SUMMARY

A new emerging technology is the Distributed Acoustic Sensing (DAS) or Distributed Vibration Sensing (DVS) whose principle is to use the optical fiber as a sensor to measure the acoustic field every meter over the entire length of the fiber. The Rousse-1 well located south-west of France, currently an injector well for a CO2 storage pilot and equipped with a fiber for optical P/T gauges, was selected for a DVS field trial, simultaneously with a micro-seismic calibration campaign. Although the fiber was clamped on tubing, compressional direct arrivals could be detected down to 4 km depth, with source-wellhead distances ranging from the wellhead to 2 km. The optical fiber could become the next generation technology for cost-effective, complete coverage of reservoir monitoring and there is significant scope for further improvement in both operational and data quality.
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Introduction

The fiber-optic technologies evolved substantially since the early 90’s, as illustrated by the development of Distributed Temperature Sensing (DTS) (Brown 2005). A new technology has emerged recently and is known as Distributed Acoustic Sensing (DAS) or Distributed Vibration Sensing (DVS). The principle is to use the optical fiber as a sensor to measure the acoustic field every meter over the entire well length with a wide range of applications including reservoir surveillance, production monitoring, completion integrity, leak detection (Mullens 2010). Most recently DAS was implemented for recording borehole seismic from surface sources (Mestayer et al. 2011). Compared to conventional acquisition with a geophone array, this distributed measurement technology for seismic exploration/monitoring can be advantageous because it:

- Provides a live dynamic acoustic profile all along the well (up to every 1m),
- Limits operational risks due to single trip deployment,
- And records/repeats large VSP (Vertical Seismic Profile) surveys in a fast/efficient manner (rig time savings) because multi-level passes are no longer required.

The present paper describes how DAS was successfully applied for seismic measurement in an active well with an existing cable clamped on the tubing and initially used for pressure/temperature monitoring.

The DVS/DAS Technology

DAS records all along an optical fiber the acoustic signal like DTS does for temperature. It works by the principle of Coherent Rayleigh Noise Optical Time Domain Reflectometry (CRN OTDR), which involves launching short pulses of highly coherent light into the fiber, and analyzing the backscattered light, due to glass heterogeneities. The time that the light takes to return is proportional to the distance it traveled. Vibro-acoustic disturbances alter, on a microscopic level, scattering zones within the glass of fiber, that results in a modification of the backscattered signal. This waveform can be analyzed for changes in amplitude or phase (or both, in the case of the advanced hDVS system used in the present trial). These time-dependent changes can be converted to a signal representative of a vibration wave impinging on the fiber that causes local variations in strain.

Figure 1 Light backscattering
The hDVS Field Test on Rousse-1

The objectives of the CO2 injection Pilot on Rousse field are to show the industrial feasibility of a complete chain of CO2 capture, transportation, injection and storage in a suitable geological object, and to validate the monitoring technologies of the whole chain. The site is located southwest of France, in the Rousse gas field close to Pau (Figure 2). The injection is done through an old producer well Rousse-1, drilled over thirty years ago into the depleted dolomite reservoir “Mano” between 4500m and 4800m depth. Aiming to monitor the structure integrity of the reservoir, the well is equipped with 4 optical P/T gauges connected to surface via an optical fiber behind tubing. A micro-seismic network completes the injection monitoring and consists of 7 subsurface arrays (4 triaxial sensors) in shallow wells on a 2km radius around the injection well (Figure 3).

In order to accurately localize the micro-seismic events a velocity model from the monitored region is required. On Rousse, a P and S wave velocity log is available on a downhole part of the injection well and a wireline thru-tubing seismic survey provided limited results. A calibration seismic campaign was planned to measure propagation velocities between the subsurface antennas and the downhole permanent sensors, close to the injection zone, by recording shot positions near the subsurface antennas (7 antennas). This consists in theory of 7 shots by 3 downhole sensors, i.e. 21 P and S-wave arrivals transit times and hodogram analysis to constrain the velocity model. This multi-offset seismic campaign provided the opportunity for running a Distributed Vibration Sensing (hDVS) field test since optical fiber is available in the completion.

Figure 3 Rousse-1 well completion (left) and microseismic network map (right)

The objectives of the hDVS test were: a) to evaluate whether the hDVS technology was able to detect the seismic waves with offsets more than 2 km from the well, down to a maximum depth of 4.4 km and b) to assess the hDVS data quality, for additional velocity information and waveform processing. The field trial to record seismic waves with a fiber clamped behind production tubing was a challenge and success was not guaranteed.
Field Test Results

The data were sampled continuously for the entire depth of the well and data analysis was performed. At zero offset, first results show that a single sweep surprisingly allows covering the entire well (Figure 4). Direct wave, casing ringing and tube wave can be identified, but first arrivals are not visible in the deepest section of the well. Further analysis showed that the noise level increases significantly with depth and below 3.5 km the signal falls below the noise level. The signal to noise ratio was slightly improved after stacking 20 individual sweeps and a velocity trend could be extracted from surface to TD of the well which is in good agreement with the geological model. First arrivals are recorded and can be picked in shallow sections behind tubing and three casings. The hDVS velocity profile was also used for micro-seismic model validation. For mid and far offsets (Figure 5), P-wave arrivals are observed over most of the well depth but a region of a few hundred

![Figure 4](image_url)

*Figure 4* Rousse-1 well completion (left), Single sweep record at well head location (middle) and derived velocity profile after 20 sweep stacking (right)
meters near the surface is obscured by surface noise and, for the largest offsets, the lowest few hundred meters are noisy. Reflected waves are also visible at depths where strong impedance contrasts occur such as Base Tertiary but data quality does not allow to proceed with waveform processing. The late event in shallow depths is interpreted to be a converted shear-wave travelling near surface.

Conclusions

This field trial demonstrated that hDVS can be used as a tool for recording downhole seismic from active surface sources even with an optical cable clamped along a production tubing. Since velocity model accuracy impacts micro-seismic event localization, collecting seismic velocity data over the entire well depth range is essential for:

- Acquiring additional transit times for velocity inversion,
- Including a wide range of incidence angles to better constrain the inversion.

In addition, when a single mode optical fiber is available in the completion, using hDVS for recording surface sources can be simpler than conventional geophone acquisition. Hundreds of measurements with a single shot can improve model calibration information compared to standard calibration shots. There is significant scope for improvement in both operational and data quality with high potential for borehole seismic applications.

From this VSP application, hDVS technology could deliver a breakthrough in distributed vibration/acoustic sensing and be the next generation technology for cost-effective, complete coverage monitoring from the exploration geophysicist to the reservoir engineer.
Acknowledgements

The authors would like to thank TOTAL E&P France for their contribution and permission to publish this work.

References


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