EVALUATION OF ACID GELLING AGENTS FOR USE IN WELL STIMULATION

By C. W. Crowe, R. C. Martin and A. M. Michaelis
Dowell Division of Dow Chemical U.S.A.

ABSTRACT

Various polymers and other thickening agents have been evaluated as gelling agents for hydrochloric acid. These materials were compared on the basis of thickening efficiency, acid stability and residue formation upon spending of the acid. Thickeners tested include xanthan polymers, guar gum, hydroxyethyl cellulose, hydroxyethylcarboxmethyl cellulose, polyacrylamide, polyvinyl alcohol, polyvinylpyrrolidone, acrylamide/sodium-2-acryamido-2-methylpropane sulfonate copolymer, and a cationic surfactant which thickens acid when used at high concentrations.

Of the thickening agents tested, the xanthan polymer showed the greatest overall potential for use as an acid gelling agent. This polymer is an efficient viscosity builder and has good stability in 15% hydrochloric acid at temperatures up to 150°F. Computer model studies, which take into consideration cool-down and gel degradation rate at various stages of acid spending, indicate viscosity is maintained when treating wells that have bottom-hole temperatures up to 220°F. Since the gelled acid retains its viscosity during spending, both reaction rate and fluid leak-off are retarded. Laboratory studies, simulating downhole spending conditions, yield a 3.6-fold increase in spending time for gelled 15% hydrochloric acid (22 cp) as compared to ungelled acid.

Well test results are presented that demonstrate the effectiveness of acid fracturing treatments employing hydrochloric acid with xanthan polymer.

INTRODUCTION

Gelled acids have been used for many years as a means to improve the effectiveness of fracture acidizing treatments. Gelling the acid allows greater fracture penetration by increasing fracture width, slowing reaction rate and reducing fluid loss. Unfortunately, most commonly used gelling agents have limited acid stability and are only effective at low temperature applications. Newer, more acid stable polymers show promise for use at the higher temperatures.

When evaluating acid gelling agents, a number of important factors must be taken into consideration.

These include the following.

1. Acid Stability - How long is viscosity maintained in the treating acid at various temperatures.

SPE Paper No. 9384 presented at the 1980 Annual Technical Conference and Exhibit. Reprinted with permission of the Society of Petroleum Engineers.

2. Efficiency - What concentration of gelling agent is required to achieve a desired viscosity.

3. Condition of Spent Acid - Is the viscosity of the spent acid low enough to insure cleanup and are insoluble reaction products formed upon spending of the acid.

Acid Stability

In order for an acid gelling agent to be effective, it must be sufficiently stable to retain its viscosity in acid under downhole spending conditions. Tests were performed in which gelling agents were mixed with preheated 15% hydrochloric acid to compare the stability of various acid thickeners. After one minute, the initial viscosity was measured with a Fann 35 viscometer at a shear rate of 511 sec^{-1}. While maintaining the solution at the test temperature, additional viscosity measurements were made over a period of one hour. Table 1 describes the gelling agents that were evaluated, while Figures 1 and 2 contain the test results.

Tests performed at 100°F demonstrate that gelling agents such as guar gum, hydroxypropyl guar gum (HPG), hydroxyethyl cellulose (HEC) and carboxymethylhydroxyethyl cellulose (CMHEC) have limited stability in 15% hydrochloric acid. Consequently, their use at temperatures above 125°F is not recommended. Even when using these acid thickeners for the treatment of low temperature wells, continuous mixing is usually necessary since batch mixes will not retain their viscosity very long at ambient temperatures.

Thickeners which possessed good stability in 100°F tests were also tested at 150°F, using the same procedure. Of the materials evaluated at 150°F, only polyvinyl alcohol (PVA) and polyvinylpyrrolidone (PVP) indicated no loss of viscosity over the 60-minute test period. Moderate losses of viscosity were observed using the xanthan polymer,[1] polyacrylamide (PAM) and the acrylamide/2-acryamido 2-methylpropane sulfonate (PAM/AMPS) copolymer. Acid thickened with 1-(2-hydroxyethyl)-2-[(Z)-8-heptadecenyl]2-imidazoline (HEPI) also had no loss of viscosity during the test; however, the initial viscosity at 150°F was only 3 cp as compared to 25 cp at 100°F. CMHEC was also tested at 150°F; however, it rapidly degraded and resulted in only 3 cp initial viscosity as compared to 15 cp at 100°F.

Thickener Efficiency

An important consideration in the evaluation of acid gelling agents is the concentration of thickener required to achieve the desired viscosity. To compare various thickeners, tests were performed to determine the concentration of each gelling agent necessary to produce 25-cp viscosity at 100°F in 15% HCl. Viscosities were measured using a Fann 35 viscometer at 300 rpm (511 sec^{-1}). Results of these tests are reported in Table 2. It is interesting to note that polyvinyl alcohol and polyvinylpyrrolidone, thickeners previously indicated to be most acid stable, were the least efficient, requiring concentrations of over four percent to achieve 25-cp viscosity. In contrast, guar gum and hydroxyethyl cellulose, two of the least stable thickeners, were the most efficient. The xanthan polymer provided a compromise of good thickening efficiency and moderate loss of viscosity over the 60-minute test period.

The most novel thickener tested was a cationic surfactant, 1-[2-hydroxyethyl-2-[(Z)-8-heptadecenyl]-2-imidazoline, which forms association polymers in acid solution. This type of gelling agent is completely stable in acid; however, changes in temperature or acid concentration cause loss of viscosity resulting from changing surfactant solubility. Also, the high concentration of surfactant required makes corrosion inhibition difficult and could lead to severe emulsion blocks. Because of these problems, the use of this type of thickener in well treating has been limited.

Condition of Spent Acid

The condition of the spent acid is an important factor when evaluating potential acid gelling agents. If the viscosity is too high, or if cross-linked gels or precipitates occur upon spending, slow cleanup or permanent formation damage may result. In order to simulate downhole spending conditions, a series of tests was performed in which 15% HCl was thickened using the concentration of gelling agent found in Table 2 to provide 25-cp viscosity. Each gelled acid sample was placed in a heated water bath for one hour and then spent using marble chips. The viscosity of the spent acid was then measured using a Fann 35 viscometer (511 sec^{-1}) and the solution examined for evidence of insoluble precipitate. Data from these tests are presented in Table 3.

Laboratory tests performed at 150°F indicated that acids prepared using the more stable gelling agents retained considerable viscosity upon spending. None of the gelling agents produced significant amounts of insoluble residue. At 175°F, the polyacrylamide thickened acid not only lost viscosity, but also produced a large amount of sponge-like precipitate resulting from acid hydrolysis[2] of the polymer. The acrylamide copolymer (PAM/AMPS), being more acid resistant, retained considerable viscosity and produced no precipitate.

However, in tests run at 200°F, the PAM/AMPS copolymer was degraded by the acid and precipitated as an insoluble residue. At 225°F, the acid thickened with polyvinyl alcohol lost viscosity and produced a large volume of precipitate. Of the gelling agents tested at 225°F, only the polyvinylpyrrolidone retained its viscosity and did not form an insoluble precipitate.

EFFECT OF SPENT ACID VISCOSITY UPON WELL CLEANUP

Theoretical calculations[3] are useful when considering the effect of viscosity on cleanup rate. These calculations (shown in Figure 3) for a typical low permeability reservoir demonstrate the relative time required to achieve cleanup with fracturing fluids having different viscosities. In this example, a 0.25-cp fluid cleans up easily and maximum flow rate is achieved after only three days of production. With a 25-cp fluid, about 30 days are required before the maximum rate is attained. The complete cleanup of a fluid having a viscosity of 250 cp required over 400 days. Consequently, the spent acid viscosity should be carefully considered when planning any gelled acid treatment. In many cases, however, the somewhat longer cleanup times may be a small price to pay for the improved long-term production results obtained by using the gelled acid. As a general rule, systems producing spent acid viscosities above 25 cp should probably be avoided. Also, gelled acids which form insoluble precipitates upon spending should be completely avoided since their use can lead to permanent formation damage.

Cross-Linked Gelled Acids

The development of cross-linked fracturing fluids stimulated an interest in similar gelled acid systems. Although the technical problems are greater, acid gelling agents such as carboxymethylhydroxyethyl cellulose, polyacrylamide and acrylamide copolymers can be successfully cross-linked in hydrochloric acid. Carboxymethylhydroxyethyl cellulose is sometimes cross-linked using polyvalent metal ions. As shown earlier, the temperature stability of this system is limited due to rapid acid hydrolysis of the polymer at temperatures above 125°F. Although complete spending of the acid does produce apparent breakage of cross-linked CMHEC gels, it results in the precipitation of the polymer as an insoluble residue. This can produce serious formation damage. These limitations have largely restricted this system to use in treating low-temperature sandstone formations where polymer precipitation is not a problem since the acid does not completely spend.

Polyacrylamide and acrylamide copolymers can also be cross-linked in acid by various aldehydes. However, this type of cross-linked acid has seldom been used commercially due to the lack of an effective gel breaker and the insoluble acid hydrolysis products formed at temperatures above 150°F. In general, the use of cross-linked gelled acids should be approached with caution since the potential for formation damage from unbroken gel and insoluble reaction products is much greater than with uncross-linked systems.

COMPARISON OF GELLING AGENTS

When comparing acid gelling agents, it is obvious that no single material is superior under all test conditions. The most efficient acid thickeners, guar gum and hydroxyethyl cellulose, have limited acid stability and are ineffective except in low-temperature applications. The most acid-stable polymers, polyvinyl alcohol and polyvinylpyrrolidone, require extremely high concentrations to achieve the desired viscosity. Polyacrylamide is not only inefficient but can also produce damaging precipitates when used at temperatures above 150°F. All things considered, the xanthan polymer appears to offer the best compromise between efficiency, stability and freedom from damaging precipitates. For this reason, this thickener was selected for more extensive evaluation to better establish its performance characteristics.

Retardation of Acid Reaction

In order to evaluate the effect of increased viscosity upon acid reaction rate, a series of spending tests was performed. In these tests, 15% HCl and 15% HCl gelled with 0.6% xanthan polymer were injected at 1000 psi into a preheated, high-pressure vessel filled with chunks of Indiana limestone. The ratio of acid volume-to-limestone surface area was designed to simulate conditions of static spending in a fracture that has a width of about 0.25 in. At regular intervals, samples of acid were withdrawn and titrated to determine the remaining acid concentration. These tests show a considerable increase in spending time for the gelled acid versus ungelled acid, even at temperatures up to 200°F. It was also noted that the shape of the spending curves for the gelled acid (Figure 4) and ungelled acid (Figure 5) was quite different. The ungelled acid spent quite rapidly during the first few minutes while the gelled acid curves were relatively flat, indicating an almost uniform reaction rate during most of the spending cycle. It was also observed that, even at 200°F, the spent gelled acid retained most of its original viscosity. At 250°F, however, the spending time was much shorter and the gel was broken.

Reaction rates of gelled and ungelled 15% HCl were also determined on marble specimens of known surface area. At 75°F and 1000 psi confining pressure, the reaction rate for 15% HCl was 1.150 $gm/m^2/sec$ as compared to 0.357 $gm/m^2/sec$ for 15% HCl gelled with 0.6% xanthan polymer. This represents a 69% reduction in reaction rate.

Viscosity Retention of Gelled Acid Under Downhole Treating Conditions

An important consideration when evaluating a gelled acid system is its retention of viscosity during the treatment. Simple measurements of viscosity decay versus time, in fresh acid, do not adequately establish the upper temperature limit for any system. Under actual treating conditions, cool-down and spending will occur as the acid progresses down the fracture, thus reducing the rate of polymer degradation. In order to develop more accurate data for use in computer model studies, additional tests were performed in which viscosity versus time measurements were determined in both fresh and partially spent acids at temperatures between 140° and 180°F. Data from this study are presented in Figures 6a through 6e.

The experimental data developed consisted of viscosity versus time for three different spending strengths at five different temperatures. These measurements were then curve-fitted to six possible equations that describe the relationship of viscosity as a function of time. It was found that the logarithmic function gave the best index of determination and, therefore, was used as the general model in the form

$$\mu = A*EXP(B*t)$$

where

μ = viscosity, cp,
t = time, minutes, and
A, B = constants.

Since the constants varied, depending on the spending strength and temperature of the different sets of conditions, the A and B coefficients were separately fit as functions of temperature for a specified spending strength. The A coefficients were fit to the logarithmic model as a function of temperature. The results indicate that the A coefficient is not only a function of time, but also of temperature. Therefore, the A coefficient was expessed as

$$A = a + b$$

where

ϕ = temperature, °F, and
a, b = constants.

Next, the logarithm of the absolute value of the B coefficients was fit as functions of temperature for the three spending strengths. The findings showed that B was a function of temperature and strength as well as time.

The resulting expression for B then becomes

$$B = d + e\phi + fC_x$$

where

ϕ = temperature, °F,
C_X = acid strength, %, and
d,e,f = constants.

With the help of statistical analysis and curve fitting, the values of a, b, d, e and f were found to be related to viscosity in the following manner:

$$\log \mu = \log(a + b\phi) + \mathrm{EXP}((d + e\phi + fC_X)t)$$

where

μ = viscosity, cp,

ϕ = temperature, °F,

C_X = acid strength, %,

t = time, minutes, and

a,b,d,e,f = calculated coefficients.

After the general form was established, the coefficients were determined using a nonlinear regression approach which is described in the Appendix.

SIMULATION OF TREATMENT CONDITIONS

After the coefficients were evaluated, they were used in the general equation. The viscosities of each acid strength and temperature were then computed, as a function of time, temperature and strength, and compared to the experimental measurements. Since the computed values agreed quite well with the measured values of viscosity, the equation was next incorporated into an acid fracturing design program. Viscosities, temperatures and acid concentrations in the fracture at the conclusion of the treatment were calculated to illustrate the condition of the gelled acid. Results of acid viscosity, concentration and temperature versus distance are shown in Figures 7a through 7e. These figures represent design runs made at bottom-hole temperatures of 180°, 200°, 220°, 230° and 240°F. In all cases, the simulated treatment was pumped at a rate of 15 bbl/min using a 10,000-gal viscous preflush to cool the well. The acid stage consisted of 25,000 gal of 15% HCl gelled with 0.6% xanthan polymer. Fracture height was 45 ft.

Under the treating conditions described, the gelled acid retained its viscosity in the fracture at bottom-hole temperatures up to at least 220°F. Above 230°F, the polymer was rapidly destroyed by acid hydrolysis. The upper temperature limit determined from this study agrees closely with that observed earlier during acid spending tests.

Figure 8 displays the viscosity of the gelled acid in a fracture at various stages of acid penetration. This clearly shows how cool-down and spending affect viscosity as the fracture grows. Initially the viscosity will decrease in the first 50 ft of the fracture, but toward the end of the treatment, the viscosity in the first 50 ft will increase. Spending and cool-down in the fracture aid the fluid in retaining its original viscosity during treatment.

Treatment Results Using Gelled Acid

Over 75 acidizing treatments have been performed using hydrochloric acid gelled with the xanthan polymer. Generally speaking, stimulation responses have been quite good and cleanup problems following treatments have been minimal. Table 4 shows treatment results from a five-well test program conducted near Levelland, Texas, on wells producing from the San Andres Formation. These were old wells which had been acidized several times previously. In this test series, oil production 90 days after treatment was increased by an average of 123% while water production increased by only 37%. Initial production following treatment was also quite good, demonstrating relatively rapid cleanup in spite of the retained viscosity of the spent acid.

Another test was performed on a series of three new offset wells, drilled in the Clearfork Formation near Andrews, Texas. This is a dolomite formation that has a bottom-hole temperature of 150°F. The first two wells were treated with 80,000 gal of emulsified fracturing fluid followed by an equal volume of 20% HCl. The third well was treated in the same manner except 80,000 gal of gelled 15% HCl was substituted for the 20% HCl. Test results were as follows.

Well Number	Oil Production Rate
1	100 bpd
2	140 bpd
3	225 bpd

It is evident that oil production following the gelled acid treatment was considerably higher than that obtained with either treatment using ungelled 20% HCl. The rate was also much higher than the field average.

Conclusions

1. Gelling agents such as guar gum, hydroxypropyl guar, hydroxyethyl cellulose and carboxymethylhydroxyethyl cellulose have limited stability in hydrochloric acid, thus limiting them to low temperature applications.

2. Considering acid stability, efficiency and freedom from insoluble residues, the xanthan polymer was the best overall acid thickener for the majority of applications.

3. Model studies indicate that 15% HCl, gelled with xanthan polymer, will retain its viscosity during treatments at bottom-hole temperatures up to 220°F.

4. Although acid thickened with the xanthan polymer retains most of its viscosity during spending, cleanup times following treatment have not been excessive.

5. Of the acid thickeners evaluated, only polyvinylpyrrolidone was stable in 15% HCl at 225°F.

APPENDIX

Given an arbitrary form of an equation to be fitted to some data,

$$y = f(x;a,b,c)$$

where a, b, and c are parameters to be determined. First of all, the equation is rearranged to the form $F(x,y;a,b,c) = y - f(x;a,b,c) = 0$. The initial estimates of these parameters are assumed giving the equations to be solved for a, b, and c as

$$a = a_0 - A$$

$$b = b_0 - B$$

$$c = c_0 - C$$

and

$$[F_aF_a]A + [F_aF_b]B + [F_aF_c]C = [F_aF_0]$$

$$[F_aF_b]A + [F_bF_b]B + [F_bF_c]C = [F_bF_0]$$

$$[F_aF_c]A + [F_bF_c]B + [F_cF_c]C = [F_cF_0]$$

where

[ ] means the summation over all
data points $[x_i,y_i]$ for $i = 1$ to N.

F_0 represents F evaluated from some pair of (x,y) using the initial values of the coefficients, i.e., a_0, b_0 and c_0. F_a represents the partial derivative of F with respect to 'a' for some pair of (x,y) again using the initial values of the coefficients. The calculation procedure is repeated using the adjusted values of the coefficients until a convergence in the maximum likelihood estimate is achieved. $F(x,y;a,b,c)$ represents the error of each measurement, and [FF] is the maximum likelihood estimate, that is, the sum of the squares of the error.

According to Mandel,[5] the error is minimized by deriving the partial derivative of F with respect to each unknown coefficient. The derivatives are first evaluated at the initial assumed values and then reevaluated at the correct values of the coefficients, equal to the correction of each added to the corresponding initial value. This is the general method of least squares for nonlinear relations as reported by Deming.[6]

In our specific case, the partial with respect to each coefficient was evaluated and denoted by a vector element. These elements were evaluated for each x,y coordinate and a matrix was constructed of size M x N where M equals the number of points and N equals the number of coefficients plus one, i.e., N equals the number of vector elements. A total of 296 measurements was used to fit the equation. Since large matrices require excessive computer memory, the matrix was partitioned into 1 x N matrices. Each partition was multiplied by its transpose and the product was summed, resulting in the total product of the M x N matrix and its transpose.

Next, Gaussian elimination was used to invert the product matrix. This was done to obtain the residuals of the coefficient and the sum of the square of the error, given by the last column of the inverted matrix. For a linear relationship, the last column would contain the actual values of the coefficients and the sum of the square of the error would equal zero. For a nonlinear relationship, it would contain the correction needed that, when added to the coefficients, would help satisfy the relation

$$2Fi/2A = 0$$

$$\text{where} \quad A = a_0 + a.$$

The sum of the square of the error was compared to an acceptable minimum value, and if the error were too large the procedure was repeated using the corrected values of the coefficients. Once the error had reached an acceptable value, the procedure was terminated, and the true values of the coefficients were equal to the final corrected values.

REFERENCES

1. Parks, C.F.: "Method of Acidizing Wells," U.S. Patent 3,236,305.

2. Woodroff, R.A. and Anderson, R.W.: "Synthetic Polymer Friction Reducers can Cause Formation Damage," SPE 6812 presented at SPE-AIME 52nd Annual Fall Meeting held in Denver, Colorado, October 9-12, 1977.

3. Williams, B.B., Gidley, J.L., and Schechter, R.S.: Acidizing Fundamentals Volume 6 of the SPE-AIME Monograph Series, 1979.

4. Whitsitt, N.F. and Dysart, G.R.: "The Effect of Temperature on Stimulation Design," J. Pet. Tech. (April 1970) 493-502.

5. Mandel, J.: The Statistical Analysis of Experimental Data, Wiley and Sons, New York, 1964.

6. Deming, W.E.: Statistical Adjustment of Data, Wiley and Sons, New York, 1943.

TABLE 1—GELLING AGENTS EVALUATED IN STUDY

GG	Guar Gum
HPG	Hydroxypropyl Guar Gum
HEC	Hydroxyethyl Cellulose
PAM	Polyacrylamide (0-4% hydrolyzed)
HEPI	1-(2-Hydroxyethyl)-2-[(Z)-8-Heptadecenyl]-2-Imidazoline
CMHEC	Carboxymethylhydroxyethyl Cellulose
XP	Xanthan Polymer
PVA	Polyvinyl Alcohol (98% hydrolyzed)
PAM/AMPS	85:15 Mole-Ratio Acrylamide/Sodium 2-Acryamido-2-Methylpropane Sulfonate Copolymer
PVP	Polyvinylpyrrolidone (M.W. 360,000)

TABLE 2—EFFICIENCY OF VARIOUS ACID

Gelling Agents	% by wt required to produce 25-cp viscosity in 15% HCl at 100°F
Guar Gum	0.55
Hydroxypropyl Guar Gum	0.79
Hydroxyethyl Cellulose	0.45
Polyacrylamide (0-4% hydrolyzed)	3.06
1-(2-Hydroxyethyl)-2-[(Z)-8-Heptadecenyl]-2-Imidazoline	1.60
Carboxymethylhydroxyethyl Cellulose	0.72
Xanthan Polymer	0.64
Polyvinyl Alcohol (98% hydrolyzed)	4.60
85:15 Mole-Ratio Acrylamide/Sodium-2-Acryamido-2-Methylpropane Sulfonate Copolymer	1.34
Polyvinylpyrrolidone (M.W. 360,000)	4.20

TABLE 3—CONDITION OF GELLED 15% HCl AFTER SPENDING
(ORIGINAL VISCOSITY = 25 @ 100°F.)

	150°F		175°F		200°F		225°F	
Gelling Agent	Viscosity,cp	Insoluble Residue	Viscosity,cp	Insoluble Residue	Viscosity,cp	Insoluble Residue	Viscosity,cp	Insoluble Residue
GG	<2.0	No						
HPG	<2.0	No						
HEC	<2.0	No						
CMHEC	<2.0	No						
HEPI	3.2	No						
XP	11.6	No	<2.0	No				
PAM	20.0	No	<2.0	Yes				
PAM/AMPS	16.8	No	9.0	No	<2.0	Yes		
PVA	26.8	No	19.4	No	13.0 @ 175°F	No	<2.0	Yes
PVP	24.6	No	21.4	No	21.0 @ 175°F	No	21.0 @ 175°F	No

TABLE 4—GELLED ACID TREATMENT RESULTS

San Andres Formation
Temperature - 150°F
Depth - 4800 ft

Production Rate, bpd (Oil/Water)

Well Number	Before	Initial	30 days	60 days	90 days
1	25/34	37/51	42/48	39/37	40/38
2	3/300	15/440	10/510	14/380	7/350
3	9/8	16/54	19/32	17/20	13/14
4	1/38	8/128	11/86	7/83	6/59
5	5/117	2/200	11/247	10/252	30/218

	Before	90 Days	Increase (%)
Total Oil, bpd	43	96	123
Total Water, bpd	497	679	37
Total Fluid	540	775	44

TABLE 5—SI METRIC CONVERSION FACTORS

Degree F (°F-32)/1.8 E + 00 = °C

cp x E - 03 = Pa's

in. x 2.54* E + 00 = cm

psi x 6.894 E - 03 = MPa

ft x 3.048* E - 01 = m

gal x 3.785 E - 03 = m^3

*Conversion factor is exact.

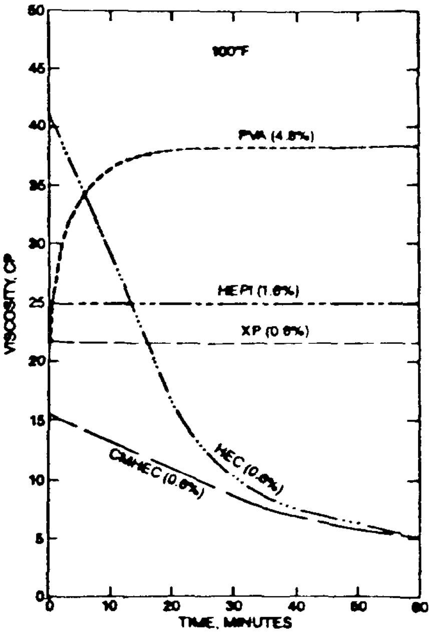

FIGURE 1—STABILITY OF GELLING AGENTS IN 15% HC1 AT 100°F.

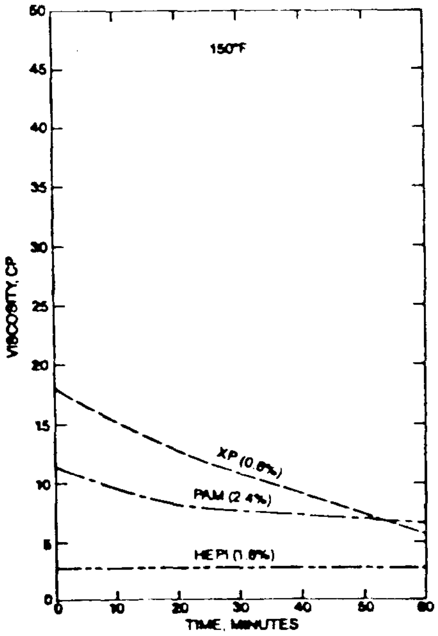

FIGURE 2a—STABILITY OF GELLING AGENTS IN 15% HC1 at 150°F.

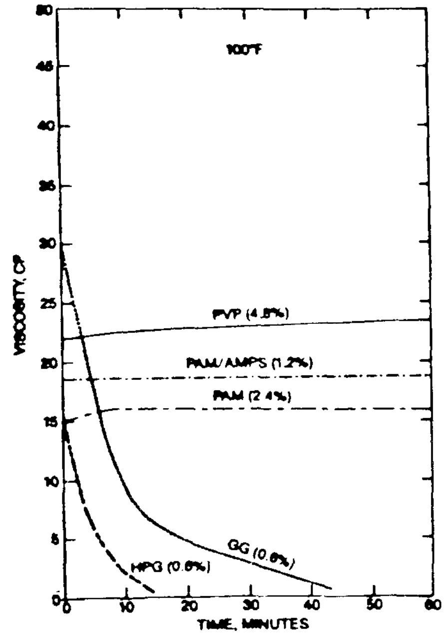

FIGURE 1b—STABILITY OF GELLING AGENTS IN 15% HC1 AT 100°F.

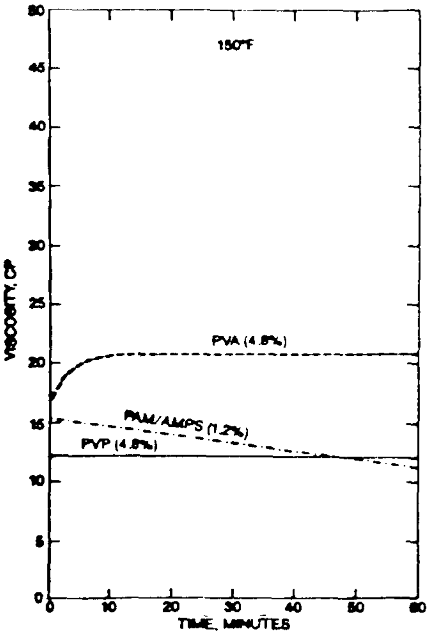

FIGURE 2b—STABILITY OF GELLING AGENTS IN 15% HC1 at 150°F.

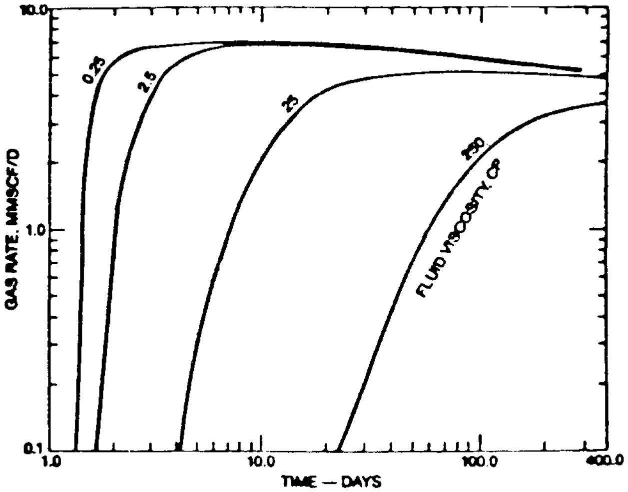

FIGURE 3—EFFECT OF FLUID VISCOSITY ON PRODUCTION RATE FOLLOWING STIMULATION.

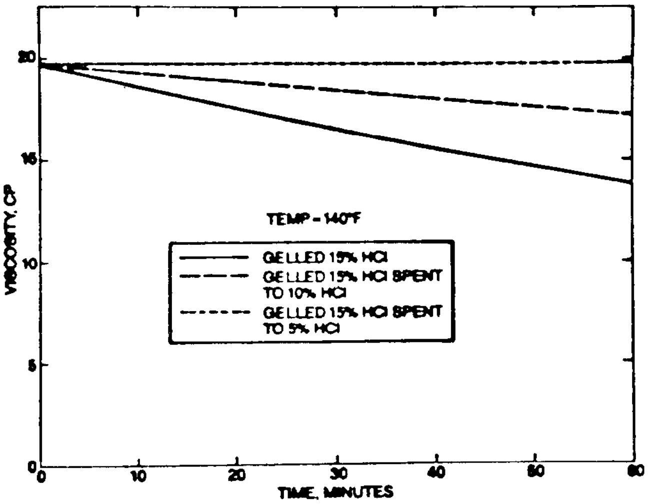

FIGURE 6a—VISCOSITY LOSS VERSUS TIME FOR 15% HC1 GELLED WITH 0.6% XANTHAN POLYMER AT 140°F.

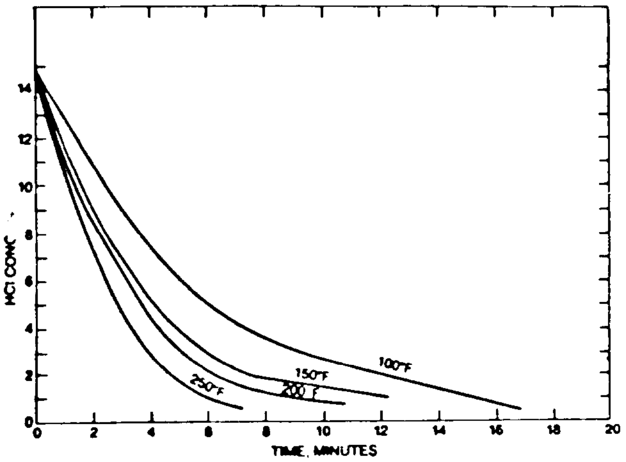

FIGURE 4—SPENDING RATE OF UNGELLED 15% HC1.

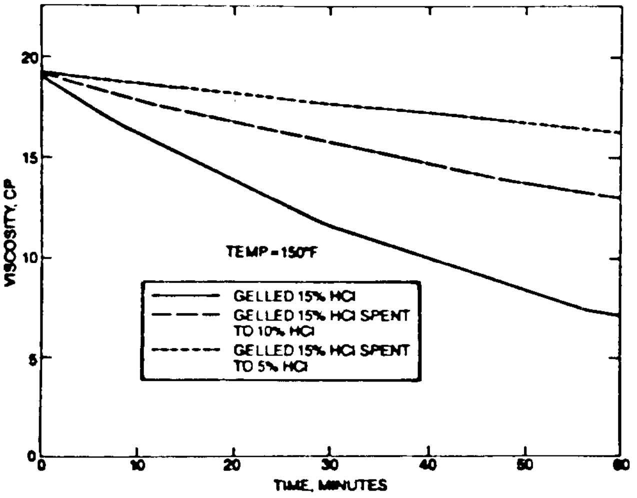

FIGURE 6b—VISCOSITY LOSS VERSUS TIME FOR 15% HC1 GELLED WITH 0.6% XANTHAN POLYMER AT 150‡F.

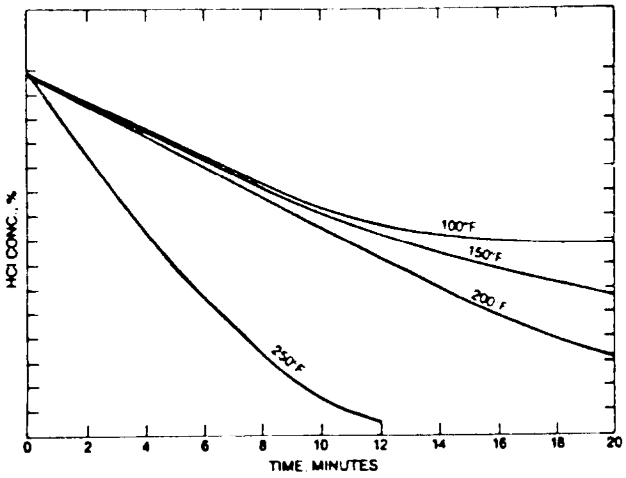

FIGURE 5—SPENDING RATE OF 15% HC1 GELLED WITH 0.6% XANTHAN POLYMER.

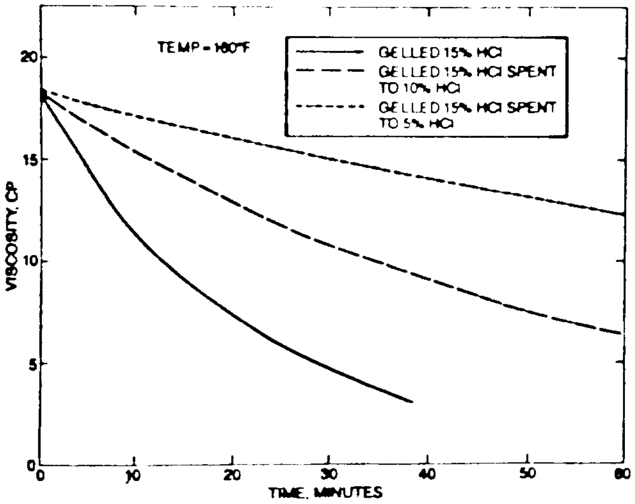

FIGURE 6c—VISCOSITY LOSS VERSUS TIME FOR 15% HC1 GELLED WITH 0.6% XANTHAN POLYMER AT 160°F.

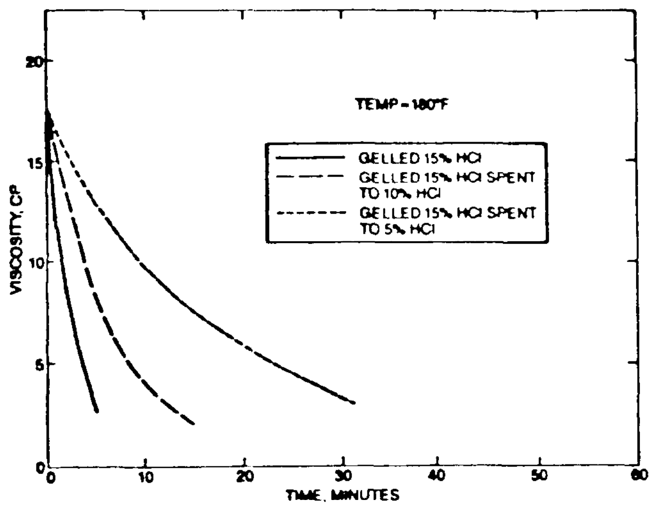

FIGURE 6e—VISCOSITY LOSS VERSUS TIME FOR 15% HC1 GELLED WITH 0.6% XANTHAN POLYMER AT 108°F.

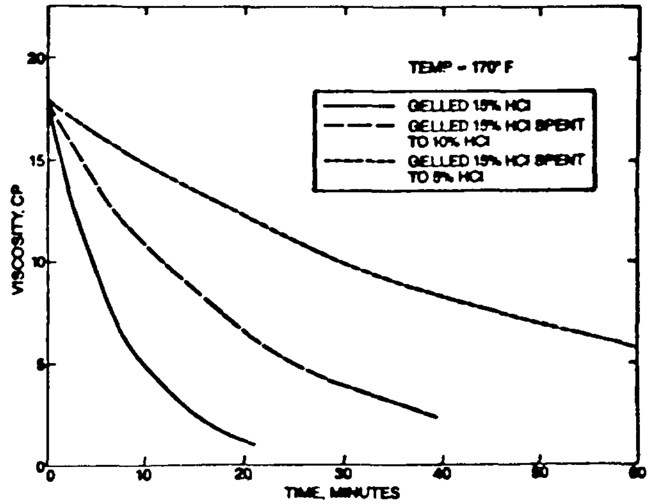

FIGURE 6d—VISCOSITY LOSS VERSUS TIME FOR 15% HC1 GELLED WITH 0.6% XANTHAN POLYMER AT 170°F.

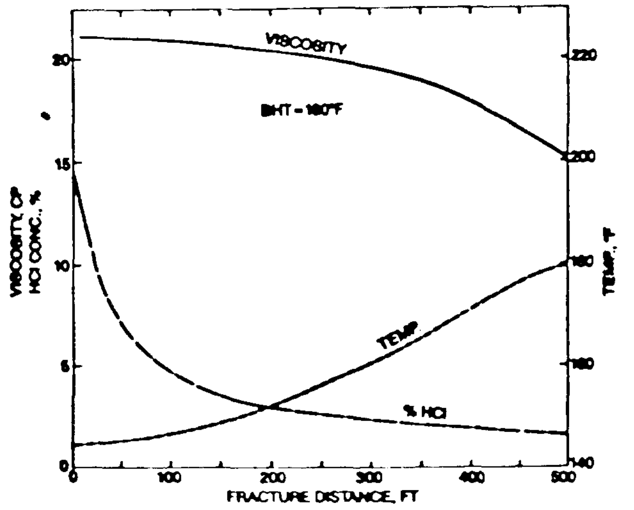

FIGURE 7a—FLUID CHARACTERISTICS OF 15% HC1, GELLED WITH 0.6% XANTHAN POLYMER, AT CONCLUSION OF 25,000 GAL ACID TREATMENT (BHT = 180°F.)

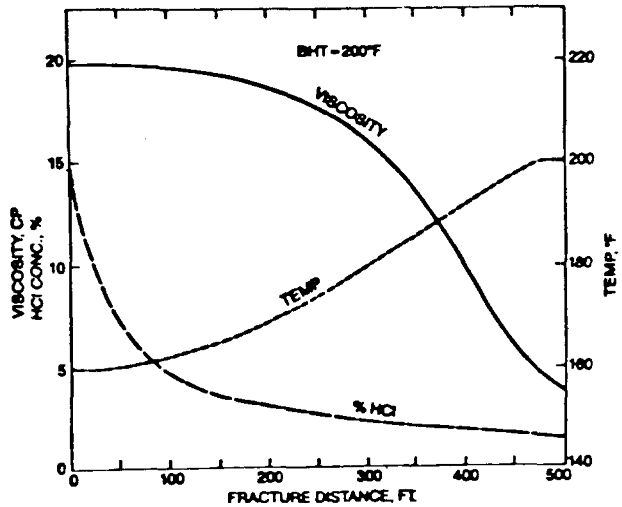

FIGURE 7b—FLUID CHARACTERISTICS OF 15% HC1, GELLED WITH 0.6% XANTHAN POLYMER, AT CONCLUSION OF 25,000 GAL. ACID TREATMENT (BHT = 200°F).

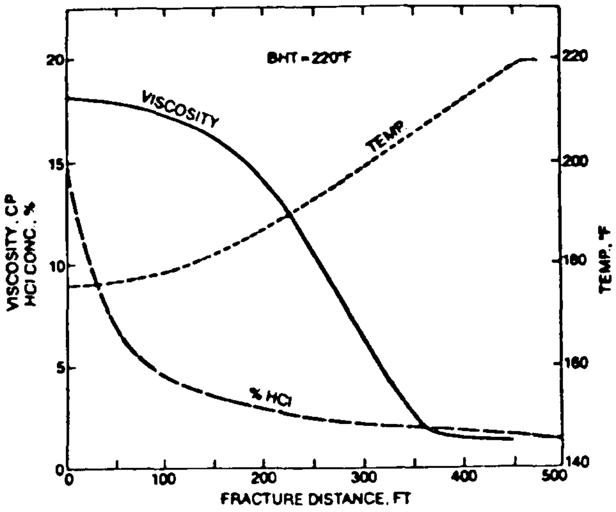

FIGURE 7c—FLUID CHARACTERISTICS OF 15% HC1, GELLED WITH 0.6% XANTHAN POLYMER, AT CONCLUSION OF 25,000 GAL. ACID TREATMENT (BHT = 220°F).

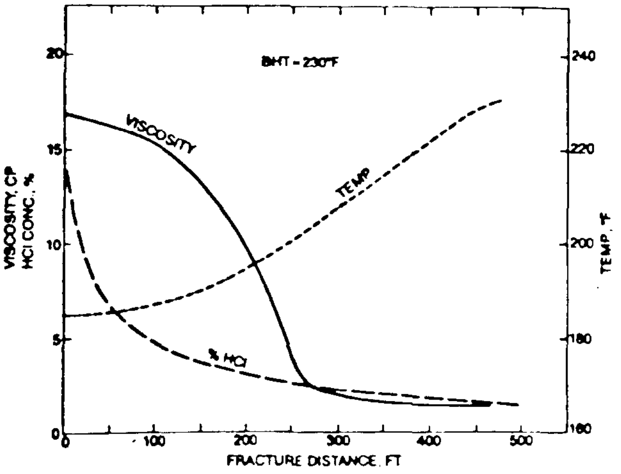

FIGURE 7d—FLUID CHARACTERISTICS OF 15% HC1, GELLED WITH 0.6% XANTHAN POLYMER, AT CONCLUSION OF 25,000 GAL. ACID TREATMENT. (BHT

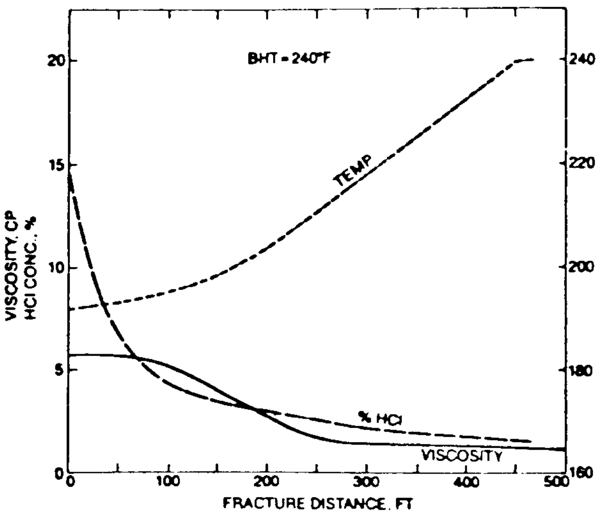

FIGURE 7e—FLUID CHARACTERISTICS OF 15% HC1, GELLED WITH 0.6% XANTHAN POLYMER, AT CONCLUSION OF 25,000 GAL. ACID TREATMENT (BHT = 240°F).

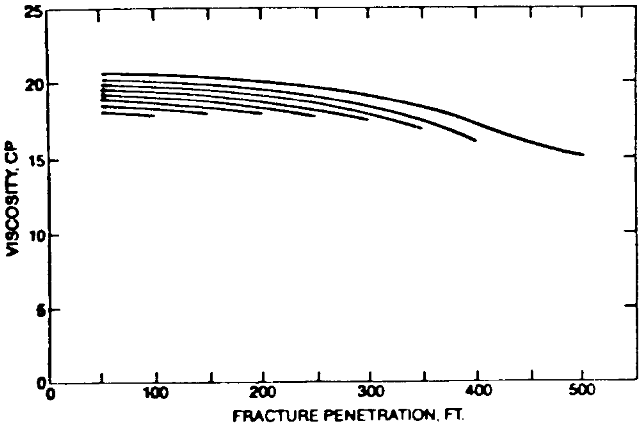

FIGURE 8—VISCOSITY OF 15% HC1, GELLED WITH 0.6% XANTHAN POLYMER AT VARIOUS STAGES OF ACID PENETRATION (BHT = 180°F, Q = 15 BPM).