The advance and adoption of wireless intelligent completions

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Wireless intelligent completion technology has the potential to change the way in which reservoirs are managed, linking highly segmented and complex wellbore systems into the digital oilfield.

The application and value of intelligent completions has been well documented since its first deployment in 1997.1 Due to high cost and complexity, advances in wireless intelligent completions remains limited to high value, single bore wells. However, new technology has proven that cable-free communication can be a cost-effective and sustainable solution across a range of well types to optimize production and improve reservoir management.

The PulseEight slimline interval control valve (ICV) has been developed by Tendeka, which provides infinitely variable choking capability and multiple integrated sensors. Qualification has been completed to Equinor’s existing standard for the qualification of ICVs which have been adapted and augmented to reflect the differences between the wireless solution and conventional technology.

The technology

An intelligent completion system must include both downhole monitoring and the ability to control or shutoff flow from individual zones within the wellbore. Conventionally, a hydraulically-operated sliding sleeve configuration has been used to provide this functionality in permanently installed intermediate or lower completions. Monitoring has been provided by electronic multi-drop gauges deployed as an independent system within the completion. The recent advent of all-electric systems has enabled the integration of sensor technology with the control valves.

For wireless intelligent completion technology, the initial ICV configurations have been developed as in-line devices to control flow from below when configured with a plug or from an upper interval when configured with a straddle, as depicted in Figure 1.

With existing Lithium Ion batteries, the technical limit for service life is around eight years in temperatures below 65°C but is significantly lower at higher temperature, resulting in service life of the technology that is often less than the well life. Providing a system that can be installed later in well life or can be retrieved to enable battery change-out, significantly increases the applicability of the technology and de-risks deployment of a new technology.

Figure 1: Retrieveable configurations for lower zone and annular flow control

To achieve this retrievability the device needs to be small enough to fit within existing tubing sizes. At only 2.5” OD the full system can be deployed in tubing sizes down to 3-1/2”, making this the smallest ICV developed to date.
The wireless ICV includes three main sections (Figure 2):

- A choke housing with infinitely variable choke, which can be sized and designed to suit the application. A multi-cycle non-elastomeric seal is included for shut-off requirements
- An actuator and electronics section which includes quartz sensors for monitoring pressure upstream and downstream of the choke housing
- A battery housing which can be sized to suit the application and maximise service life.

Figure 2: Wireless ICV hardware

Capable of operating independently, a dual actuator system is used to provide the separate functionalities of data transmission and flow control. The data transmission system is a normally open hydraulic actuator to create temporary changes to the flowing pressure with limitations on travel and a fail-open functionality. The flow control system is a fixed mechanical linkage to manage or shut-off flow and a fail-open functionality. The all-electric system is microprocessor driven and can manage flow in response to surface commands or can respond autonomously to the well environment using input from the pressure transducers. For example, this can be used to maintain a target pressure drop across the choke, or respond to detected well shut-ins.

Wireless signals are created as discrete telegrams formed by a fixed number of positive or negative pressure pulses that are created by varying the flowing pressure regime at the transmitter that are detectable at the receiver device. In compressible production fluids, significant signal attenuation may occur. However, data can be transmitted over the full well length in multi-phase and gas environments by using a low number of longer pulses with a high amplitude input signal. This limits data transmission rates to an amount required to monitor flow performance and reservoir depletion. It can also be used to provide instructions to the tool which makes it suitable for long-term application due to its low power requirements.

Surface commands or ‘Surface to Tool’ (STT) instructions are generated by manipulating the wellhead choke to create pulses that can be detected by the ICVs as a change in the downhole flowing pressure. Multiple pulses are created which provides an instruction to the device based on the amplitude, duration and time-step between each pulse. The telegram addresses individual ICVs and carries up to 16 different instruction types. These instructions can include orders to move valve position, change device settings, and requests for data.

The wireless tool transmits ‘Tool to Surface’ (TTS) data using the same telemetry process. In this case, the tool can provide well and diagnostic data, status information, or simply confirm receipt of an instruction. The signal from the tool is detected at surface using the wellhead pressure sensor and interpreted using a system software application.

Pressure pulse field trial

In April 2016, the wireless ICV was deployed into a well in the unconventional Bakken play in North Dakota.

The primary objective of the trial was to determine the ability of the device to detect pressure pulses created by the surface choke and to interpret telegram sequences. This was the first time that semi-duplex communication was demonstrated in a live well and the first use of automated pulse detection and telegram decoding algorithms.

The well had been completed with a cased and perforated multizone frac process and the composite plugs milled out in preparation for the trial. Under initial conditions, the well would produce naturally through a 2-7/8” tubing string. The ICV was therefore deployed with the tubing in a podded configuration which allowed the larger OD of the ICV to be accommodated within a 3-1/2” pipe section (Figure 3).

A total of 7,000ft of 2-7/8” tubing was run resulting in a temperature at depth of 125oC. At this temperature the single battery pack used would have a calculated service life of 245 days: more than adequate for the purposes of the trial. A manual wellhead system with electronic gauges tied into a SCADA system for recording tubing and annulus pressure was installed topsides (Figure 5) and the well tied back to onsite separator and liquid storage facility.

The well was placed on production several days prior to the commencement of the telemetry to allow the well to clean-up and reach steady production conditions. At the start of the trial, well production was recorded at 1,650psi through a 28/64” choke with a variable oil rate of 900- 1,900 BPD, a
steady water rate of 1,500 BPD and a gas rate varying between 1.8-2.1 MMscf/d. A steady pressure decline of 83 psi/day was also noted.

With no detailed productivity or well performance data available to enable telemetry modelling, a telemetry optimization plan was prepared to allow maximum flexibility during operations. The ICV was programmed with a ‘broad sweep’ test pulse sequence (TPS) that would allow the optimum choke settings for TTS communication to be selected. To determine suitable sizes for the STT communication, a suite of choke changes was made with the wellhead choke followed by a complete well shut-in to evaluate the amplitude of the resultant wellhead pressure (WHP) change and the system responsiveness.

As there was no packer in the well, a pressure response was detected on both the tubing and annular WHP gauges. The annulus gauge recorded pressure changes greater than 50psi and since it could be assumed that the annulus would be partly or wholly gas filled, it therefore provided good indication that strong pulse signals could be achieved. It was noted that well disturbances caused by choke changes resulted in increasing well instability which was further observed during the telemetry trial.

At the pre-programmed start time, the ICV was observed to move the TPS that would determine the optimum pulse configuration for TTS telegram. However, no further movement of the ICV was observed for the remainder of the trial. With the loss of TTS capability, the primary trial objective of confirming that the ICV could successfully detect and interpret STT telegrams was pursued without feedback. The trial then relied upon data recorded by the ICV to evaluate the received signals, which would not be available until the well was worked over and the valve retrieved.

**Test pulse detection**

The initial phase of the test evaluated the detection of discrete test pulses which varied in both size, duration and spacing. In planned application this test sweep enables the telemetry to be optimized and can be repeated as the well parameters change over time. In this case, the detected pulse data comes from the stored information on the retrieved ICV.

Table 1 presents the results recorded for varying pulse amplitude. All pulses were successfully detected by the ICV, including Pulse 4 which was generated following a system emergency shutdown before the well returned to stable production. Notably, a shutdown will register as a pulse with the valve meaning it would be necessary to allow the proposed telegram to ‘time out’ if this occurred in application. The well was initially producing on a 32/64” choke at 1,460psi. Pulses were created using a choke change to 30/64” which resulted in a typical surface pressure change of 60-70psi.

In the second phase of the trial, a series of telegrams were created to provide instructions to the ICV. Successful telegram transmission requires the individual pulses to be received within fixed time windows without other well pressure disturbances being mis-identified as pulses. The ICV clearly detected each pulse generated by a choke change. With the amplitude of pressure instability downhole below the pulse detection threshold, the ICV correctly decoded each of the telegrams sent from surface.

**Failure analysis and design changes**

Prior to the ICV being retrieved, transient flow analysis was performed to investigate whether the fluid dynamics of the system was compatible with pressure pulse telemetry. The analysis suggested a potential tubing leak above the valve but concluded that detectable pressure pulses were possible (Figure 5).
Table 1: Surface tool test pulse sweep

<table>
<thead>
<tr>
<th>3.5” Wireless ICV</th>
<th>Definition</th>
<th>Imperial</th>
<th>Metric</th>
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<tbody>
<tr>
<td>Minimum Tubing Size</td>
<td>3.500”</td>
<td>88.90 mm</td>
<td></td>
</tr>
<tr>
<td>Peak Temp $T_{\text{peak}}$</td>
<td>302°F</td>
<td>150°C</td>
<td></td>
</tr>
<tr>
<td>Working Temp $T_w$</td>
<td>730°F</td>
<td>110°C</td>
<td></td>
</tr>
<tr>
<td>Operating Temp Range</td>
<td>50 - 230°F</td>
<td>10 - 110°C</td>
<td></td>
</tr>
<tr>
<td>Pressure Rating $P_{\text{MAX}}$</td>
<td>10,000 psi</td>
<td>690 bar</td>
<td></td>
</tr>
<tr>
<td>Maximum Flow Rate $Q_{\text{MAX}}$</td>
<td>10,800 BDP</td>
<td>1,680 m³/day</td>
<td></td>
</tr>
<tr>
<td>Isolation Seal rating $P_{\text{ISL}}$</td>
<td>5,000 psi static (V1)</td>
<td>345 bar static (V1)</td>
<td></td>
</tr>
<tr>
<td>Maximum Unloading Pressure $P_{\text{UNL}}$</td>
<td>1,500 psi</td>
<td>103 bar</td>
<td></td>
</tr>
<tr>
<td>No. of Valve Cycles VC</td>
<td>130 with no dp / 60 at $P_{\text{UNL}}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflow Control</td>
<td>Variable position choke (fail as is)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion Resistance</td>
<td>5 years at 290 psi dp / 5 years at 20 bar dp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication Mechanism</td>
<td>Hydraulic actuator (fail open)</td>
<td></td>
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</table>

After five months, the ICV was retrieved from the well and the data recovered from the tool. A detailed investigation was performed to establish the cause of mechanical failure of the tool during the initial stages of the trial. The investigation concluded that the failure had occurred due to solid sand and oil residue plugging the filtration slots designed to prevent debris entering the hydraulic compensation bellows.

As a result, a design change was made to eliminate the requirements for the bellows and filter entirely. The change was achieved with a compensation piston which would be tolerant to debris. By changing to an open piston geometry, debris would be able to enter the choke piston area which could be tolerated while shut-in and flowed out when on production. This system was tested and requalified prior to the second field trial.

Cloud connected field trial

The primary objective of this field trial was to demonstrate the full functionality of the ICV within a well system. Since the device was to remain in the well sending regular telegrams to the surface there were multiple advantages to being able to remotely access the data, and a secondary objective of demonstrating a cloud connected system was identified. Since the simplest mechanism of recovering wellhead pressure data was with a wireless surface pressure system, the resultant planned system was entirely wireless from the ICV to the remote desktop or smartphone.

With funding support from the Oil & Gas Technology Centre, the company and OMV Group installed the downhole device and a newly developed surface system within a gas storage well in Austria, in December 2017.

The wireless ICV was deployed on slickline and mounted below a lock mandrel positioned within a 2.75” X nipple profile at a depth of 1,129m. It was programmed to send regular pressure and temperature signals to surface via the previously described pressure pulse signal contained within the flowing regime of the well. The low bottom hole temperature of approximately 40°C at this depth would allow it to function with regular telegram for nearly 18 months on a single battery.

During production, flow rates were varied to meet local gas demand with a maximum possible rate of only 6.5 MMscf/d which was remotely controlled for the multi-pad location. Local changes to the wellhead choke could only be achieved using a manual choke located on the wellhead.

A wireless pressure sensor was used to monitor the amplitude of the pulses created on surface when choking the well, as well as to detect pressure pulses created by the wireless tool. The wellhead sensor was connected to the wellhead via a ¾” NPT connection, positioned upstream of the surface choke.

A surface acquisition unit (SAU) was set up approximately 100m away in the wellsite control cabin and synchronized with the wellhead sensor via radio frequency communications. An internal hardwired Modbus was employed with the SAU linking the data logger to the systems surface application. The SAU acted as a remote terminal unit running a web service with a fixed IP address, other computers or devices within the Virtual Private Network could access the data live via a browser connected via the existing mobile telephone network. This permitted access to live outputs directly from the ICV via any networked linked computer terminal or a company specific smart phone app (Figure 6).

The Cloud Connected Completion

![The Cloud Connected Completion](image)

Figure 6: Wireless intelligent completion - system configuration

Onsite operations

As part of the installation and commissioning phase of the system, a sequence of choke changes was performed at surface to assess the time to cycle the choke, the required choking percentage, and the responsiveness of the DAQ.
system. Within the system’s TPS system, a feedback loop exists to confirm the optimum pressure pulse required by the system for effective communications to and from the device. This was defined to a simple number of turns of the surface valve to illicit the required response, which aided in the simplicity of future communications to be carried out with the system.

The wireless ICV successfully sent weekly pressure and temperature signals to surface, with the data and interpreted results available for review real-time via the wireless network link. As the well was part of a stock of gas storage wells which were running with their winter delivery stage, production rates were changeable on an hour-by-hour basis as required for peak electricity demands of the network being served. This not only challenged the robustness of the wellbore communication system but also the surface applications conducting the decoding of the signals received. Figure 7, shows that the received telegram pulse amplitude is below the amplitude of system noise but can be identified based on their known start time, consistent amplitude and length. Pulse detect algorithms were developed as a result to account for these features.

Towards the end of the trial period, surface commands were transmitted to the wireless ICV requesting changes in position. This culminated in ultimate closure of the well to demonstrate the seal integrity of the device within a gas system. It was retrieved after three months and was confirmed to be in full working order.

**Conclusion**

The benefits of wireless intelligent completions are far reaching. It can simply be deployed as a conventional completion and can be readily demonstrated as a more cost-effective solution. In addition, it can expand the application range of traditional intelligent completions.

Using low-complexity pressure pulse telemetry minimizes hardware requirements and reduces system interface challenges. In the development and trial phase it has been demonstrated:

- The retrofittable and slimhole wireless ICV is robustly qualified for extended use in a downhole environment
- Semi-duplex communications can be achieved through manipulation of a wellhead choke
- A system of signal calibration can provide optimum telemetry across a changing production environment
- The wireless ICV can successfully receive and decode surface commands
- The intelligent completion system can be readily monitored via a cloud-based interface.

**Future**

While the development of wireless intelligent completion is still at an early stage in comparison to traditional hydraulic technology, significant milestones have been achieved in its progress. This has culminated in the deployment of the world’s first wireless cloud-connected intelligent completion.

Having successfully demonstrated the viability and flexibility of the technology, the future of wireless intelligent completions holds great potential in improving reservoir management as an integrated part of the digital oilfield solution.

In the short-term, the flexibility and simplicity of today’s technology can deliver integrated systems and remotely-operated solutions to improve well management and reduce well interventions across a range of new and existing well types. Early commercial applications are focused on delivering pressure and temperature data, remote/temporary water-shut-off and autonomous operations to replace ambient valve technology.

Looking ahead, the requirement for more power must be addressed to enable greater data rates and longer service in hotter environments. The main challenges lie in the technology to store energy so that generated power can be accumulated and stored over the well life. Today’s lithium ion technology cannot meet this need and there are multiple initiatives to provide new solutions that are specific to the upstream oil and gas sector’s needs.

**References**

1. Mitch, A. F. Skarsholt, L. T., (2008), Advanced Wells: How are they being used and are they creating value: SPE paper 113142 presented at the Improved Oil Recovery Symposium in Tulsa, Oklahoma, U.S.A.