



# Well Stimulation and Sand Production Management (PGE 489 )

## Sandstone Acidizing

By

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# Sandstones Acidizing

The goal of sandstone matrix acidizing is to remove siliceous particles such as formation clay, feldspar, and quartz fines that are blocking or bridging pore throats.

This is accomplished by injecting acid formulations containing hydrofluoric (HF) acid or its precursors, as HF is the only common acid that dissolves siliceous particles sufficiently.

Standard treatments include pre-flush and/or post-flush stages of HCl acid to minimize the potential for calcium fluoride and other secondary precipitation.

# Acid system for Sandstones

## ☐ Sandstone Formations

☐ Quartz

☐ Feldspars

☐ Clays

☐ Carbonates

☐ Oxides

☐ Sulfide

# Acid selection for Sandstones

## Sandstone Acidizing

HCl solubility > 20%	Use HCl only
High permeability (100 md plus)	
High quartz (80%), low clay (<5%)	10% HCl–3% HF <sup>a</sup>
High feldspar (>20%)	13.5% HCl–1.5 HF <sup>a</sup>
High clay (>10%)	6.5% HCl–1% HF <sup>b</sup>
High iron chlorite clay	3% HCl–0.5% HF <sup>b</sup>
Low permeability (10 md or less)	
Low clay (<5%)	6% HCl–1.5% HF <sup>c</sup>
High chlorite	3% HCl–0.5% HF <sup>d</sup>

<sup>a</sup>Preflush with 15% HCl.

<sup>b</sup>Preflush with sequestered 5% HCl.

<sup>c</sup>Preflush with 7.5% HCl or 10% acetic acid.

<sup>d</sup>Preflush with 5% acetic acid.

# Reservoir Mineralogy

- ☐ Heterogeneous
- ☐ Clay minerals
- ☐ Chlorite content
- ☐ Feldspars (Na, K)
- ☐ Swelling clays
- ☐ Acid-sensitive clays (Illite)
- ☐ Cementing material

# Reservoir Mineralogy

**Table 18-2. Chemical composition of typical sandstone minerals.**

Classification	Mineral	Chemical Composition
Quartz		$\text{SiO}_2$
Feldspar	Microcline Orthoclase Albite Plagioclase	$\text{KAlSi}_3\text{O}_8$ $\text{KAlSi}_3\text{O}_8$ $\text{NaAlSi}_3\text{O}_8$ $(\text{Na,Ca})\text{Al}(\text{Si,Al})\text{Si}_2\text{O}_8$
Mica	Biotite Muscovite Chlorite	$\text{K}(\text{Mg,Fe}^{2+})_3(\text{Al,Fe}^{3+})\text{Si}_3\text{O}_{10}(\text{OH})_2$ $\text{KAl}_2(\text{AlSi}_3)\text{O}_{10}(\text{OH})_2$ $(\text{Mg,Fe}^{2+},\text{Fe}^{3+})\text{AlSi}_3\text{O}_{10}(\text{OH})_8$
Clay	Kaolinite Illite Smectite Chlorite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ $(\text{H}_3,\text{O,K})_y(\text{Al}_4 \cdot \text{Fe}_4 \cdot \text{Mg}_4 \cdot \text{Mg}_6)(\text{Si}_{8-y} \cdot \text{Al}_y)\text{O}_{20}(\text{OH})_4$ $(\text{Ca}_{0.5}\text{Na})_{0.7}(\text{Al,Mg,Fe})_4(\text{Si,Al})_8\text{O}_{20}(\text{OH})_4 \cdot n\text{H}_2\text{O}$ $(\text{Mg,Fe}^{2+},\text{Fe}^{3+})\text{AlSi}_3\text{O}_{10}(\text{OH})_8$
Carbonate	Calcite Dolomite Ankerite Siderite	$\text{CaCO}_3$ $\text{CaMg}(\text{CO}_3)_2$ $\text{Ca}(\text{Fe,Mg,Mn})(\text{CO}_3)_2$ $\text{FeCO}_3$
Sulfate	Gypsum Anhydrite	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ $\text{CaSO}_4$
Chloride	Halite	$\text{NaCl}$
Metallic oxide	Iron oxides	$\text{FeO}$ , $\text{Fe}_2\text{O}_3$ , $\text{Fe}_3\text{O}_4$

# Laboratory Tests of Reservoir Materials

- ☐ Mineral acids (HCl)
- ☐ Mud acids (HCl/HF)
- ☐ Mud acid/organic acids
- ☐ Retarded HF acids \*
- ☐ Aluminum chloride
  - ☐ Boric acid
  - ☐ Phosphonic acid
  - ☐ Single acid system

\* IPTC-18571-MS

# Chemicals in Use for Matrix Acidizing

## ☐ Acids

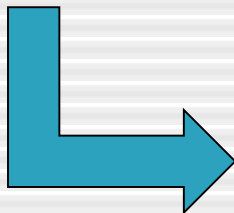
- ☐ Mineral dissolution (surface or the whole grain)
- ☐ Mobilization of mineral grains by decomposition of the rock structure

## ☐ Chelating agents

- ☐ Precipitation inhibitor
- ☐ Complexing ions in the fluid
- ☐ Reducing reactivity of specific mineral surfaces (ion exchange processes, adsorption)

## ☐ Additives

- ☐ Corrosion inhibitor
- ☐ Iron control
- ☐ Clay controller
- ☐ ... and much more



### Keep in mind!

#### Chemical compatibility with

- Reservoir fluid
- Minerals of the host rock
- Minerals of the fracture fillings
- Temperature
- Pressure

# Laboratory Tests of Reservoir Materials

- ❑ Testing the compatibility of acids and additives on reservoir material
  - ❑ (cores, cuttings, fluid and if possible of the damaging material)
- ❑ Characterization of the reservoir mineralogy before and after treatment
  - ❑ Laboratory analyses: XRD, XRF, SEM, DTA, Thin section analysis...
  - ❑ Cores, cuttings
- ❑ Acid response curves
  - ❑ Change of permeability by injection of acid and additives into a core (P/T conditions of the reservoir)
- ❑ Compatibility issues
  - ❑ Reservoir fluid analyses
  - ❑ Treating fluid - Reservoir fluid mixtures
  - ❑ Dissolution experiments for investigation possible secondary and tertiary reactions

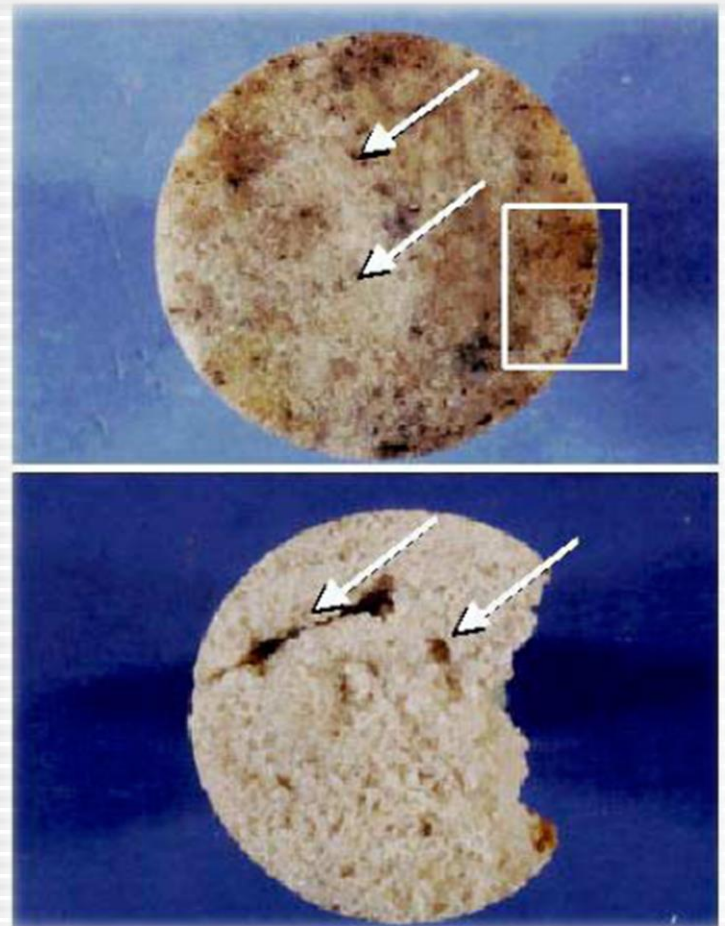
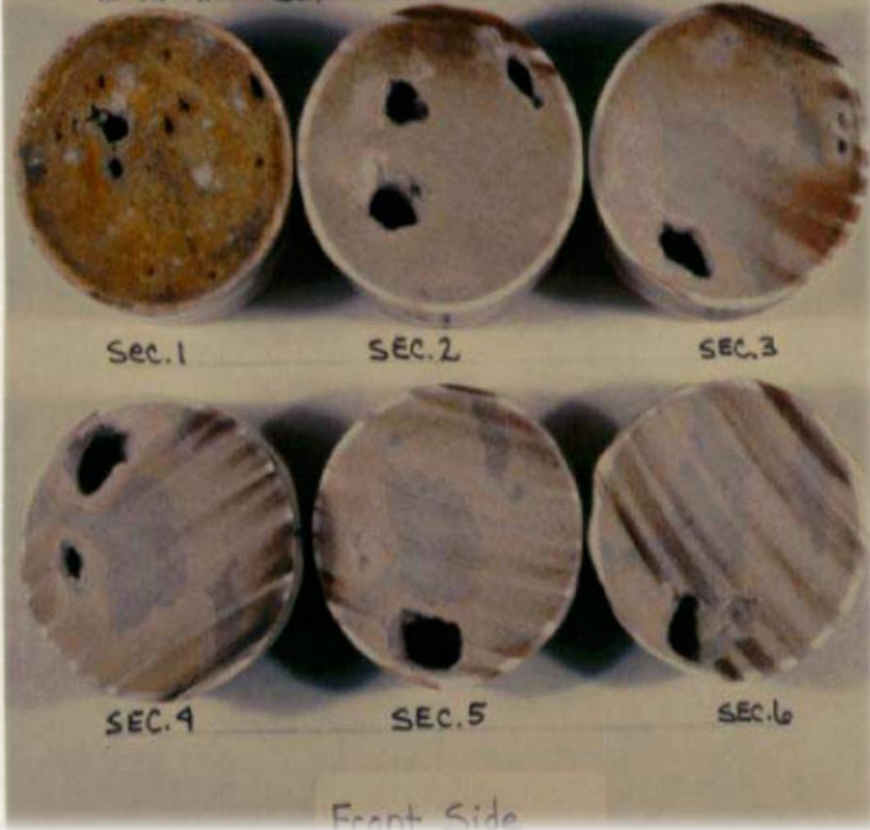
Stimulation of a core sample with Mud Acid  
12% HCl and 3% HF



# Wormhole in Sandstone

Response of 6-inch Bandera Sandstone to 12% HCl-12% HF  
at 150°F - Test #1

12-12 M.A. CLAY DAMAGED BANDERA



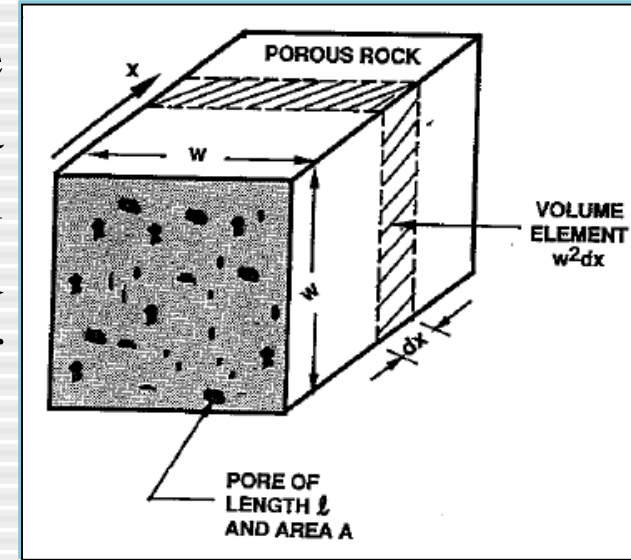
# Modelling of Sandstone Acidizing

- ☐ Porosity Model
- ☐ Permeability model
- ☐ Precipitation model
- ☐ 2-mineral model
- ☐ 2-acid, 3-mineral model

# Porosity Permeability Model

The porosity at a position  $x$  and a time  $t$  can be calculated as  $lA$ , where  $l$  is the average length of a pore, and  $A$  is the cross-sectional area. The total number of such pores in a unit volume is  $\eta dA$ , and the porosity is the sum of all such voids volumes per unit volume.

$$\phi(x, t) = l \int_0^{\infty} A \eta(A, x, t) dA$$



If the initial porosity is known before acidizing:

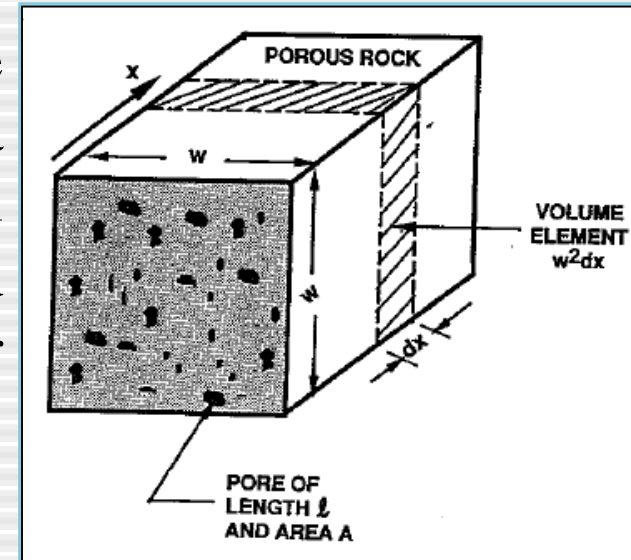
$$\frac{\phi}{\phi_0} = \frac{\int_0^{\infty} A \eta(A, x, t) dA}{\int_0^{\infty} A \eta(A, x, 0) dA}$$

# Porosity Permeability Model

The porosity at a position  $x$  and a time  $t$  can be calculated as  $lA$ , where  $l$  is the average length of a pore, and  $A$  is the cross-sectional area. The total number of such pores in a unit volume is  $\eta dA$ , and the porosity is the sum of all such voids volumes per unit volume.

Permeability is given by:

$$\frac{k}{k_0} = \frac{\int_0^\infty A^2 \eta(A, x, t) dA}{\int_0^\infty A^2 \eta(A, x, 0) dA}$$



# Porosity Permeability Model

$$\text{Labrid: } \frac{k_i}{k} = M \left( \frac{\phi_i}{\phi} \right)^n \quad (14-33)$$

where  $k$  and  $\phi$  are the initial permeability and porosity and  $k_i$  and  $\phi_i$  are the permeability and porosity after acidizing.  $M$  and  $n$  are empirical constants, reported to be 1 and 3 for Fontainbleau sandstone.

$$\text{Lund and Fogler: } \frac{k_i}{k} = \exp \left[ M \left( \frac{\phi_i - \phi}{\Delta\phi_{\max}} \right) \right] \quad (14-34)$$

where  $M = 7.5$  and  $\Delta\phi_{\max} = 0.08$  best fit data for Phacoides sandstone.

$$\text{Lambert: } \frac{k_i}{k} = \exp[45.7(\phi_i - \phi)] \quad (14-35)$$

Lambert's expression is identical to Lund and Fogler's when  $M/\Delta\phi_{\max} = 45.7$ .

## Porosity Permeability Model -Example

A sandstone with an initial porosity of 0.2 and initial permeability of 20 md contains a total of 10 vol% of carbonate and fast-reacting minerals in the damaged region. Calculate the permeability after removing all of these minerals using each of the permeability correlations.

**Solution** The change in porosity due to acidizing is the initial fraction of the bulk volume that is solid ( $1 - \phi$ ) multiplied by the fraction of solid dissolved,

$$\Delta\phi = (1 - 0.2)(0.1) = 0.08 \quad (14-36)$$

so the porosity after acidizing is 0.28. The predicted permeabilities after acidizing are as follows.

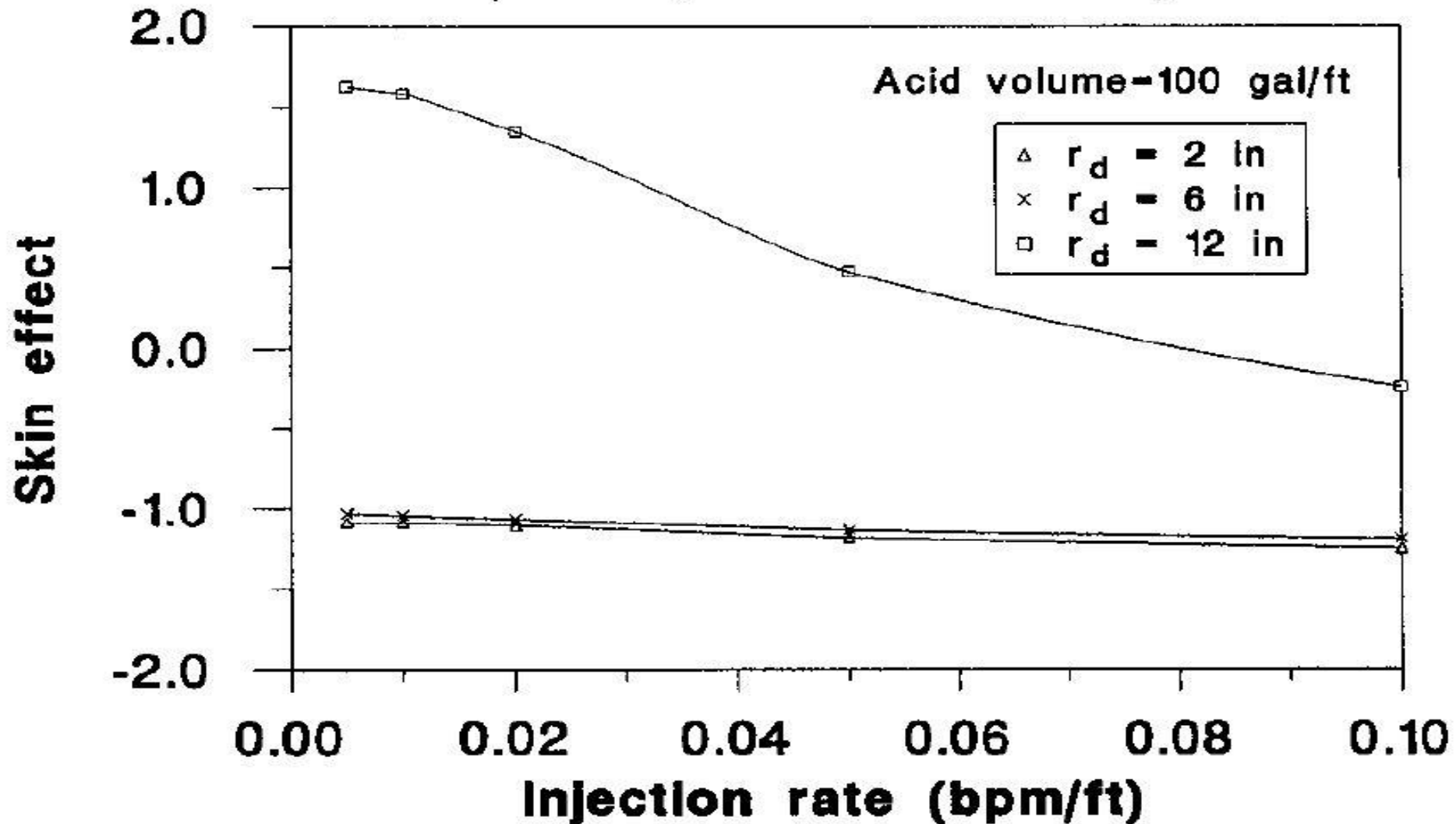
$$\text{Labrid:} \quad k_i = (20 \text{ md}) \left( \frac{0.28}{0.2} \right)^3 = 55 \text{ md} \quad (14-37)$$

$$\text{Lund and Fogler:} \quad k_i = (20 \text{ md}) \exp \left[ \frac{(7.5)(0.08)}{0.08} \right] = 3.6 \times 10^4 \text{ md} \quad (14-38)$$

$$\text{Lambert:} \quad k_i = (20 \text{ md}) \exp[(45.7)(0.08)] = 770 \text{ md} \quad (14-39)$$

# Porosity Permeability Model

(2 acid, 3 mineral model)



# Precipitation of Reaction products

- ❑ The most common damaging precipitates that may occur in sandstone acidizing are **calcium fluoride** ( $\text{CaF}_2$ ), **colloidal silica** ( $\text{Si(OH)}_4$ ), **ferric hydroxide** ( $\text{Fe(OH)}_3$ ) and asphaltene sludges.
- ❑ Calcium fluoride is usually the result of the reaction of calcite with HF, according to:  $\text{CaCO}_3 + 2\text{HF} \rightarrow \text{CaF}_2 + \text{H}_2\text{O} + \text{CO}_2$
- ❑ Calcium fluoride is highly insoluble, so the precipitation of  $\text{CaF}_2$  is likely if any calcite is available to react with the HF. Inclusion of an adequate HCl preflush ahead of the HCl-HF stage prevents the formation of  $\text{CaF}_2$ .

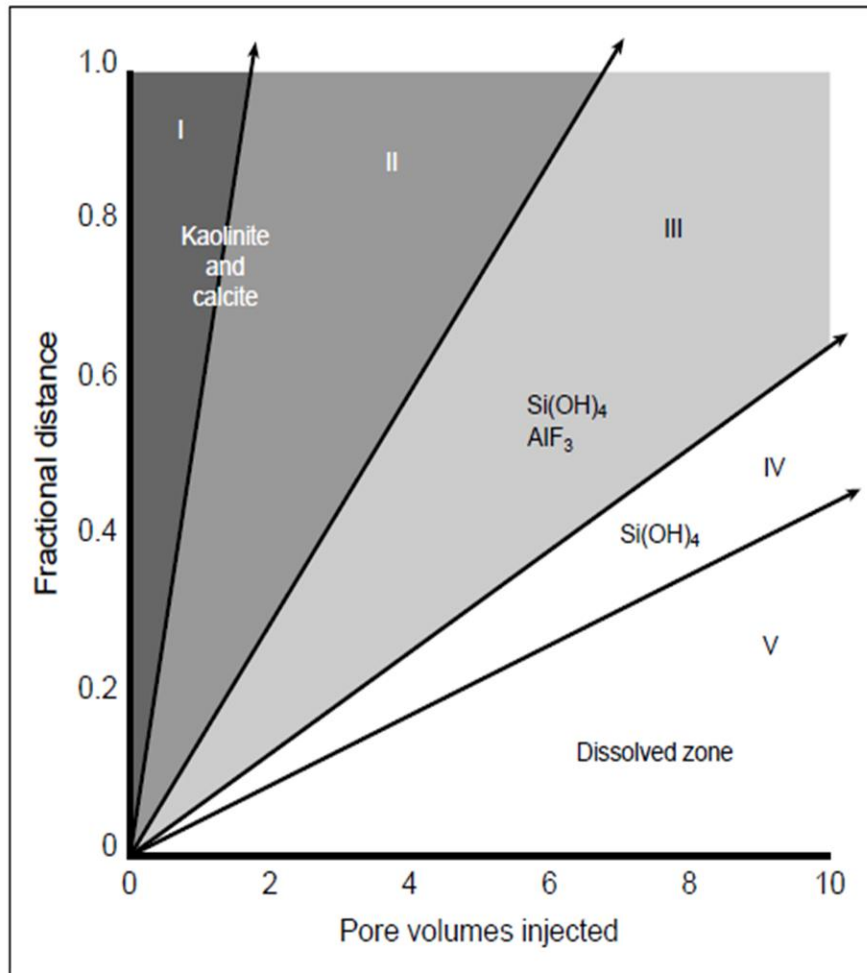
# Precipitation of Reaction products

- ❑ Contact of the crude oil by acid can cause the formation of asphaltenic sludges
- ❑ The tendency for precipitation reactions to occur in acidizing is predicted with comprehensive **geochemical models** of the chemical reactions between aqueous species and the host of minerals present.
- ❑ The most common type of geochemical model used to study sandstone acidizing is the **local equilibrium model**.

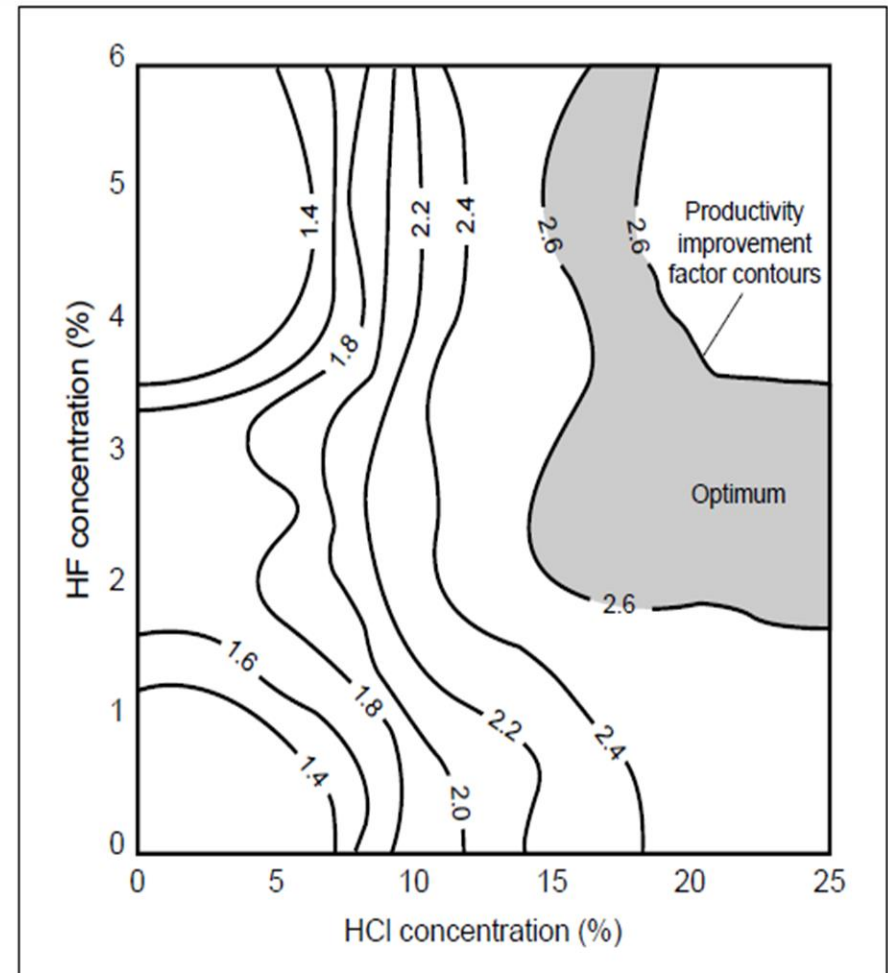
## Precipitation of Reaction products

**Precipitation models.** The two-acid, three-mineral model considers the precipitation of silica gel in its description of the acidizing process. However, there are numerous other reaction products that may precipitate. The tendency for reaction product precipitation has been studied with comprehensive geochemical models that consider a large number of possible reactions that may take place in sandstone acidizing.

# Precipitation of Reaction products

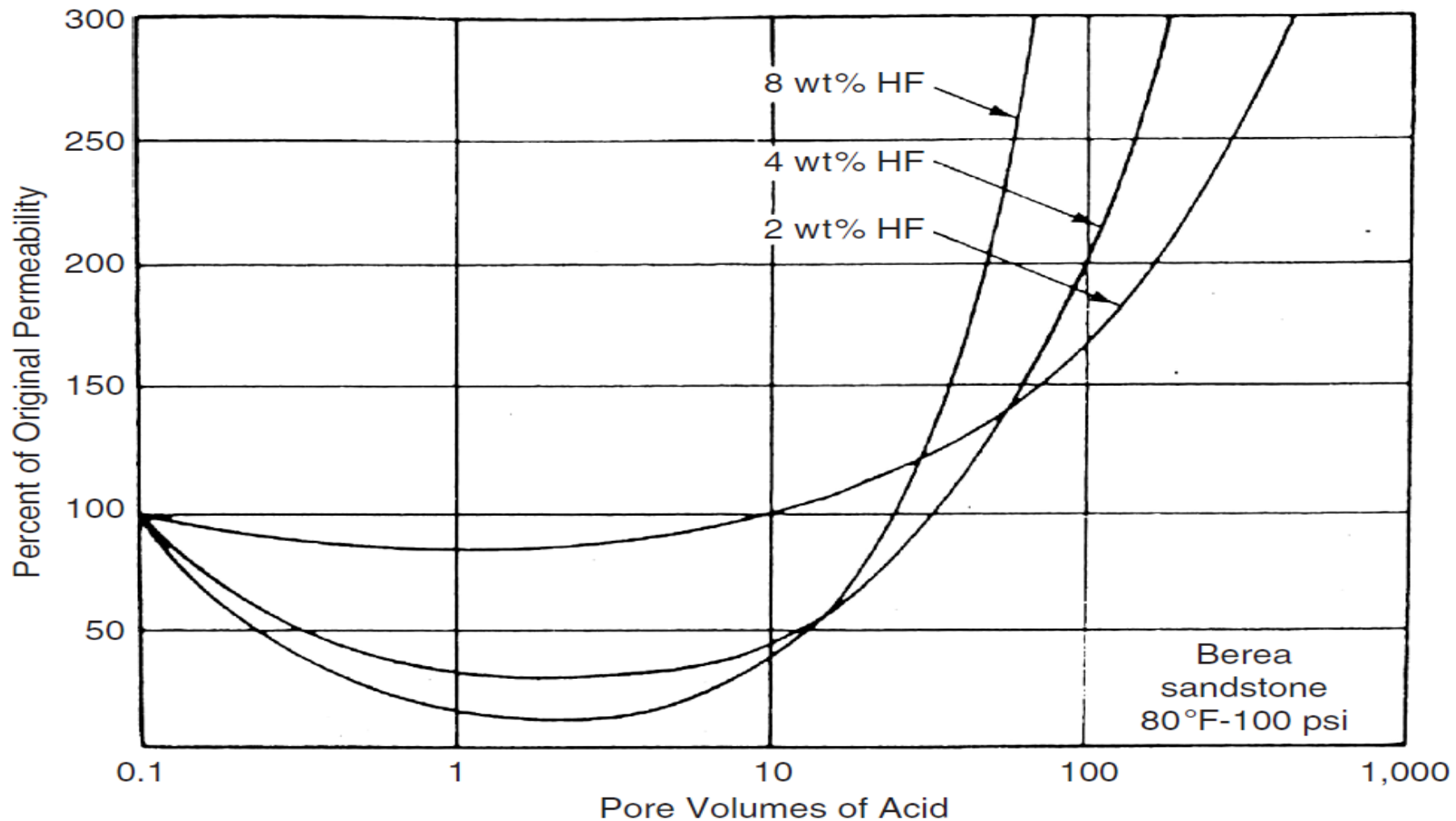


**Figure 16-2.** Time-distance diagram showing regions of possible precipitation (Schechter, 1992).



**Figure 16-3.** Productivity improvement plot (Faber et al., 1994).

# Sandstone Acidizing



**Figure 1** Typical acid response curves (Smith and Hendrickson, 1965).

# Sandstone Acidizing

- ❑ Typical acid treatment in sandstones consists of the injection of an HCl preflush, with **50 gal/ft** of formation a common preflush volume, followed by the injection of **50 to 200 gal/ft** of HCl-HF mixture.
- ❑ A post-flush of diesel, brine or HCl then displaces the HCl-HF from the tubing or wellbore.
- ❑ Once the treatment is completed, the spent acid should be immediately produced back to minimize damage by the precipitation of reaction products.
- ❑ A sandstone acidizing treatment design begins with the selection of the type and concentration of acid to be used.

# Sandstone Acidizing

- ❑ The volumes of preflush, HCl-HF mixture and post-flush required and the desired injection rate(s) are considered next.
- ❑ All acid treatments, the placement of the acid is an important issue—a strategy to ensure that sufficient volumes of acid contact all productive parts of the formation should be carefully planned.
- ❑ The types and amounts of additives to be used in the treatment must be determined on the basis of the completion, formation and reservoir fluids.

# Sandstone Acidizing

**Table 18-9. Typical stage sequence for a sandstone acidizing treatment.**

Table 18-9. Typical stage sequence for a sandstone acidizing treatment.						
Stage Number	Stage	Reason for Stage	Information Source	Stage Composition	Stage Volume	
1	Crude oil displacement	To prevent oil sludge formation by the acid	Acid–crude oil sludge test	Aromatic solvent	To achieve 3-ft radial displacement	
2	Formation water displacement	To prevent scale deposition	HCO <sub>3</sub> and SO <sub>4</sub> contents from formation water analysis	Ammonium chloride (NH <sub>4</sub> Cl) at 3%–8% depending on the salinity of the formation water	To achieve 3-ft radial displacement	
3	Acetic acid	Iron compounds in formation (pyrite, siderite, hematite), chlorite, clay, zeolites	X-ray-diffraction (XRD) analysis	3%–10% acetic acid	CaCO <sub>3</sub> (%)	Volume (gal/ft)
					0–5	25
					5–10	50
					10–15	75
					15–20	100
4	Hydrochloric acid	CaCO <sub>3</sub> or other HCl-soluble minerals	HCl solubility test and/or XRD analysis	According to core mineralogy: 3%–15% HCl	Calculated on the basis of HCl solubility and porosity (see Table 18-5) or this schedule:	
					HCl Solubility of HF (%)	Stage Volume (gal/ft)
					<5	50
					5–10	100
					10–20	200
5	Hydrofluoric acid (not used for carbonates and sandstones where HCl solubility > 20%)	To remove clay, other formation fines and mud damage	XRD analysis, SEM analysis, HCl:HF solubilities	According to formation mineralogy: 3%–13.5% HCl with 0.5%–3% HF	75–100 gal/ft	
6	Overflush	To spend acid and flush spent acid away from the near-wellbore area	Always used	3%–8% NH <sub>4</sub> Cl or 3%–5% HCl in all wells followed by nitrogen (gas wells), kerosene (oil wells) or 5% HCl (water injection wells)	One to two volumes of the HCl:HF volume or to achieve 5-ft radial displacement	
7	Diversion	To improve injection throughout the interval	Used as required for heterogeneous formation permeability	OSR for oil or low gas/oil ratio wells, foam for either oil or gas wells and water-soluble resins for water injector wells		