CARBONATE OH ACIDIZING – TECHNIQUES THAT HAVE WORKED UTILIZING COILED TUBING

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ABSTRACT
This paper will address how coiled tubing, combined with advanced acidizing technologies, can improve the ability to optimize treatment coverage in open hole (OH) completions. Two methods that have been very successful in the Permian and Anadarko Basins are foam and self-diverting acid systems.

When acid is pumped into an OH completion, it is difficult to determine precisely where the acid is going. It is vitally important to ensure that the entire interval is being treated adequately to optimize production. Coiled tubing and advanced acidizing technologies have shown tremendous promise with these stimulation techniques. This paper will also discuss the many techniques that have been attempted throughout the years with mixed results.

INTRODUCTION
A horizontal well may be drilled into a gas or oil bearing strata, as well as being used for water, steam or miscible flood injection. Horizontal wells are expensive to drill and stimulate, so why drill horizontally? The decision to drill a well horizontally may depend upon many factors and can include; the necessity for greater exposure of narrow target zones to the well bore; a reduction of solids migration to the wellbore due to reduced drawdown and the intersection of naturally occurring vertical fractures.

THE FORMATION
Simply put, the extremes of the types of rock we drill into for oil and gas are; a tight, low perm carbonate; a fractured carbonate with good porosity and permeability and a sandstone. Consider a very tight, low perm, low porosity reservoir with no upward folding to cause stress fractures. When there are no fractures and low permeability, matrix acidizing has only very limited effectiveness if any. However, a fractured carbonate reservoir with good porosity and permeability, one formed by an upward folding, are especially suited to squeezed matrix acid stimulation techniques. This type of open hole carbonate reservoir is the focus of this paper.

It is a fact that all horizontal wells are very susceptible to a variety of formation damaging mechanisms during the drilling process. The induced damage includes compressed filter cake, considered to be 2 to 5 mm thick. Pore and fracture plugging and wellbore crushing. Other possible damage may include rock polishing, aqueous phase trapping and poor fluid choices. Formation damage that one finds restricting flow in vertical wells may also occur in horizontal wells. For example, fluid incompatibilities, oil wetting the formation, anhydrite or soft rock smearing and sulphur deposition in high H2S wells. It is well known that the heaviest damage to a horizontal well is to be expected at the heel.

HORIZONTAL WELL ACID STIMULATION PROGRAMS
A successful horizontal well stimulation program design requires intercompany teamwork. Geologists, reservoir engineers, mud engineers, technologists, laboratory and specialized service company staff all have a role in designing the best stimulation program possible. Horizontal well stimulation program possibilities are fracturing with oil or water based fluids, polymer specific enzyme treatments, acidizing and other specialized treatments.

Assuming the drilling fluids have been designed to be acid compatible, then acid is the best stimulation media for removing drill fines, drill cuttings, filter cake, crushed and polished rock, and acid soluble lost circulation materials both around the near wellbore and into any extending fractures. How do we convey the acid to the damaged areas of the wellbore and formation, as well as squeezing acid into the fractures?

Over the years there have been several techniques attempted and most with the same result. A few of the techniques include, bull heading at high pump rates, using diverting agents such as wax beads, benzoic acid flakes and salt. Pumping down tubing placed at various depths along the lateral. Pumping down a work string that has been run in the hole to the toe with holes along the length of the lateral and hoping to obtain limited entry.

Pumping down a work string run in hole to the toe while pumping acid down the backside of the work string hoping to place acid all along the open hole lateral. Large volumes of acid were utilized with these methods, anywhere from 70 to 100 plus gallons per foot. The main problem with these methods is a simple well know fact, acid will go where it wants to go, not where you want it to go.

METHOD NO. 1

In 1998, an operator initiated a well deepening program to increase productivity in a deep, low pressure gas reservoir in the Delaware Basin. The Ellenburger is ± 1,600 ft thick in the Puckett field at a depth of 12,000 to 15,000 ft with an average porosity of 3.5%. Connate water saturation averages 35%. The reservoir temperature is ± 240° F and the Bottom Hole Pressure (BHP) 550 psia. The production rate is controlled by the presence of karsting and extensive fracturing. The reservoir dive is characterized by gas expansion and is well connected. There had been uniform field pressure depletion over a 47 year production history.

The field was discovered in 1952 and was fully developed in the late 1950's and early 1960's. A typical completion consisted of drilling to the top of the formation, setting 7-inch casing, and then drilling about 600 feet into the target formation. All wells were completed as open hole completions.

PROBLEM IDENTIFICATION

The first well, Gas Well No. 1, had an original completion that penetrated the top 460 feet of the reservoir. Prior to the deepening, the well was flowing 2.8 MMCFPD at 85 psig wellhead pressure. The deepening program utilized an air-mist system to minimize formation damage. A high angle borehole of approximately 65 degrees was achieved to expose approximately 3,000 feet of gross pay interval. Production following deepening was 3.5 MMCFPD at 250 psig wellhead pressure. Post-deepening well productivity was substantially less than desired and formation damage was suspected. Analyses conducted were stereomicroscopy, acid solubility, soluble iron content, X-ray fluorescence spectrometry (XRF), and X-ray diffraction (XRD).

TREATMENT PROCEDURE

Based on the sample analysis the following treatment was recommended for the removal of the near-wellbore damage in these wells. A two-phase flow, circulating model was utilized to determine the fluid and nitrogen rates needed to ensure that the treatment was performed in an underbalanced condition. Step 1 was to try to remove as much of the iron rich minerals from the wellbore as possible before performing the acid treatment. This was achieved by using a 2% KCl water solution containing a silt suspension agent and a bacteria control product. The solution was pumped in an underbalanced condition through 1.5 inch coiled tubing utilizing a phase separator and a 1.75 inch speed controlled rotating jetting tool. The 2% KCl wash started at the top of the open hole section and was evenly washed to the end of the open hole section. Once the rotating jetting tool reached the end of the open hole section, the wash solution was pumped for an additional two-wellbore volume. The next step was to acidize the open hole section. A 15% HCl acid solution containing an enhanced iron control package and silt suspension agent was pumped in an underbalanced condition through the coiled tubing, phase separator and rotating jetting tool. The treatment started at the end of the open hole section and 15 gallons per foot of the acid solution was applied evenly from the end to the top of the open hole section. The phase separator and rotating jetting tool were selected for this treatment to achieve maximum mechanical and chemical removal of the damage and to obtain 360° acid coverage. The three well project post treatment results indicated that a 7.9 fold increase in reservoir deliverability was obtained from the cleanout and stimulation treatment. See Table 1 for these results.

METHOD NO. 2

The same operator wanted to try this procedure in a San Andres horizontal open hole program in the McElroy field in Crane County, Texas. This time the acid stages were to be squeezed into the formation after the underbalanced wash. Diversion was desired along the open hole lateral.
To insure that the acid was truly being diverted, radioactive isotope tracers were added to the acid stages. Foamed 2% KCL water was recommended for diversion and the acid was pumped in four equal length stages

along the lateral utilizing 1.75 inch coiled tubing and the 1.75 inch rotating jetting tool. The acid was pumped at 1.3 bpm. The 0.70 Quality foamed diversion stages were pumped at the same combined total rate.

The well was closed in and the acid containing the first isotope tracer was pumped to the bottom hole assembly (BHA). The coil was then pulled up hole (PUH) to the top of the first stage and then run in hole (RIH) to the bottom of the first stage, still pumping the acid. The first foamed diversion stage was then pumped while PUH to the top of the first stage. The process was repeated for each of the next three stages. There were three different isotopes used and the first stage isotope was repeated in the fourth stage. The coiled tubing and OH was flushed with 0.70 Quality foamed 2% KCL water.

The coiled tubing was pulled out of the hole and rigged down overnight. The following day, a memory logging tool was RIH with the 1.75 inch coiled tubing and it was confirmed that the acid was equally squeezed into four different zones along the OH lateral.

PROCESS HISTORY

The procedure described above (Method No. 2) has been modified over the years to be applicable with varied wellbore conditions such as BHP, length of lateral, ID and the true vertical depth of the lateral.

One change was loading the hole with foam prior to starting acid. After the wellbore is filled with foam, the well is then closed in. This method assists in confining the acid in the section being acidized by having viscous fluids in front of and behind the acid being while squeezed into the formation.

Another modification to the procedure was utilizing larger coiled tubing and a larger rotating jetting tool. This resulted from laterals exceeding 5000 feet in length and job times exceeding 30 hours. With the 1.75 inch coiled tubing, friction lock would occur. The 1.75 inch jetting tool is limited to less than 1.5 bpm. The coiled tubing size was changed to 2 inch and the rotating jetting tool to 2.875 inch. The pump rates increased to 3.5 bpm, cutting the job time in half and the cost of the procedure.

Not every job has had the results described in the first procedure (Method No. 1). There is an additional benefit to the procedure, less acid per foot of OH. The results are comparable if not better than the conventional methods described using jointed work strings that required much more acid per foot.

METHOD NO. 3

A self-diverting acid system was tried in 2005. The system utilizes a single amphoteric, worm-like micelle surfactant. Since the system stimulates and diverts in a single stage, the design and operation are less complicated. The break mechanisms are hydrocarbons, water, an internal breaker and the system breaks upon the spending of the acid. Figure 1 shows that as the acid spends the system viscosity increases. It reaches maximum viscosity when the acid spends to approximately 10% and then falls off sharply to the base line viscosity. Since the viscosity begins to increase at about 19%, the HCL concentration range is 20 to 28%.

The first well was a San Andres well in Terry County, Texas, a producer drilled to a measured depth (MD) of 8088 feet. The 4.75 inch OH lateral was 1,688 feet long. The 2.875 inch rotating jetting tool was RIH while circulating at a designed speed and rate to remove the induced drilling damage. After reaching the end of the lateral, the well was circulated clean. The next step in the process was to load the coiled tubing with the self diverting acid. When the acid was at the BHA, the well was closed in and the BHA was PUH while acidizing the OH lateral to the heel. There was a 200 foot section of the lateral that did not appear to be good rock and acid was not pumped over that section. The time to complete the procedure was 6.7 hours. Figure 2 shows the actual rate and pressure plot from the job. The chart shows an increase in pressure from the beginning of the acid stage to the end of the flush.

The results of the self-diverting acid system are impressive. The field is 30 years old and the average oil production is 10 to 12 BOPD. After the well was put on production, oil production was 40 BOPD. At the end of one month it was 45 BOPD. After more than 2 years, production is still 45 BOPD.

The self-diverting acid system was used on two more horizontal OH producers in the same area with similar results. The system was also pumped on two water injection multi-lateral wells, but quantifying the results is not possible because the lateral was added to existing multi-lateral wells. Post job injection rates were the same as pre-job rates but the injection pressures were 25% to 30% lower.

CONCLUSIONS

1. Coiled Tubing is an effective tool for acid placement in carbonate horizontal wellbores.
2. Understanding the damage induced while drilling will improve the success of stimulation design and procedures in OH completions.
3. Foam is an effective diversion method when acidizing OH laterals.
4. Self-diverting acid is a very effective system for acidizing carbonate horizontal wellbores.

ACKNOWLEDGEMENTS

The author would like to thank BJ Services for permission to present and publish this paper. The author would also like to thank A.S. Metcalf and K. Cawiezel for many useful discussions.

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Table 1

Pre-deepening data

	Gas Rate (MMCFPD)	Wellhead Flowing Pressure (PSIG)	Wellhead Shut-in Pressure (PSIG)	Completion Gross Pay Height (Feet)	Deliverability Coefficient (Ca) (Mscf/D/psi2)
Gas Well No. 1	2.8	85	385	460	0.0225
Gas Well No. 2	2.6	80	361	406	0.0265
Gas Well No. 3	1.8	155	338	583	0.0130

Post-deepening data

	Gas Rate (MMCFPD)	Wellhead Flowing Pressure (PSIG)	Wellhead Shut-in Pressure (PSIG)	Completion Gross Pay Height (Feet)	Deliverability Coefficient (Ca) (Mscf/D/psi2)
Gas Well No. 1	3.5	250	368	1,660	0.0240
Gas Well No. 2	2.0	250	342	917	0.0180
Gas Well No. 3	2.9	180	350	1,407	0.0155

Post-deepening and stimulation data

	Gas Rate (MMCFPD)	Wellhead Flowing Pressure (PSIG)	Wellhead Shut-in Pressure (PSIG)	Completion Gross Pay Height (Feet)	Deliverability Coefficient (Ca) (Mscf/D/psi2)
Gas Well No. 1	12.4	215	318	1,660	0.1900
Gas Well No. 2	10.4	150	304	917	0.0950
Gas Well No. 3	8.4	245	324	1,407	0.1200

Summary

	k-postdeepening / k-predeepening	k-poststimulation / k-predeepening	Stimulation Folds Increase
Gas Well No. 1	0.296	2.340	7.92
Gas Well No. 2	0.301	1.587	5.28
Gas Well No. 3	0.494	3.825	7.74

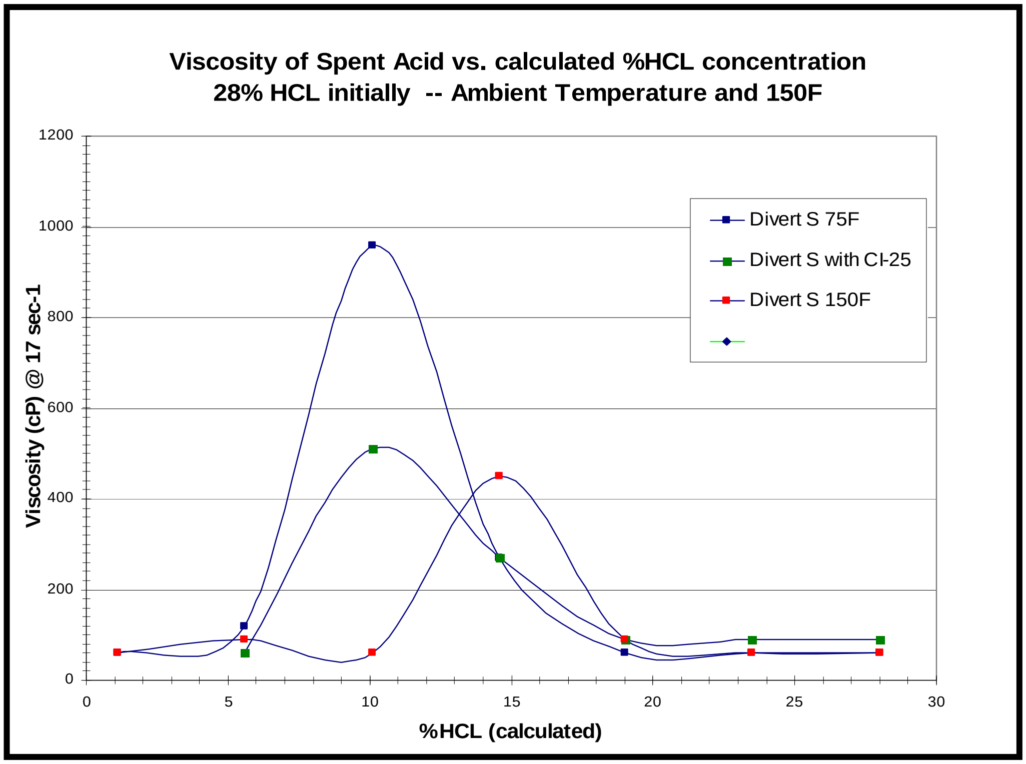

Figure 1

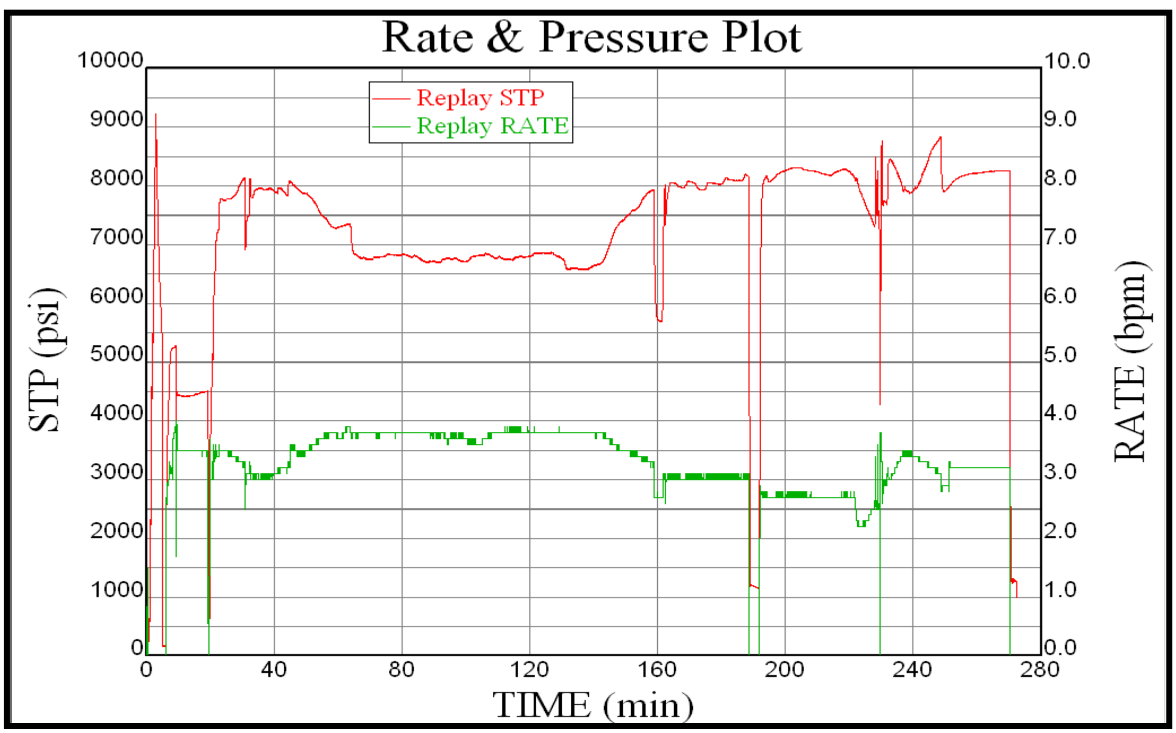

Figure 2