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Intelligent Developments: 4-D seismic 'illuminates' completions

Deepwater production is challenged by well underperformance issues that are hard to diagnose early on and expensive to deal with later. Problems are amplified by reliance on few complex wells with sophisticated sand control media. A new non-intrusive surveillance method uses acoustic signals sent via the fluid column to identify impairment in sand-screened completions in real time.

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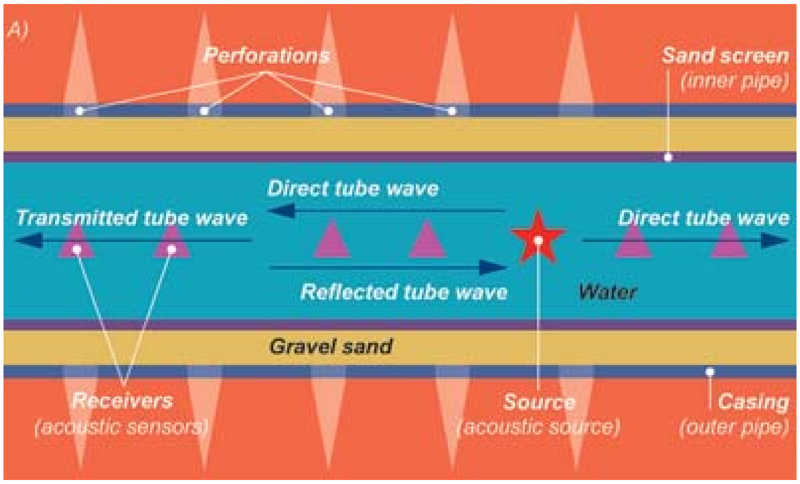

In completion monitoring, tube waves repeatedly "illuminate" the completion and near-wellbore space so changes can be interpreted in terms of important reservoir and completion parameters. (Images courtesy of Shell)

The concept of completion monitoring with acoustic waves is a natural extension of 4-D seismic ideas into the smaller-scale near-wellbore environment. In 4-D seismic, time-lapse images of the subsurface can be built so fluid flow and production scenario changes can be interpreted. In completion monitoring, tube waves repeatedly "illuminate" the completion and near-wellbore space so changes can be interpreted in terms of important reservoir and completion parameters. In both instances, monitoring consists of measuring those parameters of the reservoir or producing equipment (i.e., wells) that are needed to make the most critical reservoir management decisions.

Using 4-D seismic data, analysts can observe how a reservoir is drained and decide where to drill the next well. Completion monitoring allows geoscientists to observe if and how wells are impaired.

Permanent sensors installed downhole deliver generally better repeatability and more rich real-time information. As an extra benefit, permanent systems can also be used for passive monitoring. In 4-D seismic, this consists of listening to micro-seismic events. In real-time completion monitoring, it means listening to flow, sand production, and any malfunctioning downhole equipment.

Real-time information about a well’s inflow ability could be valuable input to well engineers or production technologists, potentially allowing them to:

- Detect changes in permeability in and around the well (and thus the inflow ability) in real time;
- Identify the well structure (screen, perforation, etc.) responsible for problems;
- Help design best practices for drawing wells without impairing them;
- Raise red flags early on when problems are not acute and can be fixed before intervention is required; and
- Help characterize cross-flow and differential depletion in wells with multiple commingled producing intervals.

A 4-D seismic approach has been adopted in which contrasting completion scenarios like impaired-unimpaired screens were created, and changes in the associated acoustic signatures were analyzed. This scenario permitted analysts to focus on distinguishing these contrasting scenarios as opposed to inverting for absolute static values of the completion properties.

Detecting sand-screen plugging

Plugged sand screens support tube-wave signals with small attenuation, while open screens have huge attenuation. Despite high attenuation, signal processing shows that the velocity of the fast tube wave signal is greatly reduced in open screens. Conversely, decreased velocities and large attenuation of the fast tube wave characterize open screens.

Relatively large differences between signatures of plugged and open screens suggest that it is possible to distinguish levels of partial plugging or intermediate permeability of sand screens.

Acoustic data can be easily interpreted by visual inspection. When the source is in the plugged section, there is a fast tube wave velocity of ~ 1,000 m/s (3,281 ft/s) and little attenuation. Highly permeable open screen reduces this velocity to ~ 600 m/s (1,968 ft/s) and leads to extremely high attenuation.

Detecting flowing perforations with passive permanent system

While active surveillance represents the main task, a permanent non-intrusive system opens opportunities for passive measurements.

In a test designed to detect flow perforations using passive acoustic data, 48 perforations connected to the water line via a manifold. The water line was chosen to simulate a static flow through the perforations. Water was injected equally through all perforations inside the completed well to simulate reservoir production.

Flowing perforations generate very low-frequency "noise" of about 0-50 Hz. For a single perforation, this noise has a structure of ridges with peaks at the perforation. Where there are multiple perforations, ridges merge into plateaus.

Gysling et al (2005) describe similar "convective ridges" resulting from acoustic noise from vortices induced by turbulent fluid flow in pipes. They suggest that those vortices create coherent acoustic disturbances that can be tracked at a distance of about two pipe diameters. Acoustic sensors with fine spacing (~2/5 of the pipe diameter) track these signals and allow fluid flow velocity inside the pipe to be estimated.

It is likely that large sensor spacing leads to severe aliasing and precludes estimating such small flow velocity. Despite that, the nature of observed ridges is similar to those described for flow in the pipes. Presence of gravel sand is likely to modify considerably both flow conditions and behavior of vortices. These effects should be the subject of future studies with substantially smaller sensor spacing.

If only flow location is of interest, the same data can be analyzed in a simpler fashion following ideas of "noise logging." Increased flow rate is accompanied by increased noise strength.

Both noise logging and acoustic flow-metering approaches can likely be applied to identify flowing perforations, fluid velocities, and ultimately flow rates. Further work is needed to quantify more precisely what type of information can be extracted from these signals in realistic multiphase flows from the reservoir into gravel-packed completions.

Path to deployment

Experiment results suggest completion impairment and other processes can be monitored using acoustic data. In the short term, the best chance to apply this technology is to use wireline acoustic logging.

The disadvantage of the production logging approach is that it is not a real-time 4-D measurement. It requires downhole access and possible well shut-in. These concerns could preclude applications in subsea wells and other wells with high intervention costs. In addition, repeatability between time-lapse logging runs could be an issue.

The longer-term solution is a permanent downhole system that can be achieved using fiber-optic sensors and a passive noise source. A permanent system is desirable, first and foremost, because of limited downhole access, especially in complex deepwater or subsea wells.

A permanent system has advantages over the wireline option:

• It provides real-time information;

• There is no well shut-in required;

• It allows gravel packing and other technological processes to be monitored; and

• It enables passive measurements characterizing flow, open and closed perforations, cross-flow, and sand production.

While developing a permanent system appears insurmountable at first, the fact is that downhole tools that have fiber wrapped around downhole tubulars are already under development. For example, a real-time casing imager, or RTCI (Childers et al), is expected to monitor sand screen deformation in complex deepwater wells as a means to assess compaction. RTCI requires fiber helically wrapped around the entire screen. This technology is addressing challenges related to downhole placement and connection of the fiber.

If an RTCI is deployed, the acoustic system has an even easier ride, especially since it only needs point sensors that can be deployed at predetermined locations in the most protected place (i.e., on the outside of the base pipe).

Outlook

Just as 4-D seismic revolutionized the ability to manage reservoir production, real-time completion monitoring has the potential to revolutionize the ability to manage deepwater wells by understanding evolution of flow, drawdown, and impairment in real time.

Further progress could be achieved by performing field trials with available acoustic logging tools run inside sand screens. In 4-D seismic, various fluid flow scenarios are used to predict seismic response, then benchmarked against real measurement. Similarly, RTCM would require the ability to take possible production technology scenarios, predict their acoustic signatures, and benchmark them against actual downhole measurement.

While quantitative inversions may or may not be achievable, such closing-the-loop methodology of 4-D seismic proved of superior value to reservoir management. Acoustic in-well monitoring following this same methodology would lead to substantial progress in managing deepwater wells.