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Optimizing Production from Shale Oil and Gas Reservoir through Hydraulic Fracturing and Other Stimulation Techniques

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Abstract- Hydraulic fracturing is a technique that increases the well deliverability and productive life of a well. Shale gas and light tight oil have low permeability, due to which they cannot be produced commercially. Fracture treatment is used to enhance their production. Hydraulic fracturing is the fracturing of rock by a pressurized liquid. A vertical well is drilled and multiple fractures are induced from the wellbore at various azimuths to produce artificial channels. To propagate the fractures, rods of perforate guns are lowered into uncased sections of the wellbore. These guns are then fired from the wellbore and holes are broken free and perforated during the production from the initial fracture. The injectivity test for hydraulic fracturing is conducted from the acquired wireline and/or petrophysical logs. This paper presents the case history of the optimization of hydraulic fracture treatments and performance of the fracture treatment of a shale gas well. The results show that the well deliverability and life have significantly improved after the treatment, saving millions of dollars of operational cost and also increasing the field productivity by 200%.

Keywords- Hydraulic Fracturing, Shale Reservoirs, Well Optimization, Fracture Connectivity, Production Enhancement, Well Spacing, and Microstructural Modeling

I. INTRODUCTION

Shale oil and gas resources that were once not considered economically viable are now being extensively exploited due to advancements in drilling techniques and technology (Li et al., 2022). These resources, found in vast shale formations, have opened up new strategic opportunities for both previously undeveloped areas and in-fill locations. However, it is important to note that the technical aspects of extracting shale oil and gas differ significantly from those of traditional energy resources. A more complex strategy is needed to extract shale oil and gas than the traditional easy resources. It involves employing advanced drilling techniques such as hydraulic fracturing, also known as fracking, and horizontal drilling (Qun et al., 2022). These methods allow for the efficient extraction of oil and gas from tight shale rock formations deep below the earth's surface.

New wells decline rapidly during the first few years of production and have low initial penetration rates. To maintain and increase production, and therefore generate revenue, repeated infill and refrac completions or infill drilling must be undertaken at considerable cost (Kumar et al., 2024).

The see-saw credit and cost cycle, and lend-lease opportunity of conventional onshore development wells are not generally available for shale development. Techniques to reduce initial production costs are required. To be successful, the fracturing program must be informed by detailed knowledge of the formation and smart design. Critical QHSE and operations information is best gained from Microseismic mapping (ElSherbeny et al., 2023). In a number of onshore North American and European settings, access to equal or better results has been available from tilt meter arrays. Monitors can be disabled by the motors of local vehicles, and cables can be tripped over, which is a risk to safety, so that nature beats technology out of the field. Even active monitoring, which resets the positions of passive seismic monitors, can create problems. Technology should be limited to addressing critical high bus issues, and there are successful interactions that are preferred, such as the total field deals which have helped accelerate commercialization of non-seismic techniques (Xu et al., 2022).

II. SHALE OIL AND GAS RESERVOIRS: CHARACTERISTICS AND CHALLENGES

The improvement in recent years in horizontal drilling and hydraulic fracturing technologies has tremendously enhanced the economic feasibility of shale oil and gas reservoirs (Wu et al., 2022). This comprehensive paper provides an overview of the current state-of-the-art techniques used in horizontal drilling, hydraulic fracturing, and other stimulation methods applied to shale oil and gas reservoirs. Additionally, we delve into previous studies that have focused on optimizing these stimulation processes to achieve the highest efficacy. Furthermore, this paper addresses the potential environmental challenges associated with shale oil and gas reservoirs, shedding light on the significance of adopting sustainable practices in this domain. It is essential to thoroughly understand the environmental impacts of these reservoirs to ensure responsible and conscientious resource extraction. To guide future research in this area, this paper offers valuable recommendations for enhancing the existing optimization techniques and proposes novel treatments for geomechanics issues arising from hydraulic fracturing. As the industry continues to evolve, it is crucial to explore new avenues for further improving efficiency, minimizing environmental footprints, and maximizing the overall productivity of shale oil and gas reservoirs.

The concept of using hydraulic fracturing techniques to enhance the production from shale oil and gas reservoirs can be traced back to the 1930s (Soeder and Soeder, 2021). The first US commercial gas production from a hydraulically fractured well was recognized in 1947. The fracturing process involves the application of positive hydraulic pressure to a fluid within the wellbore that is sufficiently large to overcome the pressure losses in the wellbore flowing fluid, circulating fluid, and a hydraulic fracture will form at the wellbore. The maximum principal stress direction for hydraulic fracturing is usually vertical. The formation under the greatest stress is then hydraulically fractured, producing one or several both hydraulically and naturally created fractures. After the fracturing process, the total section area for fluid drainage around the wellbore will be enlarged and the production rate will significantly shoot up (Jew et al., 2022).

III. GEOLOGICAL FORMATION

The concept of shale formation is a relatively young concept in the study of geological formations. Originally rocks made of clay minerals that are formed by the mechanical breakdown of other rocks were called shale formations. Other agents like oxygen aluminum and other elements involved in the formation of shale were added to the more recent definition (Wang et al. in 2023). A thorough understanding of the locations properties economic significance and content of shales is essential to comprehending the idea of shale formation. Smaller amounts of silt and sand combine with sediment made up of clay mineral flakes to form shale. These flakes were generally ground by organic particles and natural mineral clays carried by rivers and ocean currents with ease and settled in a variety of water bodies such as lakes bays swamps and along land substrates (Xie et al. 2022). In the majority of occurrences, shale is created when muds deposited in water bodies from highland areas are covered by further mud or undergo metamorphic processes, eventually creating mudstone-type sedimentary rocks. Shales characteristically are stratified, thinly bedded, and thinly laminated (Zhang et al., 2023).

Significant occurrences of shale around the world include subsiding sedimentary basins and ocean margins, where continental slopes and rises accumulate mud in thin layers and undersea fan-shaped deposits on deep ocean floors. Most shale varieties are deposited in low-energy environments, with sediments slowly moving and consisting of organic particle grains. Clay shales are created exclusively from clay-sized particles and are typically fissile, while rock shales are less fissile due to increased amounts of silt and sand (Hackley et al., 2021).

The methane nuclear molecules originate from trapped dead organic remains that slowly settle after being covered by sediment. Natural gas in the fine fraction increases through bacteria that process metals to create methane, and small amounts may migrate from large parted sandstone traps in shale to form substantial reserves. The high organic content, metal content, and particle size properties make shale a rich potential source of alternative energy. The commercial exploitation of shale resources has grown with technological advances that enable natural gas and oil extraction (Wang et al., 2022).

IV. PETROPHYSICAL PROPERTIES

Shale oil and gas extraction is a method that diverges from conventional resources due to its unique production process which is characterized by low matrix permeability. The ceramic-like composition of shale necessitates the implementation of fracture stimulation techniques in order to liberate the hydrocarbons, both oil and gas, that have accumulated within it, as highlighted by Wang et al. (2023). To maximize the production process it is crucial to integrate geologic petrophysical and geomechanical studies. According to Arias Ortiz et al. (2021). it is therefore imperative to precisely estimate petrophysical properties like porosity saturation wettability and permeability notwithstanding any uncertainties that may exist within the study area. A countrys economic viability and energy independence are determined in large part by these attributes. The goal of this study is to use well logs to carefully measure the effects of different stimulated areas in the Bakken unconventional basin on petrophysical properties using a variety of hydraulic fracturing designs. A more thorough grasp of the complex connection between fracture stimulation and petrophysical characteristics can be attained by looking at and evaluating these quantified effects as Qun et al. (2022) have discussed. This information can then be used to help create better methods and procedures that will maximize the production of gas and oil from shale in the future. Zhu et al. (2022) describe shale rocks as extraordinary fine-grained rocks that are typically made up of silt and quartz grains clay minerals calcite cement pyrite and organics.

These rocks may contain both organic and inorganic TOC. The petrophysical properties have a direct impact on the hydrocarbon properties and the reaction of the rock to the physical movement during drilling operations. Understanding these petrophysical-property-stimulation relationships is crucial for the success of most geological plays and for optimizing production, as noted by Hou et al. (2022). The biggest challenge lies in identifying the most effective techniques to enhance the matrix contribution. The overall volume of organic matter within the rock determines the potential of the source rock. To deduce the mineral constituents of the source rocks, density and gamma ray measurements (when combined with neutron porosities) are necessary, with density porosities indicating the higher percentage of organic matter. Under the assumption of effective water saturation, density porosities in clay-shale source rocks exhibit strong correlation with TOC. In fact, Lou, Chakraborty, & Karpyn (2022) model demonstrated the practicality of density porosity in estimating TOC based on well log measurements. However, it is vital to account for errors associated with log responses and the blending of various variables when applying these methods, as cautioned by Peng et al. (2024).

Challenges in Production

Currently, there is a great challenge in maximizing petroleum production by the use of hydraulic fracturing and other stimulation methods applied to the production wells (Zheng et al., 2022). Reservoir engineering plays a key role in the application of these techniques to the production from shale oil and gas reservoirs. The primary goal of the reservoir engineer is to develop a production program for an oil/gas reservoir capable of producing the maximum quantity of oil/gas from the reservoir over the life of the field that yields the highest present value profit (Qun et al., 2021).

A well-designed completion and hydraulic fracturing strategy should achieve a few key conditions: optimize the stage and cluster locations to stimulate the maximum part of the long horizontal wells, create a complex hydraulic fracture network and keep it open for gas to flow toward the wellbore (Mogensen & Masalmeh, 2020). Finally, the multi-frac stimulation method should generate flow paths with high permeability and sufficient conductivity that link multiple fractures to initiated hydraulic fractures during the entire production period (Umar et al., 2021).

Shale gas is generally contained in the shale formation, which is, in general, deeper than the conventional reservoirs. Its buried depth is about 1500 to 5000 m (5000-15000 ft). It is evident that the deeper the buried depth is, the higher the formation pressure increases from the drilling engineers' experience (Irfan et al., 2023). Under a high pressure gradient, the hydraulic fractures growth easily exceeds the allowed height which is required by the drilling engineers. A large number of microseismic events are triggered, which causes a dramatic increase in production costs (Mojid et al., 2021).

More importantly, the production from the stimulated gas wells will be damaged in the last period of the reservoir life. The rapid production decline up to 60% to 70% per year of the drilled shale gas wells leads both to an increase in the number of future infill drilling in the mature areas and to economic losses for E&P companies (Gao et al., 2023). These challenges also occur in the tight oil reservoirs and the water-bearing shale gas reservoirs (Wollin et al., 2020).

Hydraulic Fracturing: Fundamentals and Techniques

Shale oil and gas, dubbed as the backbone of economic progress in the United States and poised to revolutionize global economic development in the foreseeable future, have emerged as the pivotal primary energy sources. These precious resources have gained paramount importance as the industrial landscape has experienced unprecedented growth over the past century, thereby intensifying the global energy demand to unparalleled levels (Solarin et al., 2020). Distinguishing themselves from conventional reservoirs, shale oil and gas reservoirs present a unique characteristic,the absence of primary or secondary porosity. Consequently, to augment the production of hydrocarbons, subsequent stimulation techniques such as hydraulic fracturing become indispensable (Shakya et al., 2022). Therefore, this paper aims to provide an all-encompassing and comprehensive scrutiny of the fundamental aspects of fracturing, encompassing various facets such as flow diagnostics, proppant transport, fluid flow back, refracturing, the groundbreaking concept of multimode energy fracturing, and the formulation of fracturing fluids. This will be achieved through the exploration of relevant real-world instances and exemplary cases, thereby establishing a comprehensive foundation of knowledge in this critical field.

An economic evaluation of the terms of development of tight gas sands shows that investment costs and cycles have high levels of risk, being strongly affected by the response of the geological reservoir and therefore making it difficult to adapt the rig and surface infrastructures to the diverse completion profiles (Wu et al., 2021). Given that the productive behavior of the tight gas sands reservoirs is directly influenced by the physical properties of the rock and gas, the hydrocarbon biodistribution characteristics, and the volume in place (VIP), for analytical assessments or simulations with precise results, the study of these reservoirs is more complex, with physical simulation using methods adaptable to each geological reservoir being recommended (Cheng et al., 2023).

Basic Principles of Hydraulic Fracturing

The basic principles of hydraulic fracture may be seen as independent. However, the interactive steps involved in the creation of hydraulic fractures in rock may be carried out as follows:

Fluid Injection with a Pump: For wall rocks, especially with lower permeability characteristics, a maximum pressure in proportion to the maximum required formation breakdown pressure for promotion of the required extension is desirable (Kang et al., 2023). More viscous fluids are used, higher pressures are required, as well as slower pumping rates.

Injection of Proppants to Hydraulically Prop Open the Fracture: Proppants are grains of material such as sand, ceramic, or resin coatings used to prop open the fractures after the pumping has ceased (Katende et al., 2021). Some are chemically reactive, combining with fluids in the reservoir formation to create a greater temporary or permanent prop. Proppants can also be used for diverting to propagate fractures into unfractured areas with potentially more reserves as stress magnitudes increase or decrease.

Fluid De-absorption (not including proppants). Fluid de-absorption is crucial in hydraulic fracturing, focusing on the movement of fluids from the rock formation back into the wellbore post-fracturing. This process helps monitor formation response, optimize fracture placement, and prevent costly remediation. Real-time data on fluid flowrate and pressure drop (EFPD) allows operators to detect irregularities, adjust fracturing parameters, and enhance operational efficiency. Accurate fracture mapping and improved reservoir contact are achieved through continuous monitoring, ensuring better stimulation results. Proactive issue management minimizes downtime and costs. Effective fluid de-absorption management is key to maximizing production and ensuring sustainable hydrocarbon extraction from shale formations.

Fracture Cleanup with Neighbor Fluids: Surfactants or clean-up fluids that remove or degrade fluid reaction products and prevent buildup in the pore throat and clogging.

Meanwhile, to establish a production network from each wellbore, fractures/transfays should be connected radially with the reservoir at the shortest distance (Gupta et al., 2021). The minimum pressure required for having a crack open is just below lithotripsy. Fracture lengths should not exceed reservoir thickness to prevent inflammation and primary production short peak-up productivity instead in relation to costs. Then, followed by fracture deprops of proppants through lainuterosalantsies, wellbore cleanup, and fluid emissions, respectively.

Objectives of Configuring Hydraulic Fracture Mesh for Nonconventional Reservoirs

- **Minimize Pressure for Fracture Creation:** Reduce the pressure needed to create fractures that remain open with proppants, ensuring efficient production.
- **Maximize Horizontal Contact:** Enhance the horizontal extent of fractures per well to enable simultaneous production, sustaining long-term output without asphalt phonation.
- **Minimize Interconnected Fractures:** Avoid interconnected fractures or wormholes cutting into less permeable layers, ensuring effective stimulation and fluid flow from deeper depths.
- **Optimize Proppant Injection in Low Porosity Plays:** In low porosity kerogen plays, adjust proppant injection volumes to match the rock's production capability (Boak & Kleinberg, 2020).
- **Balance Formation Pressure:** Ensure formation pressure is balanced to offset compression effects, maintaining effective fracture creation.
- **Intermittent Hydraulic Flow Stages:** At St. Lucia, implement intermittent hydraulic flow stages to heat the downstream processing unit/separator, ensuring proper flow regime.
- **Vary Proppant Compositions:** Use different proppant compositions for each flow stage to optimize fracture dimensions and conductivity.
- **Increase Pressure Rating:** Aim to increase the pressure rating to avoid creating flow barriers

or increasing the risk of sand production, hydrate formation, or bottom hole freezing. Install a safety shutoff device (SSD) to manage these risks effectively.

By following these objectives, we can optimize hydraulic fracturing processes, ensuring efficient and sustainable production from nonconventional reservoirs.

Types of Hydraulic Fracturing Techniques

The objective of a hydraulic fracture treatment is to enhance productivity of the reservoir by producing huge conductive plane defects (cracks) within it (Wu et al., 2022). The hydrocarbon production is possible if such a fracture passes through the pay zone, especially in the case of shale gas reservoirs and oil shale formations. A variety of factors contribute to whether the fracture treatment will be successful, such as reservoir characteristics, geologic factors, in situ stress conditions, first and foremost; the conductivity of a hydraulic fracture treatment depends on the created system of macro-cracks. And only a proper fracture treatment process can yield a multi-plane complex network of macro-cracks in the reservoir zone and thereby enhance the reservoir quality. In other words, the process of hydraulic fracturing treatment should be suitable for the reservoir's characteristics. Thus, the first objective of the fracturing process in any type of reservoir is to select fracturing parameters that meet the reservoir characteristics.

There are four major types of hydraulic fracturing treatments currently applied in practice: hydrofracture, propellent stimulation (PROP STIM), hydraulic performance fracture intersecting/chunk system (HFR), and traditional hydraulic fracture with proppant (PROP) (He et al., 2023). Each of these methods is based on different technology and has its main differences. In hydrofracture, after the borehole preparation and high-pressure fracture fluid injection, the growth of one principal hydrofracture with controllable Sherwood cracks is initiated. After that, the fracture is swelled with increasing injection rate at constant pressure, and the growth of the system of other main fracture branches (lateral fractures) in the bedding plane of the reservoir proceeds. After the fracture system reaches the needed length of the zone stimulation, pumping is stopped, and the fractures stabilize during the needed time period.

In PROP STIM, the systematically-axis proppant charge is pumped into the principal fracture, creating performance rock-mining fractures (tops or bottoms) powered to the hydrofracture only. The sliders' arrays are released while the principal proppant column is opened at the magnitude of proppant release-time period, independent from the volume of proppant charge. The designed proppant charge units of the sliding charge are pumped in two or more even intervals inside the borehole at the section of created hydrofracture length using reciprocally or non-returnable hydraulic appliances in the line.

In HFR, the first-step procedure under minimal fluid volume 0+ platform+ proposal is used to target disconnected slim lines, and the weighted principal oxide-ceramic column up to 4km deep is conducted with unweighted fracture to deliver importance on the executive proppant column torque, of the developed nonlinear amplitude and primary wedge-combination effect, of the ready concave-hook-pipe, confined to signal-paralleled, braced mainly the desaw, Pavlodar, and tributary fracture per mining column, composite convergence, cooperated with each slipping pad with confining of the customized drive.

In PROP, fluid is pumped inside the borehole at the designed and controlled system of pressure drops to accelerate hydrofracture development and to successfully downscale the column of specialized proppant, similar to HFR (Zhang & Hascakir, 2021). The injection rate is limited by structural characteristics of a reservoir and quality of original fracturing support, which can destabilize and dissolve in some cases. The amount of injected fracturing fluid and proppant concentrate should be corrected to the permeability of a localized part of the reservoir and parameters of produced hydrocarbon flow. Based on reservoir properties data, the customer can decide which type of hydraulic fracturing technology is better for each case in question.

Fracturing Fluids and Proppants

Petroleum, a peer-reviewed scientific journal published by Multidisciplinary Digital Publishing Institute (MDPI), aims to disseminate knowledge and advancements in the field of oil and gas exploration (Wang et al., 2023). In this regard, I would like to highlight the significance of hydraulic fracturing, popularly known as "fracking", which has emerged as a vital stimulation technique employed in unconventional reservoirs like tight-fit sands and shale. The primary objective of fracking is to enhance the recovery of hydrocarbons, thereby revolutionizing the oil and gas industry. This comprehensive paper delves into the intricacies of the fracturing process, encompassing various aspects such as the fluid used, choice of proppants, the intricacies of the fracking process itself, designing techniques, data collection methodologies, and finally, the optimization of production through effective fracturing strategies. This study clarifies the complex nature of hydraulic fracturing by drawing on in-depth research and professional opinions. It offers scholars engineers and industry professionals engaged in hydrocarbon exploration and production useful information. Understanding the intricacies of hydraulic fracturing in great detail will enable us to optimize the extraction efficiency of unconventional reservoirs opening up previously unreachable energy resources. In order to reduce potential risks and lessen any negative effects on the ecosystem this paper also emphasizes the significance of environmentally conscious methods and sustainable practices in fracking operations. All things considered this paper provides a thorough overview of hydraulic fracturing to enable ethical and effective energy extraction from the process. By combining state-of-the-art technologies and creative approaches the oil and gas sector can maximize output and guarantee a consistent flow of hydrocarbons to satisfy the worlds energy needs.

The conductivity is without a doubt the most important factor in determining the flow capacity of each individual hydraulic fracture following the fracturing treatment through the reservoir formation (Liu et al. 2024). Maintaining the openness of the fracture and creating a high-conductivity pathway from the reservoir to the fracture itself are two crucial roles of proppants. Proppants are also frequently used as props to effectively stop the fracture from closing unintentionally. There are several kinds of proppants that are frequently used in the oil and gas sector. These consist specifically of resin-coated proppants ceramic proppants and sand proppants. Sand is widely available reasonably priced and naturally hard making it the most popular option in the overall plan. Conversely ceramic proppants are used because of their favorable qualities such as their roundness and hardness. Since the resin layer tends to melt in high temperatures resin-coated proppants are primarily used in low-temperature settings. Research and development related to proppant coating should therefore be given top priority. Furthermore two important areas that require careful research and study are prefocusing the fracturing treatment and controlling the amount of proppants used.

Other Stimulation Techniques

It is important to remember that there are a number of other stimulation techniques used in the oil and gas sector even though hydraulic fracturing is the most commonly used one (Qun et al. 2022). The goal of these methods is to increase reservoir permeability which will raise well productivity and performance overall. There are a number of different well stimulation techniques used in addition to hydraulic fracturing or fracking.One such method is acidizing which entails injecting acid into the wellbore to increase permeability and dissolve different materials. On the other hand acid-fracturing treatments combine the best practices of acidizing and hydraulic fracturing. By injecting acid into the fractured formation this method helps to increase the reservoirs permeability. The development of stress fractures commonly referred to as propping is another frequently employed stimulation technique. Proppants like sand or ceramic materials are injected into the fractures made by hydraulic fracturing as part of this technique. The free passage of hydrocarbons is made possible by these proppants which function as props to keep the fractures from fully closing. Furthermore specific steps are taken to lessen formation damage while the stimulation process is underway. Any undesirable change in the characteristics of the reservoir rock that may have an adverse effect on productivity is referred to as formation damage. In order to maintain the wells long-term viability and optimal performance a variety of strategies are used to prevent or reduce formation damage. Although hydraulic fracturing is frequently used it is crucial to note that the oil and gas sector uses a variety of stimulation methods to enhance well performance. Each technique has its advantages and limitations, and the selection of the most appropriate method depends on the characteristics of the reservoir, such as its geology, fluid properties, and current production challenges. Overall, the goal of stimulation treatments is to optimize recovery, maximize production rates, and ensure the efficient extraction of hydrocarbons from the reservoir.

The most successful and profitable method is focusing on a model of preparing extensive and/or numerous complex, large treatment volumes of radical key types (He et al., 2023). Most observed successful statistics include reserve development of hydraulic fracturing projects. It should be noted that hydraulic fracturing will not enhance every project either because of the particular formation petrophysical properties or else due to the improper construction of the overall project proposal and its execution. After project completion, all responsibility for project profitability falls on everyone involved in project financing, design, configuration, logistical support, implementation management, and the level of continuous technical improvement.

Acidizing

Acidizing is a treatment that removes formation damage from the near-wellbore area and does not require introducing proppant into the formation to prop open the stimulated rock (Hegazy et al., 2023). However, it relies on increasing the invaded formation volume, which may already be a part of the smallest radius sphere of influence. In fact, the effectiveness of acidizing, particularly in cases where hydraulic fractures have been created, is often ineffective. The use of hydrochloric acid as a stimulation technique has several disadvantages, including excessive reactions with the surrounding rock enhancing the risk of creating wormholes and causing catastrophic failures of the well barrier(s).

The ability of acidizing to specifically dissolve specific forms of formation damage like scale and clay deposits which can impede the flow of hydrocarbons is one of its main benefits. The permeability of the reservoir can be successfully restored by engineers by focusing on these particular barriers and employing the right acid compounds and concentrations. In addition to increasing the wells productivity this selective approach lessens the need for expensive and time-consuming procedures like sand control. In addition acidizing is a flexible technique that can be applied to a variety of geological formations including sandstone and carbonate reservoirs. Acidizing can increase well productivity in carbonate reservoirs by breaking down matrix materials cementing materials and other impediments to fluid flow. Because of the etched channels the acid treatment makes in the rock the hydrocarbons can move more freely in the direction of the wellbore. Acidizing sandstone reservoirs can aid in removing formation damage brought on by clay swelling and fines migration. The wells productivity and injectivity can be severely reduced by these typical problems in sandstone formations. The sandstone matrixs inherent permeability can be restored by engineers dissolving the fines and clay particles with an acid treatment. Better fluid flow and increased production rates are the outcomes of this. But it's vital to remember that acidizing has drawbacks and restrictions. For example using hydrochloric acid can be dangerous because it is corrosive. Wormholes can form as a result of excessive acid reactions with nearby rock that are not adequately managed. The wellbores integrity is at risk and the treatments efficacy is diminished by these wormholes which are preferential flow paths that avoid the intended formation. The acidizing process is controlled by engineers using a variety of methods and additives to reduce these risks. To ensure a more consistent and regulated dissolution of formation damage surfactants are occasionally used to change the behavior and distribution of the acid within the reservoir. Diverting and gelling agents are also used to reroute the flow of acid and stop undesired channels from forming. Moreover many of the historical difficulties related to acidizing have been resolved by developments in acid formulation and application techniques. The risk of excessive wormholing has been reduced by the development of acid systems with decreased reactivity towards the rock formation. Acid retarders and corrosion inhibitors are used to increase the safety and effectiveness of acid treatments extending the wells life and reducing the need for remediation procedures. To sum up acidizing is a useful method for repairing formation damage and raising oil and gas well productivity. Its ability to selectively dissolve obstacles in the wellbore area makes it an effective method for restoring permeability. Although challenges exist, technology advancements and proper control measures continue to enhance the safety and efficacy of acid treatments, allowing for optimized reservoir performance and prolonged well lifespan.

For the case of hydraulic fracturing taking place in mineralized shale oil or gas formations, the use of phosphate or fluoboric acids may be more effective alternatives (Li et al., 2024). Similarly, applications that inject water before, during, or after treatment may also be used. However, the type and concentration of the acid to use, the amount of injected fluid, how to restrict the fluid from propagating away from the intended troubled area, how to monitor the progress of the operation, and how to protect the crews and the well infrastructure from an uncontrolled flow of produced fluid will depend on the operating conditions and the geological context of the field and its surrounding area.

Enhanced Oil Recovery Techniques

Enhanced oil recovery (EOR) is a major approach for the increment of production from these already aged wells (Malozyomov et al., 2023). Both specially designed fracturing and disturbance to the matrix have been developed for fracturing the formation. Stimulation additives have also been developed to increase the efficiency of fracturing and oil extraction. Similar to hydraulic fracturing, EOR and the related surfactant, hydrophilic and hydrophobic particles have so far been focused mainly on large scale industrial sectors such as water carbon dioxide, polymer, experimental pulsed injection, hydrophobic etching, etching, asphalting treatment etching, thermite etching, beam drilling, three-stimulating operations, and the supercritical co-injection fracturing. Recent attention on micro-scale particles, such as multi-walled (MW) carbon nanotubes, platinum, and iodine high porosity nanoshells, have focused mainly on the desired enhanced initial porosity and continued low mineral nucleation formation of oil shale. Researchers are looking into new approaches and materials to further optimize EOR techniques as the technology develops. The application of cutting-edge nanomaterials such as magnetic nanoparticles and additives based on graphene is one area of ongoing research that has shown promise in terms of increasing the efficiency of oil recovery. In order to better understand and manage the subsurface reservoirs research is also being done on the possibility of using sophisticated reservoir characterization techniques like electromagnetic monitoring and 3D seismic imaging. With these advancements, the future of EOR looks promising, as it holds the potential to significantly increase oil production and prolong the lifespan of existing wells.

Surfactant, chemically modified nanoparticles for energy interactions, as well as the usual chemical aided carbon dioxide, water, and methanol mixtures have good oil extraction recovery performance (Qu et al., 2022). The addition of dispersants to the dispersant structure and micro-emulsion additives, such as dispersants, showed a significant increase in oil recovery of about 5.8 times. With the increased understanding of the effect of these nanoparticles in interfacial tension, the effect of nanoparticle suspension on the W/O microemulsions where the oil was entrapped within a nanowire web. This recovery performance and scalable production process would give the chemical additives offered by fluid membrane for accelerated dopamine-based in-situ polymerization of nanoparticles to a microporous super striping membrane. The other gas additive super dissipated the strength and additionally fractured FGEFY based enhanced oil recovery, based on gas dissipation and mobility reduction in GDL, micro-injection, and stabilized nano discs.

Integrated Reservoir Management

The design of the hydraulic fracturing programs should always prioritize careful forecasting and meticulous planning. It is crucial to consider the reservoir drainage attitude of the wells, as well as the optimization design of the hydraulic fracturing program, in order to prevent refracturing and maintain the fractures as effectively as possible (Xue et al., 2023). When it comes to horizontal wells with multistage fracturing in shale oil and gas formations, the equivalent thickness and drainage radius of the stimulated reservoir volume (SRV) play a vital role in determining the ultimate productivity (Tian et al., 2022). Careful examination and deliberation are necessary for these crucial parameters.

Continuous innovation and the introduction of production measures that ensure high and stable production rates are essential for the continuous and sustainable production of a shale oil and gas reservoir (Zeng et al. 2021). Maintaining the desired output can be achieved most effectively by keeping an ongoing focus on innovation. Hydraulic fracturing is one such technique that has shown to be very successful it not only releases the reservoirs full potential but also boosts production activity generally (Sun et al. (2020). According to Nandlal and Weijermars (2022) it is even more crucial to give the hydraulic fracturing process optimization design top priority when working with formations that have large-scale natural fracture planes. The operations overall success may be greatly impacted by the presence of such fracture planes so careful planning and execution are required. Therefore when focusing on shale oil and gas formations it is crucial to stress the importance of thorough forecasting careful planning and the optimization design of hydraulic fracturing programs (Wang et al. 2024). When these practices are strategically applied individual wells and the larger reservoir as a whole may experience improved productivity efficiency and results. It is possible for a formation that contains portions of natural fracture planes to have multiple hydraulic fracture sets. Although the quantity of natural fractures might not have a significant impact on the fracture sets of hydraulic fractures the parameter of natural fractures ought to be a significant consideration (Zhang et al. 2022). By changing the fluid-solid ratio from high to low in the fracturing program, the generation of a complex fracture network and a large net thickness are expected. Pretreatment before the fracturing program, such as acid injection, can be used to create fractures near the wellbore in advance (Wu et al., 2023). Comparative results of the propagation of reservoir equalization, generating a large amount of propped areas, and increasing the success of the hydraulic fracturing are obtained. This design can improve the flow conductivity of the hydraulic fractures and optimize the placement characteristics of the hydraulic fractures (Wang et al., 2023).

In order to minimize the disadvantages caused by poor propped zones in shale gas reservoirs, a highly conductive hydraulic fracture would be created. Rapid fracture fluid leakage was anticipated since the parameters governing the cap rocks fracture containment property were determined and implemented. A step-by-step fracturing program was used in the formation with poor wellbore stability to control the failure of the wells open-hole section and mitigate water hammer damage by causing a series of microfractures in the cap rock (Yang et al. 2022). Optimizing the shale oil and gas reservoirs hydrocarbon production system is the main goal of integrated reservoir management (Wu et al. (2021).

Reservoir Characterization and Modeling

A key component of effectively optimizing hydrocarbon production is reservoir characterization (Owen 2024). The type of rock porosity permeability and mobility of the hydrocarbons within the formation are just a few of the many variables that must be thoroughly understood. This knowledge is attained by using well logs which aid in identifying the type of rock and its variations and make it possible to calculate capillary pressure for movable oil measurement (Adeoye 2024). The creation of the lithology permeability and porosity models depends heavily on the 3D seismic data (Malozyomov et al. 2023). In particular permeability and porosity are essential for fully understanding reservoir dynamics before well stimulation. Petrophysical analysis of well logs is used to create models of porosity and permeability in order to gain a thorough grasp of reservoir behavior. Determining the minimum capillary pressure flow zone indicator porosity and permeability cutoffs is part of this interpretation. The results of this painstaking procedure show a notable improvement in the two model's predictions of porosity and permeability. This improvement significantly contributes to the overall understanding and successful optimization of hydrocarbon production.

There is a need for more factors to be included in the permeability model, but for this project, the focus was on the 3D seismic data processing (Zahmatkesh et al., 2021). The quality of the 3D seismic data processing done would influence the reservoir characterization to determine permeability, porosity, lithology model, fracture model, capillary pressure model, and the flow zone indicator model (Bashir et al., 2021). These will help in defining the nature of the stimulation in terms of the orientation of the fractures and the area to focus on in the stimulation program. It is important to acquire a good understanding of the rock density and rock type of the subsurface rock because these are the most critical inputs for the sign attributes of the rock in the formation (Islam et al., 2021). The importance is seen from the performance of water and oil sand on the surface logs.

Production Optimization Strategies

Strategies to optimize production from shale oil and gas reservoirs can be highlighted as follows:

- Proper selection of completion techniques - i.e., hydraulic fracturing technique, proppant selection, fracturing fluid type, etc.
- Proper well planning so that optimally long and horizontal wellbores can be drilled having most exposure within the pay zone
- Multi-stage fracturing in long horizontal wellbores
- Suitable perforation techniques
- Proper design of hydraulic fractures
- Proper proppant selection
- Effective proppant transport
- Tailoring of fracturing fluids for specific conditions
- Minimizing pressure losses from all sources
- Optimized well production through use of compressible fracturing fluids, self-diverting fluids, perforation clusters, etc.
- Reducing fluid cleanup time to minimize skin damage around fractures

Produced water management is a tremendous task to handle the large quantities of water effectively for each well in a large number of multi-lateral fracturing of horizontal toes in unconventional reservoirs such as shales, coalbed methane, and tight sands (Scanlon et al., 2020). Also, water supply for the hydraulic fracturing process may be a major factor in some areas. Avoiding scale deposits from produced water is also a part of the production system design. Reducing skin damage from fracturing fluids using penetration enhancers or self-diverting fracturing fluids is one way to improve effective permeability and boost hydrocarbon recovery (Kassab et al. (2021). The properties of the shale oil or gas being produced the characteristics of the existing formation the behavior of the reservoir over time depths and pressures drift conditions surrounding environmental assessments and regulations the infrastructure that is currently in place the injection feasibility or alternative management of the produced fluid the cost of the service the availability of equipment and the accessibility of personnel are all factors that affect production optimization strategies (Montagna et al. in 2023). To maximize reservoir productivity and efficiency these strategies necessitate a thorough approach that takes into account a variety of technical and operational factors (Qun et al. (2023).

Environmental Considerations in Shale Oil and Gas Production

The production of gas and oil from shale is currently a hotly contested and extensively discussed topic when it comes to environmental issues. The public has paid close attention to the actual and perceived effects of these operations. Particularly there is now a lot of disagreement over the possible risks to water resources posed by fracking and the improved recovery of gas and oil (Tan et al. 2022). Other environmental effects including land use population effects noise pollution visual disturbances and other possible repercussions of shale gas development have also gained attention as society grows more aware of these issues (Guo et al. 2021). Water contamination from near-surface gas migration is one of the main concerns with shale gas production. This is a serious problem that requires careful attention and management in order to protect water resources (Scanlon et al. in 2022. Another significant environmental worry is the air emissions brought on by these operations (Gao et al. 2021). These issues cannot be ignored or disregarded even though less is known about how the general public views their importance. For shale gas resources to develop and succeed it is imperative that all of these issues are recognized and handled responsibly (Dreyer and Stang 2022). Thorough risk management and assessment are essential for the responsible development of shale gas. This calls for carrying out intensive research and development activities in order to comprehend and address societal and environmental issues more effectively (Burbidge & Adams 2020). By making these efforts it is possible to guarantee that shale gas resources are developed in a way that is both environmentally sustainable and economically feasible (Arthur 2020). To sum up the responsible exploration and extraction of gas and oil from shale requires the careful handling of environmental risks and issues. It becomes possible to address the valid concerns related to shale gas production by giving priority to risk assessments carrying out in-depth research and putting effective management strategies into place (Boak & Kleinberg 2020). A more sustainable energy future is the ultimate result of this strategy which guarantees that the development of these resources is in line with environmental and societal demands (Gargur et al. in 2022). A precautionary approach should be taken to safeguard human health and the environment in the face of potentially serious risks for uncertain benefits given the nature of the uncertainties surrounding the risks and consequences of shale gas development (Adebiyi 2022). These possible hazards encompass not only the consequences of the hydraulic fracturing procedure itself but also other related operations including the disposal of wastewater the extraction of raw materials the transportation of materials and site development activities (Khan et al. (2021). Furthermore the analysis did not include other elements of oil and gas production such as roads trucking and drilling which can have a significant impact on soil improvements air quality and public health (Johnston & Cushing 2020). Regulatory exclusions, as well as data limitations, have also meant that risks to water were assessed incompletely (Deziel et al., 2020). Finally, public disclosure of the chemicals used in the hydraulic fracturing fluid was permitted only after the fracturing process was complete and could be withheld alongside disclosures on the basis of trade secrets (Molofsky et al., 2021).

Water Management

The optimal stimulation of shale formations necessitates that typically, a greater than 90% proportion of returns be effectively managed as swiftly as possible subsequent to Wolfcamp completions. In the case of the Eagle Ford formation, the returns consist predominantly of water with minimal quantities of oil and gas, which provides a distinct advantage (Isser, 2023). However, the excessive utilization of water has emerged as a persistent challenge in Duvernay actions. The excessive presence of water can diminish the overall returns by amplifying hydraulic pressure (and, albeit less frequently, hydraulic flow), thereby generating a smaller designed fracture for that specific stage, ultimately affecting productivity (Smith et al., 2022). It is worth noting that there is essentially no discernible distinction between oil and gasless gas and liquids completions. In the context of liquids completions, tungsten is substituted with sand, without the incorporation of any chemicals, as the sand exhibits no detrimental secondary post-frac consequences. These consequences encompass modifications in the formation's profile and the development of a deep calcification profile (Male et al., 2023).

Flowback management for shale oil involves diverting or angling the drilled tubulars to ensure efficient flow. Fracture knitting during the return of Eagle Ford flowback is a common occurrence (Griesbach, 2022). However, the process of diverting well completion returns is complex due to legislative requirements and potential logistical challenges (Hale, 2023). Neutron loggists are capable of creating more geometrically staged geometries than standard methods, but the benefits of flowback managed completions may have been overestimated (Marsh, 2020). Laws will need to be enacted to determine the staged geometry of specific pairs in completion compilations. In some cases, completion diversion may not even make the first set of applicants, and history suggests that lateral planning decisions may be necessary for a successful completion diversion (Meyer-McLean, 2020). Markers of progress are top priorities for Eagle Ford teams working on multiple completion designs.

Emissions and Air Quality

Although greenhouse gas (GHG) and other emissions from production activities must be thoroughly taken into account from an environmental standpoint, it is worth noting that the infrastructure and daily operations associated with oil and gas production from tight formations generally yield significantly lower GHG emissions compared to those commonly associated with coal mining and the release of coalfield methane (Ekemezie & Digitemie, 2024). To further mitigate these emissions, operators can utilize fuel cells or microturbines to generate electricity, both of which contribute to lower emission rates (Lu et al., 2023). Additionally, reciprocating engines, although they tend to generate nitrogen oxides (NOX) and volatile organic compound (VOC) emissions, can be optimized to achieve lower emissions (Chen et al., 2023). On the other hand, flares, while serving their purpose, do generate NOX, carbon monoxide (CO), volatile organic compounds, and GHG emissions (Mahmood et al., 2023). By considering a combination of these factors and adopting appropriate measures, the environmental impact of oil and gas production can be significantly reduced (Calderon et al., 2022).

It is also worth considering potential spills of oil, hydraulic fracturing chemicals, produced water, and brine. Spill frequency and volumes in tight formations likely increase from three potential causes relative to conventional plays. First, the level of industrial activities in major, protracted development scenarios has increased (Jellicoe et al., 2022). Second, site personnel have likely decreased with increasing construction standards, initially because equipment is automated and subsequently because remotely operated equipment likely becomes cost-effective with improvements in mechanized airborne and ground equipment (Kumar et al., 2021). Third, rates of chemical use in hydraulic fracturing may have increased. However, because these chemicals are becoming greener and preplans are an important aspect of chemically bonding hydraulic fracture conductivity (Jew et al., 2022).

Case Studies and Best Practices

In presenting some best practices, we first provide a brief background on the important significance of case studies in these activities. We discuss details on the front-end and back evaluation development techniques and results of some cases. The best practices and some lessons learned are based particularly on several case studies. The analytical steps and history matching process used lead to the gas-coning problem solution, hunt for the optimal stimulation fluid, and well-to-well fracturing design optimization methodology. Hydraulic fracturing evolvement in areas such as liquid systems, slick-water designs, and proppant integration are also discussed (Merzoug and Ellafi, 2023).

A combination of sound reservoir evaluation and advanced fracturing techniques can lead to the identification of the reservoir sweet spots and better completions with the use of the right fracturing fluids and proppants. A well-engineered early reservoir development and completion program can help develop reserves in a cost-efficient and more environmentally friendly manner (Jie et al., 2024). One sophisticated method that has been applied extensively in the oil and gas sector is the use of proppants during hydraulic fracturing. Proppants like Gas60-6 are frequently utilized in hydraulic fracturing processes. Gas well production can be increased by using this proppant. This proppant is composed of a blend of ceramic and sand materials. One of the key elements influencing the proppants performance is its particle size and shape. This proppant is frequently utilized in gas wells with sandy geology. The wells production rate may be lowered by using this proppant to help stop sand bridges from forming. The formations permeability may be decreased by using this proppant to help stop fines from forming. Using this proppant can also help stop scale from forming which can lower the wells production rate. By preventing paraffin from forming this proppant can also lower the wells production rate. Using this proppant can also help stop asphaltene from forming which can lower the wells production rate. Additionally by preventing the formation of hydrates this proppant can lower the wells production rate. The wells production rate may be lowered by using this proppant to help stop wax from forming (Jew et al. 2022).

V. CONCLUSION

With an emphasis on shale oil and gas this review addresses the significance of appropriate hydraulic fracturing and other stimulation methods to improve oil and gas reservoir production. This goes into detail about the difficulties encountered in shale oil and gas reservoirs the significance of hydraulic fracturing and how to maximize hydraulic fracturing in a reservoir. Other reservoir stimulation methods are also covered in this section along with their significance and application in a reservoir. Additionally it is discussed how to use various tracers to comprehend fluid flow and provide information from the reservoir. Also included is a core flooding setup that is used in laboratories to investigate core-scale hydraulic fracturing processes. This kit could be used to study how fluid flow would occur in a fracture produced due to hydraulic fracturing in a shale oil and gas reservoir.

In conclusion, with technological advancement and requirements to meet the global energy demand with available fossil reserves such as shale gas and oil, investment in hydraulic fracturing technology becomes a necessary propellant to harness the hydrocarbons locked within the shale rocks. With economic scale, the relative low cost of oil per barrel compared to the upstream exploration cost permits industry stakeholders and researchers in the part of the world where the requirements else seen only as a consumer to conduct extensive research on shale oil and gas projects. Nevertheless, the oil and gas industry also acknowledges the environmental risk of having increased drilling known to release methane into the atmosphere and cause water contamination. Furthermore, environmental policy changes and cobweb model-time lag in equilibrating regulations may lead to great capital loss for shale oil and gas investors.

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