Intelligent Well Completions –

Ready to Achieve its Potential 20 Years On

Intelligence is defined as the ability to reason, plan and comprehend complex events and make an informed decision based on this information, and when the first intelligent well completions were installed in 1997 they really met this definition. They were micro-processor driven and teeming with sensors to deliver computer managed control and feedback operations. Their capabilities and potential were game-changing and the industry was excited. Unfortunately, these early systems were beset by reliability issues. Hydraulically operated downhole valves were achieving better early reliability and dominated the market, reaching a 300-installation milestone within 10 years.

BY ANNABEL GREEN

It was realised early that the value of in-well flow controls to adjust flow profiles could not be realised without the data to aid decision making. So while the control and feedback capabilities of the early systems were not replicated, downhole electronics providing multi-drop sensor capability became inextricably linked to hydraulic valve systems. These electronic gauge systems have far exceeded intelligent completions in the extent of their use.

System Element	Hydraulic ICV with E-monitoring		All-electric system
	Hydraulic System	Electronic System	
Downhole Equipment			
ICV type	Hydraulically operated multi-position valve		Electrically operated infinitely variable position valve with electronic position sensor
ICV pressure rating	10,000 psi		10,000 psi
ICV temperature rating	165° C		150° C
Downhole gauges		Independent multi-drop quartz gauges	Multi-drop quartz gauges integrated into ICVs
Hydraulic control lines	Minimum 3		0
TEC cable		1	1
Total number of feedthroughs (inc. DTS)	5		2
Surface equipment			
Units required	Hydraulic supply module Well control module Hydraulic control unit Well control unit	PDHG interface card	IC interface card.
Operability			
Time to change ICV position	30mins per position (max 5 hrs)		2 mins max
Position control option	Hydraulic only		Feedback options through position sensor or target flow rate
Position accuracy	Subject to hydraulic volume control at downhole condition		Accurate to =/- 0.1mm
DOF interface	Automated input option	Output only	Compatible with automated well optimisation software control

Hydraulic ICV with Electronic Monitoring vs All-electric systems – functionality *(illustrations: Tendeka)*

Today's innovations in intelligent well completions are again driven by electronics, providing greater functionality and system control. Reliability of these systems can now be demonstrated and the game changing potential is once again exciting.

Hydraulic Versus Electric Systems – Comparative Reliability Assessment

The following example is taken from technical paper SPE250690 [1], which described the installation of independent hydraulic and electric systems of 28 wells over the first 6 years of operation in a subsea oilfield offshore Nigeria and include oil producers, water injection wells and gas injection wells. The hardware included dual zone variable type ICVs, PT sensors, flowmeters and densitometers.

The study divided the electronic and hydraulic systems into subcomponents and defined their performance by a 1 – denoting operational, or a 0 – denoting failure.

100% reliability was recorded on the electric sensors and connection systems (infant failures are discounted from reliability studies using Weibul techniques). A failure of the common close line of the hydraulic system was recorded after 134 days of operation, resulting in a reliability of 92%.

The most notable failure was of the metal-to-metal (MTM) seal on the ICV which gives a calculated reliability of 46%.

The overall system reliability in oil producers was still recorded at over 90%. In both water and gas injection wells no failures were recorded.

S/N	Well Name	Online Data	Densitometer: P/TSensor	Densitometer: Electrical Cables & Connectors	Flowmeter: P/TSensors (2)	Flowmeter: Electrical Cables & Connectors	Flowmeter: Venturi	Triple Gauge Package: P/TSensors (3)	Triple Gauge Package: Electrical Cables & Connectors	Interval Control Valves: Zone / Completion	Interval Control Valves: ICV Size (in)	Interval Control Valves: Sliding Sleeve and Valve Trim (2)	Interval Control Valves: Hydraulic Line & Connectors (3)	Interval Control Valves: Metal-to-metal Seal	Comments
1	Well-P1	28-Jul-2008	1	1	1+1	1	1	N/A	N/A	Single Zone	N/A	N/A	N/A	N/A	Single Zone Completions - No ICVs
2	Well-P2	31-Jul-2008	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	0	1	ICV failed in open position (12-Dec-2008) - Hydraulic (Common Close) Line Failure
										Lower Zone	3-1/2	1	0	1	ICV failed in open position (12-Dec-2008) - Hydraulic (Common Close) Line Failure
3	Well-P3	3-Aug-2008	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	1	
4	Well-P4	3-Aug-2008	1	1	1+1	1	1	N/A	N/A	Single Zone	N/A	N/A	N/A	N/A	Single Zone Completions - No ICVs
5	Well-P5	4-Aug-2008	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	1	
6	Well-P6	14-Aug-2008	1	1	1+1	1	0	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	1	Venturi is not functioning as desired - possibly clogged with debris
7	Well-P7	27-Oct-2008	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	1	
8	Well-P8	30-Jan-2009	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	0	Leaky lower ICV
9	Well-P9	26-Apr-2009	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	1	
10	Well-P10	30-May-2009	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	0	Leaky lower ICV
11	Well-P11	30-Jul-2009	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	0	Leaky lower ICV
12	Well-P12	8-Aug-2009	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	0	Leaky lower ICV
13	Well-P13	3-Dec-2010	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	0	Leaky lower ICV
14	Well-P14	10-Jul-2012	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	1	
15	Well-P15	3-Jul-2013	1	1	1+1	1	1	1+1+1	0	Upper Zone	4-1/2	1	1	1	Infant failure of triple gauge failure (immediately after installation)
										Lower Zone	3-1/2	1	1	1	
16	Well-P16	7-Nov-2013	1	1	1+1	1	1	1+1+1	1	Upper Zone	4-1/2	1	1	1	
										Lower Zone	3-1/2	1	1	1	
17	Well-P17	12-Aug-2014	1	1	1+1	1	1	N/A	N/A	Single Zone	N/A	N/A	N/A	N/A	Single Zone Completions - No ICVs

Note: 1 = Functional, 0 = Failed, N/A = Not Available / Installed

Status of Agbami Oil Producers – intelligent well completions equipment installed

The Future of Intelligent Completions

Intelligent completion technology medium term goals have been summarised as follows [2]:

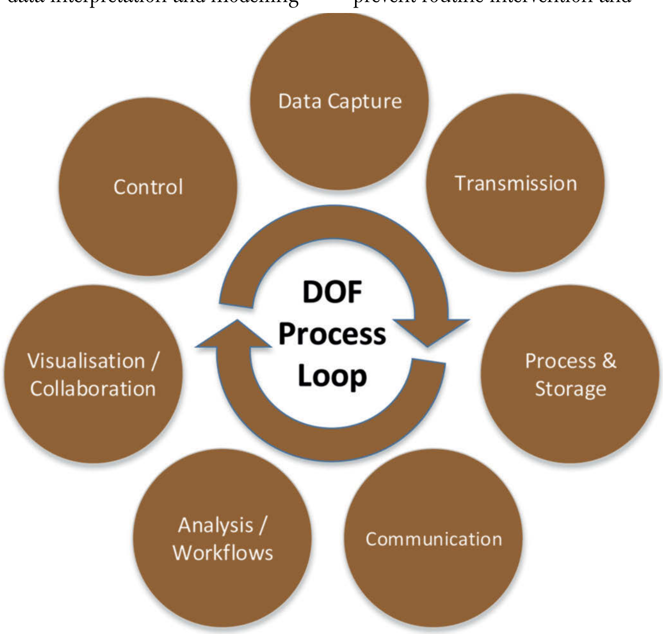
- Prevent routine intervention for reservoir management purposes.
- Leverage systems giving multiple horizon or reservoir penetrations per well.
- Self-optimise and automate wells and process facilities.
- Design processes on an optimum system rather than component basis.
- Intelligent completion system reliability should exceed 95% operability 10 years after installation.

Key to achieving many of these goals is the integration and automation of this intelligent completion technology with current digital oilfield (DOF) technology.

Existing DOF process loops are heavily people dependant and rely on robust high speed communication between the field and office. Delays in responding to changes in the well performance and recognising opportunities to optimise performance on a well-by-well or field basis reduce the benefits of this technology. Closed feedback loops linking offshore data interpretation and modelling capability directly to the in-well control and monitoring systems provide the opportunity to leverage the value of this technology on a systems rather than completions basis.

Hydraulic ICVs have been used to prevent routine intervention and have achieved advances on reliability but lack sufficient functionality. This has remained largely unchanged since the introduction of variable control valves over a decade ago. This stagnation, along with a need to increase the number of control intervals, reduce completion complexity and ultimately improve reliability is driving a return to all-electric systems. It is anticipated these systems will rapidly overtake the older hydraulic systems in application. [3]

Since all intelligent systems rely on electrical systems for monitoring, the additional requirement for a hydraulic system is to drive the ICVs results in increased cost and operational complexity. Consequently, the uptake of hydraulic ICVs has been limited to high cost subsea and multi-lateral environments, with some applications in mature complex reservoirs. Growth of this technology has thus been limited. The same move to all electric systems is



Key Elements of a Digital Oilfield Solution

reflected in other industries from defence, space, aeronautics and automotive. The same move has been seen within the oil industry in subsea control systems, advanced logging tools and drilling technology as improvements in process and control are sought.

This change in intelligent completions is reflected in the most recent technology developments from within the service companies and technology sponsorship within the majors. It has been aimed at addressing the limitations of multiple control line systems and ultimately reducing cost and complexity of the systems.

Leveraging the increases in downhole electronics reliability in other downhole sectors of the oil industry, all intelligent completion providers have launched all-electric or electric-hydraulic systems within the last four years. This is driving the technology to the next level to meet future well operability demands.

The Wireless Advantage

Electronic technology opens up the possibility of in-well wireless communication eliminating the requirement for control lines. With pressure monitoring and control commonly available at surface, telemetry which utilises the well fluids kinetic energy, provides a low power, low complexity means of wireless communication. This pressure pulse telemetry has been proven robust in compressible fluids providing a means for data transfer without any addition hardware beside the downhole tool itself. [4]

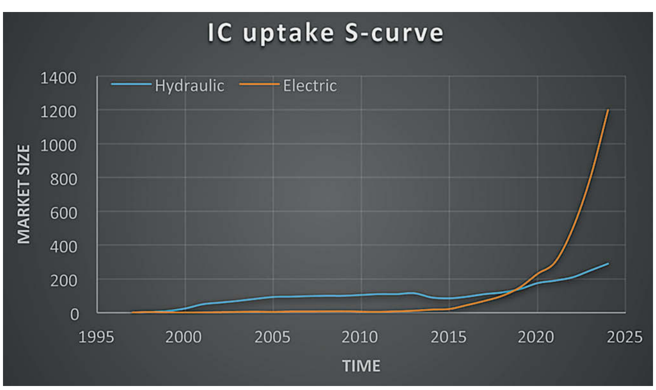
This wireless capability is conducive to increased zonal control and multi-lateral completions but also greatly reduces the cost and complexity of delivering basic functionalities, opening up the benefits of intelligent well completions to marginal and mature fields. Mature fields currently account for over 70% of conventional hydrocarbon production with water breakthrough, differential depletion and water or gas capacity management problems already commonly existing. Wireless retrofit solutions can provide the means for optimising these wells and reducing well management costs.

Watch this Space

The use and acceptance of microprocessor driven technology in the downhole environment opens a new world of possibilities for digital well operations. After 20 years, intelligent well technology is only beginning to realise its full potential of remote operation, computer control, automation and digital oilfield integration: changing the way wells are operated to reduce costs and improve reservoir management. ■

The History of Intelligent Well Delivery

Late 1980s	The first electronic gauges are installed achieving a 5-year probability of success of 40% to 50%.
1995	The first multi-drop gauge systems are installed. Electronic gauge 5-year probability of success increased to 75%.
1996	First hydraulically operated on-off valves are deployed without monitoring. Early reliability studies indicate a 5-year probability of success of 80%.
1997	First electric intelligent completion installed, featuring infinitely variable ICVs with integrated transducers using a single control line. 5-year probability of success <40%.
2000	Baker Hughes launches an all-electric intelligent completion. Initial systems still operational in subsea environments after 10 years operation. [4]
2001	Schlumberger deploys their first all-electric intelligent completion. Reliability studies at this time indicate 5-year reliability of electronic systems is 90% at less than 100° C, decreasing to 50% at 150° C. The most common failure mode is the cable and connections. [4]
2006	Hydraulic systems reaches the 300 installation milestone, reporting a 5-year probability of success of 90%.
2007	Over 10,000 electronic gauges now installed with 5-year probability of success over 90%. [4]
2010	Halliburton launches hybrid hydraulic-electric intelligent completion system combining hydraulic ICVs with electronic monitoring. [4]
2011	Halliburton launches second-generation hydraulic ICV to improve operations at higher pressures and temperature, and increased control of valve position through hydraulic metering.
2013	Tendeka launches wireless pressure temperature gauge as first step towards all-electric wireless intelligent completion. The technology eliminates failure modes and completion design limitations due to electric cables and connectors.
2013	Aramco and Schlumberger announce trials of all-electric intelligent completion system for multi-lateral and extreme reservoir contact wells. [4]
2014	Baker Hughes launches multi-node all-electric intelligent completion system for horizontal wells.
2015	Baker Hughes launches all-electric intelligent completion system for HPHT deep water applications.
2017	Tendeka launches PulseEight all-electric intelligent completion system.



IC uptake – hydraulic ICVs are expected to rapidly overtake the older hydraulic systems in application

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[3] SPE150408 – Evaluating the performance of intelligent completions, 2012.
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The Author:

Annabel Green joined Tendeka from Weatherford where she spent more than 14 years in numerous technical and R&D roles – both in Aberdeen and overseas. Ms Green has broad experience in sand control, reservoir completions and general completion technology across global markets. Prior to her time at Weatherford, she worked for Schlumberger as an open hole-logging engineer in the North Sea. She holds several patents and is the co-author of a number of sand control-related SPE papers. Ms Green graduated from a Leeds University with a degree in Mechanical Engineering.