Maximizing Reservoir Fluid Insights From Mud Gas and Drill Cuttings

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INTRODUCTION

Reservoir fluid analysis has evolved into a relatively mature discipline after many decades of research and innovation. Various fluid sampling technologies are now available for both downhole and surface samples. Advances in fluid analysis technologies, whether conducted in laboratories or directly downhole, have made data acquisition for reservoir fluid properties relatively straightforward in exploration and appraisal wells. However, fluid analysis methods for development wells remain limited. Techniques such as sampling while drilling and nuclear magnetic resonance (NMR) can yield more accurate reservoir fluid properties compared to traditional petrophysical logs, including density-neutron logs. Nevertheless, the additional cost and operational risks associated with these methods often preclude their use in development wells. Consequently, there is a pressing need for cost-efficient and effective new methods for reservoir fluid analysis in development wells.

ORIGINAL CONCEPTS AND INNOVATIONS

Along with the digitalization in the oil industry, Equinor is at the forefront of innovation by utilizing traditional mud gas data as a novel reservoir fluid data source for estimating fluid properties while drilling (Yang et al., 2019; Arief and Yang, 2020). For the first time, advanced mud gas (AMG) data have been successfully employed to predict valuable reservoir fluid properties, such as gas-oil ratio, saturation pressure, density, and viscosity. The most significant advantage of using mud gas data is its near real-time interpretation, which substantially impacts business by informing real-time well decisions, including geosteering. Figure 1 illustrates the typical workflow for identifying reservoir fluids while drilling using advanced mud gas data.

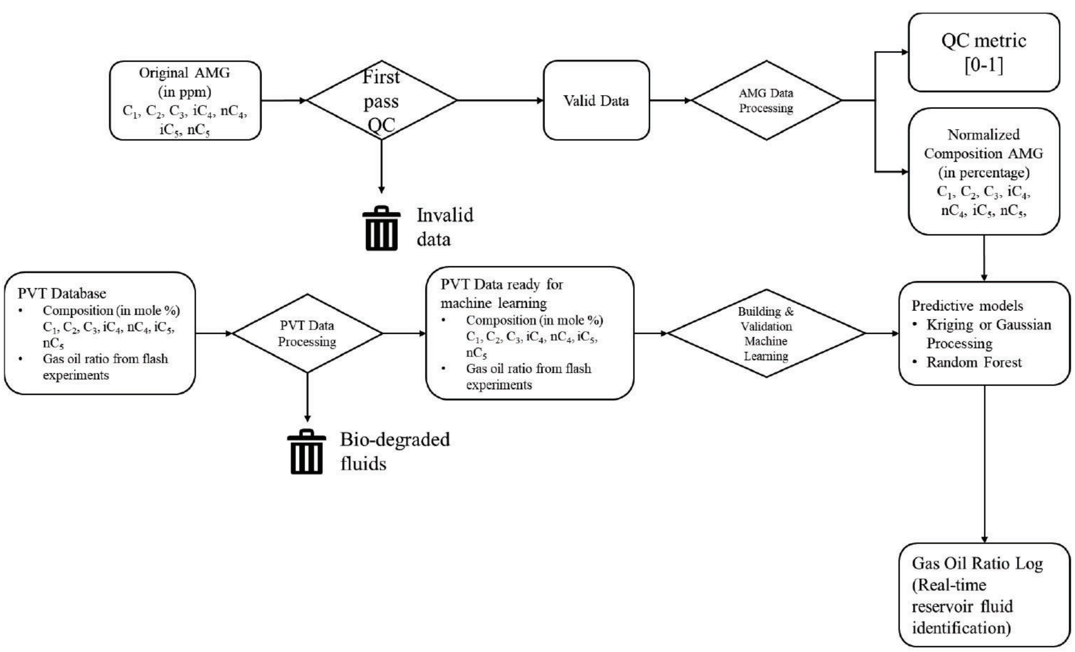

Fig. 1—Real-time fluid identification workflow using a data-driven machine-learning model from the pressure-volume-temperature (PVT) database and advanced mud gas data

Standard mud gas is collected from all wells during drilling and does not require additional data acquisition efforts. Despite the vast availability of mud gas data, its quality is often compromised due to the lack of heating in the degasser, recycling corrections, and extraction efficiency corrections (EEC). However, the application of the pseudo-EEC method, especially for oil-based mud, allows for the confident use of C_1 to C_3 compositions from standard mud gas to predict fluid types (Yang et al., 2022).

Advanced mud gas data offer significantly improved quality, particularly in C_1 to C_5 compositions, making it highly recommended for challenging reservoirs, such as those with volatile oil and gas condensate, due to the high similarity of C_1 to C_3 components between reservoir gas and reservoir oil. The advanced mud gas service, though beneficial, is optional and not always available due to operational constraints. These include space limitations on the rig/platform/drilling site, stringent safety requirements, regional availability of the service, and the time needed for installation.

Drill cuttings are readily available from most wells, making them a valuable resource for reservoir fluid analysis. Geochemical methods, particularly gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS), have been employed to estimate key oil properties such as API gravity and viscosity. However, most studies focus on drill cuttings obtained with water-based mud. Identifying reservoir fluids in highly contaminated drill cuttings from wells using oil-based mud presents a significant challenge. Consequently, there is a strong business demand for methods to predict reservoir fluid properties from drill cuttings in oil-based mud environments.

In the upstream industry, the use of gel permeation chromatography (GPC) coupled with ultraviolet (UV) absorbance detection has been primarily limited to studies on asphaltenes, petroleum fractions, and molecular weight measurements. Recent pioneering studies (e.g., Elias and Gelin, 2015) have demonstrated the capability of the GPC-UV method to predict API gravity from drill-cutting samples with oil-based mud in unconventional reservoirs. A key finding from these studies is the relative insensitivity of the GPC-UV method to oil-based mud, which significantly enhances its utility for broader applications.

This insensitivity opens the door to using drill cuttings as a reliable input for deriving broad reservoir fluid properties. A recent study on the GPC-UV method (Yang et al., 2024) reveals that this method can be applied on a large scale in conventional fields worldwide. The multiple-wavelength GPC-UV isoabsorbance analysis provides a powerful tool for qualitatively identifying fluid types and properties (as indicated by the cover of this issue of *Petrophysics*). When combined with digital analytics, the GPC-UV method holds the potential to transform drill cuttings into effective PVT samples. This capability has significant applications, ranging from well placement to reservoir management, production optimization, flow assurance, and plug and abandonment (P&A) operations.

Lastly, it is crucial to emphasize the importance of utilizing mud gas and drill cuttings for reservoir fluid prediction in the overburden. Large data acquisition programs in the overburden are rare, and typically, no PVT samples are collected. However, for well P&A operations, having a thorough understanding of the subsurface, particularly the flow potential in the overburden, is essential for designing cost-efficient P&A strategies.

With the readily available mud gas logging data and drill cuttings stored from drilling operations, it is now feasible to acquire essential reservoir fluid properties using surface logging data. This approach can significantly enhance subsurface understanding and optimize well P&A designs, ultimately leading to more efficient and cost-effective P&A operations.

BROAD FIELD IMPLEMENTATIONS

At Equinor, reservoir fluid estimation from mud gas and drill cuttings is managed under the Real-time Fluid Identification (RFID) project. Thanks to the integrated nature of this technology and its alignment with business needs, the RFID software plugin solutions have been incorporated into both the company-wide petrophysical software (Geolog) and the real-time drilling platform software. Prior to the development of RFID technology, Equinor deployed advanced mud gas logging on average one well per year, primarily for petroleum system studies on exploration wells. After launching RFID solutions at Equinor, we observed an exponential increase in applications, particularly in development wells. In 2023, the deployment of advanced mud gas logging services expanded significantly, reaching 35 wells.

The Snorre Expansion Project (SEP) utilized RFID technology on five development wells from December 2020 to February 2021. Johanne Grevstad, subsurface manager in SEP, remarked on the value the technology provided during drilling, “We obtained extra information about the fluids and used this to make decisions on the fly. The data can also be used to calibrate and improve our models. The collaboration with the cross-disciplinary group and the supplier, Halliburton, was excellent! I definitely recommend this technology for other wells when there is a special need to understand the fluid type while drilling."

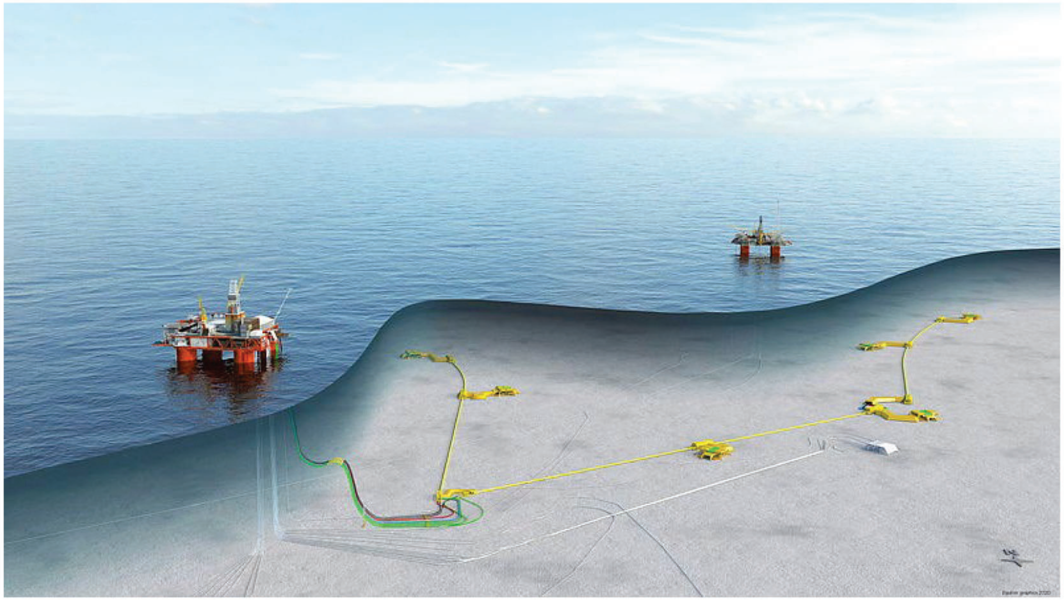

Fig. 2—Snorre Field on the Norwegian Continental Shelf.

Synøve Tevik, vice president of Exploration and Production Norway, highlighted the advantages of RFID, noting, "Making good and quick decisions based on a large reservoir database analyzed for us by the algorithms, and simultaneously while we are drilling, is fantastic. We need to ensure that our development wells deliver to their highest potential, and this tool gives us a significant advantage in achieving that."

Equinor also recognizes the environmental benefits of the technology. Ane Lie Larsen, technology manager in Technology, Digital, and Innovation (TDI), stated, "By obtaining real-time reservoir fluid data, we can adjust and plan the well location to optimize production. This can lead to higher production rates and reduce the need for gas compression, which can also help lower CO_2 emissions from production."

CORE ELEMENTS OF THE SUCCESS STORY

RFID digital innovations have significantly advanced mud-logging services, extending their applications into new business areas like well decision making for development wells and assessing flow potential in the overburden. This breakthrough technology garnered notable recognition when it won Equinor's first Subsurface Digital Challenge in 2017. The achievement is largely credited to the unwavering support from Equinor's TDI management, who convened a robust cross-disciplinary team comprising subsurface, drilling, and wells professionals, as well as data analytics experts, to drive the development of RFID technology.

Traditionally, mud gas data was viewed as noisy and unreliable. However, when integrated with a well-established reservoir fluid database and petrophysical logs, the accuracy and predictability of the mud gas data improved significantly, meeting the standards required for critical well decisions.

Another important factor contributing to this success has been the close collaboration with service providers worldwide. On the digital solution side, Equinor established a long-term partnership with SparkBeyond, whose ideation machine platform provided essential feature insights. Bluware has a long collaboration with the RFID project, spanning from coding the machine-learning algorithms to software plugins. Applied Petroleum Technology (APT), a geochemistry service company based in Oslo, has been a vital partner in developing the GPC-UV method. High-quality mud gas data is essential for the RFID technology, and collaborations with service companies such as SLB, Halliburton, and Baker Hughes, with whom

Equinor has integrated contracts, have been crucial for maintaining data quality for large-scale applications. Independent service providers have also contributed through valuable discussions and knowledge sharing.

RFID's innovation and collaborative success were recognized when Equinor won the Best Data Management and Application Solution Award at the World Oil Awards in 2022. Nicholas John Ashton, vice president for TDI Subsurface, expressed his admiration for the award-winning technology.

"The success story of this innovation exemplifies 'One Subsurface.' The industry is transitioning to low-cost and low-carbon realities. This cross-disciplinary technology not only addresses an industry challenge but also creates significant business value. Congratulations to the team!"

This accolade underscores the impact of digital innovation, cross-disciplinary integration, and strong internal and external collaborations in driving the success of the RFID project.

Fig. 3—The RFID team won a World Oil Award in 2022 for Equinor.

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