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How Visual Data Analytics Has Transformed Downhole Video

Tobben Tymons, EV cam

Video images have traditionally provided intuitive visual analysis in a wide range of wellbore diagnostic situations. Step changes in computer vision techniques and image processing have led to the ability to make measurements from images (visual analytics). This paper demonstrates several applications where the application of this new data analytics source, combined with state-of-the-art acquisition technology, have further improved understanding of complex well issues while reducing operational time, risk and cost. Examples include hydraulic fracturing, well integrity, erosion, restrictions and leaks.

The method consists of a three-stage workflow:

1. Acquisition of full circumferential, depth-synchronized video data of the wellbore. An array of four orthogonally positioned cameras, pointing directly at the pipe wall, concurrently record overlapping images, enabling a continuous full-well video dataset to be obtained.
2. The four depth-matched video streams are synchronized and “stitched” together through the application of computer vision algorithms to provide a continuous 360° map of the wellbore with submillimetre pixel density.
3. The acquired image is calibrated and measured before new and unique diagnostic enhancing data analysis methods are applied.

The paper will provide real-world examples, presented as case studies, for applications including well integrity evaluation, screen condition assessment, and analysis of perforations. Each case study will demonstrate how visual data analytics used to quantify downhole features, combined with the ability to capture a complete, high definition view of the pipe wall, provides detailed and highly intuitive information that leads to an enhanced understanding of the well and the factors affecting its performance.

We will demonstrate that the application of this imaging system together with new visual analytic methods exceeds the limits of conventional logging technologies for multiple industry challenges, such as:

- Sand Control: comprehensive evaluation of sand screen condition, including identifying the source of sand inflow and quantification of restricted flow area due to solids deposition within the base holes.
- Water shut-off: Identifying the source of water and hydrocarbon entry in wells with high water-cut and/or complex flow regimes.

The paper will demonstrate that data analytics when applied to images from the latest generation of downhole video imaging systems has enabled the development of new diagnostics methods that provide unique insight on high value operational issues. This step change in information empowers decision-making leading to improved economics and reduced operational risk.
Pressure Depletion Evaluation behind Casing by use of Pulsed Neutron Log Measurements: A Challenging Case in Mature Sandstone Formation

Roberto Nardiello, Baker Hughes GE

Evaluation of current reservoir pressure and depletion is important for gas bearing sand reservoirs in mature fields. An understanding of pressure depletion profiles for unperforated multiple stacked sands helps to avoid creating non-productive perforations. This case study presents a proven method to determine reservoir gas density and pressure and identify depletion in cased wellbores using multi-detector pulsed neutron log measurements. Thermal neutron capture cross section (Sigma) log is not sensitive enough to detect reservoir pressure changes. The method instead utilizes count rate ratio-based measurements exhibiting high sensitivity to pressure variations in gas reservoirs.

The approach is based on a sensitivity analysis using Monte Carlo stochastic simulation to address uncertainties in various parameters associated with challenging environments. Wellbores in mature fields, with a long history of production, typically have complex completion geometries, uncertain wellbore fluid properties and poorly defined fluid contacts.

Formation heterogeneities of mineralogy and porosity are other factors to be considered. Uncertainties associated with wellbore and formation variables must be assessed to obtain reliable reservoir depletion profiles. Sensitivity analyses using well and parameter-based Monte Carlo modelling have been performed and incorporated into the interpreted results. Thus, the impacts of those parameters on the estimated gas density and pressure are evaluated.

Application case studies from a mature gas field in Southern Europe are presented. Typically, the thick gas sand reservoirs in this field are not affected by water drive mechanism but only by gas expansion (i.e., natural depletion drive). Thus, original water in place for those sands was unchanged but pressure depletion was suspected; by estimating the degree of reservoir depletion a better picture of less depleted intervals was possible. The reliable results were successfully obtained with uncertainty assessments. Analysis of pressure depletion in the primary target formations of the field was used for subsequent reservoir management decisions.
Utilising multi-detector pulsed neutron technologies to understand behind pipe saturations in Rumaila, Iraq

Oliver Grimston, BP

Rumaila, Iraq, is a supergiant oilfield and produces through multiple reservoirs- clastic and carbonate. It utilises recovery mechanisms such as natural aquifer drive and water flooding which have impacted the initial fluid distribution. To evaluate changes in fluids, multi-detector pulsed neutron (MDPN) logs are acquired within the field. MDPN measurements require careful interpretation accounting for logging conditions and formation environments to provide an accurate result of multicomponent fluid saturations so well work activity can be optimised, and production and recovery can be maximized. Over the past couple of years, more MDPN tools have been brought to the market hence increasing the competition between vendors. To assess their compatibility, field trials are required to understand nuclear attributes as well as benchmarking nuclear models. While all tools follow the same physical principle, the responses can be variable which is dependent on instrumentation design, characterization and nuclear attributes extraction. The presentation will cover the data integration approach taken by the production team using historical and latest generation MDPN data, some acquired for the first time in the clastic and carbonate formations of Rumaila field. It will also cover BP’s in-house saturation logging workflow, address the nuclear attribute screening and selection process for the two reservoirs (clastic and carbonate) and the associated movement mechanisms. The sigma and CO analysis will be shown for two wells and it was concluded that nuclear model driven interpretation aids the accuracy of fluid saturation result. The uncertainty in MDPN derived saturation can be reduced if the deviations from notional values are known.
Flow Regime Diagnostic in Producer and Injectors using Ultrasonic Doppler Sensors

Virginie Schoepf, Openfield

*Openfield authors: L. Abbassi, E. Donzier, V. Schoepf, E. Tavernier.*

Standard and newer generation spinners of all diameters operating in low velocity environment are often limited to detect small entries if their thresholds are greater than fluid movement. Conversely, fluid viscosity, density and even more significantly possible contamination of spinner jewel bearings with solid particles (paraffin, sand) may as well impede the rotation of the propellers’ blades. Furthermore, harsh logging conditions can also lead to loss of propellers.

In these situations, an alternative measurement to diagnose flow regimes and inform about in situ fluid velocities is required. In more ‘spinner’ friendly situations, the alternative measurement will complement the flow diagnostic and make it more accurate.

A novel flow diagnostic measurement based on Doppler physics has been developed. The measurement does not require direct contact between the borehole fluid and the sensing element, inhomogeneities inside the fluid being detected by multiple ultrasonic transducers. The sensor operates from very low to high velocity flow but is dependable on the presence of inhomogeneities (fluid bubbles, solid particles, turbulences). The ultrasonic Doppler sensors can be mounted on the axis of the compact array tool string (0.86 m/less than 1 meter) or independently from each other for instance as an array of sensors with use of elongated probe design. The very short toolstring will typically carry auxiliary measurements (Pressure, Temperature, Holdup, MML(CCL), Tool Orientation and Deviation, Spinner).

The presentation will describe the sensor technology and the application of Doppler physics before showing some examples of yard test experiments.

During the presentation, we will also show some videos of flow loops and Doppler shift measurements to illustrate the challenges in processing versus flow regime.

![Flow Regime Diagnostic Diagram](image)

*Figure 1: Different Types of Doppler Spectra and corresponding Flow Patterns*
Figure 2: Doppler Measurements vs Spinner Data in gas-water mixture (lab conditions)

Figure 2 shows a test in flow loop in gas-water mixture where we vary rate with a pump- Doppler frequency shift measurement (most right track). Spinner is showed for comparison.

References:

Cased hole gas zone identification through RA scale

Reza Khastoo & Zoran Markovic, Scientific Drilling & HWLAC

This presentation demonstrates, using data acquired from a Lower Slochteren, Southern North Sea gas well, the efficacy of neutron-detecting pulsed neutron capture [PNN] tools for cased hole reservoir evaluation through areas of radioactive (RA) scale. Conventional pulsed neutron capture technologies use gamma-ray detectors [PNG], making through casing evaluation of the reservoir in the presence of RA scale, highly problematic.

An additional challenge posed by the well conditions was the relatively elevated bottom hole temperature of 158°C (316°F) and the operator’s preference for slickline conveyance and, in turn, memory data acquisition. The extent of the RA scale was evaluated and verified with the use of MPLT data – as indicated most prominently by the spinner and temperature response – and Multi-finger Caliper data (acquired concomitantly to the PNN) and by comparison with the gamma-ray log obtained prior to the extensive accretion of scale. The chemical properties of the RA scale are examined with reference to the theory of PNN measurement and the source of the radioactivity is postulated.

The data acquisition operation was deemed a success, enabling the operator to confirm the gas-bearing intervals for re-perforation to increase production from zones blocked by the scale.

The novelty of PNN technology for such applications may generally go unnoticed by operators. This case provides compelling evidence for a dependable cased hole reservoir evaluation technology – variables permitting – whenever RA scale is prevalent.
The Essentials of Fibre-Optic Distributed Temperature Analysis

George Brown, Absheron Consulting Ltd

Temperature logs have been used to monitor producing wells since the early 1930’s (Doll and Perebinossoff, 1936) and a considerable number of papers have been dedicated to the measurement and its analysis over the years. The data generated can been used to calculate the flow contribution of oil and gas wells and also to evaluate water injection profiles, determine the effectiveness of fracture jobs, identify cement tops, crossflow between zones, flow outside the casing and other flow and well bore related events.

With the modern production logging tool (PLT) analysis of the temperature data is often viewed as secondary to that of the spinner flowmeter and gradio-manometer which give flow and fluid composition directly, with temperature data only being used as an indicator of gas influx.

However, the fiber-optic distributed temperature system (DTS) can generate many temperature logs (from every two seconds upwards) over the life of the well either pre-installed with the completion or deployed on slickline or via coiled tubing. This enables well productivity to be evaluated without the need for other PLT data.

The example shown opposite compares the flow analysis computed from DTS data in a deviated producing well to that of the PLT spinner in the same well. The DTS analysis is achieved by fitting a thermal model to the DTS measured flowing and shut-in temperatures. The comparison demonstrates that DTS alone can produce flow rate results comparable to that of a PLT. Note that pre-installed DTS flow analysis can be obtained at any time during the life of the well without the need for a PLT intervention and without the cost and risk associated with such an operation.

In recent years the cost of PLT logs have increased considerably because many wells are now drilled with high deviation, or even horizontally, through the reservoir and so the PLT tools must be conveyed on coiled tubing or well tractor. If it is possible to install an optic fiber with the completion a great deal of information about the well performance can be derived by continuous monitoring the distributed temperature without the need for a PLT to be run.

This presentation will outline how DTS temperature is measured along an optic fiber, show the installation options available and examples of DTS use and analysis in producing and injecting wells.
Efficient Well Diagnostic using simple yet powerful Distributed Temperature Sensing (DTS) – A Case Example

Kamaljeet Singh, Schlumberger

Overview
A European operator observed A annulus pressure. The intervention program required the knowledge of the tubing to A annulus leak before rig move.

Challenge
Conventional leak detection services using noise logging, production logging, and discrete temperature logging on its own would not be able to efficiently locate the leak in the tubing to A annulus since the leak rate was very low, erratic and not sustained for long. Under these conditions, conventional sensors cannot be used to locate the leak depth with accuracy, and the operation was also likely to take a lot more time (possibly days).

Solution
A solution of DTS and PLT (Memory) in a single trip was proposed to fulfil the objectives under the challenging conditions. The DTS would pick the leak location(s) immediately by recording the data across the whole well in few hours. The PLT would then be used to record additional complementary data across the pinpointed leak location(s).

Results
The leak diagnostic for the well was completed within a few hours, first recording the static temperature profile across the whole well, followed by data recording under leak condition. The results were analysed in near-realtime and three leak depths were identified. The PLT tool was then moved to one of these points to obtain the leak rate information.

Conclusion
The case example and solution are applicable to many wells in the North Sea’s ageing assets and the audience would benefit from this simple and novel technique for well diagnostic.

Bio
Kamaljeet Singh works as Principal Production and Well Integrity Domain Champion at Schlumberger Europe, based in Aberdeen, UK. In his current assignment, he works with Oil & Gas operators in the North Sea and Europe. Kamaljeet has 20+ years of experience in wireline logging, production enhancement, reservoir & wells optimization, well interventions, plug & abandonment operations. He has worked in Asia, Middle East, Africa, and Europe in various assignments in the Field, Personnel, Training & Development, Sales, Marketing and Technical roles. He also works with Schlumberger Engineering Centres to review and test new technologies.
Figure-1 The DTS traces, deltaT plot and gradient plot are used to pick up the leak depth.

Figure-2 3D plot of temperature v/s time v/s depth. This helps in the visualization of the changes in the temperature and identify potential leak points.
Evolution of DTS Into a Simple to Use, Ruggedized, Portable, Cost Optimized Interrogation System

Michael Webster & John Davies, Solasense

Distributed fiber measurements are increasingly a part of well surveillance. Current distributed interrogation units tend to be complex to use, cumbersome, and requiring an external power supply and protective transit containers for shipping to site. These are delicate instruments and can suffer from reliability issues in a rugged oilfield environment. They also represent a significant capital outlay leading to increased costs for both operators and service providers. There is however a new generation of DTS interrogation unit which is emerging onto the market. These devices are portable, battery-operated and intuitive to use, that offer both performance and reliability.

Emerging from the telecoms instrumentation industry, these unit comes from decades of experience in OTDR field test equipment development rather than spin offs from academia. The unit performs an OTDR check prior to the main DTS survey helping to trouble shoot potential fiber and connector issues proactively. Some of these units even incorporate the ability to compensate for hydrogen darkening of the fiber without the need for complex operator calibration.

The optical surveillance sector has gone through an arms race striving to develop bigger better more complex systems with a focus on accuracy resolution as the measure of success. This level of sophistication does come at a financial cost as well as the skill level needed by the service sector to operate these complex devices. The advent of these new systems changes the philosophy and focuses on portability, ease of use with the minimum of training. These features help move DTS surveillance from a specialist service to a commodity mainstream product.
Through-Tubing Casing Inspection: Methodology and Case Studies

Marvin Rourke, GOWell

Well Integrity (WI) failures have had widespread public notoriety in recent years. Operators, regulatory agencies and stakeholders are paying significantly more attention to Well Integrity with new or updated operating standards such as NORSOK and ISO/TS16530 being implemented. This is coupled against a backdrop of aging wells and infrastructure, a lower cost regime and developments in more challenging environments.

Implementing a successful Well Integrity management system includes analysis of multiple risk factors and implementing suitable mitigation strategies. One of these strategies is periodic tubular monitoring for corrosion, erosion and mechanical damage. Through early detection of tubular damage and other barrier defects the well operator can significantly reduce risks associated with serious leaks or barrier failures.

Evaluating corrosion and tubular damage through multiple concentric casing strings requires the use of magnetic or electro-magnetic (EM) physics. There are various techniques employed by the industry, this presentation will focus on two methods; one that is being widely used for multi-barrier surveillance and one emerging technology.

The first part of the talk will cover the technique and various applications of Pulsed Eddy Current (PEC) multi-pipe metal thickness measurements. The presentation will focus on various applications of a thru’ tubing PEC device via numerous case study examples.

The second part of the talk will discuss a new development whereby tubing eccentricity and thru’ tubing casing deformation can be evaluated. The applications include 1) quantifying casing deformation due to geo-mechanical stress, 2) locating tubing position within casing prior to P&A, 3) identify tubing-casing contact points which can accelerate corrosion and 4) azimuthal orientation of completion items.

The talk will conclude with some thoughts and pointers to the future direction of casing inspection.

Real-time field Log showing significant 9-5/8” corrosion behind a 7” production casing
Open hole 3-D imaging and casing integrity logging in a single run using phased array ultrasound

Duncan Troup, Archer Well

A new technique based on phased array ultrasound provides complete casing integrity verification and 3-dimensional imaging and measurement of open hole immediately below the casing shoe in a single run in hole.

The integrity of a casing string is of paramount importance in the safe and economical operation of a well. Not all wells are completely cased, and it is often economical and sometimes necessary to leave a section of open hole below the deepest casing shoe. In these cases, the uppermost section of the open hole can become part of the integrity envelope of a well and should be included in diagnostic monitoring programs.

Conventional methods of casing evaluation have relied on caliper tools with a number of fingers in physical contact with the casing wall. These tools have a high degree of radial accuracy, but suffer from a number of drawbacks. The number of fingers is limited, and consequently there is a gap in measurements between adjacent fingers and they are only capable of measuring the interior condition of the casing. They are also unsuited for use in most open-hole environments where there may be large and irregular variations in hole diameter, a condition very likely to occur immediately under a casing shoe.

An alternative approach is to use a focused beam of ultrasound to measure very accurately the internal diameter of the casing, and at the same time to detect the thickness of the metal wall remaining at that point. A circumferentially mounted array of transducer elements allows 288 individual measurements of ID and wall thickness around the casing, allowing high resolution analysis of the interior and exterior surfaces of the casing. The focused ultrasound beam is able to inspect the borehole environment without requiring any physical contact, and generate high resolution 3-dimensional images to fully understand the borehole properties immediately below the shoe.

Results from a recent trial where the phased array ultrasound tool was deployed into a solution mining well with a 13-3/8” casing string installed revealed many interesting features, such as areas of ovalisation, as well as evidence of exterior metal loss. With the tool switched to imaging mode, a number of passes were made to a depth of 5m below the casing shoe and the data used to generate 3 dimensional models of the borehole environment, which were then used for total volume calculations.

This new approach to well integrity analysis increases the resolution available for interior casing inspection, adds direct measurement of remaining wall thickness and allows comprehensive evaluation of the open hole immediately below the casing shoe.