DIADEMA, THE FIRST UNDERGROUND STORAGE FACILITY FOR NATURAL GAS IN ARGENTINA. CONSIDERATIONS REGARDING ENVIRONMENTAL PROTECTION, SAFETY AND QUALITY

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ABSTRACT
In the most southern part of the American continent, the first underground storage facility for natural gas in Argentina has been recently developed, completing with satisfactory results an injection and production cycle over 2001 and 2002 (Fig. 1).

The Diadema underground storage facility, located nearby the city of Comodoro Rivadavia, has been built to partially meet the great demand of gas for domestic and industrial use during winter season in the central and northern areas of the Patagonia, when the oil fields supplying the region with associated gas are unable to comply with gas demand. Consequently, it is necessary to store the gas coming from the gas fields located in the Tierra del Fuego island during summer and to retrieve it during winter for local distribution.

REPSOL YPF took the initiative to develop with Géostock technical support this commercial project, consisting in the conversion of a depleted gas field by refurbishing old production wells, drilling new wells and installing surface equipment, using the most modern technology and complying with drastic conditions regarding safety, quality and environmental protection. This project has successfully completed the process of obtaining the Certification of an Integrated Management System.

This paper presents the main geological features of the Diadema facility, points out the studies related to reservoir modelling and simulation, describes the surface and subsurface equipment at present in operation and those planned for future expansions, and indicates the operational aspects in relation to gas movements and monitoring implemented for environmental protection.
achevé avec succès le processus d’obtention de la Certification d’un Système de Management Intégré.

Cet article présente les principales caractéristiques géologiques du stockage de Diadema, en indiquant les études réalisées pour la modélisation et la simulation du réservoir, et donne une description des installations de surface et de sub-surface actuelles ainsi que de celles prévues pour des extensions futures, sans oublier de mentionner les aspects opérationnels relatifs aux mouvements de gaz et à la surveillance mise en place pour la protection de l’environnement.

INTRODUCTION

The Diadema project is aimed at optimizing natural gas and oil development and production in Golfo San Jorge basin fields, since this is an area producing oil with associated gas, with limited operation flexibility for normal supply of gas demand during the winter season, as well as for the management of surplus volumes of summer production.

Besides the General San Martín gas pipeline is being used at its full capacity in winter, thus becoming a ‘bottleneck’ for gas coming from the Austral and Golfo San Jorge basins, and limiting the transportation of the available gas in the producing fields to meet the consuming areas demand.

The situation is exactly the opposite in summer, a period during which there is idle transport capacity available resulting from the strong reduction in gas demand.

The Diadema Project allows to store surplus gas from producing fields during the summertime and contributes to the optimisation of the production of liquid hydrocarbons and associated gas in the fields connected to the General San Martín main gas pipeline, thus avoiding gas flaring and / or shutting off high GOR wells in those fields. The natural gas stored in the reservoir during the summertime will be later on withdrawn during high demand periods (Fig.°2).

This project will also increase the gas supply to Comodoro Rivadavia city, so Diadema will be a new point-of-delivery into the gas distribution system. This will contribute to improve the reliability and quality of the natural gas supply to the city, thus allowing to reduce or avoid (with future expansions) current gas supply shortages to “large users” (power plants, industrial plants, etc.).

Although a reservoir gas injection Pilot Test, technical studies and a complete cycle of gas injection/withdrawal have already been performed to support the project, other technical evaluations and investments are required to confirm the maximum storage capacity and future natural gas injection and withdrawal regimes.

BACKGROUND

In 1992, the former Gas del Estado company developed a Pilot Reservoir Gas Injection Test (Banco Verde, Fig.°3), for which some existing wells were conditioned (2 injection wells and 5 monitoring wells).

Twenty five million cubic meters of gas were injected at a 400,000 to 600,000 m3/day rate, with a 25 to 30 bar wellhead pressure. This operation was carried out without compression equipment due to the low pressure prevailing in the reservoir.

Inter-well interference tests and isochronal tests (production) were made to verify the reservoir’s performance under different working conditions.

The results confirmed the project viability, indicating that the reservoir had good petrophysical conditions and the appropriate capacity to meet local storage needs.

After that gas injection test, the field owner company (CAPSA) operated the gas field during quite a long period through the production well O-11, which made it possible to record the extracted volumes and declining wellhead pressures. This operation finished in December 2000, when said well was shut off to restart the reservoir gas injection operation.

Between 1999 and 2000, Repsol-YPF and Géostock performed studies of the reservoir and of its related surface facilities. These studies included the following: Reservoir Numerical Simulation, bottom hole static pressures analysis, monitoring wells workover, gas pipelines revamping and metering systems, as well as the setting up of new facilities.
CAPSA and Repsol-YPF signed a “Contract of Use” of the surface facilities and of the appropriate gas reservoir for the so called “Banco Verde” horizon located in the Repsol-YPF licensed area of the Diadema field, which allows Repsol-YPF to carry out injection and withdrawal operations of the stored gas, originating in the development and production of other fields in the region.

GEOLOGY AND RESERVOIR

The Diadema field is located 40 km Northwest to the city of Comodoro Rivadavia on the Northern flank of the San Jorge basin.

Among different hydrocarbon productive levels, lies the so-called “Banco Verde” horizon, belonging to the Salamanca Formation of the cretaceous-tertiary age, at an average depth of 650 metres below the wellhead level.

The Banco Verde horizon is made up of high-porosity (25 to 30%) and high-permeability (0.1 to 1.5 Darcy) sandstone, deposited by a marine transgression in an estuary environment. Its top is covered by clays deposited on a coastal lagoon environment.

The Banco Verde horizon is a depleted gas reservoir with a 15 meter average thickness and an original pressure of about 26 to 28 bar.

Structurally, the field is divided into blocks caused by direct faults with an East-West and Northeast-Southwest strike.

The gas storage operations are carried out in the so-called Repsol-YPF licensed block, which is intersected by various faults named Cañadón Brooks “A”, “B”, “C”, etc. Most of these faults have an east-west orientation with vertical throws of up to 40 metres.

EXISTING FACILITIES

- **Gas Pipeline.** This is a 10” - 12” diameter and 7.1 km length gas pipeline, fit for high-pressure (up to 65 bar) operation, which connects the reservoir with the 12” diameter branch pipe owned by Camuzzi Gas del Sur S.A. gas distribution company. In turn, this pipeline also connects to the General San Martín main pipeline, downstream the Manantiales Behr Compression Plant.

  The 10” - 12” interconnection gas pipeline that provides for natural gas flow to and from the reservoir, connects to gas injection/production wells (at present 7 wells) and to a gas line for the field’s internal consumption.

  Several restoration works were performed on this pipeline under the NAG-100 applicable standard, including the following: Hydraulic test (Maximum Operation pressure: 65 bar), installation of the new cathodic protection system, upgrading the path running parallel to the gas pipeline, etc.

- **Metering.** The metering system used is the orifice plate system to control the injection flow into the wells, and a bi-directional ultrasound flow-metering system has been installed at the interconnection point with the gas distribution company, with state-of-the-art technology for on-line controls and operation monitoring functions (SCADA).

- **Injection System.** For distributing the arriving gas towards the 7 injection/production wells, a manifold and connection pipes were built with a flow-metering system with a 300,000 m3/day capacity per well, at a 26 bar pressure (Fig.°4).

- **Withdrawal System.** To provide a maximum withdrawal rate of about 600,000 m3/day during winter season, a 2,000 HP compressor plant was built, with a suction pressure of 7 to 15 bar and a discharge pressure of 60 bar, a dehydration plant with TEG absorption, gas / liquid separator, gas metering and regulation systems, manifolds, on-line gas quality control systems (chromatograph and hygrometer) and data transmission and communications systems (RTU). The gas to be produced from the storage facility is compressed and dehydrated for its re-entry into the distribution system under the quality specifications required by the ENARGAS (gas regulatory agency).

NATURAL GAS INJECTION AND WITHDRAWAL CYCLES

Based on the information available on the gas field characteristics and the results of reservoir simulation studies, several scenarios of gas injection and withdrawal cycles were
considered during the preliminary stage of project development. The most likely operating conditions were simulated in order to predict the mean reservoir gas pressure in relation to the injected and withdrawn gas volumes. However, some uncertainties regarding the actual behavior of the reservoir remained until the first injection and withdrawal campaigns.

The so-called “Case 1” was selected, as it was considered the best suited for the early stage of the project, without disregarding the study of future expansions based on a reservoir pressure increase of up to 26 bar and a higher number of gas injection/production wells.

Because of the very low residual gas pressure prevailing inside the reservoir at the time of gas field abandonment, the gas storage operation required the injection of a large quantity of gas in order to re-establish a reservoir pressure compatible with the foreseen operating conditions.

The gas injection into the depleted reservoir started at the beginning of 2001. The two existing wells which were used for the gas injection during the Gas Injection Pilot Test in 1992 were first equipped for that purpose. Later, three other existing wells were also equipped for gas injection and two new wells were drilled and equipped at the beginning of 2002 in order to increase the gas injection capability and to provide an appropriate gas withdrawal rate during the production campaigns. About 50 Mm3 of gas were injected into the reservoir before the first withdrawal operation which took place in August 2001. The amount of gas produced during that first withdrawal operation was however very limited (only about 2 Mm3 of gas were withdrawn in about 2 weeks).

Gas injection into the reservoir resumed after this short production period and continued until the end of May 2002, when the total net volume of injected gas was about 220 million m3. Then started a complete withdrawal campaign for the southern hemisphere winter period of year 2002. During that withdrawal campaign which lasted nearly five months, a total volume of about 67 Mm3 of gas was produced from the reservoir. This achievement was totally in accordance with the originally defined target and proved that not only the depleted gas field had a sufficient capacity for the required working gas volume, but also that the number and location of the operation wells were appropriate to provide a sufficient gas deliverability for the present needs.

Normal injection/withdrawal cycles for the Diadema gas storage facility consist of an injection period of about 7 months, from October to March, and a production period of about 4 to 5 months, between May and September. The injection/withdrawal cycles may however vary significantly from one year to another depending on the actual weather conditions in the region during winter, which can change drastically.

RESERVOIR MONITORING

To have a detailed control of the gas bubble in the reservoir, workovers of existing wells located in the Repsol-YPF licensed block as well as in neighbouring blocks were carried out.

Prior to the beginning of the gas injection operations, measurements of static gradients with memory gauges were recorded in all wells identified as monitoring wells, to know what was the current pressure and to identify the gas/water contact in the reservoir.

Since well O-11 was a producing well up to December 2000, causing disturbance within the drainage radius itself, the injection wells were shut off during 15 days prior to the beginning of the gas injection operations to record the reservoir stabilized pressure.

Upon the commencement of gas injection into the reservoir, every single injection well, the bottom hole pressure was recorded with a memory gauge, during a minimum of four uninterrupted days, which provided records with complementary information on the reservoir parameters necessary for the fine-tuning of the numerical simulation model.

Since the beginning of the gas injection stage, monthly static pressure measurement campaigns have been ran in the monitoring wells while well head pressures of the same wells have been recorded on a daily basis, especially in the wells close to the O-10 and O-11 injection wells, under a systematic measurements schedule both at the reservoir level with a memory gauge and at the well head level with a pressure gauge and a dead weight scale.

The present monitoring network includes 12 monitoring wells drilled at the Banco Verde level, which allows to measure the gas pressure in various areas of the reservoir.
NUMERICAL MODELLING AND SIMULATION OF THE RESERVOIR BEHAVIOR

A computerized numerical modelling of the Diadema reservoir has been developed during 2001 in order to attempt to predict its behavior and to optimize the storage operating conditions. The model was built up using the geological information and gas production data, though scarce, which were available at the time. The model had to take into account the structural features of the porous layer and particularly the more or less impervious barriers formed by the faults and creating compartments within the reservoir.

At the early stage of gas injection, some parameters of the model were adjusted to match the predicted gas pressure distribution within the reservoir and the pressures observed on the monitoring wells. Afterwards, the model was periodically updated with the latest gas movement data and in-situ pressure measurements. This follow-up allowed to monitor the deviations between the theoretical behavior forecast by the model and the actual evolution of the reservoir data, and therefore to identify possible inaccuracies in the reservoir characteristics introduced in the model.

The model allowed to evaluate the amount of gas present in each reservoir compartment and to optimize the location of the new injection/production wells. Along with the increase of the injected gas volume, it was also found that the actual reservoir area occupied by the stored gas extended beyond the originally considered limits, thus requiring additional monitoring wells.

FUTURE EXPANSION OF THE WORKING GAS AND DELIVERABILITY

An increase in the present working gas volume in a near future is already considered in order to meet a possible higher gas demand during the winter season. This would be achieved by using additional reservoir compartments adjacent to those presently occupied by the stored gas and also by a possible increase in the range of operation pressures. Specific studies are presently being carried out in order to prepare such a development. These include to review abandoned wells data, geological studies and a monitoring program in wells located close to the present storage area.

This expansion could be implemented after the completion of the second injection/withdrawal cycle. This expansion is expected to provide an overall storage capacity of up to about 200 Mm3 of working gas. If implemented, this expansion would require new injection/production wells, along with additional associated surface equipment, to bring the total deliverability of the facility to some 2.0 Mm3/day.

INTEGRATED MANAGEMENT SYSTEM

In November 2002, Repsol-YPF successfully concluded the certification process (BVQI) of an Integrated Management System (IMS), including the following standards:

- Quality (ISO 9001: 2000)
- Environment (ISO 14001: 1996)
- Safety and Work Health (BS8800:1996)

The IMS includes the Storage Gas pipeline Interconnection with the Gas Distribution system in the city of Comodoro Rivadavia, the Gas Compression and conditioning Plant, the Reservoir, Gathering and Gas Injection / Withdrawal and Monitoring Wells.

The main aspects identified on which objectives have been set for the year 2003 are the following:

- Higher Aquifer: quality control of water, through sampling every six months at the so-called “Patagonia” and “Rio Chico” horizons (3 new wells are being drilled at the moment).
- Old Wells: Verification of the isolation behind casing, in deep drilled oil wells in the area of gas bubble influence.
• Gas Reservoir: Gas bubble control at spill points and in blocks connected by unsealed faults, i.e. monitoring of gas migration towards neighbouring areas (North and West of “O” and “I” wells). To perform this control three additional existing wells are being conditioned to be monitored.
• Gas Compressor Plant: Escape gases composition control of the Compressor Equipment, Gas Balancing (Gas Inlet, Gas Outlet, Gas Fuel, Gas Field Consumption, etc.), Residues destination, Water and electricity saving.
• Native Vegetation: Replant native vegetation, in the surrounding area of the compressor plant and gathering system.
• Gas Control: On line gas control (Scada)
• Monthly Statistics: Accidentology, technical parameters
• Work Environmental Control: Noises, illumination, dust, etc
• Satisfaction Poll: To internal and external customers of the gas storage activity.

In this way, Repsol-YPF has adequate control tools to provide a natural gas underground storage service in the Patagonic region, which will allow to meet their clients needs and expectations, guaranteeing people safety and health protection and environmental preservation.

CONCLUSIONS
1. Diadema constitutes the first commercial natural gas underground storage project in Argentina, which will use the transmission idle capacity of the General San Martín gas pipeline during summertime for reservoir injection purposes. In its first stage of development, it will be used internally by Repsol-YPF, to comply with its obligations under the sale contracts of natural gas coming from the Golfo San Jorge basin.
2. This project directly impacts on oil development and production and on associated gas producing fields in the region, thus contributing to preventing gas flaring and the potential shutting off of high GOR wells in summer. This situation leads to an increase in the hydrocarbons production in the Austral and Golfo San Jorge basins, a fact that helps the economy of the provinces through higher annual royalty revenues.
3. Its proximity to the Comodoro Rivadavia city, makes the natural gas supply more reliable and of a better quality, turning Diadema into a new point-of-delivery into the distribution network, which will operate independently from the main transportation system during the winter season.
4. Future expansion have been planned, based on the growing gas needs in Central Patagonia, and the successful results of the first gas injection/withdrawal campaign

ACKNOWLEDGEMENTS
The authors extend their acknowledgment to Repsol-YPF and CAPSA for allowing them to present and publish this paper.

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Figure 1 – Diadema Underground Gas Storage location

Figure 2. Connection to the transmission and distribution pipelines
Figure 3 – Geological cross-section

Figure 4 – Project flowchart