PRECISION CASING LEAK SQUEEZE USING CROSSLINKED POLYACRYLAMIDE

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ABSTRACT

Crosslinked polyacrylamides have proven themselves to be successful, when properly applied, in shutting off water-producing zones and thief zones in a variety of formations. The same principles that allow polyacrylamides to inhibit water movement effectively in pay zones should also be helpful in controlling fluid movement in a variety of situations such as:

1. Low injection rates of 0.25 to 1.5 BPM
2. Microannulus leaks
3. Casing shoe and liner top leaks
4. Mechanically induced holes or corrosion in casing
5. Potential bridging of solids in commercial squeeze fluids which may result in limited penetration or several attempts before a successful squeeze is achieved
6. Fresh water-sensitive formations requiring controlled pH.

INTRODUCTION

The need for squeeze operations arises in oil and gas wells when primary cement fails to protect casing from corrosive formation fluids[1] or fails to prevent interzonal communication of fluid behind the casing. During a squeeze, fluid is pumped under hydraulic pressure into the problem area. Many different types of cement compositions have been developed to address the variety of problems encountered.[2]

One of the most common areas where cement squeezes have repeatedly failed is in the repair of small leaks. The difficulty of squeezing small leaks arises from dehydration of cement slurries under pressure and from the inability of most formations to accept a solid-liquid mixture without fracturing. Once a fracture is initiated during a cement squeeze, slurry pumped at a sufficiently high rate continues to propagate the fracture, resulting in both technical and economic failure.[3] An experiment conducted by a major service company with a 6/9 mesh gravel bed indicated that neat cement penetrates less than two (2) inches into the gravel bed before dehydration occurs and causes bridging.[4]

The need for repeated squeezes also arises in casing having poor integrity. In situations where casing integrity is poor, the use of a cement retainer for squeeze repairs causes additional sites for leaks to occur where the retainer slips bite into the casing wall. The drilling out of cement and the cement retainer causes additional potential leaks in the poor integrity casing due to abrasion during drilling.

Although squeeze cementing techniques for water shut-off have undergone modifications in recent years, certain problems inherent to the nature of cement slurries and petroleum reservoirs continue to prevent adequate cement squeezes from being obtained in many cases. Some factors hindering the successful completion of a cement squeeze include the dehydration and eventual bridging of cement slurry[5] in small mechanically induced openings or corrosion pinholes, and the inability of cement to penetrate deeply into the formation at pressures below the fracture point.

As rising water production and corrosion problems increase, more and more wells are shut in because they become uneconomical to operate. Those wells often could be saved if undesirable water movement could be reduced or eliminated. Advances made in polymer technology and applications since the early 1980s have allowed greater flexibility in modifying the design of crosslinked polymer so that proper concentrations are placed in the near-wellbore areas that will benefit most from selective plugging. Cleanup after a polymer squeeze workover is also rapid, as the polymer can be circulated out of the wellbore with no drilling out requirements.

Information presented in this paper suggests that an extension of the squeeze process using crosslinked polyacrylamide solutions will greatly improve the probability of obtaining a successful squeeze where the use of cement is repeatedly unsuccessful or impractical.

DISCUSSION

Crosslinked polyacrylamide solutions can be economical remedies for low-rate/low-pressure casing leaks, especially where the bridging of particles from cement slurries causes cement squeezes to be ineffective. Characteristics of polymer squeeze operations include the following:

1. Precision equipment capable of continuous pumping and monitoring the squeeze fluid at rates as low as 0.1 BPM and below formation parting pressure.

2. Low-density (8.4 lb/gal) and low-viscosity (10-20 cp) polymer solutions that are injected into the affected area.

3. A true, solid-free solution of polyacrylamide allows the application of hydraulic pressure across long intervals in the wellbore without the potential threat of bridging.

4. Controlled time-delayed gellation to change the phase of the squeeze fluid.[6]

5. Adjustment of the polyacrylamide fluid composition to yield a gradual loss of injectivity to the point of total plugging.

6. Utilization of a retrievable packer to avoid drilling operations.

7. Utilization of capable personnel experienced in the design and application of polyacrylamide systems.

8. Applications in poor integrity casing (thin wall) where slip bite causes mechanically induced holes as well as initiation of corrosion sites.

The proper design and application of surface crosslinked polyacrylamide systems focuses on the placement of gel at the source of undesirable water. For that reason, close scrutiny of the on-site gel and water analyses, as well as the close monitoring of treatment operations, is necessary. In the past, most of the failures of polymer treatments can be attributed to a combination of the lack of adequate treatment monitoring, chemical incompatibility, inflexibility of treatment design, and inexperience. Today's polymer treatments, utilizing precision mixing and injection equipment along with experienced technical personnel, are proving to be adaptable to special injectivity situations beyond the capabilities of cement squeezes.

Advantages associated with the use of polymer over cement for remedial squeezes include the following:

1. Less time spent on workover.

2. No drilling out required.

3. The treatment penetrates deeper into the void space around the casing and into the formation.

4. No bridging occurs unless desired, in which case the appropriate materials can be added to the polymer.

5. Small batches are employed so that concentrations of each batch can be adjusted for changing injectivity requirements, allowing the polymer setting time to be varied from a few minutes to several hours.

6. The polymer solution tends to stabilize clays.

7. No danger of sticking the packer exists if the polymer solution communicates to the annulus uphole, and low-pressure squeezing prevents the possible collapse of casing above the packer.

CONCEPT

Successful polymer treatments for shutting off water have incorporated on-site water and chemical analysis, precision chemical blending, continuous monitoring and interpretation, and, most importantly, having the process design engineers on location to adjust treatment characteristics as the need arises.

Obtaining a high-quality chemical blend for a bulk crosslinked polyacrylamide gel is essential to avoid undissolved particles that can coagulate and bridge off around the zone to be squeezed. The chemical blend must be compatible with reservoir fluids, mix water, and with temperature and pH conditions present. Pressure and rate changes that are observed during the treatment are evaluated and often compensated by changes in chemical concentrations to allow for a gradual decrease in injectivity to the point of plugging the target zone.

TREATMENT DESIGN

Unlike a cement squeeze, crosslinked polyacrylamide squeezes can penetrate deeply into pinhole corrosion sites in pipe, channels, microannuli, high permeability streaks, and natural or hydraulically induced fractures. After an estimated squeeze volume is calculated, total pump time is determined, and the polymer blend is divided into batches with varying concentrations to allow the treatment sufficient time to penetrate the squeeze zone and to begin building gel strength after leaving the work string. Polymer selection is based on adsorption characteristics, formation temperature, crosslinking capability, ease in handling, and economics. Care must be exercised to design treatment injection rates and pressures before or during the preflush in order to prevent fracturing of the formation.

FIELD APPLICATION

The following information outlines the preparations and treatment process for performing a polymer squeeze operation.

Laboratory Analysis on Location

Water analyses performed on location with the aid of a mobile laboratory are used to provide physical and chemical properties of the reservoir water and the mix water available. Simultaneously, polyacrylamide samples are blended, crosslinked, and heated to the temperature of the squeeze zone in the mobile laboratory to simulate downhole conditions. Gel samples are examined hourly to observe the rate of increase of gel strength and the time at which the gels are no longer pumpable. Laboratory testing prior to 1986 was usually performed in central facilities often far removed from the wellsite; and as a result, chemical and physical properties of the mix water were frequently different from that actually used on location. While the laboratory analyses are being conducted, the preflush is pumped in order to prepare the well for polymer injection.

Preflush

The purpose of a preflush in conjunction with a crosslinked polyacrylamide squeeze is in part to clean microorganisms and other organic material from the surfaces to be treated with polymer. Crosslinker added to the preflush minimizes metal ion dispersion out of the gel and into the connate water during the completion of the crosslinking reaction and cleans off the mineral surface of the formation. The crosslinker added in the preflush thus contributes to ultimate gel strength and stability. A step-rate test may also be performed during the preflush in order to determine the initial injectivity of water into the zone to be squeezed.

The periodic examination of the gel samples should continue during the preflush in order to determine the length of time that the individual concentrations will yield pumpable gels and to indicate needed adjustments to the initial chemical concentrations of the treatment. Injection rate and pressure limitations will be set before or during the preflush in order to eliminate the possibility of hydraulically fracturing the formation.

Treatment

Once the polymer treatment volume and stage concentrations have been determined, bulk mixing of the polymer batches begins and polymer injection follows as soon as the first batch is thoroughly blended. For near-wellbore plugging operations, the batch blending mode of operation is preferable due to the high degree of quality control available. Gel samples can be taken from each batch and placed in an oven to simulate the gellation process at the approximate downhole temperature.

During the treatment, a Modified Hall Plot[7] of Cumulative Bottom Hole Treating Pressure (BHTP) versus Cumulative Injected Volume is constructed from measured BHTP (or BHTP calculated from surface treating pressure). Figure 1 is an example of a Modified Hall Plot produced from data taken on location and exhibits characteristics typically observed during treatment, with a continuous decrease in injectivity. The plot is then used to measure change in injectivity as polymer gel injection continues. The setting time of the polymer can be adjusted to adapt to the changing wellbore injectivity as the treatment progresses. As the injectivity decreases, or the maximum treatment design volume is reached, the treatment is terminated and the postflush started. Treating pressure and injection limitations could also prove to be factors dictating the end of the treatment.

Postflush

The objective of the postflush made up of water is to clear the tubing of polymer without overdisplacing the treatment into the squeezed zone. For that reason, having the static fluid level data prior to injecting any fluid is important so that the postflush displacement volume can be calculated accurately.

Depending on the situation, the postflush could consist of solids to give an additional pressure surge as the fluid reaches the perforations or target depth.

INDIVIDUAL TREATMENT HISTORIES

The following field applications of polymer are presented to show the success of plugging produced water or loss of injection water and to indicate the potential for success in the application of polymers for squeeze operations. (Table 1)

Case 1

The well was completed in the Ellenberger formation in Winkler County, Texas, from 10,532 to 10,588 feet from surface. Several cement squeezes had been performed downhole from the current perforations in order to reduce water coning from a strong bottom water drive. An acid treatment of 6,000 gallons of 15% HCl had allowed the perforated interval to communicate to the bottom water, and as a result the well was pumping at the operating limit of the fluid lifting equipment.

A 600-barrel polymer treatment was recommended to shut off at least enough water so that the well could be pumped off. However, indication from the

Modified Hall Plot constructed on location was that injectivity was decreasing more rapidly than projected, and the treatment was stopped after 575 bbl had been injected. The BHP vs. Cumulative Volume Injected curve in Figure 2 also indicates the gradual increase in squeeze pressure as the treatment progressed. Total fluid production dropped from 513 BPD to 36 BPD as a result of the treatment.

Case 2

The well was completed in the San Andres formation in Crane County, Texas, at a depth of 3,526 - 3,817 ft from surface. After two frac treatments had placed approximately 223,000 lb of sand into the formation, the well was producing 500 BPD total fluid and could not be pumped off. A 550-bbl polymer treatment was recommended, but only 150 bbl was injected before the Modified Hall Plot indicated that the postflush should be started in order to preserve oil production . Figure 3 shows that wellhead injection pressure (WHIP) increased as more polymer solution was injected. The slight breaks in the curve are caused by injection rate changes. The total fluid production after the treatment dropped to approximately 107 BPD, resulting in a WOR of 14 compared to a pretreatment WOR of 166.

Case 3

The well was completed in the Yates/Queen sandstone in Ward County, Texas, as a part of a line drive waterflood pattern. Perforations at 2,519 to 2,819 ft were yielding 968 bbl total fluid with a fluid level at the surface prior to polymer treatment, and the well was uneconomical to produce. A 600-bbl polymer treatment was recommended, but the well took only 105 bbl of polymer before the postflush was started. The treatment was terminated because pressure and rate limitations had been reached, and continued injection at that point would have parted the formation. The WHIP vs. Cumulative Volume curve of Figure 4 indicates the dramatic increase in squeeze pressure up to the end of the treatment. Total fluid production after the treatment decreased after treatment by nearly 500 BPD, resulting in additional injection support of approximately 500 BPD. The treatment also resulted in a change in Fluid In/Fluid Out (FI/FO) from 0.63 to 1.2, indicating the pressurizing of the injection pattern area rather than depleting pressure.

Case 4

The well was completed in the Ellenberger formation in Winkler County, Texas, at a depth of 9,477 - 9,482 ft from surface. The strong bottom water drive in the naturally fractured Ellenberger dolomite had forced the operator to progressively recomplete uphole, and in this case, polymer was pumped below a cement retainer set at 9,464 ft so that the well could be reperforated in an upper zone. Slightly over 500 bbl of polymer was injected through the cement retainer to plug the lower zone. The plot of bottomhole pressure versus cumulative injected volume in Figure 5 exhibits a pressure drop when the injection rate was reduced by approximately 50 percent after nearly 100 bbl had been injected through the retainer.

Case 5

The well was completed as a Water-Alternating-Gas injector in the San Andres formation in Gaines County, Texas, as a part of a CO_2 flood in the area.

Injection perforations treated with polymer and cement are located at a depth of 5,391 - 5,537 ft from surface. A total of 75 bbl of polymer was injected into the zone and flushed with a tubing volume of water, resulting in the WHIP vs. Cumulative Volume curve in Figure 6. After polymer injection, 50 sacks of Class "C" cement was mixed and spotted, and the desired squeeze pressure was achieved with 25 sacks of cement into the formation. Excess cement was circulated out and the well was shut in overnight. After drilling out and reperforation operations were completed, stabilized injection into the target zone decreased from 69 percent before to 24 percent after the squeeze.

CONCLUSION

The analysis of data presented indicates that the use of crosslinked polyacrylamide will grow in importance in the area of squeeze operations. In particular cases where a low-density/low-viscosity fluid must be used to repair low injectivity leaks through casing, some of the advantages to using crosslinked polyacrylamide as a squeeze material are as follows:

1. The solid-free, low viscosity, and low density nature of crosslinked polyacrylamide permits the application of hydraulic squeeze pressure across long intervals in the wellbore without the potential threat of bridging.

2. Typical treatment volumes of crosslinked polyacrylamide ranged from 75 to 500 bbl for the wells analyzed, which emphasizes the flexibility with which batch concentrations and volumes can be altered to obtain shallow or in-depth penetration of the squeeze fluid. The objective of varying batch concentrations and volumes is to induce the gradual loss of injectivity to the point of total plugging.

3. Workover time can be reduced by polymer squeeze operations as drilling out is not necessary. The risk of damage in poor integrity casing is reduced and the possibility of sticking tools is virtually eliminated.

4. Workover expenses are reduced, as crosslinked polyacrylamide can be blended continuously in small batches.

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Table 1
Summary of Treatment Histories

		TOTAL FLUID PRODUCTION	
FORMATION	COUNTY, STATE	Before (BPD)	After (BPD)
Ellenberger	Winkler, Texas	513	36
San Andres	Crane, Texas	500	107
Yates/Queen	Ward, Texas	968	500
Ellenberger	Winkler, Texas	148 (TA'd)	0
		INJECTION PERCENTAGE (Into Target Zones)	
		Before	After
San Andres	Gaines, Texas	69	24

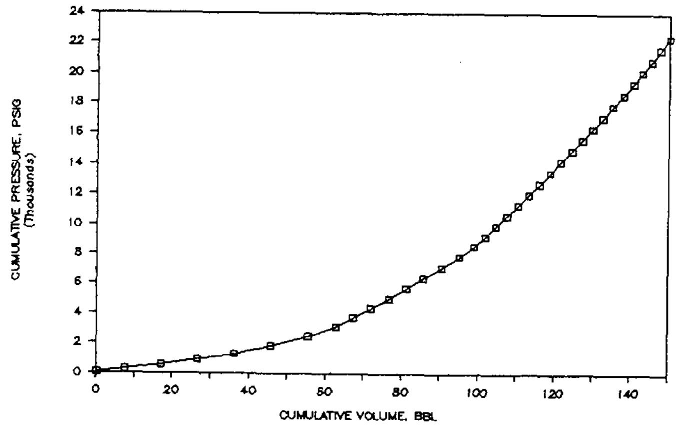

Figure 1 - Modified Hall Plot
(bottom water drive
reservoir)

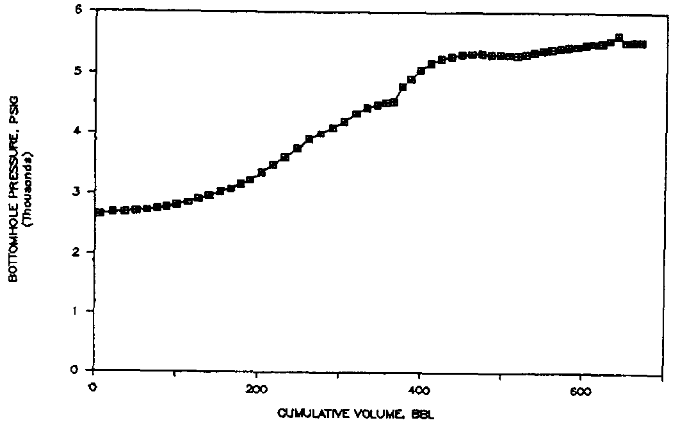

Figure 2 - Pressure response
(bottom water drive
reservoir)

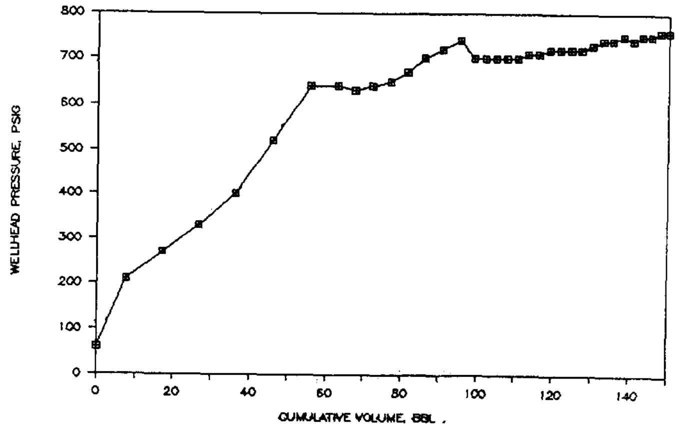

Figure 3 - Pressure response
(hydraulically fractured
well)

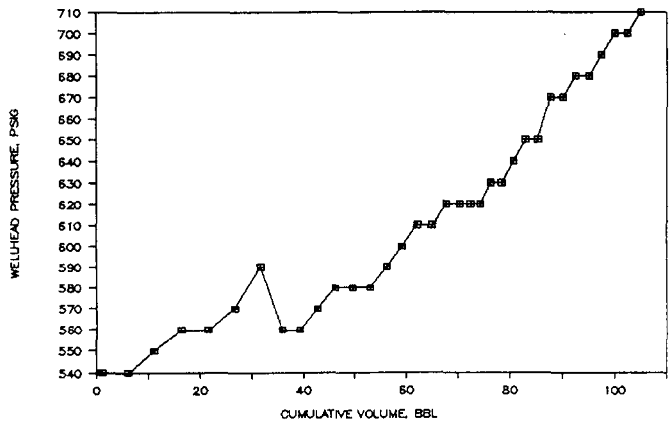

Figure 4 - Pressure response
(stratified sandstone
reservoir)

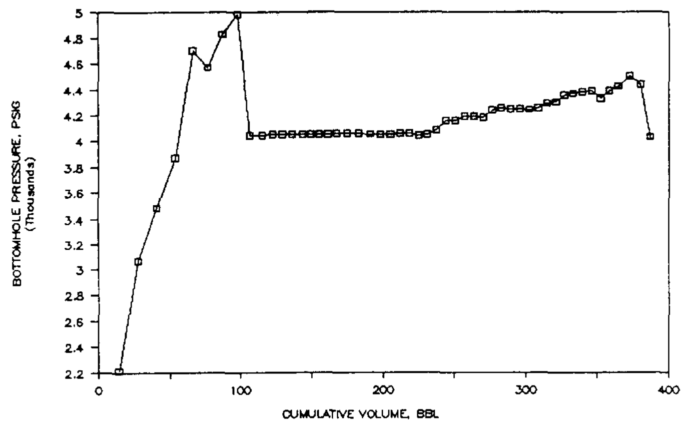

Figure 5 - Pressure response
(bottom water drive
reservoir)

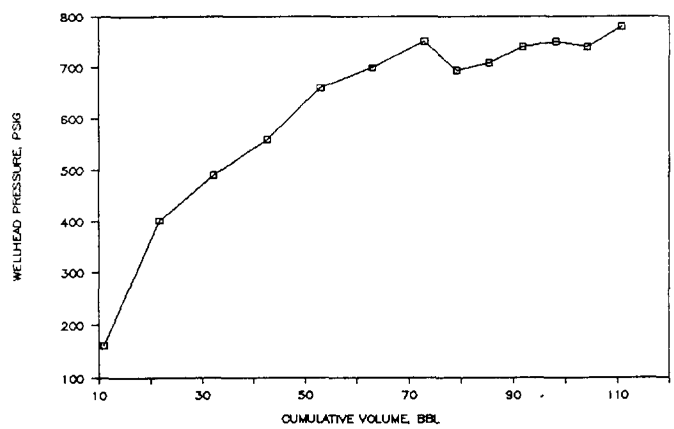

Figure 6 - Pressure response
(injector well)