Pre-salt production development in Brazil

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Brazil's 'pre-salt' reservoir is a layer of oil-bearing rock of carbonate composition, positioned under a thick layer of salt and located in the Santos and Campos basins (Figure 1). Lying under it are the source rocks, shale rich in organic matter. These sediments are the result of the evolving process of Brazil's southeast and eastern basin formation, due to the South America-Africa breakup around 120 million years ago.

The major exploration and production efforts are being applied on the Santos Basin Pre-Salt Cluster (SBPSC), that include six blocks operated by Petrobras with different partners: Galp (Caramba and Jupiter) Shell and Galp (Bem-Te-Vi), BG and Repsol (Carioca and Guará), BG and Partex (Parati), BG and Galp (Lula, Cernambi and Iara). The area is located 300 to 350 km away from the coast, with reservoir depths between 5,000 and 6,000 metres below the sea level, in ultra deep water (1,900 m to 2,400 m) under a thick salt layer (in some areas, up to 2,000 metres).

In the Lula and Cernambi fields, the total recoverable volume was estimated as 8.3 billion barrels of oil equivalent from carbonate reservoirs with highly variable geological properties. The oil has an API gravity between 28 and 30, gas-oil ratio between 200 and 350 m^3/m^3 and variable contents of CO_2 (8 to 15 per cent). The Brazilian government has transferred to Petrobras another 5 billion boe of potential reserves in other parts of the Santos Basin Pre-Salt Cluster.

Development strategy

A phased strategy will be applied to the SBPSC in order to allow exploration to be carried out with development. The immediate priority is to reduce uncertainties related to the reservoir – especially the basin's geological character, hydrocarbon recovery methods, definition of the best well geometries, flow of oil through subsea pipelines, separation and use of CO_2, and design of the processing plant, risers and mooring systems. This acquisition of geological and production information is the priority of what is called "Phase 0". This phase involves drilling and testing of appraisal and reservoir data acquisition wells and, since 2009, a series of Extended Well Tests (EWTs) performed with two small FPSO (floating production, storage and offloading) vessels. In all, this will lead to production of around 100,000 barrels a day.

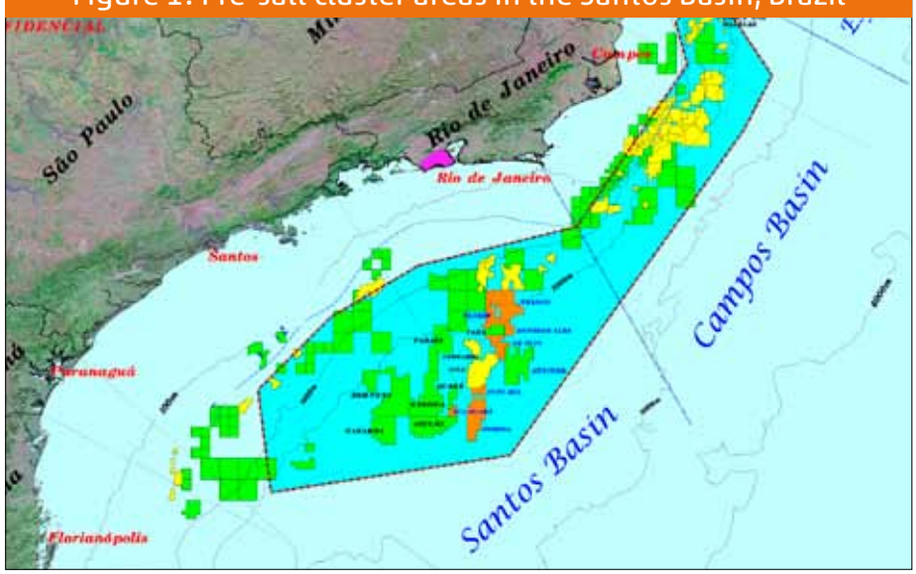
The following phase - Phase 1A, aims to reach the production of 1 million barrels a day using using technologies developed in the Campos Basin:

- two anticipated spread moored FPSOs pilots in Guará and Lula NE, scheduled for 2013;
- two additional spread moored FPSOs to operate in Guará and Cernambi, scheduled for 2014 and;
- eight production systems, comprising new built FPSOs with similar engineering project, to be installed in order to support the following projects. For the gathering systems, flexible risers, decoupled rigid risers or coupled rigid risers can be applied. These eight FPSOs are scheduled to start operation gradually, from 2015 to 2017.

These units will operate with processing plants ranging from 120,.000 to 150,000 barrels a day and 5 to 8 million cubic metres of gas capacities.

Definitive development of the fields will start in 2017 with Phase 1B. Further production systems will be required for the optimal exploitation of the fields, using technological and logistic solutions specially developed for the conditions of the SBPSC.

Figure 1: Pre-salt cluster areas in the Santos Basin, Brazil



Technological challenges

Due to the oil and reservoir characteristics as well as the environmental scenario, the development of the Pre-Salt in the Santos Basin raises technological challenges in several disciplines.

Reservoir characterisation

Pre-Salt reservoirs are Aptian rocks, mainly microbial, heterogeneous carbonates (Figure 2). The main challenge posed by the Pre-Salt reservoirs is to use the knowledge of the paleo-environment where these carbonates developed, as well as seismic attributes, in order to optimise drainage of the reservoir. The geological characteristics of the Pre-Salt raise some difficulties as to the quality of seismic data, because of the uneven surface of the top of salt, the internal variations within the salt layers which cause heterogeneous scattering of the seismic energy, and the limited vertical resolution in the reservoir which, due to the high velocity of the seismic waves in the carbonate, is very common in deep reservoirs.

Oil recovery

Secondary recovery must be implemented to improve oil recovery in the Pre-Salt carbonates. These rocks are usually oil wet, and this characteristic affects the performance of water injection, which will be tested in the Lula Pilot field.

Another complication in the case of water injection is related to rock-fluid interaction, which is more important in carbonate. To understand the phenomena and to assess the risks involved, as well as to define mitigation actions, rock-fluid interaction tests are being carried out with the reservoir rock and the salt cap rock. Alternative recovery methods will be implemented in the Pre-Salt reservoirs. Gas injection is already being tested in the Lula Pilot and the water alternating gas method (WAG) will also be tested in the field.

Well engineering

The main issue related to well engineering is the construction cost. Deep reservoirs in deepwater require special rigs and skilled people to improve the learning curve and reduce well construction duration. In order to reduce the overall cost, several initiatives are being carried out related to well design; control and constant improvement of rigs´ performance; using lighter rigs in the initial phases of the wells, well tests and deployment of 'Christmas trees' (often referred to as X-Mas trees, the equipment installed on the bottom of the sea that controls the production of the wells), and drilling of deviated wells.

The great depths of the reservoir and the great distance from shore add to well costs that represent approximately 50 per cent of the overall cost of a typical Pre-Salt development project. But there is room for improvement, such as: logistics, optimisation procedures for the construction of wells, simplifications in the design of wells and in the equipment being used in drilling.

The penetration both in salt and carbonate rocks has increased as wells have been built, with a significant reduction in the average cost of a well. By understanding the mechanical properties of salt and carbonate rocks and through close cooperation with the service companies, the average rate of current drilling of vertical wells is more than twice the rates obtained in the first wells. Different concepts and new technologies that could lead to further reduction are being tested.

Salt rock shows high creep strain rates, constituting a potential hazard to well drilling. The evolution of the well closure with time, caused by creep, can result in imprisonment of the drill string or successive operations to correct the diameter of the well. The low temperatures in the Santos Basin Pre-Salt reservoirs and the predominance of halite in the salt layer are favorable factors. At the opposite side the high stresses associated with great depths are concerns, even when dealing with halite. As mentioned, this challenge is being overcome, at least considering the salt characteristics in the Lula Pilot area.

Another focus is on materials to be deployed in the well, whose supply can add time and cost. Special resistant casing must be used to avoid well collapse due to the salt movement, and due to the presence of contaminants in the reservoir fluids and also characteristics of the formation water. Corrosion resistant alloys must be considered for completion of wells below the salt layer.

Expert cementing is also required in the Pre-Salt to guarantee a reliable isolation between the pay zones and also well integrity considering the cap salt rock. Special cement slurries are being applied in order to avoid risks of channeling and to guarantee that the cement properties will not be affected by the produced or injected fluids.

Another important issue is the definition of the best well geometry for each Pre-Salt area. Small scale reservoir simulation is used to quantify the benefits of different well geometries. Field results are encouraging. Three deviated wells have already been drilled in the Lula Pilot area, and →

→ the next step will be the construction of a high angle well in the Lula Pilot.

Flow assurance

The salt layer is a good heat conductor. So, the reservoir temperatures are lower than expected for rocks at great depths but more critical for wax deposition and hydrate blockages. Notwithstanding, with more than two years of production in the Lula Field, no significant problems were reported in pipes.

Wax deposits may occur in long flowlines or in the risers. The conventional solutions are to use thermal insulated flowlines, to manage heating and assure flow from the wellhead to the platform as well as frequent pigging the pipes to prevent wax accumulation. The high pressures involved in the flow, together with low temperatures, can result in a risk of blockages by hydrates. But the high values of gas-oil ratio (GOR) are a positive factor in operational procedures during shutdowns, because of the lower hydrostatic pressure.

Thermodynamic simulations have forecast the possibility of calcium carbonate, barium and strontium sulphate precipitation. Low sulphate sea water injection is an option to prevent sulphate scale formation. Chemical treatments may be required to prevent calcite precipitation in the perforations and subsea equipments. To cope with this challenge, Petrobras' expertise in the Campos Basin, as well as support from international institutions, are being used to define the chemicals to be applied and investigate interaction that sea water or EOR methods may have with the reservoir rock.

The possibility of hydrates in the water-alternating gas injectors was thoroughly investigated. Among the improvements that are being considered are a special design for the standard Pre-Salt X-Mas tree, allowing the injection of hydrate inhibitors; the use of separate injection flowlines for gas and water; special procedures to be applied during fluid change; heating of the injection water, among others.

Subsea technology

The deeper the water, the higher the loads due to the weight of the mooring lines.The use of lighter materials with higher stiffness is necessary to limit the motion of the Production Unit. The higher loads due to the risers´ weight impact the platform structural engineering and possibly the riser lifetime, possibly requiring special materials. A good alternative solution, which is being applied, is to decouple the risers from the motions of the production floater.

The ongoing qualification process of flexible risers for the Pre-Salt environment deserves special attention. Coupled flexible risers have been applied in the Lula Pilot area, and no problems have been detected to date. For the Guará and Lula-North East Pilots, decoupled steel cathenary risers´ system were ordered.

CO_2 – how to process it and what to do with it

Petrobras has decided, for environmental reasons, it will not vent the naturally produced CO_2. But separating CO_2 from the natural gas is expensive and put huge space and weight requirements on the FPSOs. So designing low cost plants with reduced footprints and weight and low energy consumption has been a challenge.

The gas processing units have been designed to separate CO_2 from the natural gas after which the CO_2 rich stream is re-injected into the reservoir. The natural gas is exported through gas pipelines but can also be reinjected partially or entirely along with the CO_2 rich stream.

The sustainable hydrocarbon production from the Pre-Salt reservoirs will require, minimisation of emissions of its non-anthropogenic CO_2. Alternatives are under study for the CO_2 capture and storage: reinjection in the oil producing reservoirs, in salt caves, in salt water aquifers or in depleted gas reservoirs. Special attention was given to the gas processing plants in the floating production units. In this way, the process known as Carbon Capture and Storage will be applied.

The CO_2 capture is planned to be done with membranes technology, which is suitable for high CO_2 content. In the Lula Pilot the gas will be exported to the fixed platform of the Mexilhão field (located in shallow waters, 220 km from the Lula FPSO). Currently, the preferred storage option is to reinject the CO_2 in the reservoir, pure or with the treated gas current.

Logistical challenges

The Santos Basin is located around 290 km distant from Rio de Janeiro coast and 350 km from São Paulo coast, in ultra deep waters. This poses logistical challenges for the supply of bulk materials, transport of people (helicopters or boats), pipeline laying vessels, drilling & workover rigs, and terminals for oil export through commercial crude carriers

As a result we are studying the selection of existing harbours and airports to be adapted, the design of offshore

oil terminals, in deep and in shallow waters, floating hubs for fluids and materials, power generating offshore hubs, design of an auxiliary location for helicopter refuel /maintenance, and extensive automation to manage, control and supervise operations from onshore.

Logistics challenges for the associated gas

The deployment of large diameter gas pipelines is a technological challenge for installation vessels, due to the heavy loads involved. In ultra-deep water, the thickness of the pipe walls will be greater than 1.4 inches (3.6 cm), to withstand the high pressures at the seabed, resulting in huge weights. Additionally, the large wall thicknesses of the pipes require most accurate welding, as well as control techniques and inspection.

New technologies for exploitation of gas have potential to give more flexibility for evacuating the gas. In this sense, Petrobras and partners have been evaluating the potential application of technologies such as: FLNG (Floating Liquefied Natural Gas), CNG (Compressed Natural Gas), GTL ("Gas-to-Liquid") and GTW ("Gas-to-Wire).

Boosting Brazilian economy

Development of the Pre-Salt holds great potential for the petroleum industry and for Brazil. In shipbuilding, the opportunities include construction of several floating production units, offshore drilling rigs and supply boats; inspection and maintenance services for the fleet, and so on. The equipment industry stands to gain from the construction ofsalvage equipment, load transport equipment, compressors, turbines, pressure vases, special valves, equipment with special metallurgy to support high pressures and aggressive environments. For the service industry the opportunities will be enormous, not only due to the increasing demand for specialised services – drilling and completion offshore services, project and construction of oil and gas process units, handling of subsea equipments, subsea inspection services, project management – but also due to the logistics demands, such as different ways of transportation, load handling and transportation, facilities and supply technologies, management and technology for material stock.

The Brazilian government's clear policy to promote increasing local content both in construction and design of all sorts of material, equipments and services offers an excellent opportunity for the international petroleum industry suppliers to set up in Brazil, especially when associated with Brazilian companies.

As for Petrobras, the company and its partners hope to follow the highly successful experience of the Campos Basin, where, through actions of synergy involving several areas of competence, Petrobras quickly managed to adapt technologies and arrange the logistics, in addition to critical resources, to place the fields discovered in production.

The next challenge is to develop the Pre-Salt cluster in the Santos Basin, with emphasis not only on Lula Field, but also on the other accumulations discovered, which will be operating by 2017. Both from the industrial technology and economic points of view, Petrobras and partners has all the conditions to explore for and produce oil and natural gas from the Pre-Salt cluster for a long time to come. ■

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Figure 2: Slices from Pre-Salt carbonates showing the high heterogeneity