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Applications of Geomechanics in Petroleum Reservoirs: A Brief Review

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ABSTRACT

Geomechanics plays an essential role in the drilling and production of petroleum reservoirs beginning with pre-drill well planning and continuing with wellbore stability support while drilling and sand production management. This paper will cover an overview of geomechanics from its fundamental knowledge and geomechanical models to its applications in petroleum reservoirs. Major current applications in this domain include the characterization of rock properties, such as porosity, permeability, and mechanical strength. One important application of geomechanics in petroleum reservoirs is in hydraulic fracturing, a technique used to stimulate the production of oil and gas from unconventional reservoirs such as shale formations. It can also be applied in petroleum reservoirs in wellbore stability analysis. As oil and gas wells are drilled deeper and in more complex formations, the stability of the wellbore becomes increasingly important.

Keywords: Geomechanics, Reservoir, Hydraulic fracturing, Permeability, wellbore stability.

INTRODUCTION

Geomechanics is the science that allows you to study and understand rock behavior under various operations affecting the subsurface environment during the life of an asset. The ability to deploy geomechanics combined with rapid advances in hardware technology allows us to make fast, well-informed decisions that minimize risk while drilling to improve oil recovery and develop fields in a manner that would have been unthinkable 5 to 10 years ago. A new risk-based approach to geomechanics analysis, called 'depth of failure,' is having game-changing results and solving serious problems when constructing horizontal wells in troublesome unconventional shale plays. This approach combines technically sound engineering with drilling and geomechanics integration and provides a solution that is more valuable to the drilling community. This workflow is being implemented to allow complex wells to be drilled successfully, where failure had previously been a high risk (Shannon Higgins-Borchardt, et al, 2015; Pwavodi et al., 2023). Geomechanics has become increasingly important because more and more new projects involve viscous or immobile oils, higher temperatures, pressures and depths, and reservoir materials that are weak, intensely fractured, or highly compressible. When drilling, rock is removed and is replaced with fluids as a means of manmade stability. The type of fluid, its density, or the completion of the wellbore can be carefully selected using geomechanics principles to help avoid kicks, blowouts, stuck pipe, and wellbore instability. For complex Deepwater wells, extended reach wells, and drilling in unconventional plays this is even more critical. These all require a good understanding of geomechanics. Injection and production from oil fields contribute to changes in pore pressure and this, in turn, changes stress. Such changes, unless studied carefully, could contribute to compaction and subsidence problems, fault and fracture reactivation phenomena, loss of fluids through fractures, loss of reservoir seal, and well integrity problems. Major petroleum geomechanics areas of interest include borehole stability, hydraulic fracture stimulation using proppants leading to permeability improvements, sand production management, reservoir stress evolution, subsidence, casing shear, thermal stimulation geomechanics effects, and massive liquid and solid waste injection. Each of these processes involves at least flow stress coupling, many of them THM coupling, and some of them (e.g., shale stability) involve full THMC coupling. Some applications in each of these areas are highlighted, though special emphasis is given to the geomechanical understanding of thermal

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exploitation. (Dusseault, 2011).

METHODOLOGY

Geomechanics plays an important role in the exploration and production of petroleum reservoirs by providing a better understanding of the subsurface rock behavior and deformation under various conditions. The application of geomechanics in petroleum reservoirs involves the integration of geological, geophysical, and engineering data to develop models that can be used to optimize reservoir performance and minimize risks associated with drilling and production activities.

One key area where geomechanics is applied in petroleum reservoirs is in the analysis of reservoir compaction and subsidence. This involves modeling the deformation of the reservoir rocks as they are subjected to changes in reservoir pressure and fluid production. By understanding how the reservoir rocks deform, engineers can optimize well placement and production strategies to minimize compaction and subsidence and maximize hydrocarbon recovery (Zoback, 2010).

Another important application of geomechanics in petroleum reservoirs is in the analysis of wellbore stability. This involves modeling the interaction between the wellbore and the surrounding rock formation to predict the likelihood of wellbore failure due to drilling-induced stresses or production-induced compaction. By understanding the potential for wellbore failure, engineers can design drilling and completion programs that minimize risks and maximize production.

In addition to these applications, geomechanics is also used in the analysis of hydraulic fracturing and other stimulation techniques used to increase well productivity. By modeling the behavior of the subsurface rocks during stimulation, engineers can optimize fracturing parameters to maximize the effectiveness of the stimulation and minimize the risk of induced seismicity.

Overall, the application of geomechanics in petroleum reservoirs is a critical component of reservoir management and optimization. By providing a better understanding of subsurface rock behavior and deformation, geomechanics can help reduce risks and increase hydrocarbon recovery.

APPLICATION OF GEOMECHANICS IN THE Oil & GAS INDUSTRY

Drilling	• Wellbore stability evaluation and management • ROP prediction & drilling optimization • Bit design & selection • Pore pressure prediction
Completion	• Solids control & completion design • Perforation design • Casing design & well engineering • Reservoir stimulation (frac treatments & injection) • Waste disposal (including cuttings reinjection)
Reservoir	• Well and platform location, & trajectory planning • Reservoir compaction & subsidence • Reservoir performance and dynamics (permeability, sweep efficiency) • Fault activation (loss of containment & loss of wells) • Underground storage (including gas (methane, CO2...), rad waste)

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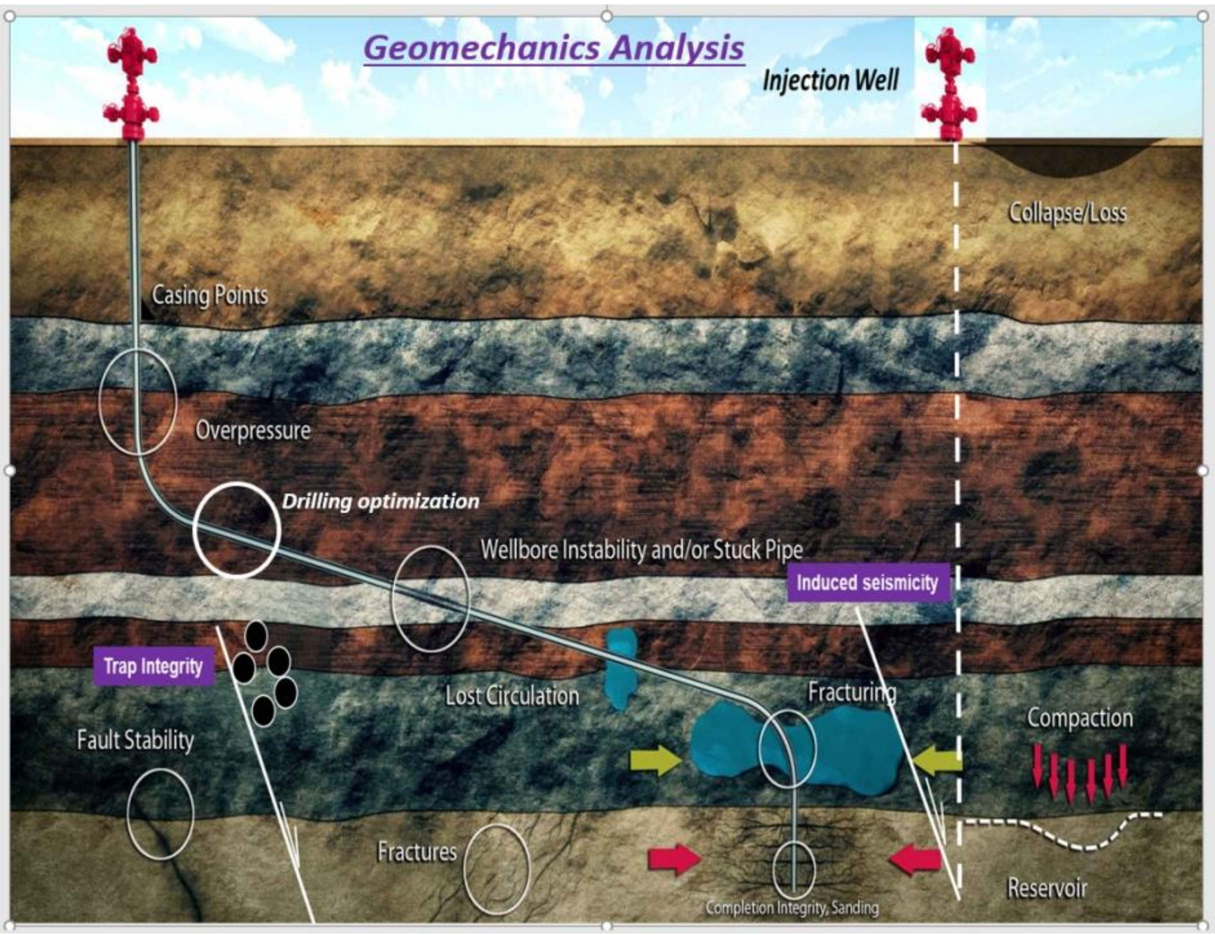
APPLICATION OF GEOMECHANICS IN PETROLEUM RESERVOIRS

Activities in development and production of oil and natural gas, such as drilling wells, production of crude oil and natural gas, injection of fluids for improved oil recovery (IOR), enhanced oil recovery (EOR), and



well stimulation, may change the mechanical state (effective stress) of the underground. Consequent compaction or expansion of the rock or initiation and propagation of fractures can change the flow path of the fluid or permeability, affecting the production behavior of crude oil and natural gas. The changes in the mechanical state may also raise risks in surface subsidence or uplift as well as induced earthquakes. Geomechanics enable us to investigate the various monitoring data and to analyze the mechanical state of underground and its consequences to ensure safe and efficient development of oil and natural gas.

Geomechanics plays an essential role in understanding the behavior of petroleum reservoirs and their interactions with drilling, completion, and production operations. Here are some examples of how geomechanics can be applied in petroleum reservoirs:

Fig.1: Application of Geomechanics in different fields; petroleum reservoirs. (Eslam, 2022)

Formation Evaluation

Geomechanics plays a crucial role in the evaluation of petroleum reservoirs. By understanding the geomechanical properties of the reservoir rocks, geoscientists and engineers can predict the behavior of the reservoir, including fluid flow, production rates, and potential for induced seismicity. Here are some specific ways geomechanics can be applied in formation evaluation:

Determining rock properties: Geomechanical models can be used to determine the rock properties such as

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mechanical strength, porosity, and permeability. These properties are essential for understanding the behavior of the reservoir, identifying the optimal production zones, and designing the appropriate drilling and completion strategies. (Nwaezeapu et al., 2018; Aniwetalu et al., 2018; Li, et al., 2019)

Identifying potential fractures and faults: Geomechanical modeling can help identify potential fracture and fault zones in a reservoir. These zones can have a significant impact on reservoir productivity and can be targeted for further exploration and production. (Zoback, et al., 2003; Ibekwe et al., 2023)

Estimating reservoir compaction: Geomechanical models can be used to estimate the amount of reservoir compaction that can occur during production. This information is critical for designing the appropriate drilling and completion strategies and for predicting reservoir performance. (Mavko, et al., 2009; Oguadinma et al., 2017; Oguadinma et al., 2021; Oguadinma et al., 2023)

Predicting wellbore stability: Geomechanical modeling can be used to predict wellbore stability during drilling and production. This information is critical for designing the appropriate drilling and completion strategies to prevent wellbore instability and reduce drilling costs. (Zoback, 2007; Ibekwe et al., 2023)

Evaluating hydraulic fracturing: Geomechanical modeling can be used to optimize hydraulic fracturing treatments by predicting the extent of fracture propagation, fracture complexity, and fracture network connectivity. This information is essential for designing the appropriate completion strategies and for predicting the success of the hydraulic fracturing treatment. (Weng, et al., 2016)

Wellbore Stability Analysis

Geomechanics plays a crucial role in wellbore stability analysis in petroleum reservoirs by providing a framework for understanding the mechanical behavior of the surrounding rock formations and predicting potential failure mechanisms. The application of geomechanics involves integrating geological, geophysical, and engineering data to develop a comprehensive understanding of the reservoir and its behavior under various operational and environmental conditions.

One approach to wellbore stability analysis is to use numerical modeling techniques, such as finite element analysis (FEA), to simulate the behavior of the rock formations surrounding the wellbore. FEA can help predict the stresses and strains in the rock formations and identify potential failure mechanisms, such as tensile or shear failure, which can lead to wellbore instability.

Another approach is to conduct laboratory experiments, such as triaxial compression tests, on core samples taken from the reservoir to determine the rock’s mechanical properties, such as strength, modulus, and ductility. These properties can then be incorporated into numerical models to improve the accuracy of the predictions.

In addition to numerical modeling and laboratory testing, geomechanics can also be applied in wellbore stability analysis through field observations and monitoring. Techniques such as borehole imaging, acoustic logging, and microseismic monitoring can provide valuable information on the behavior of the rock formations surrounding the wellbore.

One example of the application of geomechanics in wellbore stability analysis is the work conducted by Akbarzadeh et al. (2020) in a deepwater field in the Gulf of Mexico. The authors used FEA to model the wellbore stability of a deepwater well and identified potential failure mechanisms, such as tensile failure and borehole breakout. The results of the study were used to develop a wellbore stability management plan, which included optimizing drilling parameters and wellbore trajectory to minimize the risk of wellbore instability.

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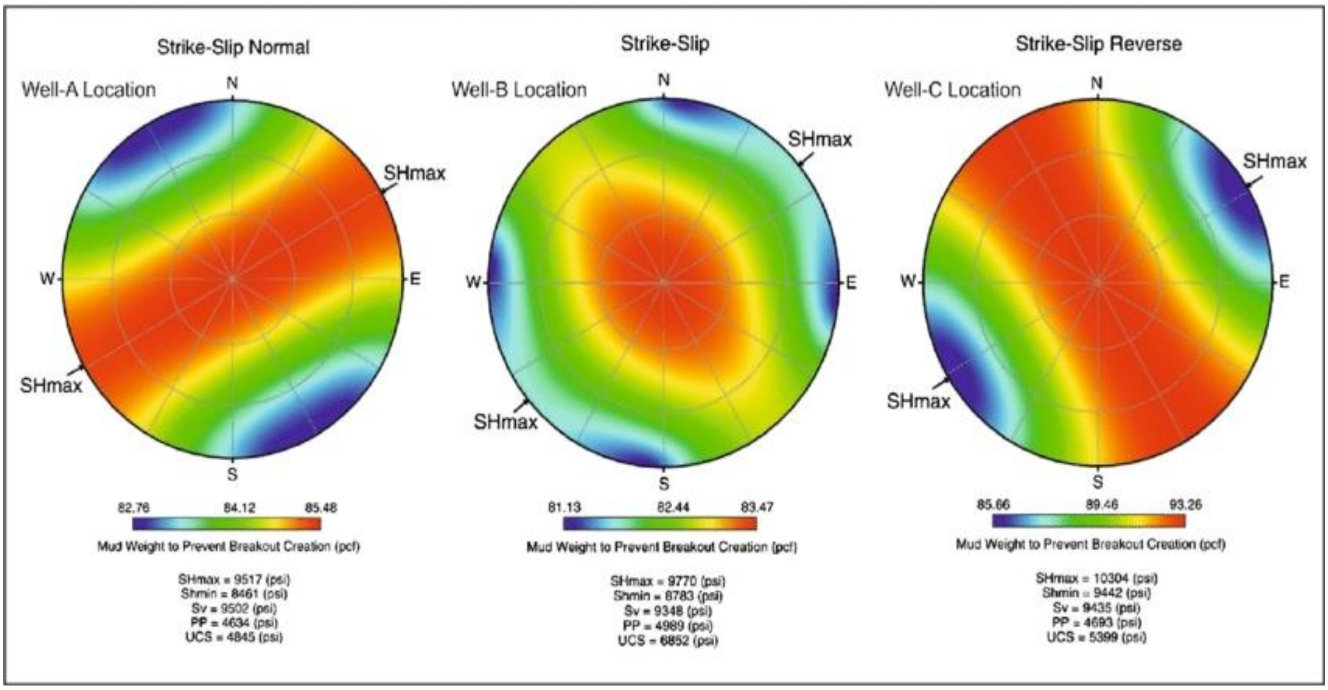

Fig.3 Analysis of wellbore stability in different drilling directions. Note the minimum mud weight required to prevent borehole breakouts in different drilling directions. (Mohsen et al., 2020)

Hydraulic Fracturing

Geomechanics plays a critical role in hydraulic fracturing, particularly in the design and optimization of the fracturing process, as well as in the evaluation of the fracturing effectiveness and the prediction of its long-term effects on the reservoir.

Some of the ways in which geomechanics can be applied in hydraulic fracturing include:

Determination of in-situ stress conditions: The understanding of the in-situ stress conditions is essential in the design of hydraulic fracturing operations. Geomechanical analysis can help in determining the direction and magnitude of the in-situ stresses, which can guide the selection of the fracturing orientation and the optimization of the fracturing parameters.

Analysis of fracture propagation: Geomechanical models can be used to simulate the propagation of the hydraulic fractures and to predict their geometry, complexity, and connectivity. This can help in optimizing the fracture design and in assessing the effectiveness of the fracturing process.

Evaluation of reservoir response: Geomechanical models can also be used to evaluate the response of the reservoir to the fracturing process. This includes the assessment of the changes in the reservoir pressure, permeability, and porosity, as well as the potential for induced seismicity and other long-term effects (Zoback, 2010; Oguadinma et al., 2014; Oguadinma et al., 2021; Oguadinma et al., 2023; Ibekwe et al., 2023).

Optimization of completion design: Geomechanical analysis can also be used to optimize the completion design, including the selection of the casing and cementing strategy, as well as the design of the stimulation fluids and proppants.

One of the key challenges in applying geomechanics to hydraulic fracturing is the complexity of the reservoir and the uncertainty in the input parameters. However, with the increasing availability of data and

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the development of advanced geomechanical models, it is becoming possible to better understand the reservoir behavior and optimize the fracturing process.

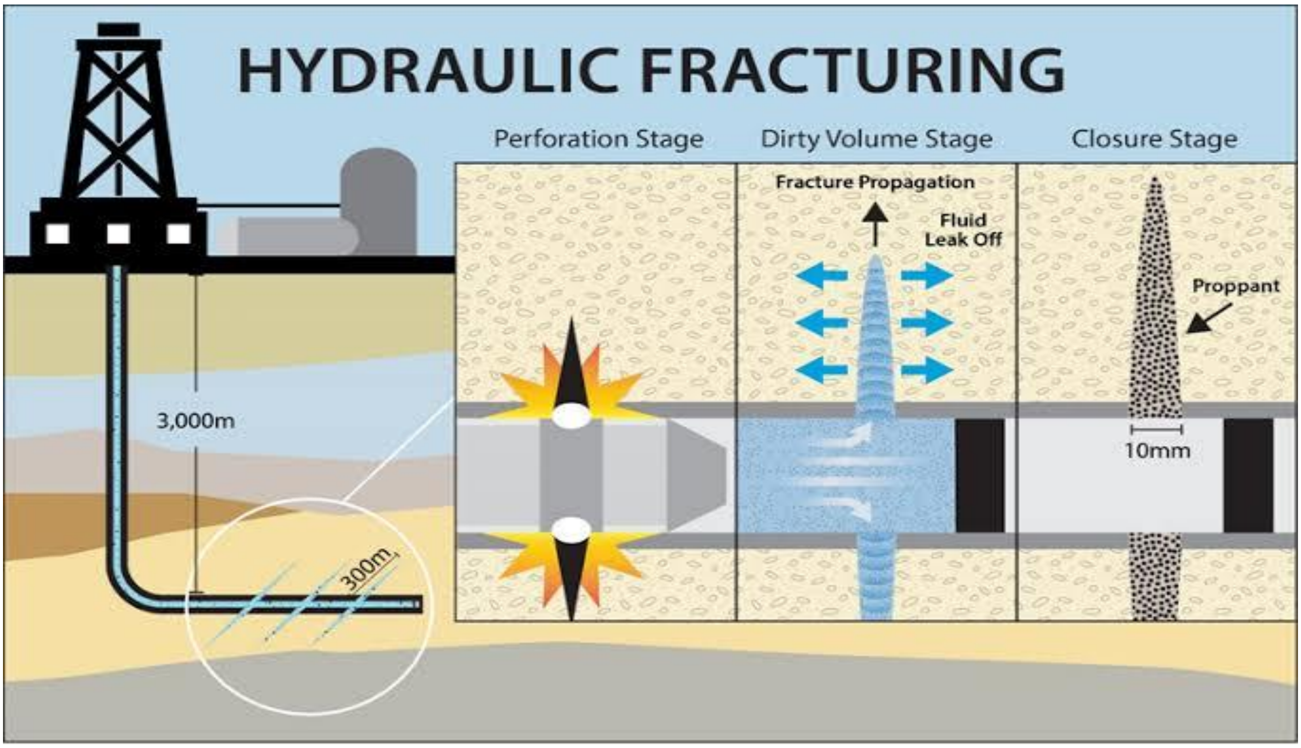

Fig 4: Process of hydraulic fracturing showing the perforated stage, dirty volume stage and closure stage (Geological Society of Oman, 2020)

Reservoir Characterization

Geomechanics can be applied in reservoir characterization in petroleum reservoirs by providing information on the mechanical properties and behavior of rock formations. This information can be used to better understand the behavior of the reservoir during production and to optimize production strategies.

One application of geomechanics in reservoir characterization is the use of seismic data to map the stress field within the reservoir (Zoback, 2010; Oguadinma et al., 2016). This can help identify areas of the reservoir that are prone to fracturing or compaction, which can affect reservoir performance. Other applications of geomechanics include the use of wellbore data to estimate rock strength and deformation properties, and the use of geomechanical models to simulate the behaviour of the reservoir under different production scenarios.

Enhancing Oil Recovery

Geomechanics can be used to study the behaviour of reservoir rocks during enhanced oil recovery (EOR) operations, such as water flooding, steam injection, or chemical flooding. This information can be used to optimize EOR strategies and maximize oil recovery.

Geomechanics can play a crucial role in enhancing oil recovery in petroleum reservoirs by providing insights into the mechanical behaviour of the reservoir rocks and the fluid flow dynamics. One of the key applications of geomechanics is to optimize the design and implementation of hydraulic fracturing and other well-stimulation techniques to maximize the production of oil and gas. Geomechanics can also be used to evaluate the integrity of wellbore and surface facilities to minimize the risk of well failure and environmental damage. (Zoback, 2010).

Geohazard Assessment

Geomechanics plays a crucial role in geohazard assessment in petroleum reservoirs. By understanding the geomechanical behaviour of the reservoir rock and its surroundings, engineers can identify potential hazards that may affect the production of hydrocarbons. Geomechanics can also provide insights into the stability of the reservoir over time and help optimize production strategies.

One application of geomechanics in geohazard assessment is the prediction of fault reactivation. Faults are common in petroleum reservoirs, and their reactivation can lead to seismicity and surface deformations, which can be hazardous to personnel and infrastructure. Geomechanical models can be used to assess the potential for fault reactivation and to determine the stress conditions that may trigger seismicity (Wibowo et al., 2019; Ibekwe et al., 2023).

Another application is the assessment of caprock integrity. The caprock is a layer of impermeable rock that lies above the reservoir and prevents hydrocarbons from escaping to the surface. If the caprock fails, hydrocarbons can leak to the surface, potentially causing environmental damage. Geomechanical models can be used to assess the stability of the caprock under different stress conditions and to identify potential failure mechanisms (Zoback et al., 2007; Oguadinma et al., 2016; Oguadinma et al., 2021).

Additionally, geomechanics can be used to optimize production strategies in petroleum reservoirs. By understanding the geomechanical behavior of the reservoir rock, engineers can design production strategies that minimize the risk of reservoir compaction and subsidence, which can damage infrastructure and affect the recovery of hydrocarbons (Zhou et al., 2019).

Overall, geomechanics plays a critical role in geohazard assessment in petroleum reservoirs. By understanding the geomechanical behavior of the reservoir and its surroundings, engineers can identify potential hazards and design production strategies that minimize risk.

Another important application of geomechanics is to monitor the reservoir response to production operations, which can help in identifying potential problems such as reservoir compaction, casing deformation, and induced seismicity. This information can be used to optimize the production strategy and to prevent operational issues that may impact safety and efficiency.

Moreover, geomechanics can help in characterizing the reservoir properties such as porosity, permeability, and stress distribution, which are critical parameters for predicting the behavior of the reservoir during production. This information can be used to calibrate the reservoir simulation models and to improve the accuracy of production forecasts.

Overall, geomechanics plays a significant role in enhancing oil recovery in petroleum reservoirs by providing valuable insights into the mechanical behavior of the reservoir and the fluid flow dynamics. It can help in optimizing the design and implementation of production operations and in predicting and preventing operational issues.

CONCLUSION

Geomechanics is an essential tool for understanding the behavior of petroleum reservoirs. It allows for a better understanding of the physical properties of the reservoir and its surrounding rock formations, which can be critical in designing drilling and production operations. The use of geomechanics in petroleum reservoirs includes determining the stresses and strains on the reservoir and its surrounding rock formations, modeling and predicting the behavior of the reservoir under different conditions, and evaluating the impact of various drilling and production operations on the reservoir.

One of the most significant benefits of geomechanics in petroleum reservoirs is the ability to identify potential problems before they occur. By analyzing the stresses and strains on the reservoir, geomechanics can predict whether or not the reservoir is at risk of fracturing or collapsing, which can be critical in preventing costly and potentially dangerous accidents.

Furthermore, geomechanics can help optimize drilling and production operations by identifying the best locations for wells, predicting the behavior of the reservoir during drilling and production, and identifying the most efficient and safe methods for extraction. This can lead to increased production and reduced costs.

In summary, geomechanics plays a vital role in understanding and managing petroleum reservoirs. Its ability to predict the behavior of the reservoir and its surrounding rock formations, identify potential problems, and optimize drilling and production operations make it a crucial tool for the petroleum industry.

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