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Acid Fracturing: A Perspective

Yuhan Lingxue[1], **Haoran Qingyun**[1], **Li Hua**[1]*
[1]*Independent Researcher, Yichang, China*

INFORMATION

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Contact
*Li Hua
li_hua102@proton.me

ABSTRACT

This paper provides a comprehensive overview of acid fracturing, a critical technique employed in the petroleum and natural gas industry to enhance productivity. We delve into the underlying principles, mechanisms, and applications of acid fracturing, highlighting its role in mitigating formation damage and improving reservoir permeability. The study explores various acid fracturing techniques, including matrix acidizing, fracture acidizing, and stimulated reservoir volume (SRV) creation. We discuss the selection of appropriate acid types, concentrations, and injection rates based on reservoir characteristics and wellbore conditions. Furthermore, we examine the challenges and limitations associated with acid fracturing, such as acid spending, formation damage, and environmental concerns. To address these issues, we propose potential solutions and future research directions. This paper offers valuable insights for industry professionals seeking to optimize their acid fracturing operations and improve performance.

1. Introduction

Hydraulic fracturing is a widely used technique to enhance hydrocarbon production. It involves creating a network of fractures around a wellbore by injecting high-pressure fluids, proppants, and chemical additives. This process increases reservoir permeability, allowing for improved hydrocarbon flow (Economides et al., 1989; Barati et al., 2014; Zhang et al., 2019; Li et al., 2020). Recent studies have focused on advancing hydraulic fracturing simulation and numerical modeling techniques (Alagoz et al., 2023a; Alagoz et al., 2023a; Dehdouh et al., 2024; Laalam et al., 2024).

Researchers have also explored the evolution of frac fluids (Alagoz et al., 2021; Alagoz et al., 2024), from traditional high-viscosity options to modern formulations suitable for both conventional and unconventional reservoirs. The fracture network created through fracing not only improves reservoir conductivity but also opens up new production opportunities. This technique can be applied to both vertical and horizontal wells. The substantial increase in hydrocarbon production efficiency has made fracking economically viable for accessing previously untapped reserves in tight unconventional formations (Alpkiray and Dundar, 2023). Fracing involves the extraction of natural gas or hydrocarbons from shale and other low-permeability formations. By injecting high-pressure fluids, proppants, and chemicals, the rock is fractured, allowing trapped hydrocarbons to flow to the wellbore. This process requires significant quantities of water, chemicals, and sand.

2. What We Know About Acids

Acid gases are substances that react or dissolve in water to form acids. This research paper focuses on five specific acid gases: sulfur trioxide, nitrogen dioxide, hydrogen chloride, hydrogen bromide, and hydrogen iodide. Notably, hydrogen chloride is the gas that reacts with water to produce hydrochloric acid.

The selected gases meet the following criteria (Brown et al., 1947; O'Neil, 2006).

Anaerobic Reactivity: They react with water in the absence of oxygen, aligning with the anaerobic conditions typically found in reservoirs.

Steel Compatibility: The gases exhibit minimal corrosion effects on low-alloy steel, commonly used in downhole completion systems. This ensures the longevity and integrity of equipment during injection and shut-in periods.

Strong Acid Formation: The gases react with water to produce strong acids, which are essential for effective matrix acidizing treatments.

While these acid gases may react with moisture on steel to initiate corrosion, this effect can be mitigated. Future research may explore strategies to further reduce this potential issue.

2.1. Strong Acid

Strong acids are those that fully dissociate into their constituent ions when dissolved in water. This means that every molecule of the acid breaks down to produce a hydrogen ion (H^+) and its corresponding anion. For example, hydrochloric acid (HCl) dissociates completely into H^+ and Cl^- ions. Key characteristics of strong acids:

- 100% of the acid molecules ionize in solution.
- This leads to a low pH value, indicating a highly acidic solution.
- Strong acids are highly reactive and can readily react with other substances.

Examples of common strong acids are Hydrochloric acid (HCl), Sulfuric acid (H_2SO_4), Nitric acid (HNO_3) and Perchloric acid ($HClO_4$).

2.1.1. The R of Hydronium Ions

While hydrogen ions are often discussed, they actually exist as hydronium ions ($H3O^+$) in aqueous solutions. This is because the hydrogen ion is attracted to the lone pair of electrons on a water molecule, forming a covalent bond. However, both representations (H^+ and $H3O^+$) are commonly used to describe the acidity of a solution.

2.1.2. Importance of Strong Acids

Strong acids have numerous applications in various industries and scientific fields. They are essential for a wide range of chemical reactions and processes, including:

- Production of fertilizers, plastics, pharmaceuticals, and other chemicals.
- Acid-base titrations, pH measurements, and other analytical techniques.
- Acidulants to enhance flavor and preserve products.
- Removal of stains, dirt, and bacteria.

2.2. Acid-Based Reactions

Acids are defined as a substance that donates a hydrogen ion, while a base is a substance that accepts a hydrogen ion. The dissolution of carbonate rocks in reservoirs is a classic example of an acid-base reaction, where the carbonate minerals act as bases. Acids such as carbonic acid and those listed in Table 1 can dissolve carbonate minerals, but strong acids are more effective due to their higher concentration of hydrogen ions (Averill and Eldredge, 2014).

For instance, limestone, primarily composed of calcium carbonate ($CaCO_3$), reacts with acidic solutions to form calcium sulfate ($CaSO_4$), water (H_2O), and carbon dioxide (CO_2). This reaction can be represented by the following equation:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$$

Similar reactions occur between other strong acids and carbonate minerals like dolomite. These acid-rock reactions produce gaseous products, which can have a similar effect to solution gas drive in reservoirs. In the context of acid gas injection, this phenomenon is referred to as a reaction gas drive.

Table 1. Strong acids

Name of Acid	Formula	Ionization (all in aq)
Hydroiodic Acid	HI	$H^+{}_{(aq)} + I^-{}_{(aq)}$
Hydromic Acid	HBr	$H^+{}_{(aq)} + Br^-{}_{(aq)}$
Perchloric Acid	$HCIO_4$	$H^+{}_{(aq)} + ClO_4{}^-{}_{(aq)}$
Hydrochloric Acid	HCI	$H^+{}_{(aq)} + CI^-{}_{(aq)}$
Sulfuric Acid	H_2SO_4	$H^+{}_{(aq)} + HSO_4{}^-{}_{(aq)}$
Nitric Acid	HNO3	$H^+{}_{(aq)} + NO_3{}^-{}_{(aq)}$

3. Acid Applications

3.1. Acid Fracturing

Acid fracturing is primarily used in limestone formations. This technique is particularly effective in carbonate reservoirs as it can stimulate these layers without causing damage. It's a type of hydraulic fracturing that aims to create conductive channels extending from the well into the reservoir. While the overall fracture geometry is similar to other hydraulic fracturing methods, the key distinction lies in the use of acid to enhance fracture conductivity and maintain it over time (Yongqiang et al., 2023).

3.2. Matrix Acidizing

Matrix acidizing is a technique used in both carbonate and sandstone formations. In sandstone formations, its primary purpose is to remediate formation damage caused by perforation operations or other factors that impede fluid flow. Acid is injected into the formation, where it dissolves solid materials clogging the pores, improving fluid flow towards the well (Malic and Hill, 1989).

Matrix acidizing in sandstone is most effective when the formation damage is soluble in acid. In undamaged sandstones, acidizing typically has limited impact. However, in formations with fractures or natural vugs, acidizing can be more beneficial. In carbonate reservoirs, matrix acidizing is often characterized by the formation of wormholes, which are channels etched into the rock by the acid (Fig. 1). This process enhances fluid flow in the near-wellbore region (Nierode and Kruk, 1973).

3.3. Formation Damage

Hydraulic fracturing can lead to formation damage through several mechanisms, including:

- Solid particles can be carried by the fracturing fluid and become trapped in the formation.

- Incompatible fluids within the formation can cause issues like phase separation or emulsification.
- Unbroken polymer gels can obstruct fractures, limiting fluid flow.
- Trapped particles can undergo chemical or physical changes, further contributing to damage (Alagoz et al., 2022).

Using low viscosity fracturing fluids with appropriate additives can help mitigate these issues by reducing particle migration and improving fluid flow properties. Additionally, hydraulic fracturing tends to reduce formation damage by creating fractures that provide a more direct pathway for fluid production, minimizing the need for flow through the surrounding formation.

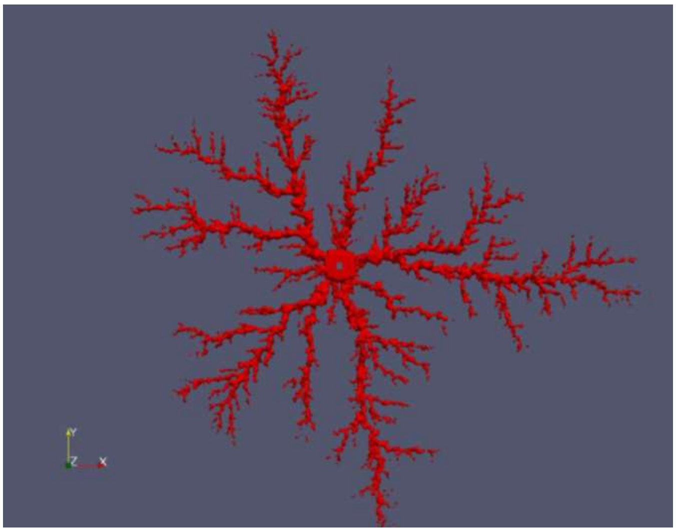

Fig. 1. Worm hole illustration by acids (Schwalbert et al., 2019)

4. Selection of Acidizing Methods

In acidizing operations, decision-making hinges on a thorough understanding of well-specific data, which encompasses reservoir rock characteristics, well pressure profiles, and productivity indices. This comprehensive evaluation allows operators to define clear objectives, such as enhancing production rates, while guiding the selection of the most effective treatment method. A systematic analysis of available acidizing techniques, along with their respective advantages and limitations, enables the selection of the most appropriate system. For instance, matrix acidizing may be chosen to dissolve formation damage near the wellbore, while fracture acidizing might be favored to extend treatment into the reservoir matrix. Alternatively, in cases where only minor cleanup is needed, an internal acid wash might suffice. Importantly, the latter method often bypasses the need for complex design considerations. Thus, by integrating all relevant data and carefully assessing potential approaches, acidizing operations can be tailored to maximize well productivity effectively.

5. Conclusion

In conclusion, hydraulic fracturing and acidizing techniques play a pivotal role in enhancing hydrocarbon production, particularly in low-permeability formations. Through a comprehensive understanding of well-specific data, including reservoir properties, pressure profiles, and production indices, operators can make informed decisions regarding the most suitable acidizing method. Matrix acidizing is often employed to dissolve formation damage, while fracture acidizing is used to extend fractures into the reservoir matrix. Additionally, in cases requiring minimal intervention, an internal acid wash can effectively clean the well without the need for complex designs. Each method's success depends on careful evaluation of formation characteristics and fluid behavior, ensuring the chosen approach aligns with the well's needs and maximizes productivity. Future advancements in acid chemistry and acid-fracturing technology will likely continue to improve the efficiency of these operations, reducing formation damage and increasing hydrocarbon recovery.

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