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Improving Sandstone Matrix Acidizing for Oil Wells by Gas Preconditioning

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Abstract

Experience has shown that for sandstone formations, oil wells respond to matrix acidizing in a different manner as compared to gas wells. For oil wells, the improvement in permeability resulting from the stimulation treatment peaks at a certain acid volume and then drops as the volume of acid injected increases. For gas wells, however, the resulting improvement in permeability is roughly proportional to the volume of acid injected, and is normally better than that obtained with oil wells. It is, therefore, expected that stimulation of oil wells in sandstone formations could be improved by displacing the oil in the zone to be acidized with gas. Gas injection prior to acidizing is sought to minimize the formation of emulsions or sludges between the spent acid products and the oil that otherwise would be contacted.

This paper presents the results of an experimental investigation on the effect of gas pre-conditioning of the damaged sand on permeability improvement by matrix acidizing. Experiments were conducted on Berea sandstone cores saturated with 29.2 ^{o}API crude oil at selected reservoir conditions of 180 ^{o}F and 3000 psi pore pressure. Carbon dioxide and nitrogen were separately used for pre-conditioning prior to stimulation and the results were compared against stimulation without gas pre-conditioning.

It was found that with regular stimulation, improvement in permeability peaked at a certain acid volume. With gas (CO_2 or N_2) pre-conditioning, however, continuous improvement in permeability was obtained with increasing the volume of acid injection. Further, using gas pre-conditioning with a small volume of acid (that would otherwise not be sufficient to even recover the original permeability with regular acidizing) resulted in permeability improvements of up to 200% of the original pre-damage permeability. At an acid volume that would just restore the original permeability with regular stimulation, gas pre-conditioning resulted in permeability improvement close to 300% of the original permeability. Pre-conditioning with either CO_2 or N_2 provided superior results compared to regular stimulation. However, CO_2 was found to be more effective than N_2. This is attributed to the fact that CO_2 has better miscibility than N_2 and would, therefore, provide more efficient displacement of the oil out of the zone to be stimulated.

Introduction

Sandstone matrix acidizing, employing mud acid systems, is a commom operation in oil and gas fields. The main objective of this stimulation operation is to remove near wellbor damage, caused by drilling and/or workover operations, in order to restore or, perhaps improve the permeability of near-wellbor formation. Typically, sanstone matrix stimulation involves three stages: (1) a preflush stage where an aqueous solution of HCl is injected to displace formation brine and dissolve any carbonates that may be present, (2) a mud acid treatment to dissolve silicious and damaging material, and (3) an afterflush where a solution of HCl is injected to displace the reaction products. Mutual solvents have been also used in the latter stage to restore wettability.

Sandstone matrix stimulation has been the subject of extensive investigations for over 40 years. Extensive experimental work has been conducted to investigate the reactions of various mud acid systems with damaging and formation materials[1-6]. Theoretical analysis and modeling of the stimulation process have also been studied by some investigators[6-8]. Others presented procedures and design criteria for effective stimulation operations[9-11]. The problem of sludge formation and its effect on stimulation efficiency has been studied experimentally by Suzuki[12]. Malekzada et al.[13] investigated acid stimulation treatments of horizontal wells and studied the combined effect of formation damage and presence of impermeable barriers on well productivity. They also presented new equations for evaluating the length of the horizontal well that actually contribute to production.

Gidley[14] studied the response of sandstone formations to the individual components of the acid system employed. He observed that gas wells and oil wells responded differently to the volume of mud acid used in the treatment. For oil wells, the response to the treatment peaked at a certain acid volume (averaging about 75 gallons per foot of formation thickness). However, for gas wells, in the range of acid volumes studied (20 to 200 gal/ft), the stimulation response was roughly proportional to the acid volume used. Based on these observations, it was believed that the response of oil wells to matrix stimulation could be improved if the oil well was conditioned, by gas injection, to simulate a gas well for the stimulation treatment. Accordingly, a laboratory study and some field tests were conducted[15] where CO_2 gas was injected prior to the stimulation treatment. Gas injection displaced the oil from the zone to be treated and, therefore, eliminated the formation of sludges that otherwise would be produced from reactions between the spent acid and oil. This resulted in appreciable improvement in stimulation response.

It is evident, from the published work[12, 14], that the crude oil present in the zone to be acidized causes a problem in stimulating oil wells due to the reactions between the oil and the spent acid products. Such reactions produce precipitates that are capable of plugging the pore spaces and limit fluid conductivity. Gas preconditioning of oil wells has been shown to have a potential for improving oil-well stimulation treatments. However, only the work of Gidley et al.[15] on this subject has been reported. The objectives of the present study were to further study oil-well stimulation improvement by gas preconditioning, and to investigate the possibility of using gases other than CO_2 for preconditioning purpose.

Experimental Setup and Procedure

Experimental Setup. A schematic of the experimental setup used in the present study is shown in **Fig. 1**. A Ruska-type, high-pressure, high-temperature rated core holder was used to hold the 1 in. diameter, 4 in. long Berea sandstone core that was placed inside a rubber sleeve. A hand pump was used to apply a 4,000 psi confining pressure on the core. A Nitrogen cylinder equipped with a pressure multiplier and backpressure regulator was used to maintain the core at an average pore pressure of 3,000 psi. Four transfer cells were manifolded to a high-pressure positive displacement pump, and to the core holder in such a way that the transferred fluid coud be directed to either ends of the core holder. The cells were used to transfer brine, oil, drilling mud, and acid to the core holder. High-pressure Nitrogen and Carbon Dioxide cylinders, equipped with a pressure regulator and a flow meter, were manifolded and used to supply gas to the core holder through a 30 ft. stainless steel coil. The core holder, gas supply coil and transfer cells were placed inside a temperature-controlled high-temperature oven. Produced fluids were collected in a fraction collector.

Berea sandstone cores saturated with crude oil (29.2 ^{o}API, 5.3 cP viscosity at 3,000 psi & 180 ^{o}F) and residual saturation of 2% KCl brine were used in the experiments. The drilling mud, having a density of 60 Pcf, was formulated with Bentonite and fresh water. The mud acid used was an aqueous solution of 12% HCl and 3% HF. Nitrogen and Carbon Dioxide were used separately for gas preconditioning.

Experimental Procedure. Three sets of experiments were conducted. The first set involved regular acid stimulation using different volumes of acid. This was taken as the base case. The second and third sets of experiments involved N_2 and CO_2 preconditioning, respectively, prior to acidizing.

A fresh core sample was first saturated with brine while under vacuum. Next, the core permeability was determined first at room conditions. Then the pressure and temperature were raised to reservoir conditions and the absolute permeability was again determined using brine. Oil flow was then started to displace the brine and bring its saturation to the residual, and the effective oil permeability was determined. Mud circulation was then started to create damage to the core. This was followed by flowing oil through the core and determining the after-damage effective oil permeability. The stimulation process was then implemented using a specific volume of mud acid. Finally, the post stimulation effective oil permeability was determined. The procedure was repeated using different acid volumes to determine the effect of the acid volume used on permeability recovery/improvement.

The same procedure was followed for the second and third sets of experiments, but with the additional step of gas injection (preconditioning) being implemented prior to acidizing.

Results and Discussion

Stimulation without Gas Preconditioning. A total of six regular stimulation (stimulation without gas preconditioning) experiments were conducted using mud acid volumes ranging from 50 to 320 pore volumes. The results are summarized in **Table 1**. **Figure 2** shows the permeability restoration as a percent of the original, pre-damage permeability versus pore volumes of mud acid used. The results showed that using small volumes of acid (form 50 to less than 150 pore volumes) removed some damage, but did not restore the original permeability. A complete restoration (recovery) of permeability was obtained with 150 pore volumes of acid. At higher acid volumes, improvement over the original permeability was obtained reaching a peak of about 144% at 235 pore volumes of acid. The improvement in permeability then dropped with increasing the volume of acid used. This trend was in line with the results of previously published work.

Stimulation with N_2 Preconditioning. Five experiments with N_2 preconditioning were conducted using different acid volumes and different volumes of N_2. The results are summarized in **Table 2** and reproduced in **Fig. 3**.

With 100 pore volumes of acid used, where regular stimulation could restore only 65% of the original permeability, preconditioning the core with 100 pore volumes of N_2 resulted in a post-treatment permeability of 122% of the original permeability. When 150 pore volumes of acid were used, which were just enough to restore the original permeability without preconditioning, N_2 preconditioning resulted in about 143% restoration in permeability. Comparing the results of the two experiments, where 100 and 200 pore volumes of N_2 were respectively used with 150 pore volumes of acid, **Table 2**, showed that increasing the preconditioning gas volume did not have a significant effect on permeability improvement. Therefore, the experiments conducted with larger acid volumes employed even smaller preconditioning gas volumes than previously used. The improvement in permeability continued to increase with increasing the treatment acid volume and reached 323% at an acid volume of 320 pore volumes with only 75 pore volumes of N_2 used for preconditioning. Comparing this with the corresponding permeability improvement of 104% with regular stimulation, the advantage of N_2 preconditioning is evident.

Stimulation with CO_2 Preconditioning. Six stimulation experiments with CO_2 preconditioning were conducted; the results are summarized in **Table 3** and illustrated in **Fig. 4**. The results again proved that stimulation with gas preconditioning resulted in significant improvement in permeability as compared to regular stimulation. Comparing these results with those obtained with N_2 preconditioning showed that CO_2 preconditioning had an advantage over N_2 preconditioning. This is believed to be due to the fact that CO_2 has better miscibility than N_2 and, thereore, will be more effective in displacing the oil from the zone to be treated. The results, **Table 3**, also showed that there was no significant improvement obtained by increasing the preconditioning gas volume above 75 pore volumes.

Conclusions

To summarize the findings of the present study, the permeability restoration (improvement) as a percent of the original, pre-damage permeability is plotted versus the pore volumes of acid used for the three sets of experiments in **Fig. 5**. Examination of the figure leads to the following conclusions:

- The response to regular matrix stimulation of oil-bearing sandstone formations increases with increasing the volume of acid used, reaches a peak at certain acid volume and, then drops with further increase of acid volume.
- Gas preconditioning of the damaged oil zone results in a stimulation response similar to that obtained with gas-bearing sandstones, i.e., the response is roughly proportional to the volume of acid used.
- Preconditioning the damaged zone by gas (either CO_2 or N_2) injection results in significant improvement in the response to matrix stimulation as compared to regular stimulation.
- With acid volumes, that would not even restore the original permeability in regular stimulation, gas preconditioning would result in improvements over the original permeability.
- Preconditioning the damaged zone by CO_2 injection produces better response to stimulation treatments as compared to that obtained with N_2 preconditioning. However, N_2 precondtioning may be preferred in some situations to avoid corrosion problems and reduce treatment cost.

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TABLE-1 RESULTS OF REGULAR STIMULATION EXPERIMENTS

Core	Pore Volumes		Effective Oil Permeability (md)			Permeability
Number	Acid	Gas	Before-Dam	After-Dam	After-Acid	Restoration (%)
M-5	25	0	204	45	69	33.8
M-7	50	0	202	23	51	25.2
M-8	75	0	204	50	93	45.6
M-13	100	0	484	135	315	65.1
M-14A	150	0	475	50	478	100.6
M-14B	235	0	475	50	682	143.6
M-14C	320	0	475	50	495	104.2

TABLE-2 RESULTS OF STIMULATION WITH N_2 PRECONDITIONING

Core	Pore Volumes		Effective Oil Permeability (md)			Permeability
Number	Acid	Gas (N_2)	Before-Dam	After-Dam	After-Acid	Restoration (%)
M-19	100	100	200	100	244	122.0
M-25	150	100	315	120	450	142.9
M-26	150	200	320	118	460	143.8
M-33	235	75	550	180	1370	249.1
M-34	320	75	550	140	1778	323.3

TABLE-3 RESULTS OF STIMULATION WITH CO_2 PRECONDITIONING

Core	Pore Volumes		Effective Oil Permeability (md)			Permeability
Number	Acid	Gas (CO_2)	Before-Dam	After-Dam	After-Acid	Restoration (%)
M-35	320	75	550	170	2100	381.8
M-36	235	75	500	135	1650	330.0
M-37	150	100	500	143	1450	290.0
M-38	100	125	550	115	1100	200.0
M-39	150	75	500	180	1500	300.0
M-40	100	75	500	120	1000	200.0

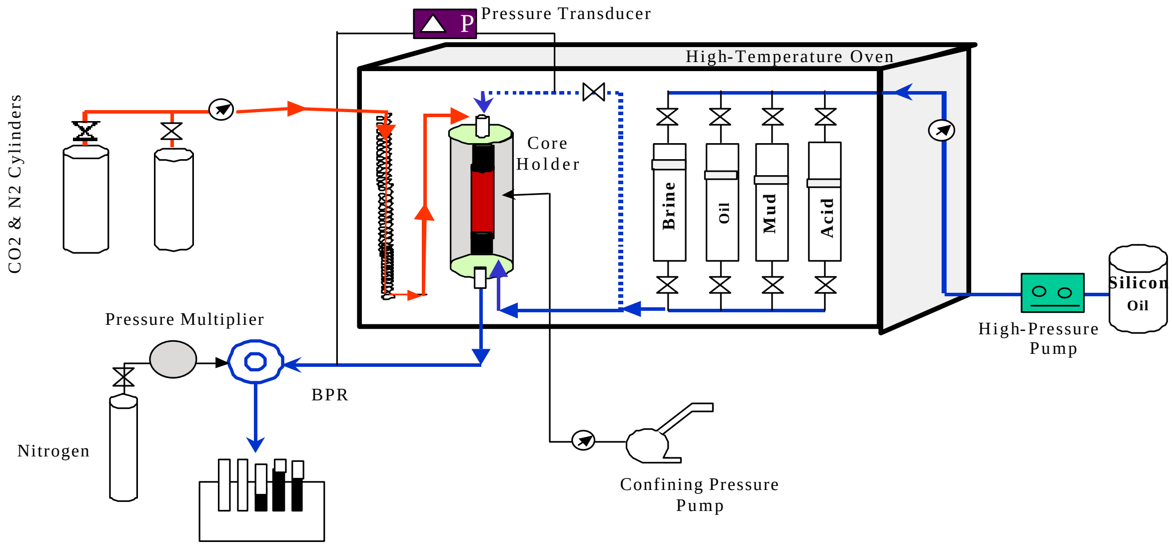

Fig. 1-Schematic of the experimental setup

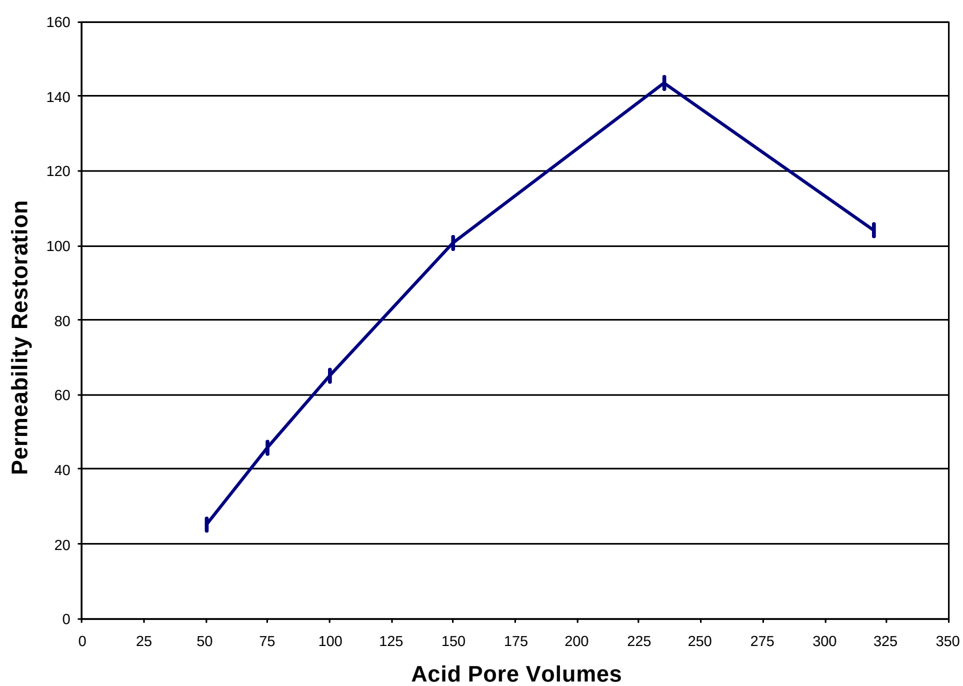

Figure-2 Results of permeability restoration vs mud acid volumes for regular stimulatic

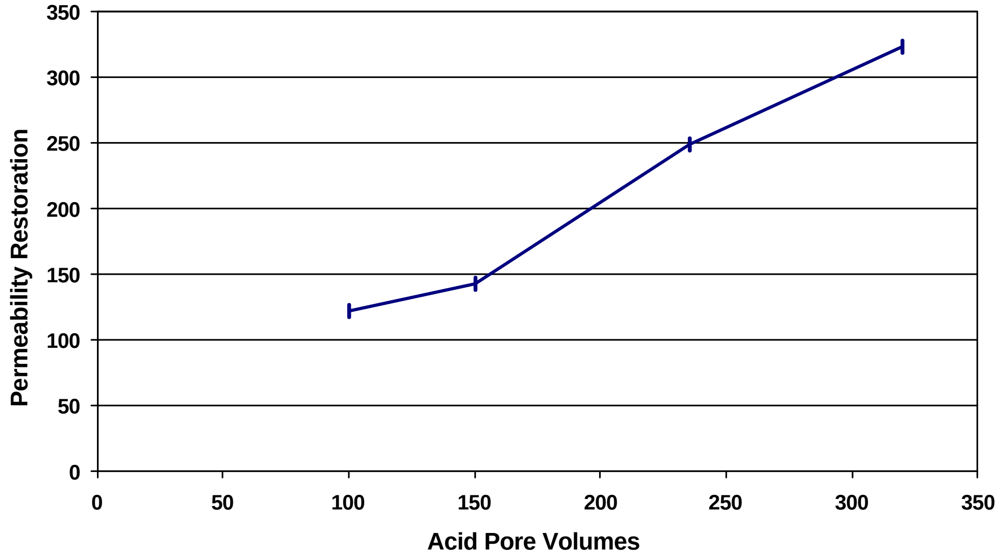

Figure-3 Results of permeability restoration Vs acid pore volumes for N2 reconditioning

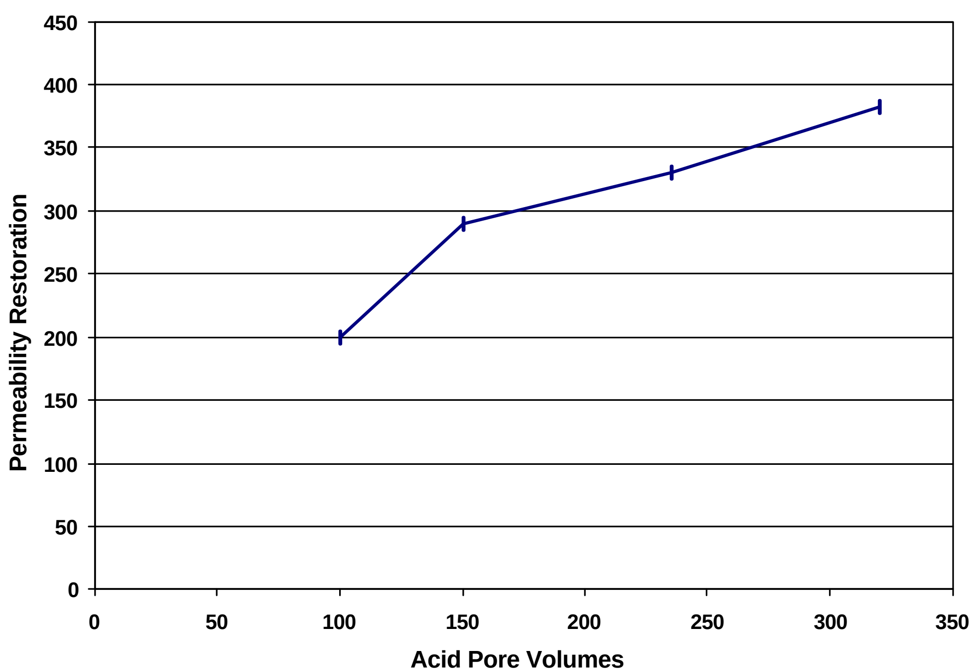

Figure-4 Results of permeability restoration Vs acid pore volumes for CO_2

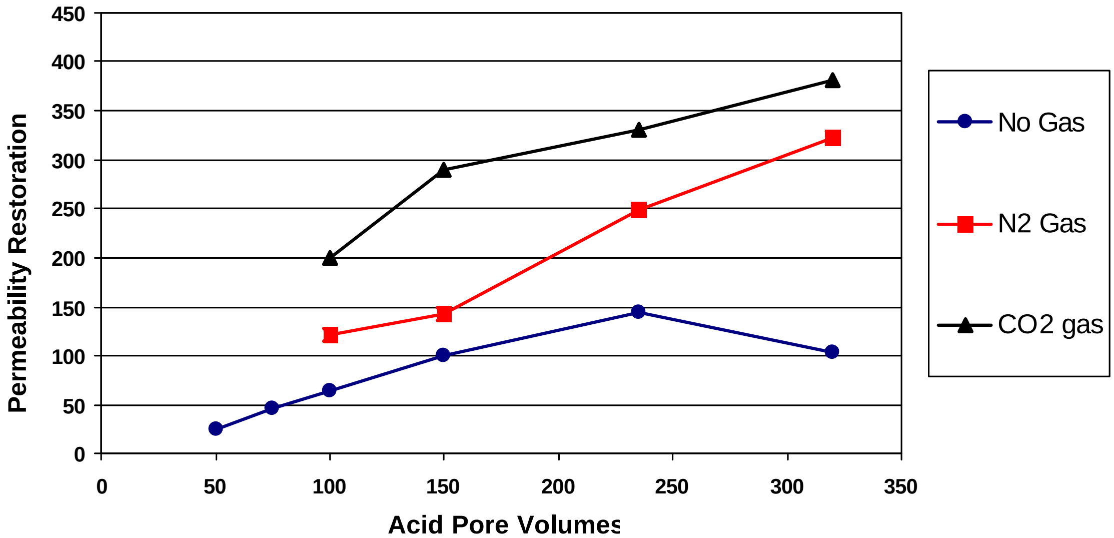

Figure-5 Comparison of permeability restoration results