Science Journal of Energy Engineering
2023; 11(2): 19-25
http://www.sciencepublishinggroup.com/j/sjee
doi: 10.11648/j.sjee.20231102.11
ISSN: 2376-810X (Print); ISSN: 2376-8126 (Online)

A Glance on Hydraulic Fracturing: Benefits, Concerns, and Future

Mubarek Alpkiray[1, *], Emre Can Dundar[2]

[1]Petroleum and Natural Gas Engineering, New Mexico Institute of Mining and Technology, Socorro, USA
[2]Engineering Department, Turkish Petroleum Corporation, Ankara, Turkey

Email address:
mubarek.alpkiray@student.nmt.edu (Mubarek Alpkiray), edundar@tpao.gov.tr (Emre Can Dundar)
[*]Corresponding author

To cite this article:
Mubarek Alpkiray, Emre Can Dundar. A Glance on Hydraulic Fracturing: Benefits, Concerns, and Future. S*cience Journal of Energy Engineering*. Vol. 11, No. 2, 2023, pp. 19-25. doi: 10.11648/j.sjee.20231102.11

Received: June 23, 2023; **Accepted**: July 19, 2023; **Published**: August 5, 2023

Abstract: Natural gas and oil are extracted from subterranean rock formations via hydraulic fracturing. This procedure includes applying high pressure to a solution of water, sand, and chemicals to fracture the rock, allowing the gas and oil to flow more freely. Hydraulic fracturing has been the topic of heated debate despite being used more frequently recently due to worries about its potential effects on the environment and public health. The terminology, procedures, and proppants used in hydraulic fracturing operations are all covered in this document. Also, it covers the environmental issues raised by hydraulic fracturing, including as waste management and disposal and groundwater contamination. Economic benefits of hydraulic fracturing are discussed, including increased domestic production, job creation, and reduction in dependence on foreign oil. Advancements and innovations in hydraulic fracturing, including the use of alternative fluids, enhanced recovery techniques, and new technologies, are also discussed. Finally, the paper concludes with a discussion of the future of hydraulic fracturing, including projections for future growth, its impact on the energy industry, and the ongoing debate over its future. This paper aims to provide a comprehensive and impartial overview of hydraulic fracturing, and to inform readers about the benefits and drawbacks of this technology.

Keywords: Unconventional, Shale Gas, Natural Gas Extraction, Hydraulic Fracturing, Proppants

1. Introduction

Fracking, or hydraulic fracturing, is a procedure that releases trapped oil and natural gas by injecting a solution of water, sand, and chemicals into subsurface rock formations. High pressure is applied to the fluid mixture as it is injected into the rock, causing minor rock cracks that allow the trapped hydrocarbons to escape. This method has been employed for many years in the oil and gas sector to recover resources from unconventional formations, including as shale and tight sands. The development of new technologies and techniques has allowed for a more widespread use of hydraulic fracturing.

The definition of hydraulic fracturing encompasses the various stages of the process, from the design and construction of the wellbore to the injection of the fluid mixture into the rock formation. The wellbore is drilled into the rock formation using specialized drilling equipment, and the fluid mixture is then injected into the wellbore and into the rock formation. The fluid mixture creates fractures in the rock, and the sand proppant is used to keep the fractures open. The fractures allow the oil and natural gas to flow more freely into the wellbore, where it can be extracted [1].

The hydraulic fracturing process is highly engineered and each step is carefully monitored to ensure the safety of the environment and the workers involved in the operation. It is important to carefully consider the induced seismicity potential in energy technologies to ensure the safe and sustainable use of hydraulic fracturing.

2. Brief History of Hydraulic Fracturing

The first trials with hydraulic fracturing, which increased the flow of oil and gas from low-producing wells, were carried out in the 1940s. The method was initially employed in vertical wells, but due to technological restrictions, its application was constrained. Hydraulic fracturing didn't become a practical way to reach unconventional oil and natural gas deposits until the 1990s, when horizontal drilling technology was developed. Energy corporations were able to reach previously unreachable enormous deposits of oil and natural gas thanks to the use of horizontal drilling and hydraulic fracturing.

Over the last few decades, hydraulic fracturing has been increasingly used to extract oil and natural gas from shale formations, which have become some of the most important sources of domestic energy in the United States. In recent years, the use of hydraulic fracturing has become a highly controversial issue, with some arguing that the process is safe and economically beneficial, while others argue that it poses significant risks to the environment and public health [3]. Despite the debate, hydraulic fracturing has become a critical component of the U.S. energy strategy and will likely continue to play a major role in the industry for many years to come.

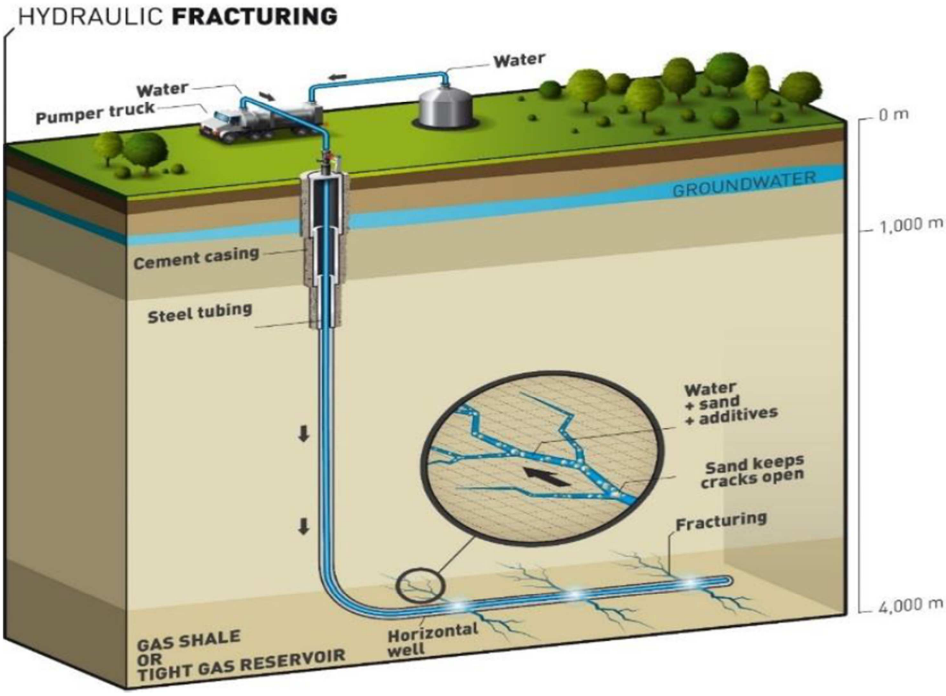

Figure 1. *Process of hydraulic fracturing [2].*

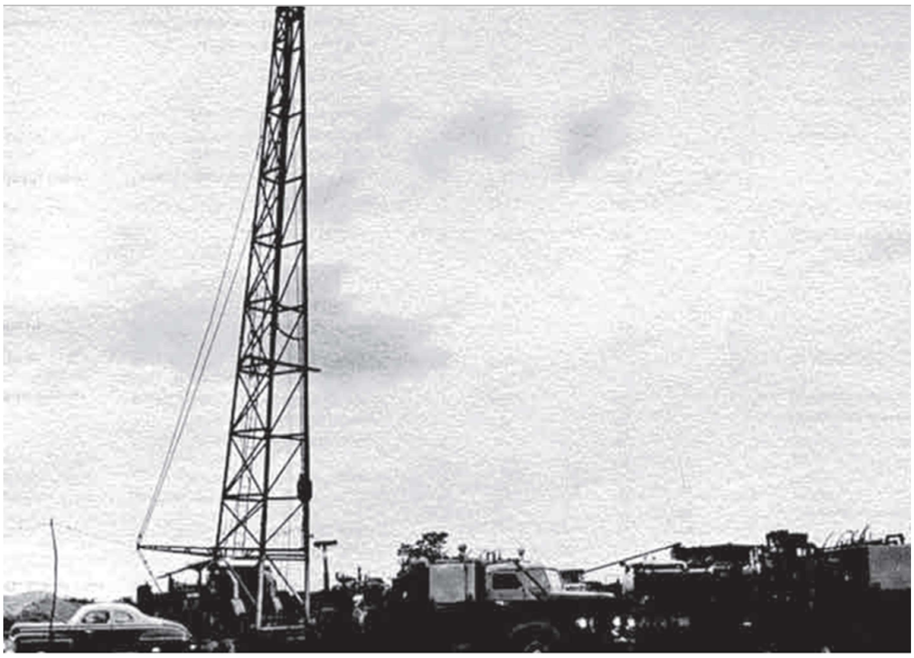

Figure 2. *In Stephens County, Oklahoma, and Archer County, Texas, Halliburton performed the first two commercial fracturing procedures on March 17, 1949. [4].*

3. Purpose of Hydraulic Fracturing

Increasing the flow of oil and natural gas from subsurface rock formations, especially unconventional formations like shale and tight sands, is the goal of hydraulic fracturing, sometimes referred to as "fracking." A combination of water, sand, and chemicals are injected into the rock formation under high pressure to induce microscopic cracks that facilitate easier passage of hydrocarbons into the wellbore. Increased oil and gas flow can considerably boost a well's output, making it feasible to recover previously undiscovered resources on a financial basis.

The use of hydraulic fracturing has revolutionized the oil and gas industry by allowing companies to access vast reserves of domestic energy. The increased production has led to a significant reduction in the country's dependence on foreign oil, creating jobs and boosting local economies. However, the environmental and public health implications of hydraulic fracturing have sparked controversy and debate. Despite this, hydraulic fracturing remains an important part of the U. S. energy strategy and its use will likely continue to play a significant role in the industry for many years to come.

4. Process of Hydraulic Fracturing

4.1. Step by Step Explanation of Hydraulic Fracturing

The process of hydraulic fracturing involves several stages, including the design and construction of the wellbore, the injection of the fluid mixture into the rock formation, and the monitoring and management of the fluid and gas flows. The first stage, the design and construction of the wellbore, is critical to the success of the hydraulic fracturing operation. The wellbore must be designed to ensure that the fluid mixture is injected into the correct formation at the correct depth, and that the well is constructed in a safe and environmentally responsible manner.

Once the wellbore is constructed, the fluid mixture is injected into the rock formation at high pressure, creating fractures in the rock and releasing the trapped hydrocarbons. The fluid mixture is carefully monitored during the injection process to ensure that it is being delivered to the correct location and at the correct pressure. The fluid and gas flows are also closely monitored to ensure that the process is proceeding as planned and that any issues can be quickly addressed. The monitoring and management of the fluid and gas flows is critical to the safety and environmental protection of the operation, and to its economic success.

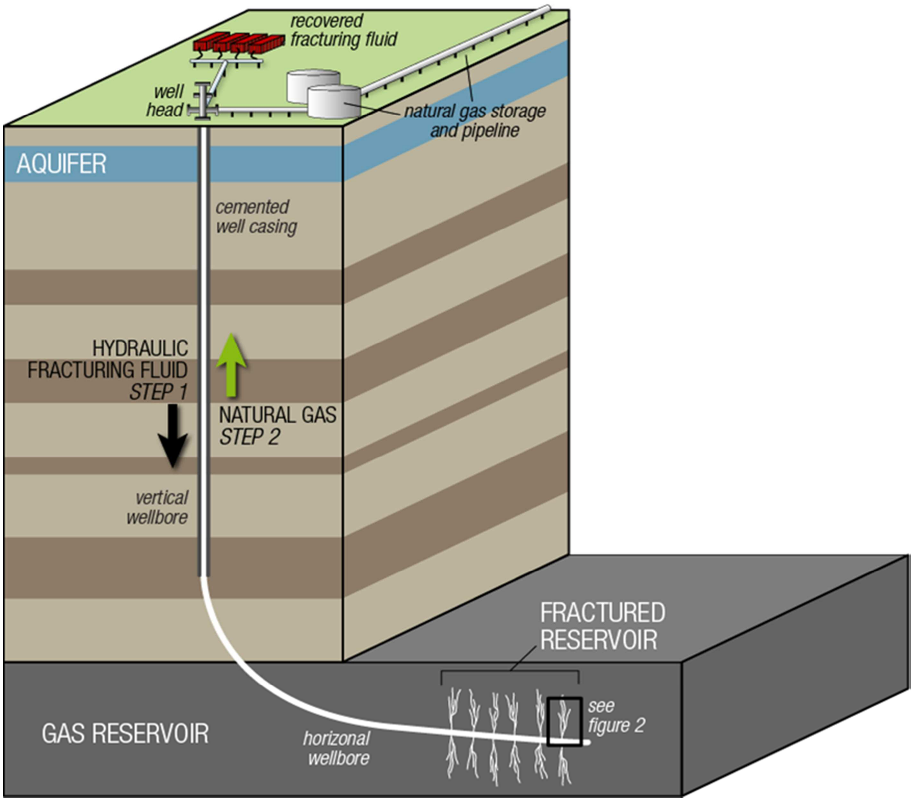

Figure 3. *Schematic illustration of hydraulic fracturing [5].*

4.2. Geomechanics Usability in Hydraulic Fracturing

The development of fracking operations highly requires implementing geomechanics analysis providing stress measurements of either vertical or deviated wellbores. The common idea analysis of hydraulic fracturing for calculating stress magnitudes is first proposed by Hubbert and Willis [6].

This approach also provides to determine stress orientation in Figure 4. Zoback and Haimson [7] presented to estimate the least principal stress magnitude. A basic definition of geomechanics idea to do hydraulic fracturing is based on tensile failure during exceeding fluid pressure over the least principal stress magnitude.

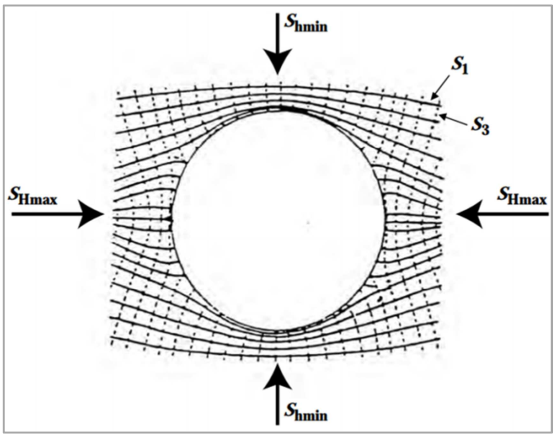

Figure 4. *A demonstration of principal stress orientations around a circular wellbore based on Kirsch 1898 proposal [8].*

The least principal stress is obtained by applying hydraulic fracturing or leak-off test in Figure 5. Depending on the faulting system, the least principal stress can vary with the magnitude values. Drilling-induced fracture is another type of fracture based on increases in mud weight and results in lost circulation cases [9]. Additionally, the knowledge of the interpretation of maximum horizontal principal stress is a crucial part of geomechanics. Once hydraulic fracturing is induced, the pressurized fluid intends to go in the direction of maximum horizontal stress providing simulating and analyzing fluid interactions and rock deformations.

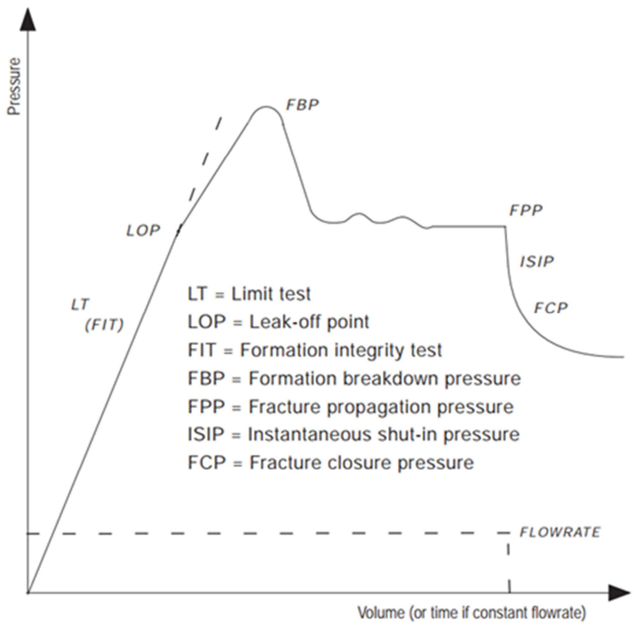

Figure 5. *A demonstration of leak-off test varying stress values based on fluid pump [8].*

4.3. Types of Fluids Used in Hydraulic Fracturing

In hydraulic fracturing, a fluid mixture consisting of water, sand, and various chemicals is employed. The sand and chemicals are carried into the rock formation by water, which is also used to fracture the rock. In order to maintain the cracks open and improve the flow of oil and natural gas into the wellbore, sand, also known as proppant, is utilized. The addition of the chemicals improves the flow of the fluid mixture into the rock formation while also reducing friction and inhibiting bacterial development.

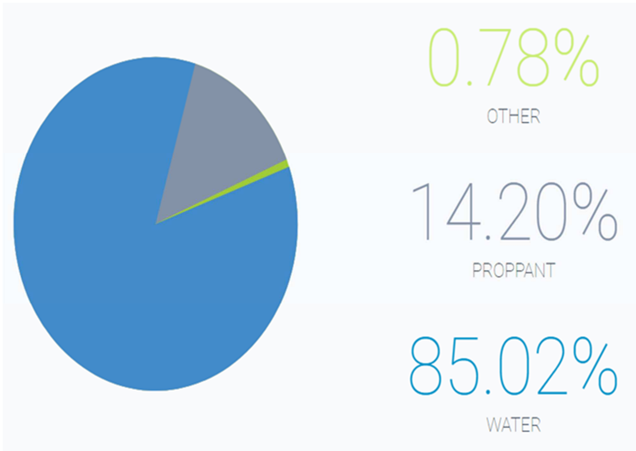

Figure 6. *Fracturing Fluid Composition [9].*

The composition of the fluid mixture and the choice of chemicals can have a significant impact on the success of the hydraulic fracturing operation, as well as its environmental impact. Energy companies must balance the need for effective and efficient hydraulic fracturing operations with the need to minimize the impact of the chemicals on the environment and public health. The use of chemicals in hydraulic fracturing has become a highly controversial issue, with some arguing that the risks posed by the chemicals are overstated, while others argue that the risks are significant and that the use of chemicals should be regulated more closely. Despite the debate, the use of chemicals in hydraulic fracturing remains an important aspect of the process, and energy companies must continue to find ways to minimize their impact while still achieving the goals of the operation.

4.4. Proppants Used in Hydraulic Fracturing

Proppants are a critical component of hydraulic fracturing operations, as they serve to hold open the fractures in the rock created by the injection of the fluid mixture. The primary types of proppants used in hydraulic fracturing are sand, ceramics, and resin-coated sand. Sand is the most commonly used proppant, as it is readily available and inexpensive. Ceramics, on the other hand, are more expensive but offer better performance in high-pressure, high-temperature environments. Resin-coated sand provides a balance between cost and performance, and is a popular choice for many hydraulic fracturing operations.

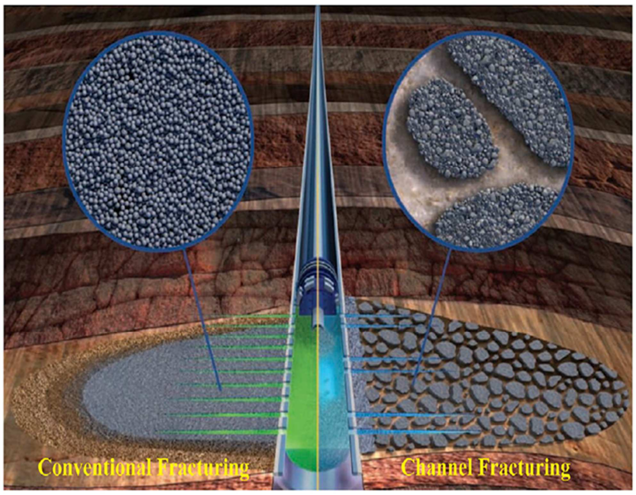

Figure 7. *Distribution of proppants in channel fracturing (right) and conventional fracturing (left) [10].*

The selection of the proppant used in a hydraulic fracturing operation is based on a number of factors, including the characteristics of the rock formation, the desired production rate, and the environmental conditions at the well site. The choice of proppant can have a significant impact on the success of the hydraulic fracturing operation, as it can affect the size and longevity of the fractures, as well as the flow of oil and natural gas into the wellbore. It is of considerable significance to highlight that in the hydraulic fracturing process, sand or other similar materials are pumped into the fracture to keep it open. The slurry moves these proppant particles in an upward, outward, and downward orientation as they travel along the fracture. The proppant particles may settle inside the fracture as a result of gravitational forces. Therefore, proppant dis-embedment and displacement can occur due to the gravitational forces acting on the proppant particles. Another factor that can contribute to this is the decreasing of the in-situ stress as the reservoir pressure declines. In this case, it is vital to perform an accurate estimation of in-situ stresses, as it is of great importance in the oil and gas industry from the exploration to the field development and production phases [11]. To illustrate this phenomenon, it has been demonstrated that severe slugging can influence the width of hydraulic fractures and impact their aperture over time. This indicates a potential risk of proppant dis-embedment and displacement [12]. The development of new proppant technologies and materials continues to be an area of active research, as energy companies seek to improve the performance of their hydraulic fracturing operations [13-16].

5. Environmental Concerns

5.1. Groundwater Contamination

Hydraulic fracturing has been widely recognized as a safe and effective method for extracting natural gas and oil, and with proper precautions in place, it poses a minimal risk to groundwater resources. The injection of fluid into the rock formation is carefully monitored and managed to ensure that no contaminants are released into the surrounding environment. Energy companies take great care to construct and seal the wellbore properly to prevent any release of chemicals into the aquifer, and to monitor the water quality in the vicinity of the wellbore.

While there have been isolated reports of groundwater contamination in areas where hydraulic fracturing operations have taken place, these incidents are rare and are often due to factors such as poor well construction or inadequate fluid management practices, rather than the fracking process itself. The benefits of hydraulic fracturing are substantial, including increased domestic production, job creation, and reduced dependence on foreign oil. The energy industry is continuously innovating and finding new ways to minimize the environmental impact of hydraulic fracturing, making it a valuable and sustainable energy production technique for the future.

5.2. Waste Management and Disposal

Waste management and disposal is a major environmental concern associated with hydraulic fracturing operations, as the large volumes of fluid and other materials generated during the process can pose a threat to water and air quality if not properly managed. The waste generated by hydraulic fracturing operations includes the fluid used in the fractures, as well as the flow back fluid that returns to the surface after the fractures have been created. This fluid can contain toxic chemicals, heavy metals, and other contaminants, and must be properly managed and disposed of to minimize the risk of environmental damage.

In addition to fluid waste, hydraulic fracturing operations also generate solid waste, including drill cuttings, filter cakes, and other materials. These materials can also contain contaminants, and must be properly managed and disposed of to minimize the risk of environmental damage. To minimize the environmental impact of hydraulic fracturing waste, energy companies must utilize best practices for waste management and disposal, including the use of closed-loop systems that minimize the release of contaminants into the environment and the proper disposal of solid waste in lined landfills or other secure facilities. In addition, energy companies must monitor the water and air quality in the vicinity of the well site and respond quickly to any indications of contamination.

While there have been isolated reports of environmental damage from hydraulic fracturing waste, energy companies have taken proactive steps to minimize these impacts through careful management of waste materials and adherence to industry regulations. The ongoing debate about hydraulic fracturing has also driven calls for greater transparency in the industry and a more comprehensive understanding of the benefits and risks of this important energy production technique. With continued efforts to minimize its impact, hydraulic fracturing is well positioned to be a responsible and sustainable solution to the world's energy needs.

6. Economic Benefits of Hydraulic Fracturing

Hydraulic fracturing has had a significant impact on the energy industry and has provided numerous economic benefits, including an increase in domestic oil and gas production, job creation, and a reduction in dependence on foreign oil. One of the primary economic benefits of hydraulic fracturing is an increase in domestic oil and gas production, which has had a positive impact on the energy market. The process has allowed for the extraction of previously untappable oil and gas reserves, leading to increased production and reduced reliance on imports. This has not only helped to reduce the cost of energy for consumers, but has also created new opportunities for domestic oil and gas companies, boosting economic growth and job creation in the industry.

In addition to increasing domestic oil and gas production, hydraulic fracturing has also created jobs in the energy sector, as well as in industries that support the drilling and production process. From roughnecks to engineers, hydraulic fracturing has created employment opportunities across a wide range of industries, providing a boost to local economies and helping to reduce unemployment. Finally, the increased domestic oil and gas production made possible by hydraulic fracturing has helped to reduce dependence on foreign oil, which has important national security implications. By reducing the amount of oil imported from abroad, the country is less vulnerable to supply disruptions, price spikes, and other geopolitical risks.

In conclusion, hydraulic fracturing has had a major impact on the energy industry and has provided a wide range of economic benefits, including increased domestic oil and gas production, job creation, and reduced dependence on foreign oil. While there are environmental concerns associated with the process, these benefits cannot be ignored and must be considered when making decisions about the future of energy production.

7. Advancements and Innovations in Hydraulic Fracturing

7.1. Alternative Fluids in Hydraulic Fracturing

Hydraulic fracturing has traditionally used water-based fluids, but alternative fluids such as carbon dioxide and nitrogen have been introduced to reduce the environmental impact of the process. These alternative fluids offer several benefits, including reduced water usage, lower risk of contamination, and improved production efficiency. Carbon dioxide-based fracturing fluids have shown to increase the production of oil and natural gas while reducing the water consumption and environmental impact of the hydraulic fracturing process.

7.2. Enhanced Recovery Techniques in Hydraulic Fracturing

The development of enhanced recovery techniques has played a crucial role in improving the efficiency and productivity of hydraulic fracturing. Multi-stage hydraulic fracturing is one such technique that allows for the simultaneous stimulation of multiple stages within a single well, resulting in increased production of oil and gas. Multi-stage hydraulic fracturing can significantly increase the production of unconventional oil and gas resources while reducing the number of wells required to extract the same amount of resources.

7.3. Technological Advancements in Hydraulic Fracturing

New technologies have played a critical role in optimizing the hydraulic fracturing process, making it safer, more efficient, and more environmentally friendly. Advanced sensors and monitoring systems have been developed to improve the accuracy and reliability of the hydraulic fracturing process, while more efficient and effective hydraulic fracturing equipment has been introduced to reduce downtime and increase production. The integration of advanced technologies in hydraulic fracturing has shown to significantly increase the production of oil and gas while reducing the environmental impact of the process.

8. Future of Hydraulic Fracturing

The future of hydraulic fracturing is a subject of much debate and speculation in the energy industry. Projections for future growth vary, but it is generally accepted that hydraulic fracturing will continue to play a significant role in the energy industry in the years to come. The impact of hydraulic fracturing on the energy industry is multifaceted, as it has the potential to increase domestic oil and gas production, create jobs, and reduce dependence on foreign oil. The future of hydraulic fracturing holds great promise, with numerous benefits that are increasingly being recognized and acknowledged. As the energy industry continues to grow and evolve, hydraulic fracturing will play a crucial role in shaping a sustainable energy future. The debate over its impact and use is natural, however, it is important for all stakeholders to come together, consider all the facts, and work towards finding a positive and productive solution that leverages the many advantages of hydraulic fracturing.

The growth of hydraulic fracturing is projected to be strong, and its impact on the energy industry will be immense. The energy industry is continuously evolving, and as it does, the role of hydraulic fracturing will become increasingly important. By embracing this technology and working together, the industry can ensure that hydraulic fracturing is used in a safe, responsible, and sustainable manner, for the benefit of all.

9. Conclusion

The conclusion of a review article on hydraulic fracturing should summarize the key points made in the preceding sections and provide some final thoughts on the future of this important energy extraction technique.

9.1. Summary of Key Points

Fracking, commonly known as hydraulic fracturing, is a method for removing oil and natural gas from subterranean deposits. In order to release trapped hydrocarbons using this technique, a high-pressure injection of a solution of water, sand, and chemicals into the well causes the formation to split. The process of hydraulic fracturing has been widely used for decades, but has recently come under scrutiny due to concerns about its environmental impact, particularly with regards to groundwater contamination and waste management. Despite these concerns, hydraulic fracturing has also been shown to have significant economic benefits, including an increase in domestic oil and gas production, job creation, and a reduction in dependence on foreign oil. In addition, the industry has seen numerous advancements and innovations, including the use of alternative fluids, enhanced recovery techniques, and the development of new technologies.

9.2. Final Thoughts on the Future of Hydraulic Fracturing

In conclusion, hydraulic fracturing will likely continue to be a controversial and hotly debated issue in the energy industry for years to come. While there are certainly environmental and public health concerns associated with this technique, there are also compelling arguments in favor of hydraulic fracturing as a means of increasing domestic energy production and reducing dependence on foreign oil? Ultimately, the future of hydraulic fracturing will depend on the ability of stakeholders to balance these competing interests and find a sustainable path forward.

As the energy industry continues to evolve and change, it will be important for researchers, policymakers, and industry leaders to work together to find solutions that promote economic growth, energy security, and environmental sustainability. Whether hydraulic fracturing will play a central role in this future remains to be seen, but it is clear that this technique will continue to be an important and highly debated issue in the years to come.

References

[1] Irofti, D., Ifrene, G. E., Pu, H., & Djemai, S. (2022, June). A Multiscale Approach to Investigate Hydraulic Attributes of Natural Fracture Networks in Two Tight Sandstone Fields, Ahnet, Algeria. In 56th US Rock Mechanics/Geomechanics Symposium. One Petro. https://doi.org/10.56952/ARMA-2022-0450

[2] Soomro, T., Memon, A., Lashari, Z. (2017). Environmental Impacts of Shale Gas Exploitation. Australian Journal of Engineering and Technology Research. 2. 4-2017. 10.6084/m9.figshare.4909448.v1.

[3] Ifrene, G. E., Irofti, D., Khetib, Y., & Rasouli, V. (2022, June). Shear Waves Anisotropy and Image Logs Integration for Improved Fracture Characterization. In 56th US Rock Mechanics/Geomechanics Symposium. OnePetro. https://doi.org/10.56952/ARMA-2022-0319

[4] Montgomery, Carl T., and Michael B. Smith. "Hydraulic Fracturing: History of an Enduring Technology." J Pet Technol 62 (2010): 26–40. doi: https://doi.org/10.2118/1210-0026-JPT

[5] Zuppann C. W. and Steinmetz J. C. Hydraulic Fracturing: An Indiana Assessment https://igws.indiana.edu/OilGas/HydraulicFracturing

[6] Hubert, M. K., & Willis, D. G. (1957). Mechanics of hydraulic fracturing, Traus. Of AIME, 210.

[7] Zoback, M. D., & Haimson, B. C. (1982, August). Status of the hydraulic fracturing method for in-situ stress measurements. In The 23rd US Symposium on Rock Mechanics (USRMS). OnePetro.

[8] Alpkiray, M. (2021). Implementation of Geomechanical Approach in Geothermal Drilling During Lost Circulation Phenomena (Doctoral dissertation, New Mexico Institute of Mining and Technology).

[9] Fracfocus.org https://www.fracfocus.org/learn/what-is-fracturing-fluid-made-of (Accessed: 1 Feb 2023).

[10] D'huteau, E., Gillard, M. R., Miller, M. M., & Peña, A. (2011). Open-Channel Fracturing — A Fast Track to Production.

[11] Aoun, A. E., Soto, R., Rabiei, M., Rasouli, V., Khetib, Y., & Irofti, D. (2022). Neural Network based Mechanical Earth Modelling (MEM): A case study in Hassi Messaoud Field, Algeria. Journal of Petroleum Science and Engineering, 210, 110038.

[12] Khetib, Y., Ling, K., Ifrene, G. E. H., Allam, L., Omar, B., & Aoun, A. E. Experimental and Simulation Investigation of Severe Slug Flow Attenuation Using a Dampening Pipe Volume. Available at SSRN 4236231.

[13] Alagoz, E. Interaction of Fracturing Fluids with Shales: Proppant Embedment Mechanisms. 2020. The University of Texas at Austin, Austin/Texas, MS Thesis. https://repositories.lib.utexas.edu/handle/2152/89282

[14] Alagoz, E. and Sharma, M. M. 2021. Investigating Shale-Fluid Interactions and Its Effect on Proppant Embedment Using NMR techniques. Paper ARMA 2021-1129, 55th US Rock Mechanics/Geomechanics Symposium held in Houston, Texas, USA, 20-23 June. https://onepetro.org/ARMAUSRMS/proceedings-abstract/ARMA21/All-ARMA21/ARMA-2021-1129/467923

[15] Alagoz, E., Wang, H., Russell, R. T., Sharma, M. M. 2022. New Experimental Methods to Study Proppant Embedment in Shales. Rock Mech Rock Eng 55, 2571-2580 https://doi.org/10.1007/s00603-021-02646-1

[16] Alagoz, E. and Yaradilmis, Y. 2023. Evaluation of Resin Coated Proppants: A New Custom Method. International Journal of Earth Sciences Knowledge and Applications, 2023 (5) 2.