ACID FRACTURING: VARIANCE IN ROCK SOFTENING AS A FUNCTION OF ACID SYSTEMS

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ABSTRACT

Fracture acidizing of carbonates has yielded increases in production in many areas. But depending upon the rock strength and the reservoir closure pressure this may be lower than expected. Also, as a result of closure and rock strength, production may decline at a higher rate than after a proppant fracture treatment.

Laboratory results are presented describing the effect on the strength (Softening) of a dolomite and limestone after exposure to various acid systems. A dolomite saturated with potassium chloride water exposed to neat, emulsified, gelled and crosslinked 15wt% hydrochloric exhibited strength improvements going from neat to one of the fluid loss controlled systems by approximately 70%. A limestone tested similarly showed approximately 100% strength improvement. Tests were also performed on the rocks in a dry state and saturated with synthetic oil. These tests also had marked improvements in from 25 to over 100%. Treatments using an increased volume of acid systems with lower matrix leak-off should provide longer-term production responses.

BACKGROUND

Stimulation of carbonate reservoirs is typically the result of a need for restoration or enhancement of production to a more economic level. Acid Fracturing is the most widely used technique for stimulating limestone or dolomite formations.[1-7] A great deal of laboratory testing has been performed over the years to evaluate reaction kinetics, heat of reaction, diffusivity, conductivity, fluid loss, diversion and Brinell Hardness with respect to acid reactivity with carbonates. [6] It was also determined that gelation and emulsification of the acid cause a significant reduction in the effective diffusion coefficient. Additional evaluation of fluid loss additives, retarded acids and acidized fracture conductivity showed that the addition of an effective fluid loss additive can significantly improve stimulation from an acid fracturing treatment.[8] As above it was found that viscous and emulsified acids provide retardation of the dissolution of carbonates under field acid fracturing conditions. In addition, a method of predicting the resultant acid fracture conductivity using rock embedment strength and closure stress was developed.[8] A continuation of this work resulted in a finite fracture conductivity model predicting stimulation ratios from acid treatments with good agreement to observed field results.[9]

In addition, several papers have been written on the use of laboratory testing of acids and formation samples to improve acid fracturing stimulation results.[10-13] These studies have used core flow acid etching of surfaces, Brinell Hardness before and after acidizing as well as rotating disk analysis of reaction rate coefficients, orders and diffusivity. The results of which have proven successful in the design changes to facilitate significant improvements in stimulation results.

This paper presents an evaluation of rock embedment strength of limestone and dolomite core samples before and after being reacted with various acid systems. Specifically, it compares the effects of leak-off to the matrix and how the control of this leak-off reduces softening of the rocks. Also included, are model comparisons of the conductivity and the effects of the strength changes having on the stimulation results and what that could mean over time.

EXPERIMENTAL

Acid Etching

Hydrochloric acid reacts with acid-soluble minerals at different rates. In a rock containing a mixture of minerals, the more rapidly reacting ones will dissolve faster leaving raised areas where the less reactive minerals occur. Likewise, differences in particle size can create differential etch patterns that result in a highly conductive fracture when a carbonate formation is fractured with acid. The ability of an acid-etched fracture to remain open without the use of proppant can be evaluated by acid etching tests. The etched surface is subjectively evaluated as to its roughness and relief (height difference between high and low points).

A whole core sample is sawed with a diamond-bladed saw to create a flat vertical surface. The core is suspended in a large beaker containing hydrochloric acid at a specified concentration and temperature, for a specific time interval. The core is removed from the acid and rinsed with water to quench the reaction. The surface of the acidized formation sample is examined and photographed. Sample surfaces are compared before and after etching.

Brinell Hardness

In formation fracturing applications, it may be necessary to determine the Brinell Hardness (BH) and embedment of the proppant into the formation. An ELE steel ball penetrometer is used to determine the Brinell hardness of the formation. Rock mechanics equations are used to determine the proppant embedment on one fracture face. A 0.0610-inch steel ball is used with the ELE Load Frame to penetrate the sample. The sample normally consists of a one-inch diameter cylinder with a height between 0.5 and 2 inches and containing flat end faces. One end of the sample is exposed to acid or fracturing fluid to simulate rock softening due to fluid exposure. After cleaning and drying the sample, the sample is placed on the load frame with the flat unexposed face serving as a base. After contacting the sample with the steel ball, both dials are set to zero. The applied force is increased to a minimum of 10 gauge units (GU) or 35 kg before reading the first penetration distance H in gauge units (1 GU = 0.01 mm). The applied force is then increased to 100 GU in increments of 10 or 20 GU while reading the penetration distance H. For soft rock samples; a 0.120-inch steel ball can be used. A spreadsheet calculates the Brinell Hardness (BH) in units of kg/mm^2 and proppant embedment (h) in units of inches or units of percent particle size. As a general rule, the percent embedment does not change as a function of particle size for a constant closure stress. Previous testing also indicates that embedment is not a problem for BH values above 50 kg/mm^2, but embedment is a problem for BH values less than about 30 kg/mm^2.

RESULTS

Table 1, lists some core samples of limestone and dolomite and their rock embedment strengths before acid etching and the softening effect of neat acid on the samples. The differences in softening effects even when the strength differences are similar is a function of the matrix permeability and the subsequent lea-off of live or partially spent acid into this matrix. Figures 1 and 2, illustrate the effects of change in rock embedment strength and closure stress respectively on the predicted conductivity from an acid frac design model. The conductivity at the wellbore is 9.375 times larger for a rock with 100,000-psi embedment strength over one with 25,000 psi. Even increasing the rock strength to 50,000 psi still makes the conductivity of the 100,000-psi rock 3.75 times greater. The effect of closure stress is greater. The predicted of conductivity at 0-psi stress at the wellbore compared to that at10000 psi is 250 times greater.

Figure 3 shows a theoretical representation of what could happen to conductivity at the wellbore over time as reservoir pressure, closure stress and formation hardness change. The data labeled conductivity represents the change assuming only a change in closure stress. Here the conductivity decreases from 16000 to 2000 md-ft. However, if some softening is used to correct the conductivity could decrease to 300 md-ft.

Figures 4 and 5 demonstrate the variance in softening of dolomite and limestone by various acid systems respectively. The dolomite has a permeability of 5 md and even with a higher permeability than the 1 md limestone was not softened as much as the limestone. Neat acid softened the dolomite rock from 1.5 to 175 times as much as gelled, crosslinked and emulsified acids. While the limestone was softened from 1.4 to 414 times by the neat acid over the other three. The relative permeability effects of the emulsified acid (diesel and acid) on leak-off contributed greatly to the higher strength of the rocks after being acidized. Similarly the extremely high viscosity of the crosslinked acid prevented a great deal of the acid to leak off into the permeability allowing almost no change in strength of either lithology after acidizing.

CONCLUSIONS

1. Acids penetrate formation matrices and reduce the strength of the rock.
2. Rate of penetration is a function of permeability and leak-off control.
3. Fluids with the highest control of leak-off to the matrix of a rock exhibit the least amount of rock strength reduction.
4. Whether a rock is saturated with water or is dry has only a minor effect on results.
5. Softening effects are greater on limestone than dolomite.

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Table 1

Lithology	Rock Embedment Strength, psi	Percentage Softening
Dolomite A	379327	64
Dolomite B	343559	81
Limestone A	60120	4.5
Limestone B	99533	43
Limestone C1	70425	28
Limestone C2	51072	38
Limey Dolomite	59041	34
Dolomite C1	62027	20
Dolomite C2	129988	63

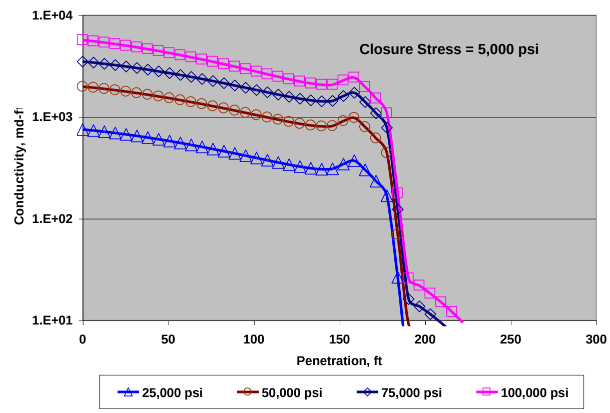

Figure 1 – Effects of embedment strength on predicted conductivity when the closure stress is held constant.

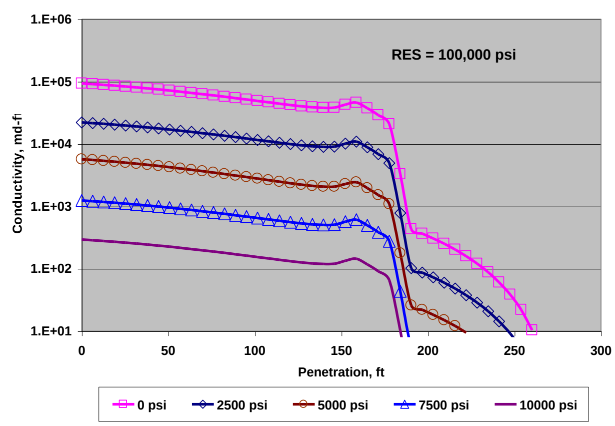

Figure 2 - Effects of closure stress on predicted conductivity when the embedment strength is held constant.

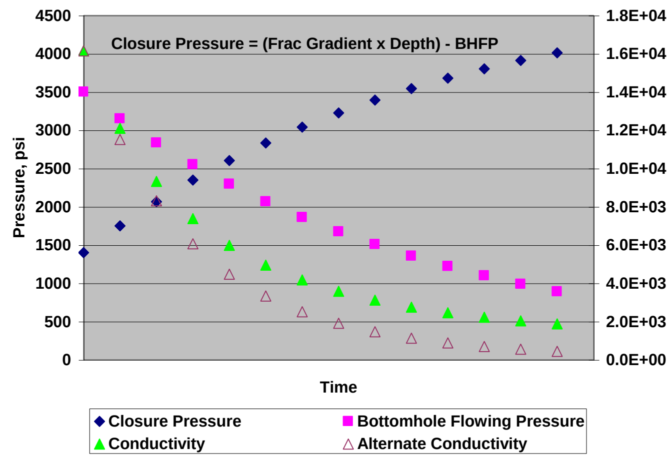

Figure 3 – Illustration of what could happen to conductivity with changes in the reservoir.

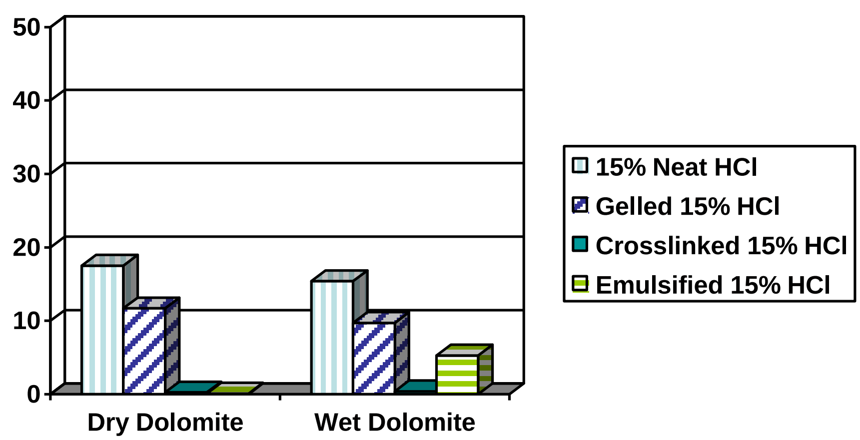

Figure 4 – Effect on limestone of various acids with regard to softening of the rock.

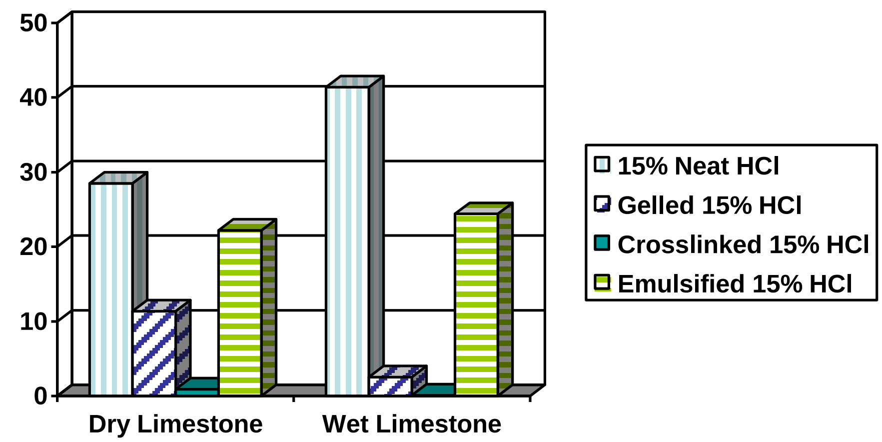

Figure 5 - Effect on limestone of various acids with regard to softening of the rock.