NEW, DEEP-PENETRATING ACIDIZING TECHNIQUE USES ALTERNATE STAGES OF PAD FLUID AND ACID

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INTRODUCTION

Although not recognized as a definite acidizing technique, fracture acidizing has probably occurred in a majority of acidizing treatments throughout the history of the process. Injection rates of most early acidizing treatments were high enough to cause fracturing, and it was common practice to "breakdown" the formation at the beginning of the treatment. Since the introduction of hydraulic fracturing, fracture acidizing has been recognized as a fracturing process, and it is now commonly used in an effort to increase live acid penetration into the reservoir rock. Extensive studies have been made to evaluate the effect of many variables (temperature, pressure, concentration, etc.) on acid penetration. Data from these studies have been incorporated into acid treatment design programs so that the operator will have a tool to use in planning more effective and economical acid treatments. The industry has long recognized, however, that actual results obtained by acidizing carbonate formations were not equal to increases predicted by the design programs.

During the past decade, considerable research has been directed toward shortening the gap between actual and predicted results. Some of the approaches taken have been:

1. Acid retardation
2. Increased acid concentration
3. Increased fracture width to decrease the area-volume ratio
4. Improved matrix leakoff control
5. Improved computer calculations.

All these approaches had one basic purpose—to increase live acid penetration of the reservoir rock. Each improvement did provide better response, either separately or when used in various combinations. Too large a gap still remained, however, between the predicted and actual results. The problem with these improvements was that each of them was based on the assumption of flow conditions with *matrix leakoff*. It is now recognized that such conditions do not exist due to natural hairline fractures that exist in most carbonate formations. In an undisturbed state, these fractures exert little influence on overall permeability, but leakoff of acid during an acid fracturing treatment not only occurs into the matrix but also into these hairline fractures. Calculations can be made to show that very small volumes of acid can enlarge these hairline fractures so that they can increase the average permeability from less than 1 md to more than 900 md. Large volumes of following acid can then leak off into these fractures, and penetration will then be much less than predicted by design programs assuming only matrix leakoff.

A new acid fracturing technique using alternating stages of pad fluid and acid has been proven highly successful in achieving results that approximate predicted results of acid fracturing treatments. This success is believed due to the fact that the technique reduces leakoff into the hairline fractures as well as the matrix. A description of fluid flow behavior during acid fracturing will show how the new technique provides better penetration and better results from such treatments.

FLOW BEHAVIOR

When fracturing a carbonate formation with acid, the mechanics are initially the same as in any hydraulic fracturing treatment. A fracture is initiated and the acid enters the fracture. Here the similarity ends. Acid, being a reactive fluid, begins to react with the formation. Acid leaking off into the matrix and into hairline fractures enlarges flow channels, and acid-flow out of the fracture is intensified. The end result is that the acid penetrates only a short distance into the rock before leaking off and spending. Flush fluids following the acid may propagate the fracture and penetrate farther, but this serves no useful purpose since there is no acid in the added length to etch the fracture faces and provide conductivity after the treatment is completed. About a decade ago, it was recognized that achieving desired fracture area in massive carbonate formations would require extremely large volumes of fluid. If acid were used to create this area, cost would be prohibitive. A new technique termed "Frac Pad and Acid" was introduced at that time. This technique consisted of using a nonreactive and inexpensive pad fluid to create fracture area. Acid was pumped behind the pad fluid to etch the newly created fracture faces and provide conductivity. This technique increased the effectiveness and reduced the cost of acid fracturing treatments. While results were greatly improved, they still did not match predicted results.

INTERMITTENT FRAC PAD AND ACID

The Intermittent Frac Pad and Acid technique is a variation discovered when a conventional stage "Frac Pad and Acid" treatment, using diverting material to separate the stages, was changed during the pumping operation because of excessive pressure. The second-stage diverter plug was omitted due to the excess pressure and the third stage was performed as designed. Results from this treatment were considerably above field average. Several other treatments and laboratory studies have since substantiated the new technique.

The discovery actually made during this treatment was that a thickened, viscous fluid or pad used in alternate stages with acid can add significantly to leakoff control of the acid. This is illustrated in Fig. 1 by three cores — one-inch diameter by six inches long.

The core on the left shows what happens when acid is impressed against a limestone formation. In this case it channels through in 15 seconds. The second core shows what happens when a thick pad is

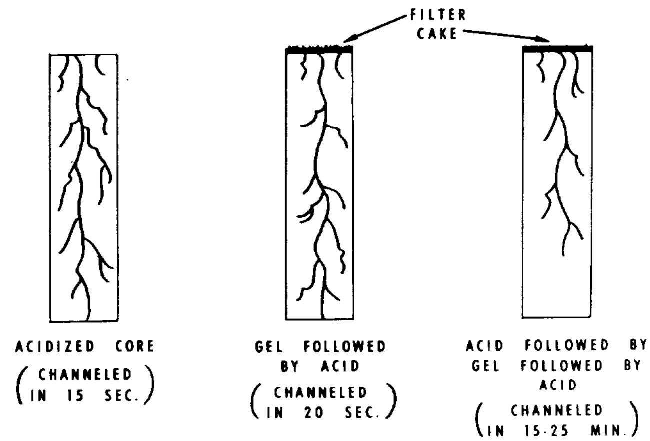

FIGURE 1

allowed to build up a filter cake on the rock first. It only slows the acid channelling by a few seconds because the filter cake is very thin. It takes approximately 20 seconds for the acid to penetrate this cake. But the third case illustrates what happens when acid is allowed to channel part way into the core and then the pad is impressed against the rock so it penetrates the channels. After this pad has filled the beginning wormholes, acid is again charged against the surface. This time, however, it takes 15 to 25 minutes for the acid to penetrate. What has happened is that the easy flow paths for acid were enlarged enough to accept the pad fluid. After the viscous pad was in the channels, the following acid could not penetrate those same flow paths and had to seek out other tighter, more difficult-to-enter flow paths. The net result was effective control of acid leakoff.

During an actual treatment, the pad fluid initiates a fracture and widens it. When acid enters this fracture, it leaks off into the matrix and intersecting hairline fractures, enlarging the flow channels. The acid will not penetrate very far from the wellbore. If this acid stage is followed by another pad stage, the pad fluid will fill the fracture and flow channels created by the acid slug. An immediate, subsequent acid slug then will be prevented from leaking off in this first part of the fracture. It will etch the fracture faces and penetrate farther from the wellbore before leaking off. Each succeeding pad and acid stage will thus penetrate farther from the wellbore than the preceding stage. Thus, a treatment will consist of many alternate stages of pad fluid and acid. As many as 10 or more acid stages may be required to achieve desired acid penetration.

One factor to consider in the design and performance of an alternate stage Frac Pad and Acid treatment is the influence of hairline fractures. Once they are opened, it is important to prevent or limit further acid leakoff into them during subsequent stages. Field experience has shown that fine sand (100 mesh) will act as a bridging agent in these fractures to help control this leakoff. It is common practice to use fine sand at a concentration of 1-3 ppg in the pad stages of the treatment.

EXAMPLE TREATMENT

An example of a typical alternate stage Frac Pad and Acid treatment is as follows:

1. Inject a small volume of acid.
2. Inject a high-viscosity fracture fluid pad volume.
3. Inject high-viscosity fracturing fluid containing 100 mesh sand at 1-3 ppg, if required.
4. Inject acid volume.
5. Repeat step 2 or 3.
6. Repeat step 4.
7. Continue to repeat steps 2 or 3 and 4 as necessary to obtain total calculated volumes.
8. Overflush with a volume of fluid to displace live acid to the proper etch distance.

Such a treatment gives consideration to formation reactivity, fluid flow behavior and rock mechanics involved. It not only provides deeper penetration with a given volume of acid, but allows efficient use of even larger volumes.

MATERIALS

Alternate stage Frac Pad and Acid treatments can be performed with a wide variety of fluids. Three of the more commonly used are gelled water, oil-in-water emulsion, and acid-in-oil emulsion. The acid-in-oil emulsion is very slow reacting and will act as a pad at moderate temperature, even though it has reactivity and will eventually spend on the rock. At temperatures over 200° F, it may be used as the acid portion of the treatment. Usually, 15% HCl or 28% HCl is used in the acid stage, but 20% HCl and 20% HCl plus 7% formic acid have also been used. Moreover, the process may employ different pads or different acids at different stages of the treatment. For example, the initial acid stages could be 15% HCl with the last few acid stages being 28% HCl, since it can penetrate farther before spending and would be moving greater distances down the fracture. There are many fracturing fluids — water-base, oil-base, or emulsion — that can be used as the nonreactive pad stage. Similarly, there are many acids or retarded acids that can be used as the reactive stage.

CASE HISTORIES

A gas well testing 500 MCFD was treated using the alternate stage Frac Pad and Acid technique. The acid portion of the treatment was 42,000 gal. of a mixture of 20% HCl and 7% formic acid. It was divided into 7000-gal. stages. Pad stages were 5000 gal. each. The pad fluid was water containing 60 lb per 1000 gal. guar gelling agent and 20 lb per 1000 gal. silica flour. Injection rate was 13.3 BPM at 9000 psi. Following the treatment, the well produced at a rate of 6000 MCFD.

Another gas well, with only a show of gas initially, was stimulated to a production of more than 1 BCFD by the alternate stage technique. In this case, 48,000 gal. retarded 20% HCl was divided into 12 stages which were separated by pads of 3000 gal. water gelled with 60 ppg guar gelling agent. The pad fluid contained 2 lb 100 mesh sand per gal. Injection rate was 15 BPM at 9500 psi.

SUMMARY

A new acid fracturing technique using alternate stages of pad fluid and acid is proving highly successful in stimulating carbonate formations. The new technique helps control leakoff and provides:

1. Deeper acid penetration into the reservoir
2. More efficient acid use
3. More effective use of given acid volumes
4. Effective use of larger acid volumes
5. Improved stimulation results which more nearly match design-predicted results.

A variety of pad fluids and reactive fluids may be used with the technique. Treatments may thus be designed to meet specific well and reservoir requirements. Fine sand (100 mesh) may be used in the pad fluid as an added aid for leakoff control into hairline fractures.

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