REAL-TIME AND CLOUD-BASED FIBER OPTIC MONITORING FOR ELECTRIC SUBMERSIBLE PUMPS AND GAS LIFT SYSTEM PERFORMANCE OPTIMIZATION

H. Izadi, A. Moore, M. Rampurawala, A. Andriianov, Chandler Frost, D. Keough, M. Sollid, M. Melnychuk

Precise Downhole Solutions

ABSTRACT

Distributed Acoustic Sensing (DAS) provides unparalleled insights into the operation and performance of Electric Submersible Pumps (ESPs) and Gas Lift (GL) systems in oil and gas wells. Our real-time Artificial Intelligence (AI)-based DAS interpretation and visualization platform, leverages real-time DAS phase data analysis to enable continuous tracking of downhole facilities. This capability not only enhances real-time monitoring but also supports production rate optimization, aligning pump and GL performance, and GL mandrels leak detection with production goals.

In GL operations, our platform transforms the way operators monitor and optimize injection processes. The platform provides precise tracking of gas injection, detecting variations that could lead to inefficiencies such as improper gas allocation or flow instability. The platform will also detect any leaks in the GL system, helping to identify any potential holes in the tubing or any issues with the gas lift valve stations. This innovative approach significantly enhances the understanding of ESP performance and efficiency, enabling early identification of anomalies that could lead to operational inefficiencies or failures.

The real-time feedback loop between DAS data and production metrics empowers operators to make informed decisions that dynamically tune the performance of both systems in response to changing reservoir conditions. The proposed system in this paper could be used in wells with several GL vales installed to detect mandrels leakages.

The integration of DAS with Our real-time AI-based DAS interpretation and visualization platform represents a significant leap forward in intelligent well monitoring. This technology offers a comprehensive framework for real-time diagnostics, dynamic optimization, and long-term performance improvement. By providing deeper visibility into subsurface operations, it enables operators to transition from reactive to proactive management of downhole facilities, delivering transformative benefits in operational reliability, production enhancement, and cost efficiency.

INTRODUCTION

The exploration of optical fibre sensing began in the 1970s, with researchers leveraging fibre technology to detect acoustic point-strain [1]. Around the same time, advancements in geodesy saw the integration of long-baseline optical interferometry using evacuated tubes [2]. The transition to an optical fibre light path for measuring long-baseline strain simplified interferometer construction, enhancing precision and practicality [3]. By the

1990s, optical fibre sensing had evolved beyond its initial applications, transforming pressure and temperature measurements. Traditional single-point sensors were gradually replaced by more sophisticated optical fibre systems, which found widespread adoption in the Oil and Gas industry. These systems fall into three categories: Point Sensors (PS), which capture pressure and temperature data at the fibre's endpoint; Quasi-Distributed Sensors (QDS), designed with multiple sensing points along the fibre to measure strain and temperature; and Distributed Sensors (DS), which utilize the entire fibre as a continuous sensing medium. The ability of a single optical fibre to replace multiple conventional sensors allows for a more efficient and comprehensive approach to monitoring pressure, temperature, strain, and acoustics [4].

At the core of fibre-optic sensing lies the principle of light backscattering, where light interacts with the internal structure of the fibre. Three primary forms of backscattering, Rayleigh, Brillouin, and Raman, serve as the foundation for different sensing techniques [5], as illustrated in Fig. 1. These interactions are classified into two categories: elastic and inelastic scattering. Rayleigh scattering falls into the elastic category, occurring due to microscopic irregularities in the fibre, which redirect light without altering its frequency. In contrast, Brillouin and Raman scattering are inelastic processes, where the backscattered light undergoes frequency shifts, producing Stokes (downshifted) and anti-Stokes (upshifted) components [6].

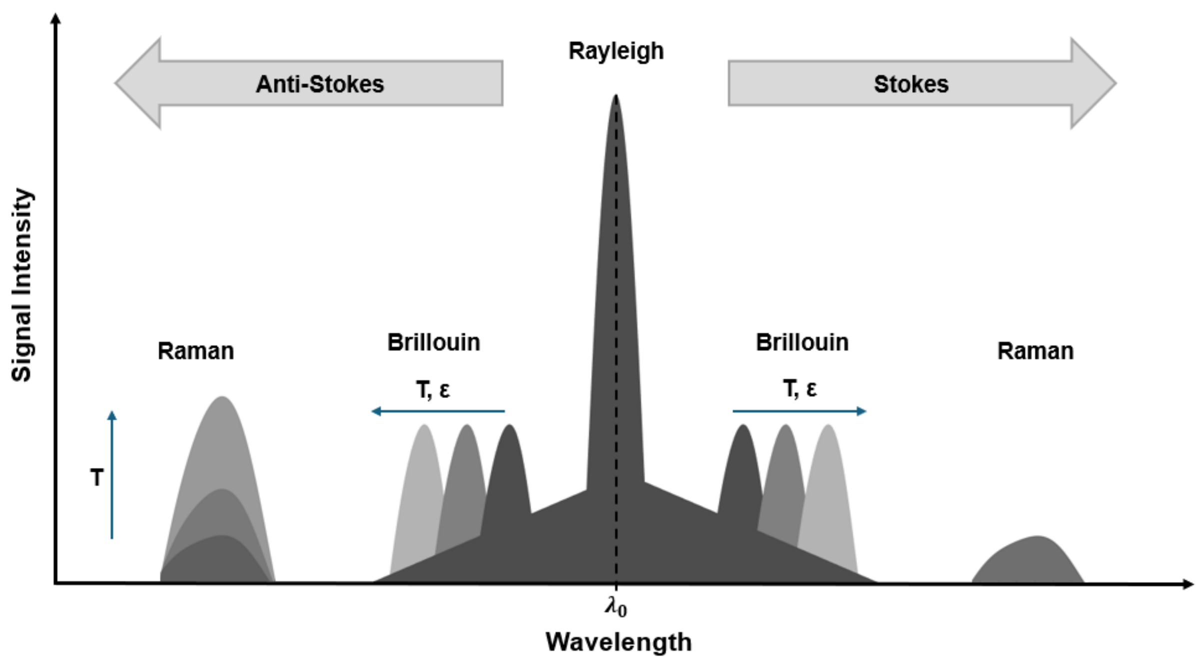

Figure 1 - Three types of scattering in fiber optic cables (redrawn and adapted from [6]).

Among the three backscattering mechanisms, Rayleigh scattering produces the most intense signal, followed by Brillouin and Raman scattering. These scattering principles form the basis of Distributed Fibre-Optic Sensing, which enables three key applications: Distributed Temperature Sensing (DTS), Distributed Strain Sensing (DSS), and Distributed Acoustic Sensing (DAS).

Each application leverages a specific backscattering effect to extract valuable data. DTS relies on Raman backscatter to measure temperature variations along the fibre [8]. DSS is designed to detect absolute strain levels, making it ideal for monitoring both static and quasi-static strain conditions [9]. Meanwhile, DAS utilizes Rayleigh backscatter to capture acoustic signals and detect dynamic strain fluctuations [10]. These distributed sensing technologies have significantly expanded the capabilities of fibre-optic monitoring, providing continuous, real-time insights across various industrial applications.

In this paper, we utilize DAS to assess the efficiency of downhole instrumentation, specifically focusing on Electric Submersible Pumps (ESPs) and Gas Lift (GL) systems. Our platform enables continuous, real-time monitoring of these artificial lift mechanisms, offering valuable insights into their operational performance and potential inefficiencies.

To the best of our knowledge, as of the time of writing this paper, there is no existing technology in the industry capable of providing a comparable level of distributed real-time, monitoring for downhole ESPs and GL systems. Traditional monitoring approaches rely on localized sensors, which offer only discrete data points and limited visibility into system behavior. In contrast, DAS transforms the entire optical fibre into a dense array of virtual sensors, capturing acoustic signatures along the wellbore. This advancement presents a novel opportunity to enhance diagnostics, optimize lift performance, and improve overall well efficiency.

REAL-TIME AND AI-BASED DAS PLATFORM

Acoustic disturbance logging using DAS technology and its widespread use has been limited by inefficiencies, particularly in the transfer and processing of DAS data, which can take several weeks. DAS systems generate massive volumes of data, typically producing several gigabytes per minute during standard logging sessions, which usually last at least 12 hours per well. As a result, transferring and processing this data creates a cumbersome, time-consuming task.

The current industry methodology involves three primary steps: (1) collecting vast amounts of data, often reaching terabytes per day, (2) transferring this data to a target system, and (3) processing specific segments of the collected data. This approach is not only labor-intensive and time-consuming but also suffers from delays, with analysis typically occurring weeks after the monitoring. This delay reduces the accuracy and reliability of detecting and predicting well conditions, as the analysis may no longer reflect the current state of the well.

To address these challenges, we have proposed a groundbreaking transformation of this process by developing an algorithm that enables real-time data processing and visualization. This project aims to enhance capabilities in (1) live data transfer, (2) real-time processing, (3) dynamic visualization, and (4) immediate interpretation, marking a significant technological innovation. The advancements introduced by this project have not been addressed in the existing literature.

Key features of our developed platform include:

- **Data Compression:** Our platform is designed to efficiently read Hierarchical Data Format version 5 (HDF5) files and compress DAS data by a factor of up to 500. This compression optimizes storage and enhances data access efficiency.
- **Real-Time Visualization:** The platform provides live visualization capabilities, allowing operators to monitor well conditions and gas leaks in real-time. DAS response maps are updated every 2 seconds, providing a comprehensive overview of the well's status.
- **Cloud-Based Solutions:** Analysis results are encrypted and stored in the cloud, ensuring secure remote access for operators. This cloud-based framework facilitates seamless monitoring and management of well conditions and gas leaks from any location.

CASESTUDY#1

This case study focuses on a Steam-Assisted Gravity Drainage (SAGD) well equipped with a GL system extending over a depth of 634 meters (Fig. 2). The primary objective of the project was inflow profiling, aimed at providing detailed insights into the production profile along the horizontal section of the well.

In the specific case here, the study monitored the performance and behavior of the GL system across various operational phases, including the initial steady-state flowing period, a shut-in phase, and the subsequent ramp-up phase. The monitoring process successfully captured critical signatures and dynamic responses of the GL system, offering valuable insights into its functionality under different well conditions. This analysis enhances the understanding of gas lift operations in SAGD wells and contributes to improved optimization strategies for production efficiency and reservoir management.

Figure 2 presents the full-spectrum visualization of the logging data, offering a comprehensive view of the well's acoustic response. In this visualization, the impact of the GL system has been masked by the presence of emulsion inflowing into the well. This masking effect makes it challenging to directly isolate and identify the contribution of the GL system in the raw full-spectrum data.

During the shut-in period, the GL system was turned off. However, within the full-spectrum visualization, distinguishing whether the GL system is inactive is not straightforward. This limitation arises because full-spectrum analysis captures a broad range of signals, including background noise and fluid movement, which can obscure specific operational states of the GL system.

To overcome this challenge, we employ frequency band analysis, which allows us to separate and highlight different physical phenomena occurring within distinct frequency ranges. Figure 3 demonstrates the results of this analysis, specifically focusing on high-frequency components. The absence of movement traces in the high-frequency range during the shut-in period indicates that there is no significant activity related to downhole facilities. This suggests that the GL system was indeed inactive during this phase, confirming its shut-off status. GL impact is visible in the ramp up and steady state flowing periods.

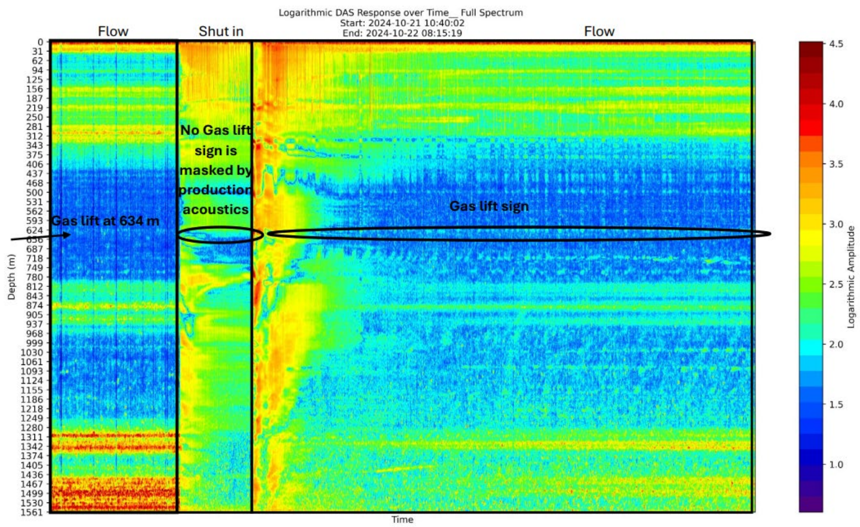

Figure 2 - Full-spectrum visualization for monitoring ESP performance and efficiency.

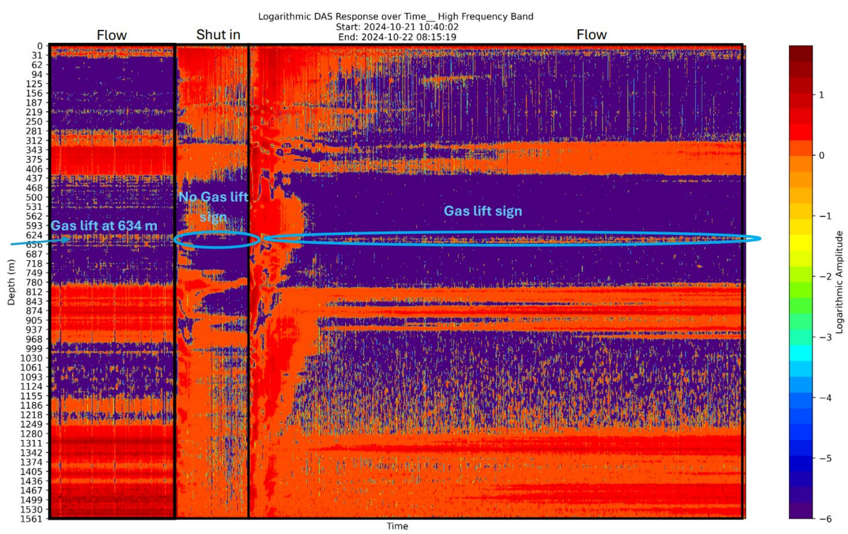

Figure 3 - High frequency band visualization for monitoring ESP performance and efficiency.

Additionally, Izadi et al. (2024) study highlights the capability of our AI-based monitoring system in assessing GL technology in terms of leak detection [11]. Our extensive experience in leak detection for surface casing vent flow (SCVF) applications has demonstrated the effectiveness of our platform in identifying gas leaks within the wellbore. The same methodology and detection principles can be applied to GL mandrels, enabling proactive monitoring to ensure their proper functionality and prevent potential failures.

CASESTUDY#2

Another well, equipped with an ESP, was logged using a DAS unit. Similar to Case Study #1, data was recorded across three operational phases: steady-state flowing, shut-in, and ramp-up flowing (Figs. 4 and 5).

In this case, in opposite of Casestudy#1, the impact of the ESP was not masked in the full-spectrum visualization during the shut-in period (Fig. 4). This was due to specific reservoir and operational limitations in well presented in Casestudy#1.

The ESP's influence was also clearly observed in the high-frequency band range (Fig. 5). Furthermore, reservoir production and depletion effects, which could introduce noise into the DAS responses, were successfully filtered out in the high frequency bands. This filtering process allowed for a clearer and more accurate visualization of ESP performance tracking.

Notably, the operator confirmed that ESP performance was intentionally lowered midway through the ramp-up flowing phase, a change that is distinctly visible in Fig. 5. Additionally, during the initial stage of ramp-up, the ESP operated at a higher power level, contributing more significantly to production. This variation in performance is evident in the DAS data, further validating the system's capability to track real-time ESP efficiency and operational adjustments.

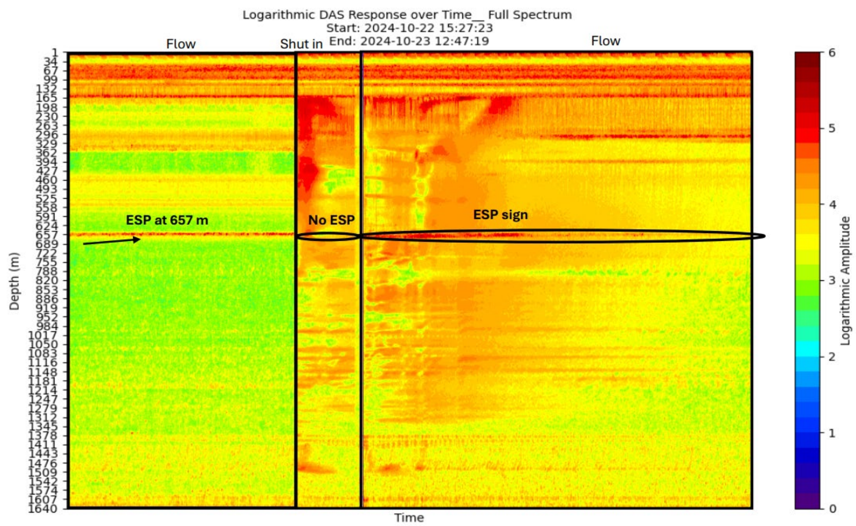

Figure 4 - Full-spectrum visualization for monitoring ESP performance and efficiency.

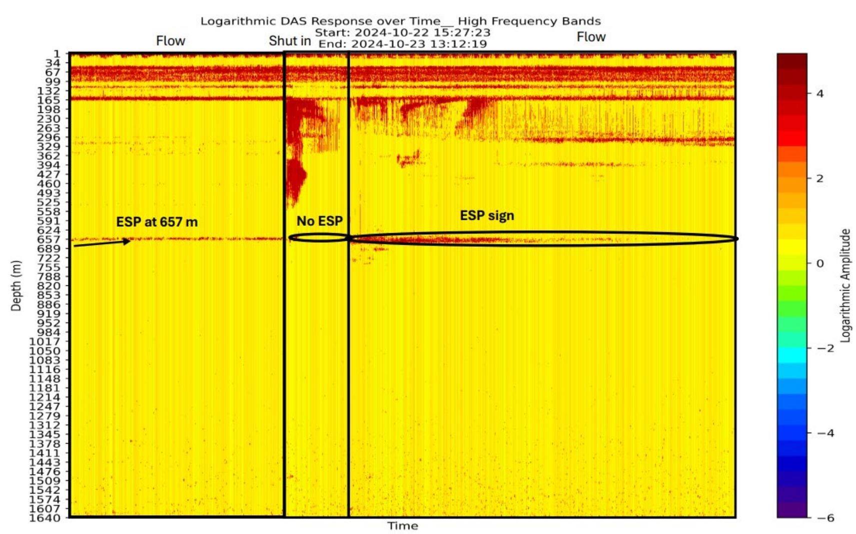

Figure - 5. High frequency band visualization for monitoring ESP performance and efficiency.

CONCLUSIONS

In the evolving landscape of oil and gas production, ensuring the optimal performance of ESPs and GL systems is essential for maintaining well productivity and reducing operational costs. DAS technology provides a cutting-edge solution by capturing and analyzing real-time phase data to monitor the efficiency of ESP and GL systems. With its ability to process and visualize data in real time, DAS enables operators to track system performance, detect inefficiencies, and predict potential failures before they impact operations. By leveraging advanced spectral analysis and cloud-enabled platforms, DAS supports proactive decision-making, ensuring peak performance and reliability across production systems. The conclusion remarks for this study are drawn as follows:

- **Real-Time Performance Tracking**: Extracts frequency-domain information from DAS phase data to accurately monitor ESP and GL system efficiency.
- **Validated Accuracy in Field Applications**: Tests on multiple wells confirm the reliability of DAS for detecting ESP inefficiencies and GL injection variations.
- **Optimized Data Processing for Speed**: Reduces DAS data size from 5 GB to just 300 KB, enabling fast real-time analysis and remote monitoring.
- **Cloud-Enabled Live Insights**: A secure, cloud-based framework ensures immediate storage, processing, and visualization of DAS data for proactive decision-making.
- **Detection of Low-Frequency Anomalies**: Identifies operational changes in ESPs and GLs, including flow instabilities and performance fluctuations, for early issue mitigation.
- **Advanced Spectral Analysis**: Enhances frequency-based diagnostics, isolating key disturbances to improve ESP efficiency tracking and GL optimization.
- **Proactive Decision-Making with AI-Driven Insights:** Real-time data integration enables informed, on-the-fly adjustments and reduces downtime and enhances operational reliability.
- **Industry-Leading Technology:** The only platform offering distributed real-time monitoring of ESPs and GLs that transforms fibre-optic cables into an intelligent sensing network.

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