Underground Gas Storage in an Undersaturated Oil Field in Argentina

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ABSTRACT

Repsol YPF has been developing an Underground Gas Storage (UGS) Pilot Project in the Lunlunta Carrizal oilfield, located in the surroundings of Mendoza City, Argentina, since 2003.

The challenge posed by this project involves a complex conversion of an undersaturated oil-depleted reservoir, with no original or secondary gas cap, to UGS for natural gas supply to the Cuyo region in winter time.

Due to the technical peculiarities of the project, several geological modeling and reservoir characterization studies have been performed. In addition, two horizontal wells were drilled through 900 m of porous media and preliminary gas injectivity tests were completed by the end of the 1990's.

Furthermore, for oilfield conversion more than 30 workover operations were conducted on the existing wells, which are mostly located at the top of the Lunlunta Carrizal anticline. Wells were appropriately conditioned to serve different purposes such as injection / withdrawal operations, gas bubble monitoring and technical abandonment for safety reasons.

This paper provides a general description of the ongoing pilot project, discusses the surface facilities designed and built for injection and withdrawal of 1.0 million m$^3$/day of natural gas with about 120 million m$^3$ of working gas, and addresses the special operating conditions required by high pressure requirements (210 bar), which call for stringent safety measures.

Finally, because of the proximity of the pilot project facilities to vineyards, rivers and underground aquifers we have worked very hard on the environmental aspects, quality and safety of the project. In this respect, an Integrated Management System has been recently certified, which includes ISO 14001, ISO 9001 and OHSAS 18001 standards.

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1.- BACKGROUND

The Lunlunta Carrizal oilfield is located in Mendoza Province, Lujan de Cuyo Department, 60 km away from the Capital City in a Southeast direction (Figure 1) and it is part of the eastern alignment of the fields of the Triassic-Jurassic Mendoza Basin with hydrocarbons being produced mostly from the Barrancas Formation.

The study area is composed of folded structures and differentially eroded homoclines and it is contained in the Barrancas anticlinal belt which is higher than 1,100 m above sea level.

The relief in the oilfield area involves piedmont hills resulting from tectonic and pluvial processes under arid or semi-arid weather conditions. Wind action, as well as gravity-driven sediment movement, exhibit subordinate participation.

The Lunlunta Carrizal oilfield consists of two producing areas known as South and North. Oil was first discovered in the South in September 1954 after the drilling of the LC-3 Well, which initially flowed oil from the Barrancas Formation at a rate of 280 m$^3$/d and a static pressure of 209 bar (with respect to reference plane) (~1400 meters below sea level).

Field development continued to increase until 1968 with 77 wells drilled. 13 of these proved dry. After several years with no drilling activity, the LCa-86 outpost well was drilled in the North Zone. It was completed in February 1988 and initial production was 45 m$^3$/d with traces of water from the Barrancas Formation. This well marked the onset of the development of this area and 31 exploitation wells and 3 outpost wells were drilled as of 1998.

An integral field study was performed in 1997 to assess the feasibility to use the Barrancas reservoir to store natural gas. Its main conclusions included: 1) Drilling of two horizontal wells with 900 steering on top of the productive formation, and 2) Tests for gas injectivity in the reservoir. These jobs were completed in 1999, using two injection wells and old compressor units adapted to meet relevant requirements.

The project came to a standstill until early 2003, while waiting for more favorable marketing conditions aimed at higher profitability and considering both the domestic market and the export market.

![Figure 1.-Location of UGS Lunlunta Carrizal](image-url)

**REFERENCES**

(1) Depleted gas field
(2) Depleted oil field
2.- GEOLOGY

The Barrancas Formation in the Lunlunta Carrizal oilfield consists of predominantly medium- to coarse- and very coarse-grained sands with pebbles and sand conglomerates. Sand mudstones are rare. This formation involves two members, an Upper Member and a Lower Member, based on a reduction in Upper Member sandstone content.

The Barrancas Formation includes a large number of sand units which are 1 to 4 m thick. It is highly heterogeneous and porous sand content may change abruptly over short distances. In addition, it is highly anisotropic probably as a result of stratigraphic factors, which involve a preferred orientation of sand bodies, and structural factors which improve reservoir quality on the high side of the structure as a result of reservoir rock fracturing.

From log and core studies performed on the wells drilled in the Lunlunta Carrizal oilfield, channel thickness was found to range from 1.0 to 17.1 m, with an average thickness of 4.3 m. Most channels are 1.0 to 5.0 m thick and probably account for simple depositional units.

The Barrancas reservoir is composed mostly of poorly-sorted sandstones and conglomerates. Rock material consists predominantly of lithic rock with rare quartz and feldspars resulting from volcanic material (Tuffs) probably of the Choiyoi Gr.

The field features a north-northwest-south-southeast elongated, asymmetric anticline with two apexes separated by a structural low, with the largest apex being the one located in the southern part (Figure 2).

![Figure 2.- Structural Map - Gas Bubble Area](image)

The northern and southern boundaries are composed of structural saddles which separate it from the Barrancas and Río Tunuyán fields, respectively. These flanks dip gently at about 2 degrees.

To the East, the structure is smooth up to some 1000 m from its apex but then subsides sharply as a result of the presence of regional-scale northwest-southeast striking reverse faults with significant fault throw.
3.- GAS INJECTION PILOT TEST

The Lunlunta Carrizal Pilot Project is designed to assess the technical and economic feasibility of building an Underground Gas Storage site in the undersaturated oil reservoir of the Barrancas Formation for a deliverability of 1.0 Mm$^3$/d during a winter period of about 100 days.

Natural gas currently injected into the reservoir is produced from the Neuquen Basin, which is located some 800 km south of Lunlunta Carrizal through the Centro Oeste Gas Pipeline (TGN S.A.) and the branch supplying Mendoza City, which is owned by Distribuidora de Gas Cuyana S.A. (Ecogas). (See Figure 3).

![Figure 3.- Interconnection with local gas pipelines](image)

Later gas is carried by the 10-in. gas pipeline owned by REPSOL YPF, from Fiscal Measurement Point N°14 (Puente Barrancas) to Storage.

Injection into the reservoir takes place from October to March every year (summer time in the Southern Hemisphere), making use of the idle carrying capacity of involved gas pipelines and availability of excess gas from the Neuquen Basin.

Estimated volumes for gas bubble development in the reservoir are as follows:

- Working Gas: 100 million m$^3$
- Cushion Gas: 150 million m$^3$

3.1.- Description of Surface Facilities

A layout of gas compression and conditioning facilities in the Lunlunta Carrizal Plant is shown in Figure 4.
3.1.1.- Compression System

- High-Pressure - Compressor Plant: It consists of two-stage reciprocating equipment to compress a flow rate of 300,000 to 900,000 m$^3$/d (gas injection into reservoir), depending on operating conditions of equipment:

  - First Stage: It involves two (2) Caterpillar – Ariel 1775 HP compressor units with an intake pressure ranging from 15 to 20 bar and a discharge pressure of 110 Bar.
  - Second Stage: It involves one (1) Caterpillar – Ariel 1775 HP compressor unit, similar to that used in the First Stage, with an intake pressure of 110 bar and a discharge pressure of 210 bar.

  The First Stage could be further used during the gas withdrawal cycle in winter, when well working pressure is lower than 110 bar, i.e. the lowest value to enter the Gas Conditioning Plant (Joule Thompson). With an intake pressure of 50 bar and a delivery pressure of up to 110 bar, the compression capacity of the first stage would be 1,000,000 m$^3$/d.

- Low-Pressure - Compressor Plant: An Ajax 630HP compressor unit is available to compress the low-pressure gas generated at Battery LC-2 as a result of the increased gas production from oil producing wells.

  Such equipment is capable of compressing up to 100,000 m$^3$/d with intake and delivery pressures of 2.5 bar and 50 bar, respectively.

3.1.2.- Gas Conditioning System

The quality of gas to be delivered to the Distribution System in Mendoza City must comply with the standards issued by the regulatory agency in Argentina (ENARGAS). Therefore, a 1,000,000 m$^3$/d Conditioning Plant has been built, that uses the expansion cooling process (Joule – Thompson).
Plant inlet pressure is 110 bar with a drop to 26 bar at plant outlet. This pressure drop allows water and hydrocarbon dew points specified for commercialization to be reached.

- Water Dew Point: 65 mg water/m$^3$ of gas
- HC Dew Point: - 4°C / 5.500 K.Pa

Injected / withdrawn gas has no sulfur content and carbon dioxide content is less than 2%.

### 3.1.3.- Gathering

All gas injector / withdrawal wells have been tied to two gathering branches, one for the northern area and the other for the southern area of the field.

- Main System (6-in. size): It connects all wells. There is only one measurement point which is located at Plant inlet.

- Control System (4-in. size): It runs parallel to the Main System and can measure injected / withdrawn flow rates separately on a “per well” basis.

Both Systems (Main and Control Systems) are provided with scraper traps at system ends (delivery and intake) to remove liquids and solids which may accumulate inside ducts during gas withdrawal.

### 3.2.- Conditioned Wells (See Figure 5)

#### 3.2.1.- Injector / Withdrawal Wells:

12 existing wells, i.e. 10 vertical wells and 2 horizontal wells, were conditioned. These include LC-7, LC-14, LC-17, LC-26, LC-28, LC-31, LC-33, LC-35, LC-61, LC-118, LC-120h and LC-121h.

Equipment installed:

- Permanent packer anchored above the top of the Barrancas Formation.
- Tubing with 2 7/8-in to 3 ½-in SEC threads.
- Two nipples (at tubing bottom below packer) designed to set plugs and isolate tubing from the reservoir.
- 5000 psi series Christmas Tree.

Bactericides and corrosion-inhibitors have been added to fresh water contained in the tubing-casing annulus which will be kept at a wellhead pressure of about 25 bar.

Tubing, packer and casing, as well as Christmas Trees, have been tested for tightness.

The injectors used in the first stage of operations are structurally highest in the reservoir to attain gas bubble development, from the top to the flanks of the structure.

Injected flow rates early in the pilot phase were approximately 200,000 std. m$^3$/d in October 2005, and gradually increased in terms of reservoir intake to 350,000 std. m$^3$/d in January 2006, using only 5 wells (LC-120h, LC-26, LC-31, LC-33 and LC-118).
3.2.2.- Monitoring and Safety Wells: A total of 12 monitoring wells located at key positions to control gas bubble evolution are used. Special emphasis is placed on the southern part of the structure.

In addition, intervention operations have been conducted on 11 wells located in the gas bubble service area for safety reasons. A retrievable plug ("N" Type) was set in these wells on top of the reservoir.

3.3.- Monitoring Program (Reservoir and Aquifers)

The monitoring program which has been implemented during the pilot phase of the UGS project involves several objectives. These include primarily:

- gaining information regarding the behavior of the reservoir - initially fully saturated with liquids - when subjected to gas injection,
- observing the distribution of injected gas in the reservoir structure,
- assessing the relative gas permeability of the reservoir formation,
- evaluating reservoir capacity and performance if the reservoir is used for gas storage.

In addition to the monitoring of the reservoir itself, the monitoring program also includes the follow-up of a water-bearing layer overlying the cap rock and the shallow aquifers of the site. The main purpose of this monitoring process is to verify that gas injection into the reservoir does not impact these water-bearing layers. This is of particular importance in this region where management of water reserves is of real environmental and economic concern.
3.3.1.- Reservoir Monitoring

The reservoir monitoring program takes into account the highly specific characteristics of the Lunlunta Carrizal oilfield and its wells drilled for oil production. Although most of these wells had been shut-in or abandoned well before the project started, several wells, mostly located around the reservoir structure, are still operating as oil producers.

In order to establish the reservoir monitoring program, a thorough review of borehole conditions was initially made to select some wells and convert them into monitoring wells. Gas-tight tubing and production packer set inside the cemented casing just above the top of the reservoir were run in these wells. For safety reasons, the other wells located within the area designed for gas storage were plugged to prevent gas entry into casing.

The monitoring program for the pilot phase of the gas storage project involves collecting and recording a wide range of data:

- at the gas injection plant: total gas injection flow rate, gas pressure and temperature at the outlet of the compressors, estimated gas volume injected daily in each injection well
- on gas injection wells: wellhead pressure and temperature, tubing/casing annulus pressure
- on monitoring: wellhead pressure, tubing/casing annulus pressure, regular downhole pressure gradient measurements
- on peripheral wells (plugged): wellhead pressure

In addition to these data, oil production is closely monitored, and daily measurements of the amount of oil, gas and water produced from onstream production wells in the area are taken. This monitoring process allows for assessment of the impact of gas injection on oil production and early detection of any gas breakthrough in oil producing wells.

3.3.2.- Aquifers Monitoring

To monitor the water-bearing layer overlying the cap rock, one well was converted to a monitoring well. For this purpose, a bridge plug was set inside the cemented casing at the top of the reservoir formation and a cement plug was placed above for bottomhole isolation. The cemented casing was then perforated at the depth of the water-bearing layer occurring some 100m above the reservoir formation and tubing and packer were run in the well. As this water-bearing layer is naturally artesian with a static pressure of about 4.5 MPa at surface, the wellhead pressure is measured daily.

As for monitoring of shallow aquifers, two new wells were drilled and appropriately equipped. The depths of the monitored intervals in these two wells are about 80m. and 170 m. below ground level, respectively. The water level is measured once a week in these two wells.

3.4.- Preliminary Results

Gas injection operations for the pilot phase are due for completion during 2006. Gas production tests will be then performed in some of the gas wells in order to evaluate well deliverability and the amount of gas which can be withdrawn from the reservoir. According to tests results, a decision will be made regarding the development of the gas storage project.

Although no significant drawbacks have been identified during the gas injection periods for the time being, the results obtained to date do not provide any prediction of the outcome of the pilot phase. Preliminary conclusions are as follows:
- The gas injectivity of the wells matches previous estimates and leads, for vertical wells, to an average gas injection flow rate of some 50,000 std. m\(^3\)/d per well.

- As anticipated, gas injectivity of the horizontal well is significantly higher than that of vertical ones, which allows a gas injection flow rate in this well of up to 150,000 std. m\(^3\)/d.

- A gas bubble seems to have formed on top of the structure, as suggested by the rapid increase in gas pressure detected by one monitoring well in the area (LC-19). Figure 6 shows pressure variations in the monitoring wells vs. injected gas volume.

- Gas breakthrough in some remote oil producing wells indicates that injected gas can migrate over long distances (up to 1 km) from injection wells.

- The distribution of injected gas within the reservoir seems to be very heterogeneous and is largely the result of the combination of a complex geological environment and the presence of areas highly saturated with water within the reservoir.

- As expected, gas injection was not found to impact the aquifers occurring above the cap rock, which is clearly positive given the large number of wells drilled in the area.

Uncertainty still remains mainly over sweep efficiency and buoyancy effects of injected gas in connection with displacement of the liquids which initially saturate the rock mass. As a consequence, residual liquid saturation in the area reached by the gas bubble is still largely unknown. Production tests which will be performed after the gas injection phase are expected to provide reliable information on this issue.

![Figure 6.- Pressure variations vs. injection gas flow rate](image)

**4.- ENVIRONMENTAL PROTECTION, SAFETY AND QUALITY**

In December 2004, Repsol YPF successfully completed the certification (BVQI) of an Integrated Management System (IMS), including the following standards:
The IMS includes the Storage Gas pipeline interconnection with the Gas Distribution System in the Mendoza City, the Gas Compression and Conditioning Plant, the Reservoir, Gathering and Gas Injection / Withdrawal and Monitoring Wells.

The main aspects of which objectives have been set for 2005 and 2006 are as follows:

- **Higher Aquifers**: quality control of water by sampling the Tertiary horizons which are composed of sweet water, every six months (2 new wells were drilled for that purpose).
- **Existing Oil Wells**: Verification of isolation of cement behind casing and casing integrity in oil production wells located in the area of gas bubble influence.
- **Gas Injection Wells**: Wellhead safety system for casing protection against high protection (tightness failure of packers and tubing).
- **Gas Reservoir**: Gas bubble control at spill points along anticline edges, particularly in the southern zone. To perform this control, 12 oil wells were conditioned for monitoring purposes.
- **Gas Compressor Plant**: Escape gases composition control in Compressor Units, Gas Balancing (Gas Inlet, Gas Outlet, Gas Fuel, Gas Flared and Gas Associated with Oil Production), Waste Disposal, Water and Electricity Savings.
- **Vegetation**: Plantation program (new species) in the area around the compressor plant affected by new facilities.
- **Gas Control**: On-line gas control (Scada).
- **Monthly Statistics**: Accidentology and technical parameters.
- **Work Environment Control**: Noise, lighting, dust, etc.

### 4.1.- Safety System for Injection Wells

The safety system (Figure 7) is designed mainly to:

- detect any well anomaly which may take place during injection,
- protect casing from any potential high pressure resulting from packer or tubing failure.

For the above reasons, the wing-valve outlet (tubing-casing annulus) has been connected to the vent line of the well. A pressure sensor and a safety valve are mounted on the new line.

The pressure sensor is designed to detect any pressure drop or increase in the tubing-casing annulus, which may be caused by tubing or packer tightness failures.

If the minimum pressure pre-set for a given well is reached, an alarm will sound in the control room and gas injection in the well will be suspended.

If high pressure is detected, the safety valve will open to drain or vent the annulus and gas injection will be suspended.

In both cases (high and low pressure), the cause of high or low pressure will be determined and the well will be conditioned to resume gas injection under normal conditions.

Safety valve opening pressures have been set below casing tightness test pressures to preserve casing integrity.
5.- CONCLUSIONS

- The Lunlunta Carrizal Project presents a major challenge for Repsol YPF as it involves developing a gas bubble in a high-viscosity (3.7 cp), undersaturated oil reservoir composed of low-permeability fluvial sandstones.

- After injecting more than 30 million std. m$^3$ of gas into the reservoir for about 4 months, the gas bubble was found to grow slightly on top of the structure. However, owing to the gaseous phase increase, care should be taken to keep injected gas within the storage area boundaries (up to – 1610 m).

- As a result of the growth of the gas bubble on top of the structure, oil producers in the central and southern parts of the field (LC-121 (H), LC-8, LC-20, LC-36, LC-37 and LC-44) have been shut in.

  Based on the above results, gas injection will continue with current wells, particularly the LC-120 (H) horizontal well on account of its optimal structural position.

- During the last months, downhole pressure gradient measurements will be taken in stand-by monitoring and injection wells in order to detect changes in the gas/water contact as a result of gas injected into the reservoir.

- After injection, gas production tests will be performed to assess recoverable gas volumes and productivity indexes. The results of these tests will be key to drawing conclusions about the future development of the project.

  As an early approach, tests can be scheduled in each gas injector and in some monitoring wells (for instance in the LC-19 Well).

- The Integrated Quality, Environmental, and Safety Management System in place at Lunlunta Carrizal Storage facility (ISO 9001, ISO 14001 and OHSAS 18001 Certifications) has provided Repsol YPF with effective improved control tools since March 2003: no accidents, optimum gas balancing, thorough aquifer protection, and forestation of areas affected by works.

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REFERENCES

