The EOR Alliance

Recent experience in EOR programs (Miscible Gas injection, Chemical EOR) on analogues of Pakistani oil fields

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AN ALLIANCE BETWEEN »»

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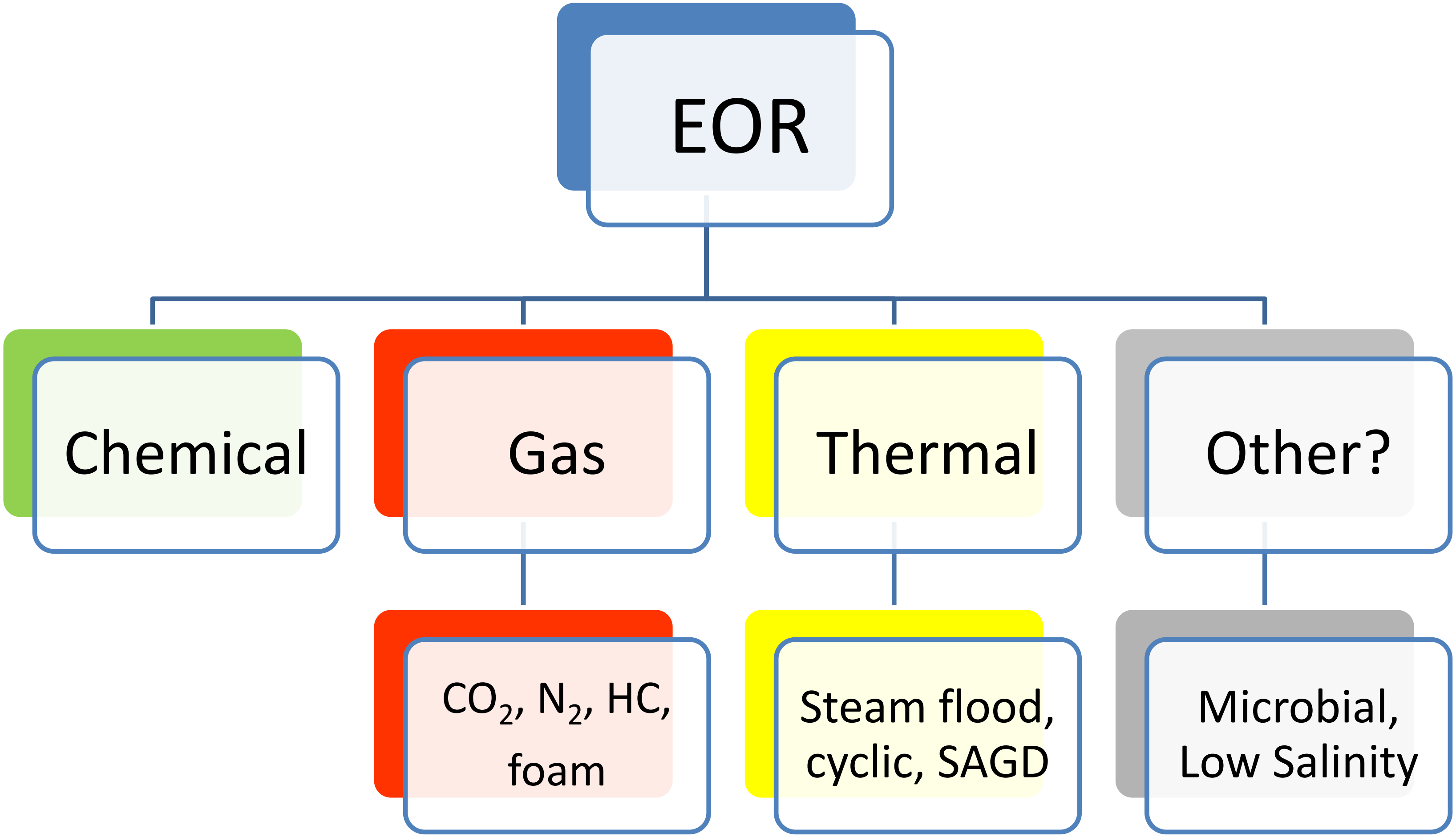
SOLVAY asking more from chemistry®

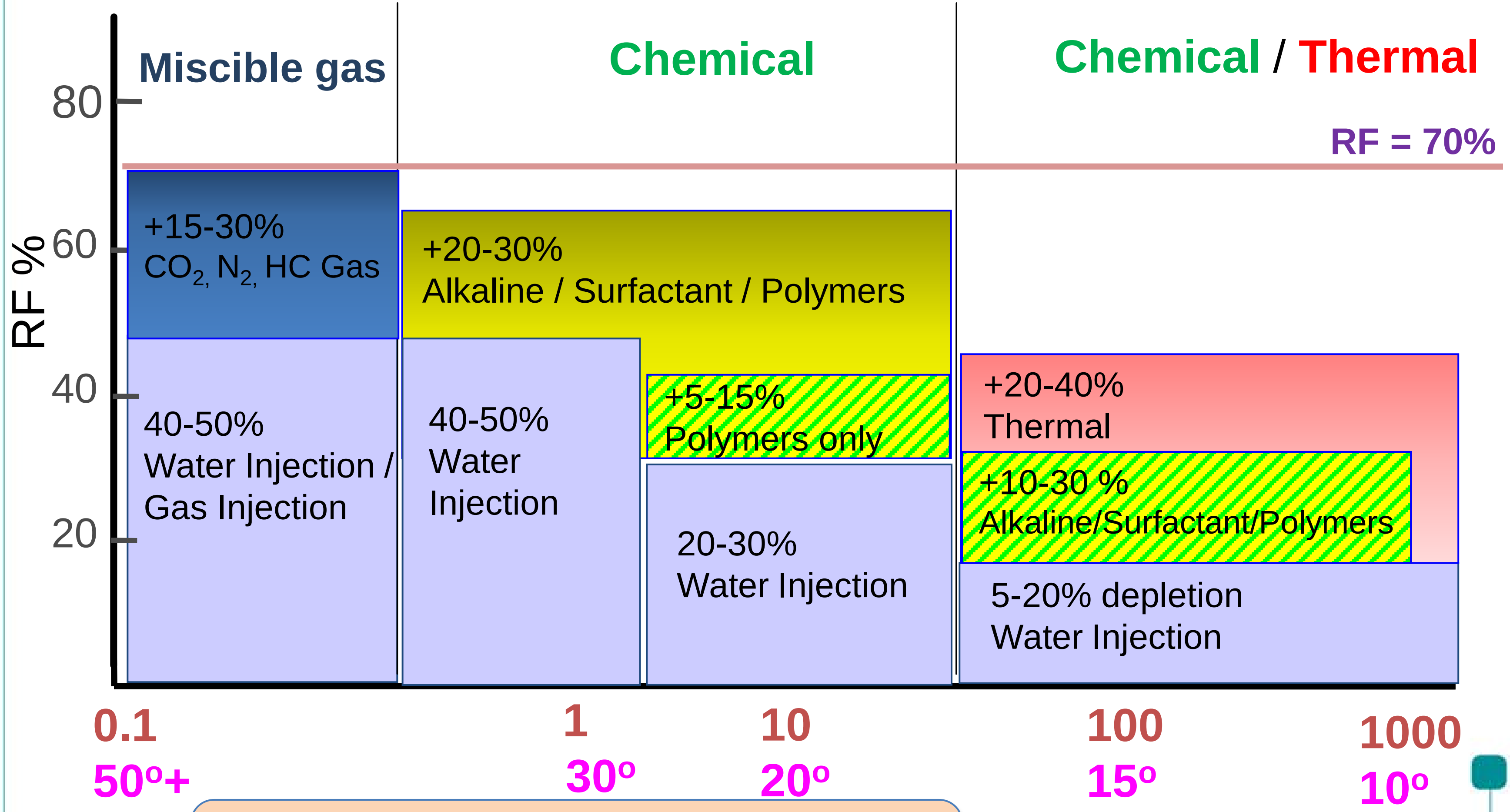
Presentation Outline

- EOR methods as a function of oil type
- Principles of Miscible Gas and Chemical EOR
- Pakistani oil fields and their analogues
- EOR screening criteria
- Q&A

Enhanced Oil Recovery



The Main EOR methods



EOR share of world oil production, currently 4%, may triple by 2030

Principles of EOR

- Oil Recovery efficiency: **$E = E_m \times E_v$**

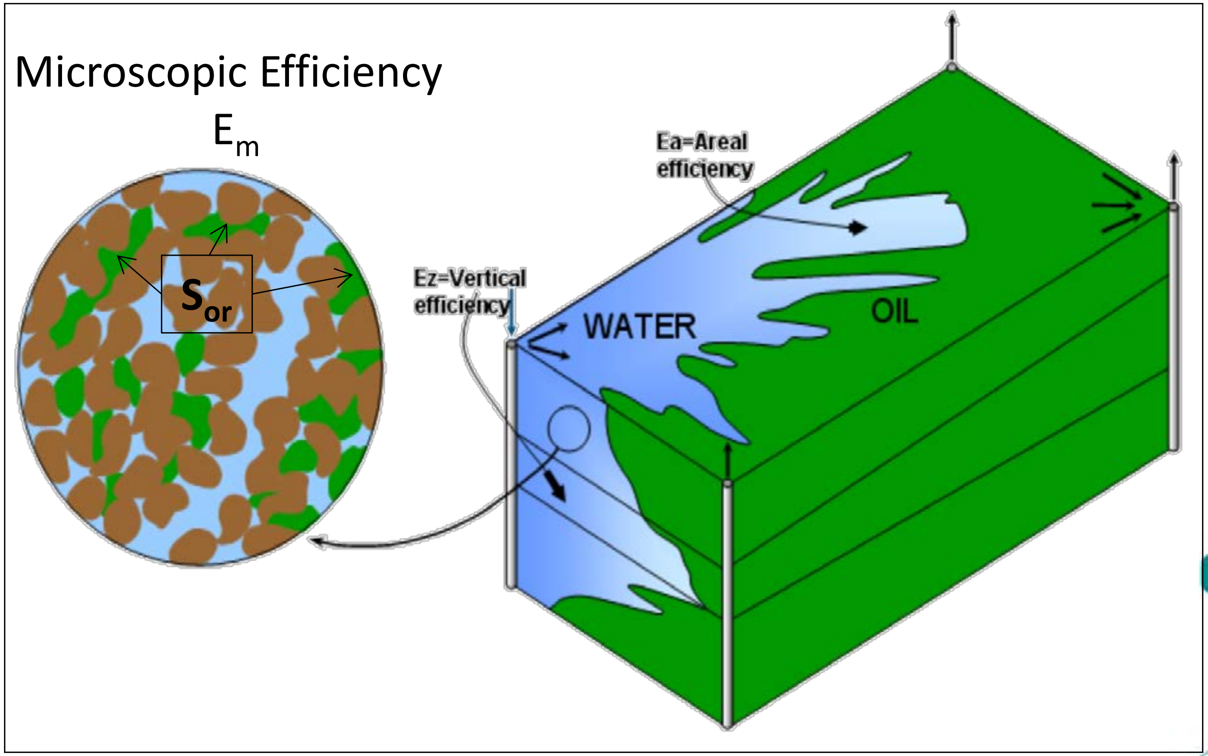
  E_m : microscopic efficiency

  E_v : volumetric sweep efficiency

  25% < E < 60%

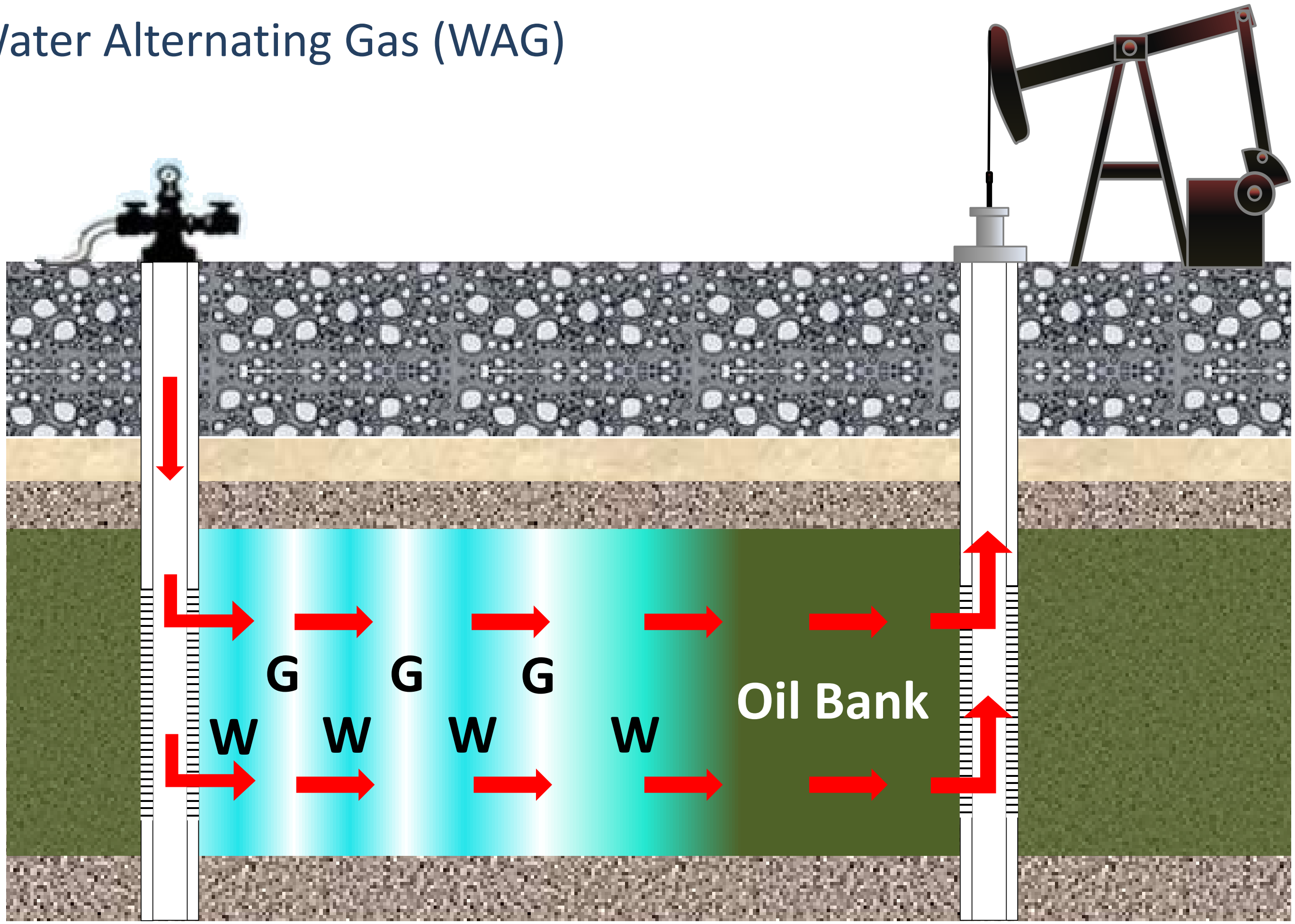
Volumetric sweep efficiency

$$E_v = E_a \times E_z$$



Gas Injection

- Water Alternating Gas (WAG)

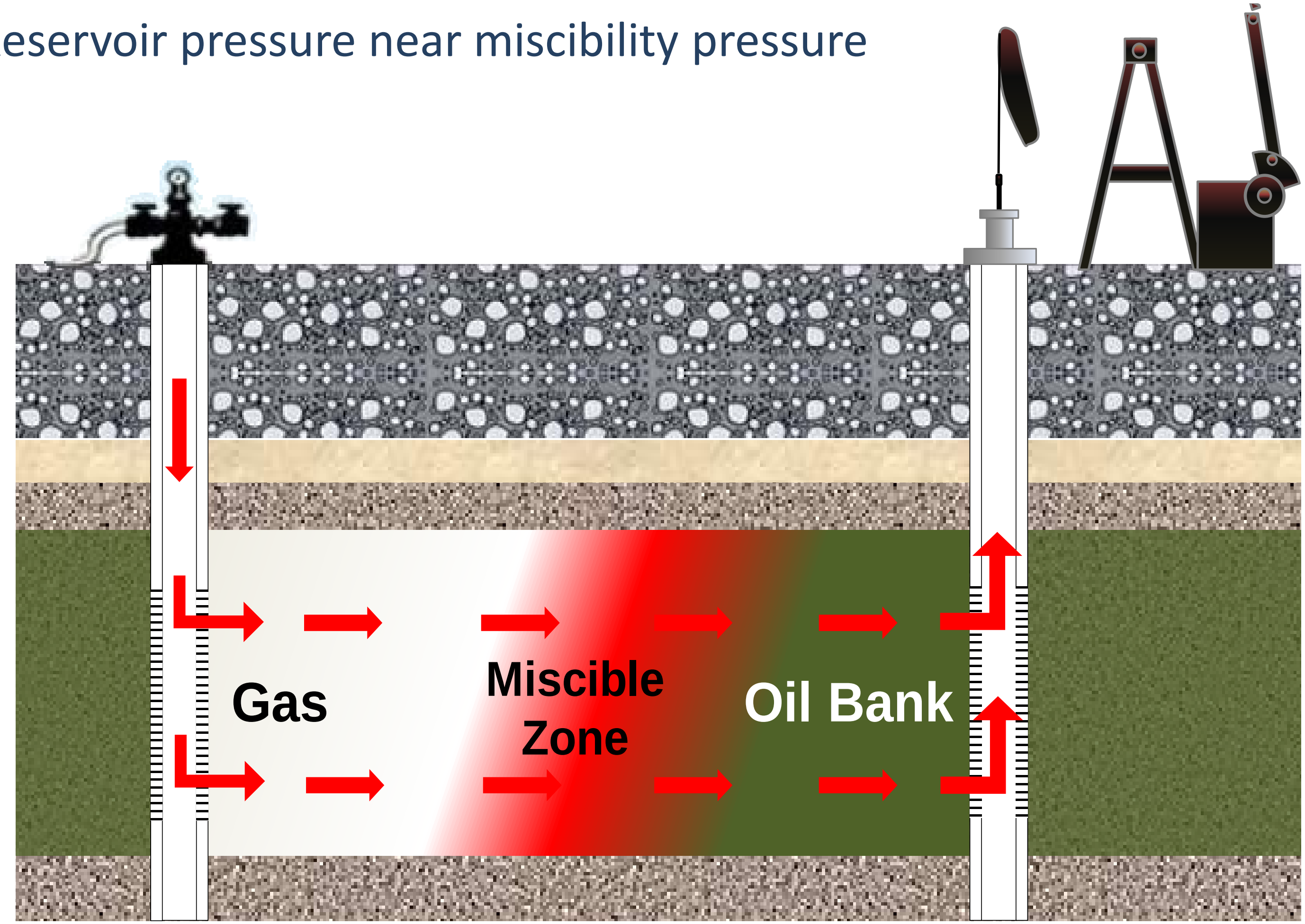


Gas Injection

- Water Alternating Gas (WAG)
  - **Principles**
    - Optimizes microscopic recovery (gas-oil displacement)
    - Optimizes volumetric recovery (water-oil displacement)
  - **Advantages**
    - Management of associated gas
    - Reduces gas mobility
    - Sweeps zones that are not flooded by water
    - Supposed to improve the microscopic efficiency
  - **Disadvantages**
    - Risk of rapid fluid segregation
    - Risk of rapid gas breakthrough
    - Decrease in water injectivity

Miscible Gas Injection

- Reservoir pressure near miscibility pressure



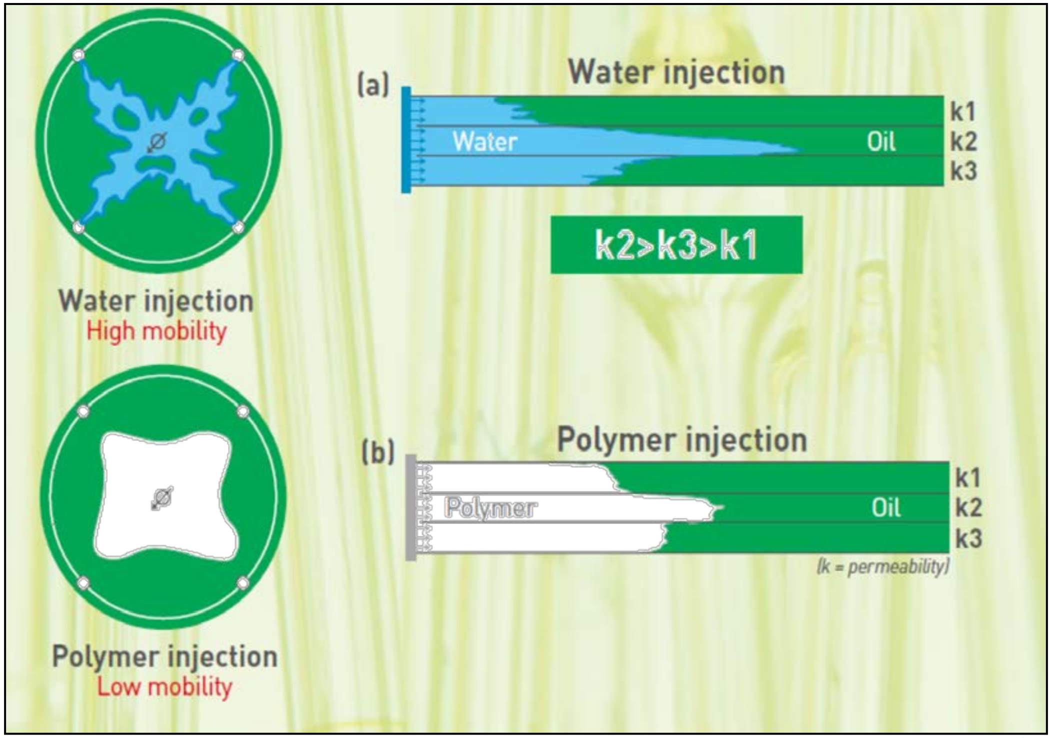
Principles of Miscible Gas

- Gas injection under miscible conditions
- Transfer C3+ from gas phase to oil phase
- Causes the oil to lighten and swell
- Through fluid expansion, enhance lighter oil recovery
- Requires fine PVT tuning and laboratory experiments (PVT analyses, slim tube experiments)

Chemical Methods

- Polymer Flooding
  - Increases μ_w 2-20 times
  - Decreases $M_{w/o}$

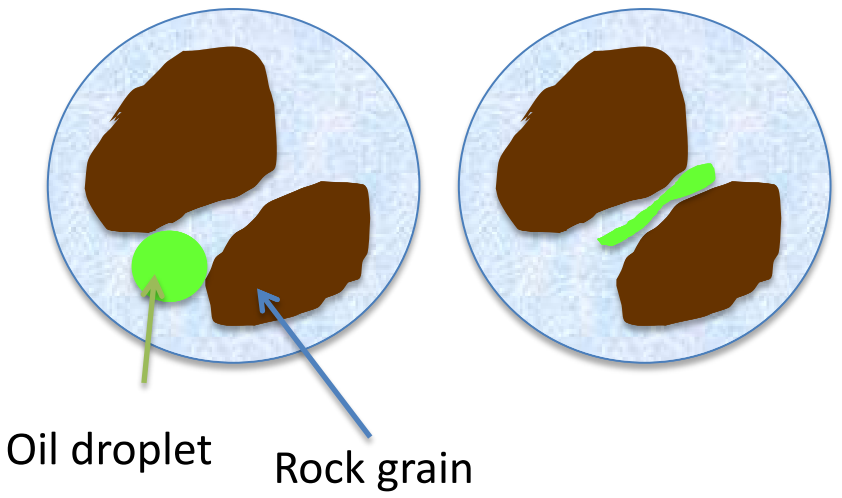
$$M_{w/o} = \frac{K_{rw} \times \mu_o}{\mu_w \times K_{ro}}$$



Chemical Methods

- Surfactant Flooding
  - used to reduce interfacial tension between oil & water to increase microscopic recovery
    - Decreases S_{or}
    - Increases E_m

$$E_m = \frac{1 - S_{wi} - S_{or}}{1 - S_{wi}}$$



Surfactant decreases residual oil saturation

Criteria for EOR selection

- Largest OOIP or Largest Remaining Reserves
- Recovery Factor < 60% for light oils (40+ ^{o}API) , < 30% heavy oil (< 30 ^{o}API)
- Additional barrel from EOR at affordable total cost (< 30 $ limit, preferably < 15$)
- Majority of Pakistani fields with light oil, suitable for miscible gas injection
- Some fields with 30 ^{o}API oil, suitable for Chemical EOR

Additional Criteria for EOR Selection

- Fluid properties
- Reservoir properties
- Geological settings
- Drive mechanism
- Production status

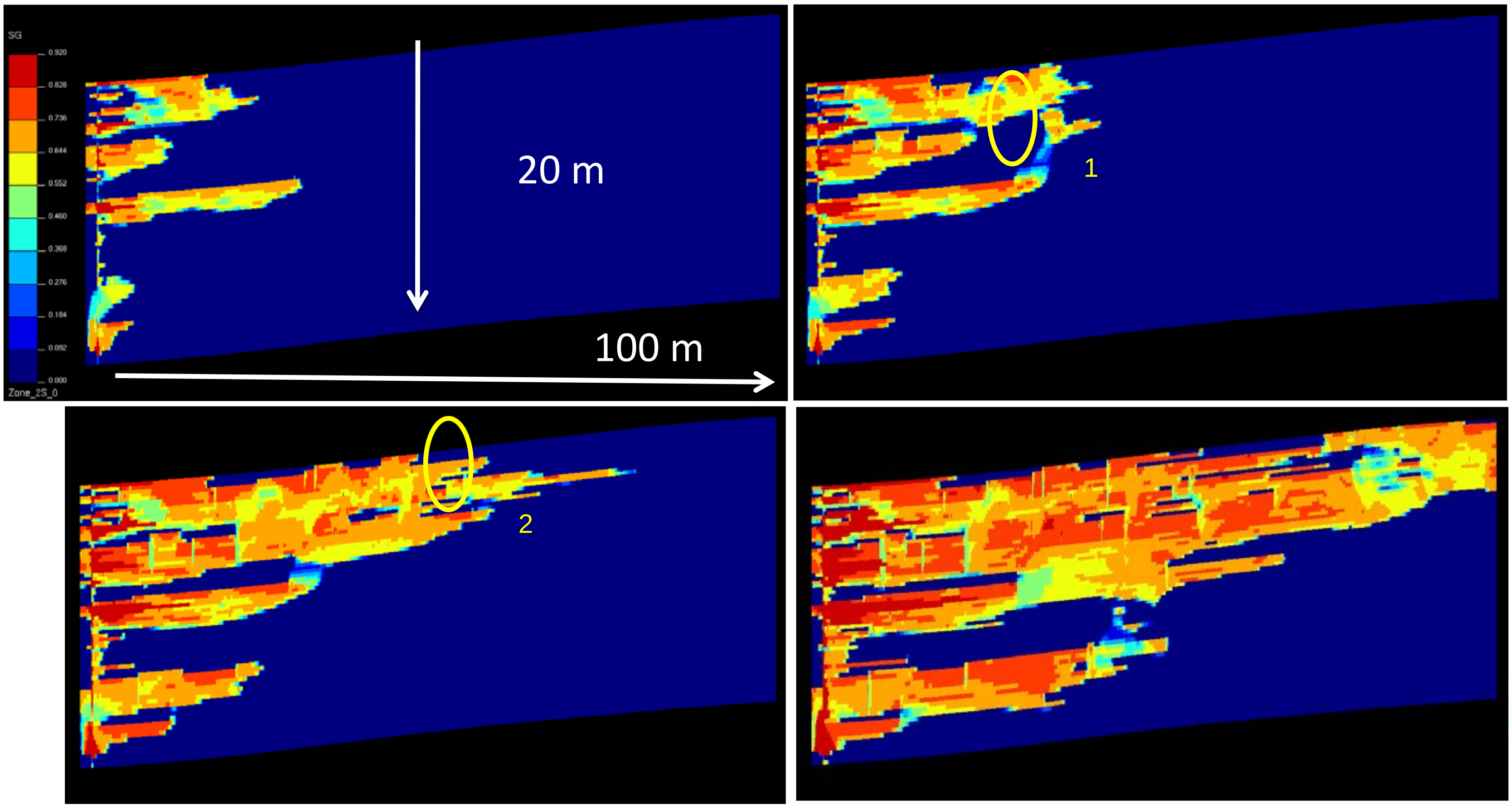
Parameter Name	Documented
Gravity (°API)	☑
Viscosity (cp)	☑
Composition	☑
Oil saturation at start of EOR (%PV)	☑
Formation and Porosity	☑
Net Thickness (ft)	☑
Permeability (mD)	☑
Depth (ft)	☑
Temperature (°F)	☑
Water Salinity (ppm)	☑
Water Hardness (g/l Ca+Mg)	☑
Clay Content	☑
Dip	☑
Vertical Heterogeneity	☑
Horizontal Heterogeneity	☑
Fracturation	☑
Gas Cap Extension	☑
Gravity Drainage	☑
Active Water Drive	☑

Hassi Messaoud Miscible Gas Injection

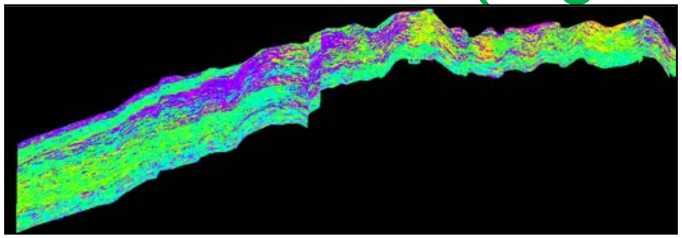
- Sandstone reservoir
  - Cambrian age
  - Low perm (average 8 mD, a lot of oil in less than 1 mD) with high permeability features (fracture corridors or high permeability streaks)
  - Thick and flat reservoir
- Light oil
  - 45 ^{o}API, 0.4 cP
  - MMP with associated gas : between 3200 and 3900 psia

Light Oil Analogue: Hassi Messaoud (Algeria)

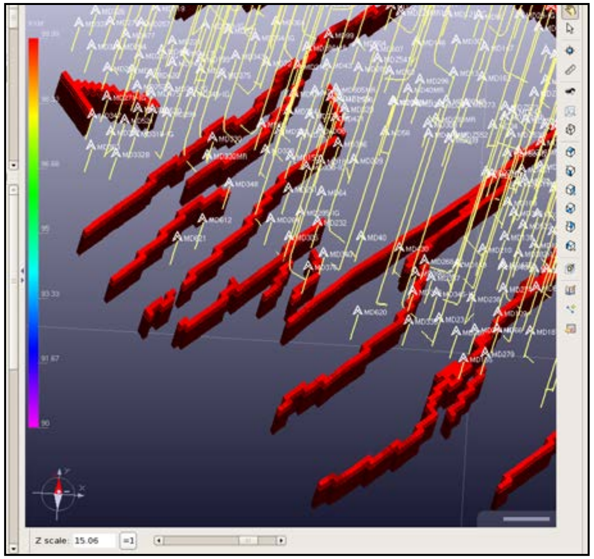
- Detailed mechanistic simulations to understand gas flood

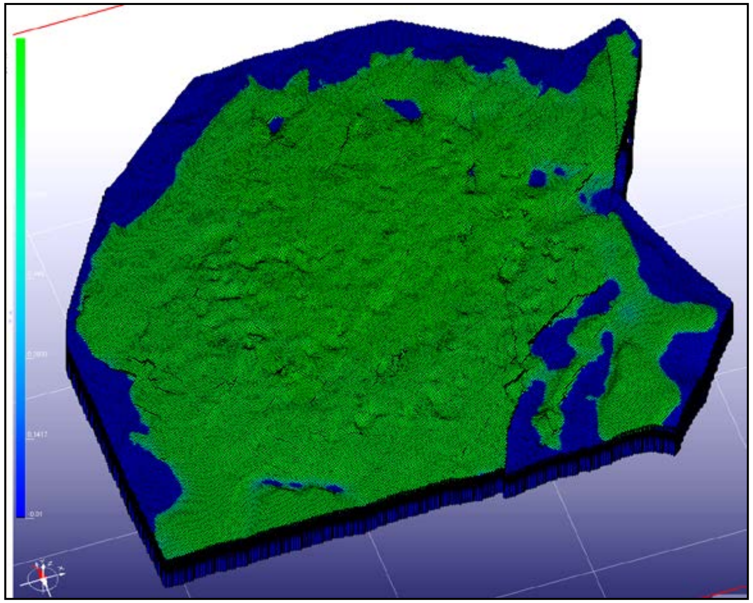


Light Oil Analogue: Hassi Messaoud (Algeria)



- Full field modeling
  - Modified black-oil
  - Influence of pressure in IFT (interfacial tension)
  - Modification of Kr-Pc curves with IFT (Transition Immiscible → Miscible); calibration with mechanistic simulations
  - Dual porosity, dual permeability to represent fracture corridors
- Model size : 2.1 millions active cells





Hassi Messaoud Gas reinjection

- Allows to obtain:
  - Pressure maintenance
  - Conservation of resources (produced gas)
  - Incremental oil production due to dynamic miscibility
  - Improved reservoir management (additional barrel < 15 US$)

Chemical EOR analogues

- Light oil Triassic reservoir: Middle East, low K < 30 mD
  - Surfactant polymer formulation can decrease interfacial tension
  - Recovery in lab: > 60% of remaining oil
- Medium oils:
  - Oman field cases: Polymer injection under industrial scale (RF +10% additional)

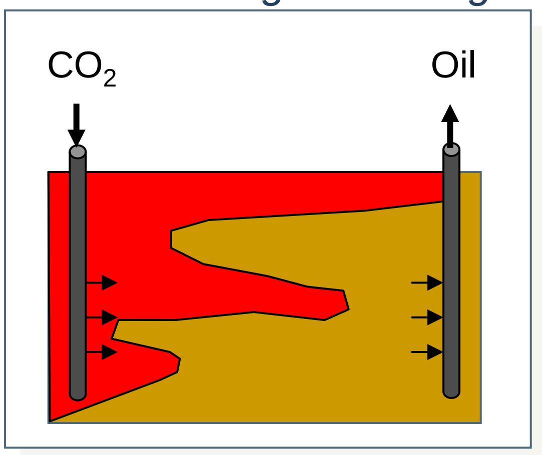
New Techniques: Foam for EOR

- Foam is a surfactant under "near gaseous " solution
- Foam decreases gas mobility and can decrease superficial tension
- Foam can combine the effect of miscible gas and chemical EOR
- Gas injection rates can be optimized

Gas Injection; WAG & Foam

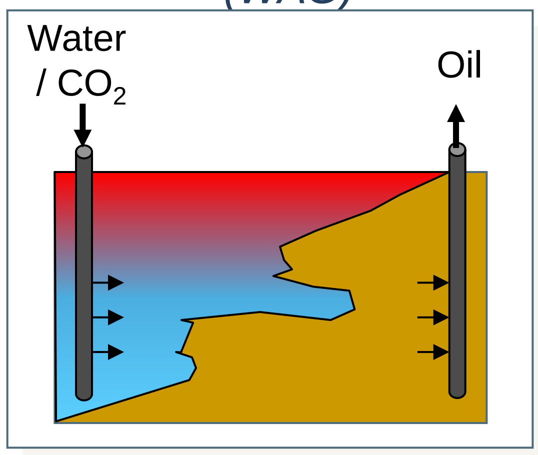
- CO_2 miscible
- N_2 (combined with Fractured medium)
- HC gas
- Foam for Mobility control

Continuous gas flooding



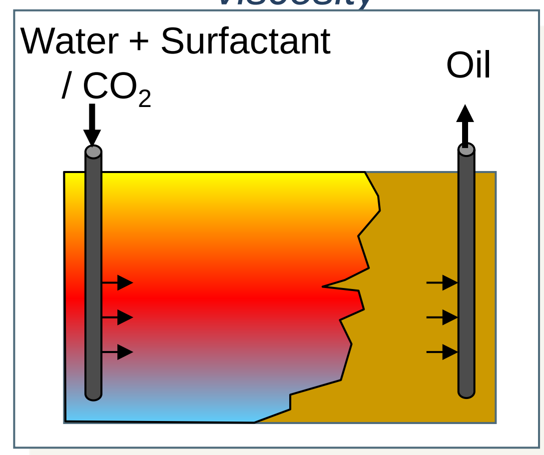
- Viscous fingering
- Gravity segregation

Water Alternating Gas (WAG)



- Reduced viscous fingering
- No effect on gravity segregation

Foam-enhanced WAG – higher apparent gas viscosity



- Further reduction of viscous fingering
- Reduction of gravity segregation

Conclusions

- Pakistani fields have significant potential for EOR applications
- Suitable EOR methods include Miscible Gas injection and Chemical (Surfactants and Polymers)
- Foam injection is a new alternative
- Further screening and prefeasibility of EOR is recommended before entering into an EOR project