



Heavy crude production successful in Brazil's deep water

Proper study and implementation brings Jubarte field's thick crude to market.

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In the deep waters off Brazil, Petrobras and Frontier Drilling do Brasil have carried out early production of heavy crude since October 2002 at Jubarte field, offshore Espirito Santo state. The *Seillean*, a dynamically positioned (DP) vessel on contract to Petrobras, was used as the floating production storage and offloading (FPSO) vessel. Three years of deepwater production has demonstrated that it is technically feasible and economically viable to explore for new heavy crude production opportunities. During early production, the field generated attractive cash flow to fund further field development.

The objectives with an early production system are to reduce the time from discovery to first production, and to determine well-stream properties and reservoir characteristics to allow the operator to declare the field commercial. A life-of-field production system can be planned, designed and optimized from the results obtained during the early production phase.

The discoveries of heavy crude in deep water in recent years demand solutions to handle low-API crude carrying sulfur and acids. Uncertainties of well-stream properties and reservoir characteristics make it difficult to design and optimize a life-of-field production system without first deploying a test and early production system to obtain the required data. Brazilian experience since 2002 has proven that heavy crude can be produced in deep water.

JUBARTE FIELD

Jubarte field is a deepwater heavy oil property operated by Petrobras, located in the South Atlantic Ocean 77 km (48 mi) southeast of Espirito Santo state, Brazil, Fig. 1. The field was discovered in 2001 in 4,347-ft (1,325-m) water depths.



Fig. 1. Location of Jubarte field offshore Brazil.

During 2002, a 3,530-ft horizontal well was drilled and tested, producing 17° API gravity, 14.5-cP viscosity crude from Well ESS-110HP, Block BC 60, Campos basin. An extended well test during 2002, using the *Seillean*, a DP FPSO, produced oil from October 24 to December 11, leading Petrobras to declare the Jubarte discovery a commercial field. Early production continued from late 2002 through January 2006 to gather production data and fast-track field development.

In general, the unique nature of the oil and the required processing made it difficult to forecast future production, cash flow and economic feasibility of developing the field. A wide range of economic and feasibility analysis was performed over the year-plus well test phase before the operator declared the field commercial.

RESERVOIR GEOLOGY

Jubarte field reservoirs are trough-confined. gravel/ sand-rich turbidites of Maastrichtian age. They make part of an up to 350 m-thick succession that is mostly composed of amalgamated turbidite beds and interbedded mudstones, with an average net-to-gross ratio of 73%. Most turbidite beds are composed of unstratified, very coarse- and coarse-grained sandstones (sometimes conglomerates) that grade upward to parallel- and ripple cross-laminated, fine- and very fine-grained sandstones. Core porosities and permeabilities range, respectively, 21 - 38% (average 28%) and 10 - 2,500 md (average 340 md).

The oil accumulation is restricted to an elongated, NE-oriented anticline whose eastern portion is truncated by an extensional fault. This fault also acted as a conduit for oil migration from underlying, early Cretaceous (rift phase) source rocks.

The reservoir top characterized by lower seismic impedance, and the reservoir base is defined by an erosive surface, which can be related to decreasing seismic impedance across most of the field, probably due to the occurrence of conglomeratic turbidites truncating hemipelagic mudstones.

UNCERTAINTIES

Producing heavy crude in deep water must overcome significant uncertainties related to the heavy crude production process. Uncertainties rest in three major topics: reservoir performance, flow assurance and, especially, processing the heavy oil.

To determine how to manage oil production and deal with doubts related mainly to production and processing aspects, the key question was: Will an acceptable production index be achieved? To answer that, more questions had to be asked and answered.

Once at the surface, Petrobras faced many more questions about managing the heavy oil production and processing the crude. Engineers wrestled with what range to use as an acceptable production rate versus what the reservoir was capable of producing.

Regarding flow assurance, the combination of deep water and heavy crude meant that the crude could "freeze" in the riser, if it lost too much heat on the way to the FPSO's holding tanks. Because of the crude's heavy weight, the pumps required to move the crude were a special concern. What kind of pump type, power and internal flow character could best move the thick crude? What would the quantity *mean time between failures* be?

Reservoir performance. The heavy crude was being produced from the one horizontal well. Its performance was determined by the aquifer strength, which forced the oil into the wellbore, and the effectiveness of shale barriers, which limited oil flow, compartmentalized the reservoir or altered the movement of the oil to the wellbore. In addition, the reservoir's relative permeability to both oil and water were unknown. Too much water flow could cause early abandonment of the field.

The sealing capacity of the main fault was also an issue. Did it leak? The reservoir itself may have suffered damage along the well path that would limit production.

Flow assurance. To help the natural aquifer pressure, Petrobras anticipated the use of an electric submersible pump (ESP) above the christmas tree to relieve some of the hydraulic head. The type and capacity needed to be calibrated with the multiflow nature of the production, as well as the pressure and temperature ranges expected.

In planning for downhole flow equipment, it was very important to know the limits created by the low temperatures at the seabed. If for some reason the well's natural flow was stopped, how long did service personnel have before the crude's stiffness would overwhelm the ESP's capacity?

Processing. Significant problems can occur during the processing of heavy oil in the offshore environment and are present at every stage of the processing cycle. Once the crude has been lifted into the FPSO, the stream must be separated into its main components: oil, water and gas. The crude must then be stored and ultimately transferred to shore for further processing. Offloading of produced crude is carried out by offloading to a shuttle tanker with a flexible floating hose connected between the two vessels, Fig. 2.



Fig. 2. Offloading operations via flex hose to a shuttle tanker.

PRE-DEVELOPMENT STUDIES

To prepare for production, the development team needed to evaluate the requirements for an FPSO vessel and develop the limits required by the processing system. Petrobras chose the *Seillean* as the central vessel in the life-of-field production system. Beginning with the production riser, the team examined key elements necessary for successful production and processing of the crude stream.

The *Seillean* is a DP Class 2 redundant FPSO equipped for test and early production operations in up to 2,000-m water depth. The FPSO is self-contained with a full-size derrick to handle the rigid production riser and subsea equipment, Fig. 3.



Fig. 3. The *Seillean*, a DP Class-2 redundant FPSO equipped for test and early production operations in up to 2,000-m water depth.

Production riser. Studies revealed that the production riser did not need insulation. Also, the addition of an ESP with a variable speed drive would increase the flowrate by about 50%, and was a significant aid to the field's natural flow.

To overcome any flow assurance issues, a 1-in. pipe was incorporated into the electrical umbilical so that the riser could be flushed when it was necessary to stop production for routine well service. For stoppages under one hour, no flushing was needed. However, if the procedure required an extended stop, service personnel would use the 1-in. line to flush the heavy crude from the riser with diesel.

Offshore Brazil has relatively benign waters, but in case of rough weather or surface emergencies, such as loss of DP, the FPSO required an Emergency Disconnect Package (EDP), Fig. 4.

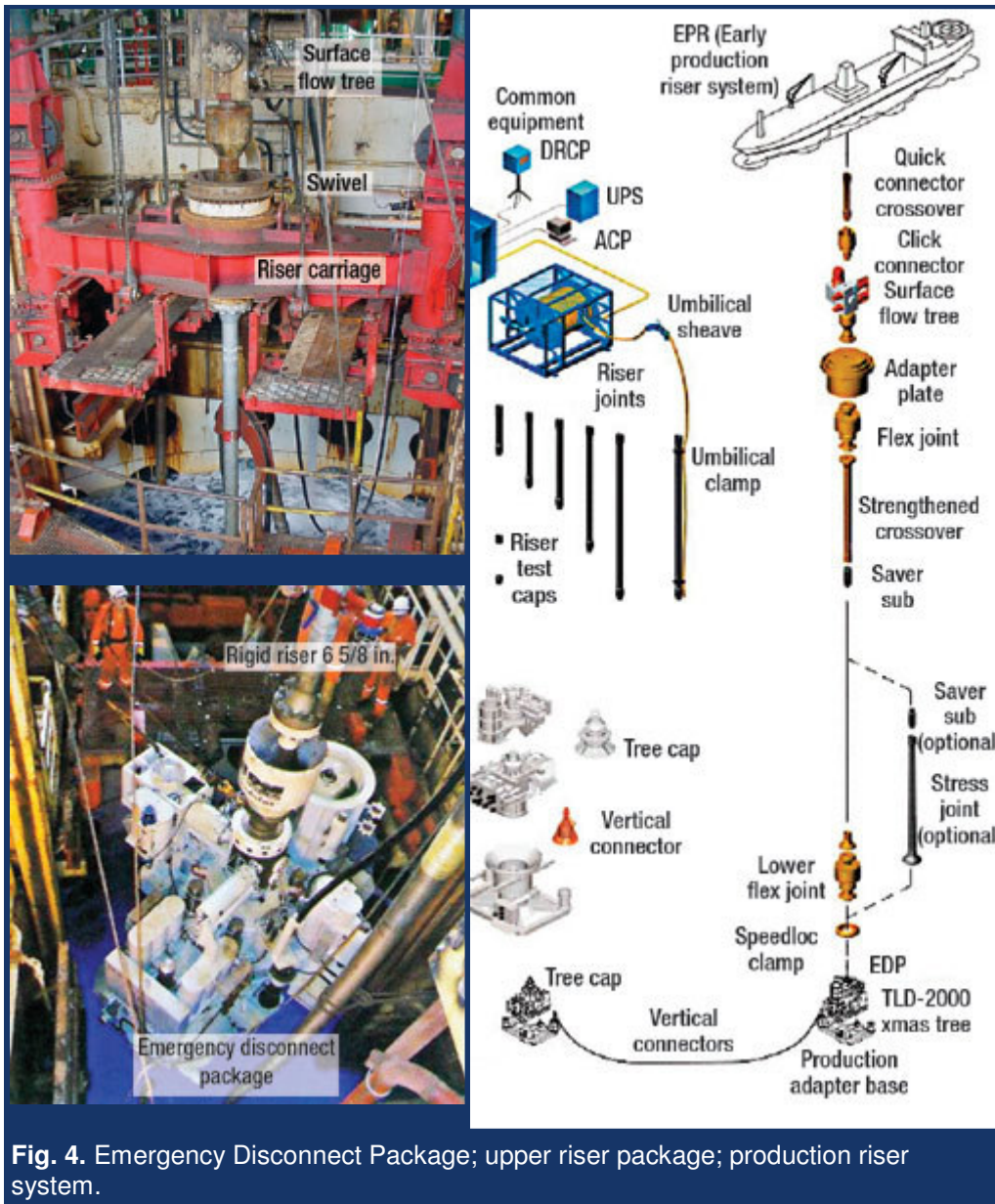


Fig. 4. Emergency Disconnect Package; upper riser package; production riser system.

The production riser system chosen included a rigid 6-5/8-in. riser with a 5-in. bore. At the base directly above the EDP in the riser string is an ESP and a lower riser assembly.

On the FPSO, a riser carriage and swivel are suspended by a tensioning system. There is also a riser handling system on the rig floor and in the derrick, and a multi-functional control system, Fig 4.

Onboard processing plant. The heavy crude comes to the surface at 48 °C and must

be maintained to avoid "freezing" in the processing system. This required additional heating capacity up to 100°C and cooling capacity to 65°C to maintain equilibrium on the FPSO. Much of this involved understanding the crude's properties, including temperature-viscosity curves and foaming conditions, and then striking a balance. The temperature of the crude while stored also had to be maintained. Much of this involved understanding the crude's properties, including temperature-viscosity curves and foaming conditions, and then striking a balance. The temperature of the crude, while stored, also had to be maintained.

OFFLOADING SYSTEM

Produced crude is offloaded to a shuttle tanker with a flexible floating hose connected between the two vessels. A DP Class 1 shuttle tanker is required in Brazilian waters for export of crude for operations in environments with significant wave heights up to 5.5 m. A mooring hawser connects the DP FPSO and the DP shuttle tanker, allowing a flexible, floating hose system to offload crude to a shuttle tanker.

UPGRADE

Before the *Seillean* could start Jubarte production, several upgrades were required to the vessel.

The crude oil heaters and coolers onboard the FPSO needed augmentation. High temperatures are needed in the separators, but the original system was not designed for low-gravity crude. An additional crude oil heater and more heating and steam capacity were added for redundancy. Another crude oil cooler was installed to give redundancy and to bring the high-temperature separated crude down to an acceptable level before transferring it to the cargo storage tanks. This redundancy allowed maintenance stoppages without compromising the ability to produce crude at full capacity.

The ESP chosen required a 900-hp variable speed drive. To meet the power requirements, another online diesel generator was needed to give sufficient power redundancy for the pump, while conducting normal DP station-keeping.

The metering system also required upgrading. The flow characteristics of the heavy crude required different meters than those on the vessel.

Several challenges related to water needed attention. The crude and water were similar in density, which made separation more difficult and time-consuming. The already high water content would likely increase over the life of the field, as well as increase the corrosion potential in the processing plant, so allowances had to be made to deal with those operating constraints. Another processing constraint was the increased tendency for heavier crudes to foam in the production and processing systems. Thus, a foam detection system was needed.

The FPSO's cargo tanks were not fitted with heating coils, yet offloading to a shuttle tanker occurred every 10–14 days. This created a concern about long-term heat loss and crude transportability. The temperature in the cargo tanks needed to be maintained above a minimum temperature to be able to transfer the crude to a shuttle tanker. This temperature was achieved using a sequential procedure: the tanks were partially filled with crude and then repeatedly topped-up. In this way, the storage tanks received new heated oil sufficient to maintain an acceptable temperature while waiting for the shuttle.

LESSONS LEARNED FROM EARLY PRODUCTION

There were many lessons learned from the pre-studies, vessel modification and challenges that were overcome during the early production phase of Jubarte field. The operator found that rather than relying on natural reservoir flow, ESPs effectively boosted production.

There were many water-related subjects, especially corrosion in pipes and heaters. One thing that is needed is to design and optimize the processing system for higher water content over the producing time of each well.

The efficiency of the crude oil coolers deteriorated over time due to scaling; temperatures above 70 °C built up solid sediments in the coolers.

Chemicals were more efficient than cyclones in preventing foaming. Compared to lighter crude, chemical costs were higher, and more inhibitors and more man-hours were required to operate and maintain the processing plant.

More time was required for separation, due to the similar density of the crude and water. The high processing temperature required for separation required building additional crude oil cooling capacity for more efficient operation and redundancy. The higher temperatures required better piping and equipment insulation.

In addition, maintaining a certain storage temperature in the cargo tanks was not as critical as anticipated. Since storage tank heating coils were not available for loading crude, the procedure of periodic filling to maintain the crude temperature above 35 °C worked. It made crude offloading to a shuttle tanker every 10 days possible.

Tank cleaning and equipment maintenance was more difficult and time consuming than for lighter crude qualities. Also, the pumps ran on higher loads during offloading to the shuttle tanker to maintain the minimum crude transfer temperature.

JUBARTE: PHASE 1

Petrobras intends to employ the P34 FPSO, beginning in 2006. It will be anchored in place and gather production from four wells; two will be on gas lift and two will produce using an ESP. The combined rate will be 60,000 bpd.

In this phase, several new technologies are being tested: a high-power ESP, a subsea boosting system, high-temperature processing of high-viscosity fluids at the platform, a compact three-phase separator (parallel to the test separator) and an electrostatic vessel.

JUBARTE: PHASE 2

Petrobras has developed a new-concept platform for Jubarte, to be employed beyond 2009. This system will be able to handle much more flow once the field is fully developed. The configuration will include 19 production wells (both ESP and gas-lift) and seven water-injection wells. The system will be able to handle up to 300,000 bpd of liquids with a maximum oil production of 180,000 bpd.


Several analyses are being performed to optimize Phase 2, including:

- Optimizing the liquid processing capacity
- Determining the best artificial lift strategy, using gas-lift and ESP
- Choosing between a dry completion unit or a subsea system
- Choosing either produced water injection or direct disposal
- Water characterization and scale control strategy
- Injection well geometry
- Oil transportation strategy.

CONCLUSIONS

The *Seillean* DP FPSO concept for testing and early production in deep and ultra-deepwater is based on a proven concept from Frontier Drilling do Brasil's operations in Brazil since 1998. Similar systems can be deployed to accelerate field development and first production in deepwater discoveries.

The concept has six years of operational experience in Brazil, with an average uptime of 98% while in production mode and more than 170 offshore offloading operations - without any environmental incidents. An ESP was installed in the production riser system to boost production of heavy crude oil in deep water, a proven technology making it feasible to produce heavy crude oil discoveries in Brazil and worldwide.

The phased development enables risk reduction by acquiring important reservoir and production information, from early production to final phase. 

LITERATURE CITED

¹ Bezerra, et al., "The appraisal and development plan for the heavy oil Jubarte field, deepwater Campos basin, Brazil," presented at OTC, Houston, May 3 - 6, 2004.

THE AUTHORS

Mats Rosengren earned a Master Mariner degree from Chalmers University of Technology, Gothenburg Sweden, in 1978. His offshore industry experience dates from 1979 and includes subsea construction, topside maintenance, drilling, workover and production. He has considerable project experience in conversion and newbuilding of the latest generation of drilling units and FPSOs for various owners. Since 2003, he has been project manager with Frontier Drilling do Brasil, for the development of next-generation deepwater FPSOs for heavy crude production, including the *Seillean*, owned and operated by Frontier Drilling.

Arild Svendsen earned a degree in basic mechanical Engineering. He attended the Electrical School and is a professional electrician with high voltage power plants in Kristiansand, Norway. Beginning in the North Sea in 1975 and later, in the Barents Sea, he has held various positions onboard moored drilling rigs, including senior toolpusher in 1987. Project contractor experience includes Troll Gas and Oil, as rig manager in 1998, with planning/ preparing of development drilling and preparation for production. In 2001, he worked for Transocean's Deepwater Division in Brazil as drillship rig manager. In 2002, he joined Frontier Drilling do Brasil Ltd, where he works as operations manager for the FPSO *Seillean*.
