

## Restoring the injectivity of water disposal wells using a viscoelastic surfactant-based acid

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### Abstract

Application of matrix stimulation treatments in horizontal wells with openhole completions is a challenging task. Acid diversion is one of the key factors that determine the success of these treatments. This is especially true when the target zone has several high permeability streaks. Proper acid placement in carbonate formations can be achieved by increasing the viscosity of the acid in-situ. This can be done by using polymer/cross-linker or viscoelastic surfactant-based acid systems. The latter system was selected in the present study because of the tight nature of the reservoir and the presence of hydrogen sulfide in the disposal water. Both factors do not favor the use of polymer-based acids, especially when a metal cross-linker is used. This is the first time a surfactant-based acid was used to matrix acidize water disposal wells worldwide.

A multi-stage acid treatment that utilized regular 20 wt.% HCl and surfactant-based acids was successfully conducted in a highly inclined water disposal well. The subject well was damaged due to invasion of particulate matters (iron sulfide and calcium carbonate) and accumulation of oil in the critical near wellbore area. The acid treatment was successful where the skin factor decreased from +22 before the treatment to nearly zero after the treatment. The injectivity index of this well has increased from 19.7 to 270.2 bbls/psi/day. The well maintained its injectivity even 9 months after the treatment. The surfactant-based acid system decreased the injection pressure by 35%. The reduction will allow pumping the viscoelastic-based acid. The surfactant-based acid reduced the CT surface weight by nearly 12.5%. This will allow placing the CT deeper in wells with extended reach. Finally, no operational problems were encountered during field application and this acid system is recommended, especially for sour environments.

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### 1. Introduction

Carbonate reservoirs are heterogeneous, with large variations in rock permeability. Stimulation fluids will flow through the path of least resistance where the

permeability is high or the damage (skin) is low. Hydrochloric acid reacts very fast with carbonate materials creating high conductivity flow paths in the formation (known as wormholes). As a result, most of the injected acid would flow through these wormholes leaving the majority of the formation untreated. Therefore, there is a need for a proper fluid diversion to enhance the outcome of matrix acid treatments (Chang et al., 2001; Taylor et al., 2003; Al-Mutawa et al., 2005; Nasr-El-Din et al., 2006).

Mechanical and chemical means have been utilized for diversion during matrix acidizing treatments with various degrees of success. Unlike cased wells, mechanical means e.g., isolation packers, are less effective in horizontal wells with open hole completion. Polymer-based acids and foam are the most preferred chemical means for diversion during matrix stimulation of carbonate formations. However, there were some concerns raised when polymer-based acids were used in tight and sour formations (Mohamed et al., 1999; Lynn and Nasr-El-Din, 2001).

Viscoelastic surfactant-based fluids have been used for diversion in carbonate reservoirs. They were used to enhance the stability of foams used for acid diversion during matrix stimulation of water injectors (Mohamed et al., 2002). They were also used to enhance acid placement and diversion during matrix acidizing of horizontal oil producers (Nasr-El-Din et al., 2006).

This paper presents the first field application of a viscoelastic surfactant-based acid used to matrix acidize a highly inclined water disposal well with an openhole completion. This field treatment has the following unique features: sour environment, presence of trapped oil, and the tight nature of the formation. The objectives of this study are to: (1) Apply the new surfactant-based acid to restore the injectivity of water disposal wells, and (2) assess field treatment and well response to the new acid system.

## 2. Analytical methods

Samples of the disposal water were collected to determine the chemical composition and its oil content and to identify the nature of the solids present. In addition, the concentrations of total iron and sulfide were determined using special procedures to ensure accurate results. The total suspended solids (TSS) were measured as dry weight of the solids retained on a 0.45  $\mu\text{m}$  Millipore type HA membrane. The solids present in these samples were separated and analyzed using X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF).

To measure the dissolved sulfide ions, 2  $\text{cm}^3$  of 2 N zinc acetate ( $\text{Zn}(\text{CH}_3\text{COO})_2$ ) and 1  $\text{cm}^3$  of 6 N NaOH

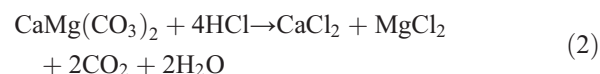
solutions were added on site on a sample of the disposal water then the collected sample was stored in an ice box. Sulfide was determined from the amount of zinc acetate precipitated. To measure the total iron concentration, 1  $\text{cm}^3$  of 20 wt.% HCl solution was added to a second water sample and then iron concentration was measured by Inductive Couple Plasma Optical Emission Spectroscopy (ICP-OES). To measure pH, an Orion model 250 A meter and a Cole Parmer Ag/AgCl single junction pH electrode were used.

Acid concentration was determined by acid–base titration using a 0.1 N NaOH solution. The chloride ion was measured using 0.1 N silver nitrate solutions with potassium chromate as indicator. Sulfate ion was measured by a turbidity method using a 0.1 N barium chloride solution.

Calcium, magnesium, sodium, and potassium were analyzed by Inductively Coupled Plasma Emission Spectrometry (Perkin–Elmer Model Zeeman-5100PC). The lower detection limit for these cations by ICP is approximately 1 mg/l.

## 3. Surfactant-based acid systems

The viscoelastic surfactant system used is a blend of an amphoteric surfactant and solvents. This surfactant is betaine with a general formula of  $\text{R}-\text{CO}-\text{NH}-(\text{CH}_2)_n-\text{N}^+(\text{CH}_3)_2-(\text{CH}_2)_p-\text{COO}^-$  (Fu and Chang, 2005), where R = a hydrocarbyl group with 14–26 carbon atoms,  $n=2$  to 4 and  $p=1$  to 5. Fig. 1 shows the surfactant molecule obtained by molecular modeling. The quaternary group carries a positive charge (cationic) in live acids. Once the acid reacts with carbonate rocks (Eqs. (1) and (2)) and the pH increases to a value greater than 2, the carboxylic group carries a negative charge and the surfactant acts as an zwitterionic surfactant.



The surfactant molecules form rod-shaped micelles when the pH values increased to a value greater than 2 and the concentration of divalent cations ( $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) increases in the spent acid (Chang et al., 2001). The rod-shaped micelles will significantly increase the viscosity of the spent acid. Entanglement of these micelles results in a 3-D structure, Fig. 2a, which will further increase the apparent viscosity of the solution (Samuel et al., 1999). In-situ build-up of the apparent viscosity will divert the acid into tight un-stimulated and/or highly damaged zones.

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