during the first 10 years.
If the CO_2 is partially injected in the bottom of Tags, the production of oil of this zone could be increased and the clay separating both zones will improve the process of detention of the CO_2, delaying advantage or even avoiding totally the breakthrough during all the life expectancy(cycle) of the field. In the other hand, after examination of the proposition, some reserves on the choice of the reservoir Tags of Fields I, are done. It recommends examining the possibility of the detention of the CO_2 in the other reservoirs of the region. For that purpose the reservoir Tags structure of the Field I is consider as potential candidate. Also, it recommends to lead a feasibility study with the cooperation of a specialized engineering consulting firm, because of the lack of experience of Algeria in this domain. It recommends among others to be inspired by the existing experience in the domain. Indeed, several projects were already introduced or realized in the world.
The partner plans the reinjection of the CO_2 in the reservoir of FieldII Tags.
Although the reservoir Tags presents good petrophysics characteristics but it is an heterogeneous reservoir and complex. The reservoir Tags contains considerable remaining reserves of gas (14 Gm3) and the risk of pollution by the CO_2 is not spread, aggravating besides the problems of exploitation operation which could result from it. Although the part does not exclude the possibility of pursuing the exploitation of oil of this reservoir, this one will not be easy because of the contamination of the production by the CO_2, requiring processing plants and production suited.

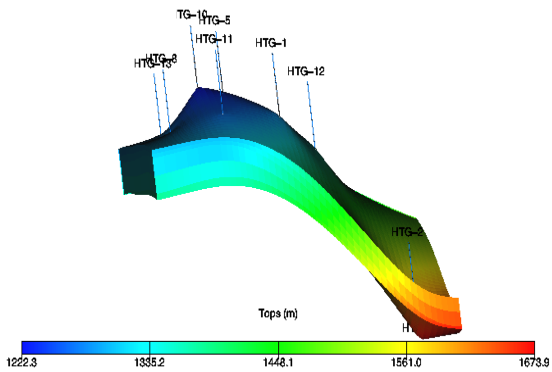
d. Conclusions

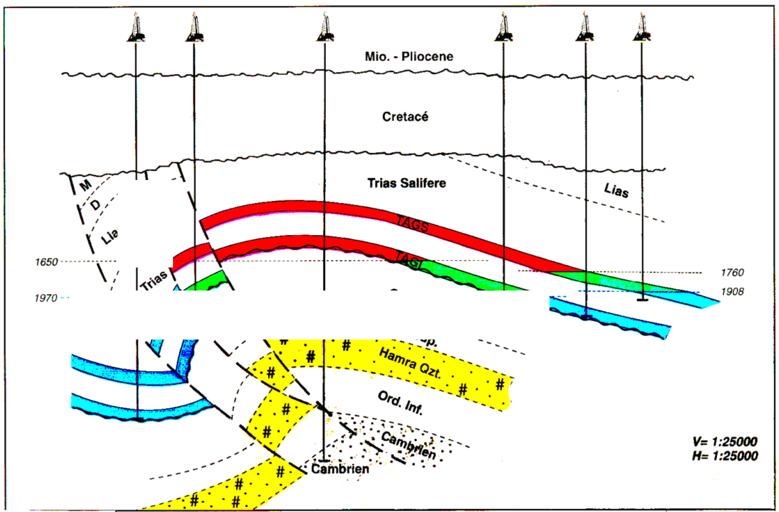
The partner introduces the possibility of using the existing wells of Tags for the injection of the CO_2. This practice is not recommended, according to the experience collectively admitted to the world.
All the wells drilled on the field of Field II cross Tags is a total of 83 wells which are so many sources of problems (corrosion, flight(leak), eruption) for their supervision and of possible interventions on these wells.

In a first place, all the wells close to wells injectors must be closed, to make sure of the good cementation of the casing.
The majority of these wells (59) are dedicated to reservoirs Tagi, and Albien who are not a member of the project and whom it is absolutely necessary to protect (before the end of 2015 for Tagi).
It reminds that the reservoir Tags is neighbouring to the other oil tanks, the continuation of the exploitation must not be compromised by the injection of the CO2.
The wells of FieldI must be secured and abandoned according to the procedure quoted previously, the economic aspect is to be considered.
An important human activity is present on the field of Reservoir I (processing centers, station (resort) of reinjection of gas, base of life, school, agricultural farm, main highway), what constitutes a major inconvenience of the point of view HSE.
On the 83 wells drilled on the field of FieldI we comptabilise:

- 33 wells at present in exploitation of the reservoir Field II-Tagi;
- 10 wells reconverted to production of gas of Gas-Cap of Field II-Tags;
- 1 well reconverted to producer of water of Albien;
- 1 well reconverted to injector of water in Tagi;
- 1 well transformed into injector of Gas (at present closed);
- 5 not exploitable producing wells;
- 11 wells were drilled for the injection of gas in Gas-Cap of Field II -Tagi (5 in exploitation(operation), 3 closed for problems of completion, 1 convert in producer of water, 1 in producer of gas and the last one is a well of observation.

Field I located in Algeria





Field II located in Algeria

The structure of Field I offer many advantages, summarized below:

- The field I is enough situated far from the base of life and the processing center of Field II. The aspect HSE is thus better insured.
- The topography of the zone presents no difficulty of access.

The structure is simple and known well (given available at present). Not divided, it confers a better waterproof ness compared with Field I Tags reservoir. There is no ring of oil in this reservoir and only the reservoir Tags produces gas.
The reservoir Tags petrophysics of good characteristics (15 % f and K of 100 mD) so good as those of Field II, so allowing the injection of the CO_2 a considerable flow rate.
The pressure of the reservoir is low (Pi=179, P =77) and present no inconvenience to the injectivity of the CO_2. (The pressure of the reservoir of Filed II tags is slightly superior).
A number limited by well (06) was drilled on the structure. Contrary to Reservoir I Tags, the wells of Field I are grouped together (included) on a small surface at the top of the structure, returning the little expensive operations of follow-up. Also the investments to be committed to secure the neglected wells are incomparable (6 wells instead of 83). The nearness of the structure of south Field I assures (insures) an availability of an additional volume of 12 billions of m3 for possible needs of long-term injection.
The major inconvenience which presents the choice of the structure of Field II remains the estrangement of the center of production, which is at a distance of 12 km. However, seen the new place of the processing center proposed the estrangement will not represent any more an inconvenience.

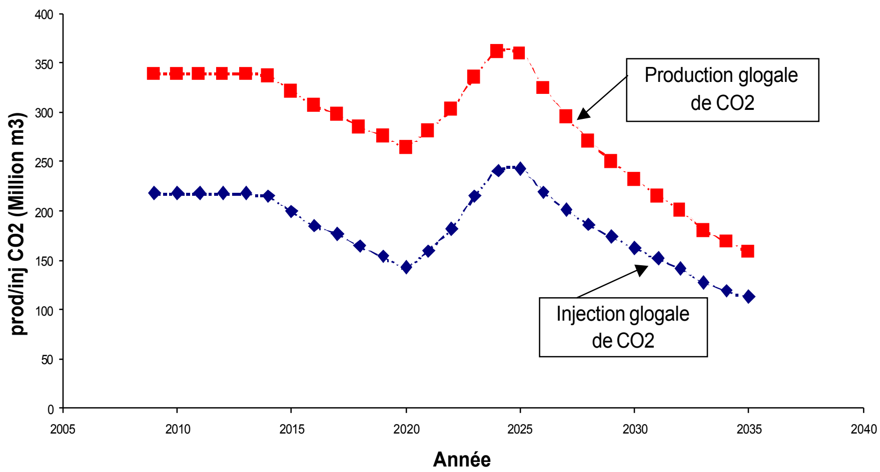


Fig. 8 : production Profil of CO_2 for some Algerian fields

A feasibility study of the injection of the CO_2 in the reservoir Tags of Reservoir II must be led by a specialized office (desk) before a definitive decision is taken on the choice of the reservoir to be held(retained).
In this study three options must be considered, condemnation of the remaining gas and the injection of the CO_2 in the gas zone. This option limits the interaction between the CO_2 and the water of the aquifer so avoiding the corrosion of wells injectors and the risks of sealing of the formation.
The CO_2 will fit naturally between the water and the gas so allowing the sweeping of that distribution of the CO_2 in the water.