A VARIETY OF TOOLS ASSIST IN STIMULATION OF PERMIAN BASIN OIL & GAS WELLS

J.W. Ely, S.K. Schubarth, B.C. Wolters & J.C. Kromer

Ely & Associates, Inc.

INTRODUCTION

Over the past several years the authors have used a variety of technological and mechanical tools to enhance and optimize hydraulic fracture stimulation of hydrocarbon reservoirs in the Permian Basin. The purpose of this paper is to review the tools and techniques which have given so much success in the Permian Basin.

We will discuss the use of a wide variety of fracturing fluids used in solving specific stimulation problems. Treatments of low viscosity linear gels, high viscosity crosslink gels and medium viscosity polyemulsion fluid as well as foams and crosslink foams will be discussed. Aggressive sand schedules, specific perforation techniques and a very new viscus fingering, "Pipeline Fracturing" technique will also be covered. This paper, though broad in scope, will summarize many successful stimulation techniques currently being used to solve specific problems in the Permian Basin.

DISCUSSION

The Permian Basin is a vast area and the many reservoirs that produce hydrocarbons run the gambit of depths, temperatures, pressures and variable lithologies. The authors firmly believe that there is perhaps no other area within the domestic United States that is a more fertile ground for some of the newer technologies which are now available as tools in stimulation. We believe that there are many tools now available for attacking some ongoing problems that have existed in obtaining economically successful stimulation in the Permian Basin. New tools combined with technology and fluids that have been available for some time have been brought together allowing us to achieve profitable stimulation treatments. Many of the areas where these tools and techniques have been applied are in older producing areas which have previously been attacked with more conventional stimulation techniques including acidizing and conventional fracturing procedures.

FRAC FLUIDS AND THEIR APPLICATIONS

Conventional Linear Gels

Linear gel fracturing with guar gum was initiated in the Permian Basin in the 1960's and has in fact found increased usage in recent years due to its simplicity and low cost. Linear fracturing gels are easily degraded and we certainly have an excellent handle on the rheological properties of these systems, both from the standpoint of pumping friction and viscosity in the fracture. Operators have found that moderate viscosity linear gels in the range of 30-50 lbs/1000 are adequate for placing high concentrations of proppant. These fluids are selected where operators attempt to minimize cost and for small fracturing treatments where damage removal may be the major problem. Additionally, if there are any substantial barriers to fracture height growth, one can minimize fracture height growth by limiting viscosity with linear gel.

Additionally, as will be discussed later, linear gels in combination with crosslink pads have given us a new technique for selective proppant placement. Linear gels, whether using guar, hydroxypropylguar or other derivitives of guar or cellulose, are indeed a valuable tool in stimulating reservoirs in the Permian Basin.

Borate Crosslinked Systems

Borate crosslinked fluids were among the very first crosslinked fracturing fluids to be utilized in the late 1960's. Early borate systems were very difficult to pump and degrade. At that time, in the late 1960's, there was no technology to successful degrade the borates at low temperatures. Additionally, many of the earlier gels utilized from 60-80 lbs/1000 gals and the were very difficult to pump and yielded excessively high friction pressure.

Today borate systems are, without a doubt, the fluid of choice for virtually all of the service companies. [1-3] They typically have only moderate friction pressure, where one uses 35 lbs/1000 gals or less base gel. These lower gel concentrations can cover a very large percentage of all of the producing wells in the Permian Basin. Additionally, there are available delayed crosslink gels and there has been significant development in the area of breaker technology including catalyzed oxidizer breakers and encapsulated breakers[4-6] to assist in complete breakdown of the borate systems.

These borate frac fluids have been used to carry very high proppant concentrations with very aggressive proppant schedules and have yielded excellent results in wells in the Permian Basin.

Polyemulsion

This very old fluid, which was first made available in the late 1960's by Exxon, has found a rebirth in the Permian Basin due to its simplicity and low cost. Polyemulsion, which is prepared by utilizing 2/3 producing oil and linear gel, is an excellent proppant transport and support medium and has found a tremendous amount of usage in Clearfork, San Andres and other Permian Basin reservoirs. It suffers from high friction pressure and is only really applicable for utilization in pumping down casing. It has been successfully used carrying concentrations of sand well in excess of 13 lbs per gallon and is an excellent medium where one wants to place proppant across an entire interval. Although not perfect in proppant transport, its high viscosity at low shear rates yields sufficient viscosity that combined with forced closure it is effectively a perfect support medium.

Foam Fracturing Fluids and Crosslinked Foam

Due to the fact that many of the reservoirs in the Permian Basin are underpressured and external energy is required for rapid cleanup, there has been widespread use of foam fracturing fluids and also crosslinked foams.[7-9] The straight foam fracturing fluids which consist typically of linear gels which may be foamed with nitrogen or CO^2, or combinations thereof, have been used since the late 1970's as a successful medium for fracturing. With the advent of crosslinked foam fracturing fluids, one can achieve a good combination of an energized fluid and excellent proppant transport. Additionally, with the advent of improved fracturing blenders and the technique termed constant Internal Phase, we have been able to place concentrations up to and exceeding 12 lbs/gal. in foam fracturing fluids. The aforementioned breaker technologies have also been very beneficial in allowing even better cleanup than was needed in the early days of foam fracturing.

Delayed Crosslink Fracturing Fluids Using Metallic Crosslinkers

The very first crosslinked fracturing fluid pumped in the oil field was an antimony crosslinked guar.[10] The antimony crosslinked guar and borate crosslinked guar systems dominated the fracturing market until the early 1970's. At that time, titanium crosslinked fluids became the system of choice. Other crosslink systems including chrome, aluminum and eventually zirconium were utilized in the oil field. In the early 1980's, the service companies recognized the advantage of utilizing delayed systems negating unnecessary shear degradation of the fracturing fluids.[11,12] Delayed metallic crosslink fluids have found excellent success in Permian Basin reservoirs. Although their usage has decreased somewhat with the advent of the high temperature stable borate, they still are a valuable fracturing fluid to be used in deeper, high temperature reservoirs. The authors feel that for temperatures in excess of 200 deg. F that delayed crosslink titanium and zirconium fluids, particularly in the low pH range, are excellent alternatives to borate systems. Field experience has shown that they both supply adequate proppant transport and yield excellent degradation inheritantly from the hydrolysis occurring because of the low pH inherent in the systems.

Summary of Available Fracturing Fluids

Quite obviously the above listed fracturing fluids are not all the fracturing fluids that are available upon the market. However, we feel that the aforementioned group of fracturing fluids allows us a wide range of excellent proppant transport and support fracturing fluids which combined with aggressive proppant schedules, intense quality control, and forced closure give us the necessary tools to accomplish profitable stimulation practices throughout the Permian Basin.

TOOLS FOR SUCCESSFUL HYDRAULIC FRACTURE STIMULATION

Listed below are various tools and techniques and procedures which we have found to yield economically successful fracture stimulation in the region of the Permian Basin. There is no single tool or technique which can stand alone in accomplishing enhanced stimulation but several of the techniques combined together executed with due diligence by service companies can indeed result in profitable stimulation in a great majority of reservoirs existing in the Permian Basin.

1. Aggressive Proppant Schedules

It has been apparent for some time to the majority of service company and operating people in the Permian Basin that higher concentrations of sand in the fracture yields enhanced fracture conductivity and subsequently better stimulation results.[13,14] There is no other material in the fracturing fluids that has any real functionality other than the propping agent. One could argue that various surfactants and other additives may enhance wettability or indeed may create some avenues for enhanced production but in reality the critical medium for hydraulic fracture stimulation on a fracture treatment using proppant is indeed the proppant itself. The authors have found in many instances that for various reasons high concentrations of moderate size proppants have yielded equal or better results compared to larger proppants even when laboratory tests have indicated opposite results. In Figure 1, a typical aggressive proppant schedule is shown. We feel that the aggressive proppant schedule yields not only higher proppant concentration in the pack but also in itself assists in the placement of the proppant utilizing the enhanced viscosity of the slurry from the high concentration of proppant.

In Clearfork, Devonian and San Andres formations, we typically average between 7 and 8 lbs per gallon. In many areas, we have found through trial and error that getting very quickly to 10-12 lbs/gal appears to give optimal stimulation results. This is of course very dependant upon closure pressure and relative conductivity needs based upon the permeability of the formation. In many areas, successful stimulation results can ensue by simply doubling or tripling the amount of proppant placed in the formation. Obviously this assumption takes into account that adequate quality control and flowback procedures are utilized.

2. Intense Quality Control

Many papers have been published over the past few years illustrating the positive results achieved by using conventional and intense quality control.[15-18] Intense quality control involves pilot testing of the fracturing fluids at bottom hole temperature conditions to be assured of adequate viscosity for transporting proppant and also a complete breakback to water at some point after the treatment is completed. The authors feel very strongly that a very large percentage of fracture treatments conducted previously, particularly those without intense quality control, may have ended up with a large portion of the fracture plugged up with fracturing gel. Field results have shown where offsetting wells have been treated with astounding results where proper quality control procedures were followed. With the typical low pressure, low temperature environment existing in the Permian Basin, one must be absolutely certain that even linear gels are degraded back to 2-3 centipoise at ambient temperature. Any viscosity of nonnewtonian fracturing fluids is greatly multiplied by the very low shear rates which would be seen either in the proppant pack or in the pore channels. We feel that there is no more important component to successful hydraulic fracturing than the utilization of both conventional and intense quality control procedures.

3. <u>Forced Closure</u>

This procedure was first described in 1990 at the National SPE Convention.[17] This particular enhanced flowback procedure has been in use in the Permian Basin since 1986. The first fracture treatment where the technique was used was a Canyon Sand treatment near San Angelo, Texas. The procedure, which involves immediate flowback of fracturing fluids at controlled rates, has yielded tremendous benefits to the stimulation results in the Permian Basin. The procedure involves absolutely no shut-in time, post treatment. It involves flowing back unbroken gel out of the fracture and utilizing inherent supercharge from the treatment to obtain more of the fracturing fluid in a shorter period of time. The technique has been shown to decrease proppant production through what we term reverse gravel packing. It has been shown to allow removal of more gel in an unbroken state, therefore removing potential damaging solids from the fracture. Tests by major oil companies have shown no negative effects by flowing gel or crosslink gel through a proppant pack. We feel that we are able to leave more of the proppant in a suspended state near wellbore and also are negating proppant smearing which occurs from ongoing fracture growth after pumping shutdown at the end of the treatment. In summary, forced closure is a procedure that most operators are starting to utilize or have been utilizing for a great period of time. We have seen no negative effects on any wells of the Permian Basin or elsewhere.

4. <u>Realistic Estimation of Fracture Height Growth</u>

Perhaps the greatest nemesis to proper design of fracture treatments in the Permian Basin has been the assumption that the fracture treatments were contained either within a producing zone or in close proximity thereof. It has been our experience in the majority of formations treated that fracture height growth has been radial in extent. What this basically means is that the fracture grows up, down and outward equally, i.e. in a penny-shape manner. For formations where there are thin pay zones, this does not bode well for very long fracture extension. In subsequent paragraphs we will discuss a technique for placement of proppant selectively using a viscus fingering technique.

In evaluating frac height logs and data from dead strings and some small amount of treatments where downhole pressure gages were used in the Permian Basin, we have seen very little evidence of contained fracture height. The exception to this has been in some morrow intervals in New Mexico and other isolated incidences where large thick shale or anhydrite sections exist above or below the producing interval.

If one utilized a GDK or Perkins Kern radial frac design model, we firmly believe that over 95% of the time you would be much more correct in trying to design your fracture treatment than by assuming any contained fracture height growth whether it be through a contained GDK or Perkins Kern or a 3D model with adequate stress barriers placed therein. The authors have done a considerable amount stress test work and frankly have found very few barriers which will withstand the kind of net pressures which exist even when pumping very low viscosity fluids.

By understanding the reality of very limited fracture height containment, one then can begin to understand why very large fracture treatments are required to drain a low permeability reservoir or secondarily can realize the necessity for smaller spacing to adequatly deplete most hydrocarbon producing reservoirs.

5. <u>Minimization of Perforated Interval</u>

When we came to understand that there was really no limit, in many cases, to fracture height growth, we also realized that there was the potential for multiple planner vertical fractures to occur in long perforated sections. There is almost an absolute certainty that some degree of inclination occurs, either from a deviated wellbore or from simple deviations or inclinations in the formations themselves. It is, therefore, quite possible that if one perforated several holes over more than 100 feet that there could very easily be several inclined fractures created. Quite obviously this would be detrimental to proper stimulation in that one would achieve several short fractures rather than a single planer vertical fracture with all the proppant contained therein. We therefore recommend quite strongly that one fix the center of the interval and minimize the number of perforations and limit the extent. Typically 10-20 ft. is all that is required to cover hundreds of feet of interval with a hydraulic fracture. Quite obviously, one must be sure that the entire fracture is in communication with the perforations by utilizing the forced closure technique and be absolutely sure one does not over-displace or have segments of the fracture nonconnected due to variations in proppant concentration during the treatment. It is our major purpose in pumping proppant that we pack a continuous concentration of proppant into the fracture, particularly at the wellbore. We recommend strongly that if any variation in proppant concentration, particularly in the downward direction in the later stage of the treatment, that the well be flushed immediately. We believe that production of proppant due to void spaces near wellbore can ensue and one can loose continuity in the proppant pack due to variable sand concentrations in the later stages of the treatment.

6. <u>Surgical Frac Designs</u>

Since the vast majority of treatments are penny shaped, or radial in nature, then one mechanism for control of fracture height growth is simply to minimize the size of the fracture treatment built around this radial growth. Additionally, by placing your perforations specifically in a section above or below an area one does not want to prop, and again minimizing the size of the fracture treatment design, selective or "surgical", placement of proppant can be accomplished.

An all too common scenario in the Permian Basin, are producing intervals of 50-250 feet with a very definitive water contact in the lower part of the section. In many cases these wells are perforated throughout the oil zone and many times into the water contact. These wells may have been acidized several times and a common problem is very high water/oil ratio. Because of the acid treatments, there are cavities near wellbore allowing proppant from previous treatments to be produced and, in many cases, there is little or no effective conductive proppant pack across the producing interval. This is most probably due to long shut-in times from conventional fracture treatments where low sand concentrations were used.

A surgical treatment for such a well would be to set a bridge plug just above the producing interval, perforating just above the bridge plug, then designing and implementing a fracture treatment that would grow up and down radially, such that one does not prop the water contact. It is apparent that the operator must have a good understanding of stress profiles and rock properties to be assured that the zone above the producing interval is not a barrier to growth and a pinching effect does not occur. A good success ratio has been achieved with the surgical treatments. We typically do not reduce water production dramatically with this type of fracture treatment because of the presence of the proppant in the water contact but we do almost invariably increase the production of oil and gas because of placement of high concentrations of proppant across the producing interval. Before implementation of this type of design, a frac height log and/or stress test should be conducted in the well to assure oneself of a good understanding of any potential barriers to fracture height growth. We believe quite strongly that minimization of the perforated interval combined with selective placement of the fracture initiation point and a realistic evaluation of fracture height growth is an absolute key to enhancement of the success of hydraulic fracturing.

7. <u>"Pipelining", Selective Placement of Proppant Pack Utilizing Differential Viscosity or Fingering Technique</u>

This particular process as described in SPE paper 24007[19], involves a combination of fracturing fluids and a good understanding of fracture height growth. For many years a very successful technique has been used in hydraulic fracturing where acid is used to differentially etch the fracture. Most companies have been pumping very viscous pads of polymer or emulsion followed by low viscosity acid. This allows differential etching because of fingering of the lower viscosity fluid through the high viscosity pad fluids.

A particular problem existed in Southeastern New Mexico in the Delaware formation where relatively thin intervals were bounded sometimes above and sometimes below by high permeability water zones. Conventional fracture treatments typically yielded good oil production but also high water cut. In cases where the water existed above the interval and boundaries existed below, low viscosity settling treatments with linear gel proved beneficial. In a majority of the cases, however, the water contact was just a few feet below the oil contact. After observing some researchers trying to displace viscous crosslinked fluid from a plexiglass chamber where proppant transport tests were being conducted, a concept was formulated. What actually was observed instead of piston-like displacement of the crosslink fluid, was a fingering phenomenon that followed precisely the entrance ports into the plexiglass chamber. After observing this procedure, a concept was formulated that we could indeed create a radial fracture, or for that matter a confined fracture, with viscous crosslinked gel and by placing the proppant section only across the producing interval, we might have the ability to selectively, using proper design techniques, place proppant in only the producing interval utilizing high differential viscosity.

The basic concept is to create the hydraulic fracture with high viscosity crosslink gel. We design the pad of crosslink gel around the desired created fracture length. We then initiate proppant laden fluid in low viscosity linear gel. By placing our perforations only in the producing interval, we have been able to achieve selective proppant placement across the producing interval. The size of the proppant stage is determined by iterations with a computer model assuming height confinement due to viscous fingering. Proppant stages are typically quite small compared to the pad and are sized to reach the created length of the pad fluid. In figure II, we illustrate a typical pressure profile from a pipeline treatment with a deadstring present. The decrease in the net pressure, which is minimal, may be due to perforation cleanup or it may be due to simply a somewhat lower net pressure as the proppant and gel move down the fracture. The increasing pressure at the end, we believe, may be the proppant nearing the tip of the fracture. The results to date with this technique have been nothing short of phenomenal. Typical designs run fairly low volumes of sand but in high concentrations. We have used this technique on small intervals in the Delaware, fairly large sections in the Devonian, and have had success in the Clearfork, San Andres and also in other areas of the country. As with all techniques in hydraulic fracturing, we certainly do not have a complete understanding of all of the mechanisms that are brought to bear with this procedure. The results we have had to date have been outstanding. The postfrac buildup analysis have indicated very high fracture conductivities with propfracture lengths calculated in excess of 200 ft. with less than 30,000 lbs of proppant. We do not feel that this technique is limited to very thin sections and in fact have successfully used it in areas where there was CO^2 breakthrough above average producing zone. In this particular zone, we squeezed off the upper part of the section and conducted the treatment down tubing, pumping a large crosslink pad followed by linear gel carrying proppant. On this treatment design shown in Figure III, the design is similar to conventional treatments other than the differential viscosity. Excellent post-treatment stimulation of the oil zone was achieved with no CO^2 production.

SUMMARY

Listed earlier are some but certainly not all of the tools, fluids and techniques available for enhancing fracture stimulation in the Permian Basin. We see no particular single technique which can on its own be successful. We believe that enhanced technology available from the oil field service companies, tied together with better understanding of fracture geometry allows the operator a tremendous amount of opportunity in being able to recover vast amounts of oil & gas from reservoirs which simply were not effectively stimulated previously.

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New Treatment Design			
Stage	Volume (gal)	Sand (lb/gal)	Cum Sand (lbs)
1	6,000	0	0
2	1,000	2	2,000
3	1,000	4	6,000
4	2,000	6	18,000
5	2,000	8	34,000
6	5,000	10	84,000

Figure I - Typical frac design (Fullerton San Andres)

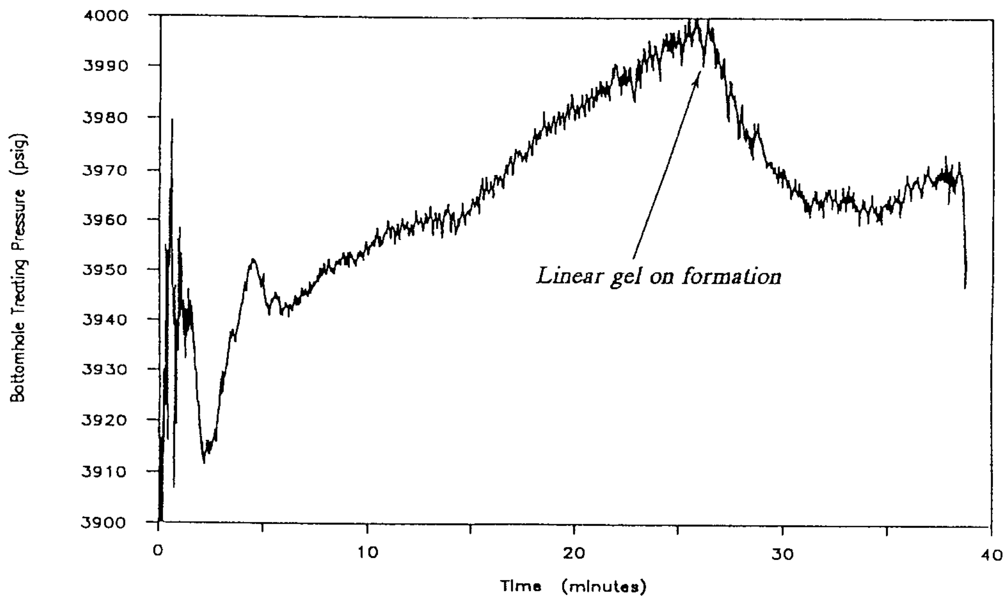

Figure II

Stage	Type Fluid	Clean Stage Volume (gal)	Type Proppant	Proppant Concentration (ppg)	Proppant Stage Volume (lbs)
1	35# Borate	15,000	--	--	--
2	40# linear	2,500	20/40 Ottawa	2.5	6,250
3	40# linear	2,500	20/40 Ottawa	5.0	12,500
4	40# linear	3,000	20/40 Ottawa	7.5	22,500
5	40# linear	3,000	20/40 Ottawa	10.0	30,000
6	40# linear	3,000	20/40 Curable resin coat	10.0	30,000

Figure III - Example pipeline design for large intervals