Organoborates Combined with Guar-Specific Enzyme Breakers Increase Production and Outperform Competetive Fluid Systems in the Grayburg-Jackson Field, Southeast New Mexico: A Case History

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Abstract

The subject matter of this paper will describe organoborate fluid systems in combination with guar specific enzyme breakers. Their application, and how they were used to improve production in the Grayburg-Jackson field of SE New Mexico. Furthermore, the paper will discuss the completion objectives in the Grayburg-Jackson field as they relate to stimulation treatments and explain how wells were normalized for the purpose of this study. Finally, production results will be examined to compare organoborate/guar specific enzyme breaker combinations verses monoborate fluid systems with non-specific breakers.

Introduction

In 1994 Devon Energy Corporation embarked upon a drilling and completion project in the Grayburg-Jackson field of Eddy County, New Mexico for the purpose of installing a secondary recovery waterflood (fig 1). The Grayburg-Jackson field produces from the Grayburg and San Andres formations comprised of several sandstone and dolomite producing intervals within each formation. Historically, these formations have required hydraulic fracture stimulation in order to be economically produced due to its low relative permeability. The low BHST of these formations coupled with the low relative permeability created some unique challenges from a fracture fluid design standpoint. The fracture fluid systems were designed in such a manner as to create long and highly conductive fractures while minimizing polymeric damage to the low perm reservoir.

Close attention was paid to the fracture treatment design as a reasonable balance had to be struck between the need for a completion that produces enough hydrocarbons in the well's early life to generate adequate cash flow for ongoing operations, and the desire to optimize ultimate reserve recovery by maximizing waterflood sweep efficiency.

Fluid Description:

Hydraulic fracture treatments in the field study area were performed with water-based fluid systems consisting of a refined, natural guar gelling agent. In all of the crosslinked treatments, borate crosslinked guar fluids were chosen in order to maximize regained proppant pack conductivity following fracture cleanup. The borate fracture systems were crosslinked at high pH by either an organocomplexed borate complexor, or by a conventional monoborate complexor. A typical fluid pH range from 9.8 to 10.2 allowed for both adequate crosslink gel viscosity and proppant transport capabilities.

During the five-year development of the Grayburg-Jackson field, various combinations of the borate complexors and gel breakers were employed. These ongoing modifications evolved in an effort to maximize each successive wells production. The breakers utilized within the organoborate fracture treatments included both patented polymer specific enzymes, as well as conventional non-specific high pH enzymes. Conventional high pH enzymes are considered to be stable up to a temperature of 120°F. Bottom hole temperatures encountered in the field study area were found to be 100°F or less. The monoborate fracture treatments were pumped with a persulfate oxidizing breaker, or conventional high pH enzymes, or combinations of both. Due to the low bottom hole temperatures encountered, a catalyst was added in conjunction with the persulfate type breaker to increase its effectiveness.

Breaker Description:

Four types of breaker chemistries were applied to both organoborate and monoborate fluid systems utilized within the Grayburg-Jackson field treatments. Initially, catalyzed and non-catalyzed ammonium persulfate (AP) breakers were applied. These breakers were chosen due to their inherent economic benefits and perceived effectiveness at the design temperatures (100°F). These AP breakers were catalyzed to increase their effectiveness at low temperatures. Even with strong catalyzation, ammonia persulfate breakers have several disadvantages associated with their chemistry. The worst of which is non-specific reactivity. Oxidative breakers by their very nature will react with many available substances including tubulars. Ammonium persulfate breakers possess a limited control of reaction rate and posses the undesirable potential of incompatibility with formation minerals or side-reactions with reservoir fluids.[1] As production response was examined, and some instances of poor breaker performance were noted, enzymatic breaker technology was applied to the fluid chemistry at Grayburg-Jackson field. Early enzyme breakers applied in the project were non-specific by nature meaning they are non-specific enzyme substrate mixtures that randomly hydrolyze the base polymer.

This random hydrolysis can result in partial degradation of the polysaccharides into predominantly short-chained polysaccharides. These crosslinked, short-chained polysaccharides are relatively insoluble and therefore, may cause permeability damage. Finally, changes were made to the fluid system in an attempt to further optimize production response. The final breaker application within the Grayburg-Jackson field was that of guar specific enzyme breaker technology.' Guar specific enzyme breakers are designed to catalyze very specific sites on the guar polymer surface. This site is the β 1,4 linkage located in the guar polymer backbone as shown in figure 2. This effectively reduces the guar polymer molecular weight thus reducing polymer fragments to simple sugars or glucose, which will more readily flow from the proppant pack.

Upon application of the guar-specific enzyme breaker technology, an increase from "normal" in the initial production response from affected wells in the Grayburg-Jackson field was recognized. However, it was not until this study was concluded that the significance of that increase was noted.

Completion and Stimulation Objectives (Overview):

A typical well in the Grayburg-Jackson field involves a 12.25 in hole drilled to a depth of 600 ft with nine ppg brine water. An 8.625 in 24 lbm/ft surface casing string is cemented to surface. The surface casing shoe is drilled-out with a 7.875 in drill bit. The hole is then deepened with 10 ppg brine water to below the San Andres formation at approximately 4000 ft. A suite of logs typical for the area are run consisting of a compensated neutron, litho-density, gamma, dual laterolog, micro-SFL, and a caliper log. After positive log evaluation, 5.5 in, 15.5 lbm/ft production casing is run and cemented. The cement is brought back to surface in accordance with Bureau of Land Management requirements. A bit and scraper run is made to prepare the production casing for perforating.

Zones of interest within the Grayburg and San Andres formations are identified from crossplot porosity values and offset well correlation. Productive intervals exist from the top of the Grayburg formation at approximately 2700 ft to the base of the San Andres formation at approximately 3,700 ft. The excessive vertical extent **of** the formations encountered requires a determination be made that best divides the intervals in preparation for a two-stage fracture treatment. A limited entry perforating technique is implemented with 0.40 in diameter holes in order to create a sufficient perforation pressure drop, or differential pressure, relative to the number of holes selected. In general, a hydraulic fracture rate of 2 bbls/minute per perforation provides effective fluid diversion for both treatment stages. Fracture gradients, and reservoir pressures, are relatively constant across each treatment stages perforated interval.

In preparation for each fracture treatment, acid breakdown treatments/ballouts with 15% hydrochloric acid (HCL) are utilized. Typical volumes pumped are 100 gallons per perforation. The acid system contains appropriate acid inhibitor for bottom hole static temperatures ranging from 90-100°F. Additionally, a suitable non-emulsifier is added along with an iron sequestering agent, such as citric acid, to prevent the precipitation of iron oxide gels.

Hydraulic fracture treatments of the Grayburg and San Andres formations are performed with water based, non-energized, fluids. The first stage treatment will typically encompasses the lower San Andres formation, which ranges in bottom hole static temperature from 96-100°F, and exhibits fracture gradients on the order of 0.9 psi/ft. Lower San Andres formation fracture treatments are comprised of **30** ppt gallons high pH borate crosslinked guar fluids. This fluid system was selected because of its superior crosslinked viscosity, and its ability to enhance regained proppant pack conductivity.

Propped fractures are designed to achieve approximately 300 ft. in length. Initially in the development of the field both 3-D fracturing models and 2-D fracturing models were utilized to determine the treatment size required to facilitate the desired propped fracture length. Pad size, proppant laden fluid stage sizes, as well as proppant amounts, were set on a per net foot of pay basis. All succeeding treatments were then designed in the same manner. **A** typical lower San Andres formation fracture treatment contains a 30 percent pad volume, with 80 percent of the total proppant placed at 5 psa or greater. The maximum proppant concentration pumped is 8 psa . The proppants pumped on the lower San Andres include Brady sand with curable resin coated sand tail-ins to eliminate proppant flowback.

The Grayburg formation and upper San Andres formation are typically fracture stimulated together comprising the second stage fracture treatment. Bottom hole static temperatures range from 93-98°F, while fracture gradients increase to between 1.0-1.1 psi/ft. The increase in fracture gradient, over that seen in the lower San Andres, is due to the fracture orientation becoming more highly deviated from vertical as the treatment interval is moved up the wellbore. The Grayburg and upper San Andres formations fracture treatments are again comprised of 30 ppt gallons high pH borate crosslinked guar fluids.

Propped fractures are designed to achieve approximately 300 ft in length. A typical second stage fracture treatment contains a 25 percent pad volume, with 90 percent of the total proppant placed at 5 psa or greater. The maximum proppant concentration pumped is **6** psa. The proppant type utilized in the Grayburg and upper San Andres formations is Brady sand.

Geology and Reservoir Background (Field Overview):

The Grayburg-Jackson field is composed of approximately 8,200 acres, which sits in the middle of a 75-mile long trend of upper Permian aged shelf. The field includes 381 active wellbores producing from the Grayburg and San Andres formations located between the depths of 2,700-3,700 ft with a total of 12 different intervals identified as potentially productive. All the facies represented through the Grayburg and San Andres formations were deposited in peritidal (shallow subtidal to supratidal) carbonate settings and siliciclastic-rich, upper shoreface to eolian sandflats, supratidal deflection flats, and ephemeral stream environments. The clastic Grayburg units are a suite of near shore terrestrial facies, while the carbonate San Andres units represent near shore shallow marine facies. Deposition was cyclic in nature characterized by rising and falling sea levels with the units composed from these numerous depositional cycles being **of** thin to moderate thickness (1-20 ft) and apparent high frequency.

Porosity and permeability vary within the Grayburg and San Andres formations. Grayburg formation average porosity and permeability values are 7.2% and 0.82 md, while the San Andres formation average porosity and permeability are 7.5% and 0.28 md respectively (full diameter core source). Permeability is a concern with respect to the reservoir potential (or fluid flow potential). Though porosity may range from poor to good (< *2%* to > 15%) permeability is more variable and strongly skewed toward the lower range of average values. This is primarily due to very fine-grained sands and abundant secondary cementation by anhydrite. Clay minerals are present, but only in small amounts (< 5% by weight), and are of concern as any reduction in the already low permeability values could reduce conductivity below an economic threshold.

The inhibition of fluid conductivity through the porous intervals due to the factors listed above has created a need for fracture stimulation of the Grayburg and San Andres intervals in order to attain the necessary flow rates needed to achieve an adequate return on investment.

Discussion of the Borate Fluid and Breaker Modifications:

At the outset of the five-year drilling program, fracture treatments were exclusively performed with conventional monoborate high pH crosslinked guar fluids. Every oil field service company has routinely used this particular borate technology for decades within the industry. Various breaker designs evolved in the Grayburg-Jackson field through the ongoing effort to maximize the performance of the hydraulic fracture treatments pumped. These breaker designs included the use **of** persulfate oxidizing breakers, conventional non-specific high *pH* enzymes, and the combination of both. The sole purpose **of** these modifications was to produce the most conductive proppant pack possible. The goal of creating a highly conductive means in which to produce hydrocarbons through a propped fracture contains two principle parts. First, the proppant must be uniformly carried, and placed within the created fracture. To accomplish this, adequate crosslinked fluid viscosity must be developed to achieve sufficient fracture width, and the proppant transport capability of the fluid needs to be able to provide perfect support of the proppant within the crosslinked fluid throughout the duration of the fracture treatment. The second essential part of creating a conductive propped fracture entails the degradation of the crosslinked polymer, and its subsequent removal from the fracture. The reduction of the polymer remaining in the proppant pack is directly proportional to the ability said fracture will have to conduct fluids to the wellbore.

With every effort being made from a breaker standpoint to address polymer damage, the only means remaining to further optimize regained conductivity would be through a reduction in the polymer amount put into the fracture during the treatment. However, such a reduction of the base gel polymer loading to levels of 20-25 ppt gallons, was not viable due to the fact that such base polymer reductions diminish the ability of the created conventional monoborate fracture fluid to transport proppant without settling. In other words, advantages gained in proppant pack regained conductivity enhancement would be counteracted by the inability to uniformly distribute proppant throughout the entire created proppant pack because of increased proppant settling.

These factors led to the decision to move away from the conventional monoborate high pH crosslinked guar fluids, and to switch to premium organoborate high pH crosslinked guar fluids with patented polymer specific enzyme breaker technology. At the time, no extensive field studies had been performed in areas where bottom hole static temperatures were extremely low. The widely held position in the industry was that any borate crosslinked fracturing fluid, and its associated breaker combination, could perform just as well as any other in low temperature applications. That premise was about to be challenged. The resulting post fracture production from 122 fracture treatments, on **6**1 wells, using organoborate crosslinked fracturing fluids with polymer specific enzymes was astounding and undeniable. There was indeed a substantial increase in oil production noted over that delivered from 1I8 fracture treatments, on 59 wells, in which monoborate crosslinked fracturing fluids with non-specific breaker technologies were utilized.

Study Results:

As discussed previously, initial post-frac production increases were observed after the application of guar-specific enzyme technology with organoborate fluid systems. Upon completion of the drilling/completion program a decision was made to look back at the stimulation treatments performed with respect to the fluid and breaker systems. The look-back study first identified an area that possessed the most consistent reservoir parameters. This area was identified as sections 3 through 10, sections 17 through 20 and sections 29 and 30, of township 17 south and range 31 east of Eddy County, New Mexico (fig 3).

To make relative comparisons it was also important to include only those wells completed with the same fluid/breaker system in both the Grayburg and San Andres formations. This was important as the two formations are commingled during production and therefore no means to separate one fluid type from another could be made. All wells in the study were stimulated with the same fluid/breaker system in both the Grayburg and San Andres intervals.

Once the wells were identified, they were then entered into a spreadsheet where net pay, fluid type, breaker type, breaker loading and production were logged. The production utilized for this includes initial production (IP) in bbls/day, 1st 30-day cumulative production (bbls), 1st 90 day cumulative production (bbls), and 1st year cumulative production (bbls). No production over the first year was used, as it would be impossible to distinguish between stimulation effects and flood response after one year.

Exactly 120 wells were selected within the area of interest that displayed like reservoir characteristics and stimulation fluid systems consistent within all intervals stimulated. Initially each section was examined for production trends that could be area specific or identified as a “sweet spot”. Examination of the individual sections concluded that total production within each section was within an acceptable statistical variance. This eliminated the “sweet spot” possibility and also proved that a good cross-section of varied fluid/breaker combinations had been applied across the area of interest.

Treatment fluid volumes and proppant volumes and types were consistent across the study area using the aforementioned fracture treatment design criteria. Therefore, the remaining variables were within the frac fluid itself. Breaker and fluid type then separated the wells of interest. Again, the average net foot of pay was recorded for each set of wells (Table 1). Upon examination of this set, no dramatic production trends were identified. Finally, wells containing guar-specific enzyme breakers pumped in conjunction with an organoborate fluid system were separated from all other fluid and breaker combinations. This separation of fluid sets yielded a comparison of 61 and 59 wells respectively. It was with this data set that a dramatic difference in early production response was identified.

Table 2 identifies the production differences for the organoborate/guar-specific wells versus the monoborate/ non-specific breakers. As can be seen, the initial production in barrels per day is approximately *75* percent greater for the organoborate/guar specific combinations. This trend continues through the first 90 days of the well’s life. Furthermore, the data reveals a cumulative production increase of 22 percent and a 90-day cumulative production increase of 19 percent. At the end of one year the trend reverses, revealing a two-percent comparative increase for the monoborate/non-specific combinations.

The next step was to normalize the wells by net foot of pay, as the monoborateinon-specific wells averaged 48 percent more net foot of pay when compared to those wells treated with organoborate/guar-specific combinations. The production data in Table 2 was divided by net foot of pay to create an average cumulative production in barrels per net foot of pay. Table 3 shows the results of those calculations. Once the wells were normalized by net foot of pay, the dramatic production increase for the organoborate/guar-specific wells was not only substantial for the first 90 days of production, but was consistent for the first full year of the well’s producing life. Table 3 reveals the differences between initial production, 30-day cumulative, 90-day cumulative and first year cumulative productions. Those differences equate to a 158 percent; an 81 percent, a 75 percent and a 45 percent increase respectively.

The 45 percent increase in the first year of production for wells stimulated with organoborateiguar-specific fluid systems equates to an additional 23.3 barrels of oil production per net foot of pay when compared to wells stimulated with monoborate/non-specific fluid systems. The average net feet of pay for wells stimulated with organoborateiguar-specific combinations is 113 feet, multiplying the 61 wells by 113 feet net and 23.3 bbls/net equates to an additional 160,607 incremental barrels of oil in the first year that can be attributed to the application of organoborate fluid systems coupled with guar specific enzyme breaker technology.

Conclusions:

The study of fluid and breaker performance in the Grayburg-Jackson field is simplistic by nature but undeniable in its findings. To the knowledge of the authors no study of this magnitude exists at low temperatures (<100° F).[2] It has been widely accepted within the industry that crosslinked borates of any type could be applied at low temperatures with very similar results. However, the contrary is most certainly the rule as thermal degradation of polymers at bottom hole temperatures less than 100 degrees F plays a small role in initial clean-up of fracturing fluid polymers. This coupled with the potential for fluid retention in low permeability reservoirs can contribute significantly to initial and early time production response from these low perm and low temperature wells. The Grayburg-Jackson field study has confirmed the following:

1. Low permeability reservoirs are dependent upon complete gel degradation for optimal production response.
2. Early time production in low temperature wells can be greatly enhanced with the use of organoborate crosslinked fluids when combined with guar-specific enzyme breaker technology.

Table Abbreviations: (Breaker & Fluid Types)

GSE – guar-specific enzyme
NSE1 – non-specific enzyme type 1
NSE2 – non-specific enzyme type 2
NSE3 – non-specific enzyme type **3**
AP- Ammonium Persulfate
OB – Organoborate
MB – Monoborate
LG – Linear Gel

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Breaker Type	No. of Wells	Fluid Systems(s)	Average Net Ft. Pay	Average Breaker Loading (ppt)	Average I.P. (bopd)	Average 30 Day Cum (bbls)	Average 90 Day Cum (bbls)	Average 1st Year Cum (bbls)
GSE	61	OB	113	1.35	140	1473	3483	8456
NSEI & AP	22	MB	138	0.8 & 2.75	83	1247	3044	9529
NSE2 8 AP	2	MB	128	0.38 & 2	66	1291	3910	9631
NSEI	23	MB	184	1.1	73	1067	2753	6840
NSE3	4	OB	183	1.6	134	1136	2782	6788
AP	8	**LG,** MB	145	3.75	72	1085	2900	7747
Total	**120**							

Table 2

Devon Energy Breaker Study - Grayburg/Jackson Field, N.M.								
Breaker Type	**No. of Wells**	**Fluid Systems(s)**	**Average Net Ft. Pay**	**Average Breaker Loading (ppt)**	**Average . P. (bopd**	**Average 30 Day Cum (bbls)**	**Average 90 Day Cum (bbls)**	**Average 1st Year Cum (bbls)**
GSE	61	OB	113	1.35	140	1473	3483	8456
NSEI & AP, NSE2 & AP, NSE2, AP, NSE3	59	MB, LG, OB	167	NSEI = 0.8, NSE2 = 0.92, NSE3 = 1.6, AF = 3.75	*80*	1210	2945	8603

Table 3

	IP (bopd)	30 Day Cum (bbls)	90 Day Cum (bbls)	1st Year Cum (bbls)
Organo-Borate/Guar -Specific Systems	* 1.24	**13.0	30.8	74.8
Mono-Borate/Non-Specific Systems	0.48	7.2	17.6	51.5
	* Avg. Initial Production. (bopd)/net ft.** Avg.Cum. Production bbs/net ft			
	158% more Initial Oil Productionlnet ft pay			
	81% more Oil in 30 days/net ft pay			
	75% more Oil in 90 dayslnet ft pay			
	45% more Oil in 1st Yearlnet ft pay			

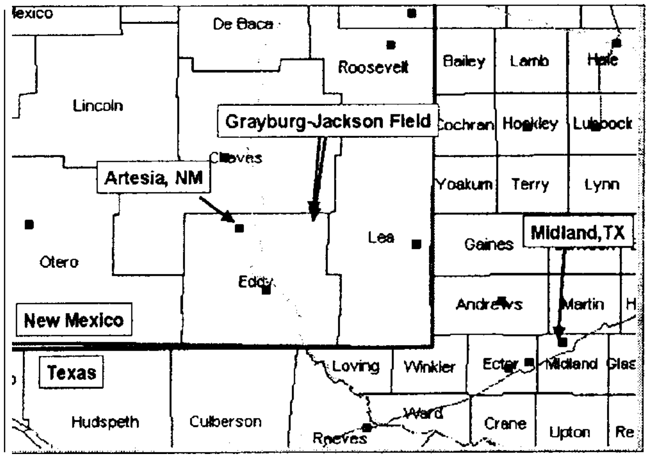

Figure 1

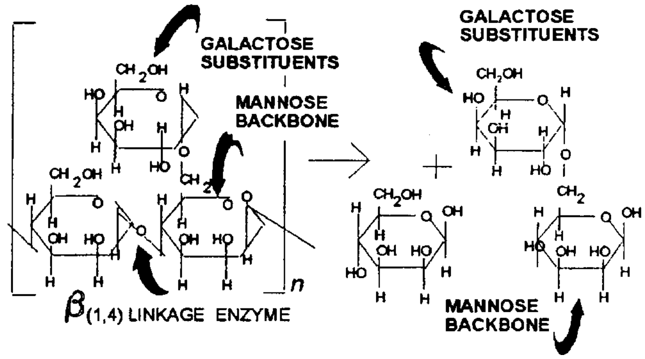

Figure 2 - Guar Enzymatic Degradation Mechanism

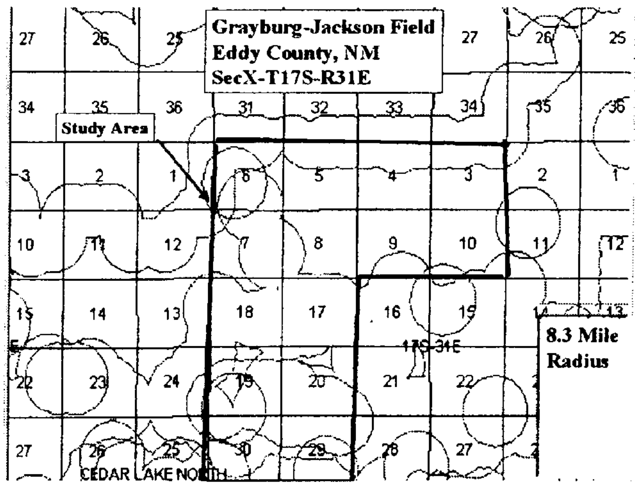

Figure 3