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Integrated Multizone Low-Cost Intelligent Completion for Mature Fields

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Abstract

A well equipped with downhole flow control and monitoring devices provide tools to manage reservoir and well performance. Many optimization techniques have been applied in conjunction with commercial reservoir simulators with detailed multisegment well model to improve ultimate recovery. It is important to know that all the benefits of the reservoir optimization can be lost if the availability and appropriate control of the artificial lift is not used.

A well equipped with three on-off type flow control valves and four pressure and temperature optical transducer: one for each zone plus one more above the production packer in combination with a rod-pump control with moderate service condition specifications is described.

Standardization of the connectivity between automation of the intelligent completion and artificial lift is necessary for a vendor-independent integration, which becomes more cost-effective by using open industry standard protocols. This also allows the use of different supervisory software, reducing the impact of changing systems already in use without losing the flexibility of choosing a solution that has some custom features or that are cheaper.

This paper will discuss both the benefits resulting of the integration between intelligent completion and artificial lift automation. The value added to provide better decision making to respond immediately to unexpected changes, the need of satisfy reliability demands of the operational people and the issues involving the use of intelligent completion in mature fields.

Introduction

Carmópolis field, a mature field in the northeast region of Brazil is a land field discovered in 1963 and since 1971 uses waterflooding as its main improved oil recovery (IOR) method. A review of the waterflooding operation through improved reservoir characterization and flow simulation, as well as the investigation of other IOR methods were done as part of PRAVAP (Petrobras Strategic IOR Program) and it was proved that it is possible to reverse the declining production trend of the field using waterflooding management as well as selectivity[1]. The results have addressed the quantification of potential gains from intelligent completion technology.

Petrobras has also chosen Carmópolis field as its first intelligent field pilot project[2] aiming to get better results on reservoir and production management.

An integrated intelligent well system was developed for the wells in the pilot. In this system the artificial lift automation is completely integrated with the intelligent completion to satisfy availability and reliability demands of the operational people and ensure that the benefits of the reservoir and production optimization will be effective.

The well completion chosen was three hydraulic/hydrostatic packers, three flow control valves and four pressure and temperature optical fiber sensors. The equipments were developed to be low cost with moderate service condition specifications.

The artificial lift method used in Carmópolis is rod pump and the regular practices are to locate the pump below perforation and to use fixed pumps.

A complete new automation system was used to integrate all systems using open standards and remote diagnostics ability.

The initial results showed better reliability, diagnostics and capex (capital expenditure) when compared with similar implementations in Petrobras. The expectation from now on is to get better opex (operational expenditure) also.

Requirements to Intelligent Completion for Land Mature Fields

The typical completion in Carmópolis field is done by perforating and equipping all zones for commingled production, using rod pumping.

Production and BSW tests for each zone are normally done by isolating the zones with a squeeze operation. These interventions have an advantage of the low cost of land production rigs, but can take several months to get the results, besides damaging of the casing due the cementing.

Although the conventional well completion in Carmópolis is very simple, reducing the intervention cost, the large number of wells (above 1000) elevates the maintenance cost of the field. Also, being a mature field, a large number of interventions is needed, mostly to change artificial lift

equipment and to increase productivity, requiring a large number of rigs to maintain the field. The operation has a very limited budget due its low production and a very limited number of rigs are available to make the interventions. The intelligent completion can help to reduce the number of interventions by allowing the opening or closing one or more production zones without the need for intervention, reducing operation costs.
On the other hand, the intelligent completion is still very expensive to be extensively used on a mature low-production field. Also, with the complexity of the tools added (flow control valves, gauges, hydraulic lines, etc.) the risk of fishing is very higher than in conventional well completion; this can lead loss of production, damages and even the loss of the well. All these factors make reliability a major issue.
The automation required to control and to acquire data from the well also makes maintenance more complicated. The instrumentation team must be trained to maintain all the automation which normally includes controllers and HPUs. In a field with limited budget and human resources, such as Carmópolis, it is important to keep the surface systems simple to maintain, with many suppliers of all equipment, which can be achieved by using open standards and protocols.

Intelligent completion x Integrated Intelligent well system

In intelligent completion, flow control devices and gauges (for pressure, temperature and/or flow) are deployed in order to optimize reservoir management. Still, even if you have this, all operation can be compromised if there is a reliability issue with the equipments.
In integrated intelligent well systems, the artificial lift automation is completely integrated with the intelligent completion. With the artificial lift automation, it is possible to diagnose lift problems and promptly actuate on the lift system to correct or optimize production. The downhole measurements given by the intelligent completion can help diagnosing or predicting faults greatly increasing the availability of the entire system. For example, the downhole pressure can be used to correct or even confirm the readings on a dynamometric chart.
On a systemic view, the integration of reservoir and artificial lift management helps to increase recovery, by ensuring the appropriate field management.
This integration also helps to reduce operation expenses. In a traditional operation, there is a diversity of systems for well monitoring and artificial lift, with many suppliers. Sometimes, the solutions are closed, so that only a given supplier can maintain a certain system. These situations imply in the necessity of separate training and specialized maintenance teams. Also, the diversity of systems does not always allow coherence of information and does not collaborate among them to offer one clear and precise diagnose of the real situation of the production.
Integrating all systems allow a clearer view of the operation not requiring separate training and simplifying maintenance. With surface and subsurface equipments operating in an integrated way, all the information can be correlated so that diagnostics and fault prediction become more reliable, maintenance more agile, reducing the total operation cost.

Integrated intelligent well system

The producer well configuration uses on-off type sliding-sleeve valves for flow control devices, one for each interval, allowing an interval to be isolated or not.
Right above every control valve (separated just by pup joints) there is a mandrel to hold the pressure and temperature sensors, based on fiber optics technology.
To isolate the intervals, an isolation packer is placed above the mandrel. These packers are customized with 5 feedthroughs for ¼"tubing, one for each control line and one for the optical cable.

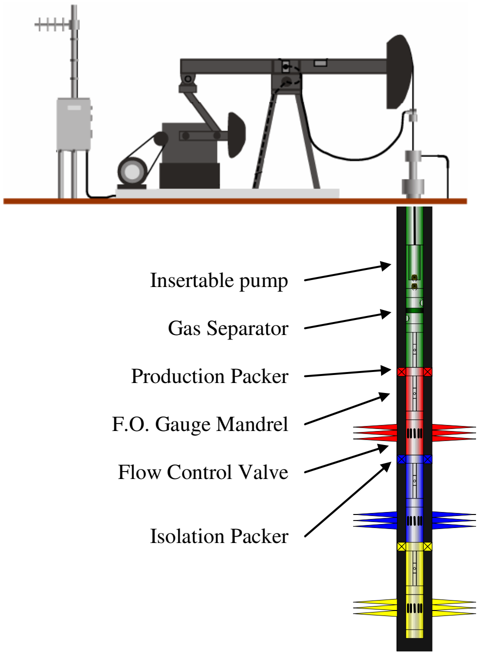

Fig 1 – Integrated intelligent well system for three interval producer well

To simplify running procedures, the module for each interval (composed by a valve, a mandrel and a packer) are pre-assembled during the system integration tests (SIT) that are performed before running the completion.
On the top of the assembly of the topmost interval is placed the production packer. Above it, another gauge mandrel is placed to measure the temperature and pressure to improve the artificial lift diagnostics and control.
Just below the nipple of the insertable pump is placed a simple gas separator. The gas separator is an in-house development that just forces the flow to go to the annulus and back to the production tubing through holes in opposed positions, using a blank plug to separate them. The turbulence created by the deviation of flow forces the free gas to separate on the annulus, as the liquid continues through the tubing and gets to the pump.
Rod pump is the artificial lift method used in Carmópolis. Since the intelligent completion is more complex to be

retrieved, and an analysis on the history of the interventions showed that most of them were related to the pump, it was chosen to use an insertable pump instead of a fixed one. This would allow the pump and rod to be replaced without the need of retrieving the tubing and, therefore, the intelligent completion equipments. The pump is placed above the gas separator.

The tubing hanger and the wellhead for these wells are also equipped with feedthroughs to pass all hydraulics and optical lines. The hydraulic line are cut at the tubing hanger and connected through the well head and to the HPU. The optical cable is fed through the tubing hanger and wellhead and connected directly in the monitoring system without any pressure isolation. It can only be done because of the low pressure and the small production of gas in these wells. If any of these conditions does not exist, a two-chamber, pressure isolation equipment is used.

The level in the well, estimated by the pressure measured by the sensor above the production packer, as well as the regular surface measurements (position and load on the beam, pressure and temperature on the production line) are processed by a controller that analyses all data and controls pumping speed. This system can periodically generate downhole and wellhead dynamometric charts and using advanced signal processing techniques to automatically analyze them, diagnose or even anticipate problems in the pumping.

All valves were hydraulic controlled by automated HPU, completely integrated with the automation, using MODBUS protocol; four ¼" lines, packed together in a flatpack are used to take the control pressure to the valves, joined to the tubing by clamps in every joint. There is a hydraulic line for opening each valve and one common close line.

For an example, to operate a valve to open, its open line must be pressurized, keeping the close line open to return. Inverting the flow causes the valve to close. In case that the valves are commanded to open or close while there are another that must be kept in the current position, its lines must be pressurized or opened for return so that no movement is to be made (both sides at the same pressure). Since this makes individual movements more complex, the automation on HPU was specified to make all the operations required to move any valve completely transparent to the operator. It also handles timings and signals completion or failure of movement procedures, based on the pressures and timing of each control line.

The monitoring system is an in-house development multidrop permanent fiber optic pressure and temperature sensors which main features are high accuracy (better than 0.1% of the full scale range), reliability and low cost.

The system uses four transducers in a single fiber in the 11x11 mm for 90°C optical cable. These sensors are based on FBG (Fiber Bragg Gratings) in which certain wavelengths of the laser are reflected back, depending on the physical characteristics of the fiber as well as the ones it is subject to. The reflection is then processed by a fiber optics sensor interrogation system that responds the pressure and temperature in engineering units, using MODBUS TCP protocol. This Surface Data Acquisition System attends Petrobras requirements to allow and to assure full connectivity and interoperability with the others automation system components.

The wells are equipped with a control panel that integrates management for both artificial lift and intelligent completion systems. This panel is controlled by three PLCs (Programmable Logic Controller): one controls panel safety, managing door alarm, internal temperature and power protection. Another one is responsible for controlling artificial lift rod pump through a variable speed driver (VSD), using regular surface measurements as well as downhole pressure and temperature measured by the optical sensor above the production packer; the rod pump can also be operated in pump-off mode. The third PLC integrates the system, collecting and storing data from all instrumentation and PLCs to transmit them to the operation center and retransmitting commands from the operation center to the PLCs. All PLCs and instrumentation were chosen to use MODBUS (either RTU or TCP over Ethernet) because it is a well-known open industry standard protocol, reducing the investment and operation costs. All devices are connected to an Ethernet switch and then to a wireless Ethernet radio allowing individual communication if needed.

The distance between the field and the operation center and between wells make the use of radio links a practical option for communication. All wells were equipped with Wireless Ethernet radios as the main communication link. An IEEE 802.11 compatible (Wi-Fi) radio is also used to allow automatic integration with an itinerant multiphase flow meter and portable devices (PDAs, Notebooks, etc.) for maintenance. The Wi-Fi network can be used as a backup link in case of failure in the main link.

At a first glance, this system may seem a large investment to mature, low-production fields economical premises but in a deeper look, an open protocol based system allows rapid changing suppliers of any of the components (as long as their products supports the open protocol) stimulating competition and reducing costs. Also, integrating all automation in a single panel eliminates redundant systems such as power line regulation and even casing also reducing the total cost. Since there is a local data storage and integration of all systems, the communication link can be a simpler wideband commercial radio, reducing investment and operational costs. As a secondary benefit, the total footprint required for the automation system is also reduced.

Carmópolis intelligent wells deployment

Different service companies are involved on four wells in Carmópolis. They are all supplying the flow control system. The monitoring system used is an in-house fiber optic development except by one of them.

Due to the complexity of the completion equipment, it was chosen to pre-assemble the intelligent completion equipments in modules to simplify the running procedure, reducing rig time and its associated costs and detailed running procedures were written. There were three assemblies composed by a packer, a fiber optics gauge mandrel and a sliding sleeve, and one with a fiber optics gauge mandrel, gas separator and the rod pump insertion nipple. The fiber optics gauges and cables and hydraulic lines in all assembly were connected and tested during the system integration test (SIT), and the assembly was taken to the well site ready to be installed. Tubing and pup joints were used to adjust the space between assemblies, just like in a conventional completion.

The modules were assembled with few meters of cable sparing, with a pigtail connector already made up and it was connected to the next module using a jumper cable made based on measurement of the section. If length was not correct or it was necessary to change a gauge or any other repair, just the jumper cable needed to be adjusted. This has simplified the operation and greatly reduced the risk of gauge damage or fiber rupture.

The assemblies are lifted into derrick with the help of an external crane and then ran in hole. The needed tubing and pup joints are then connected to correctly space the assemblies and keep the valve openings as close as possible of the perforations. On every joint, a clamp is placed to affix the optical cable and the hydraulic flatpack. If the cable or the flatpack is not closely attached to some portion of the tubing, a metallic strap is used in any portion of the tubing. The next assembly is then torqued to the tubing and the optical and hydraulic connections made. For calibration purposes, when the gauge mandrel is to be run in hole, its temperature is measured and calibrated.

If a long optical cable jumper is needed it is made with just one end connectorized. When the next assembly is reached, the needed length is measured with very little sparing and the completion is pulled out of the hole so that the end of the cable can reach the optical splicing cabinet. It cannot be done on rig floor because optical splicing is made by a very small electrical arc, offering unnecessary risk in a potentially explosive atmosphere such as the rig floor during the operation. After the connectorization, the completion is run in hole again, with connections made and cable securely attached to the tubing.

After the pump insertion nipple is placed, the running is much simpler, just adding the need of placing the clamps on every joint. At the automation crew discretion, a simple fiber optics integrity test can be done periodically to ensure that all monitoring system is working properly.

By the end of the completion running, the hydraulic lines are connected to the tubing hanger appropriate fixtures and the optical cable, cut at the necessary length to reach the automation panel and stripped from its 11 x 11 mm nylon cover, is fed through it. The optical cable is also is fed through the wellhead through a fixture. It is then connected to the automation system at the instrumentation panel.

CP-1527D Deployment

The first well deployed was the CP-1527D. Due to the releasing tension of the packers be simultaneous the total tension was higher than a regular land rig could pull, it was chosen in this well to use a permanent packer on the downmost zone. The flow control valve for this zone was a shrouded model and was placed above the packer for this zone, inside the middle zone. A special two-pressure, two-temperature sensor was used to measure the quantities on the lower zone, by using a ¼" line as pressure port. In this installation no jumper cables were used; the sensors were pigtailed with enough cable to reach the next zone.

Lessons Learned

The lower assembly was composed by the equipments for two zones, which made the assembly undesirably long, with almost 70 feet, making the lifting in to derrick very risky. Also, the length of pigtail connections could not be precise enough, making much more difficult to connect the sensors.

The HPU had several connectivity issues, such as intermittence in communication and the use of a communication protocol different than specified. It was accepted, with the agreement that all problems would be solved. The problems still persists and it was decided to not put any of the remaining HPU to work without being as specified.

Observations and results

During the deployment, a sensor broke at its connector, leaving the two downmost zones without pressure and temperature measurements. It is planned an intervention to repair this system. The flow control valves are still working properly after the first six months and the automation is working properly. This well was also the first on the pilot to use a VSD.

CP-391 Deployment

In this well, the three identical assemblies are shrouded after the SIT to protect all flow control equipment from mechanical damage in transportation and deployment, as a recommendation of the manufacturer. Since the assembly could not be repaired at the rig site, a fourth assembly needed to be made to ensure redundancy.

The distances between zones were very short, so the jumper optical cables could not be used. Since the zones were very close, any difference encountered in the length of the pig tails could be compensated by using pup joints of different sizes.

The HPU could not be put to work, again because of a connectivity issue. It took several days to be solved, but the protocol had some discordance to the specification.

In the automation panel, a VSD with regenerative characteristics are being used to evaluate the reduction of energy consumption using with this technology.

Lessons Learned

A fiber optics sensor failed on one connector and there was no spare for the same characteristics. All the sensor arrangement had to be changed so that this sensor could become the last one in the optical fiber (the signal did not have to pass through it). It was decided to keep a spare sensor for each characteristic in the next deployments

It was also decided to not accept any equipment that was entirely compliant with the specifications to avoid have to leave the system incomplete.

Observations and results

The four sensors are working properly and the artificial lift automation is also using the VSD to control the rod pump. Preliminary observations indicate that the reduction in energy use is significant enough to justify the use of regenerative types of VSD, but a deeper study is being prepared to confirm it.

CP-130 Deployment

This well was the first well with deployed equipment for 5 ½” casing. All the assemblies were shorter than 35 feet becoming easy to transport and manipulate on the rig. During the operation there were no problems with any operational procedure or test. An automation engineer left the installation without replacement and caused delay on having all system ready to work.

Lessons Learned

Contingency plan should be revised to every installation.

Observations and results

The four sensors and the artificial lift using VSD are working properly.

CP-976 Deployment

This well was the only well in which all equipments and services were from the same company. Even though we expect a simple operation we lost too much rig time running this completion when compared to the other wells. They had too much testing procedures and the double of the assemblies. The threads used were not the regular used in Carmópolis and there was no contingency plan for that. Special torque machine and more was needed.

Lessons Learned

Complex operational procedures induce to error.

Observations and results

The connectivity and interoperability of the intelligent completion and artificial lift automation equipments was not as easy as expected. A problem with fiber optic connector took 12 hours and when an error occurred on a short length jumper they decided to replace a pup joint and there was no one available due to the special threads. Still, it was preferred to make a new pup joint in a machine shop than to make new fiber optic connector.

Conclusion

With the sensors, the need of pressure and temperature logging is reduced, and the information is available just as needed.
In conjunction with the flow control valves, it is possible to make formation and production tests, without the need of an intervention, preserving the casing from damages caused by squeeze operation.
The integrated automation gives more precise diagnostics of failures in all surface and sub surface. It helps to optimize the use of human resources for operation and maintenance reducing operational costs.
The moderate service conditions could effectively reduce costs of the completion equipments, although it is still high.
Integrated well system provides the tools for increase ultimate recovery when there are availability and reliability of the whole production system.

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