Abstract

This paper will describe the CLOV deepwater mega-project in Block 17, offshore Angola. This major development encompasses four separate oil and gas accumulations in waters up to 1,400 metres and aims to recover 505 million barrels of both light and heavier oil plus associated gas in sufficient quantities that will require an export solution to shore for inclusion in the Angola LNG project.

CLOV - which comprises the Cravo, Lirio, Orquidea and Violeta fields - is the fourth large-scale development in this block within the Angolan offshore sector executed by Total. Like the previous three, it is based around floating production storage and offloading (FPSO) vessel and an extensive subsea production system. The execution of CLOV benefited from lessons learned on the three earlier projects - Girassol, Dalia and Pazflor. This resulted in a successful project measured on technical and schedule parameters as well as cost control.

This project presents significant challenges in development including the drilling of 34 development wells requiring two drill ships and the equivalent of almost 2,500 drilling days.

The heavier oil reservoirs of Orquidea and Violeta need pressure and flow support and require the use of both a large water injection scheme (six subsea water injectors) making use of produced water from the FPSO and the installation of a seabed multiphase pumping system based on helico-axial pumps. The production wells have a range of completion designs and sand control methods.

The FPSO - a purpose-built unit of 305m by 61m with topside of 37,000 tonnes net dry weight - employs an all-electric power system with variable speed drives. It also makes use of the ‘wash tank’ technique for oil-water separation. Both are firsts on projects developed by Total.

The SURF (subsea umbilical, risers and flowlines) element of the project required three hybrid riser towers, nearly 100 kilometres of infield flowlines plus a 32km gas export line.
The CLOV mega-project of 8.4 B$ (to first oil) in Block 17 offshore Angola, is the fourth in a series of deepwater developments that were initiated at the outset of the new century and marked the beginning of Total’s and the offshore industry’s West African deepwater epoch.

The cluster of fields - Cravo, Lirio, Orquidea and Violeta - is 140 kilometres (km) from the coast of Angola and west northwest from the earlier developments at Girassol (2001), Dalia (2006) and Pazflor (2011) in waters ranging in depth from 1,100 metres (m) to 1,400m. CLOV came on stream the 12th June 2014 and reached its production plateau 3 months later.

The four fields have recoverable reserves of 505 million barrels (MMbbls) of oil which are expected to be produced over a 20-year period. The oil is a mixture of good quality light Oligocene crude (75% of recoverable reserves) and lower quality Miocene crude. The presence of the latter has had a material effect on the development scenario for the complex.
While the technical challenges on such a project were considerable, a number of so-called ‘soft issues’ related to the socio-economic development of Angola and the Angolan people, ie local content and health and safety, came to the fore to make this project a significant achievement.

A number of the technical decisions taken on the project were made on the basis of what tasks could be done locally, but also with one eye on cost reduction.

**EXPLORATION**

Geophysical work in this part of Block 17 revealed geology similar - unconsolidated turbidite sandstone - to that elsewhere in this licence area. This enabled the subsurface team to make use of more than a decade of experience with analogous reservoirs - thin heterogeneous sheets with light oil but low permeability and thick easy flowing channels of heavier Miocene oil.

The complex of fields was first discovered in the summer of 1998 when the Lirio-1 well was drilled, finding a significant Oligocene accumulation with a large gas cap. The oil-bearing reservoirs in the northeast compartment of the structure were confirmed by the Lirio-2 appraisal well which also further delineated the size and extent of the gas cap.

The following year Cravo-1 proved up further light oil reserves before the first appearance of the heavier Miocene oil at Orquidea-1. The complicated nature of the reservoirs here was further revealed by additional exploration wells. Violeta-1 added to the Miocene reserves, but the Orquidea-1 well, drilled into a deeper horizon and 15-20 degrees down dip of the main reservoir, revealed more light oil which would provide an additional challenge at the well design stage as a result of difficulty in defining the well objectives.

**DEVELOPMENT**

Pre-project analysis completed in 2003 resulted in the assumption that Cravo-Lirio would follow the same path of the Rosa satellite and be a phased tieback to the Girassol FPSO hub. The latter project was sanctioned in 2004.

Subsurface work continued and revised reservoir models indicated that the reserves for Cravo-Lirio would exceed the 245 MMbbls in an earlier estimate. The question remained whether the reserves warranted a standalone development.

The first conceptual studies for these accumulations were carried out in spring 2005 to give some definition to subsea architecture, topside design and central facility. After the Lirio-2 appraisal well, drilled later that year, increased reserves, pre-project studies were launched on the basis that Cravo-Lirio would constitute a standalone hub with an FPSO with the Miocene finds as a later tieback.

A year later, following additional integrated geological and geophysical studies of the Miocene finds following two more appraisal wells - Orquidea-2 and Violeta-2 - it was decided to choose a development concept that incorporated both the Oligocene and Miocene accumulations.

There remained a number of changes yet to the concept. The original scheme would have initially re-injected produced gas into one of the CLOV reservoirs before later exporting it for use in the Angola LNG plant. As part of a cost cutting exercise, it was decided to opt for a full export scheme with reinjection at one of the other Block 17 developments as a backup.

The development of these resources was finally sanctioned by the licence group in July 2010.

**CONCEPT**

The development scheme for the CLOV complex followed closely the path that Total followed on its three earlier Angolan projects - a large FPSO with an extensive subsea infrastructure with a few differences including innovative oil processing and power systems.
The FPSO is 305m by 61m with a storage capacity of 1,78 MMbbls and is secured to the seabed with a spreading mooring system of 16 lines. There is a single processing train for commingled Oligocene and Miocene crudes, capable of handling 229,000 barrels per day (b/d) of total liquids, 160,000 b/d of annual average oil production and providing 319,000b/d of water for injection purposes using two different technologies - ultra-filtration and Minox®.

The processing system employs a wash tank system and continuous settling for oil-water separation, a concept Total had used previously on a project in Nigeria (Usan), but not before in Angola. The system uses two large below-deck wash tanks, operating in parallel, with water continuously siphoned from below and oil flowing over a weir and pumped away with the degassed wellstream refilling the tanks. The oil is then desalted in two settling tanks.

With a high gas oil ratio and a ‘no flaring’ policy, the topside is equipped with compression capacity of 6.5 million cubic meters per day (mcm/d).

Produced water (122,000b/d) which would be used for injection purposes, goes through a multi-stage purification process. Treatment through two hydro-cyclones, operating in parallel, removes the last of the oil after which two de-sanding cyclones remove particles to 10 microns.

Seawater supplements produced water with the onboard lifting pumps capable of providing up to 1,400,000 barrels per day. It is coarse filtered, then ultra-filtered to remove fine particles. Sulphate removal using a membrane system is followed by deoxygenation using the Minox® process.

Power generation is developed through three aero-derivative turbo generators rated to produce 28MW each. This power system design, again initially deployed on a Nigerian project (Akpo), drives an ‘all-electric’ machinery concept based on variable frequency drives.

**WELL SYSTEM**

One of the major enterprises on this project is the drilling programme of almost 2,500 days: 34 wells to be drilled by two drill ships – West Gemini and Ensco DS-1. By first oil, they had drilled and installed the completions in 14 wells (11 producers
and 3 water injectors) which allowed to hit the design peak (168,000 b/d) on 30th September 2014.

West Gemini

The aim of the subsurface work programme - combining geological, geophysical and reservoir studies - was to ensure delivery of the highest potential for each production well through optimising well preparation and defining the best targets.

It was also essential to develop a reservoir management scheme in order to deliver the full reserves target over the long term. Each well was meant to be as good/or better than the previous one and there was an ongoing plan to adjust well targets for optimised production and water injection delivery.

The vast majority of the wells (32) are of a horizontal design with a maximum length of 1,800m, with the other two being deviated, ie less than 65°. Like the geology of the other Block 17 developments, the Oligocene reservoirs are highly faulted and thin. In order to ensure a full understanding of the structure of the reservoir, a pilot well and the two deviated wells were drilled initially in order to calibrate vertical uncertainties and plan the remaining horizontal wells.

The well architecture is mixed - most (25) can be described as having a light casing programme with the other nine being heavy with additional 26in and 20in casing with latter being cemented.

As with all of the Block 17 reservoirs, there is potential for significant sand production which required either sand screens or gravel packs in all of the wells.

A 14 production wells and 13 of the water injectors have standalone sand screens while the remaining five producers and two injectors have selective, or intelligent, completions.

For the producers, the aim is to maintain control of water production through the ability of selectively closing zones. For the water injector, the completion design provides the capability to inject water more accurately in the zones where it is required.
SUBSEA PRODUCTION SYSTEM

The subsea production system of 34 wells - 19 producers and 15 water injectors - is typical of systems employed by Total in West Africa, but its delivery was designed to raise the local content of the project compared with earlier ones. A much higher level of assembly of subsea xmas trees and fabrication of underwater structures took place in Angola than on earlier projects, a significant part of Total’s commitment to an increase in local activity.

The subsea xmas tree system on this project is not dissimilar to what Total has deployed in the past - 10,000 psi rated vertical tree weighing 39t. Each tree is equipped with a chemical injection valve, an insert choke valve and a multiphase flow meter, installed on the well jumper.

There are eight production manifolds - four 12in 4-slot at Cravo and Liro and four 10in 4-slot on Orquidea and Violeta.

The eight four-slot production manifolds - seven with single headers and one with a double header - employ FMC’s latest UCON horizontal connector. Its configuration benefits flow assurance by providing maximum thermal insulation for the 4 degree Celsius conditions for the prevention of hydrate formation.

Two features of the subsea production system concept for the CLOV complex set it apart from what Total has done previously on its West African projects.

First was the adoption of fibre optics communication as part of a ‘comms on power’ configuration for the subsea control system. Each of the eight manifolds is equipped with a subsea router module (SRM) which handles the flow of data between the subsea production wells and the master control station (MCS) on the FPSO. This is the hub for signals to the production system including to chemical injection, choke and the xmas tree valves and the flow of an increasing amount of operational data from multiphase meters and pressure and temperature sensors, located down hole, on the xmas trees and the manifolds. The transfer of data between individual wells to SRM is via an Ethernet link.

Communication between the MCS and the water injection wells is via direct fibre optics to the subsea control module on each tree. Each of the water injection tree is also equipped with a single phase flow meter which is also linked through the fibre optic system.

The other differentiating feature at CLOV is the application of a multiphase pumping system (MPP), driven by helico-axial pumps, to provide flow boosting for the heavier oil from Miocene produced at Orquidea and Violeta. These fields have both low reservoir pressure and a high viscosity well stream.

The application of the MPP system was also an element in the overall flow assurance programme and the cost reduction exercise on the project. Its use reduced the number of the looped flowlines with the furthest well at 15km from the FPSO.

This is the first time that Total uses a subsea multiphase pump system at this depth (1,170 meters).

The system is based on one pump with a spare. The pumps generate a Pressure Differential of 45 bar with a shaft power of 1.8MW and has been designed to handle a gas volume fraction of 53% which could occur after 15 years of production.
SURF

The subsea umbilical, riser and flowline (SURF) system installed at the CLOV complex owes much to what Total has done and learned from its earlier West African deepwater developments.

It was also confronted with the need to do some things differently in order to manage cost, while also adding new elements, such as a gas export system.

Going back to Girassol, Total set the standard for how most West African flowline system would look - looped production lines to provide the facility for pigging and the filling of the network with dead crude during shutdown and single water injection lines linked to the wells by tees.

The original concept was to have separate production loops for the light oil from Cravo and Lirio. This was adapted into a single flowline loop which reduced the total length of flowlines while also reducing the number of riser towers.

The flowline concept was ‘pipe in pipe’ for insulation purposes. The 17km Cravo-Lirio flowline ring consists of a 12 inch (in) flowline in a 16in carrier pipe, while at Orquidea-Violeta the 21km dual flowline loop is made up of a 10in flowline in a 14in carrier pipe.

The 57km of water injection system consists of a 24km 12in system to Cravo-Lirio and a 33km 10in system to Orquidea-Violeta.

The 32km 12in gas export system links into the Angola gas export network at a pipeline end manifold (PLEM) located in Block 17 in a water depth of 1,190m. This system incorporates a 50t subsea isolation valve station with a pair of 12in isolation valves and an emergency shutdown valves.

The part of the SURF system where Total applied the most lessons learnt from earlier projects was in the area of the riser towers. Girassol was the first project to use such a riser system, but much has changed in the more than a decade since those initial ones were deployed. The two installed on CLOV are definitely of ‘a new generation’.

Total took advantage of its SURF contractor’s long experience with installing towed structures in the North Sea to install the riser towers using the controlled depth tow method. This minimised the loss of fatigue life on the structures.

Also, the PIP risers used within the towers - two carrying production, two carrying water for injection purposes and two for gas lift - have been strapped to the central buoyancy units rather than imbedded within the buoyancy as was done on earlier projects.

There is also a single hybrid riser which as the export link for the gas into the gas export system.

The 84 km of subsea umbilicals were a considerable element of the local content on the project as they made use of all of the capacity of the Angoflex plant.

Final piece of the SURF network is the oil offloading system. This consists of a floating terminal, or buoy, located 1.8 km from the FPSO, and connected to the production vessel by two 24in floating bonded flexible lines, the biggest of this type.

On earlier projects, the FPSO would be fitted with specialist booster pumps for the offloading system; on CLOV the FPSO makes use of its own cargo pumps to move the dead crude out to the offloading buoy. In addition, there is a backup system that allows for tandem offloading.

INTERFACE MANAGEMENT

Interfaces management has become an important issue on mega-projects such as CLOV. A high level of cooperation and communication necessary between the operator and its contractors was achieved through the use of innovative tools and basic human interaction.

With seven main contractors, interfaces management was identified early on as a major challenge. A detailed reference was defined during basic engineering, including interface basis of design, interface management procedures, contractor responsibility matrix, milestones, et al.
At the start of the execution phase, the web software eRoom which provides advanced collaborative functionalities was implemented for managing and sharing interface discussions and documents between the company and the contractors. In addition, regular face-to-face or conference calls were organised to ensure cooperation between contractors.

Cooperation is a challenge within project teams who are based in various locations and with different companies around the world and who use different tools or databases. In order to guarantee coherent data management, Total’s Project & Construction division promoted the use of a number of tools including eRoom, the electronic documentation management system PRODOM and planning software PRIMAVERA. The latest member of its toolbox is GIS – Geographic Information System – which is dedicated to geographic data and engineering layouts control and offshore operations preparation and follow-up.

To avoid inefficiencies, interfaces and workflows were implemented between these tools and most important, good communication was maintained throughout the project between the document controllers and planning engineers in packages and the GIS administrators. The innovation consisted of adapting tools to individual’s habits and preferences to ensure that the solutions would be easily and readily adopted.

**HEALTH AND SAFETY**

The CLOV project team achieved outstanding health, safety and environmental (HSE) performance on this development, aided by its contractors.

A particular highlight was the achievement by Daewoo Shipbuilding and Marine Engineering (DSME) in its work executing half of all the man-hours performed by contractors on the project. DSME performed its 17 million man-hours without a single Lost Time Injury (LTI) at the Okpo yard in South Korea and has already won two awards as a result of this.

While the goal is always to achieve zero LTI, realistic targets have to be set, Total’s target is 0.3 LTI per million manhours. On this basis anything up to five LTIs would still have been deemed a success at Okpo, yet zero was achieved.

This enhanced safety performance was the result of improvement plans worked on with DSME since 2010. The process included adoption of the ‘Incident and Injury Free’ (IIF) programme run by a US consultant, as well as poster campaigns and incentive schemes.

Understanding the safety culture of a contractor and of culture differences in general, is a vital part of the process to improve, taking a non-aggressive approach and communicating HSE expectations from top to bottom. Managers at the most senior level were involved and the values were cascaded through the workforce.

One important element was to re-emphasise the role of ‘safety captains’ at the foreman/supervisor level - maybe one for every 50 workers - who became key in delivery of IIF, along with monitoring by a strong HSE team from Total which included South Koreans.
ANGOLA AND THE FUTURE

While the description of any project such as CLOV is based on discussing technology, it is necessary to make mention of the drive to ‘Angola-ise’ this development, that is to maximise the amount of work that was to be done in country and to bring a new well-trained local workforce into the project.

While five local fabrication yards were used to fabricate a variety of project structures - including manifolds, pipe-in-pipe stalks and at least one module for the FPSO - it was the overall quantity of work done in country that was the target for Total.

At the turn of the century, when Girassol was being developed, one million man-hours of work were done in country, primarily at one fabrication yard. For the CLOV development, 10 million man-hours of work were done in Angolan fabrication facilities.

This will be Total’s ‘heritage’ project in Angola.

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TOTAL, A PIONEER IN ANGOLA DEEP WATER

- FPSO and subsea production for each project
- Increasing challenges, increasing technology
- 2015 Block 17 production: 700 kboe/d
CLOV, DEEP WATER MEGA PROJECT

► Block 17 fields: Cravo, Lirio, Orquidea, Violeta

► Total (40% Operator), Statoil (23.33%), Esso (20%), BP (16.67%), Sonangol (Concessionaire)

► 2P Reserves: 505 Mb (over 20 years)

► Oil production: 160 kb/d at plateau

First Oil On Time: Q2 2014
(47 months execution)

8.4B$ Mega-project (to First Oil)

Water depths: 1,100 to 1,400m
Oligocene Reservoirs
Cravo, Lirio, O11W
- 3/4 of total reserves
- Reservoir pressure of ~ 300 bar
- Temperature ~75 to 80° C
- Low viscosity

Miocene Reservoirs
Orquidea-Violeta Central
- 1/4 of total reserves
- Reservoir pressure of ~200 bar
- Temperature ~50° C
- High viscosity
BENEATH THE SEABED, CLOV DRILLING & WELLS

- **Reservoir burial water depth**
  - 850 to 1,800m below seabed

- **Wells architecture**
  - 34 wells (19 OP, 15 WI)
  - 32 horizontal wells, 2 deviated wells

- **Completion & Sand control**
  - 32 horizontal wells with stand alone screens
  - 7 deviated wells with openhole gravel pack
  - 7 out 34 with selective completions

- **Drilling program**
  - 2,500 days
  - 2 drill ships with dynamic positioning
CLOV SUBSEA PRODUCTION SYSTEM

- 19 production wells
- 15 water injection wells
- 8 manifolds
- 1 Multiphase pumps system

Cravo-Lirio
Orquidea-Violeta
CLOV, MULTIPHASE PUMPS SYSTEM IN DEEP WATER

► Produce low-pressure
  - Miocene oil reservoirs

► Enhance reservoir recovery

► Reduce costs

► Increase pressure drop before liquid-gas separation

A first for Total at this depth
Gas export
- 1 Single Hybrid Riser Tower
- 32 km of gas export line
- 84 km of umbilicals

Orquidea-Violeta
- Dual production line (21 km)
- 2 water injection lines (33 km)
- 1 Hybrid Riser Tower
CLOV FPSO, A CONTINUAL IMPROVEMENT SINCE GIRASSOL

- Hull 305x62x31m
- Topsides: 37,100 tonnes
- Single train process and storage for commingled crude oils
- Oil production: 160 kbd at plateau
- Oil storage: 1.78 Mb

- Oil-water separation in the hull: wash tanks and settling tanks
- All-electric concept with Variable Speed Drives
- Gas treatment: 6.5 Msm3/d
- Living quarters: 240 POB
HSE, A RELENTLESS EFFORT

► CLOV
  - 33 millions of man-hours
  - Zero fatalities, 9 LTIs

► “Incident Injury Free” program ran at DSME yard

► Safety award to CLOV and DSME for HSE management

► Good cooperation between Project and contractors' teams
CLOV, A SUCCESSFUL STORY

- CLOV Leading-edge and motivated team
- Collaborative Contractors teams
- High part of in-country fabrication
- Continuous support from Partners and Sonangol all along the project

Together to achieve successfully the CLOV Story
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