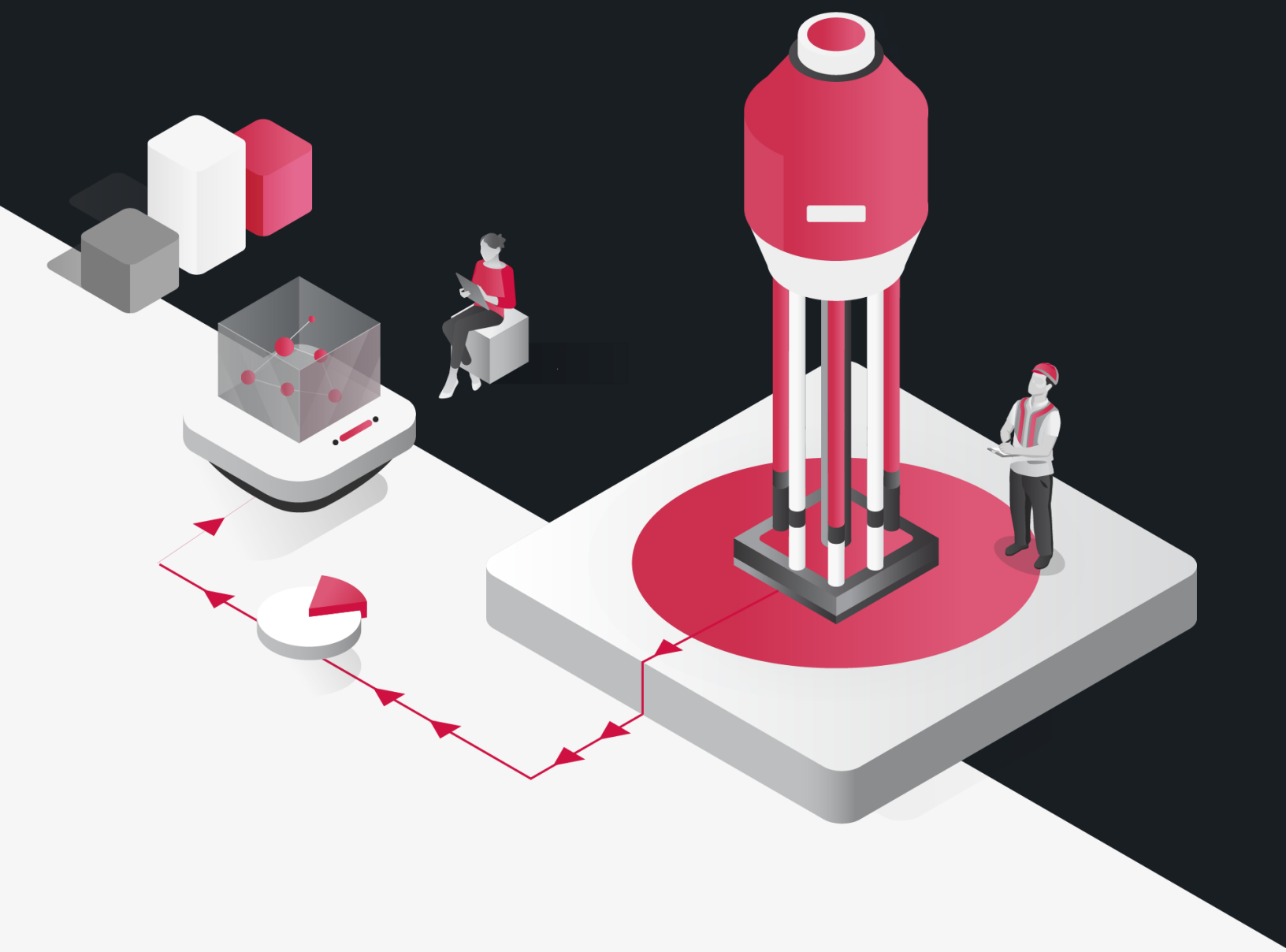

Implementing Improved Recovery Optimization Methods Using The PetroVisor™ Platform

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Whether an operator is striving to meet production quotas in a new asset or managing a mature field with declining production, the challenge can be the same. Oil and gas companies want to optimize production from each well to help attain profitability goals and return on investment. The improved oil recovery optimization solutions native to the PetroVisor platform help operators identify underperforming wells, choose the best secondary oil recovery techniques, optimize artificial lift programs and equipment, check surface facilities health, and maximize uptime.

Improved recovery optimization techniques can be applied to both new and mature fields

Greenfields

- Operational management
- Reservoir understanding
- Surface facility to reservoir tuning
- Monitoring and surveillance

Mature Fields

- Production decline
- Low reservoir pressure
- High water cut
- High gas/oil ratio
- Equipment maintenance and failure

Data Integration and Performance Monitoring

Successful improved recovery optimization programs start with consolidating existing data and implementing systems to acquire and integrate new data.Timely and accurate data—whether historical data from mature fields or new data from green fields is essential. Within the PetroVisor platform a workflow sequence is implemented through fast-loop automation that drives a quick, efficient and repeatable process. As a first step, data is cleansed and conditioned, and features are extracted automatically prior to integration. As new data arrives, scripts are automatically executed within the platform to check conditions and rules before invoking cleansing routines and data validation. Types of data that typically pass through the workflow include sensor outputs, data from SCADA systems, historical data, flat files, maps and simulation results. Translating the raw data into trustworthy KPIs (both business and technical) forms the basis for additional steps in the optimization process.

Next, KPIs are calculated at different entity levels for wells, field or equipment. Production injection data along with parameters such as choke size, wellhead temperature and pressure, yearly target totals and reservoir data are processed through the workflow. Output data includes cumulative rates, water cut, gas/oil ratio, production amounts and diagnostic plots which are used to

1) provide dashboard visualization for daily monitoring,
2) detect production problems
3) identify underperforming wells and
4) rank opportunities for workover intervention.

Screening, Surveillance and Opportunity Ranking

Once data is integrated into the PetroVisor platform, production performance checks are initiated to understand the current well or reservoir situation, and identify problems and reasons for underperforming wells. Included in this process are 1) multiphase rate estimation using virtual flow metering and well tests, 2) production deferments and losses, and 3) anomaly detection using machine learning.

Examples of problems that can be detected include:

- Water problems due to coning or channeling
- Gas related issues
- Technical problems resulting in rapid or unexpected production declines
- Sand production
- Formation damage
- Liquid loading
- Skin buildup
- Identifying underperforming wells
- Problems related to artificial lift equipment
- Flow assurance issues

Identifying underperforming wells starts by checking production history and reviewing the last validated well test. Well tests measure a well's real potential and help validate the well model. Well test validation results form the basis for production grades estimation and back allocation to contributing wells, which is critical information for the production optimization loop. During the validation, data is collected and compared to previous well tests and other criteria such as the minimum test duration or test start and cut off times. Different operators may use varying criteria for validation data. Because of this, the PetroVisor workflow checks each new well test against the operator's rules and defined criteria and compares it with previously validated well tests to determine if the new well test data should be accepted or rejected. Once well test data is accepted and production performance is evaluated, constraints and production limiters can be identified and managed, and optimum parameters can be recommended for equipment operation.

Virtual flow metering (VFM) is used to estimate multiphase flowrates and production volumes from each well. VFM can be performed as a physics-based model (empirical equation), a data-driven machine learning model, or a hybrid model combining both methods. The hybrid model often provides superior results for rate estimation because synthetic data generated during physics-based modeling is used to simulate unseen conditions such as high water cut or gas-to-liquid ratios. A machine learning VFM model trained under these conditions can provide very accurate flow estimates for process conditions and expected future well changes.

Improvement and Optimization

Using the PetroVisor platform helps operators continually optimize their improved oil recovery programs especially when working with large datasets which often require a sizeable team of engineers to analyze manually. Algorithms in the workflows are combined with regulation-based rules such as thresholds, working envelope and violation conditions for quick problem identification and remedial recommendations to situations affecting well performance. Using pattern recognition analysis, common failures can be analyzed over large datasets in fields containing hundreds of wells and perforation intervals.

Problem scores derived from aggregating issues encountered on underperforming wells are used as a final KPI measurement to rank candidates for evaluation. This scoring system combines various inputs such as pressure related signals, offset well location, production volume and injection rates.

Design, Life-Cycle Management and Autonomous Control

When implementing artificial lift and secondary recovery techniques using workflows in the PetroVisor platform, historical well data can be used to forecast problems in advance. This proactive approach helps operators take corrective action and maintain production by ensuring that pumps and equipment are working within the optimum operating envelope.

By tracking actions and measuring the expected impact, events can be forecast before they happen. Workflows are customized for each field according to local infrastructure, data availability, and production volumes. For example, if field design limits flow test frequency (due to the number of wells, production rates or flow meter capacity) VFM can be performed through the PetroVisor workflow to determine production back allocation.

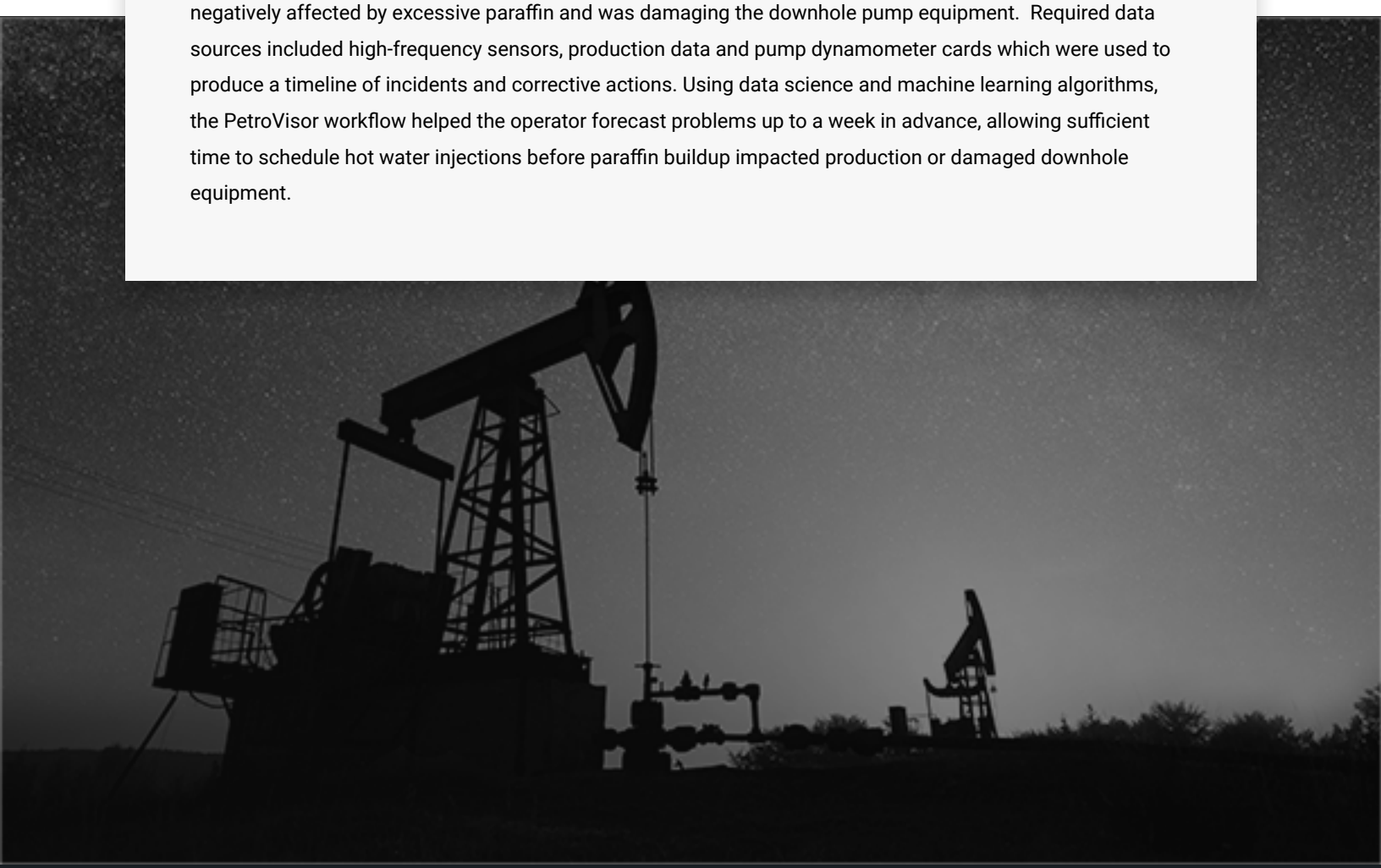
Advisory systems resident in the PetroVisor platform are based on technical and economic calculations, advanced analytics, expert knowledge and standard petroleum engineering methods. Automated workflows can be configured to continuously evaluate wells and identify top opportunities for improvement within a selected risk profile.

Examples of Improved Recovery Optimization Programs In Action

Combating paraffin buildup on sucker rods

Rod pumping is the most common form of artificial lift in North America and rod pumps are a ubiquitous sight on any drive across the United States. Sucker rods connect the surface beam pumping unit to the downhole pump components. While known for low maintenance requirements and long life, sucker rods are subjected to the forces and stress of the reciprocating action and are prone to paraffin buildup that impedes their performance and impacts well production.

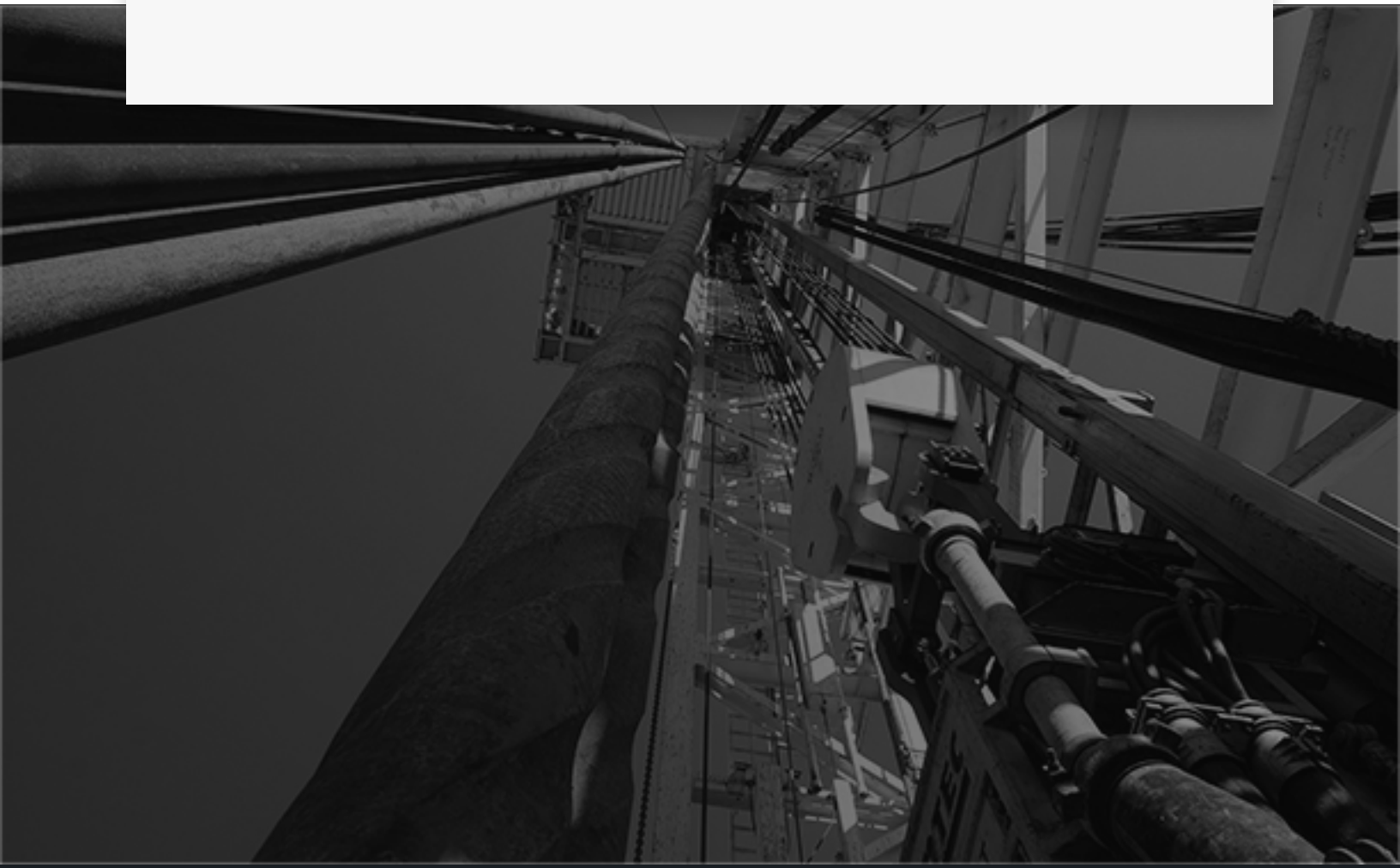
In a mature field where rod pumps were employed as the primary form of artificial lift, well production was negatively affected by excessive paraffin and was damaging the downhole pump equipment. Required data sources included high-frequency sensors, production data and pump dynamometer cards which were used to produce a timeline of incidents and corrective actions. Using data science and machine learning algorithms, the PetroVisor workflow helped the operator forecast problems up to a week in advance, allowing sufficient time to schedule hot water injections before paraffin buildup impacted production or damaged downhole equipment.



Using PetroVisor workflows to boost uptime in Gas Lift operations

Gas lift is a common recovery technique that injects gas into the production tubing to lower the flowing bottomhole pressure which helps push fluids out of the well. Widely used in both onshore and offshore fields, gas lift operations routinely encounter performance difficulties and downtime due to erratic supply of injection gas, poor gas compressor maintenance or inefficient gas injection (depth and rate).

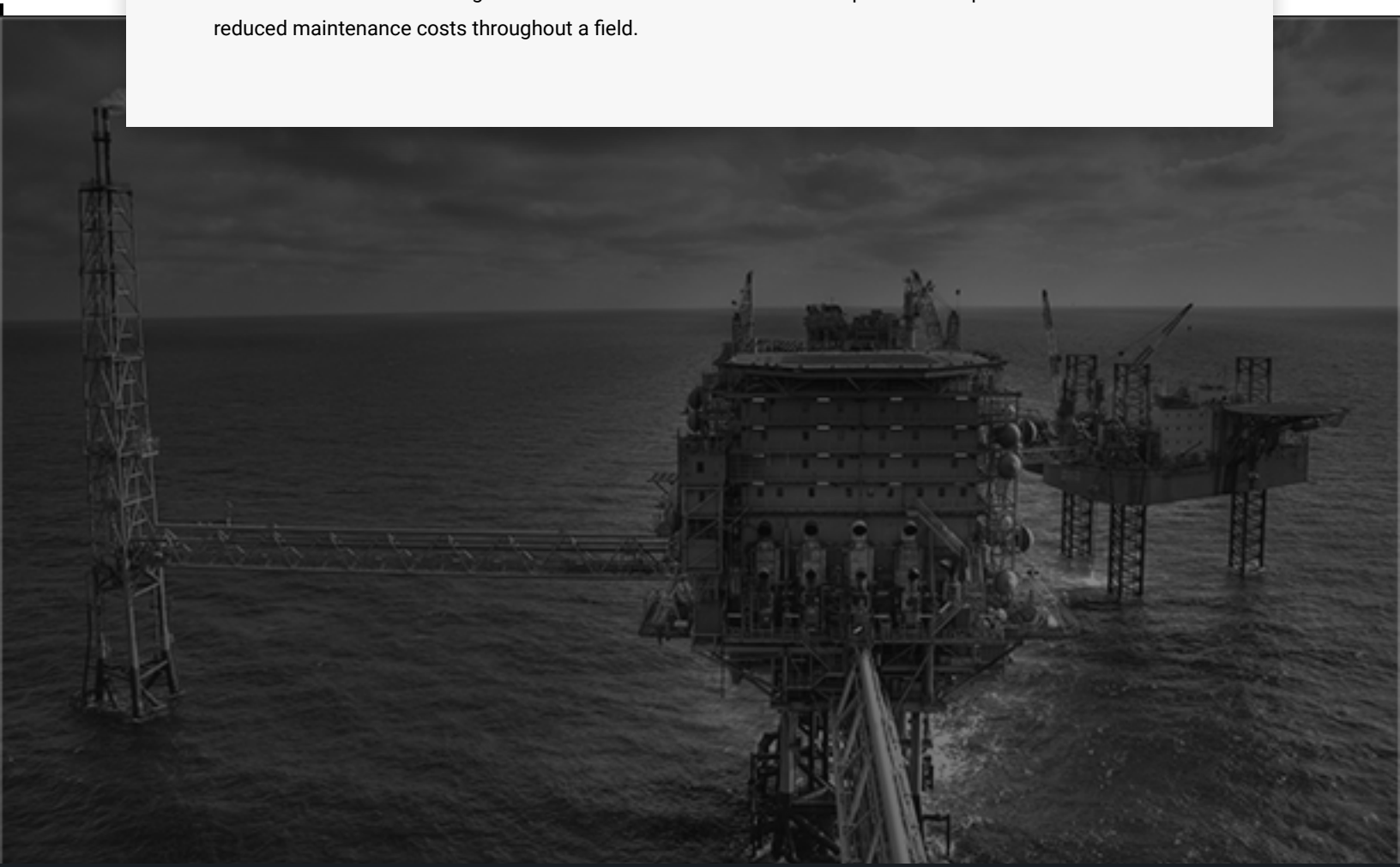
For a field that was experiencing a decline in production, the PetroVisor platform was used to conduct a stability assessment to monitor inflow response and pressure depletion response. By calculating theoretical injection rates on volumetric gas throughput on the orifice and choke, multiple injection issues were detected and corrected from replacing plugged injection valves to modifying the injection pressure. The actions taken helped optimize well output and reversed the production decline.



Reducing Electric Submersible Pump failures in an offshore field

Electric Submersible Pumps (ESPs) are a frequently-used method for maintaining production in high-rate offshore wells. Consisting of an electric motor and multistage centrifugal pump run on a production string, they are connected back to the surface via an electric power cable. While ESPs are applicable in a wide range of well environments, they have a low tolerance for solids, sand and other abrasives which often leads to clogging or excessive wear on bearings and other downhole components.

The PetroVisor platform can be used to help identify impending ESP failures using real-time data, pattern recognition, events detection, problem scores and an aging factor. Pumps that are operating outside of normal limits are flagged through alarms and notifications, and help operators take a proactive approach to ESP maintenance or modify well production parameters to extend pump life. Applying corrective actions recommended through the PetroVisor workflow can result in operational improvements and reduced maintenance costs throughout a field.



Results

Whether producing from a greenfield or mature basin, operators that are faced with declining production can benefit from the improved recovery optimization workflows native to the PetroVisor platform. From back allocation, detecting underperforming wells, optimizing artificial lift programs, or monitoring KPIs across an entire field, this unified platform helps automate business processes, improves collaboration among teams and provides complete data visibility through all operational functions. Methods such as virtual flow metering, pattern recognition and events detection help reduce the risk of underperformance and well failure and forecast well problems. Together, these workflows help customers identify and solve well performance issues that affect production across the field.