WORKSHOP ON TECHNOLOGY IMPERATIVES FOR EXPLORATION AND PRODUCTION OF OIL & GAS (21-24 December), Sivasagar

WELL STIMULATION TECHNIQUES

Dr A K Pandey
DGM(Chemistry)
Opening up new channels in the rock for the oil and gas to flow through is called **stimulation**.

Three stimulation treatments are commonly used: explosives to break up the rock, injection of acid to partially dissolve the rock, and hydraulic fracturing to split the rock and prop it open with proppants.
COURSE OUTLINE

- TYPES OF FORMATION
- FORMATION DAMAGE
- ACIDIZATION
- HYDRAULIC FRACTURING
- WATER SHUT OFF/ INJECTION PROFILE MODIFICATION
- SAND CONTROL
Types of formation rock

- **Sandstone**
  - Sand grains cemented by silica / calcium carbonate
- **Limestone**
  - Composed mainly of carbonate
- **Shale**
  - Clay mineral and quartz
- **Clay**
  - Kaolinite, Montmorillonite, Illite, Chlorite
Sources of Formation Damage

Formation damage may occur during the following operations:

- Drilling
- Completion
- Workover
- Stimulation
- Production
- Water / Gas Injection
- IOR / EOR
Formation Damage
Mechanisms

- Fines Migration
- Clay Swelling
- Induced particle plugging
- Asphaltene & Sludge deposition
- Emulsion Block
- Scale
- Bacteria
- Water Block
- Wettability Alteration
**Origins of formation damage & remedies**

- **Formation damage during drilling**

<table>
<thead>
<tr>
<th>Damage mechanism</th>
<th>Remedial measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle invasion/ Filter cake</td>
<td>Matrix acidization, Perforation, Hydraulic fracturing</td>
</tr>
<tr>
<td>Swelling and dispersion of indigenous reservoir clays by the mud filtrate</td>
<td>Matrix acidization</td>
</tr>
<tr>
<td>Mutual precipitation of soluble salts in the filtrate and formation water</td>
<td>Matrix acidization</td>
</tr>
<tr>
<td>Slumping of unconsolidated sands</td>
<td>Sand consolidation techniques, Frac and Pack</td>
</tr>
<tr>
<td>Water block / Emulsion block</td>
<td>Surfactant treatment, Matrix acidization</td>
</tr>
</tbody>
</table>
Formation damage (drilling)

- Fracture Plugging
- Shallow Matrix Damage
- Wellbore Cross Section
- Filter cake
- Pore Plugging

Drilling Damage
# Origins of formation damage & remedies

## Formation Damage during cementing

<table>
<thead>
<tr>
<th>Damage mechanism</th>
<th>Remedial measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines migration from the cement slurry into the formation</td>
<td>Matrix acidization, Perforation, Hydraulic fracturing</td>
</tr>
<tr>
<td>Precipitation of solids from the cement within the formation</td>
<td>Matrix acidization ,Perforation</td>
</tr>
<tr>
<td>Precipitation of secondary minerals following reservoir mineral dissolution</td>
<td>Matrix acidization</td>
</tr>
</tbody>
</table>
Damage by Overbalance Perforation
## Origins of formation damage & remedies

### During Completion & Workover

<table>
<thead>
<tr>
<th>Damage mechanism</th>
<th>Remedial measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydration and swelling of clay minerals</td>
<td>Matrix acidization, Clay stabilization</td>
</tr>
<tr>
<td>Movement and plugging by clay size particles in the formation</td>
<td>Matrix acidization, Clay stabilization</td>
</tr>
<tr>
<td>Plugging by invading materials from the wellbore fluids</td>
<td>Matrix acidization</td>
</tr>
<tr>
<td>Emulsion and water blocks due to lost wellbore fluid</td>
<td>Surfactant treatment, Matrix acidization</td>
</tr>
<tr>
<td>Relative permeability effects</td>
<td>Surfactant treatment</td>
</tr>
<tr>
<td>Precipitation of scales</td>
<td>Acidization</td>
</tr>
<tr>
<td>Plugged perforations due to improper perforating conditions</td>
<td>Acidization, Perforation</td>
</tr>
</tbody>
</table>
## During Sand Control

<table>
<thead>
<tr>
<th>Damage mechanism</th>
<th>Remedial measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines migration</td>
<td>Acidization, Clay stabilization, Frac &amp; Pack, Acidization with foam based fluids</td>
</tr>
<tr>
<td>Perforation plugging</td>
<td>Acidization</td>
</tr>
<tr>
<td>Polymer invasion</td>
<td>Surfactant treatment, Matrix acidization</td>
</tr>
</tbody>
</table>
## During W.I. & Different EOR Methods

<table>
<thead>
<tr>
<th>Damage mechanism</th>
<th>Remedial measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid invasion</td>
<td>Acidization, Hydraulic fracturing</td>
</tr>
<tr>
<td>Fines migration</td>
<td>Acidization, Clay stabilization treatment</td>
</tr>
<tr>
<td>Clay swelling</td>
<td>High saline fluid</td>
</tr>
<tr>
<td>Clay de flocculation</td>
<td>Surfactant treatment, Clay stabilization treatment</td>
</tr>
<tr>
<td>Formation dissolution</td>
<td>Acidization, Hydraulic fracturing</td>
</tr>
<tr>
<td>Skim oil entrainment</td>
<td>Surfactant treatment</td>
</tr>
<tr>
<td>Sand influx</td>
<td>Sand consolidation treatment</td>
</tr>
<tr>
<td>Formation of insoluble scales and Emulsification</td>
<td>Surfactant treatment, Solvent treatment</td>
</tr>
<tr>
<td>Precipitate formation</td>
<td>Acidization</td>
</tr>
</tbody>
</table>
Quantifying Formation Damage - SKIN

- Measurement of the severity of the formation damage
- Dimensionless factor expressing the reduction in the formation permeability compared to the original permeability

\[
s = \left( \frac{K}{K_{s}} - 1 \right) \times \left( \ln \frac{R_{s}}{R_{w}} \right)
\]
Skin Measurement

- $K = 200$ md
- $K_s = 25$ md
- $R_s = 8.25$ inch
- $R_w = 2.25$ inch

- $\ln \left( \frac{R_s}{R_w} \right) = 1.286$
- $K / K_s = 8$

- $S = (8-1) \times 1.286 = 9$
Skin : Effect on Production

\[ q = \frac{kh(p_r - p_{wf})}{141.2 \mu B \left( \ln \frac{r_e}{r_w} + S \right)} \]
Pressure Transient analysis

- Drawdown test

- Build up test
Pressure Transient analysis

- Injection Test
- Fall off test
ACIDIZATION
What is acidization

Matrix stimulation by acidization is accomplished by injecting chemicals to dissolve and/or disperse materials near the wellbore that impair well production in sandstones or to create new, unimpaired flow channels between the wellbore and a carbonate formation.
Acidising techniques

- Acid Spotting

- Matrix Acidisation
  - Deep Penetrating Mud Acid
  - Nitrified Acid
  - Foamed Acid
  - Selective Acidisation

- Acid Fracturing
Acidization

Remove near wellbore damage by injecting acid / reacting fluid into the formation below fracturing pressure.

Acid pumper

Acid

Displacing fluid

Well

1- 4ft

Shale Reservoir

Shale

1- 4ft
ACID PUMPER
COIL TUBING UNIT
Mechanism of Matrix Acid job:

- To inject acid into formation at a pressure less than the pressure at which fracture can be opened
- To dissolve the clays, mud solids near the wellbore which had choked the pores
- To enlarge the pore spaces
- To leave the sand and remaining fines in a water-wet condition
Fluid Selection

- Acid Type
- Concentration
- Volume
Acid formulation

Lab studies involved

• Stimulation history
• Acid solubility
• Mineralogy (type of clay)
• Emulsion test
• Sludge test
• Core flow study
Fluid Selection

Previous Stimulation History
XRD Analysis
SEM Studies
Solubility Test

Core Preparation

Acid Formulation
Volume Optimization

Acid Response Curve*

Permeability Improvement

Formation rock
Compatibility Studies
Additives

Formation fluid
Types of clays

- **Kaolinite**
  - Minimum effect by acid
  - Migrating clay, requires clay stabilizer

- **Smectite (Montmorillonite)**
  - Water sensitive (swells)
  - Can be dissolved by weak HF
Illite
- Migrating clay
- Can be treated with HF

Chlorite
- Contains High Amount of Iron
- Treatment with Iron Sequestering Agent
Type of Acid

- **Carbonate reservoirs**
  - HCl is used as basic rock dissolution chemical

- **Sandstone reservoir**
  - HCl + HF (mud acid) is used as basic rock dissolution chemical
Carbonate acidising

- Carbonate formations generally have a low permeability and can be highly fissured.
- HCl is used as the basic rock dissolution agent.
- Wormholes form in the process of dissolution of rock.
- Other additives are used as per compatibility with rock minerals.
Carbonate Acidising

Reactions

Calcite \[ 2\text{HCl} + \text{CaCO}_3 \rightarrow \text{CaCl}_2 + \text{CO}_2 + \text{H}_2\text{O} \]

Dolomite \[ 4\text{HCl} + \text{CaMg(CO}_3)_2 \rightarrow \text{CaCl}_2 + \text{MgCl}_2 + 2\text{CO}_2 + 2\text{H}_2\text{O} \]

Siderite \[ 2\text{HCl} + \text{FeCO}_3 \rightarrow \text{FeCl}_2 + \text{CO}_2 + \text{H}_2\text{O} \]
Carbonate acidising

- For effective stimulation deep worm holes are necessary to maximize conductivity between reservoir and well bore for enhancement of production.

- The reaction rate between conventional Plain HCl and carbonate is very fast at reservoir temperature.
Carbonate acidising

- For effective stimulation of carbonate reservoir following acid systems are used
  - Emulsified acid system
    - Acid emulsified with hydrocarbon (diesel)
  - Gelled acid system
    - Acid modified with gelling agent (polymer/viscoelastic surfactants)

Role of emulsified/Gelled acid is

- To provide retardation
- To achieve deep penetration
- Compatible at high reservoir temperature
Sand stone acidization

Causes of Damage

- Mud & Mud filtrate invasion
- Cement solid & filtrate invasion
- Cutting invasion
- Perforation damage
- Created emulsions
Sand stone acidisation

- Mud acid (HCl + HF) is used as basic rock dissolution agent for acidization of sandstone reservoir.
- A preflush of HCl or organic acid is normally used prior to injection of mud acid.
- Additives are selected based on the rock mineralogy and reservoir fluid properties.
- An overflush is injected to push all the mud acid to formation.
Sand stone acidisation

Reactions

- **Sand**
  \[ 4\text{HF} + \text{SiO}_2 \rightleftharpoons \text{SiF}_4 \text{ (silicon tetrafluoride)} + 2\text{H}_2\text{O} \]
  \[ \text{SiF}_4 + 2\text{HF} \rightleftharpoons \text{H}_2\text{SiF}_6 \text{ (fluosilicic acid)} \]

- **Clay**
  \[ \text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2 + 36\text{HF} \rightarrow 4\text{H}_2\text{SiF}_6 + 12\text{H}_2\text{O} + \text{H}_3\text{AlF}_6 \]
Sand stone acidization

\[
\begin{align*}
H_2\text{SiF}_6 + 2\text{Na}^+ & \rightarrow \text{Na}_2\text{SiF}_6\downarrow + 2\text{H}^+ \\
H_3\text{AlF}_6 + 3\text{Na}^+ & \rightarrow \text{Na}_3\text{AlF}_6\downarrow + 3\text{H}^+
\end{align*}
\]
Hydrofluoric acid (HF) treatment

OVERFLUSH

SURFACTANT

HF ACID

NaCl

KCl

SURFACTANT

FORMATION WATER

Liner

Perforated Cement

Perforated Casing

Sand pack
Acidization steps in general

- **Pre-flush Stage (5% - 10% HCl)**
  - 50 to 100 gal/ft of formation in general
  - To remove carbonates
  - To push NaCl or KCl away from wellbore

- **Acid Stage**
  - HF to dissolve clay / sand
  - HCl to dissolve carbonates

- **After-flush stage (10% EGMBE)**
  - To make the formation water wet
  - To displace acid away from wellbore
Acid additives

- Corrosion Inhibitor
- Surfactant
- Non-Emulsifier
- Anti-sludge Agent
- Iron Controller
- Mutual Solvent
- Friction Reducer
- Clay Stabilizer
- Diverting Agent
Corrosion Inhibitor

- Factors Affecting Corrosion During an Acid Treatment
  - Temperature
  - Contact Time
  - Acid Concentration
  - Metal Type
  - Corrosion Inhibitor Used
Surfactant

- Can act to:
  - Change surface and interfacial tensions
  - Disperse or flocculate clays and fines
  - Break, weaken emulsions
  - Change or maintain the wettability of reservoir
  - Reduce acid-induced sludging
  - Create or break foams
  - Promote or prevent water blocks
Non-Emulsifier

• Contains water soluble group (polymer)
• Temperature sensitive
• More versatile & results in
  • Prevention of emulsion formation
  • Lowered surface tension
  • Damage prevention
Anti Sludge agent

- “Sludge” is a precipitate formed from reaction of high strength acid with crude oil
- Methods of sludge prevention
  - Solvent (Xylene, Toluene) pre-flush to minimize physical contact
  - Use of low strength acid
  - Anionic surfactant to minimize precipitation of colloidal suspension
Iron Controller

- **Methods of Iron Control**
  - Chelating (iron chemically bound) e.g. Acetic acid, Citric acid
  - Sequestering (iron retained in solution) e.g. EDTA, NTA

- **The Precipitation of Iron**
  - Ferrous Ion (Fe++) pH 7 or Greater
  - Ferric Ion (Fe+++ ) pH 2 to 3

- **Sources of Iron**
  - Scale: Iron oxide, Iron Sulfide, Iron Carbonate
  - Formation: Chlorite, Pyrite, Siderite
Mutual Solvent

Reasons for using a mutual solvent

- To maintain a water wet formation
- To water wet insoluble formation fines
- To reduce water saturation near the wellbore
- To help reduce the absorption of surfactants and inhibitors on the formation
Clay Stabilizer

- **Reasons for using Clay Stabilizer**
  To keep clays and fines in suspension and to prevent migration and swelling of clays

- **Normal treating concentrations**
  normally up to 1% (V/V)
Diverting Agent

Why Diverting Agent?

To place the reactive fluid evenly

- Among the pay zones in wells completed in multiple layers with permeability contrast
- Wells completed in single layer with very long interval with heterogeneity within the layer
- Wells completed in single layer with different magnitude of damage within the layer
Diversion Techniques

- **Mechanical diversion techniques**
  - Mechanical isolation of pay zones with packers

**Chemical diversion techniques**

- **Ball sealers**
- **Particulate diversion**
- **Foamed acid diversion**
- **Viscous fluid diversion**
  - Self diverting acid (SDA) based on polymer/surfactants
  - Diversion with Emulsified acid
  - Diversion with viscous slug
Ball Sealers

- Ball sealers are rubber-coated balls that are designed to seat in the perforation.

- Reactive fluids carry the balls and place on the perforation tunnel of high perm zone, blocks them, diverts acid to other intervals.
Particulate diversion technique

- Fine particles are added and placed against the high perm/less damaged zone.
- Creates a relatively low permeable filter cake on the formation face of high perm zone.
- Resists flow of reactive fluid to high permeable zone and divert the fluid to the zone of interest.
## Particulate diversion technique

<table>
<thead>
<tr>
<th>Diverting agents</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oil soluble resin/ polymer</td>
<td>0.5 – 5.0 gal/1000 gal</td>
</tr>
<tr>
<td>2. Benzoic acid (not to use with HF)</td>
<td>1.0 lbm/ft</td>
</tr>
<tr>
<td>3. Rock salt</td>
<td>0.5-2.0 lbm/f</td>
</tr>
<tr>
<td>4. wax beads</td>
<td>1.0 – 2.0 lbm/ft</td>
</tr>
<tr>
<td>5. Naphthalene flakes (not to use in injection wells)</td>
<td>0.25 – 1.0 lbm/ft</td>
</tr>
</tbody>
</table>
Foamed diversion technique

- Foams are stable mixture of liquids and gases.
- In oil field, foam is produced by Injecting Nitrogen into water mixed with foamer.
- Nitrogen gas is trapped into the liquid, occupies 50-60% of total volume of foam.
- Foam restricts the flow of reactive fluid to high perm layer and diverts the fluid to low perm layer.
Viscous fluid diversion technique

Self-diverting Acid (SDA) system

- Acid modified with polymer/surfactant
- Preferably enters into the high perm zone and increases the viscosity in-situ during acid spending process
- Diverts remaining acid to the low perm or more damaged zone at elevated pressure.
Acid diversion process
Flow Back
Retarded Mud Acid
(For Retarding and clay stabilizing)

- Used mainly to increase penetration depth.
- Chemistry
  - $\text{NH}_4\text{HF}_2 + \text{HCl} \Leftrightarrow 2\text{HF} + \text{NH}_4\text{Cl}$
  - $\text{H}_3\text{BO}_3 + 4\text{HF} \Leftrightarrow \text{HBF}_4 + 3\text{H}_2\text{O}$
    (Tetra Fluo-Boric Acid)
  - $\text{HBF}_4 + \text{HOH} \Leftrightarrow \text{HF}$ (Slow generating)
- Limitation
  - Suitable for low BHT wells
# Acid formulation design

<table>
<thead>
<tr>
<th>Treating Fluid</th>
<th>Formulations</th>
<th>Volume of fluid/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre flush</td>
<td>3% NH₄Cl + 6.5% HCl + 3% Acetic acid</td>
<td>690 Lit</td>
</tr>
<tr>
<td>Mud acid</td>
<td>6.5% HCl + 1.5% HF + 3% Acetic acid + 0.5% Citric acid + 0.3% surfactant + 1% ACI</td>
<td>1150 Lit</td>
</tr>
<tr>
<td>After flush</td>
<td>6.5% HCl + 3% Acetic acid 10% EGMBE</td>
<td>690 Lit</td>
</tr>
</tbody>
</table>
Hydraulic Fracturing

• Hydraulic fracturing is the most common mechanism for increasing well productivity

• In certain carbonate reservoirs fracturing is performed with acid

• In other carbonate and sandstone reservoirs propped fracturing is used
Why Fracture?

• By-pass near wellbore damage
• Increase well production by changing flow regime from radial to linear
• Reduce sand production
• Increase access to the reservoir from the well bore
Near Wellbore Permeability Damage

Un-damaged reservoir

Damaged permeability zone

Wellbore

$r_w$

$r_e = \text{Drainage radius}$

$r_s$
Radial Flow Regime

By its nature, radial flow is inefficient
Effect of Hydraulic Fracture on Flow Regime

If properly created, hydraulic fractures can change flow regime from radial to linear.
Pressure Traverse In HF Job

Idealized Surface Pressure and Rate response during an HF treatment

Breakdown pressure
Propagation pressure
Pipe Friction
ISIP
Injection Rate
Pumping stopped
**FRACTURE ORIENTATION - G. THEORY**

**FRACTURE:**

- Plane perpendicular to least principal stress

**Horizontal Fracture**
- If $B > C \cdot E \cdot A$ min
- $F_G \geq 1.0$ PSI/ft
- $F_G = \frac{BHP}{Depth}$

**Vertical Fracture**
- If $B > A \cdot E \cdot C$ min
- $F_G \leq 1.0$ PSI/ft

A, C resultant overburden - G. rock stress.
Fracture Orientation

Fracturing Gradient = bottom-hole frac-pressure/ Depth
Fracture Orientation

Fracturing Gradient = bottom-hole frac-pressure/ Depth
Purpose Of Fracturing

To increase productivity by penetrating blocked permeability near the well bore.
Purpose Of Fracturing

To increase the total volume of oil that a well can produce in primary recovery before the economic limit of production is reached.

More recoverable oil, thanks to fracturing

Slope of curve = decrease of oil
Fracturing - Classification

- Acid Fracturing
- Non Acid Fluid Fracturing
  - Water Based
  - HC Based
  - Poly Emulsion
- Non Conventional
  - Nuclear
  - Explosive
  - HEGS (high energy gas stimulation)
Good Candidates For Fracturing

- Sufficient Recoverable Reserves
- Sufficient Reservoir Pressure
- Low Permeability (Less Than 10 mD)
- O/W And O/G contacts Not Very Close
- Good Cementation
General Criteria For Well Selection

- State of depletion of producing formation
- Formation composition & consolidation
- Formation permeability
- Formation thickness
- Isolation of the zone to be treated
- Condition of well equipment
- Production history of the well
- Offset production history
- Location of water, oil-water and gas-oil contacts
Frac Fluids - Properties

- Reservoir Compatibility
- Low leak off rate
- Ability to carry the propping agent
- Low friction loss
- Easy removal from the formation
- Stability at reservoir condition
- Availability
- Safety
- Cost economics
Type Of Frac Fluids

- Water base
- Oil base
- Acid base
- Fluid emulsions
- Foamed fluid
Characteristics Of Major Fluid Systems

- Water base
  - Gelled water: medium viscosity, low friction
  - Cross linked water gel: high viscosity, high proppant carrying capacity, low friction loss (with the help of delayed cross linker)
- **Oil base**
  - Compatible with reservoir, high viscosity, high friction loss

- **Emulsion base**
  - Good viscosity, low fluid loss, good clean up

- **Acid base**
  - Low viscosity, unstable at high temperature
Fracture Height Coverage

What we want

Pay Zone

What we may get

Or
Multizone Stimulation

What we want

Pay Zone
Pay Zone
Pay Zone

What we may get
Fracture Growth Vs. Time

Pay Zone

What we want

What we may get
Spearhead

- Spearhead reduce breakdown pressure
  - Typically 5 - 10 bbl HCl acid ahead of pad
- Formations can be difficult to breakdown, due to perforation damage, etc.
  - Pump 50% into formation at matrix rates
  - Shut down 5 minutes
  - Pick up rate and Frac the last 50% of acid
  - Continue with main Frac
PAD

- Initiate fracture
- Breakdown the perforations
- Develop width required for proppant
  - like a wedge to initiate fracture
- Sometimes use extra-viscous pre-pads
- Sometimes referred to as ‘clean fluid’
PAD

- Small pads may not develop sufficient width for proppant, potentially causing screen-outs.
- Excessive pad may delay closure for a significant period of time, allowing proppant convection out of zone.
RATE

- Rate must exceed leak-off into the formation in order to propagate the frac

  - Typically performed 15-25 bbl/min

  - In some cases, either higher or lower rates are required.
Proppant Schedule

- Defines the proppant addition rate into the slurry
- Typically 1 - 16 ppg
  - e.g. 5 ppg means that 5 lb of proppant is added to 1.0 gallon clean fluid, for a total of 1.225 gallon slurry.
- Increase either in a ramp or increments of 1 - 2 ppg.
Proppant Stages

- Immediately follow the pad
- Slurry is ‘clean’ fracturing fluid mixed with proppant - sometimes referred to as ‘dirty fluid’
- Continue to generate length and width
- Start proppant at 1 -3 ppg
- Slowly increase proppant concentrations.
Proppant Stages

- Perforation and near-wellbore may not accept higher concentrations of proppant early in the treatment (i.e., if wedge isn’t large enough)
- Erode the perforation and the formation
Flush

- Immediately follows the proppant stages
- Pump clean (non-sand-laden) fluid to displace the proppant to within a short distance of the perforation and remove it from the wellbore
- Use low friction, economical fluid
- Often friction reduced based fluid is used.
Under-Flush

- Volume by which the proppant is under-flushed to the perforation
  - Safety factor to ensure that proppant in not accidentally over-flushed into the perforation, as this gives poor conductivity near the wellbore

- Usually, under-flush:
  - 3 bbl down tubing
  - 6 bbl down casing or annulus
Real Time Monitoring
Fracture Initiation
Proppant Initiation
Ideal Frac Completion

WATER CONTROL

WHY & HOW
Why Water Control

- For every barrel oil we produce 3 barrel water.
- For a typical well with 80% water cut the we spend $4/bbl for water

Reasons of additional cost
- Lift and separation
- Treatment & disposal
- Corrosion & Scaling
- Formation damage, loss of productivity
Water Types

- **Sweep water**: 1. Active aquifer  
   2. Injection water
- **Good water**: Unavoidable  
  1. Water in oil at OWC  
  2. Oil in water emulsion  
  3. Injection water
- **Bad Water**: Avoidable  
  1. Water competing with oil  
  2. Mechanical failure  
  3. Operational mistake
Good Water
Bad Water

- Casing Leak
- Channeling
- Coning
- Crossflow
- Fracture
- Rise of OWC
- Breakthrough
Casing, tubing or packer leaks
- Channeling -
Flow behind casing
Coning
Movement of oil water contact
Vertical Window - Cross-flow
Fracture or Fault from a water layer
Injection water breakthrough

Injector

Producer
Well Diagnostics & Candidate selection

Key to water control is proper diagnosis

- Screen wells suitable for water control
- Determine the type of problem
- Find the correct water entry point
- Find the best control system
- Find suitable placement method
TOOLS & TECHNIQUES

Well History:
- Drilling history
- Well geometry
- Mud loss history
- Filtration loss

Well Diagnostics & Candidate election
Well Diagnostics & Candidate election

TOOLS & TECHNIQUES

- Geological data
- Reservoir data
- Water analysis data
- Oil analysis data
Well Diagnostics & Candidate election

TOOLS & TECHNIQUES

Production history
- Recovery plot
- Production history plot
- Decline curve
- Diagnostic plot
Well Diagnostics & Candidate election

TOOLS & TECHNIQUES

Well Logs

- Open hole logs
- Cased hole logs
- Production logs
- USIT
- FMI
Water Control Solutions

Mechanical
Physical
Chemical
Water Control Materials

Mechanical Solutions & Well Techniques

- Packers
- Bridge Plugs
- Casing Patches
- Infill Drilling
- Side Tracking
- Pattern Flow Control
- Horizontal
- Multilateral
Physical Plugging Agents
Conventional Cement Squeeze
Ultra Fine Cement
Foam-cement
Particulates
Sand Plug
Conventional Cement Squeeze
Often performs well as a blocking agent
Good solution for large casing hole
Long life
Near wellbore application
Poor penetration
Provide Mechanical strength to Polymer gel
Economical
Ultra-fine Cement (Size - < 10 micron)
Better penetrability than conventional cement

- Small size casing hole
- Micro-channels
- Can be mixed with ultra fine silica
- Thermal stability
- Expensive
Hydrocarbon based ultra-fine Cement

- Reacts slowly upon contact with water
- Moderate penetration depth
- Can be used in conjunction with polymer gel
Foam Cement

- Reduced weight
- Moderate penetration depth
- Can be used in conjunction with polymer gel
Particulates

- Clay gels
- Carbonates
- Various Loss control materials

To be used in combination with other chemical system,
Sand plug

- Rig-less alternative to cement plug
- Low cost
- To be applied with binder
- Supporting agent to low strength polymer gel
- Inexpensive
Monomer Systems

- Water thin gellant
- Thermal & catalytic activation
- In-situ polymerization
- Designable placement time
- Matrix treatment in low permeable reservoir
- High volume application possible
- Applicable upto 140 °C
- Total to partial sealant
- Easy to mix
Cross-linked Polymer Systems

- Mainly acrylamide ter-polymer
- Organic or Inorganic cross-linker
- Variable concentration
- Low to very high viscosity
- Designable placement time
- Applicable in sand stone & carbonate
- Large volume application possible
- Applicable upto 140 °C
- Total sealant
Cross-linked Polymer Systems

Application
- Bottom water shutoff
- Coning
- Channel from Injector
- Casing leak
- Fracture into injector/aquifer
- Plugging operation/zone abandonment
- Gas shutoff
Relative permeability Modifier (RPM)

- Xantham co-polymer (XC)
- Inorganic cross-linker
- Low to very high viscosity
- Shear thinning
- Applicable in sand stone
- Large volume application possible
- Applicable upto 100 °C
- Designable gel strength
Relative permeability Modifier (RPM)

- Permeability of oil/water up to 10
- Bull head treatment possible
- Needs mechanical support
- Low cost
- Applicable in 3-D conning & unpredictable watered out zone
Resins

- 2 or 3 component system
- Low viscosity
- Permanent solution
- Irretrievable
- Relatively higher cost
- Applicable for channel repair and casing leak
Placement Strategies

- Casing Leak
- Channeling
- Coning
- Crossflow
- Fracture
- Rise of OWC
- Breakthrough
SAND CONTROL
Geological Sands

- **Marine deposited sands:**
  - Cemented with calcareous or siliceous material.
  - Well consolidated.

- **Erosion deposited sands**
  - Cemented with soft clay/silt.
  - Partly consolidated.
  - Unconsolidated.
Factors Affecting Sand Production

- Overburden, Friction, Differential Stresses.
- Cementing material, Degree of consolidation.
- Fluid viscosity, Production velocity, Drag forces.
- Capillary forces, Water production.
• OVERBURDEN
• CEMENTING
• CAPILLARY
• DRAG
Sand Control

Definition
- Stop sand movement & maintain maximum production.

Success measures:
- Stop sand movement.
- Maintain maximum production
- Pay out cost.
Why Sand Control?

- Sand fill up Hole, Casing, Tubing
- Erosion Down hole tubular, Safety valves,
  Chokes, A/L equipment
- Sand accumulation Surface lines, Equipment
- Abrasive wear
- Surface control, Valves, Pipes
- Buckling of casing
- Handling & disposal
Methods Of Sand Control

- Restrictive production rate.
- Mechanical methods: Slotted liner, Wire-wrapped screen, Pre-packed screen, Frac pack, Gravel pack, High rate water pack.
- Chemical methods.
- Combination methods.
STEP: 1

Resin coated sand is pumped through perforations, filling voids and re-stressing formation. It will harden in this shape to form a permeable mass.
STEP: 2

The mass is drilled out to return the well to production. The production of the mass remaining hdps prevent production of sand.
Gravel Pack

- Consists of sized particles placed in the annular space between an unconsolidated formation and a centralized screen.
- open or cased hole.
Laboratory Analysis

- Sand sampling:
  - Rubber sleeve cores.
  - Conventional cores.
  - Side-wall cores.
  - Bailed samples.
  - Produced sand.

- Sieve analysis

- Clay content.
Sieve Analysis
FIGURE
CHART FOR VISUAL ESTIMATES OF ROUNDNESS AND SPHERICITY
(From Krumbein and Sloss, 1963)*

KRUMBEIN & SLOSS CHART

ROUNDNESS

SPHERICITY
Well Preparation

- **Perforation:**
  - Type: Over balance, TCP, EOB
  - Density: 12 SPF
  - Entry hole dia.: 0.75”

- **Perforation Cleaning:**
  - Back surging
  - Perforation washing
TYPICAL GRAVEL PACK SYSTEMS
Sequence Of Operation

1. Clear bottom
2. Perforate/ Re-perforate
3. Scrap the well
4. Set bridge plug
5. CTC
6. Make up GP assembly
7. Tag bridge plug
8. Set packer
9. Mark circulating / Squeeze / Reverse position
10. Acidize in squeeze mode
11. Pump slurry till screen out/pack
12. Reverse out excess gravel
13. Stab seal