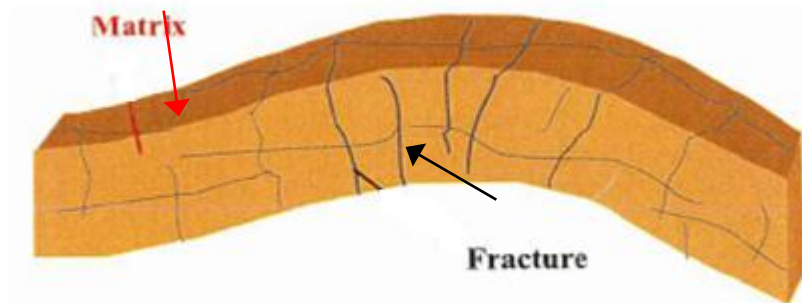# Water Injection in Fractured Reservoirs

**Hassan Karimaie**

Department of Petroleum Engineering and Applied Geophysics
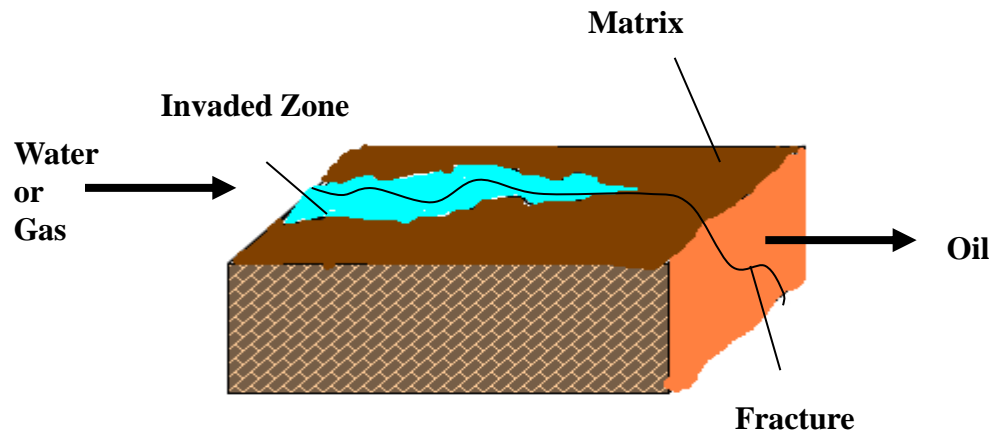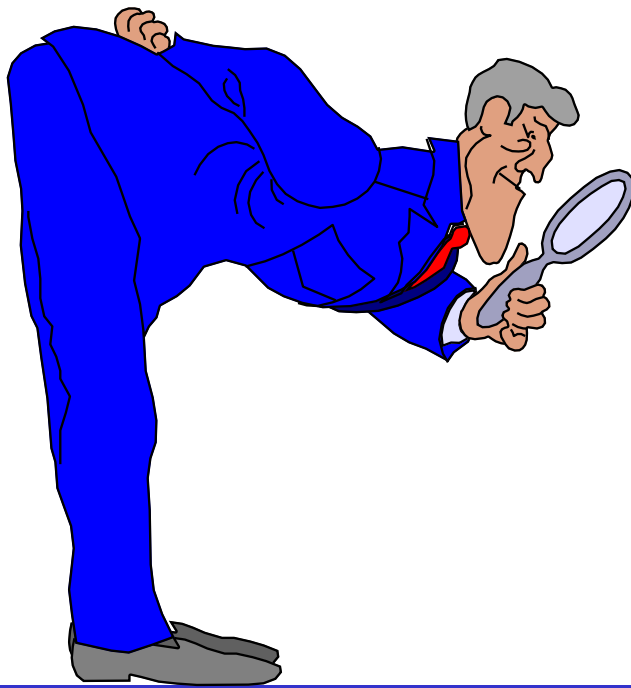NTNU

26-Oct-15

1

# Outline:

- ➢ Background
  - ✓ Matrix / fracture system in fractured reservoirs
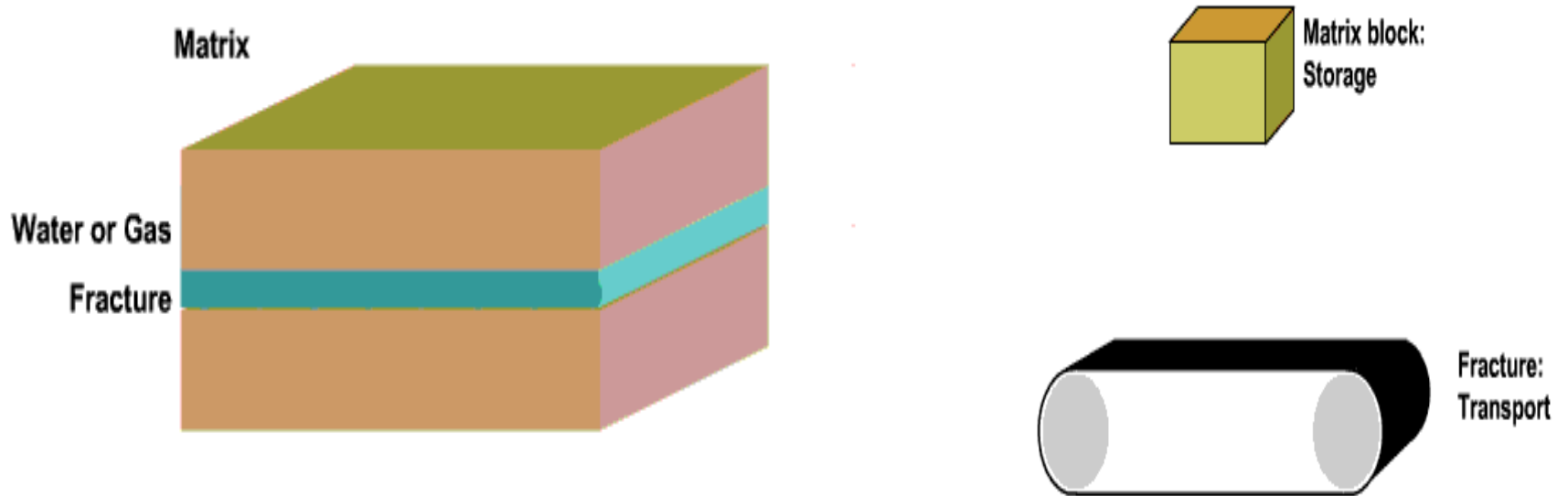- ➢ Water injection in NFR
  - ➢ Normal procedure in industry: Immersion test or Amott test
  - ➢ Water rising in the fracture or Immersion?
  - ➢ Cocurrent and Counter current imbibition
  - ➢ Experiments
  - ➢ Results and discussion
  - ➢ Conclusion
  - ➢ References

26-Oct-15

# Background
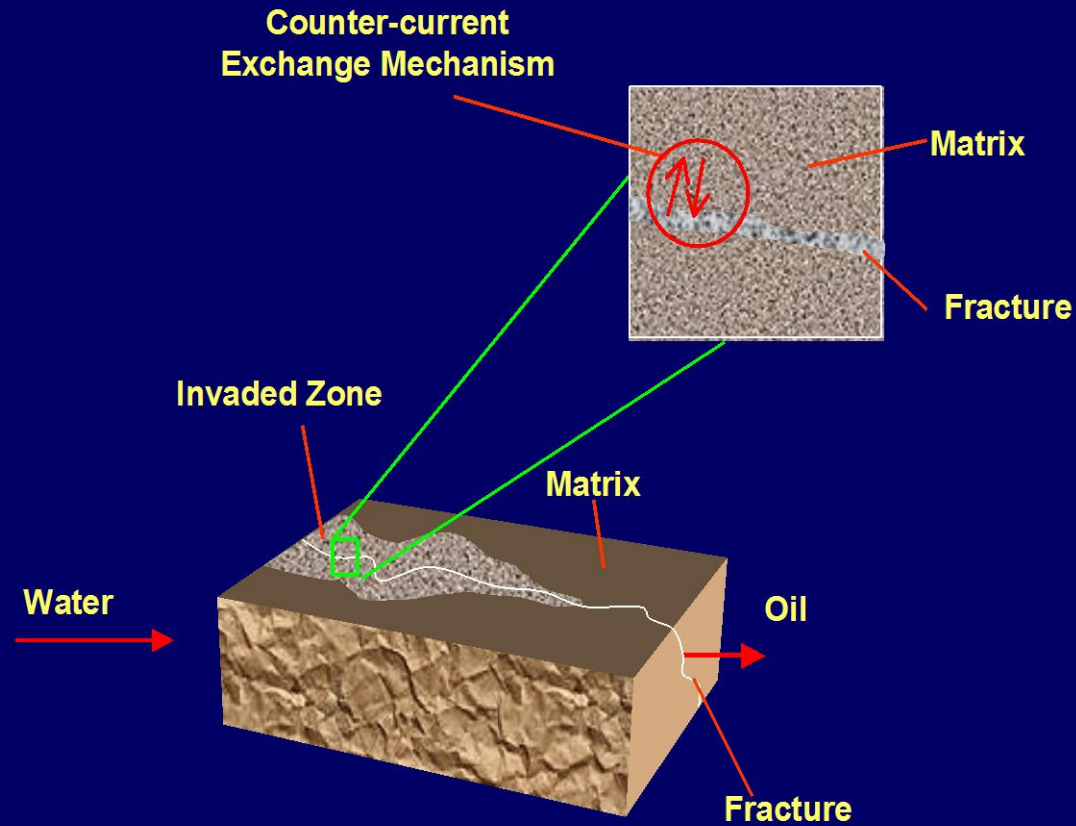
➢ Unique feature of NFR:

✓ Early breakthrough of injected fluid

✓ More uniform fluid composition
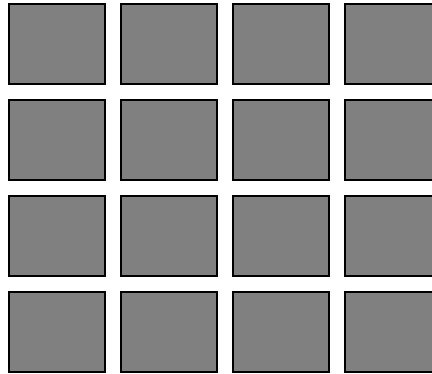
✓ Small pressure drop

✓ Absence of transition zone

**Water or Gas**

**Invaded Zone**

**Matrix**

**Oil**

**Fracture**

26-Oct-15

# Analogue model

Matrix

Water or Gas

Fracture

Matrix block: Storage

Fracture: Transport

# Concept of Dynamic Imbibition Process
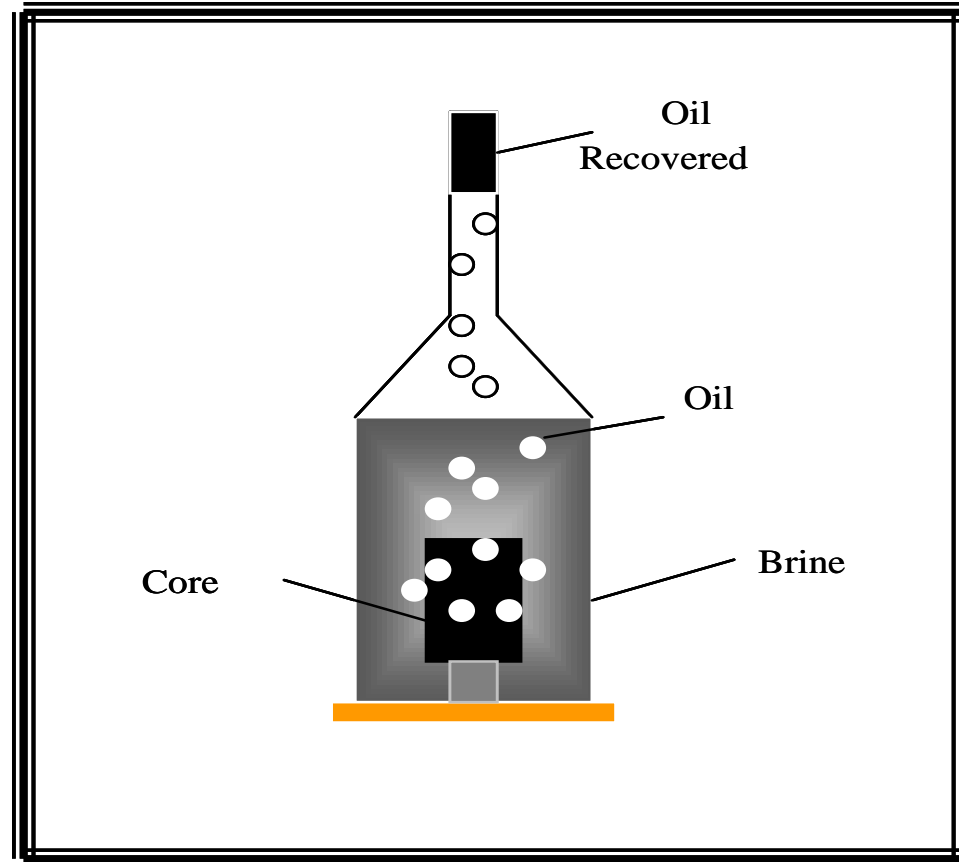
# Problem Definition



Idealization of fractured porous media
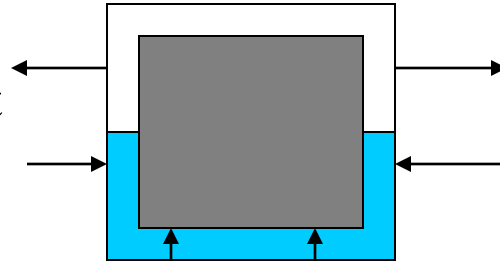
Warren & Root model

# Laboratory experiment:
## Is immesrion test or Amott test the right experiment for NFR?
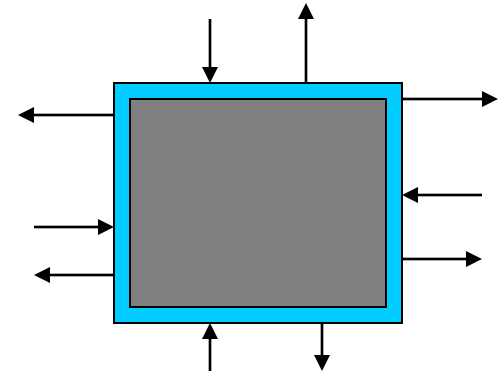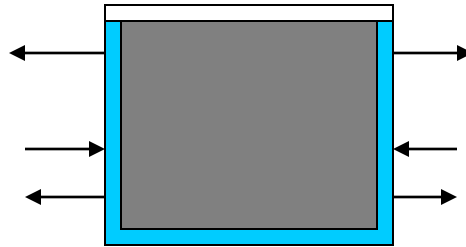


Oven

Oil Recovered

Oil

Core

Brine

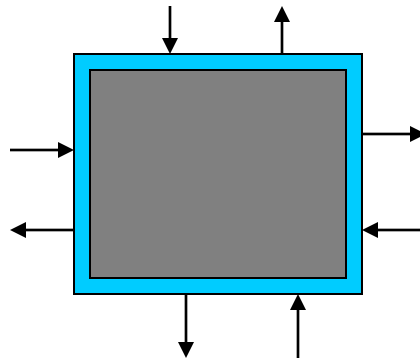26-Oct-15

# Visual Observation (Single Block)

•Low rate, No Counter-Current

•High rate, Co-Current

•And Counter-current

•Very High Rate

•Counter Current

# Cocurrent and counter current imibibition

1-Counter-Current Imbibition:
Water and oil flow through the same faces in opposite directions

**Nonlinear Diffusion Eq.:**

$$\frac{\partial}{\partial x}\left(D(S_w)\frac{\partial S_w}{\partial x}\right) = \frac{\partial S_w}{\partial t} \qquad (1)$$
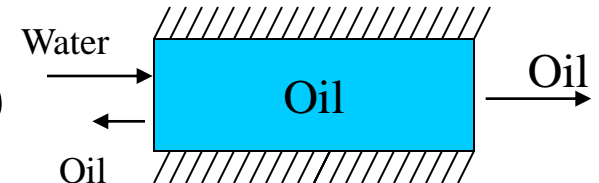
2-Co-Current Imbibition:
Water and oil flow through the opposite faces in the same direction.

**Nonlinear Convection- Diffusion Eq.:**

$$\frac{\partial}{\partial x}\left(D(S_w)\frac{\partial S_w}{\partial x} - q_t f(S_w)\right) = \frac{\partial S_w}{\partial t} \qquad (2)$$
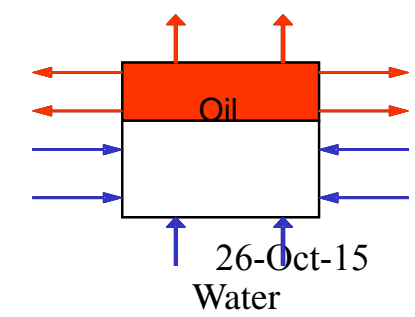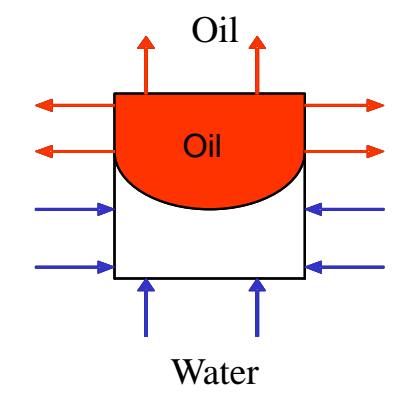
26-Oct-15
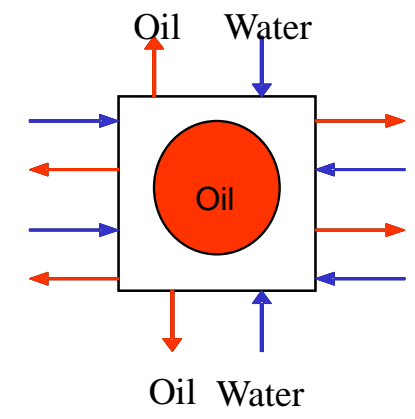
# Capillary-Gravity ratio
# (Schechter *et al*. 1994)

$$N_B^{-1} = C\frac{\sigma\sqrt{\phi/k}}{\Delta\rho g H}$$

➢ When

✓ $N_B^{-1} > 5$  Capillary forces are dominant
Counter-current flow

✓ $0.2 < N_B^{-1} < 5$ Both capillary and gravity forces
Co- and counter-current flow

✓ $N_B^{-1} << 1$  Gravity forces are Dominant
Co-current flow
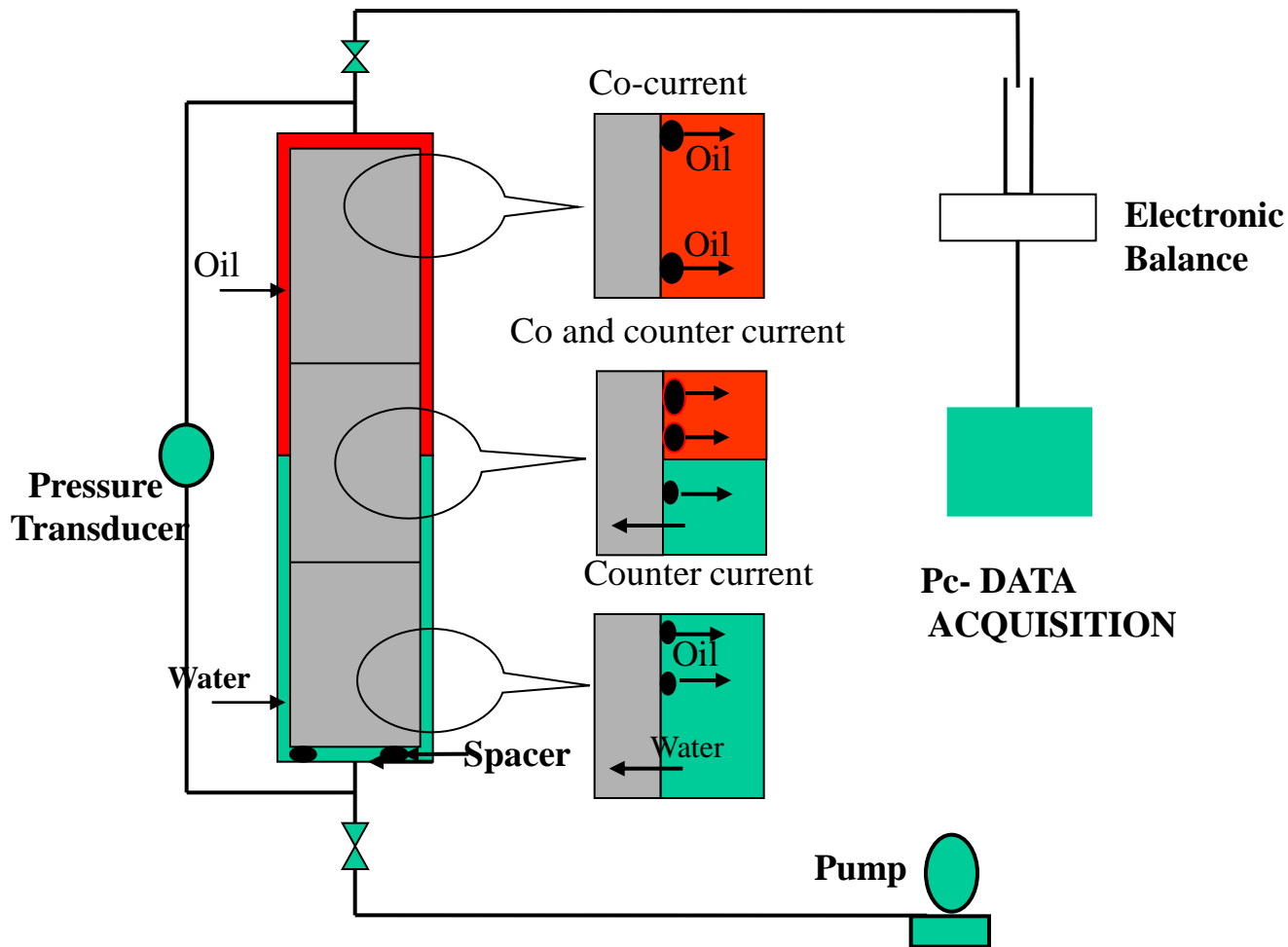
$C = 0{,}4$ for capillary tube model

26-Oct-15

# Water injection in fractured media

|  | Water wet sample (Bentheimer sandstone) | Non-water-wet sample (Limestone outcrop-Asmari,Iran) |
|---|---|---|
| Length (cm) | 116 | 116 (stack of blocks) |
| Diameter (cm) | 3.8 | 6.25 |
| Permeability (md) | 1400 | 0.5-1 |
| Porosity % | 23 | 15 |
| Fluid system | Kerosene-brine | n-decane-brine |

# Methodology: Experimental Set-up
## rising water level



Co-current and counter-curret imbibition test

# Methodology: Experimental Set-up
## (immersion)



**Oil**

**Brine**

Counter current

Oil

Water

Oil

Oil

Oil

**Screw**

**Spacer**
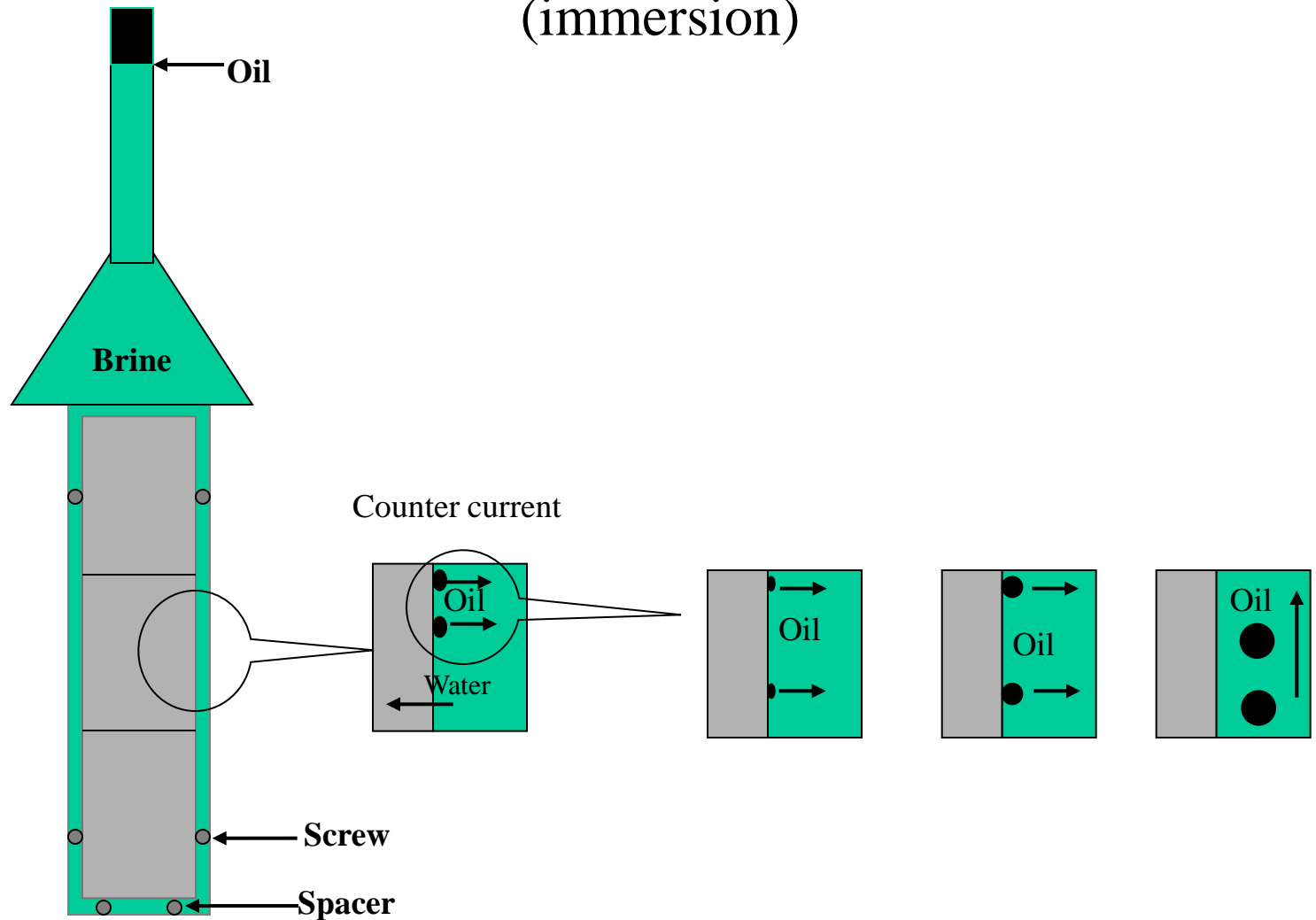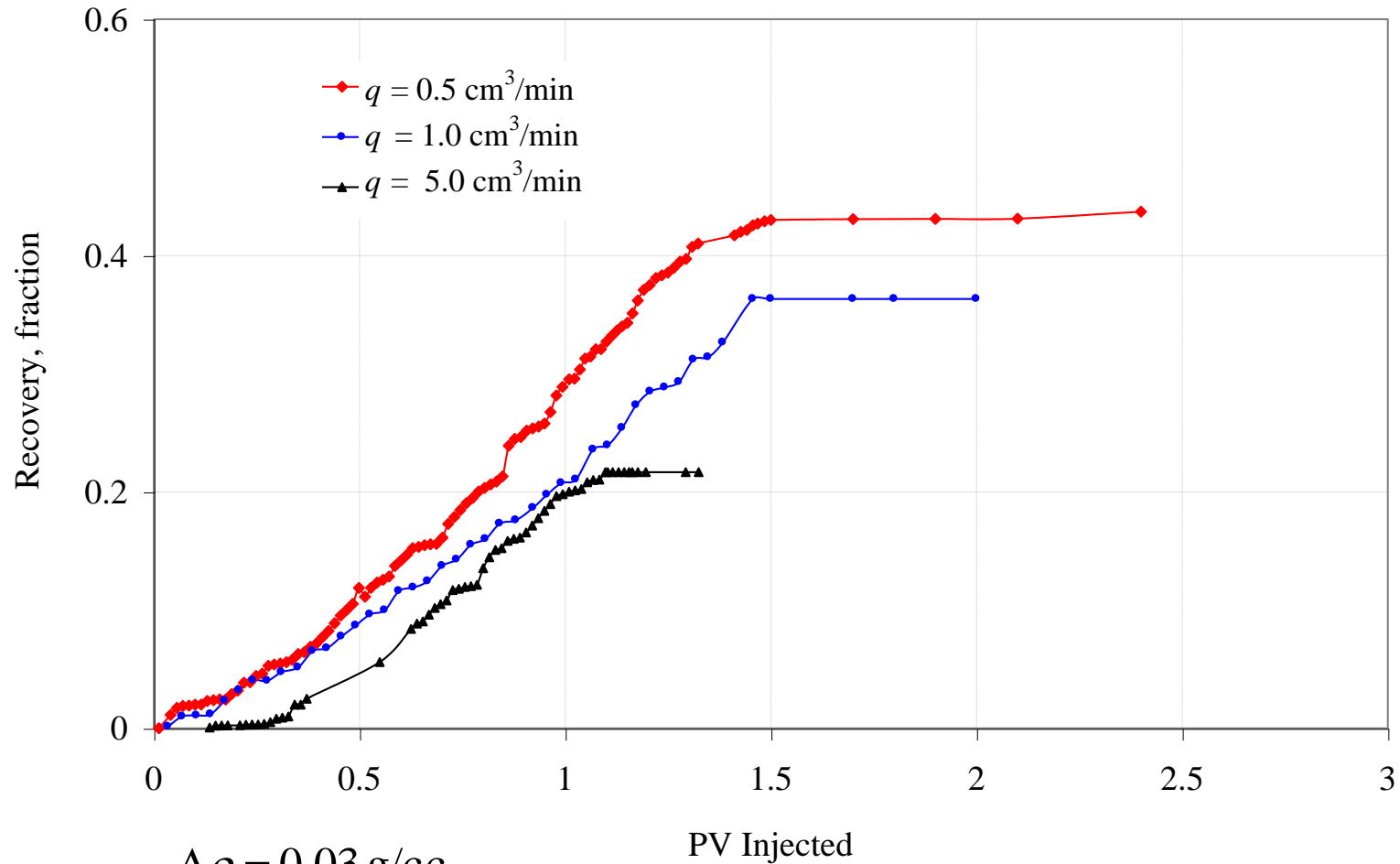
Counter-currentTest

26-Oct-15

# Results: water-wet sample



$$\Delta\rho = 0.22 \, \text{g/cc}$$

$$N_B^{-1} = 2.6$$

26-Oct-15
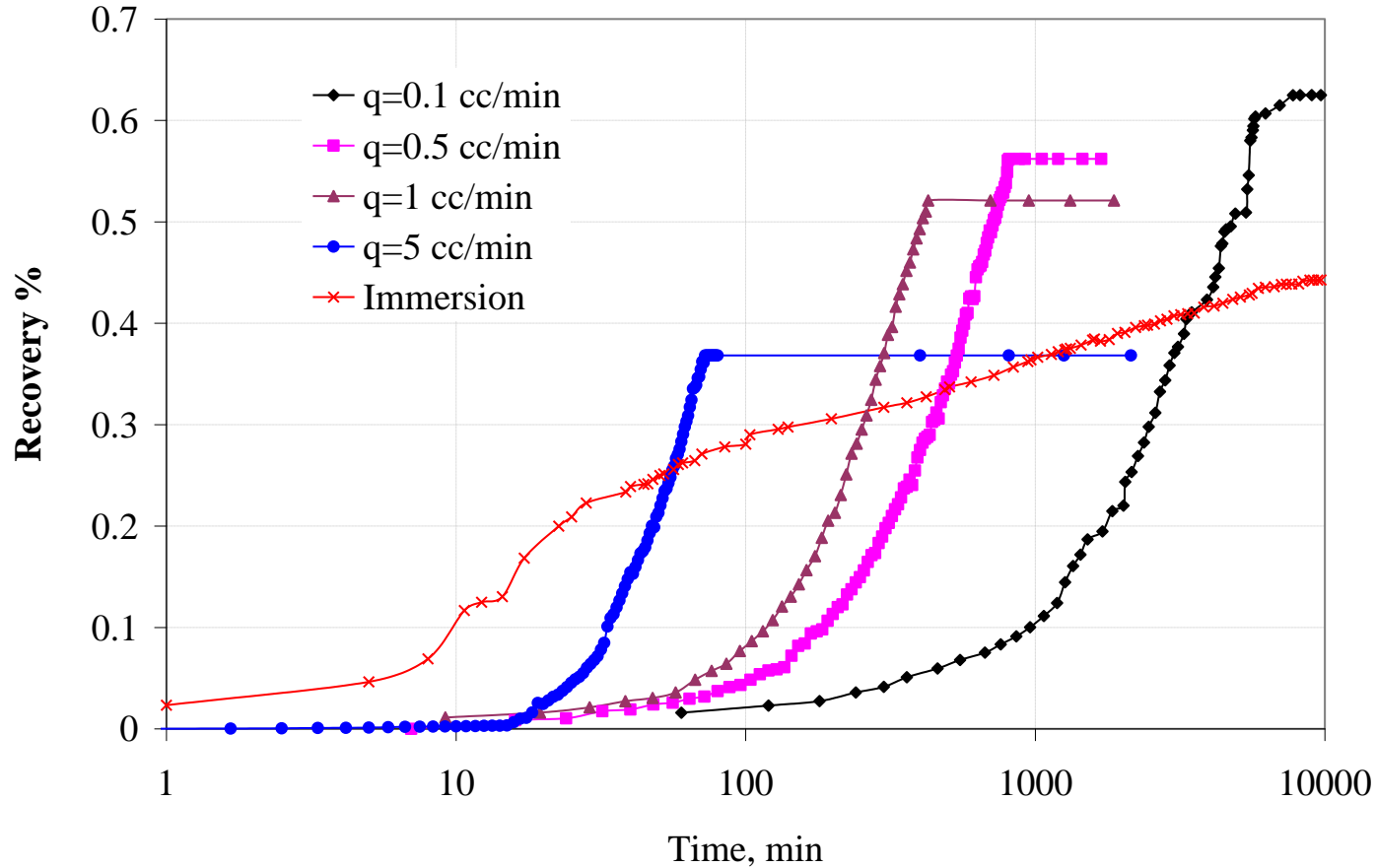
# Results: water-wet sample



$\Delta\rho = 0.03 \, \text{g/cc}$

$N_B^{-1} = 31.8$

26-Oct-15

15

# Results: water-wet sample

26-Oct-15
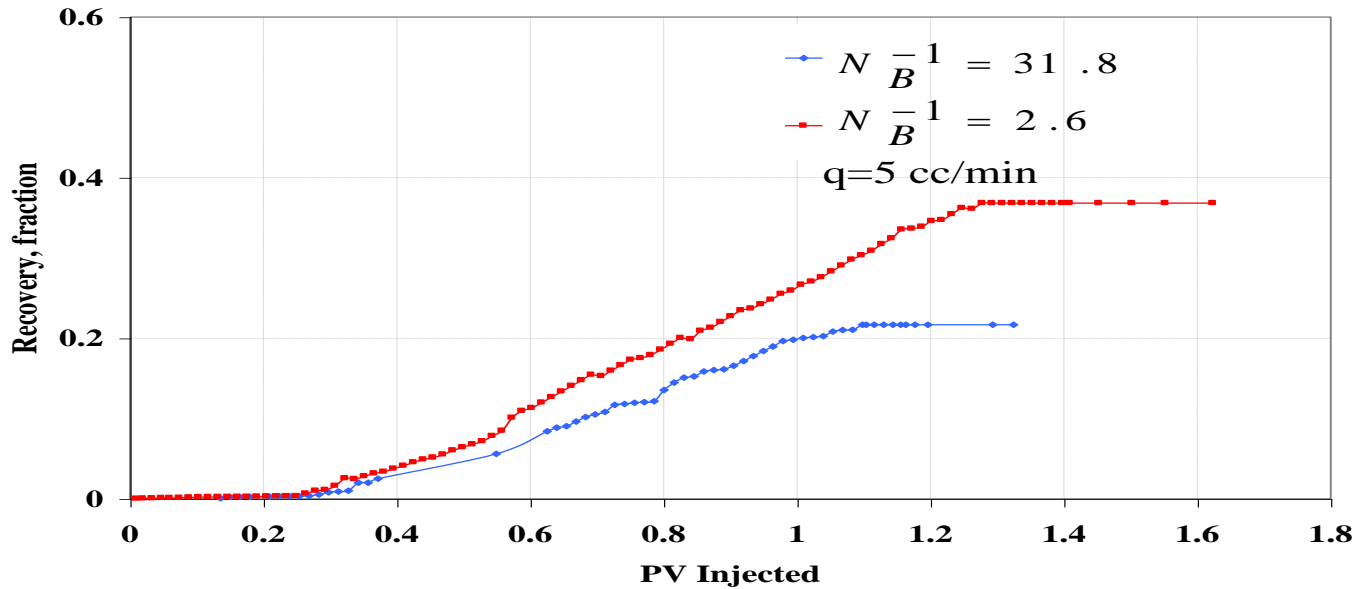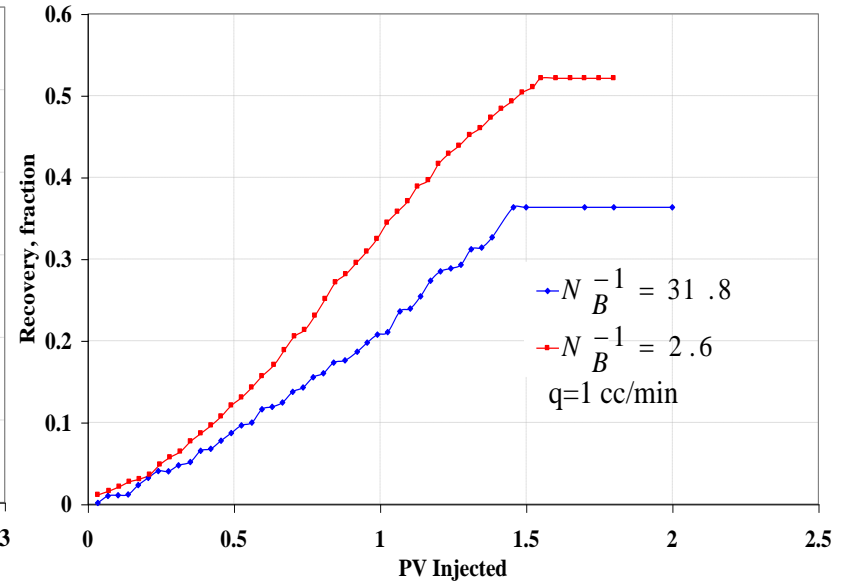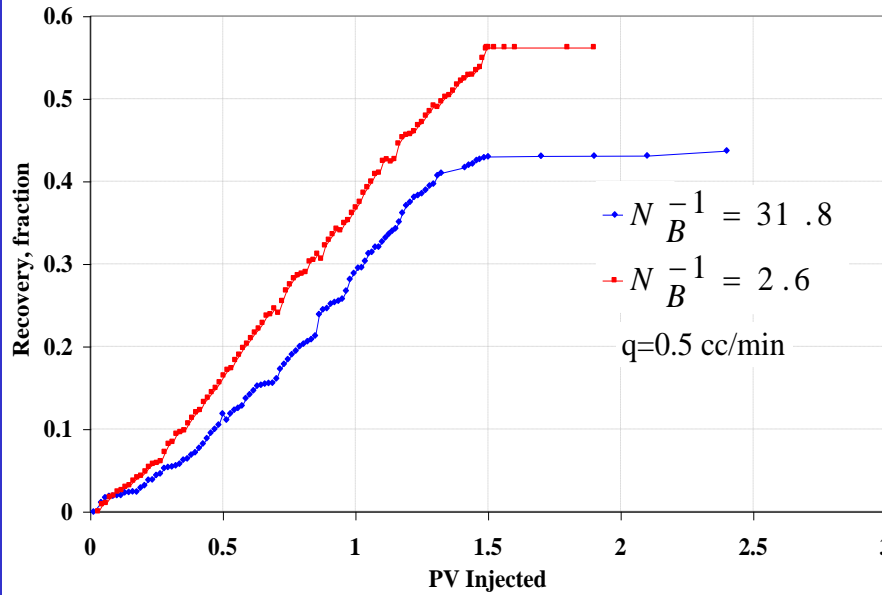
# Conclusion

- ✓ Oil recovery due to water injection is highly influenced by gravity.

- ✓ Co current and counter current flow may occur in NFR depends on injecion rate, matrix block height, porosity, permeability, density difference and interfacial tension.

- ✓ Depending on injection rate, co-current flow may be more efficient than counter-current flow.

- ✓ Bond number is an important dimensionless number for characterising co.current and counter-current flow.

26-Oct-15

# References:

- **H. Karimaie**. "Aspects of Water and Gas Injection in Fractured Reservoirs". Thesis for the degree of philosophiae doctor at NTNU. December 2007. ISBN 978-82-471-5532-5, ISSN: 1503-818.

- **H.Karimaie**, O. Torsæter, M.R.Esfahani, M. Dadashpour and S.M. Hashemi."Experimental Investigation of Oil Recovery during Water Imbibition". Journal of Petroleum Science and Engineering (JPSE) 52 (2006) 297-304.

- **H.Karimaie** and O.Torsæter. "Effect of Injection Rate, Initial Water Saturation and Gravity on Water Injection in Slightly Water-Wet Fractured Porous Media". Journal of Petroleum Science and Engineering (JPSE) 58 (2007) 2937-308.

- Pooladi-Darvish, M and Firoozabadi. A. "Experiments and Modeling of Water Injection in Water-Wet Fractured Porous Media". JCPT volume 39, No.3. 2000 (March).

26-Oct-15