A New Emulsion Polymer Improves Tight Gas Production

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Abstract

Historically, tight gas formations such as the Strawn limestone in Crockett County, Texas and the Devonian in Andrews and Midland Counties, Texas have been treated with pad and acid treatments consisting of gelled water, gelled acid and crosslinked hydrochloric acid.

A new emulsion polymer has been developed which significantly increases the efficiency of these treatments. The new emulsion polymer exhibits a polymer size approximately 15 times smaller than that previously known to the industry. The polymer also utilizes a highly specific external activator to initiate and promote hydration. This process allows the micro-sized polymer to effectively disperse prior to hydration, thereby dramatically reducing the potential to form un-hydrated masses ("lumps" or "fisheyes"). Both macro and microscopic "lumps" can be particularly detrimental to the formation matrix.

This paper will document the increased well production of the Strawn formation in Crockett County, Texas and the Devonian formation in Andrews and Midland Counties, Texas as a result of the polymer's use, outline the treatment, and describe the chemistry of the new emulsion polymer and its operational efficiency and versatility.

Introduction

The Strawn Limestone formation in the Hunt-Baggett West Field located in Crockett County, Texas is a naturally fractured low permeability "tight gas" reservoir[1]. Several types of treatments have been performed in the past in an attempt to maximize the production of the gas reservoir. This has proved difficult primarily due to the low permeability and natural fracturing of the formation[1]. These treatments have included conventional acidizing with linear hydrochloric acid, gelled pad and hydrochloric acid treatments, fracture treatments utilizing Zirconium crosslinked CMHPG commingled with CO_2, high pH borate type fracture treatments, and finally and most successfully, gelled pads and crosslinked hydrochloric acid treatments pumped in multiple stages.

The Devonian formation in the Magnutex Field located in Andrews County, Texas is a water driven oil and gas limestone reservoir[2]. Historically, the treatments performed in this reservoir have ranged from linear hydrochloric acid treatments to a variety of aqueous crosslinked fracture treatments utilizing proppants. Most recently and successfully the formation has been completed laterally and treated with a crosslinked hydrochloric acid.

The Devonian formation in the Pegasus Devonian Field located in Midland County, Texas is a naturally fractured low permeability oil and gas limestone reservoir[3]. The treatments performed, again, have varied from linear acid treatments to a variety of fracture treatments in an attempt to maximize production. The most recent and successful treatments have consisted of large volumes of crosslinked hydrochloric acid pumped in various stages at high rates.

The production history of the Strawn formation in Crockett County, Texas and the Devonian formation in Andrews and Midland Counties, Texas following treatments with crosslinked hydrochloric acid utilizing the new acid emulsion polymer chemistry is the object of this paper's study. Also considered will be the treatment volumes, polymer chemistry, and operational considerations in conventional and continuous gelling as applied to crosslinked hydrochloric acid.

Formation Characteristics, Lithology, and Acid Fracturing Potential

Strawn Formation, Hunt-Baggett West Field, Crockett County, Texas[1]. The Strawn formation in Crockett County Texas is comprised primarily of microcrystalline limestone. Analysis on samples cored from 9,406', 9,410', 9,413', and 9,418' indicated the average composition to be 98.25% limestone and 1.5% dolomite/ankerite quartz. The average solubility in 15% hydrochloric acid was 99.38% as measured at 30 minutes at 150 degrees Fahrenheit. Acid etching analysis with 15% hydrochloric acid at 200 degrees Fahrenheit indicated the formation of a differential etching pattern sufficient to create a conductive fracture without a propping agent.

The core also revealed the existence of both horizontal and vertical (open) natural fractures. Styolites and calcite filled fractures were also observed. Fossils noted in this biomicrite limestone included sponge spicules, pelecypod fragments, and fusulinids. Porosity observed in these samples was predominately inter-crystalline micro-porosity. Secondary porosity was associated with replacement of fossils. Noted also was the porosity associated with the natural vertical and horizontal fractures. The average porosity of the pay zone was 7.3% and the average gas permeability less than one millidarcy. Since the matrix of this sample was relatively impermeable the fractures appear to the main source of permeability.

Acid Fracturing. Acid fracturing was selected as an effective alternative to proppant fracturing and as a cost effective treatment in view of the results of the core analyses previously described. These analyses indicate that acid fracturing would provide sufficient differential etching to produce a highly conductive fracture without the use of proppant. The mineralogy within the limestones is varied such that the more reactive minerals will dissolve faster leaving raised areas that develop the highly conductive fracture[1]. Crosslinked hydrochloric acid was selected due to its low reaction rates[4] at elevated bottom hole temperatures (approximately 195 degrees Fahrenheit), high fluid viscosity[4, 5], and controlled leak-off[5] to the natural fractures.

Devonian Formation, Magutex Field, Andrews County Texas[2]. The Devonian formation located in Andrews County, Texas in the Magutex Field is an oil and gas reservoir comprised primarily of dolomite and limestone. The average porosity is 6% and the average permeability is 83 millidarcies. The average bottom hole temperature is 187 degrees Fahrenheit. Specific core analyses were unavailable at the time of the writing of this paper.

Acid Fracturing and Coil Tubing Clean Out. Coil tubing was selected as the delivery medium for the removal of drilling damage and debris. Acid fracturing was selected as the primary means of stimulation due to the solubility of the dolomite and limestone in hydrochloric acid. A crosslinked acid treatment was selected due to the higher bottom hole temperature, lower dynamic acid reaction rates, and increased leak-off control needed to extend the acid-etching radius[6].

Devonian Formation, Pegasus Devonian Field, Midland County Texas[3]. The Devonian formation in Midland County, Texas is comprised primarily of microcrystalline limestone. Analysis performed July 16, 1998 on samples cored from 11,544', 11,546', 11,560', and 11,595' indicated the average composition to be 96.6% calcite, 1.2% quartz, and 1.2% iron bearing dolomite. The average solubility in excess 15% hydrochloric acid was 98.8%. Two porosity types were discovered within the core, those being inter-particle porosity between micrite crystals and micro-fracture porosity (Figure 1). Average porosity appears to be approximately 2.5% and average permeability appears to be 0.01 millidarcy.

Acid Fracturing. Acid etching analysis with 15% hydrochloric acid (at less than 200 degrees Fahrenheit) indicated for the depth 11,544', 11,546', and 11,550' hard surfaces with the larger sparry calcite crystals providing good differentially etched surfaces[3]. Acid etching analyses also indicated for the depths 11,560' and 11,595' the carbonate dissolved away and left a significant amount of acid insoluble fines on the etched surface. Acid etching and acid reaction coefficient analysis[3] indicated additionally that the rocks should yield a rugose and highly conductive fracture after treatment with crosslinked acid (Figure 2). Additionally, the rock will require large amounts of fracture area and should respond well to crosslinked acid treatments. Acid fracturing with crosslinked acid was selected because of the retarded reaction rate, leak-off control, longer fracture lengths[6], and the removal of acid insoluble fines.

Case Histories

Strawn Formation, Hunt-Baggett West Field, Crockett County, Texas. The case histories of the wells detailed below in the Strawn formation in Crockett County, Texas listed as "Case 1, Offset" through "Case 6, Offset" are wells which were not treated using crosslinked hydrochloric acid utilizing the new emulsion polymer. The actual treatment volumes are detailed for each well. The case histories of those wells listed as "Case 7", "Case 8", and "Case 9" are those that were treated with crosslinked hydrochloric acid utilizing the new emulsion polymer. Each case describes the general treatment, and treatment volume. All the wells considered in this paper were active producers at the time of the writing of this paper.

The daily production reported has been calculated on the 90 day actual production totals. The 30 day and 90 day production data is actual production from the first day production data was available to the time frame indicated.

Case 1, Offset[7]. The well was vertically drilled in 1980, completed to 9,420', and later plugged back to 9,255'. The net pay (perforated interval) is 8,822' to 9,113'. The well was treated in 1980 with 7,500 gallons of linear hydrochloric acid.

The average production rate was 182.7 thousand cubic feet (mcf) per day and the average accumulative production was 4,957 mcf per 30 days and 16,447 mcf per 90 days.

Case 2, Offset[7]. The well was drilled 15 miles Southeast of Ozona, Texas and completed vertically to 9,315'in 1984. The well was stimulated with 7,500 gallons of linear hydrochloric acid.

The average production rate was 858.8 mcf per day and the average accumulative production was 6,227 mcf per 30 days and 77,295 mcf per 90 days.

Case 3, Offset[7]. The well located 11 miles Southeast of Ozona, Texas was completed in 1981 to a vertical depth of 9,190'. The well was subsequently plugged back to 9,145'. The net pay (perforated interval) is 8,882' to 9,138'. The well was treated with 1,000 gallons of linear hydrochloric acid in 1981.

The average production rate was 25.4 mcf per day and the average accumulative production was 537 mcf per 30 days and

2,287 mcf per 90 days.

Case 4, Offset[7]. The well, 12 miles Southeast of Ozona, Texas, was drilled in 1980, completed to a depth of 9,400' feet (vertical) and plugged back to 9,068'. The net pay (perforated interval) is 8,891' to 8,976'. The treatment consisted of 7,500 gallon of linear hydrochloric acid in 1980.

The average production rate was 411.2 mcf per day and the average accumulative production was 11,160 mcf per 30 days and 37,012 mcf per 90 days

Case 5, Offset[7]. The well location is 15 miles Southeast of Ozona, Texas. The well was vertically completed in 1980 to a depth of 9,440', which was plugged back to 9,342'. The net pay (perforated interval) is 8871' to 9,232'. The well was treated with 7,500 gallons of hydrochloric acid.

The average production rate was 60.9 mcf per day and the average accumulative production was 1,654 mcf per 30 days and 5,484 mcf per 90 days.

Case 6, Offset[7]. The well located 15 miles Southeast of Ozona, Texas was completed in 1980 to a vertical depth of 9,044' and plugged back to 8,975'. The net pay (perforated interval) is 8,852' to 8,925'. . The well was treated with 7,500 gallons of hydrochloric acid.

The average production rate was 297.7 mcf per day and the average accumulative production was 9,047 mcf per 30 days and 26,790 mcf per 90 days.

Case 7[8]. The well was completed in 1998 to 9,320'. The net pay (perforated interval) was 8,902' to 8,972'. The well was treated with 7,980 gallons of linear gelled water pad and 19,400 gallons crosslinked hydrochloric acid pumped in alternating stages.

The average production rate was 419.3 mcf per day and the average accumulative production was 13,984 mcf per 30 days and 37,739 mcf per 90 days.

Case 8[8]. The well was completed in 1995 and plugged back to 9,274'. The net pay (perforated interval) is 8,932' to 9,031'. The well was treated in 1998 with 31,500 gallons of linear gelled water pad and 21,000 gallons crosslinked hydrochloric acid pumped in alternating stages.

The average production rate was 368.2 mcf per day and the average accumulative production was 13,243 mcf per 30 days and 33,140 mcf per 90 days.

Case 9[8]. The well was completed in 1998 to 9,287'. The net pay (perforated interval) is 8,959' to 9,030'. The well was treated with 32,000 gallons of linear gelled water pad and 21,000 gallons crosslinked hydrochloric acid pumped in alternating stages.

The average production rate was 551.2 mcf per day and the average accumulative production was 21,344 mcf per 30 days and 49,608 mcf per 90 days.

Average Production of Offset Wells, Case 1 through Case 6. The average production rate of the six offset wells 306.1 mcf per day and the average accumulative production was 5,597.0 mcf per 30 days and 27,552.5 mcf per 90 days (Table 1).

Average Production of Case 7, Case 8, and Case 9 Treated with the Crosslinked Hydrochloric Acid Utilizing the New Emulsion Polymer. The average production rate of the three wells was 446.2 mcf per day and the average accumulative production was 16,190.3 mcf per 30 days and 40,162.3 mcf per 90 days (Table 1).

Discussion of the Strawn Formation, Hunt-Baggett Field, Crockett County, Texas[8]. The average production rate of the wells treated with crosslinked hydrochloric acid utilizing the new emulsion polymer appears to be 45.77% greater in daily production and an accumulative production of 289.27% greater for 30 days and 45.77% greater for 90 days.

A case may be made that the treatment sizes could be the predominate factor affecting production; for example "Case 1, Offset" through "Case 7, Offset" were treated with approximately 7,500 gallons of linear hydrochloric acid while "Case 7" through "Case 9" were treated with approximately 18,000 gallons crosslinked hydrochloric acid. It must be emphasized that the production data is overwhelmingly greater for the three wells treated with the crosslinked acid and the new polymer emulsion. Surprisingly, the production of the three wells treated in 1998 (after the formation was produced 14 to 18 years) significantly exceed those six case wells that were treated in 1980 through 1984 when the reservoir pressure was relatively un-depleted. This in itself implies that the treatment (and volume) was ideally suited to the formation lithology and characteristics. Damage due to drilling, the lack of conductive fractures, restriction in the formation matrix, etc., may have been overcome by the treatment.

Devonian Formation, Magutex Field, Andrews County, Texas; Case 10[9]. The well was completed on September 5, 1998 as a 1,400' open hole lateral completion from 13,294' to 14,985' (measured depth). The total treatment consisted of a clean-out treatment and a primary crosslinked acid treatment pumped in multiple stages. The initial treatment consisted of 20,000 gallons of gelled hydrochloric acid pumped through coil tubing, the "Roto-Jet®" tool, and a down-hole "Liquid/Gas Phase

Separator". The primary treatment consisted of 80,000 gallons linear gel pad, 40,000 gallons gelled hydrochloric acid, and 70,000 gallons of crosslinked hydrochloric acid utilizing the new emulsion polymer chemistry. The staged treatment was performed at 80 barrels per minute (bpm). (Note: The well was not tested prior to the treatment. The well is considered a "wildcat" due the lateral completion. Offset production was not available at the time of the writing of this paper. Post treatment production was interrupted on two occasions for the repair of a submersible pump.)

Average Production[9] of Case 10 Treated with the Crosslinked Hydrochloric Acid Utilizing the New Emulsion Polymer. The average daily production rate after treatment with gelled acid through coil tubing was 139 barrels of oil and 95 mcf gas averaged for the first 24 day period. The average daily production rate following the primary crosslinked acid treatment for the first 11 days was 239 barrels of oil, 150 mcf gas, and 239 barrels of treatment and formation water. (The down hole submersible pump was repaired.) The average daily production rate for an 8 day period after the well was placed back on line was 343 barrels oil, 96 mcf gas, and 94 barrels treatment and formation water. The production for November 30, 1998 was 356 barrels of oil, 257 mcf gas, and 98 barrels of treatment and formation water (Table 1).

Discussion of the Devonian Formation in the Magutex Field, Andrews County. An accurate production history was difficult due to the constant recovery of treatment water and the down-hole problems that temporarily interrupted production. Recovery of the treatment continues with the production increasing as the treatment fluid is recovered. This is evident if the initial daily production rate (239 barrels oil, 150 mcf gas, and 239 barrels of water) is compared with the final day the production rate was viewed (356 barrels of oil, 257 mcf, and 98 barrels of water).

Devonian Formation, Pegasus Devonian Field, Midland County, Texas; Case 11[10]. The well was perforated from the true vertical depths (TVD) of 11,642' through 11,745' with corresponding measured depths of 13,442' through 15,737'. The lateral was 4,000' in length. The average estimated bottom hole temperature was 200 degrees Fahrenheit. The zone was treated August 8, 1998 with 40,000 gallons crosslinked pad, 80,000 gallons hydrochloric acid, 42,000 gallons crosslinked acid with the new emulsion polymer, and 7,000 gallons gelled acid with the new emulsion polymer pumped in stages

The average daily production rate was 1.78 million cubic feet (mmcf) gas and 22.6 barrels of condensate (based on the 90 day actual totals). The average accumulative production was 56 mmcf gas and 541 barrels of condensate per 30 days and 160 mmcf and 2,035 barrels of condensate per 90 days (Table 1). Offset production was unavailable at the time of the writing of this paper.

Discussion of the Devonian Formation, Pegasus Devonian Field, Midland County, Texas. Although no offset data was available, the production of the well after the treatment with crosslinked acid utilizing the new emulsion polymer warrants further investigation into the completion method and the treatment that yielded such substantial production.

New Polymer Chemistry

Emulsion polymers have been used in the industry for a variety of applications. These include use in drilling muds, as friction reducers and gelling agents for aqueous fluids and hydrochloric acid, and as the base polymers for crosslinked acids. The polymers have inherently suffered from a variety of chemical, operational, and application problems. These problems have limited the success of the treatment fluids in which they have been applied. These problems include high innate viscosity, fast or short hydration times in acids, unpredictable performance in fresh waters and light brines, inability to be continuously mixed (gelled on the fly), and large discrete polymer sizes.

Conventional Emulsion Polymers for Crosslinked Hydrochloric Acid. Conventional emulsion polymers generally appear to be white viscous liquids composed of an organic solvent, water, surfactants, and a polymer emulsified in an oil external emulsion. Oil external emulsions, although dependent on the ratios of organic solvent to water, are inherently high in viscosity. Several emulsion polymer solutions tested were in excess of 300 centipoise[11] as measured on Fann VG Meter (R1/B1 rotor bob configuration) at 511/sec at 72 degrees Fahrenheit. These high viscosities are necessary to develop a stable system that will not degrade over time (shelf life) and allow the polymer solution to settle. Further, the conventional emulsion polymer contains a surfactant(s) or de-emulsifier(s) which when mixed in an aqueous fluid such as acid and water, will invert the emulsion polymer releasing the polymer for hydration. This occurrence is normally very rapid. Subsequently, during gelling, a high shear rate (ie. at the blender with a low polymer additive rate) is necessary to prevent the formation of un-hydrated masses (fisheyes) on the micro to macro level.

The New Emulsion Polymer for Crosslinked Hydrochloric Acid[11]. The new emulsion polymer was formulated to encompass tight, low permeability acid soluble formations and for operational ease and versatility. The polymer is composed of a highly specialized organic solvent, a highly specific micro-sized polymer, specialized surfactants, and water emulsified in a relatively low viscosity (less than 40 centipoise @ 511/sec @ 80F) oil external emulsion. The polymer emulsion was formulated with an unconventional new gelling process that promotes a highly efficient hydration process with an extremely low potential to form "fisheyes".

New Emulsion Polymer Gelling Process[11]. The gelling process is dissimilar to conventional emulsion polymers in that the polymer is first dispersed into the acid followed by a highly specific gelling "activator" that initiates and propagates hydration. This two fold process allows for the complete dispersion of the polymer prior to hydration. The potential for the formation of un-hydrated masses or "fisheyes" on even the micro level is significantly depressed. The fluid also achieves a more complete hydration yielding consistent optimum base gel viscosities. The gelling efficiency is such that acids, fresh waters, and light brines are gelled with equal efficiency. Further, acids which have been pre-gelled can be gelled to a higher viscosity without the high potential of the formation of "fisheyes" normally associated with increasing the viscosity of a pre-gelled acids.

Laboratory tests have indicated that acids, waters, and light brines can be gelled (hydrated) with the slightest of agitation (such as a light swirling action with a stir rod).

Crosslinked 28% Hydrochloric Acid[11]. The crosslinking of 28% hydrochloric acid with conventional emulsion polymers has been troublesome and unpredictable due to the low development of base gel viscosities and the bulk formation of "fisheyes". This is primarily due to the acute activity of the polymer in 28% hydrochloric acids. The polymer hydrates rapidly with a higher potential (than lower strength acids) to form "fisheyes" with a corresponding resultant viscosity less than optimum. The addition of polymer to a pre-gelled 28% hydrochloric acid solution results in an even more elevated potential to form "fisheyes".

The new emulsion polymer gelling process is applicable to the gelling of 7.5% to 28% hydrochloric acid with equal efficiency. The addition of polymer to a pre-gelled 28% hydrochloric acid yields an increased viscosity without the formation of "fisheyes." Crosslinking is achieved conventionally once the optimum base gel viscosity is attained.

Continuous Mixing Capability[11]. The continuous mixing of conventional emulsion polymers has been difficult, at best, due to the high viscosity of the emulsion polymers, the need to dilute the polymer for metering, the instability of the resulting solution, and the subsequent difficulty in accurate metering. In addition, rapid polymer hydration rates that promote the formation of "fisheyes" and the lack of equipment dedicated to the mixing and blending of hydrochloric acids has also made continuous mixing difficult.

The new emulsion polymer's gelling process coupled with the low viscosity of the liquid polymer, ease and accuracy of metering, and dedicated equipment to the blending and gelling of hydrochloric acids has allowed the industry to consider the first emulsion polymer capable of being continuously mixed. Crosslinkers, surfactants, de-emulsifiers, breakers, anti-sludge iron control additives, etc. are run as the fluid is passed through the blender.

Advantages of the continuous mix process include the ability to gel only the volume of fluid needed for the treatment, treatment volumes that can be adjusted during the actual treatment without prior preparation, and less volumes for disposal after the treatment (no residual chemicals in tanks). Economic and environmental advantages and treatment versatility are realized by the continuous mixing of fluids.

Micro-Sized Polymer Increases the Flow Back Potential[8]. The new emulsion polymer is composed of a highly specific emulsion polymer that has been reduced in size by a factor of 15 as compared to conventional emulsion polymers[12]. The polymer size is so minute that the solution appears to be a transparent amber color rather than a turbid mixture. The micro-size and gelling efficiency of the emulsion polymer promotes a more consistent and optimum base gel viscosity. Subsequently, optimum crosslinked acid viscosities are consistently achieved, as are optimum reaction rates at bottom hole temperatures.

Due to the micro-size of the polymer and its highly consistent dispersion, the recovery of the fluid ("flow back") is significantly enhanced. It is theorized that the polymer is able to migrate throughout the formation matrix more efficiently during the recovery process. Importantly, the gelled base fluid is free of "macro" and "micro" "fisheyes" and viscosity oscillation which may impede production or damage the formation matrix. (The terms "macro" and "micro" sized "fisheyes" alludes to those visible to the eye to those below the visible threshold but that detract from the optimum viscosity of the base gel).

In low permeability formations such as the Strawn Limestone in Crockett County and the Devonian Limestone in Andrews and Midland Counties it is thought that even a relatively small number of "fisheyes" (micro to macro level) will detrimentally affect production. This has been evidenced by the post treatment fluid recovery with the new emulsion polymer. On the average, longer sustained flow back periods (prior to the well ceasing to flow) were noted[8] as compared to previous similar treatments without the use of the micro-sized polymer. The fluid is considered less damaging and it is theorized that lower pressures may be required to recover the fluids.

Operational Considerations[11]. The operational considerations refers to the industry accepted process by which "batch mixing" is accomplished by circulating the fluid with a mixing unit (blender), adding polymer, and circulating until an optimum viscosity is attained. The fluid is then delivered to the blender for down hole injection. The "continuous mix" process is whereby during the treatment, a mixing unit (hydration unit) draws clean (un-gelled) fluid from the storage tanks and continuously adds the polymer, surfactants, and other required gelling agents. The unit then delivers the hydrated fluid to the down-hole unit (blender) where it is transferred to the high pressure pumps for injection into the well bore. In the "continuous mix" process the tanks are not exposed to the treatment fluid chemicals and polymers.

Conventional "Batch Mix" Operation for Tank Volumes[11]. The batch mix process involves the transportation of the acid to a suitable storage tank. A mixing unit is then tied to the storage tank with an appropriate number of hoses and circulated at a nominal rate. The new emulsion polymer is metered into the fluid and dispersed. The proper concentration of emulsion polymer activator is then added to the mixture followed by the inhibitors, anti-sludge iron control additives, surfactants, etc. and circulated until an optimum viscosity is attained. The optimum concentration of crosslinker and breakers are added while the treatment is being performed. All appropriate quality control measures should be taken to ensure optimum fluid performance.

It is not necessary to dilute the emulsion polymer prior to metering. The viscosity of the polymer is such that it can be transferred directly from a drum or tote to the mixing unit.

Conventional "Batch Mix" Operation for a Transport Volumes[11]. The centrifugal pump of the transport or a separate mixing unit may be used to circulate the acid volume in the transport. The proper concentration of emulsion polymer is then added and dispersed. The proper concentration of emulsion polymer activator is then added with the other required additives, ie. inhibitors, anti-sludge iron control additives, surfactants, etc. and circulated until an optimum viscosity is attained. The crosslinker and breakers are added while the treatment is being performed. All appropriate quality control measures should be taken to ensure optimum fluid performance.

"Continuous Mix" Operation[11]. The enhanced gelling capabilities of the new emulsion polymer are such that it may be continuously mixed. Normal continuous mix volumes are approximately 15,000 gallons (total of gelled and crosslinked acid) or greater. (Some environmental concerns may mandate the continuous mixing of the hydrochloric acid and gel so that no residual acids or chemicals remain in the storage tanks).

The acid volume contained in the tank(s) should be analyzed for iron concentration, acid strength, and other applicable quality control tests performed (breaker tests etc.) prior to performing the treatment. Further, if the acid is to be blended from fresh water and concentrated acid (continuous mix of the hydrochloric acid) the mixed acid should be periodically analyzed to ensure proper concentration (percent).

A mixing unit is "hooked up" to the acid storage tank(s) with an appropriate number of hoses corresponding to the total down-hole fluid rate. The unit meters the proper concentration of all required gelling additives, hydrates the acid to optimum viscosity (3 minutes at 80 degrees Fahrenheit), and then delivers the gel to the down hole unit (blender). Specifically, the emulsion polymer, emulsion polymer activator, anti-sludge iron control additives, inhibitors, surfactants etc., are added continuously to the mixed acid at the mixing unit, hydrated and delivered to the down-hole unit.

The hydration unit maintains and delivers an adequate volume of gel at optimum viscosity to the down hole unit throughout the treatment. The crosslinker and breaker are added by the down-hole unit and pumped to the high pressure pumps for injection into the well bore.

Summary

It has become evident that for tight, naturally fractured, low permeability, and high solubility formations with limited porosity such as the Strawn Limestone in Crockett County, Texas and the Devonian formation in Andrews and Midland Counties, Texas crosslinked acid performs efficiently in the formation of highly conductive fractures. The production data assimilated in this paper strongly suggests that the preferred fracturing system is crosslinked hydrochloric acid utilizing the new emulsion polymer and the associated technology to maximize production, economize treatments, and increase operational versatility.

What has not been specifically discussed in this paper is the economic advantage in acid fracturing as compared to proppant fracturing at the pressures that would be encountered at the depths depicted in the various case histories and the associated cost of such treatments. This consideration alone would warrant a substantial investigation in the merits of acid fracturing in these naturally fractured, low permeability, high solubility, limestone and dolomite formations.

Other considerations, which were not expressly discussed, were pre-job acid pickling for the removal of soluble iron, the effective application of anti-sludge iron control agents and surfactants. Each should be considered an integral part of the acid treatment.

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SI Metric Conversion Factors

bbl x 1.589877	E-01=m^3
°F x (°F-32)/1.8	E+00=°C
ft x 3.048	E-01=m
gal x 42	E+00=bbl
gal x 3.785412	E–03= m^3
lb x 4.535924	E-01=kg
psi X 6.894757	E+00=kPa

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Table 1 - Production Results

A. Strawn Formation, Hunt-Baggett West Field, Crockett County, Texas.
Wells Treated with linear hydrochloric acid.

Case Well	*Average Daily Production Rate	30 Day Accumulative Production (Actual)	90 Day Accumulative Production (Actual)
Case 1, Offset	182.7 mcf	4,957 mcf	16,447 mcf
Case 2, Offset	858.8 mcf	6,227 mcf	77,295 mcf
Case 3, Offset	25.4 mcf	537 mcf	2,287 mcf
Case 4, Offset	411.2 mcf	11,160 mcf	37,012 mcf
Case 5, Offset	60.9 mcf	1,654 mcf	5,484 mcf
Case 6, Offset	297.7 mcf	9,047 mcf	26,790 mcf
AVERAGE	*306.1 mcf*	*5,597.0 mcf*	*27,552.5 mcf*

***Daily average calculated on the 90 day actual production.**

B. Strawn Formation, Hunt-Baggett West Field, Crockett County, Texas.
Wells treated with linear pads and crosslinked hydrochloric acid utilizing the new emulsion polymer.

Case Well	*Average Daily Production Rate	30 Day Accumulative Production (Actual)	90 Day Accumulative Production (Actual)
Case 7	419.3 mcf	13,984 mcf	37,739 mcf
Case 8	368.2 mcf	13,243 mcf	33,140 mcf
Case 9	551.2 mcf	21,344 mcf	49,608 mcf
AVERAGE	*446.2 mcf*	*16,190.3 mcf*	*40,162.3 mcf*

***Daily average was calculated on the 90 day actual production.**

C. Devonian Formation, Magutex Field, Andrews County, Texas.
Wells treated with linear pads and crosslinked hydrochloric acid utilizing the new emulsion polymer.

Case Well	Average Daily Production Rate	Average Daily Production Rate	Average Daily Production Rate
Case 10, First 11 Days	239 bbl Oil	150 mcf Gas	239 bbl Water
Case 10, Next 8 Days	343 bbl Oil	96 mcf Gas	94 bbl Water
Case 10, Final Day	*356 bbl Oil*	*257 mcf Gas*	*98 bbl Water*

D. Devonian, Formation, Pegasus Devonian Field, Midland County, Texas.
Wells treated with linear pads and crosslinked hydrochloric acid utilizing the new emulsion polymer.

Case Well	*Average Daily Production Rate	30 Day Accumulative Production (Actual)	90 Day Accumulative Production (Actual)
Case 11	*1.78 mmcf & 22.6 bbl condensate*	*56 mmcf & 541 bbl condensate*	*160 mmcf & 2,035 bbl condensate*

***Daily average was calculated on the 90 day actual production.**

Figure 1[3] - Natural Fractures; Devonian Formation; Pegasus Devonian Field, Midland County, Texas

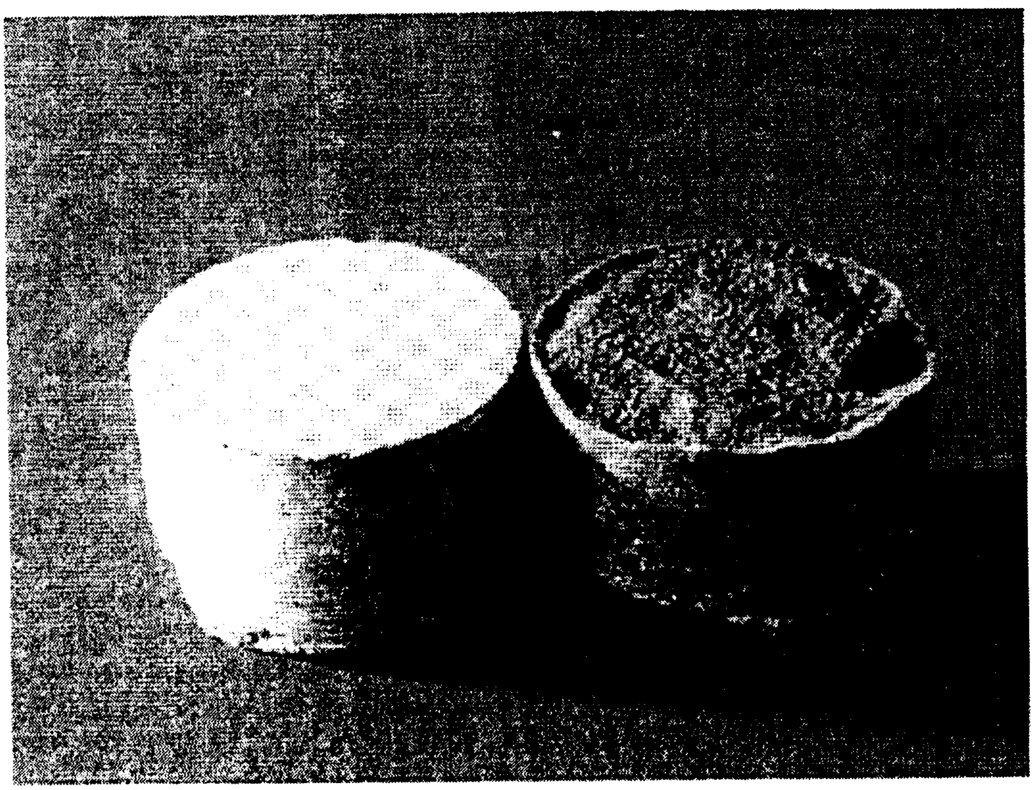

Figure 2[3] - Crosslinked Acid Surface Effects; Devonian Formation; Pegasus Devonian Field, Midland County, Texas