

## MATRIX STIMULATION TREATMENT OF GEOTHERMAL WELLS USING SANDSTONE ACID

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### **ABSTRACT**

Mud acid (HCl-HF) is generally used in stimulation of oil and geothermal wells that suffer formation damage but its application has been limited to restoring the natural permeability of the formation. A combination of rapid spending with clays and silicates, matrix unconsolidation in the near wellbore and subsequent precipitation of various reaction by products has somewhat restricted the usefulness of mud acid for matrix stimulation treatments.

This paper discusses the application of a new acid system (sandstone acid) recently used in treating sandstone formations at some geothermal wells in the Philippines. The new HF acid compared with the usual mud acid systems has lower reaction rate and limited solubility with clays, but higher reaction rate and dissolving power with quartz.

### **INTRODUCTION**

Sandstone formations are generally made up of quartz, silicate grains, feldspars, chert and mica. These minerals are bonded together by secondary minerals that precipitated from connate water, occupying partially the original pore spaces, such as over growth quartz, carbonates and pore lining clays. The porous fraction and hence the permeability of the formation **rock** is sometimes reduced by invasion of water base filtrates either from drilling, completion, workover or treating fluids (Di Lullo and Rae, 1996).

These fluids can damage the matrix by swelling and dispersing clays or even by inducing the precipitation of scales. Some particles can also invade the high permeability formation under high differential pressure and plug the porous formation,

Hydrochloric-hydrofluoric (HCl-HF) acid mixtures generally described as mud acids are normally used to treat sandstone formations since these mixtures dissolve clays from drilling mud and react with most constituents of the sandstone formation (Williams et al., 1979). Dissolution of these naturally occurring minerals enlarges and interconnects the pores in the matrix allowing the produced fluids to move easily.

The main factors that contribute to matrix dissolution by the HF acid are the availability of minerals and these minerals' surface area during matrix stimulation treatments. Pore lining and flocculated clays, carbonates, scales and invading particles are more vulnerable to acid attack than any other framework minerals. Moreover, clays have higher surface area than quartz, thereby increasing clay dissolution and leaving quartz minerals virtually untouched. Thus, as more HF acid is injected, more clays and cementitious materials are dissolved especially in the big pores. The formation then becomes progressively weaker until it eventually re-compacts to lower porosity and permeability levels.

Reaction products of sandstone dissolution using HF acid are normally amorphous compounds and complex fluosilicates, fluoaluminates and fluoride salts which by nature have extremely low solubility (Williams et al., 1979). These by products reach saturation at very low concentrations and produce precipitates with varied consistencies.

Consequently, to prevent permanent damage from occurring, the dissolving power of HF acid is adjusted so that no more than minor damage to the formation can occur. As secondary precipitation and unconsolidation effects on well productivity are difficult to predict, they are not usually accounted for in the acid job design. **Thus**, discrepancies between

predicted and actual production increases are usually obtained from these acid treatment jobs.

Several retarded or slow reacting HF acid such as fluoboric, fluoroaluminic and hexa-fluoro-phosphonic were also developed to increase the depth of permeability improvement (Gdanski, 1985; Ayorinde et al., 1992). Most of these acid systems rely on the use of weak organic acids and their secondary reactions to slowly generate HF acid. Stimulation results using these acid systems were found to be better but were not substantial since it is believed that live acid penetration is marginally increased and unconsolidation and precipitation effects are slightly retarded. The marginal reduction in reaction rate of these acid systems could not overcome the large contrast in surface area between clays and quartz minerals. Various "in-situ generated" HF acids were also developed with questionable to poor results due to premature or improper mixing of solutions, both in the tubulars and in the formation.

The performance of all of these HF acid systems indicates that effective stimulation of sandstone formation hinges on the enhanced dissolution of quartz around the pores as quartz occupies the major fraction of sandstone formations. It is then essential that an ideal HF acid should dissolve quartz faster, limit the solubility of clays/carbonates and reduce or delay formation of secondary precipitates to effectively stimulate sandstone formations.

### **NEW HF ACID MIXTURE**

Mud acid as used in the oil and geothermal fields, is a dilution of HF acid in HCl. This is usually prepared by dissolving ammonium bifluoride ( $\text{NH}_4\text{HF}_2$ ) in HCl (Williams et al., 1979). A mixture of 1% HCl and 123 pounds of  $\text{NH}_4\text{HF}_2$  will generate 1% HF solution. Regular mud acid (12:3 HCl-HF) is hence made from 15% HCl, where 3% HCl is used to hydrolyze the fluoride salt. Excess HCl is added with the sole purpose to increase the solubility of by products of the reaction with formation minerals.

A new retarded HF acid mixture for damage removal and stimulation of sandstone formations was recently developed by Di Lullo and Rae (1996). The new acid system is applicable for moderate to deep penetration and makes use of a phosphonic acid complex (HEDP) to hydrolyze the fluoride salt ( $\text{NH}_4\text{HF}_2$ ) instead of the HCl (Di Lullo and Rae, 1996). The new acid has five hydrogens available that dissociates at different stoichiometric conditions and termed as "HV acid".

Mixtures of HV acid and  $\text{NH}_4\text{HF}_2$  produce an ammonium phosphonate salt and hydrogen fluoride and termed as "sandstone acid". Twenty gallons of HV acid per 1000 gallons of water are then required to react with approximately 123 pounds of  $\text{NH}_4\text{HF}_2$  to produce a 1% HF solution.

Di Lullo and Rae (1996) also discussed in their paper the chemistry and development of sandstone acid and presented the following synergistic effects:

1. An aluminum-silicate-phosphonate coating is formed over the clays by chemi-adsorption when sandstone acid starts to react with the formation. The coating formed has a thickness narrower than a micron as evidenced from SEM analysis and can be readily dissolved by weak HCl and to a lesser extent by organic acids. This film blocks further reactions with these clays limiting their dissolution and therefore preventing disintegration of the pore matrix.
2. HV acid as most phosphonates has outstanding adsorption and water wetting properties that catalyze HF reaction with quartz. Even though the reaction rate is lower than mud acid, quartz solubility becomes higher with time. Dynamic quartz solubility tests conducted with sandstone acid showed fifty percent higher dissolution than with mud acid.
3. Sandstone acid possess superior dispersing properties like other anionic phosphonates, and has sub stoichiometric sequestering properties. The acid system is also an excellent antiscalant thereby deferring/inhibiting formation of precipitates in the near wellbore area.

Titration of sandstone acid with a solution of sodium silicate (20 Be) to pH 3.8 (12,000 ppm Si) showed no formation of precipitates and the solution remained stable for over 12 hours at atmospheric conditions. The same titration test performed with regular mud acid became cloudy at 6,000 ppm Si and produced heavy precipitates at 12,000 ppm Si even though the pH was still acidic at 1.6.

In addition, the acid system does not rely on low pH to prevent fluoride and fluoro-silicate precipitation, therefore excess HCl is not needed and corrosion is much reduced. The slow HF release mechanism created by sandstone acid also aids in reduction of corrosion.

### Multitap coreflow tests

Coreflow laboratory studies were also conducted by Di Lullo and Rae (1996) to compare the performance of sandstone acid against mud acid. Several tests using four cores in series (multitap) with a total length of around 9.6 inches were run using 10 pore volumes each of sandstone and mud acids at 1.5% HF acid concentration. Berea sandstone cores containing low clay/carbonate content were used to limit the permeability improvement based on the amount of feldspars and quartz dissolved throughout the duration of the test. Results of the coreflow tests showed uniform improvement in permeability using sandstone acid and the inadequacy of the mud acid to treat sandstone formation which disintegrated the first core, stimulated the next two and plugged the last core (Di Lullo and Rae, 1996).

### GEO THERM A P P L I C A T I O N

At present, all of the acid jobs being conducted by PNOC-Energy Development Corporation (PNOC-EDC) in the Philippines use the mud acid (HCl-HF) system to treat formation damage caused by drilling mud and mineral (silica) deposits (Malate et al., 1997; Bufling et al., 1995). The acid jobs conducted have generally used a preflush of 10%HCl and mainflush of 10%HCl-5%HF concentration.

Due to the significant improvements obtained from these matrix acid stimulation jobs, PNOC-EDC applied this technology as a regular wellbore enhancement technique to geothermal wells that suffered formation damage. This technique was also recently utilized in stimulating some of the production wells in the Bacman II Geothermal Production Field (BGPF) located in the southernmost part of Luzon island.

During the middle part of 1997, the development of BGPF experienced a shortfall in production capacity of around 5 MWe. Analysis of the wells drilled in this area showed that wells OP-3D and OP-5DA were damaged by mud during the drilling process. As a remedial measure, PNOC-EDC programmed these wells for matrix acidizing in August 1997.

Petrologic analysis of all these production wells also revealed that the well's permeable zones intersected conglomeratic volcanic sandstones characterized mainly by calcareous (calcite) cementation in the pore lining, while some exhibit silt to clay-size matrix and minor quartz veins (Ramos, 1992). The presence of clays and these naturally occurring minerals has made PNOC-EDC test the applicability

of using sandstone acid to treat this kind of formation instead of the regular mud acid.

Using the sandstone acid system proved to be a better alternative since it can completely replace the HCl in the HCl-HF mud acid thereby decreasing the amount of HCl and the volume of corrosion inhibitors required in the treatment design. Furthermore, the new acid system reduced the total cost of materials involved in the process.

The acid job design also maintained a dosing rate of 75 gallons per linear foot of targeted payzone with the sandstone acid mixture of 10%HCl-3%HF. The target payzones were determined from the permeable zones identified from pre-acid completion tests. The acid treatment data for the two wells is summarized in Table 1 below.

Well	Target Zones (mMD)	Main Flush Volume (barrels)	Average Injection Rate (bpm)	Average Treating Pressure (psig)
OP-3D	1904-1954	296	10.2	2,500
	2342-2392	296	10.0	2,720
	2545-2595	298	10.8	2,750
	2693-bot.	307	10.5	2,000
OP-5DA	2200-2250	296	10.4	2,820
	2397-2447	270	10.4	2,760
	2647-2695	295	10.5	2,850
	2695-bot	322	10.5	2,680

*Table 1. Summary of acid treatment data.*

### A R E S U L T S

Pre-acid and post-acid treatment tests were conducted on these wells to gauge the wellbore improvement gained from the acid jobs. Improvement indicators used in the analysis of the stimulation results include increases in injectivity index, changes in downhole temperatures and pressures and other reservoir parameters.

Data from injection and pressure transient tests were analyzed using a welltest interpretation software called Saphir (Kappa Engineering, 1995) to determine reservoir parameters such as transmissivity and skin. The final and most important measure of wellbore improvement, however, is still the productivity of the well.

The two wells registered significant reduction in downhole pressures during the post-acid injection tests. The observed decline ranged from about 1.2 MPag (-174 psi) seen in OP-3D and 2.5 MPag (-360 psi) in OP-5DA. This signified decline in

flow resistance thereby improving the well's acceptance.

It should be noted also that the **observed** reduction in downhole pressures in these wells was found to be relatively larger than the downhole pressures recorded in similar muddamaged production wells previously treated using mud acid.

Considerable improvement in well characteristics were attained after the acid treatment as indicated by the results of the post-acid welltest analysis. Negative skin values were obtained indicating that initial skin damage have been removed.

Discharge tests conducted in the wells after acid treatment showed remarkable improvement in their power outputs. Production capacity of well OP-3D increased from 2.7 MWe to **5.5 MWe** equivalent to 104% improvement while OP-5DA increased from 1.5 MWe to 4.1 MWe for a 173% improvement. The results of the acid treatment are summarized in Table 2 below.

Wellbore Parameter/ Discharge Test Results	OP-3D		OP-5DA	
	Pre- acid	Post- acid	Pre- acid	Post- acid
Injectivity Index, II (li/s/MPa)	6.8	30.1	9.9	14.0
Pressure drop, $\Delta P$ MPag		1.2	-	2.5
kh darcy-m	3.22	3.18	3.10	3.20
Skin	+3.2	-5.5	+8.3	-4.7
Discharge WHP MPaa	0.7	0.71	0.7	0.7
Power Output MWe	2.7	5.5	1.5	4.1

**Table 2. Summary of acid treatment results.**

## SUMMARY

A new HF acid system (sandstone acid) is found to be more effective than regular mud acid in treating sandstone formations. This acid mixture has properties that slow down and limits reaction with clays and speeds up reaction with quartz. The overall effect is more dissolving power and deeper penetration of live HF acid.

The sandstone acid mixture developed for sandstone formations was successfully applied in some geothermal wells in the Philippines producing

improvement in overall well characteristics such as reduction of skin, decline in downhole pressures and positive production output increases.

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