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ENHANCING ACID STIMULATION TREATMENTS IN THE PETROLEUM FIELDS

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Abstract:

This literature study specifically examines methods to enhance acidizing treatment in the oil fields, which are situated in the Western Desert. Acidizing is a chemical process that stimulates the permeability of rock formations around wellbores, hence increasing the flow of oil. The article presents a comprehensive examination of the matrix acidizing and acid fracturing techniques that are often used in carbonate and sandstone formations. The text underscores the need of choosing suitable acid concentrations and assessing reservoir conditions to enhance treatment results and avert unfavorable repercussions. The research emphasizes the important function of hydrochloric acid (HCl) in increasing oil production and examines the use of acid combinations, such as HCl and hydrofluoric acid (HF), for particular purposes. The analysis focuses extensively on the impact of formation damage and the skin effect on the effectiveness of acid therapy. The text discusses many methodologies for detecting and evaluating formation damage, including as well performance analysis, well logging, and core analysis. The research also examines techniques for enhancing acidizing therapy when faced with formation damage and the skin impact. The mentioned aspects include pre-treatment assessment, design of acid systems, implementation of diversion techniques to improve acid distribution, and the integration of acidic additives and enhancers. The significance of doing a post-treatment review to assess the effectiveness of the therapy and ascertain the need for further corrective actions is highlighted.
Keywords: acidizing therapy, matrix acidizing, acid fracturing, formation damage, skin reaction.

1. Introduction

The matrix acidizing procedure refers to a chemical stimulation approach whereby acid mixes are injected into rocks around the wellbore at pressures below their fracture thresholds. The primary objective of this process is to enhance the permeability of rock formations by dissolving sediments, so facilitating the unrestricted flow of oil into the wellbore zone and establishing a clean zone inside the reservoir. Matrix acidizing is commonly used for tighter carbonate and sandstone formations. In the industry, it is advised to use acids with mass concentrations ranging from 10% to 15%. On the other hand, acid fracturing is employed for carbonate formations, with higher acid mass concentrations ranging from 20% to 30% [1,2]. This methodology entails the injection of acid to generate channels, sometimes referred to as wormholes, wherein the subsequent cracks in the rock may potentially facilitate the migration of hydrocarbons under pressure.

It is important to mention that in some specialized scenarios, such as those involving sediments with high water saturation, an additional technique known as acid washing may be necessary [3,4]. The two procedures listed above are often distinguished based on their injection rates and fracture pressures. According to Rabbani et al. [5], the selection of appropriate acidizing procedures is influenced by the physical parameters of the reservoir, including rock permeability. When formulating a matrix treatment, such as the dissolution of calcites, quartz, or clay minerals, it is crucial to thoroughly evaluate the many damage processes that might impact the reservoir's response to acid treatments [2].

Hydrochloric acid (HCl) is well recognized for its significant role in augmenting oil production. It offers distinct advantages in the removal of dolomite and limestone constituents from reservoirs, making it a widely used technique in carbonate acidizing [6]. Mixtures of HCl and hydrofluoric acid (HF) are often used in some applications to enhance the dissolution of sandstones and other silicate components present in reservoir rocks [5,7]. The primary goals of well stimulation include the mitigation or circumvention of formation damage, resulting in a decrease in debris generation, and the ultimate removal of gravel packs [8,9].

Although matrix acidizing is a widely used technique, there is a limited amount of research available on its impact on the physical properties and recovery variables in oil reservoirs. Morsy et al. [10] conducted a study to examine the impact of HCl treatment on the porosity, spontaneous inhibition, and formation distribution of investigated wells. Their evaluation was characterized by a relatively intricate methodology, which focused on the utilization of specific parameters such as formations' decipherability and crack distributions. In contrast, the studies conducted by Wilfred and Umeleuma [11] have provided insights into the involvement of mixed acids in the acidizing procedure. However, it is important to exercise caution when determining the mineralogy of the formation, water saturation in the reservoir, and the introduction of additives in the investigated oil fields. This precautionary approach is necessary to prevent undesirable consequences, such as the formation of emulsions.

2. Formation damage

The mitigation of formation damage and the assessment of skin impact are crucial factors in enhancing the efficacy of matrix acidizing procedures inside oil fields. Matrix acidizing is a well-established stimulation method used in the oil and gas industry to improve the productivity of reservoirs by selectively dissolving or eliminating any formation damage in the vicinity of the wellbore. Nonetheless, the efficacy of the therapy may be impeded by the occurrence of formation damage, such as the skin effect [12].

Formation damage is a term used to describe the compromised permeability or diminished flow capacity of the rock formation in the vicinity of the wellbore. The occurrence of this phenomenon may be attributed to a range of reasons, including the infiltration of drilling fluids, the movement of fines, the precipitation of solids, the deposition of organic matter, and interactions between fluids and rocks. Formation damage is a phenomenon that imposes limitations on the flow of fluids and diminishes the effectiveness of matrix acidizing treatments [9].

The skin effect refers to the quantification of the incremental pressure drop or resistance to fluid flow in the vicinity of the wellbore relative to the unaltered reservoir. The skin factor is a dimensionless quantity that serves as a representation of the phenomenon. A positive skin factor signifies an increase in pressure drop, while a negative skin factor suggests an augmentation in flow near the wellbore. The occurrence of skin effect may be attributed to several reasons, including formation damage, wellbore geometry, fluid characteristics, and completion procedures [13].

2.1. Identification of Formation Damage and Skin Effect

2.1.1. Well Performance Analysis

The analysis of well performance entails the systematic monitoring and examination of production data and pressure dynamics. This process allows the identification of potential formation damage and the assessment of the skin effect. Occurrences of formation damage or a skin effect might be indicated by deviations from anticipated productivity and pressure behavior.

2.1.2. Well Logging and Imaging Techniques

The study focuses on the methods and techniques used in well logging and imaging. Different types of well logging instruments, including resistivity, neutron, and density logs, may be used to detect the existence of formation damage. Imaging methods like as micro-resistivity imaging and nuclear magnetic resonance (NMR) have the capability to provide comprehensive insights into the near-wellbore area, facilitating the visualization of damage extent.

2.1.3. Core Analysis

The acquisition of core samples from the reservoir and subsequent laboratory examination might provide empirical data pertaining to the occurrence of formation damage. Various core analysis methods, including as measures of porosity and permeability, study of pore size distribution, and examination of mineralogical composition, may be used to ascertain the kind and magnitude of formation damage.

2.2. Types of Formation Damage

2.2.1. Mechanical Damage

Mechanical damage refers to the occurrence of damage caused by the infiltration of drilling fluids, leading to the creation of filter cakes or mud solids in close proximity to the wellbore. These solid particles have the capacity to obstruct the passageways of pores and thereby decrease the permeability of the medium.

2.2.2. Chemical Damage

One potential cause of damage in reservoirs is chemical interactions that occur between the fluids inside the reservoir and the minerals present in the formation. These reactions may result in the production of solid deposits, such as scales or mineral clogs, which have the potential to obstruct pore spaces and decrease the permeability of the reservoir.

2.2.3. Organic Damage

The presence of organic substances, such as asphaltenes or paraffins, may lead to the deposition and accumulation of these compounds in the vicinity of the wellbore, hence impeding fluid flow and diminishing permeability.

2.2.4. Fines Migration

The migration of tiny particles, such as clay minerals, may transpire as a result of pressure gradients or changes in fluid composition. The particles have the potential to migrate into the pore throats, resulting in obstruction and a decrease in permeability.

2.3. Improving Matrix Acidizing Treatment in the Presence of Formation Damage and Skin Effect

2.3.1. Pre-treatment Evaluation

Prior to treatment, a comprehensive assessment of reservoir and well data is conducted, including well performance analysis, well logging, and core analysis. This evaluation aids in the identification of the kind and magnitude of formation damage. The acquisition of this information is important in order to facilitate the development of a proficient matrix acidizing treatment [13].

2.3.2. Acid System Design

The process of acid system design involves the careful selection of acid formulation, concentration, and additives in order to efficiently dissolve or eliminate the particular kind of formation damage that exists in the reservoir.

2.3.3. Utilization of Diversion methods

In scenarios where the occurrence of formation damage is characterized by non-uniform or localized patterns, the implementation of diversion methods becomes imperative in order to achieve optimal acid distribution over the whole of the productive reservoir zone. In order to enhance treatment efficiency, acid diversion may be achieved by the use of mechanical or chemical diverters. This process involves redirecting acid into the affected regions [14].

2.3.4. Acidic Additives and Enhancers

The incorporation of supplementary substances, such as surfactants, chelating agents, or corrosion inhibitors, may augment the efficacy of acid treatment by ameliorating the detrimental effects on the formation, diminishing the creation of emulsions, or averting the corrosive interaction between the acid and wellbore materials [15].

2.3.5. Post- Treatment Evaluation

The evaluation conducted subsequent to treatment, including production logging and pressure analysis, assumes a critical role in gauging the efficacy of the matrix acidizing therapy and ascertaining the need for further remedial measures.

3. Acid stimulation

Acid stimulation, also known as acidizing or acid treatment, is a well stimulation method used within the oil and gas sector to augment the productivity of reservoir formations. The process involves the use of acids in the wellbore and its surrounding area to dissolve or eliminate formation damage, enhance permeability, and optimize fluid flow [9].

3.1. Theory of Acid Stimulation

The underlying principle of acid stimulation is predicated on the chemical interaction between the acid and the rock formation. The acid used in these treatments often consists of a blend of HCl and other chemicals. Upon contact with the reservoir rock, the acid has a chemical reaction with specific minerals found within the formation, mostly carbonates and select silicates. The acid has a chemical reaction with the minerals present, resulting in their dissolution and the subsequent formation of channels or passageways inside the rock. This process ultimately leads to an increase in the rock's permeability. The procedure referred to as acid dissolution is used to eliminate several forms of formation damage, including drilling mud particles, scale deposits, and other precipitates that impede fluid movement by obstructing the pore spaces [9].

3.2. Acid Stimulation Techniques

3.2.1. Matrix Acidizing

Matrix acidizing is a widely used acid stimulation technology that is mostly utilized for the treatment of the near-wellbore area. The acid is introduced into the reservoir formation by injection, using a pressure level that is lower than the pressure required to induce fracture in the formation. The acid treatment is strategically formulated to induce the formation of wormholes or channels inside the rock matrix, with the objective of enhancing the hydrocarbon flow towards the wellbore. Matrix acidizing is known for its high efficacy in carbonate reservoirs; however, it may also be used in sandstone formations [16].

3.2.2. Fracture Acidizing

Fracture acidizing is a technique that entails the injection of acid into an already-existing fracture network inside the reservoir. This methodology is used in cases where the reservoir has inherent or created cracks that have the potential to greatly augment the movement of fluids. The acid is injected into the cracks at an elevated pressure in order to induce their propagation and extension, enhancing the connection between the reservoir and the wellbore [17].

3.2.3. Acid Fracturing

Acid fracturing is a method that integrates the processes of hydraulic fracturing with acidizing. The process involves the injection of a combination of acid and fracturing fluid into the reservoir with the aim of generating or augmenting cracks. The dissolution of minerals by acid on the fracture surfaces leads to the expansion of fractures, enhancing the flow capacity. Upon the conclusion of the acid treatment, it is common practice to use proppants in order to sustain the fractures' aperture and impede their closure [16].

3.2.4. Sandstone Acidizing

Sandstone acidizing is a unique acid stimulation method used specifically for sandstone reservoirs. In contrast to carbonate formations, sandstone rocks consist mostly of silica and have limited solubility in acidic environments. Sandstone acidizing involves the utilization of acid to eliminate clays or particles that have the potential to obstruct the pore spaces and diminish permeability. The use of acid treatment facilitates the dispersion or dissolution of clay particles, enhancing the permeability of fluids inside the rock matrix [17].

3.2.5. Acid Diversion

The use of acid diversion procedures is a common practice in acid stimulation treatments aimed at achieving a consistent and even dispersion of acid throughout the reservoir formation. Mechanical or chemical diverters are used in order to redirect the acid towards regions within the formation that exhibit more damage or lower permeability. This serves to hinder the creation of preferred flow routes and ultimately enhances the efficacy of the treatment. It is important to acknowledge that acid stimulation therapies need meticulous planning and implementation in order to mitigate formation impairment and guarantee safety. During the treatment design process, considerable consideration is given to factors such as the concentration of acid, the rate of injection, the contact duration, and the compatibility with reservoir fluids and materials [14].

4. Acid Additives

Acid additives play a vital role in acid stimulation treatments by enhancing the acid's efficacy and enhancing the overall performance of the treatment. These additives are selected with care and incorporated into the acid formulation in order to resolve specific challenges encountered during acidizing operations. They can alter the acid's properties, reduce formation damage, enhance fluid compatibility, and improve treatment outcomes [18].

4.1. Types of Acid Additives

4.1.1. Anticorrosion Agents

Corrosion inhibitors are compounds used to prevent acid-induced corrosion of the metal components of the wellbore and production apparatus. Typically, acid treatments involve the application of strong acids, such as HCl, which can corrode metal surfaces. On metal surfaces, corrosion inhibitors form a protective film, averting acid attack and decreasing the rate of corrosion. They are typically organic compounds that form a barrier between the acid and the metal by adsorbing onto metal surfaces. In acid treatments, phosphonates, amines, and organic acids are frequently used as corrosion inhibitors [19].

4.1.2. Surfactants

Surfactants, also known as surface-active agents, are additives that modify the interfacial tension between acid and reservoir fluids, thereby enhancing fluid flow and penetrability. They can diminish the capillary forces that contain fluids within a formation, allowing the acid to penetrate deeper into the rock matrix. Additionally, surfactants can aid in the elimination of emulsions or confined gas bubbles, thereby enhancing the acid's contact with solid surfaces. By decreasing interfacial tension, surfactants improve the wettability of the rock, thereby enhancing fluid flow and acid distribution. In acid treatments, non-ionic, anionic, and cationic surfactants are frequently used [7].

4.1.3. Clay Stabilizers

Clay stabilizers are additives used to reduce swelling or dispersion of clay minerals present in the reservoir formation. Clays can be highly reactive and can swell or migrate into formation pores, causing formation damage and lowering permeability. Clay stabilizers interact with clay particles to prevent enlargement or migration and preserve the formation's integrity. These additives can be polymers or inorganic compounds that modify the physicochemical properties of clay by adsorbing onto its surfaces. Polyphosphates, lignosulfonates, and zirconium compounds are frequently used as clay stabilizers [20].

4.1.4. Iron Control Agents

Iron control agents, also referred to as iron sequestrants or iron chelating agents, are employed to prevent the precipitation of iron compounds during acid treatments. Iron may exist in reservoir fluids or be discharged from the formation as a result of acid-rock reactions. Iron precipitation can result in the formation of particulates or scales that can clog pores and impede fluid passage. Iron control agents chelate or form complexes with iron ions to prevent their precipitation and maintain their solubility. Organic acids such as citric acid and EDTA (ethylene diamine tetra acetic acid) are common iron chelating agents [15].

4.1.5. Clay Dispersants

Clay dispersants are additives used to disperse or dissolve clay particles in the reservoir formation. These additives prevent clay particles from aggregating or swelling, ensuring that they remain suspended in the fluid. Clay dispersants reduce the risk of clay migration, pore blockage, and formation injury by keeping clay particles dispersed. In acid treatments, organic acids, lignosulfonates, and phosphonates are commonly used as clay dispersants [20].

4.1.6. Emulsion Breakers

Emulsion breakers, also known as demulsifiers, are additives used to break up emulsions that form during acid treatments. When acid comes into contact with reservoir fluids containing hydrocarbons or water, emulsions can form. Emulsions can impede fluid flow, reduce acid penetration, and diminish treatment efficacy. Emulsion crushers destabilize the emulsion by decreasing the interfacial tension between the oil and water phases, thereby facilitating phase separation. Typically, they are surfactants or organic compounds that facilitate droplet coalescence and coagulation.

4.1.7. Fluid Loss Control Agents

Fluid loss control agents are additives used to prevent excessive fluid loss during acid treatments. When acid is injected into a reservoir, it can seep into the formation, reducing the amount of acid available for repairing formation damage. Fluid loss control agents produce a filter coating or seal on the formation face, thereby reducing fluid loss and sustaining a higher acid concentration in the vicinity of the wellbore. These additives can be polymers, particulates, or fibers that prevent fluid flow by bridging the capillary entrances [21].

4.1.8. pH Buffers

pH buffers are used to stabilize the pH of acidic solutions during treatment. During the reaction with the formation minerals, the pH of the acid can change, and sustaining the intended pH range is essential for the treatment's efficacy. pH buffers assist in regulating and maintaining the desirable acidity level, ensuring optimal mineral dissolution and preventing excessive acid consumption. In acid treatments, common pH buffers include sodium carbonate, sodium bicarbonate, and ammonium chloride.

4.1.9. Scale Inhibitors

Scale inhibitors are additives that prevent the precipitation of scale-forming minerals, including calcium carbonate and calcium sulfate, during acid treatments. Scale formation can occur when acid reacts with the formation's minerals or when incompatible fluids combine. Deposits of scale can reduce permeability and impede fluid passage. Scale inhibitors inhibit crystal growth by adsorbing onto their surfaces, thereby preventing scale formation. Phosphonates, polyacrylates, and other organic compounds may be present [20].

4.1.10. Biocides

Biocides are additives used to control the growth of microorganisms, such as bacteria and fungi, that can flourish in the reservoir and create biofouling or well sourness. Due to the presence of organic matter or changes in fluid composition, acid treatments can create favorable conditions for microbial development. Biocides are added to the acid formulation to eradicate or inhibit the growth of microorganisms, thereby preventing the formation of biofilm, corrosion, and well sourness. It is essential to remember that the selection and administration of acid additives depend on reservoir-specific conditions, treatment objectives, and additive compatibility. To guarantee the efficacy and safety of the acid treatment, proper testing, compatibility studies, and field experience are necessary.

5. Carbonate Acidizing

Carbonate acidizing is a technique used in the oil and gas industry to increase the productivity of carbonate reservoirs. Carbonate formations, such as limestone and dolomite, are predominately composed of calcium carbonate ($CaCO_3$) and have distinctive characteristics that necessitate specific acidizing strategies [22].

5.1. Acidizing with Hydrochloric Acid

Due to its intense reactivity with carbonate minerals, HCl is the most frequently employed acid for acidifying carbonate. The reaction between HCl and calcium carbonate produces water, carbon dioxide, and soluble calcium chloride. The reaction aids in the dissolution of carbonate minerals and the elimination of formation damage, thereby increasing the reservoir's permeability. The acid concentration and injection rate are meticulously devised based on the characteristics of the formation in order to optimize dissolution and prevent excessive acid penetration [22].

5.2. Gelled Acids

Gelled acids are acid formulations containing viscosifying agents that increase the viscosity of the acid. The addition of gelling agents, such as polymers or cross-linking agents, enhances acid diversion and carbonate formation penetration depth. Gelled acids can amplify the acid wormholing effect, which generates preferential flow paths for more uniform acid distribution and treatment coverage. Additionally, the gelling agents reduce fluid leakage and increase acid contact time with the formation. Guar gum, hydroxypropyl guar (HPG), and hydroxyethyl cellulose (HEC) are three common gelling agents found in gelled acids [23].

5.3. Emulsion Acids

Emulsion acids are acid formulations that contain surfactants and emulsifiers in order to form a stable emulsion of acid and hydrocarbon phase. The emulsion assists in regulating the acid reaction rate and optimizing acid distribution within the carbonate reservoir. The surfactants and emulsifiers decrease the acid's reactivity, allowing for a delayed, more regulated dissolution of carbonate minerals. Emulsion acids are particularly valuable in heterogeneous carbonate formations due to their superior acid diversion and penetrability into zones with limited permeability. The stability and viscosity of the emulsion can be modified to accommodate reservoir conditions and treatment objectives [23].

5.4. Natural Acids

Alternative acidifying formulations for carbonate reservoirs include formic acid, acetic acid, and citric acid. Organic acids have delayed reactivity than HCl, making them appropriate for carbonate formations containing a high proportion of acid-soluble minerals. Organic acids are less corrosive and have a smaller impact on the environment compared to mineral acids. They can dissolve carbonate minerals and repair formation damage while minimizing the risk of excessive acid penetrating the formation. Organic acids are frequently combined with other acidifying techniques, such as gelled acids or emulsion acids, to improve treatment effectiveness [23].

5.5. Combination Acidizing Methods

In some instances, a combination of acidizing methods may be used to maximize the efficiency of carbonate reservoir remediation. For instance, a treatment could consist of an initial phase of gelled acid or emulsion acid to improve diversion and penetration, followed by the application of hydrochloric acid to improve the dissolution of carbonate minerals. This combination approach assists in addressing the difficulties associated with heterogeneous reservoirs and allows for treatment designs that are tailored to the reservoir's specific characteristics. It is essential to observe that the choice of acidizing formulation depends on a number of variables, including reservoir characteristics, wellbore conditions, and treatment objectives. To ensure an effective and secure acidizing operation, the acid type, concentration, viscosity modifiers, and additives are meticulously selected based on the formation mineralogy, permeability, temperature, and other parameters [22].

6. Wormhole Formation

The development of wormholes plays a crucial role in acid stimulation treatments, especially in carbonate reservoirs. A wormhole is a term used to describe a complex system of linked channels or passageways that are formed inside reservoir rock as a result of mineral dissolution via acid-induced reactions. These wormholes serve as preferred flow pathways for fluids, providing for greater communication between the reservoir and the wellbore. The optimization of acid stimulation treatments and the improvement of fluid flow efficiency require the maximization of wormhole length [24].

6.1. Factors Affecting the Formation of Wormholes

The focus of this discussion is on the concentration of acid. The acid concentration used in the treatment process is a pivotal factor in the creation of wormholes. The rate of dissolution is enhanced by higher acid concentrations, resulting in a more pronounced formation of wormholes. Nevertheless, an overabundance of acid concentrations may lead to fast etching and the formation of broad channels, which may not be favorable in some circumstances. In order to get the appropriate wormhole length, it is necessary to meticulously tune the acid concentration, taking into consideration the reservoir features and treatment goals [24].

The duration of acid contact is a crucial parameter that significantly influences the creation of wormholes in the rock. Increased contact durations facilitate enhanced dissolution of minerals, resulting in the development of elongated wormholes. The duration of contact may be regulated by manipulating the injection pace and the amount of acid administered. Nevertheless, it is important to take into account the reactivity of the acid and the potential hazards associated with excessive dissolving, as this might result in channel breakthrough or over-etching. The concept of formation permeability refers to the capacity of a geological formation to allow the flow of fluids, such as water or hydrocarbons. The impact of reservoir formation permeability on the development and length of wormholes is significant.

Formations with higher permeability provide enhanced fluid accessibility and enable the production of elongated wormholes. The acid has the capability to infiltrate the formation to a greater depth, facilitating the dissolution of minerals over a broader expanse and consequently leading to the construction of more extensive networks of wormholes. In rocks with poor permeability, the attainment of extensive wormholes might present more difficulties owing to constrained acid penetration and limited dissolving capabilities [25].

The field of study known as mineralogy focuses on the scientific examination and classification of minerals. The mineral composition of the reservoir rock has a substantial influence on the initiation and development of wormholes. Various minerals have different levels of reactivity when exposed to acids. Carbonate minerals, such as calcite or dolomite, exhibit increased solubility in the presence of acid, rendering them more susceptible to the development of wormholes. The inclusion of clay minerals or silicates has the potential to impede the process of dissolution and impose constraints on the extent of wormhole formation. A comprehensive understanding of the mineralogy of the formation is of utmost importance in ascertaining the appropriate acid type and concentration necessary for the successful development of wormholes [25].

6.2. Strategies for Maximizing the Length of Wormholes

The use of acid diversion procedures may optimize the length of a wormhole by ensuring the even dispersion of acid throughout the reservoir formation. In the field of acid diversion techniques, mechanical or chemical diverters are used to effectively redirect the acid towards regions within the formation that exhibit either more damage or less permeability. Acid diversion methods provide enhanced dissolution and wormhole growth in previously untreated regions by redirecting acid away from favored flow pathways, boosting the total length of the wormhole [25].

Step-rate testing is a method used to assess an individual's cardiovascular fitness. Step-rate testing is a methodology used to enhance the efficiency of acid injection rates in the context of treatment procedures. The injection rate is incrementally increased in successive phases while simultaneously observing the pressure reaction. This methodology facilitates the determination of the optimal injection rate for achieving maximum effectiveness in wormhole creation. Step-rate testing has the potential to enhance treatment efficiency and increase the length of wormholes by identifying the best injection rate.

Sequential stimulation is a technique that entails the implementation of several acid treatments in a phased fashion. The first acid treatment induces the formation of shorter wormholes in close proximity to the wellbore, while successive treatments are focused on reaching deeper zones or untreated regions. This methodology facilitates the expansion of wormholes into previously unexplored territories, thereby optimizing the overall extent of the wormhole network. Sequential stimulation has been shown to be advantageous in the context of heterogeneous reservoirs or reservoirs that exhibit changing permeability [24].

The selection of acid additions has the potential to influence both the creation and length of wormholes. Specific additives, such as surfactants, have the capability to decrease interfacial tension and augment acid penetration, resulting in the formation of elongated wormholes with increased length. The use of clay stabilizers serves the purpose of mitigating clay migration and preserving the structural integrity of wormholes. The use of additives that enhance the uniform distribution and dissolution of acid may significantly contribute to the optimization of wormhole length [23].

Advanced reservoir modeling and simulation approaches may be used to forecast and enhance the emergence of wormholes. The aforementioned models have the capability to replicate acid injection and dissolution phenomena, taking into account many elements like reservoir permeability, mineral composition, acid characteristics, and injection parameters. Engineers may use modeling tools to evaluate different situations and ascertain procedures that optimize the length of wormholes prior to executing the therapy in practical settings [23].

7. Sandstone Acidizing

The primary objective of sandstone matrix acidizing is to effectively dissolve or eliminate siliceous particles, including as clay, feldspar, and quartz, which impede the flow of hydrocarbons and diminish permeability in the vicinity of the wellbore. The desired outcome may be attained by the introduction of hydrofluoric acid (HF acid) or its precursor substances. Following its discovery in 1935, HF was widely used for the purpose of mitigating damage and addressing issues associated with drilling and production damage in sandstone formations. Originally, the primary use of this acid was restricted only to the elimination of the mud filter cake. However, it is currently being employed to address many issues, including the removal of siliceous particles and the mitigation of damage in the vicinity of the wellbore. The efficacy of this acid in the treatment of sandstone formations with low concentrations of calcium minerals has been shown [26].

The particles involved in sandstone formation, including sand grains, feldspar, and clays, exhibit reactivity when exposed to HF due to the specific tendency of fluoride ions (F^-) to react with silica and clay constituents. Shafiq and Mahmud [26] demonstrated the inherent reactivity of HF with silica, therefore establishing its remarkable use in the field of sandstone acidizing. The effectiveness of hydrochloric, sulfuric, and nitric acids in reacting with sandstone formations was found to be limited, as shown by Smith and Hendrickson's study in 1965. In the year 1940, Dowel proposed the concept of combining HCl with HF as a means to minimize the likelihood of precipitation of reaction products. The substance in question is often referred to as mud acid. In the context of sandstone acidizing, it is customary to introduce the mud acid into the system with a specific composition consisting of 3% HF and 12% HCl, as outlined by Abdelmoneim and Nasr-El-Din [27].

The process of sandstone acidizing presents significant difficulties and challenges, mostly stemming from the complex interactions between various fluids and the minerals present in the porous medium. The interactions between fluids and minerals have the potential to induce precipitation processes, which may lead to a reduction in the permeability of the reservoir. The achievement of desired outcomes in the removal of damage during sandstone acidizing is sometimes hindered by the occurrence of many phases of fluids-formation reactions. During the process of sandstone acidizing, it is possible for precipitation processes to take place, resulting in the occurrence of formation damage and subsequent decrease in both permeability and porosity [26].

The use of mud acid for acidizing is a prevalent method employed in the oil and gas sector to enhance the efficiency of reservoir formations by dissolving or eliminating any damage present within the formation. Mud acid, sometimes referred to as clay acid or retarded acid, is a composite solution that includes HCl and other substances that augment its efficacy and regulate its reactivity.

7.1. Fluid Design for Mud Acid Acidizing

The topic of discussion pertains to the fluid design used in the process of mud acid acidizing. The fluid design for mud acid acidizing entails the careful selection of acid type, concentration, and volume in order to get the required stimulation outcomes, taking into account formation features and operational limitations [28]. Several elements are taken into consideration while implementing fluid design:

7.1.1. Classification of Acid

Mud acid is often composed of a blend of HCl and several supplementary substances. Additives are used to alter the reactivity of the acid, regulate corrosion, and inhibit excessive clay swelling. Typical additives often used in many industries include corrosion inhibitors, clay stabilizers, iron control agents, and surfactants [7].

7.1.2. Concentration of Acid

The acid concentration pertains to the proportion of HCl inside the mud acid combination. The determination of concentration relies on the parameters of the formation, including mineralogy, porosity, and permeability, in addition to the required reaction rate. Concentrations often span from 5% to 28%, while higher concentrations provide more pronounced acid reactions [7].

7.1.3. Acid Volume

The acid volume refers to the cumulative quantity of mud acid that is introduced into the well. The determination of treatment coverage is contingent upon many factors, including the dimensions of the wellbore, the properties of the reservoir, and the intended outcome of the treatment. The volume must be enough to provide consistent coverage of the target formation and to accommodate fluid losses and dilution effects [7].

7.1.4. Byproducts of Mud Acid Reactions

During the process of mud acidizing, a series of chemical reactions take place between the acid and the minerals present in the formation. These chemical reactions have the potential to yield secondary substances [16]. The typical byproducts resulting from interactions with mud acid encompass:

- **Iron chloride ($FeCl_2$) and iron sulfide (FeS)**

Iron chloride ($FeCl_2$) and iron sulfide (FeS) are often generated as secondary products during mud acid reactions. The formation or wellbore may experience clogging or formation damage due to the possible precipitation of these byproducts, necessitating appropriate management [16].

- **Acid-Soluble Minerals**

Mud acid has the ability to dissolve minerals that are soluble in acid, including carbonate minerals such as calcite and dolomite, as well as some silicate minerals. The process of mineral dissolution aids in the mitigation of formation damage and the improvement of reservoir permeability [16].

7.2. Methods to Control Precipitates

To ensure successful mud acid acidizing and prevent the formation of precipitates, several methods can be employed [22]:

7.2.1. Techniques for Retardation

Retardation techniques include the incorporation of additives into the composition of mud acid in order to regulate its reactivity and decelerate the pace of chemical reactions. Prominent retardation agents include many organic acids, including acetic acid, formic acid, and citric acid. These additions serve to mitigate the likelihood of precipitate development and enhance the acid's ability to penetrate deeper into the formation.

7.2.2. Acid Additives

Acidic additives may be included in the composition of mud acid in order to regulate the occurrence of precipitates. These additives have the potential to function as chelating agents, forming complexes with metal ions in order to hinder their precipitation. Illustrations of such additives include iron control agents, scale inhibitors, and sequestering agents [15].

7.2.3. Pre-flush and Post-flush Fluids

Pre-flush and post-flush fluids are used as a means to mitigate the interaction between mud acid and formation minerals that are incompatible, thereby decreasing the likelihood of precipitate formation. Pre-flush fluids include several options, such as water, brine, or other fluids that are suitable. On the other hand, post-flush fluids are often formulated to effectively remove any leftover acid and its byproducts from both the wellbore and the formation [22].

7.2.4. Optimization of Acidizing Fluid Design

The optimization of fluid design parameters, including acid content, injection rate, and contact duration, may effectively mitigate the potential for precipitate formation. The successful stimulation of wells may be ensured by the appropriate design and implementation of acidizing treatments, which should include the incorporation of real-time monitoring and control measures. By using these strategies, the production of precipitates can be minimized, thereby optimizing the overall treatment process [16].

8. Chemical Diversion Techniques

Chemical diversion methods are often used in well stimulation and acidizing operations to optimize fluid distribution within the reservoir and augment the effectiveness of the treatment process. The aforementioned procedures include the use of chemical agents to redirect the treatment fluid away from zones with high permeability or sections of the formation that have previously undergone stimulation, towards regions that possess lower permeability or have experienced damage. This improves treatment uniformity and increases contact between the treatment fluid and the reservoir rock [21].

8.1. Gelled Diversion Methods

The gelled diversion approach encompasses the introduction of a cross-linked polymer gel or a viscous fluid into the wellbore. The gel substance creates a transient obstruction or seal inside regions with high permeability, redirecting the following treatment fluid towards places with lower permeability. The gels that are often used for diversion purposes include polymer gels, cross-linked guar gels, and viscoelastic surfactant (VES) gels [29].

a) Application

The use of gelled diversion methods has shown to be very efficient in reservoirs characterized by heterogeneity, where there are distinct variations in permeability zones. These devices aid in the prevention of fluid channeling and facilitate the equal distribution of therapy. Gels find use in both matrix acidizing and hydraulic fracturing procedures.

b) Potential Challenges

There are many possible issues that are related with gelled diversion strategies.

- The importance of gel stability and compatibility lies in the need to ensure the stability and compatibility of the gel system with both the treatment fluid and the reservoir conditions. The deterioration of gel or the occurrence of early gelation has the potential to impede fluid diversion and diminish the overall efficacy of the therapy.
- Gel residue may persist inside the wellbore or in close proximity to the formation face subsequent to the treatment. The presence of this residue has the potential to hinder the production of a well or disrupt subsequent operational activities. It is essential to adhere to appropriate cleanout protocols in order to effectively eliminate any residual gel [30].

8.2. Particulate Diversion Technique

The technique of particulate diversion encompasses the introduction of solid particles into the wellbore with the purpose of creating temporary obstructions in high-permeability zones. The particles used in this context include granular materials, including but not limited to sand, resin-coated particles, and degradable fibers [31].

a) **Applications**

Particulate diversion methods are often used in matrix acidizing treatments to redirect the acid towards locations with lower permeability. These devices have the ability to regulate the movement of fluids and facilitate the even dispersion of acid. Particulates are also used in hydraulic fracturing operations for the purpose of managing fracture expansion and mitigating excessive fluid loss to fractures with high permeability [31].

b) **Potential Problems**

There are potential challenges and concerns that are linked to the use of particle diversion strategies [31].

- The efficient transportation and suspension of particles are crucial for ensuring the successful diversion process. The deposition or accumulation of particles inside the wellbore or in close proximity to the formation face may obstruct the flow of fluids and adversely impact the efficacy of treatment processes.
- Residual particles may persist in the wellbore or in close proximity to the formation face after the treatment. These particles have the potential to hinder the flow of fluids, reduce the productivity of wells, or result in damage to the formation. It is important to ensure thorough and effective cleaning and elimination of any remaining particles.

8.3. Foam Diversion Technique

The foam diversion technique is a method that entails the introduction of foam into the wellbore. The foam serves as a transient obstruction, redirecting following treatment fluids away from zones with high permeability and towards areas with lower permeability. Foams used for diversion purposes are often produced by the combination of a foaming agent with an appropriate gas, such as nitrogen or carbon dioxide [32].

a) Applications

Foam diversion methods are often used in the context of matrix acidizing and acid fracturing operations. These devices demonstrate efficacy in regulating the flow of fluids, reducing the occurrence of channeling, and facilitating the even distribution of acid. Foams may also serve as a viable option in water shut-off treatments for the purpose of impeding undesired water infiltration [32].

b) Potential Challenges

There are many potential issues that are related with foam diversion strategies.

- The maintenance of foam stability is of utmost importance under reservoir circumstances, including factors such as temperature, pressure, and interactions between rock and fluid. The efficiency of diversion might be compromised due to the collapse or deterioration of foam.
- The management of foam mobility is a critical aspect in order to avoid the undesirable consequences of excessive foam propagation or a decrease in diversion efficiency. The optimization of foam performance may be achieved by effectively managing foam quality, injection rate, and surfactant concentration [33].

9. Post-job Evaluations

Matrix acidizing is a well stimulation technology commonly utilized in the oil and gas industry to increase reservoir productivity. It entails injecting acid into the formation to dissolve or eliminate formation damage such as scales, clays, and particles, hence enhancing reservoir permeability and fluid flow. While matrix acidizing may be beneficial, post-job assessments are required to evaluate the treatment's performance, identify areas for improvement, and optimize future acidizing operations [16].

9.1. The Impact of Post-Job Evaluations

Post-job assessments are essential for determining the efficacy of matrix acidizing treatments and identifying possible areas for improvement. They give useful information on the treatment's performance, reservoir response, and any difficulties encountered throughout the procedure. The following are the primary advantages of doing post-job evaluations:

- Post-job assessments enable operators to analyze the performance of the acidizing treatment in terms of increased well productivity, fluid flow, and hydrocarbon recovery. Operators may decide whether or not the therapy met the goals by examining the treatment outcomes [2].
- Post-job assessments assist in identifying any leftover formation damage or new damage induced by the acidizing treatment. This data is critical for determining the treatment's success and arranging following remedial or stimulating actions.
- By analyzing post-job data, operators may improve future treatment designs. Operators may modify their acidizing tactics and enhance treatment efficiency by finding the acid type, concentration, injection rate, volume, and other factors that produced the greatest results.
- Post-job assessments allow you to examine the safety and environmental components of the acidizing process. This involves assessing the management, storage, and disposal of acid, as well as the possible environmental implications.

9.2. Post-Job Evaluation Techniques:

To optimize matrix acidizing treatments in oil fields, many methodologies and considerations may be used during post-job assessments. Among these methods are:

9.2.1. Analysis of Well Performance

Analyzing post-treatment production data, pressure data, and well test results may provide information about treatment success. Production rates, flowing pressures, skin factors, and pressure transient analysis are all important characteristics to consider. The comparison of pre- and post-treatment data aids in determining the influence of the acidizing treatment on well production [9].

9.2.2. Analysis of Fluids and Cores

Taking fluid and core samples from the wellbore and evaluating them for pH, acid content, dissolved particles, and other characteristics might aid in determining the acid's penetration and response inside the reservoir. Core analysis offers information on acid penetration depth, formation damage dissolving, and porosity and permeability alterations [13].

9.2.3. Evaluation of Formation Damage

Conducting post-job formation damage evaluations aids in identifying any residual or new acidizing treatment damage. Core flow testing, permeability measurements, and laboratory examination of formation samples may all give useful information about the degree and kind of damage [20].

9.2.4. Modeling Acid Reactions

Operators may simulate the acidizing treatment using acid reaction modeling software and compare the model predictions to the actual treatment outcomes. This contributes to the model's accuracy, a better knowledge of acid-rock interactions, and the refinement of future treatment schemes [24].

9.2.5. Learnings and Knowledge Sharing

Post-job assessments allow for the documentation of lessons learned and the sharing of information obtained from the acidifying treatment. This involves compiling a complete database of treatment data, operational issues, and best practices for future reference and training.

9.3. Suggestions for Improvement

Several considerations may be taken to enhance matrix acidizing treatments in oil fields based on the results of post-job evaluations:

- Analyzing the acid formulation and its performance during therapy might help discover areas for improvement. To improve penetration, reactivity, and dissolution, the acid type, concentration, retardation agents, and other additions may be adjusted.
- The injection method, including injection rate, volume, and location, may be optimized to enhance acid distribution throughout the reservoir. To achieve equal treatment coverage and eliminate preferred routes, techniques such as diversion agents, numerous injection locations, and injection sequencing might be used.
- Using real-time monitoring and control systems during acidizing processes enables for fast modifications and interventions if problems arise. Operators may make data-driven choices and maximize treatment performance by continuously monitoring injection settings, pressure responses, and downhole conditions.
- Integrating reservoir characterisation data, including as geology, petrophysical, and production data, with post-job assessments aids in the refinement of reservoir heterogeneity and the identification of target zones for future acidizing treatments. Operators may adapt acidizing treatments to individual reservoir conditions using this integrated method.

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