Fracturing Fluid Breakers

This Best Practices article describes the latest Halliburton technology to help design engineers and fracturing customers select and use fracturing fluid breakers effectively. Chemical descriptions of breakers and the breaking process are presented here. Note that this article focuses on water-based fluids and does not cover oil-gelled fluids and breakers.

To help readers optimize the fluid system for hydraulic fracturing treatments, this article covers several aspects of fracturing fluid breakers:

- Definition and use of breakers
- Performance criteria for selecting breakers
- Types of breakers
- Testing methods
- Selection guide chart

Definition and Use of Breakers

Fracturing fluids are used to help create a hydraulic fracture and then to transport enough proppant into the fracture to enable production of the hydrocarbon-bearing reservoir. Fracturing fluid usually consists of water thickened with guar or derivatized guar polymers.

After the proppant is mixed with the viscous fracturing fluid and pumped downhole to form a fracture, the fracturing fluid must be removed from the proppant pack. It should be removed without moving the proppant from the fracture and without damaging the conductivity of the proppant bed. To accomplish this removal, the operator must thin the viscous fluid that transported the proppant to a near-water state for optimal removal from the propped fracture. Chemicals used to reduce the viscosity of fracturing fluids are called breakers.

Water-based fracturing fluids are usually made viscous by the addition of 20 to 70 lb of guar or derivatized guar polymer per 1000 gallons of water. Guar polymer, which is derived from the beans of a guar plant, is referred to chemically as a galactomannan gum. A mixture of guar dissolved in water forms a base gel, and suitable crosslinking agents are added to form a much more viscous fluid, called a crosslinked fluid. The water-based fluids discussed here may be crosslinked with metals, such as zirconium, titanium, or boron compounds. The viscosity of base gels are typically 20 to 50 cp; when it is crosslinked, the viscosity of the base gel is increased by 2 to 100 times depending on the temperature, test method, and type of crosslinker used.
How Breakers Work

Guar polymer is considered to have a molecular weight of approximately 2.2 million\(^{(1)}\). Breakers reduce the molecular weight of guar polymer by cutting the long polymer chain. As the polymer chain is cut, the fluid’s viscosity is reduced, as shown in Figure 1. Reducing the guar polymer molecular weight to chains of about 10,000 molecular weight converts the fluid to near water-thin viscosity. A single guar polymer must be cut into approximately 200 small pieces to eliminate viscous effects.

![Figure 1—Relationship of Average Polymer Molecular Weight and Fluid Viscosity](image)

On the other hand, crosslinking the guar increases its molecular weight to extremely high values. The actual number of crosslinks that are possible and that actually form depends on the shear level of the system: the total molecular weight is inversely proportional to the shear the fluid receives. The exact number of crosslink sites is not well known, but it could be as few as one to ten. The number of crosslinks, and thus the molecular weight of the resulting polymer, significantly alters fluid viscosity.

Crosslinks produced by borate ion are known to be reversible and can be completely eliminated at neutral or acidic pH. Crosslinks formed by zirconium, titanium, antimony, and aluminum compounds, however, are not reversible and may be broken only by unconventional methods\(^{(2)}\). Fracturing fluid breakers are designed to reduce guar polymer viscosity by breaking down its molecular weight. This process can occur independent of crosslinking bonds existing between polymer chains.

After the proppant is placed in the fracture and pumping stops, the fracture closes. The pores of the proppant bed are filled with the fracturing fluid and should be cleaned out. As noted above, the fracturing fluid
must be removed to maximize conductivity of the proppant-filled fracture. Removal of the fracturing fluid is facilitated by using breakers to reduce fluid viscosity. Unfortunately, another complicating factor also exists.

Filter Cake Concerns

As the hydraulic fracture is being formed and propagated in formations with permeability, fluid leaks from the fracture into the formation matrix. As this process occurs, the guar polymer does not penetrate the formation matrix. Because of the large size of the polymer, a filtration process occurs upon the fracture face. A filter cake of guar polymer is formed while the water, KCl, and breakers pass into the formation. Careful examination of this filter cake, which may be formed from crosslinked or uncrosslinked guar, reveals a semi-elastic, rubberlike membrane. Analysis shows the filter cake consists of approximately 95 percent water and 5 percent guar polymer. Even with this high water content, a filter cake can have these properties since the water is very tightly bound to the guar. Nonfilter cake fluid consists of approximately 99.5 percent water and 0.5 percent polymer.

When the fracture closes, the permeability of the proppant bed may be damaged severely by the polymer filter cake. Many studies have been done to try to quantify the effects of filter cake on fracture conductivity\(^3\),\(^4\). These studies have resulted in two generalizations about breakers with respect to removing polymer filter cake.

- Higher breaker levels are required to remove filter cake than to break fracturing fluids that contain lower levels of polymer.
- Linear gel fluids and borate-crosslinked fluid filter cakes can be removed by a large amount of flowing water. In some conditions, linear gel and borate-crosslinked fluids can be viewed as cleaner; but without the required water for cleanup, zirconium- and titanium-crosslinked fluids may be equivalent to borates.

Breaker Selection

Breakers must be selected to meet the needs of each situation. First, it is important to understand the general performance criteria of breakers. In reducing the viscosity of the fracturing fluid to a near water-thin state, the breaker must maintain a critical balance. Premature reduction of viscosity during the pumping of a fracturing treatment can jeopardize the treatment. Inadequate reduction of fluid viscosity after pumping can also reduce production if the required conductivity is not obtained.

Figure 2 shows three hypothetical break profiles of a fracturing fluid viscosity. The ideal viscosity (curve 1) versus time profile would be if a fluid maintained 100% viscosity until the fracture closed on proppant and then immediately broke to a thin fluid. A more realistic viscosity
profile is one similar to curve 3 of Figure 2 for fluids containing most soluble breaker chemicals. Some breaking inherently occurs during the 0.5 to 4.0 hours required to pump most fracturing treatments.

One guideline for selecting an acceptable breaker design is that at least 50% of the fluid viscosity should be maintained at the end of the pumping time (curve 2). This guideline may be adjusted according to job time, desired fracture length, and required fluid viscosity at reservoir temperature. For example, curve 2 would be suitable for a 2-hr pump time.

![Figure 2—Comparative Break Profile](image)

**Selection Criteria**

Several methods of characterizing the rheology of fracturing fluids are available\(^6\). Rheological test results can be used to select a breaker or breaker package that gives the desired viscosity during and after pumping. The following criteria should also be considered when selecting a breaker:

- Breaker influence on proppant transport
- Breaker influence on fracture conductivity
- Economic considerations

**Proppant Transport**

Testing methods and databases on proppant transport are currently in the early stage of development. Traditionally, proppant transport has been equated with viscosity, and therefore, breaker effects on proppant transport are considered negative. Several recent publications have discussed various aspects of proppant transport\(^6\). As testing methodol-
ogy becomes more established for evaluating fluids for proppant transport, breaker effects also need to be thoroughly evaluated. Fluids used for fracture treatments designed for very long propped lengths may require perfect or near-perfect proppant transport. These fluids need to be evaluated for breaker effects on proppant transport.

**Fracture Conductivity**

Breaker effects on conductivity are difficult to quantify. In permeable formations with enough leakoff to form filter cake, the resulting damage to the proppant bed is dominated by polymer present as filter cake. Breaking filter cake gel requires larger breaker loads than does the remaining fluid in the fracture, which contains a much lower polymer concentration. But the higher breaker loadings needed to remove filter cake may make it difficult to maintain the viscosity required during pumping. Sometimes the higher breaker levels are obtained by using controlled-release products or stable, soluble breakers that continue to dissolve the filter cake as fracture fluid filtrate flows back into and through the fracture during production.

Unfortunately, all conductivity test results are dependent on the test procedure used. Results are especially influenced by the fluids pumped throughout the pack to simulate fracture cleanup or load water recovery. For example, borate fluid conductivity values may be overestimated since excessive amounts of water are generally passed through the pack relative to load water production from actual wells.

**Economics**

Economics should be considered when choosing breakers just as any other expense item in stimulation costs. Regardless of the design, materials, and pumping of a fracturing treatment, an undamaged, conductive fracture must be obtained for the treatment to be successful. Since breaker costs are usually a small percentage of total costs, cutting costs by skimping on breakers is not recommended. Maximum possible breaker activity for the lowest cost possible is ideal when a choice is possible. Not using the required breaker concentration or type could become very costly if the desired results are not obtained.

**Breaker Types**

Chemical breakers used to reduce viscosity of guar and derivatized guar polymers are generally grouped into three classes: oxidizers, enzymes, and acids. All of these materials reduce the viscosity of the gel by breaking connective linkages in the guar polymer chain. Once the connective
bonds in the polymer are broken, the resulting pieces of the original polymer chain are the same regardless of what type of breaker was used.

A breaker should be selected based on its performance in the temperature, pH, time, and desired viscosity profile for each specific treatment.

Oxidizing Breakers

Sodium, potassium, and ammonium persulfate have been used effectively as breakers for over 30 years. In these type of breakers, oxidation-reduction chemical reactions occur as the polymer chain is broken. The resulting polymer materials may not be oxidized themselves. The persulfate breakers work as follows:

1. The persulfate ion breaks into two halves called radicals. This process is known as chain initiation.

   \[
   S_2O_8 \rightarrow SO_4^+ + SO_4^-
   \]

2. Persulfate radicals oxidize water to form sulfate and two new radicals called hydroxyl radicals.

   \[
   SO_4^+ + H_2O \rightarrow SO_4^- + OH^-
   \]

3. A hydroxyl radical reacts with guar to form water and a guar radical. Many different guar radical species can be formed depending where the hydroxyl radical reacts. One guar radical can react internally or externally with guar, forming a different guar radical.

   \[
   OH^- + Guar \rightarrow Guar^- + H_2O
   \]

4. When a certain guar radical species is formed, it can react again with water, which removes one bond from the guar polymer chain. This reaction produces two shorter polymer chains and gives off an hydroxyl radical.

   \[
   Guar^- + H_2O \rightarrow 2 Guar + OH^-\]

5. The hydroxyl radical of step 4 continues on the path of step 3. Each time this sequence occurs, a reduction in the polymer molecular weight occurs. This entire process is the breaking chemistry.
6. Hydroxyl radical termination step.

\[
\text{Guar} + \text{OH} \rightarrow \text{Guar}
\]

Some have said that persulfate breakers only react twice. It is true that they form only two hydroxyl radicals, but these two hydroxyl radicals may react, be regenerated, and react again hundreds or thousands of times. This reaction is a true catalytic process, which makes persulfates very effective breakers for guar-type polymers.

The rate at which a persulfate molecule breaks into two radicals is temperature-dependent. Below 120°F this process occurs very slowly, and the reaction must be catalyzed to obtain acceptable break rates. A catalyst is a material that accelerates and participates in a chemical reaction but is regenerated and not consumed. A variety of catalysts, including various organic amines and inorganic materials, may be used\(^7\). Above approximately 200°F, persulfate decomposes very quickly. Figure 3 shows data from a study of the decomposition rate of sodium persulfate as a function of temperature. It is not advisable to use persulfate at fluid temperatures above 200°F. Although it is an excellent breaker above 200°F, it decomposes so quickly that the breaks cannot be controlled\(^8\). Persulfate breakers, however, may be used effectively in wells exceeding 200°F in the portion of a treatment that is cooled in the formation and if temperatures of the fluid during pumping exceed 200°F for no more than a few minutes.

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**Figure 3**—Decomposition of Persulfate in pH 10 Aqueous Solution
Enzyme Breakers

Enzymes are referred to as Nature’s catalysts because most biological processes involve an enzyme. Enzymes are large protein molecules, and proteins consist of a chain of building blocks called amino acids. The simplest enzymes may contain fewer than 150 amino acids while typical enzymes have 400 to 500 amino acids. Compared to persulfate with a molecular weight of 236, enzymes are large molecules with molecular weights of approximately 10,000. Compared to guar, which has a molecular weight of 2 million, enzymes are small.

Since enzyme activity is so integral to biological chemistry, the types and function of enzymes have been studied extensively. Enzymes are locked into their required structure by weak bonds between the amino acids of the enzyme protein. All enzymatically catalyzed reactions have one common factor: for an enzyme to function, the protein, which is composed of amino acids, must exist in a precise physical configuration. This configuration allows the enzyme to impose special chemical forces on the chemical bond of the substrate in the reaction being catalyzed. These special forces allow the intended reaction to occur much faster and/or at lower temperature.

Enzymes in Industrial Applications

Many industrial processes require higher temperatures than the temperatures found where living organisms produce enzymes. These higher temperatures normally exceed the temperatures where enzymes can retain their required physical configuration. When this temperature is exceeded, the enzyme rotates to another shape, and its ability to catalyze is destroyed. At this point, the enzyme is deactivated. Sometimes when the temperature is lowered, enzymes return to the required configuration for activity. At other times, however, the enzyme does not regain activity because it is permanently denatured. Denaturization is any chemical reaction that permanently deactivates the enzyme.

High temperatures limit the use of enzymes in industrial applications. Research at HES has shown that hemicellulase enzymes become denatured at approximately 150°F (Figure 4). In breaker applications, the enzyme’s required lifetime must be considered in establishing precise temperature maxima for enzymes. Another factor that affects the activity and temperature stability of enzymes is the fluid pH. As pH values increase between 8 and 10, the time an enzyme can tolerate high temperatures shortens. Most enzymes, including hemicellulases, do not function above pH 10 and 11.

No viable enzyme breakers currently exist within the petroleum industry for activity above 200°F, yet organisms do exist and live in boiling water temperatures. For example, bacteria live and produce enzymes in the geysers around Yellowstone National Park. The technical process required to obtain these enzymes from these bacteria has not been developed to economically allow oilfield application of such products. No
enzymes with a one-hour lifetime in boiling water are currently available commercially in any industry; therefore, enzyme breaker technology for use over 200°F cannot be predicted within the stimulation industry in the foreseeable future.

### How Enzymes Work

Breaker enzymes cause hydrolysis, or the addition of water, to the guar polymer. The same reaction products are formed when either enzymatic or oxidizing breakers are used. Hydrolysis of the polymer involves the direct addition of water to the connecting linkage of the guar polymer. Hydrolysis is facilitated by increasing temperature or decreasing pH. An enzyme can also accelerate hydrolysis under a given condition. For example, at a pH of 5 and a temperature of 150°F, the hydrolysis of guar can take days to occur, but with a small amount of enzyme catalyst, this same degree of polymer hydrolysis happens in a few minutes.

As discussed earlier, enzymes exert forces on the chemical bond of a substrate molecule, and these forces allow the hydrolysis reaction of the substrate molecule to occur faster. Because the enzyme must associate with the substrate very precisely for the enzyme catalysis to occur, the lock-and-key analogy is commonly used to explain how enzymes work\(^{(9)}\). The energy industry is interested in enzymes that will effectively break guar-type polymers, so Halliburton technology is focused on this area.
Choosing an Enzyme

Enzymes are categorized by their performance type, not their chemical composition or structure. For example, enzymes that break down proteins are called proteases; enzymes that break down starch are called amalyses; and enzymes that break down cellulose are called cellulases. Any enzyme that breaks down guar, which is a hemicellulose, is called a hemicellulase.

Most commercial enzymes are actually mixtures. Single-enzyme products are very expensive and are not readily available technically nor are they economically viable. As indicated by the lock-and-key analogy, all enzymes are used for very specific applications. Enzymes that are optimal for guar degradation would have no activity on a protein, for example; hence, enzymes that work on guar are polymer-specific.

Since commercial oilfield-applicable enzymes are mixtures, certain products may exhibit activity for breaking guar, guar derivatives, and cellulose derivatives such as hydroxyethyl cellulose (HEC). To avoid stocking several enzymes, a commercial product that provides adequate activity for guar, guar derivatives, and HEC is used. Variation in the break rates of available commercial enzymes is observed; however, cost-performance optimization for a single polymer would provide only incremental benefit.

Acid Breakers

Acid also provides the same break via hydrolysis as an enzyme. Acid, however, poses various difficulties for practical applications.

Difficulties with Acid Breakers

Acid is not used as a guar polymer breaker very often because of cost, poor break rate control, chemical compatibility difficulties, and corrosion of metal goods. Another difficulty with acid breakers is that the formation may act as a buffer. A small amount of acid introduced as a breaker may be totally consumed by the formation water and minerals. This absorption could quickly change the pH of the fracturing fluid to a point where breaking may not occur. Most formation brines have a pH between 6 and 8. Fluid pH values change to the formation pH value when fracturing fluids contact the formation (Figure 5).

If the pH of recovered load waters is measured, the fracturing fluid pH is normally close to the pH of the formation water, regardless of the initial fracturing fluid pH. It is difficult to determine exactly when the pH change occurred. HES research measurements suggest that pH changes brought on by diffusion between fluids do not occur rapidly. For example, two containers at pH of 5 and 10 connected with a 4-in. water-filled tube did not change pH appreciably after 16 hours. This observa-
tion suggests that bulk mixing must be involved if a pH change between the fracturing fluid and the formation is observed.

If the formation pH is below that of the fracturing fluid and the formation pH is low enough to provide breaking, an automatic break could be observed. The question of exactly when a thick, viscous fluid in the fracture will contact enough formation brine to change the pH remains unanswered. It is possible that recovered load water pH is near the brine pH because flow has allowed mixing and that remaining unmoving fluid in the fracture remains unchanged.

The stability of a guar or derivatized guar polymer is a function of pH and oxygen concentration of the water\(^\text{[10]}\). When oxygen effects are removed, viscosity is reduced faster at lower pH and at higher temperatures. Use of acid as a breaker for guar polymers probably is limited to temperatures above 250°F. For fluid stability above 275°F, fluid pH should be above 9. Lowering the pH destabilizes the fluid. Between 150 and 250°F, fluids may be adequately stable at all pH values greater than 5. To obtain an acid break, fluid pH values are reduced to below 5. Guar polymer becomes very unstable at all temperatures when the pH is below 5. However, large amounts of acid are required to drop fluid pH values this low and also to overcome formation buffer effects.

![Figure 5—Borate Fluid Viscosity with Various Final pH Using 30 to 35 lb HPG/Mgal at 125 to 175°F](image-url)
**Possibilities for Acid Breakers**

The applications for acid breakers is limited, with two exceptions that involve delayed-release type acids. First, a delayed-release acid may be used to uncrosslink a borate. This relationship is shown in Figure 5 and discussed in a recent publication\(^{(11)}\). Second, delayed-release acid may also be useful with enzyme breakers. Especially at low temperatures, the use of enzymes in borate crosslinked fluids is often effective. To allow the enzyme to be effective in the pH 9 to 11 borate fluid, delayed-release acids can be used to lower the fluid pH value to a range where the enzymes are effective. Either a delayed-release enzyme or an enzyme not denatured by the initial high pH value is required in this case.

**Controlled-Release Breakers**

Any oxidizing, enzyme, or acid breaker added to the fracturing fluid and available for immediate reaction should not be considered a controlled-release additive. Conventional breakers normally are soluble in the fracturing fluid and their reactivity usually increases as temperature increases. Any breaker added to the fluid and not immediately available for reaction is a controlled-release breaker. Two types of controlled release additives are used: solid and liquid materials.

**Solid Controlled-Release Breakers**

Solid controlled-release breakers are usually encapsulated. These solid products allow an active breaker species to become available in the water phase by diffusion, crushing, or solubilization.

![Release Profile of Encapsulated AP Breaker at 175° in pH 10 Aqueous Solution](image)

Figure 6—Release Profile of Encapsulated AP Breaker at 175° in pH 10 Aqueous Solution
Many possible techniques for forming solid, encapsulated controlled release breakers exist. Perhaps the most pertinent method is a fluidized bed coating\(^{(12)}\). In this method, a particle of active breaker, such as sodium persulfate, is placed in a chamber and fluidized by air flow. This fluidized bed is then spray painted with a thin, continuous coating. The coating may vary from 10 to 50\% of the particle weight depending on the desired thickness and the size of the initial breaker particle. Smaller particles of breaker require heavier coatings to obtain the same film thickness as a larger particle.

Spray-coated, controlled-release solid breakers are usually released by diffusion. Figure 6 shows a typical release profile. Diffusion occurs through small (1 to 2 micron) holes left in the coating during the spraying process. These tiny holes act as metering ports through which water diffuses in and dissolved breaker diffuses out. The desired release rate at any temperature is obtained by spraying on the coating until the correct amount of these tiny holes remains.

It has been previously suggested that controlled release by crushing would be desirable\(^{(13)}\). In practical terms, obtaining a perfectly pinhole-free coating that is brittle enough to be crushed when the fracture closes is very difficult. Although crushable release coatings are possible, they are not currently being used in the petroleum industry.

Other types of solid controlled-release breakers can be obtained by forming solid mixtures of inert materials and solids. These mixtures are limited, though, because active material exposed to the water is released immediately while some material may never be released. Another possible but limited breaker type would be a very slowly soluble material. Although possible, these materials are sometimes impractical because of excessive early release and/or the increased solubilization rate in high temperatures.

**Liquid Controlled-Release Breakers**

Liquid controlled-release breakers are usually miscible and undergo chemical reactions to form active breaker species. Liquid controlled-release breakers may be used if the following general condition exists:

\[
B + \text{Guar} \rightarrow \text{Guar} + \text{Guar}
\]

Where \(k_2 > k_1\)
An example of this sequence is an organic acid such as formic acid (B) that was reacted with methanol (DR) to form an ester called methyl formate (DRB). At certain temperature conditions, methyl formate can break down slowly \( k_1 \) to allow control of the breaking reaction \( k_2 \).

Many organic compounds are capable of reacting with water and forming breakers. Generally, the water reaction forms an acid, so then the concerns about acid breakers apply. An inherent problem with these types of breakers is that temperature accelerates the breakdown \( k_1 \) so they cannot be controlled adequately over a broad range of temperatures.

Release of breaker from a coated material through a diffusion is usually less temperature dependent than chemical reaction rates \( k_1 \), so solid-coated breakers have an advantage. Another advantage of solid controlled-release breakers is that they are filterable solids, so they do not leak off into the rock matrix. Solid-controlled release additives stay with the filter cake in the fracture, which provides high concentrations of breaker to improve filter cake cleanup \( ^{14,15} \).

### Testing Methods

This section briefly describes each type of test so that a design engineer could evaluate data from the tests or request tests as needed. The following tests are used in selecting breakers:

<table>
<thead>
<tr>
<th>Laboratory Tests</th>
<th>Field Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Static Bottle Test</td>
<td>• Well Flowback Analysis</td>
</tr>
<tr>
<td>• Dynamic Bottle Test</td>
<td>• Production Analysis</td>
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<tr>
<td>• Viscosity Profile Rheology</td>
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<td>• Conductivity Measurements</td>
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<tr>
<td>• Static Proppant Suspension</td>
<td></td>
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<tr>
<td>• Dynamic Proppant Suspension</td>
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</table>

**Static Bottle Test**

The static bottle test is the easiest, most common test. The tester can determine if approximately correct breaking conditions exist by

1. Placing the gel and breaker in an airtight bottle.
2. Holding this sample in a temperature bath at reservoir temperature for the desired break time.
3. Evaluating the resulting gel.
Table 1--Static Break Data for HYBOR G3295 Fluid

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Concentration of OptiFlo III Breaker (lb/1000 gal)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
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<td>C</td>
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<tr>
<td>5</td>
<td>C</td>
</tr>
<tr>
<td>8</td>
<td>C</td>
</tr>
<tr>
<td>24</td>
<td>C</td>
</tr>
</tbody>
</table>

This test is often used to screen various breaker concentrations. For crosslinked fluids, the tester can see whether complex gel is weakening, and, if enough crosslink character is broken, the viscosity may be measured with a Fann Model 35 or similar device. For temperatures above 200°F, a pressurized container must be used.

The weakness of this test is that no information about the viscosity profile during the breaking process is obtained. Passing this test indicates that the fluid should break, but the test results can lead to excessive breaker loadings. Table 1 gives an example of static break data for HYBOR G3295 fluid. The data are recorded for crosslinked (C), weak crosslinked fluids (WC), or as viscosity at 511/sec, at different concentrations of OptiFlo III breaker (lb/1000gal).

Since crosslinked fluids are time- and shear-dependent, the break rate is also shear-dependent. Static break tests predict break times that are longer than those found if the fluid is under shear.

Dynamic Bottle Tests

Dynamic bottle tests compensate for a weakness of the static test. To include some shear in the breaking process, a tester can place the static bottle in a roller oven to keep the gel in constant motion during breaking. This movement accelerates the break rate.

An ideal modeling of breaking conditions would be to shear the fluid in the same conditions as those experienced during fracturing. After the pump time, the fluid would be kept static until the break is complete.

Dynamic bottle tests, or similar methods imparting an undefined shear level to the fluid, are not widely used because test shear rates are difficult to quantify. For break times over 8 to 12 hours, a static break test is more acceptable since most of the time the fluid will be static after pumping.
Viscosity Profile Rheology

Obtaining the viscosity profile of a fluid containing breaker is desirable not only to show the fluid breaks but also to confirm that viscosity loss did not occur too rapidly. For fast break times (2 to 4 x pumping time), this test is selected to study breaker type and concentration. The Model 50 Fann viscometer or similar instrument is used for these measurements. Most fracturing fluid testing laboratories and some mobile units on location have these instruments. Another way to measure break profiles in the field is to use a Model 35 Fann VG meter equipped with an R1B2 sleeve-and-bob configuration. For borate crosslinked fluids below 200°F, this method may be useful for balancing viscosity loss versus getting a quick break. Figure 7 shows sample break data measured with a 50 Fann viscometer.

Figure 7—50 Fann Break Data

Conductivity Measurements

The conductivity experiment includes leaking-off fracturing fluid through two core faces, creating a filter cake, and then placing proppant between these cores and applying appropriate closure stress and temperature. After the desired breaking time, the tester flows water, gas, or oil through the proppant. The resulting permeability of the proppant (regained conductivity) is measured and compared to a similar system without filter cake. The amount of damage caused by the gel filter cake depends on the gel type, breaker type, breaker concentration, temperature, test method, and many other factors. Compared to clean sand, regained conductivity may vary from 10 to 90 percent.
One problem with these tests is that the results are dominated by the filter cake. Whether filter cake of equal thickness is formed in actual low permeability reservoirs compared to the lab tests is questionable. Although they are certainly real, filter cake damage as seen by conductivity tests may be overestimated based on actual production data from wells, which is higher than lab tests might predict. Figure 8 shows sample data.

Figure 8—Conductivity at 250°F with 2 lb/ft² Proppant

Conventional breakers used in the fracturing fluid at concentrations low enough to prevent excessive viscosity loss during pumping may not significantly improve the regained conductivity. To remove the filter cake, a high concentration of breaker and chemicals are required to remove the crosslink\(^{17}\). The use of encapsulated breakers has been proposed, but even increased breaker loadings may not completely clean up the filter cake during the duration of these tests\(^{18}\).

Static Proppant Suspension Tests

A tester can mix the fracturing fluid and desired concentration of proppant to estimate proppant transport. Most crosslinked fracturing fluids are shear-thinning, which means they are at their highest viscosity when static. If a fluid will not support proppant when static, one could predict that under shear, proppant transport will be less than ideal. Breaker influence on sand suspension can be determined by observing the relative settling rate in a jar. Figure 9 shows sample settling data.
Dynamic Proppant Transport

No reliable, established method to evaluate proppant transport currently exists within the well stimulation industry. Many research efforts are in progress to develop procedures for direct and indirect proppant transport measurements\(^{(19)}\). Breaker influence on a fluid’s capability to carry proppant inherently must be negative, but future research must be done to define the magnitude of that influence.

Well Flowback Analysis

Regardless of whether lab tests were done, field results and data should be considered in subsequent breaker designs. When a fracturing treatment is completed, if most of the load water and gel are recovered, the breaking is considered successful. Usually, however, much less than 100% of gel and load water is recovered, yet the well flowback rate may not indicate a breaking problem. Definitive answers about whether a gel is completely broken are very difficult to obtain since absorption and dilution in the formation normally prevent a good material balance.

Recovering thick, crosslinked fluid from a well indicates a breaking problem. Be aware that some fluids, especially borates, may have a near water-thin viscosity in the high temperatures downhole, but as they cool to surface temperatures the fluid may appear crosslinked.

A well with adequate pressure that will not clean up also indicates a problem.
Production Analysis

The final criteria for breaker testing and all other elements of a fracturing treatment is obtaining production. Although it is seldom done, production and/or pressure transients can be analyzed to determine the effective length of a fracture.

Posttreatment analysis benefits both the customer and the service company. By determining the effective propped fracture length, the tester can evaluate the treatment design and the breaker selection and loading. Table 2 lists several breakers and outlines their general characteristics. Production analysis should be the final and ultimate criterion in breaker selection whenever possible.

Table 2--Breaker Recommendation Summary

<table>
<thead>
<tr>
<th>Breaker</th>
<th>Type</th>
<th>Temperature (°F)</th>
<th>Concentration (lb/Mgal)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>GBW-30</td>
<td>Enzyme</td>
<td>60</td>
<td>140</td>
</tr>
<tr>
<td>SP/Cat-3/Cat-4</td>
<td>Oxidizer/Catalyst</td>
<td>80</td>
<td>130</td>
</tr>
<tr>
<td>SP/AP</td>
<td>Oxidizer</td>
<td>130</td>
<td>200</td>
</tr>
<tr>
<td>ViCon NF¹ (gal)</td>
<td>Oxidizer</td>
<td>140</td>
<td>350</td>
</tr>
<tr>
<td>Matrixflo II (gal)²</td>
<td>Acid Buffer</td>
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¹Use Cat-3 and or Cat-4 < 200°F
²Acid release agent for uncrosslinking borates or for use with enzyme breakers in borate fluids.
References


