FRACTURE PRE-TREATMENT: A PATENTED PROCESS HAS BEEN DEVELOPED TO INTENSIFY BREAKER ACTIVITY, MINIMIZE POLYMER DAMAGE, AND MAXIMIZE POST FRACTURE PERMEABILITY

Henry Lopez, Doug Walser, Mark Malone and George Woo
BJ Services Company, USA

ABSTRACT

A novel process has been developed to reduce the polymer damage associated with aqueous fracture treatments inclusive of the filter cake and polymer residue and their detrimental effects to fracture conductivity, formation permeability, and the resultant oil and gas production. This novel approach differs from conventional breaker applications in that the formation is first treated with breakers and then the fracture treatment is performed. The process advances that a "Fracture Pre-Treatment" fluid enriched with breakers is pumped ahead of the primary fracture treatment and proppant. The process also advances that the breakers coat the formation matrix to include the formation surfaces, pore throats, and permeable network through natural leak-off prior to the dynamic deposition of the filter cake during the fracture treatment.

Since the breaker enriched Fracture Pre-Treatment fluid is pumped prior to the main body of the fracture treatment (and proppant), the dynamic pressure differential between the fracture and the formation contains the Fracture Pre-Treatment fluid behind or in the formation during the fracture treatment. Thus the main body of the fracture treatment is unaffected by the Fracture Pre-Treatment fluid. The fracture treatment is completed in the conventional manner with standard breaker concentrations, the well is shut in to allow the fluid to break, and the flow-back process is then initiated. During the flow-back of the treatments the pressure dynamics are reversed releasing the fracture treatment and Fracture Pre-Treatment fluids. The breaker enriched Fracture Pre-Treatment fluid flows from the formation matrix into the fracture sweeping it with a concentrated breaker solution.

This unique process concentrates the breakers on the formation side of the filter cake, increases the total mass of the breakers that can be applied and further exposes the filter cake and polymer residue to the breakers upon flowback of the fracture treatment and Fracture Pre-Treatment fluid. These combined factors enhance the degradation of the filter cake and polymer residue, thereby promoting increased regained fracture conductivity, formation permeability, and further enhancing oil and gas production.

INTRODUCTION

The oil and gas industry has in most recent years undertaken a concerted search for cleaner and less damaging fluids used for a variety of downhole applications in order to further enhance oil and gas recovery. The objective has been to minimize the damage that is subsequent to most downhole treatments or processes from the drilling and completion to the production of the well. Thus has been the inception of the "clean fluids" or "clean technology" concept. Such discoveries as highly efficient ultra low polymer fracture fluids, polymer specific enzymes for fracturing and drilling, methanol based fracturing fluids, anti-sludge acidizing additives, micro-sized high mobility polymers for acids, post-frac polymer clean up fluids, and other technologies can be attributed to this single effort. The philosophy of prevention verses cure has also been widely accepted in the industry due in part to several studies that have been performed to that end[1].

The new patented Fracture Pre-treatment Process was developed specifically to reduce the polymeric damage associated with hydraulic fracturing treatments, specifically filter cake deposition and polymer residue. This paper describes the three fold mechanism of the new Fracture Pre-Treatment Process and includes (1) pre-treating the formation with breakers prior to the deposition of the filter cake, (2) increasing the total breaker mass, and (3) enhanced exposure of the filter cake and polymer residue to concentrated breakers. The objectives of the Fracture Pre-treatment Process are to minimize polymer damage and maximize post fracture permeability. These concepts and objectives are viewed as consistent with that of the "clean technology" concept.

FRACTURE PRE-TREATMENT PROCESS

A fluid enriched with specialized breaker(s) is pumped ahead of the main body of the fracture treatment (and proppant), allowed to leak-off, and then the fracture treatment is performed in the conventional manner using conventional breaker types and concentrations. Due to the pressure dynamics of the treatment, the fracture treatment is unaffected by the Fracture Pre-Treatment fluid. Notably, the Fracture Pre-Treatment fluid is not intended to be a replacement for the internal breakers normally ran in the fracture fluid.

The formation surfaces, pore throats, and permeable network are coated by the specialized breaker(s) contained in the Fracture Pre-Treatment fluid prior to the establishment of the filter cake and the deposition of the polymer residue. The specialized breakers are selected for their efficiency, tenacity, and tendency to adhere to the surfaces contacted. Polymer specific enzymes are preferred due to their effective polymer degradation, reaction with the distinct polymer only (not on pipe, formation, etc.), recurring reaction (repeatedly reacts without spending), and ability to adhere to the formation through ionic charges. It is critical that the breakers in the Fracture Pre-Treatment fluid not spend (become inert) while they are within the formation matrix during the post frac shut-in period but remain active for the subsequent flow-back.

The concentration of breakers in the Fracture Pre-Treatment fluid itself and the total Fracture Pre-Treatment fluid pumped is limited only by the consideration of the final effect (degradation) on the polymer residue and economics and not by the propped fracture fluid stability considerations as in normal fracture treatments. Shut-in times and flowback after the fracture treatment are also performed in the conventional manner.

After the main fracture stimulation and the appropriate shut-in time the bottom hole pressure is released and the fluid is recovered (flowed-back). During the flow-back, the fracture fluid followed by the Fracture Pre-Treatment fluid is expelled from the formation, through the fracture face and filter-cake and into the propped fracture toward the well bore. Since the Fracture Pre-Treatment fluid was placed on and into the formation prior to the deposition of the filter cake (during the fracture treatment), the filter cake is also attacked from the formation side and from within by the breakers run in the fracture treatment. The fracture face, filter cake and propped fracture length are subsequently swept with concentrated active breaker solution aggressively degrading the filter cake and polymer residue (Exhibit 3 & 4).

This unique process concentrates the breakers on the formation side of the filter cake and polymer residue, increases the total mass of the breakers than can be applied, and further exposes the filter cake and polymer residue to concentrated breakers upon flowback of the fracture treatment and Fracture Pre-Treatment fluid. These combined factors enhance the degradation of the filter cake and polymer residue, thereby promoting regained fracture conductivity, formation permeability, and further enhancing oil and gas production.

Fracture Pre-Treatment – Other Applications

The initial concept included the application of the Fracture Pre-Treatment in conventional aqueous crosslinked fracture fluids such as borates and metal crosslinks. It became apparent that the Fracture Pre-Treatment Process could be applied to a wider variety of processes and that the application should not be limited to the breaking of aqueous stimulation fluids. Other applications include foam fracture stimulation, gravel packing, gelled and crosslinked acids, gelled and crosslinked oils, and in some instances drilling fluids. Its application should not be limited to any particular fluid but rather, should be considered in any application where polymer damage is thought to be a significant factor in limiting oil and gas production and an appropriate breaker exists for that polymer. The application can also be used where gelled or crosslinked fluids may wish to be aggressively disrupted.

Foam Fractures & Linear Fluids (CO2, N2, & Binary Gases)

Foam fracturing fluids containing such base fluids as linear gels or low pH crosslinked fluids can be especially sensitive to some breakers such as polymer specific enzymes and some oxidizers, especially at higher bottom hole temperatures. Whereas only very low concentrations of internal breakers can be run in these fracture fluids, very high concentrations of breakers can be utilized in a Fracture Pre-Treatment fluid. Further, large volumes of the Fracture Pre-Treatment fluids can be pumped (if so desired) since it is pumped independently of the fracture fluid. The Fracture Pre-Treatment fluid may also be placed into the formation using CO2, N2, and Binary fluids (C02 & N2 mixture) as stable foams as desired.

Borate Fracture Fluids

High pH borate crosslinked fluids are in common use as fracture fluids throughout the industry. The high pH is intrinsic to maintaining a stable crosslinked viscosity and proppant support. A common phenomenon of the borates is that lowering the pH can result in a dramatic and immediate loss of crosslinked viscosity. It is also known that lower viscosity fluids (i.e. guar based polymers) are more susceptible to the activity of internal breakers. **Also,** some internal breakers that are incorporated into the fluids are more active in a low pH environment than a high pH environment. These phenomenon can be used advantageously to intensify the destructive impact of the Fracture Pre-Treatment fluid on the polymer by pumping a Fracture Pre-Treatment fluid prepared in a moderately acidic fluid with breakers that are especially active in that pH environment. During flowback the pH of any contacted fluid is reduced as is the viscosity rendering it more susceptible to the concentrated breaker of the Fracture Pre-Treatment fluid and internal breaker within (ran during the fracture treatment). Such a process would also be beneficial in a dry gas well environment where there is little or no connate water available to aid in lowering the pH of the fracture fluid and assist in breaking the fluid.

Gelled & Crosslinked Acids

The use of crosslinked acids has continued to increase in highly soluble formations in both oil and gas wells because of their highly retarded reaction rates and excellent fluid loss control. The crosslink is known to be tenacious and in some instances difficult to break. A Fracture Pre-Treatment fluid could be pumped with a soluble breaker consistent with the breaking mechanism of the crosslinked acid to ensure a more complete exposure of the treatment to the concentrated breaker upon flow back.

Gelled Oils & Crosslinked Oils

Both gelled oils and crosslinked oil gels have also enjoyed a resurgence in the recent past. The gelled oils and crosslinked oil gels can also be tenacious and at times difficult to break. Again, the Fracture Pre-Treatment fluid could be pumped with a breaker consistent with the breaking mechanism of the gelled or crosslinked oil to ensure a more complete break is achieved upon flow back.

PROCESS APPLICATION

The application of the pre-treatment process is relatively uncomplicated in design. While other potential applications have been discussed, it is the opinion of the authors that the best application exists in the area of hydraulic fracturing. The use of pre-fracture diagnostic testing or mini-frac analysis has been on the increase in recent years as new computer software has enabled operators to analyze pump-in or injection test data on location in relatively short time frames. The purpose of the injection test is to obtain reservoir and fluid data that can define such parameters as closure pressure, near wellbore friction, and most importantly, fluid efficiency. While these tests are performed to optimize the fracture treatment, they also provide an excellent opportunity to perform a Fracture Pre-Treatment. The pump-in treatment could simply be treated with the appropriate types and concentrations of breakers. The pump in treatment should be designed to encompass the entire zone height thereby entering most of the pay in the near well-bore area. This fluid will serve as a pre-pad, which will leak-off into the formation matrix and away from the created proppant pack, thus placing it behind the filter cake. Upon the recovery of the fracture treatment, the pump-in fluid is forced to flow back through the filter cake or its flow restricted by the filter cake, thus providing additional reaction time.

If a pump-in test or mini-frac were not planned prior to the fracture treatment then the recommended placement technique would be to inject the pre-treatment fluid in a volume calculated just as in a pump-in test. The Fracture Pre-Treatment fluid could be pumped into the fracture at fracture or matrix rates (Darcy) and then allowed to leak-off. Care should be taken during the operation to ensure that the pre-treatment fluid is not exposed to the fracture or treatment fluid at anytime during the placement, as it is designed to degrade the fracture fluid upon contact. A spacer consisting of conventional fluids and breakers could be pumped between the fracture fluid and the Fracture Pre-Treatment fluid to help isolate the fluids if so desired.

The pre-treatment fluid may include clay control additives and should always include a de-emulsifying surfactant with excellent surface tension reduction properties to ensure optimum flowback. The main component of the system in all cases is the appropriate breaker. Encapsulated breakers are discouraged, as the injection into the formation matrix may not be possible with some encapsulated breakers due to their size. The use of enzyme breakers is recommended due their proven performance'. increased activity, and polymer specific characteristics. Breaker concentrations should be approximately five to ten times the normal concentration (as in the fracture fluid) at a given temperature. It is this concentrated loading that has provided regained proppant pack conductivity greater than 90% in the laboratory (Exhibit 3) and thus becomes the objective in performing the Fracture Pre-Treatment Process. It is recommended that upon placement that a shutdown occurs before continuing the actual fracture treatment to allow complete leak-off of the pre-treatment fluid into the formation matrix. In areas where leak-off conditions are extreme (very high) a shutdown may not be necessary for an effective leak-off.

POLYMER DAMAGE

Polymer damage has long been associated with hydraulic fracture treatments performed to stimulate the production of oil and gas. This damage is due primarily to the dynamic pressure differential between the hydraulically induced fracture and permeable formation face. The differential pressure allows a driving force for fluid tlow from the fracture to the formation. During this leak-off a filter cake is dynamically deposited on the inner walls of the fracture or formation faces (Exhibit 4). The formation acts as a "sieve" and filters the particulate mass from the fluid, which in the case of hydraulic fractures is comprised primarily of organic or synthetic polymers. It is thought that most fracture treatments will experience some leak-off and filter cake deposition. The amount of leak-off and the subsequent deposition of the filter cake is dependent on many variables and can include formation permeability, porosity, fracture to formation pressure differential, fluid leak-off efficiency, fluid particulate concentration and size, fluid viscosity, treating rate, and treating time.

The experimental work of Mayerhofer, Economides and Nolte[2] has shown that the amount of polymer present in tilter cake deposition or the mass of polymer present can be explained by mass balance, a straight line or linear function. Simply put the higher the initial loading of polymer in the fracture tluid utilized in the primary stimulation treatment, the greater the subsequent filter cake damage. The total polymer mass pumped downhole may inhibit production by physically blocking the flow of hydrocarbons and by the sheer polymer mass (hydrostatic pressure). Additionally, studies have confirmed that fracturing fluids incorporating different polymers and crosslinkers exhibit practically the same leak-off characteristics in static fluid-loss tests and therefore do not vary significantly in the amount and type of filter cake deposited[4]. In additional studies by Gulbis[6], it was revealed that non-crosslinked (linear) systems fully develop filter-cake. Therefore, fluid selection in itself may not significantly lessen the effects of filter cake development and should not be the primary preventative measure to lessen the effects of polymer damage.

The oil and gas pathway from the reservoir to the perforations would include tlow from the reservoir through the filter cake and propped fracture and into the tubulars. Since the fluid must pass through the filter cake at the formation faces, it can be an effective physical barrier to the flow of hydrocarbon production. The effectiveness of the filter cake as a barrier is dependent on many factors and can include permeability, porosity, breaker efficiency, residual filter cake thickness, area of the fracture covered by the filter cake, pressure differential from the formation to the fracture, fluid(s) viscosity, flow rates and finally chemical degradation of the pressure induced polymer filter cake. The chemical degradation of polymers has heretofore been the most effective means for its removal from the fracture face. The only preventative measure other than the subject of this paper, is the exclusion of the polymers in stimulation fluids in their entirety. While this solution is logical, it is not practical with current fracture fluid technology.

It is generally thought that the majority of polymer damage and subsequent loss of production results from the filter cake within the fracture. Other residual polymer damage may also be significant such as discrete polymer residue bridging within the pore throats blocking fluid flow. Permeability damage to the producing formation can also occur when polymer fragments are large due to an inadequately broken fluid caused by low concentrations of breaker or inadequate contact time. Molecular weight studies of broken polymer fragments have shown that enzyme breaker technology and high concentrations of such enzymes can dramatically reduce damage effects in both the filter cake and permeability of the rock itself[4] (Exhibit 1-4).

BREAKER TECHNOLOGY & BREAKER EFFICIENCY

The efficiency of breakers used in degrading fracturing tluid polymers must have an impact on the filter cake, polymer residue and the subsequent oil and gas production. Logic would dictate that the more effective the polymer degradalion, the less filter cake and polymer residue remains within the fracture and formation matrix, and the higher the regained conductivity of the fracture. Given that breaker efficiency is a crucial juncture, some mention should be made of breaker efficiency and technology.

In the application of breaker technologies during the pumping of the fracture treatment, several assumptions are often made. It is often assumed that the breaker will accompany the fluid to its ultimate end and even into the smallest of pore throats and spaces. This may not be the case if the breaker is an oxidizer (in solution) that is carried within the fracture fluid and into the formation and may spend on virtually any material, i.e. tubulars, formation material, fluids, etc. Encapsulated oxidizers may also encounter difficulty in accompanying the fluid into the matrix due to its size and the restrictions encountered in the formation. It is also often assumed that the concentration of internal breaker that is sufficient to maintain fluid stability during the fracture treatment is sufficient to break a significant portion of the filter cake and polymer residue. The assumption may too be suspect depending on the type, efficiency, and tenacity of the breaker. Recent findings in studies by Malone et.al.[5] have indicated that breaker and fluid type can significantly impact post-frac production performance (Exhibit 3). These same studies have also indicated that thermal degradation of polymer in low temperature (<100F) reservoirs alone is not sufficient to effectively remove polymer damage (Exhibit 2).

Breaker technologies have advanced tremendously in the past ten years. Enzymatic and oxidizing breakers are used frequently and both can be encapsulated in order to deliver a more concentrated dosage with its immediate effect delayed by the encapsulating process. Enzymes have also undergone advancements with the advent of polymer specific enzymes. These polymer specific enzymes concentrate the breaker activity specifically to one polymer type and to no other compound thereby focusing its breaker energy to the polymer and increasing its efficiency (Exhibit 1 and *2)*.

While advancements in breaker technology have resulted in superior breaker systems, an equilibrium must still be achieved between the need for superior fluid clean-up characteristics and adequate proppant support. The percent-regained conductivity relative to the original conductivity of the proppant pack created in a laboratory environment has become the standard of measurement for the potential of a fluid system for damage. Fluid and breaker systems that yield a regained conductivity in the range of 50% are in common use today. However, it has long since been the goal to utilize fluid and breaker systems that will yield a regained conductivity approaching 100%. To accomplish this in a laboratory test cell, extreme loadings of breakers must be utilized and fluid stability is sometimes sacrificed, thereby increasing the chances of a premature screen-out (if the fluid could be used in a hydraulic fracture treatment).

Pre-Fracture Treatments with extreme loadings of enhanced or specific breaker systems can be utilized without sacrificing fluid stability. This pre-treatment allows the enhancement of regained conductivity in excess of 90% (Exhibit *2),* without affecting the transport of higher proppant concentrations, which will further enhance the conductivity of the hydraulically induced proppant pack.

SUMMARY

The Fracture Pre-Treatment Process’ is a patented process that has been developed to intensify breaker activity, minimize polymer damage and maximize fracture permeability and enhance the subsequent oil and gas production. The Fracture Pre-Treatment Process consists of a breaker-enriched fluid that is pumped prior to the main body of the fracture treatment (spearheaded). This fluid is leaked-off into the formation prior to the fracture treatment. The propped fracture fluid is then pumped in the conventional manner with conventional breaker concentrations. Since the Fracture Pre-Treatment Process has leaked-off into the formation, the pressure dynamics during the fracture treatment prevents it from affecting the propped fracture fluid. **A** spacer containing conventional concentrations of breakers can be pumped behind between the Fracture Pre-Treatment fluid and the propped fracture treatment to isolate the Fracture Pre-Treatment fluid from the main body of the propped fracture fluid if so desired.

This unique process concentrates the breakers on the formation side of the filter cake and polymer residue, increases the total mass of the breakers than can be applied, and further exposes the filter cake and polymer residue to concentrated breakers upon flowback of the fracture treatment and Fracture Pre-Treatment fluid. These combined factors enhance the degradation of the filter cake and polymer residue, thereby promoting regained fracture conductivity, formation permeability, and further enhancing oil and gas production.

The Fracture Pre-Treatment Process is considered a logical progression and practical extension to the application of breakers in order to minimize polymer residue throughout the formation matrix and propped fracture to further Maximize oil and gas production.

ACKNOWLEDGEMENTS

The authors would like to thank **BJ** Services Company for the time, support and the opportunity provided for this work and the corresponding patent.

SI METRIC CONVERSION FACTORS

(°F-32)/1.8	E + 00 = °C
gal X 3.785412	E – 03 = m^3
lbm X 4.535924	E – 01 = kg

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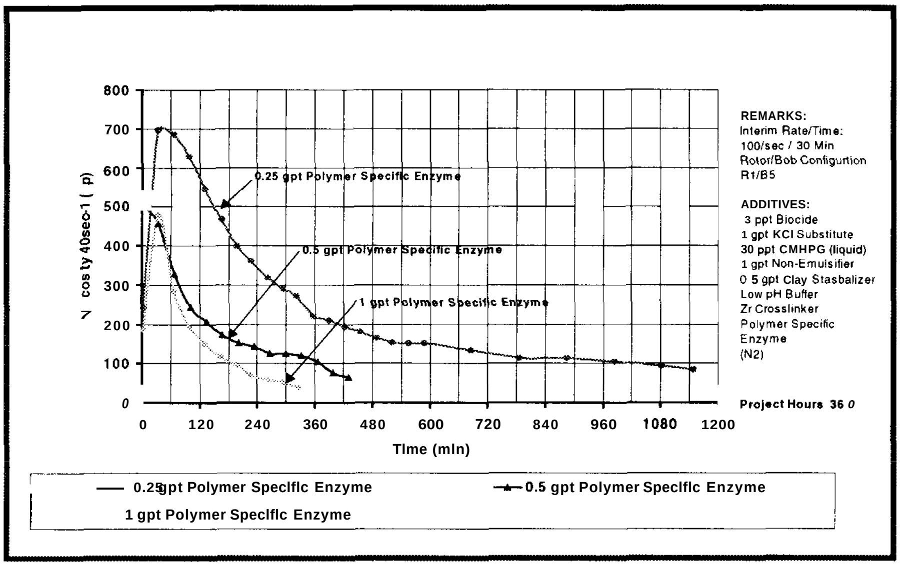

Exhibit 1 - Effect of Various Concentrations of Polymer Specific Enzyme on a CMHPG Crosslinked with Zirconium