

EVALUATION AND OPTIMISATION OF MATRIX ACIDIZATION IN SANDSTONE RESERVOIRS AND CARBONATE RESERVOIRS

M.Nalini, Dr.R.Giri Prasad
M.Tech Student, Associate Professor and HOD
Dept. of Petroleum Technology,
Aditya Engineering College (A)

ABSTRACT:

The aim of this paper was to structurally approach matrix acid stimulation optimisation. In order to get a solid grounding in the various disciplines of matrix acidizing the first chapters are dedicated to the theoretical background. Near-wellbore damage with its contributing mechanisms is focused on in the opening chapter culminating in the selection of a candidate well and the type of stimulation treatment. The main mechanisms and chemical reactions occurring during the etching process depending on the type of reservoir rock and the type and strength of the acid solution are presented along with their potential risks of creating further damage in sandstone formations. A sequence of the different injected batches is standard in matrix acidizing. Hence, their purpose is discussed. A matrix acid stimulation will always require acid solution additives depending on the treatment. The various types of additives are discussed in the closing chapter of the literature review. The different types of acids and additives currently used in OMV are listed. The issue in optimising matrix acid stimulations is to make the treatments comparable. The prerequisites which must be valid have been defined and stimulated wells with the same set of conditions have been analysed. In order to evaluate the gross effectiveness of the treatments, the Productivity Index has been defined as a success criterion. The evaluation of the treatment progression has been done introducing the instantaneous Injectivity Index of a stage hitting the formation face. The pressure correlation, computed on the basis of a memory gauge recording downhole and a real-time measurement at the surface, mostly matched. Relative Injectivity and the Productivity Index change correlated qualitatively in the majority of the cases.

I.INTRODUCTION TO ACID TREATMENTS

1.1. HISTORY OF ACID SIMULATION

Oil and gas operators have used acid treatment (acidizing) to improve well productivity for almost 120 years. Acidizing predates all other well stimulation techniques, including hydraulic fracturing which was not developed until the late 1940s. However, until the early 1930's, acidizing use was limited by the lack of effective acid corrosion inhibitors to protect the steel tubulars in the wells. With the development of effective corrosion inhibitors, the use and further development of acid treatment (acidizing) of oil and gas wells proliferated, leading to the establishment of the well stimulation services industry. Today, acidizing is one of the most widely used and effective means available to oil and gas operators for improving productivity (stimulation) of wells. Acidizing is commonly performed on new wells to maximize their initial productivity and on aging wells to restore productivity and maximize the recovery of the energy resources.

1.2. ACIDIZING BASICS

Acidizing involves pumping acid into a wellbore or geologic formation that is capable of producing oil and/or gas. The purpose of any acidizing is to improve a well's productivity or injectivity.

There are three general categories of acid treatments:

- a. Acid washing
 - b. Matrix acidizing
 - c. Fracture acidizing.
- a) **Acid washing**: The objective is simply tubular and wellbore cleaning. Treatment of the formation is not intended. Acid washing is most commonly performed with hydrochloric acid (HCL) mixtures to clean out scale (such as calcium carbonate), rust, and other debris restricting flow in the well.
 - b) **Matrix acidizing**: Here, the acid treatment is injected below the formation fracturing pressure. The purpose of matrix acidizing is to restore or improve an oil or gas well's productivity by dissolving material in the productive formation that is restricting flow, or to dissolve formation rock itself to enhance existing, or to create new flow paths to the wellbore.
 - c) **Fracture acidizing**: This involves pumping of acid above the formation fracturing pressure. Here, the injected acid will etch the channels in the rock that comprises the wall of the fracture.

1.3. KEY FACTORS OF ACID SELECTION

There are majorly two key factors that dominate the treatment selection and design process when planning an acid job. They are

- Formation type
- Formation permeability

Formation type:

Knowing the type of formation being acidized and details of its composition (mineralogy) is critical to achieving positive results. In carbonate formations, the acid job design is typically based on the use of hydrochloric acid (HCL). The objective when acidizing carbonate formations is to dissolve carbonate based materials to create new or clean existing pathways or channels that allow the formation fluids (oil, gas, and water) to flow more freely into the well. In sandstone formations, the acid job design is typically based on the use of hydrofluoric acid (HF), also known as mud acid, in combination with HCL. Sandstone minerals are not appreciably soluble in HCL alone but are much more so in mixtures containing HF. The objective when acidizing sandstone formations is to dissolve fine sand (quartz), feldspar, and clay particles that are blocking or restricting flow through pore spaces, thereby allowing the formation fluids to move more freely into the well. If a sandstone formation contains appreciable carbonate minerals, then HCL may be added to the treatment. Most simple acid job designs use blends of HCL and HF to respond to the heterogeneous nature of geologic formations. The strengths of the acids and their volumetric ratios (HCL: HF) are based on the detailed mineralogy of the formation being treated.

Formation permeability:

Formation permeability determines the pumping pressure required to place the acid into the formation. In general, the lower the permeability, the higher the pumping pressure. In high permeability formations the acid can be pumped into the matrix of the formation at relatively low pumping pressures. If the pumping pressure is below the formation fracture pressure, the treatment is called "matrix acidizing."

In lower permeability formations the acid cannot be pumped into the formation matrix as readily, but is pumped through existing or induced fractures at higher pumping pressures. If the pumping pressure is above that which will part or fracture the formation, the treatment is called "fracture acidizing" (or "acid fracturing").

There are two subsets of fracture acidizing.

- The first type is performed as a preliminary step in a hydraulic fracturing operation, such as in shale or extremely low permeability sandstone or carbonate formations.
- The second type is a fracture acid job, primarily applicable in carbonate formations, where the acid is pumped alone or following a fracturing fluid stage

1.4. OPERATIONAL CONSIDERATIONS:

Acidizing oil and gas wells is a routine practice that has been used for a very long time. As a result, oil and gas operators and their service providers have considerable expertise and experience in safely and effectively conducting this work. Similarly, regulators that steward oil and gas operations have developed a well-founded regulatory framework to manage this work, protect the environment, and protect public health and safety. The volume of acid used in an acid job is generally determined by the length of the formation (footage) being treated in the well. Acid volumes used per foot of formation can vary depending on the design objectives and the characteristics of the specific formation. Typical acid volume ranges are between 10 and 500 gallons per foot. While a volume of 500 gallons per foot may appear to be large in a matrix acid job, assuming 25% porosity, the acid would be displaced less than 20 feet from the wellbore.

1.5. ENVIRONMENTAL MANAGEMENT CONSIDERATIONS

The oil and gas industry has been using acids for well treatment for well over 100 years. As a result, the industry has a great deal of experience with the safe and environmentally sound handling and management of these fluids both before and after their use. Operator, service companies, and regulatory agencies have sound procedures in place that protect both workers and the public.

All equipment used in pumping the acid should be well maintained and all equipment components that will be exposed to pressure during the acid job should be tested to pressures equal to the maximum anticipated pumping pressure plus an adequate safety margin prior to the start of pumping operations, in accordance with industry standards and pressure pumping service provider operating guidelines. The operator should consider the use of barricades to limit access to areas near acid and additive containers, mixing and pumping equipment, and pressure piping. After the acid job is successfully pumped and the well is brought to production, the operator should consider using separate tanks or containers to isolate the initial produced fluids (spent acid and

produced water).

II. FORMATION DAMAGE IN RESERVOIRS

In the removal of near-wellbore formation damage, acidizing finds its primary application. In a well producing in a radial-flow regime, most of the pressure drop to the wellbore occurs within a short penetration distance into the reservoir. In fact, 50% of the total flowing pressure gradient takes place within 20 ft of the wellbore. If no damage is present, 25% of the pressure gradient is within 1–3 ft of the wellbore. If formation damage is present, it will contribute largely to pressure drop and will dominate well performance.

2.1. RESERVOIR GEOLOGY AND MINERALOGY:

In damage assessment, it is necessary first to find information on the reservoir geology, as well as the mineralogy. An understanding of the rock type and other features, including permeability and porosity, is critical. This includes the nature of porosity and how permeability is distributed across the producing interval—or the injection interval.

2.2. RESERVOIR FLUIDS:

This includes the fluid types (oil or gas) and the fluid properties. Fluid properties include carbon dioxide (CO_2) or hydrogen sulfide (H_2S) content in gas, gravity of oil, paraffin and asphaltene contents, and volume and properties (ionic composition and scaling tendency) of produced water.

III. CHARACTERISTICS OF MATRIX ACIDIZATION

3.1 ACID SYSTEMS

Acid systems in current use can be classified as mineral acids, dilute organic acids, powdered organic acids, hybrid (or mixed) acids, or retarded acids. The most common numbers of each category are given in Table 3.1.

Table 3.1: Categories of Acid and Example Systems

Category	Examples of acids used in well treatment
Mineral acids	Hydrochloric acid Hydrochloric-hydrofluoric acid
Organic acids	Formic acid Acetic acid
Powdered acids	Sulfamic acid Chloroacetic acid
Mixed acids	Acetic-hydrochloric acid Formic-hydrochloric acid Formic-hydrofluoric acid

Retarded acids	Gelled acids Emulsified acids
----------------	----------------------------------

3.2 STOICHIOMETRY OF ACID-SANDSTONE REACTIONS

Acidizing treatments in sandstone formations normally employ a mixture of HCL and HF. This acid mixture is used because HF is reactive with clay minerals and feldspar that may be restricting the permeability near the wellbore. HCL alone is sometimes used to treat sandstones, but these treatments are normally successful only when the sandstone has a high carbonate content.

Chemical reactions between HF and silica (SiO_2) or calcite ($CaCO_3$), two important mineral constituents of sandstones, are comparatively simple. The reactions of HF with aluminosilicates, such as clays or feldspars, are complex. This complexity stems for two difficulties. Clays and feldspars may not be represented by a single stoichiometric equation.

IV. DESIGN CONSIDERATIONS IN MATRIX ACIDIZING OF SANDSTONES

4.1 DAMAGE INDUCED BY ACID

The permeability was observed during injection of HF-HCL mixtures to monitor changes that occurred for various acid concentrations and applied pressure gradients (flow rates) in different sandstones. A plot of permeability change as a function of the amount of acid injected was subsequently called an Acid Response Curve (Fig. 4.1).

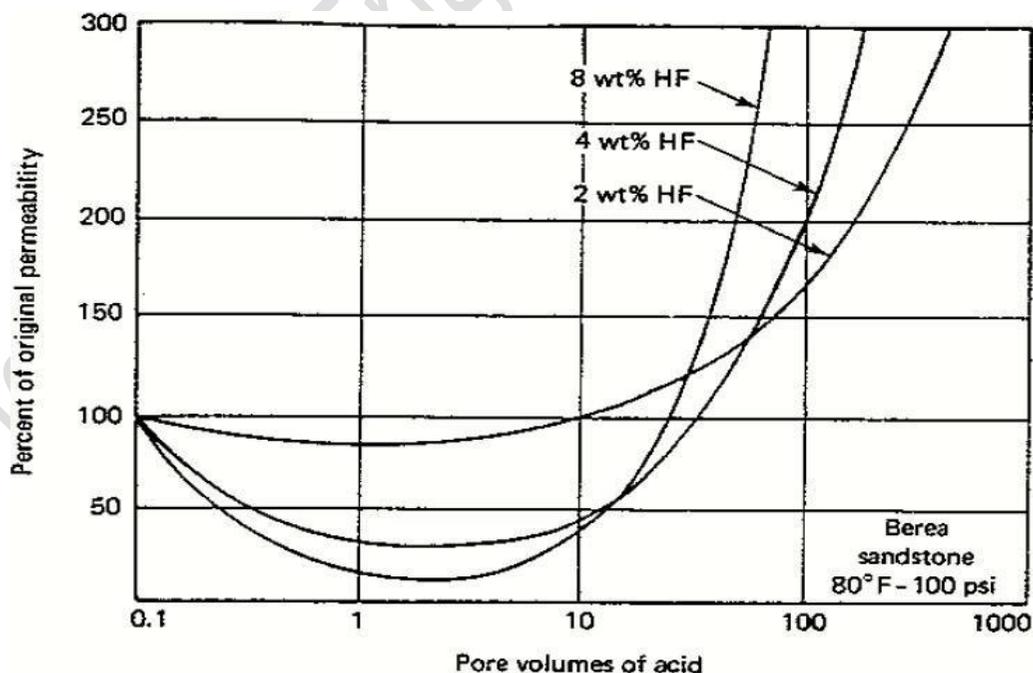


Figure 4.1: Graph showing effect of HF concentration on core response to HF-HCL mixtures.

These studies showed that upon continued injection of the HF-HCl mixture, the permeability initially decreases, reaches a minimum, and then increases as shown in Fig. ##. Smith et al. reasoned that the initial permeability reduction was caused by the partial disintegration of the sandstone matrix and the down-stream migration of fines that plug flow channels. Continued exposure of the fines to unspent HF was thought eventually to result in their dissolution. Therefore, the subsequent permeability increase was thought to come from clearing the pore channels plugged by fines and the enlargement of other pore channels by the acid. Labrid has taken extensive equilibrium data for the sandstone-HF reaction and has proposed that the decrease in permeability observed during acidization is caused at least in part by the precipitation of orthosilicic acid or other reaction products.

Damage by Fines Migration

Figure 4.2 shows that as the acid flow rate through a Berea core is increased (the pressure gradient is correspondingly increased as shown on the curves), the permeability loss becomes more pronounced. Interestingly, large volumes of acid are required to restore the core to its original permeability.

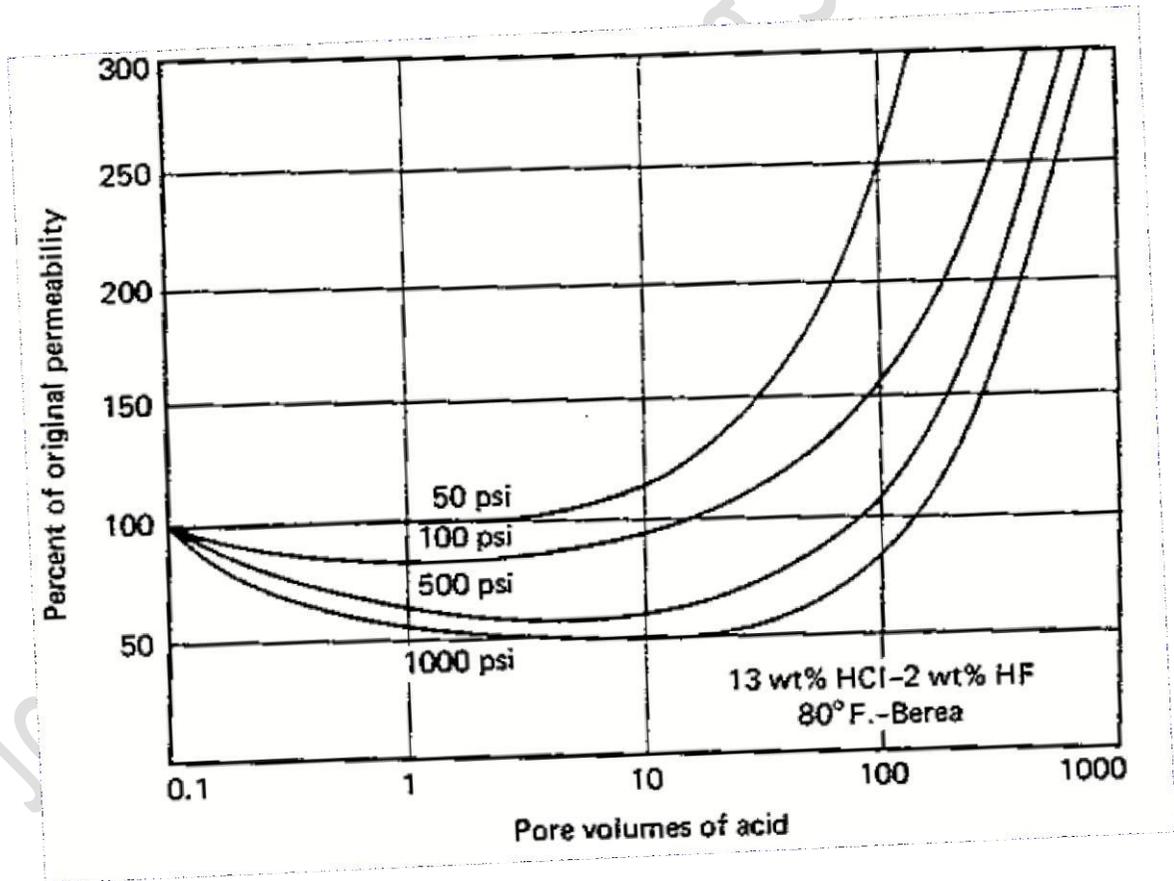


Figure 4.2: Graph showing effect of acid flow rate on Berea core response to 2 wt% HF-13 wt% HCL.

The increased permeability decline may be caused by an increase in the quantity of fines released because of the increased drag forces at high flow rate. Large volumes of acid are probably required to achieve a given permeability increase because all the HF was not reacted when injected at higher flow rates.

Carbon Dioxide Damage

Figure 4.3 shows that the solubility of CO_2 in spent acid solutions is exceeded when 15 wt% HCl is used to treat the formation. This assumes that all of the HCl reacts with carbonates and that the reaction products are calcium chloride and carbon dioxide ($CaCl_2$ and CO_2). If 15wt% HCl reacts to completion, the spent acid solution will contain about 20 wt% $CaCl_2$; thus, the lower two curves must be used to obtain the CO_2 solubility.

The dashed curves apply when 5 wt% HCl is used. In this case, the solubility exceeds the amount produced and a separate CO_2 -rich phase is not expected to form.

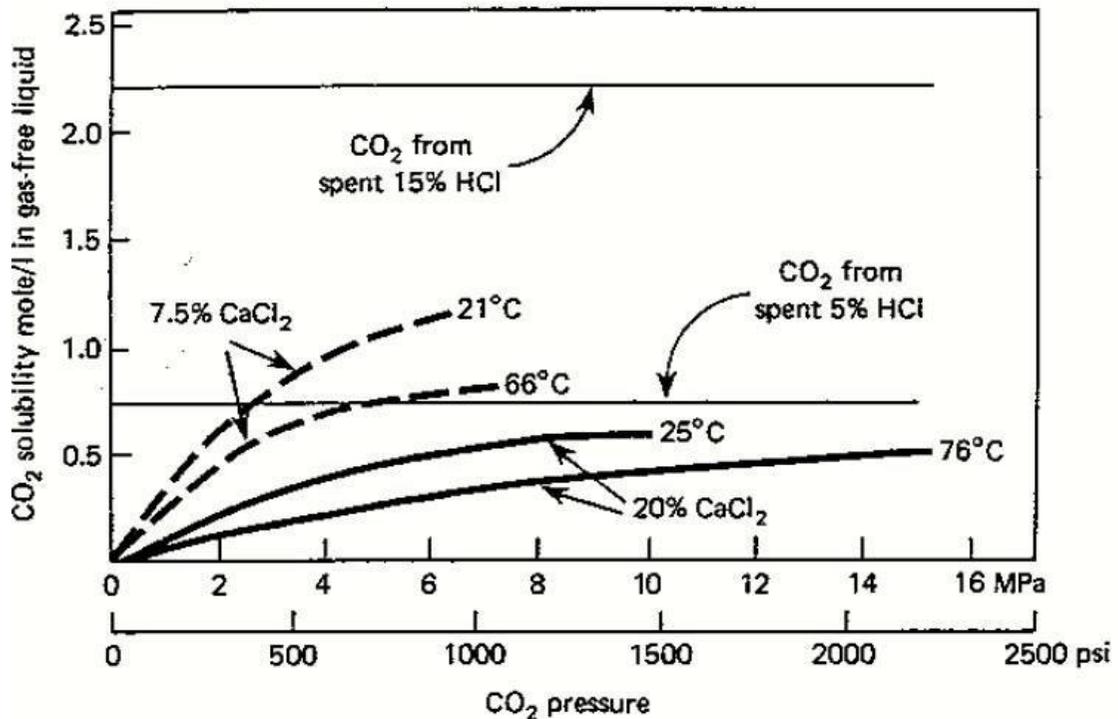


Figure 4.3: Graph showing solubility of CO_2 in spent acidizing solution.

V. STEPS IN SANDSTONE ACIDIZING

The general approach to sandstone acidizing is as follows:

1. Select an appropriate candidate well for acid stimulation.
2. Design an effective treatment.
3. Monitor the treatment for subsequent improvement.

Well performance is largely dependent on reservoir quality and the nature of the formation matrix, as well as on the presence and type of damage.

The sandstone acidizing design approach to be taken is introduced and presented in this chapter as a six-step process, inspired by Harry McLeod.

The six-step process to successful sandstone acidizing is as follows:

1. Ascertain whether acid-removable skin damage is present.
2. Determine appropriate fluids, acid types, concentrations, and treatment volumes.
3. Establish the proper treatment additive program.
4. Determine the treatment placement method.
5. Ensure proper treatment execution and quality control.
6. Evaluate the treatment.

This process begins with investigation and assessment of the stimulation candidate well to ascertain whether sufficient productivity improvement is, in fact, possible. Then, it is necessary to evaluate the damage present, as well as the reservoir quality and mineralogy, to determine the appropriate fluids needed. These considerations include acids, acid types, concentrations, and volumes. The proper additive program must then be determined, avoiding excessive or unnecessary additives.

VI. ADDITIVES IN ACIDIZING FLUID

6.1. CORROSION INHIBITOR

A corrosion inhibitor is always necessary. It must be added to all acid stages (pickling treatment, acid preflush, main acid, and acid overflushes). Corrosion inhibitors are often cationic polymers that oil-wet sandstones. In general, a corrosion inhibitor concentration greater than 1% may be questionable, unless downhole temperature is greater than 250°F. At higher temperatures, inhibitor concentration should generally not exceed 2%, unless corrosion protection requirements are very stringent. Special-alloy tubulars, such as any of the variety of chrome tubing, will likely

require higher inhibitor loadings, especially for high-temperature protection. Table 6.1 summarizes the industry's acceptable corrosion limits.

Table 6.1. Corrosion inhibition—acceptable 24-hour limits

Temperature	Corrosion Limit (lbs/ft ²)
<200°F	0.02
200–275°F	0.05*
275–300°F	0.09†

6.2. IRON CONTROL AGENT

Iron control is required in any acid treatment. Therefore, an iron control agent is almost always needed. There are many service company iron control products. However, products fall into two general categories: (1) iron complexing or iron-sequestering agents and (2) iron-reducing agents. One or more of these products can be used in an acid mixture. Combinations can be effective, especially at higher temperatures, at which dissolved iron contents may be high. Iron control agents react with dissolved iron and other dissolved metal ions to inhibit solids precipitation as acid spends and pH increases. Iron control agents do not reduce the amount of iron dissolved, nor do they reduce or prevent acid reaction with iron compounds. They do prevent reprecipitation of iron compounds by maintaining iron cations in solution.

Table 6.2. Properties of common iron control agents.

Iron Control Agent	Temperature Limit	Application(s)	Concentration Range (pptg*)
Erythorbic acid:			
Acid form	>350°F	Reducing agent; use in <20% HCl and HCl-HF	10–100
Sodium salt	>350°F	Same as for acid form, except do not use in HF	8–80
Citric acid	150–200°F	Sequestering agent; can use in all acids	25–200
EDTA:			
Acid form	>350°F	Use in HCl and HCl-HF; limited solubility	30–60
Disodium salt	>350°F	Use in HCl only; do not use in HF	40–80
Tetrasodium salt	>350°F	Use in HCl only; do not use in HF	50–100
NTA:			
Acid form	>350°F	Use in all acids; has low solubility in weak acids	25–350 (commonly 50–100)
Trisodium salt	>350°F	Same as for acid form, except do not use in HF	25–350 (commonly 50–100)
Stannous chloride	—	—	Variable
Glacial acetic acid	225°F	—	Buffer

Note: Liquid concentrate forms of these iron control agents also exist.
* Pounds per thousand gallons of acid.

VII.CASE STUDY 1 – WESTREN ONSHORE FIELDS, INDIA

Field A contains sandstone reservoirs and siltstone reservoirs. Various oil well and water injector wells have been drilled Field's permeability varies widely from 8 to 90 mD and porosity varies from 14% to 28%. The field is on the rising Eastern margin of Ahmedabad

— Mehsana block of Cambay Basin. It was observed that mainly three sands have which will be termed here as Layer I, II and III of the field. The gross thickness of the pay zones varies from 2 — 10 m, whereas the effective thickness varies from 2 — 6 m at a depth of 830 m to 990 m. Resaves were found of having large vertical and lateral heterogeneity. The reservoirs in general are tight and have low Reservoir temperature is in the range of 65 C to 76 C. Wax content of the crude is observed to be high.

ORGANIC ACID

Conventional mud acid system comprises of 12% HCl and 2% HF However, when clay sensitive minerals are present, use of HCl can create formation damage. To avoid many problems associated with this conventional organic acid can be used. It can give better result when HCl sensitive minerals like Chlorite or Siderite is present in high amount Though the stability of these minerals in HCl depend on Si: Al ratio (Hartman R L. et.al., 2006) and content of Fe, in general higher Fe is suspected, mineral stability may be less mHCl (Ross, 1969). An HCl preflush in acid sensitive formation will create damage even at low temperature which can be avoided by using organic acid over wider range of temperature (Hartman, R.L_ et al., 2006). Other benefit of using organic acid includes its chelating nature.

Table 7.1: Emulsion test for Field A

Well	Acid formulations					
	HCl%	HF%	A/Acid%	Surf%	CA / EDTA%	ACT%
Well X	15	Nil	3	0.5	0.5	0.5
	12	3	3	0.5	0.5	0.5
	6.5	1	3	0.5	0.5	0.5
	Nil	Nil	10	0.5	0.5	0.5
Well Z	15	Nil	3	0.5	0.5	0.5
	12	3	3	0.5	0.5	0.5
	6.5	1	3	0.5	0.5	0.5
	Nil	Nil	10	0.5	0.5	0.5

Table 7.2: Solubility Test for Wells of Field A

Well No.	Payzone/ Layer	Solubility in 15 % HCl (%)	Solubility in Mud Acid (12% HCl + 3% HF) (%)	Solubility in 15 % Acetic acid (%)	Iron content (% Fe)
Well X	Layer III	3.62	26.42	1.23	1.38
Well Z1	Layer I	1.14	19.87	0.71	-
Well Z2	Layer II	20.36	42.44	17.01	1.10
Well Z3	Layer II	1.90	20.83	0.58	-

Table 7.3: Mineralogy Data for Wells of Field A

Mineral	Well 1	Well 1	Well 1	Well 4	Well 5
Payzone	I	II	III	II	III
Ilmenite %	17	17	12	8	5
Quartz %	62	54	41	42	56
Siderite %	9	4	3	8	4.5
Chlorite, %		9	20	23	23
Kaolinite, %			6		1

Table 7.4: Summary of result of Acidization of Field A.

Well	Acidization plan details	Injectivity before acidization		Injectivity after acidization		Skin before acidizing	Skin after acidizing	Change in skin
		Rate (lpm)	Pressure (psi)	Rate (lpm)	Pressure (psi)			
1	Preflush: 12% HCl Mainflush: 12% HCl + 3% HF	200	1500	350	1200	5.67	1.62	-4.05
2	Preflush: 7.5% HCl Mainflush: 7.5% HCl + 1% HF	150	1800	350	1400	9.76	2.14	-7.62
3	Preflush: 10% HCl Mainflush: 10% HCl + 1% HF	150	1500	300	1300	7.94	2.44	-5.5
X	Preflush: 10% Acetic acid Mainflush: 10% Acetic acid + 1% HF	160	1800	160	900	12.9	0.46	-12.44
X2	Preflush: 10% Acetic acid + 10% HCl Mainflush: 10% Acetic acid + 5% HCl + 1% HF	150	1800	150	900	8.35	1.96	-6.39

VIII.CONCLUSIONS

One and gas operators have safely and successfully used acid to improve productivity of oil and gas wells for nearly 120 years. Today, acidizing is one of the most widely used processes for stimulating oil and gas wells. Two types of acids are most commonly used; hydrochloric acid in all formation types and hydrofluoric acid in sandstones and certain shales. Other types of acids,

such as organic acids, may also be used in specialized situations. Since geologic formations are near homogeneous, blends (particularly for sandstone formations) of HCl and HF are usually pumped with the blend ratios based on formation mineralogy.

The success of matrix acidization depends on choosing the correct acid formulation based on the reservoir mineralogy and petrophysical properties. Acids can induce damage into the formation, which has to be considered during designing phase. Sufficient amount of preflush acid has to be injected in order to reduce the precipitates formed and to precool the formation. Sufficient amount of afterflush acid has to be inserted to displace spent acid and precipitates away from near wellbore region and recover wettability of the formation.

Journal of Engineering Sciences

BIBLIOGRAPHY

1. Ohia, Nnaemeka; Igwilo, K. & Duru, U “WELL PRODUCTIVITY ENHANCEMENT USING MATRIX ACIDIZING – A NIGER DELTA CASE STUDY” Federal University of Technology, Owerri – Nigeria ISSN: 2395-3470.
2. Lindsay D. M., “An Experimental Study of Sandstone Acidization” MS Thesis, The University of Texas at Austin, 1976.
3. Reservoir Simulation 2nd Edition Michael. J. Economides Kenneth G. Nolte.
4. Oil Well Stimulation, Robert S. Schechter.
5. Successful Matrix Acidization Using Organic Acid System for Sandstone Reservoir of Western Onshore Fields of India – Sohil Shah, S. K. Singh, V. K. Bahuguna, and K. W. Rajendra, Oil & Natural Gas Corp.
6. Lindsay, D. M., “An Experimental Study of Sandstone Acidization” MS Thesis, The University of Texas at Austin, 1976.
7. Schechter, R. S., daMotta, E. Ponce, and Plavnik, “Optimizing Sandstone Acidization” SPE 19426.
8. Williams, B B., Gidley, J. L., and Schechter, R. S., Acidizing of Fundamentals, Mono. Ser SPE, Richardson, Texas, 1979.
9. C. F. Smith, A. R. Hendrickson, “Hydrofluoric Acid Stimulation of Sandstone Reservoirs” Tulsa, Okla.
10. Harry. O. Mcleod Jr, “Matrix acidization” SPE 13752.
11. “Acidization of sandstone with buffered Hcl Acid system” by M.J. Smith and G.J. Clark ,Amerigo R&D Ltd; A.R. Hendrickson Intl ,SPE 14826
12. “optimization of sandstone acidization” by Eduardo Ponce da Motta and Benjamin plavnik ,SPE 19426
13. “A comprehensive model of matrix acidization” by yong fan ,SPE 38169
14. “High temperature acidization to prevent fines migration” by T. Huang ,SPE 73745
15. “Effect of oil saturation on rock propagation during Matrix Acidization of carbonate rocks “, by R. Kumar ,SPE 169330