A NEW NONDAMAGING, AQUEOUS CROSSLINKED GEL WITH IMPROVED FRACTURING PROPERTIES AND PERFECT PROPPANT SUPPORT

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INTRODUCTION

This paper will discuss the properties and applications of a new water-base fracturing fluid. In particular, it will discuss its leak-off characteristics, its rheological behavior, and its proppant-transport capability. Additionally, it will give examples of its use in the field, including production information.

Beginning in the late 1960's, intensive research was done in the area of improved stimulation fluids. This led to the development of a variety of crosslinked fracturing fluids based on both organic and synthetic polymers. These fluids featured extreme viscosities, perfect or near perfect proppant transport, and good pumpability without excessive friction drop. In nearly all cases, high polymer loadings were required for optimum performance. In the case of the natural polymers, the higher loadings resulted in excessive residue and consequent sand-pack damage. The synthetic polymers left no damaging residue; however, they were prohibitively expensive.

The subject gel was designed to overcome the limitations of the early crosslinked gels. It features a moderate polymer loading which, when complexed with an organometallic chelate, furnishes high but not excessive viscosity combined with perfect proppant transport. It features good leak-off control and is residue-free when broken.

The base polymer of this system is carboxymethylcellulose which is hydrated prior to pumping. The complexing agent is added continuously after sand is dispersed in the base gel. Since the concentration of organometallic chelate is low, an air-drive proportioner has been designed and built with suitable control and monitoring features. This device is also described in the paper.

SYSTEM DESCRIPTION

The makeup water for this system is restricted to fresh water with 1 or 2% KCl added or, alternatively, 10 lb of $CaCl_2$ can be used. The system is designed to complex at a pH range between 4 and 5. A weak organic acid must be added to lower the pH to the desired range. As mentioned previously, the base polymer is carboxymethylcellulose and the recommended loading is 30 lb per 1000 gal. of water. After a suitable pH adjustment, the polymer is hydrated in a normal manner in the available storage tanks. Gel viscosity at this point ranges from 19-22 cp, depending on the chloride selected and its concentration. Higher polymer loadings can be used to increase the ultimate viscosity when crosslinking occurs but, under normal circumstances, this should not be required.

This system is only suitable for continuous mixing since the viscosity of the crosslinked system is too high to maintain adequate suction at reasonable injection rates. An organometallic chelate is used to crosslink the fluid. This material is a liquid and is added immediately past the blender supercharge pump after the sand has been added and dispersed in the blender tub. The required concentration of complexer solution is only 1 gal. per 1000 gal. of base polymer. This addition rate is too low for accurate metering with conventional chemical pumps, so a separate metering system was constructed. This unit uses a gas-drive from either a nitrogen bottle or a separate air compressor. A calibrated rotameter is used so that the addition rate is constantly monitored and is adjusted for variations in injection rate. Figure 1 is a schematic of this separate unit. The use of two supply tanks allows one tank to be refilled while the other is in use

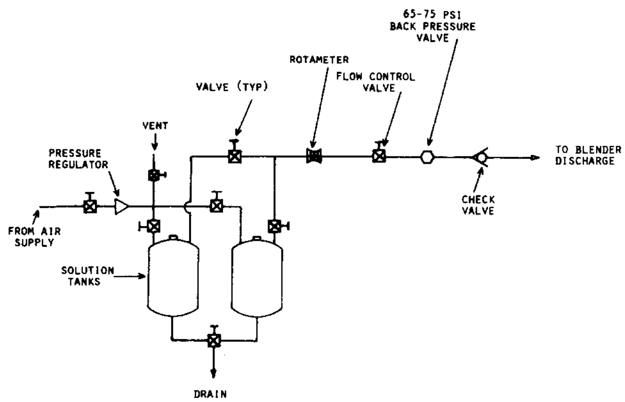

FIG. 1 — COMPLEXER INJECTION UNIT

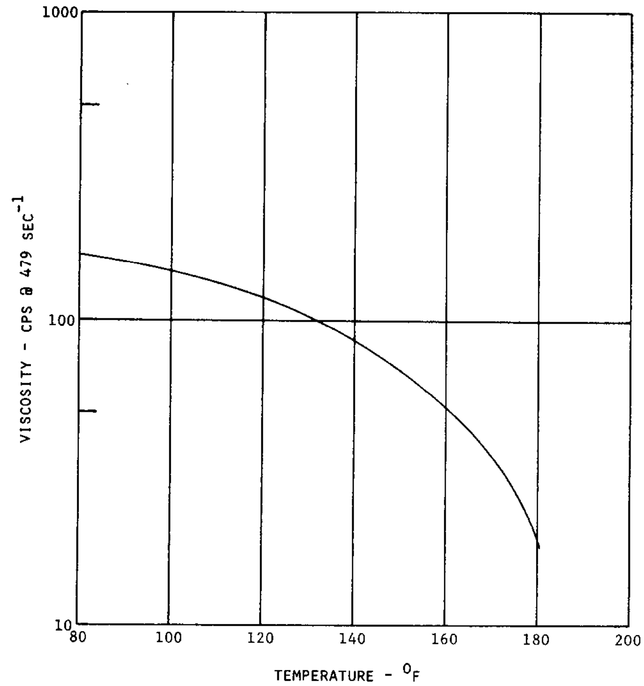

FIG. 2 — VISCOSITY VS TEMPERATURE

so that job size is not limited to tank capacity.

Repeated field testing has shown that viscosity rise is almost immediate since fully formed gels are caught at the blender discharge manifold. Sand is perfectly supported in these samples, and measured viscosities agree quite well with laboratory experience. Because of the special metering system, this fluid has performed with a high degree of reliability in all uses to date, and a high degree of confidence can be placed on uniform gel quality. This has eliminated the problems that beset other crosslinked polymer systems, namely, slugs of uncomplexed gel due to metering failure.

SYSTEM RHEOLOGY

This system was designed as a moderate environment gel and no attempt has been made to achieve ultra-high viscosities. It is designed to provide good viscosity combined with perfect sand support at reasonable bottomhole temperatures. It is well to note that in crosslinked systems, sand support is not necessarily viscosity-dependent, but rather, viscosity is a by-product of the crosslinking mechanism. In the majority of crosslinked systems, high viscosity is only valuable in providing wider fractures. While wide fractures are required while placing high concentrations of large-mesh proppants, excessive width can seriously affect fracture penetration. For example, in an identical set of circumstances, increasing the fracture width from 0.25 in. to 0.35 in. will result in a fracture length decrease of 29%.[1] The aim in the majority of treatments should be optimum width, not maximum width.

Figure 2 shows the viscosity behavior of this system with increasing temperature. The range of useful viscosity is from 160 cp at 80° F to 54 cp at 160° F. This range defines the limits of perfect sand support. The use of a cooling pad ahead of the treatment extends the range of this fluid to 200° F BHT which encompasses a vast majority of treatments.

Figures 3 and 4 show the flow behavior index (n′) and the consistency index (K′) with increasing temperature.[2] Like all complexed fluids, this system exhibits a strong Wiessenberg effect (spindle climb) which rules out the use of standard rotational viscometers to define its flow properties. The flow data presented were generated on a precision capillary viscometer using a 0.52-in. flow tube.

Figure 5 shows the viscosity behavior with increasing shear rate for temperatures of 100°, 120°, and 140° F. Fracture shear rates can be estimated by the following formula:

$$\text{Shear Rate} = \frac{40.5Q}{w^2H} \ \text{sec}^{-1}$$

Where:

Q = injection rate, BPM
w = fracture width, in.
H = fracture height, ft

This system has flow properties that make it applicable for all but the most severe fracture

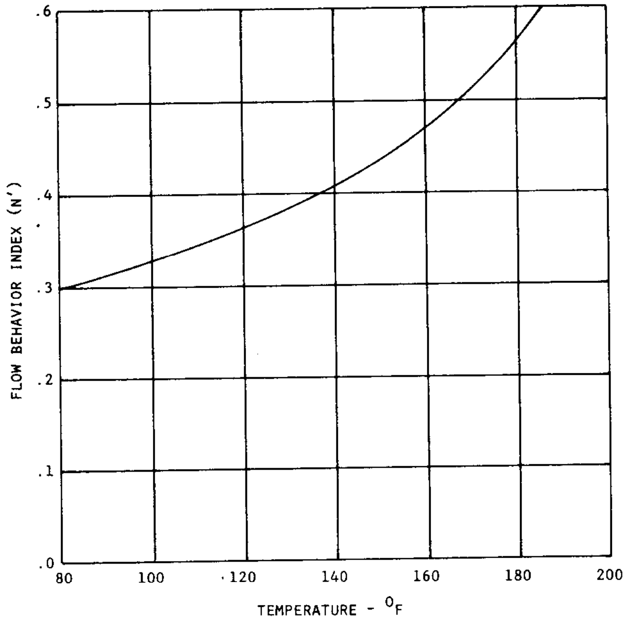

FIG. 3 — FLOW BEHAVIOR INDEX VS TEMPERATURE

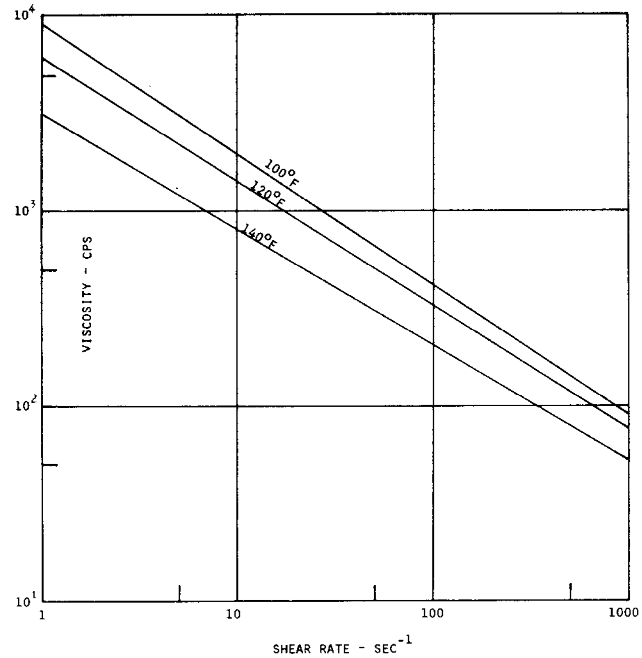

FIG. 5 — VISCOSITY VS SHEAR RATE

environments; and due to its moderate polymer-loading feature, it can be utilized more economically than the higher polymer-loading crosslinked gels.

FLUID-LOSS PROPERTIES

As is common with most crosslinked systems, this

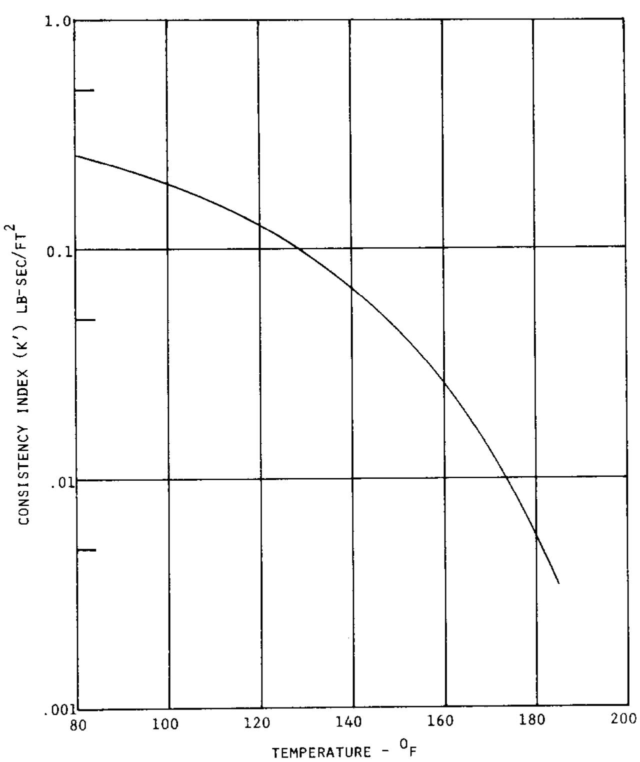

FIG. 4 — CONSISTENCY INDEX VS TEMPERATURE

fluid exhibits no spurt loss when subjected to standard fluid-loss tests. The addition of fluid-loss additives improves the fluid-loss properties of the gel, but the fluid-loss properties of the gel itself are good enough that additives can be eliminated in all but the most severe leak-off situations. Figure 6 shows the fluid-loss coefficient (C_{III}) with increasing temperatures for 2% KCl water. The fact that fluid-loss additives are seldom required makes the system completely residue-free. Recent studies have shown that severe damage to the sand pack can result from the use of natural polymers and fluid-loss additives.

FRICTION REDUCTION

Friction pressures were defined from a comprehensive review of the available pressure records combined with laboratory testing. Friction reduction has varied from 40-55% in actual field cases, depending on the size of the tubular goods used. Studies are continuing in order to better define friction properties in different configurations.

APPLICATIONS AND DESIGN

This fluid is applicable to any formation where water-base fluids are normally used and BHT does not exceed 200°F±. The system is compatible with all conventional additives used in fracturing fluids,

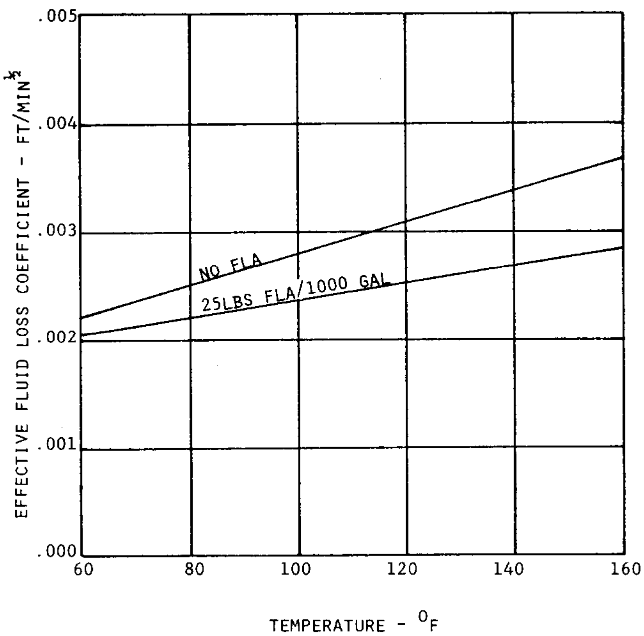

FIG. 6 — EFFECTIVE FLUID-LOSS COEFFICIENT VS TEMPERATURE

including all classes of surfactants so that a wide variety of formation peculiarities can be taken into account. This system has been used in many different formation types and depths. An external breaker is used for BHT's up to 150°F and no breaker is required above this temperature. To date, no breaking problems have been encountered and clean-up has been rapid and complete.

In the area of design, there are two main precautions that must be observed when using crosslinked gel systems and both relate to their perfect sand-support feature. In this type of system, it is essential that an adequate pad volume be pumped,[3] and a careful sand-addition schedule should be adhered to.[4] As sand-laden fluid is pumped deeper into the fracture, leak-off causes a progressive dehydration of the slurry. This means that the sand concentration is constantly increasing with time; and at a point where concentration equals the bulk density of the proppant, it is no longer a slurry and a tip sand-out would occur. For ordinary gels, where sand transportation is strictly dependent on viscosity, sand concentration is decreasing constantly since sand continuously falls to the bottom of the fracture, forming a sand bank.[5] For this reason, problems with sand concentration at the fracture extremity are avoided. With systems featuring perfect or near perfect support, this increasing concentration must be accounted for in the treatment design.[4] As an example, consider the following conditions:

Well depth	= 7600 ft
Fracture height	= 20 ft
Injection rate	= 8 BPM
Fluid-loss coefficient	= 0.0045 ft/$\sqrt{\text{min}}$
Pad volume	= 5800 gal.
Frac volume	= 22,000 gal.
Fracture length	= 685 ft

If sand were started at a concentration of 1 ppg and continued through the treatment, the following concentration profile would result:

Distance from Wellbore, ft	Sand Concentration, ppg
0	1.00
137	1.45
274	2.29
411	4.14
548	9.65
685	43.03

From the above, it can be seen that, for the conditions stated, it is likely that a job failure would occur if the concentration were kept at 1 ppg throughout the treatment. Harrington, et al., in a recent paper presented an analytical technique that is well-suited to the crosslinked gels.[4]

The technique referred to above, in combination with this fluid, will allow the design of partial monolayer treatments in areas where this type treatment is desired. Some of the case histories presented illustrate a successful application of the partial monolayer technique.

CASE HISTORIES

The following case histories are representative of a much larger number of successful treatments performed using this fluid system.

New Wells

Example 1

Location:	West Flowers Canyon Field Stonewall County, Texas
Formation:	Canyon Sand
Perforations:	4210 ft to 4392 ft
Frac fluid:	45,000 gal.
Proppant:	75,000 lb 20/40 sand

Injection rate:	20 BPM via 4000 ft 2-7/8 in. tubing at ±4000 psi
I.P.:	300 BOPD

Production after 120 days: 130 BOPD + 65 BWPD

Example 2

Location:	West Flowers Canyon Field, Stonewall County, Texas
Formation:	Canyon Sand
Perforations:	4300 ft to 4404 ft (46 shots)
Frac fluid:	63,000 gal.
Proppant:	77,000 lb 20/40 sand
Injection rate:	22 BPM via 4455 ft 2-7/8 in. tubing at ±4400 psi
I.P.:	250 BOPD

Production after 90 days: 138 BOPD + 120 BWPD

NOTE: Both of the above treatments were staged with solid blocking material in conjunction with temperature surveys.

Old Well Workovers

Example 1

Location:	Goldsmith North Devonian Field, Ector County, Texas
Formation:	Devonian
Perforations:	7895 ft to 7945 ft
Frac fluid:	15,000 gal.
Proppant:	5180 lb 10/20 sand, 2220 lb 8/12 glass beads
Injection rate:	9 BPM via 7791 ft 2-7/8 in. tubing at ±3950 psi
Production:	*Before* - 359 BOPD; *After* - 530 BOPD

Example 2

Location:	Block 11 Devonian Field, Andrews County, Texas
Formation:	Devonian
Perforations:	7076 ft to 8098 ft, 8007 ft to 8072 ft
Frac fluid:	16,000 gal.
Proppant:	2750 lb 12/20 glass beads
Injection rate:	15.5 BPM via 7918 ft 2-7/8 in. tubing at ±5800 psi
Production:	*Before* - (shut-in 1974) 18 BOPD + 1 BWPD *After* - 218 BOPD + 960 BWPD *Production after 30 days* - 67 BOPD + 819 BWPD

Example 3

Location:	Block 11 Devonian Field, Andrews County, Texas
Formation:	Devonian
Perforations:	8120 ft to 8193 ft, 8203 ft to 8228 ft
Frac fluid:	14,000 gal.
Proppant:	2750 lb 12/20 glass beads
Injection rate:	21 BPM via 8000 ft 2-7/8 in. tubing at ±5600 psi
Production:	*Before* - 40 BOPD + 1000 BWPD *After* - 110 BOPD + 462 BWPD

It is interesting to note that the last three examples represent an application of partial monolayer propping.

CONCLUSION

1. This system fills the need for a moderate-duty, crosslinked, synthetic polymer-based fracturing system.
2. It has excellent fluid properties that make it suitable for all but the most severe downhole environments, and upon breaking is residue-free.
3. It is a highly reliable system by virtue of a special, high-accuracy complexer injection system.
4. Its proppant transport is virtually perfect which allows maximum propped fracture length. This feature allows the design of partial monolayer proppant spacing.
5. It has been used successfully in a wide variety of formation types and depths and is rapidly displacing the natural polymer complexed gels in popularity.

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