Techniques to Maximise Oilfields Production
In The Republic of South Sudan
By:
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Plans to increase production rate can be categorized into two main areas:

A) Short term Plans.

A) Medium and Long term Plans.
Plans to increase Production Rates

A) Short Term Plans (Workover)

Workover operations are used to solve:

1. Low reservoir permeability.
2. Formation damage.
3. Water production.
4. Casing damage.
Plans to increase Production Rates

B) Medium and Long Term Plans

Medium and long term plans can be categorized as:

1. IOR (improved Oil Recovery).
2. EOR (Enhanced Oil Recovery)
Plans to increase Production Rates

B) Medium and Long Term Plans (IOR)

IOR includes:

- Infill wells.
- Water Injection.
- Artificial Lift.
Plans to increase Production Rates

B) Medium and Long Term Plans (EOR)

EOR is considered a tertiary recovery method. It is mainly after the mobility relationship between water and oil.

EOR include:

a) Polymer flooding.
b) Surfactants & alkaline injection.
c) Thermal methods.
d) Miscible flooding ($\text{CO}_2$)
A) Short Term Plans (Workover)
<table>
<thead>
<tr>
<th>Excessive Water Production</th>
<th>Squeeze &amp; Re-perforating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Shut Off by Plugs</td>
</tr>
<tr>
<td></td>
<td>Chemical Water Shut Off</td>
</tr>
</tbody>
</table>
There are many factors that can influence water influx:

1] **Geological**
   - Size of structure and its location
   - Relatively thin upper layers with lateral variation
   - Thin shale break which will easily allow channeling

2] **Well Location**
   - Up dip/Down or Crest/Flank

3] **Drive Mechanism**
   - Strong or weak water drive

4] **Oil-Water Contact**
   - Bottom or edge water

5] **Thickness of Net Pay**

6] **Operational Parameters**
   - Pressure drawdown
   - Pump frequency
   - Choke size – during testing.

7] **Completion interval**
   - Stand off OWC
Water Production Mechanisms

(Curve 1):
- Completion Into Water and the problem of fresh water resistivity.
- Channel behind Casing (week current behind)

(Curve 2):
- Casing Leaks
- Channel behind Casing
- Stimulation Out of Zone
- Barrier Breakdown

(Curve 3):
- Bottom Water
- Coning or Cresting
- Channeling through High Permeability

(Curve 4):
- Fracture Communication between injector and Producer
Excess Water Production Concerns and Challenges

- **Excess water production is a concern in view of:**
  - It is causing water handling problems at FPFs
  - Water treatment and disposal problems
  - Restricting flow of low P.I intervals
  - Optimizing ESPs in view of change in P.I
  - Severe sand production which reflect on sand fill and hence perforation coverage

- **Steps to be taken to arrest this excess water production problem**
  - As proper diagnosis to identify the source of excess water production:
    - Proper well history is a key element.
    - Same like the doctor starts with asking the patient about his health history.
  - Aggressive water shut off to be taken up to reduce water cut and increase oil production.
Reasons and Route Cause of high water cut Production

- Adverse Mobility ratio in such fields like Bamboo, Heglig & Munga
- Production mechanism - ESP & PCP caused High draw down
- Bottom & Edge water encroachment (Mid Field)
- Injection water breakthrough in Unity (Talih West Field)
- Flow behind casing due to poor Cementation in some wells (BAM-X, NE-X & NE-Y)...

(How can we solve this?)
Add new technique to determine excessive water production mechanisms as seen in petroleum production wells has been developed and verified.

Log-log plots of WOR (Water/Oil Ratio) vs. time show different characteristic trends for different mechanisms.

The time derivatives of WOR was found to be capable of differentiating whether the well is expecting

- Water coning,
- High-permeability layer breakthrough,
- Near well bore channeling and
- Layer Conductivity

This case WOR and WOR' increase = layer conductivity = good water.

WOR and WOR’ decrease at 2000 days because of an injector shut down in the near area. Note that they resume their increase on the same slopes sometime after when water comes from farther wells. Some sharp increase corresponds to near well bore flow followed by a remedial squeeze treatment.
In-Jun-99 from Zarqa X (2176-2192.5mkb)

Start W-Injection IN Nov-01

Drop in O/Liq due to Press

Oil Dec wc inc-bad w
Layer Conductivity From WI-X to UN-X in ZC Distance (695m)
PROPOSAL ACTION PLAN for SEPARATE LAYER INJECTION

UN-X (CURRENT)

Zarqa-A

2069 -2074 mkb

Zarqa - C

2186 - 2198 mkb

Zarqa - D

2267 - 2275 mkb

PLT

Zarga A 12.75
Zarga C 84.94
Zarga D 2.31

Back
High Water Cut Diagnosis Methods (Operation)

- **Classic Methods:**
  - Swab Test
    - Swab of Multi layers will Take long time of Rig
    - Some times misleading (it is almost at static condition)

- **Other Methods:**
  - Run PLT
    - Get Reservoir parameters (pressure, BHP, PI) under dynamic condition
    - PLT conducted Ex: (He-X, TAS-X, Munga-X)
1) No contribution then single layer completion instead of commingling.
General Water Shut of techniques

- **Classic Methods:**
  - **Cement Squeeze:**
    - Open ended tubing STC EX: MG-X,Y
    - Drillable Cement Retainer (DCR)
  - **Water Shut off with Drillable Bridge Plug (DBP) EX: HE-X**

- **Other Techniques:**
  - Mechanical Water Shutoff
  - Chemical Water Shut off
  - Plan to use Multi Packer (on progress)
Classic Water Shut off Techniques

- Cement squeeze and reperforate:
  - Open ended tubing STC and cement retainer DCR:
    - Successfully implemented at TY-X on 13 August 2008
    - Bentiu X lower was permanently cement squeezed
    - Bentiu X upper was cement squeezed and partially re-perforated
    - Aradeiba was squeezed cement and totally re-perforated

- Well performance Pre/Post WSO job:

<table>
<thead>
<tr>
<th>Pre Workover</th>
<th>Post Workover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Gross</td>
</tr>
<tr>
<td>21 Mar '08</td>
<td>2039</td>
</tr>
</tbody>
</table>

TY-X Well Schematic
Classic Water Shut off Techniques

- Water shut off using Drillable Bridge Plug DBP
  - Was successfully being utilized at HE-X in July 2008
  - Bentiu lower was isolated with DBP set at 1731.0 mKB

- Well performance Pre/Post WSO job:

<table>
<thead>
<tr>
<th>Pre Workover</th>
<th>Post Workover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Gross</td>
</tr>
<tr>
<td>28 May ’08</td>
<td>2917</td>
</tr>
</tbody>
</table>

- Lesson Learnt
  - Better diagnosis & Good reservoir evaluation will Lead to have an excellent result in the re-completion
The tool works by applying differential hydrostatic pressure against the switches, which are calibrated to open and then close at certain pressure values (24 Mpa, 18 Mpa and 12 Mpa).

**Limitation of Mechanical Water shut off Tool:**

- The candidate should be 7” casing (availability of 7” packer).
- No. of producing zones (three).
- Differential pressure to operate tool switches (on and off).
- Surface pressure must not exceed 24.4MPa. (Well head pressure limitation).
- Well depth should be more than 2200 mKB.
- Sand production induces premature switches failure.

**1st Trial EH-X:**
- Failure causes were due to packer leakage and switch check valve malfunction.

**2nd Trial EN-X:**
- Sand production caused the switches to stuck and led to confusion in producing zones combination and hence test results.
Lesson Learnt:

- Sand presence affected the tool switches operation.
- The tool should match the application GNPOC wells not vice versa.
- Provision of fixable ESP to accommodate different reservoir scenarios for test and production (i.e. formation pressure and PI).
Chemical Water shut off Technique

- The chemical works by applying plugging agent, high conductivity zones can be shut off selectively.

- **Chemical WSO challenges**
  - Chemical shelf life.
  - No or little improvement in oil gain posts the WSO job.
  - Deep study should be carried out to select reliable chemical type.
  - Very limited candidate meeting the operation requirements.
  - Operation and logistic.
  - Effort & long time consumed for pre-job preparation and potable water supply.
  - Its intensity and initial gelling time can be adjusted at a certain extent according to the reservoir condition; temp.
  - Well used to produce 5712 BLPD, 407 BOPD with 92% WC before job execution.

- **1st trial HE-X:**
  - Post job the well produced 200 BOPD with 84% WC and the gross was limited to max. 1800 BLPD as per RE recommendation.
  - The well continued production at low controlled rate for six months.
  - since no improvement in oil gain achieved, RE advised to revert back to the previous condition ( currently the gross is 5159, oil 445 and 91% WC)

- **2nd trial HAM-X:**
  - Well used to produce 2772 BLPD, 62 BOPD with 98% WC before job execution.
  - The well was abandoned after classic re-completion job.
Lesson Learnt:
- Deep study should be carried out to select reliable chemical type.
- Very limited candidate meeting the operation requirements.
- Its intensity and initial gelling time can be adjusted at a certain extent according to the reservoir condition; temp.
Production Performance of HE-X After (WOJ)

**Improvement in oil production Before and after WOJ**

- Production from Bentiu-X only
- Production from Bentiu-X & ardeiba

**Decrease in water production before and after WOJ**

- Avg WATER_RATE (bwpd)
- Avg WATER_RATE (bwpd)
Mitigation Plan to Develop Bentiu-X & Bentiu-Y:

Installation of dual ESP can revive production from Bentiu-3 keeping upper layers unaffected.

Well Potential:

- Upper layers = 1035 bopd
- Lower layer = 382 bopd
- Total = 1473 bopd
### Talih X PLT Result

#### Contributions by phase

<table>
<thead>
<tr>
<th>Zones ( m )</th>
<th>Qw res. B/D</th>
<th>Qo res. B/D</th>
<th>Qg res. B/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>GD-2</td>
<td>228.39</td>
<td>181.88</td>
<td>0.00</td>
</tr>
<tr>
<td>GD-3</td>
<td>206.94</td>
<td>55.57</td>
<td>0.00</td>
</tr>
<tr>
<td>GD-4</td>
<td>2500.70</td>
<td>23.33</td>
<td>0.00</td>
</tr>
<tr>
<td>GH-1/2</td>
<td>605.76</td>
<td>58.94</td>
<td>0.00</td>
</tr>
<tr>
<td>GH-3</td>
<td>252.23</td>
<td>2.11</td>
<td>0.00</td>
</tr>
<tr>
<td>GH-4</td>
<td>2.98</td>
<td>0.82</td>
<td>0.00</td>
</tr>
<tr>
<td>GH-5</td>
<td>210.91</td>
<td>4.82</td>
<td>0.00</td>
</tr>
<tr>
<td>ZA-1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>ZC-1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>ZD-1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

- Ghazal-X produced 2500 bbl/d water
  - As if we are wasting effort of injector daily
- No Contribution from Zarga at presence of Gahzal, although TAS-X down dip well produced ~ 250 bopd
  - Completion Strategy to be revised for new wells and for existing wells on opportunity basis
### PLT Munga-X Result

<table>
<thead>
<tr>
<th>Zones m</th>
<th>Qw res. B/D</th>
<th>Qo res. B/D</th>
<th>Qg res. B/D</th>
<th>W</th>
<th>O</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1A</td>
<td>180.10</td>
<td>5.20</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-1B</td>
<td>4210.19</td>
<td>65.22</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-1C</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B-1B interfere B-1A,

- ✓ Action taken is reducing perforation interval to 2 meter, decreased the water production
  - ✓ B-1A
  - ✓ B-1B
- ✓ Result is very successful,
- ✓ same idea conducted in Munga-X with very successful result
Munga-X Performance after & Recompilation PLT Job
Clear water production reduced
MG-X Performance after Re comp based on PLT Result of MG-Y

- Oil Rate (CD): 1038 bbl/d
- Water Cut% (CD): 36%
- Liquid Rate (CD): 1627 bbl/d
- Cumoil: 1.06 MM

Well Performance: MG-X
Last DB Date: Nov 2009  Current: 12/27/2009

Graphs showing:
- Oil Rate (PD) (bbl/d)
- Liquid Rate (PD) (bbl/d)
- Water Rate (PD) (bbl/d)
Strategy forward in addressing water production

Immediate

- Application of Y-Tool PLT. Permanent installation of Y-Tool at key wells in a block to reduce cost.
- Completion strategy:
  - single layer completion for future wells.
  - Exploratory wells Perforation interval should be adjusted & optimized far away from OWC
- Continue Drilling of Horizontal wells to delay water coning

Medium Term

- Establish RMP, optimize Water Production and enhance Recovery Factor.
- Application of New Technology
  - Multi packer Completion
  - Electro Treatment

Long Term

- Chemical Water Shut Off
  - In depth study and screening criteria should be set up for Mechanical and chemical water shut off
Medium and Long Term (IOR)
IOR drilling horizontal wells:
- reduces water coning due reduce draw down in the reservoir.
- Long length exposed to pay zone increase production.
- More effective in the sand oil formation with short distance to water.
- Horizontal wells are now completed with new methods in additional to traditional open hole, cased hole, slotted line or pre-perforated pipe.
- Smart completion involves permanent zonal solution with external packers, downhole choke & other device for controlling the inflow.
Where do we use IOR water injection?

- Water injection will not improve recovery in area of strong water drive.
- It is possible where depletion is observed and has edge water influx.
- It is less expensive to drill water source well into shallow aquifer and directly to the injector without further treatment while produced water needs treatment unit.
IOR (water management)

- Diagnose the entire water cycle (reservoir, producers, facilities, injectors).
- Updated the field development plan.
- Identify workover opportunities.
- Apply suitable technology.
  - Producers.
  - Injectors.
  - Surface.
Medium and Long Term (EOR)
Definition of Heavy Crude Oil or Extra Heavy Crude Oil

Heavy crude oil or extra heavy crude oil is any type of crude oil which does not flow easily. It is referred to as "heavy" because its density or specific gravity is higher than that of light crude oil. Heavy crude oil has been defined as any liquid petroleum with an API gravity less than 20°. (Dusseault, M.B)
Extra heavy oil

Extra heavy oil is defined with API gravity below 10.0 °API (i.e. with density greater than 1000 kg/m³ or, equivalently, a specific gravity greater than 1). With a specific gravity of greater than 1, extra heavy crude is present as a dense non-aqueous phase liquid when spilled in the environment.
Heavy oil occurs in both carbonate and sandstone reservoirs of Paleozoic Age along the perimeters of the basins in the same sediments where light oil occurs. The oil is heavy because escape of light ends, water washing of the oil, and biodegradation of the oil have occurred over million of years.
HEAVY CRUDE OIL
± 10 ≤ API ≤ ± 20

- LIGHT VISCO HEAVY OIL: 40 – 1000 cP
- MED VISCO HEAVY OIL: 1000 – 10,000 cP
- HI VISCO HEAVY OIL: > 10,000 cP
Methods to Improve Recovery Efficiency

- Natural Flow
- Artificial Lift
- Enhanced Oil Recovery
- Production/Injection Control
- Strategic Wellbore Placement

Conventional Oil Recovery
EOR

CHEMICAL INJECTION

Lower Viscoisty, Alter wetting or Reduce SOR

STEAM INJECTION

Lower Viscoisty Reduce SOR

Limitations:
- Depth
- ESP
- Higher Pressure
- Rock damage
Depth Limitations for Enhanced Oil Recovery Methods

<table>
<thead>
<tr>
<th>EOR Method</th>
<th>Depth [ft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon-Miscible</td>
<td>Very good Deep enough for required pressure</td>
</tr>
<tr>
<td>Nitrogen and Flue Gas</td>
<td>Very good Deep enough for required pressure</td>
</tr>
<tr>
<td>CO$_2$ Flooding</td>
<td>Deep enough for required pressure</td>
</tr>
<tr>
<td>Surfactant/Polymer</td>
<td>Limited by temperature</td>
</tr>
<tr>
<td>Polymer</td>
<td>Limited by temperature</td>
</tr>
<tr>
<td>Alkaline</td>
<td>Preferred zone High cost</td>
</tr>
<tr>
<td>Fire Flood</td>
<td>Deep enough for required pressure</td>
</tr>
<tr>
<td>Steam Drive</td>
<td>Normal range (possible)</td>
</tr>
</tbody>
</table>
### Screening Criteria

#### Preferred Oil Viscosity Ranges for Enhanced Oil Recovery Methods

**Oil Viscosity - Centipoise at Reservoir Conditions**

<table>
<thead>
<tr>
<th>EOR Method</th>
<th>0.1</th>
<th>1.0</th>
<th>10</th>
<th>100</th>
<th>1,000</th>
<th>10,000</th>
<th>100,000</th>
<th>1,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon-Misc.</td>
<td>Very good</td>
<td>Good</td>
<td>More Difficult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen, Flue Gas</td>
<td>Good</td>
<td>More Difficult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ Flooding</td>
<td>Very good</td>
<td>Good</td>
<td>More Difficult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surfactant/Polymer</td>
<td>Good</td>
<td>Fair</td>
<td>Very Difficult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not Feasible</td>
</tr>
<tr>
<td>Polymer</td>
<td>Good</td>
<td>Fair</td>
<td>Difficult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not Feasible</td>
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<tr>
<td>Alkaline</td>
<td>Good</td>
<td>Fair</td>
<td>Very Difficult</td>
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<td></td>
<td></td>
<td>Not Feasible</td>
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<tr>
<td>Steam Drive</td>
<td>Not economically feasible</td>
<td>Good</td>
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<td></td>
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<tr>
<td>Special Thermal</td>
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<td>Various Techniques Possible</td>
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<tr>
<td>Mining / Extraction</td>
<td>Not Feasible</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not Established Limits</td>
</tr>
</tbody>
</table>
EOR

Screening Criteria

Permeability Guides for Enhanced Oil Recovery Methods

<table>
<thead>
<tr>
<th>EOR Method</th>
<th>Permeability (millidarcy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon-Miscible</td>
<td>Not Critical If Uniform</td>
</tr>
<tr>
<td>Nitrogen and Flue Gas</td>
<td>Not Critical If Uniform</td>
</tr>
<tr>
<td>CO₂ Flooding</td>
<td>High Enough for Good Injection Rates</td>
</tr>
<tr>
<td>Surfactant/Polymer</td>
<td>Preferred zone</td>
</tr>
<tr>
<td>Polymer</td>
<td>Preferred zone</td>
</tr>
<tr>
<td>Alkaline</td>
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<tr>
<td>Fire Flood</td>
<td>Preferred zone</td>
</tr>
<tr>
<td>SteamDrive</td>
<td>Preferred zone</td>
</tr>
</tbody>
</table>

Higher permeabilities are usually better.
EOR

Carbonate Oil Reservoirs or Heavy oil reservoirs or Resinic Oil Reservoirs.

Commonly Oil Wetting Reservoirs

Commonly Mix Wetting Reservoirs

Commonly Water Wet Reservoirs

Potential of Oil Recovery Factor From Surfactant Flooding

Oil Recovery Factor of Water Flooding or Natural Water Flooding
**Heavy Oil with high viscosity oil Reservoir**

Water flooding is a common and inexpensive secondary oil recovery technique for light oils. For viscous oils, the adverse mobility ratio between the water (about 1 cp) and the oil (40 - 10,000 cp) phase severely hampers the performance of the waterflood.

Water fingers through the oil phase and leaves most of the oil behind leading to poor recoveries. This could happen also in heavy oil reservoir with water drive.
EOR

Chemical Flooding

- Lowering interfacial tension to allow the oil to be recovered.
- Wettability change of the formation rock from oil-wet to water-wet.
- Wettability change from water-wet to oil-wet.
- Emulsification and entrapment.
- Solubilizing the rigid films at the point of the oil-water interface.
EOR

Thermal Flooding
Conclusions and Recommendations

- Decline in oil production is attributed mainly due to high water cut. Water cut in mature fields is on rising trend which has severe negative impact to fields reserve (EUR).

- Excess water production is headache for operating company and will cost time and money better to leave in reservoir.

- Better diagnosis, understanding will lead to successful remedial action.

- Diagnostic plots which was carried out to that well (UN-X) Produced high WC indicates this high water cut mostly related to layer Conductivity.

- Control liquid rate for New wells & WO wells.