A DAS VSP Pilot Survey for 3D Imaging and 4D Monitoring at the Culzean Field, UKCS

Introduction

The Culzean field, located in Block 22/25a in the UK Central North Sea, produces gas condensate from High Pressure, High Temperature (HPHT) Triassic reservoirs located at a depth of approximately 18000 feet. The field was discovered in 2008, and production commenced in the summer of 2019 through three production wells tied back to the Culzean Well Head Platform. Production from the Culzean field is expected to result in substantial pressure loss within the reservoir. In nearby analogue fields (e.g. Elgin, Franklin), this pressure loss has resulted in stress-arching and movement within the overburden. It can therefore be expected that similar behaviour will occur at Culzean and monitoring of overburden movement is key to maintaining safe operations.

It was recognised that monitoring of overburden changes could be achieved at Culzean by acquiring Vertical Seismic Profiles (VSP) using fibre optic cables, which were to be installed in each well to convey information from downhole pressure and temperature gauges, as seismic receivers. The method, known as Distributed Acoustic Sensing (DAS), offers the opportunity to acquire frequent, low cost, 4D monitor surveys. Wang et al. have demonstrated that DAS surveys of this type can be used to complement 4D surface seismic data to provide frequent overburden monitoring. However, Saxton et al. have shown that a key limitation to the effectiveness of DAS VSP surveys is noise generated by production flow within the well, which severely degrades the seismic data quality.

At the outset of the project, it was identified that understanding of this noise was key to the successful application of DAS VSP survey for 4D monitoring at Culzean. During spring 2019, a pilot DAS VSP survey programme was acquired at Culzean prior to the wells entering production. The survey was designed to provide 4D baseline measurements, data for 3D imaging and a rich dataset that could be used to assess data quality using the DAS method at Culzean for various acquisition geometries, and whether 4D monitoring would be feasible using this method.

This paper details the rationale and objectives behind the baseline survey, the design of the survey, along with an overview of the operations and key findings of the initial results.

Culzean DAS VSP Survey Objectives

The Culzean DAS VSP survey was to provide data to act as a baseline for future 4D surveys and provide a 3D VSP to aid with well planning whilst also investigating methodologies for removing noise generated by production flow. Several key objectives were identified at the survey planning stage:

1. The Survey was to be acquired safely, and without incident.
2. The survey was to be recorded prior to well start-up in three wells (C2, C4 and C6) to provide a baseline dataset without production noise. Initial evaluation of data recorded by the method would be made on the cleanest possible data, and this data would provide a benchmark for analysis of data recorded with noise.
3. The Survey should be fully repeatable to enable 4D monitoring.
4. The survey was to be acquired with a small seismic source deployed from a vessel which could hold position using Dynamic Positioning (DP). This would allow multiple shots to be fired at each station and allow close approach to the platform complex. Deploying in this manner would control cost and offer fast mobilisation for future surveys.
5. The programme would include acquisition of walk-above surveys that match conventional wireline VSP surveys previously acquired in each well (Jones et al) to provide a comparison of the methods. The walk-above surveys are expected to be the prime 4D monitoring tool.
6. The survey would encompass multiple survey designs that could be used for future subsurface imaging and 4D monitoring. These would include well-specific fixed offset, walk-above and walkaway surveys, together with a 3D survey recorded simultaneously into multiple wells.
7. A repeat survey would be acquired of one element of the programme to assess geometrical repeatability for the acquisition, it’s effect on 4D data quality, to determine expected resolution of 4D signals and quantify requirements for future acquisition.
8. Each part of the programme should be acquired with an abundance of shots to allow evaluation of the impact of shot stacking on data quality, with and without production noise.
9. A measurement of production related noise was to be undertaken once the wells were on production. The noise records would then be added to the noise-free data to assess the degradation in data quality, should future surveys be acquired with the wells on production.

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| 1. | Fixed offset survey above C2 well.  
|    | i. 200 Shots acquired  
| 2. | Walk-above surveys of C2, C4 and C6 wells  
|    | i. Replicating previous VSP surveys  
|    | ii. Station interval 5m. 12 shots per station.  
| 3. | Repeat walk-above survey of C2 well  
| 4. | Walkaway survey of C2 well. 50m shot interval  
| 5. | 3D survey - 8 x 9km.  
|    | Shot grid 100 x 50m |

**Figure 1 - Culzean DAS Baseline Survey Programme**

The final Culzean DAS VSP programme is presented in **Figure 1**. The survey was acquired using a 1000 cubic inch seismic source deployed from a locally sourced DP class vessel. All phases of the programme were successfully acquired without incident, with a total of over 20,000 shots recorded simultaneously in three wells throughout the programme. The survey provides a rich dataset to evaluate the DAS method and applicability for 4D monitoring at Culzean.

**Survey Results**

The first shot of the survey (**Figure 2**), acquired during a fixed offset survey, immediately showed that the DAS method provides high quality VSP data in non-flowing wells. The data shows up- and down-going arrivals with high signal strength compared to the background noise. The record displays a complete VSP from surface to the downhole termination of the fibre, acquired with a single shot. The ability of the system to acquire a large depth range for each shot is a distinct advantage over conventional, wireline VSP operations which require shots for each tool level. The record also highlights noise features observed in similar surveys; noise in the shallow data due to activity on the platform, and occasional noise on groups of channels throughout the well that are interpreted to be due to casing imperfections.

**Figure 2 – Shot display from fixed offset above C2 well.**
The shot record shows an abrupt loss of signal with depth as the well penetrates the top of the chalk package due to transmission loss of the seismic energy at the top of the chalk package. This affect can be observed in all shots acquired, irrespective of location with respect to fibre. Processing of the walk-above data has shown that, without production noise, the DAS method results in data that is comparable to conventional VSP data. Figure 3 displays a comparison between the along well bore section of the C2 well for the conventional VSP and DAS VSP data overlain on surface seismic data. The results show similar responses at the major reflectors and similar amplitude responses. Bandwidth is higher with conventional VSP acquisition, with the DAS section being noisier. This is attributed to the impact of the casing noise recorded during the DAS survey.

![Figure 3](image)

**Figure 3** – Vertical incidence VSP sections from the C2 well for conventional (left) and DAS (right) VSP surveys. Sections clearly demonstrate equivalent data quality between the two methods.

### Noise records

Noise records were recorded in each well once production flow was fully established, some months after the baseline survey was completed. The records were taken in each well using the same recording system settings as used during the baseline survey. This allows the noise records to be summed with the noise free data to simulate data that would be recorded in producing wells.

![Figure 4](image)

**Figure 4** – Impact of production noise in C4 well. Figure shows walk-above shot acquired pre-production (left), noise record taken with production flow (centre) and the two records summed (right).
Figure 4 shows a single shot record from the C4 well with and without production noise. Three panels are shown; the initial, noise-free shot, the recording of the noise during production, and the combined data. The impact of production noise is observed to be severe. Strong down-going first arrival energy can, however, be identified through the noise for a portion of the well. The strong energy allows good quality transit times to be extracted from the data, even with noise present. The first arrival times are a key part of the 4D monitoring strategy, as any changes to the overburden will result in seismic velocity changes, which will alter the first arrival times in subsequent surveys. Changes to first arrival times can therefore be analysed in a 4D sense to determine overburden changes at Culzean. However, down-going energy from the shallow part of the well, where rig activity results in noisier records, and the deep part of the well, where the primary signal is dimmed on the noise-free records, are difficult to identify and good quality arrival times are more difficult to pick. Up-going energy is not visually identifiable within the record, which may limit the DAS VSP technique for use in seismic imaging once production noise is established.

Conclusions

The Culzean DAS VSP pilot survey was successfully acquired to meet all objectives laid out in the survey planning. The survey acquired without incident a rich, repeatable dataset using a low-cost methodology that can be used to fully evaluate the applicability of the DAS VSP method for 4D monitoring both at Culzean and for other fields. Acquisition of data prior to production has shown that, given noise-free conditions, the DAS VSP method can deliver data with a comparable quality to conventionally acquired VSP data. Processing of the baseline survey has revealed that quality final products can be delivered from a variety of survey geometries. Records acquired during production clearly show that the noise associated with hydrocarbon flow is substantial, and the key limitation to the use of the DAS VSP method at Culzean. However, early analysis has also shown that first arrival times can be picked from data acquired with production noise in portions of the well, and this could form the basis of 4D monitoring. Analysis of the data is ongoing, but solutions to mitigate against production noise, either from processing or acquisition, are required to unlock the full potential of the method. However, the Culzean baseline programme has provided a rich dataset that will be used to analyse and optimise DAS VSP data and derive improved solutions in both acquisition and processing for future surveys.

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References

