Sleipner Fluid Dynamics*
(Fluid Dynamics of the Hydrostatic Offshore Conditions at the Sleipner Site [Buoyant Behavior of CO₂])

Bert van der Meer¹

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¹Senior reservoir Engineer, TNO Built Environment and Geosciences, Princetonlaan 6, 3508 TA Utrecht - The Netherlands (Bert.vanderMeer@tno.nl)

Key Point

The pressure gradients are the main driving force for CO₂ migration under hydrostatic, and therefore buoyant, conditions.

References


Utsira Sandstone Order of Magnitude

Total surface 26,000 km²
Sleipner Site

Courtesy StatoilHydro

Golden, Tuesday, Aug. 10, 2010
Introduction (Sleipner)

**Basic Data**

- Aquifer
- shallow (800 m SS)
- Thickness 200-250 m
- Temperature ~40 °C
- Hydrostatic (80 bar)
- High permeable (D)
- Extremely large (26,000 Km²)
- Restricted test site
- Injection ~ 1Mt/y so far ~11 Mt
- Injection on temperature control
Sleipner 4D seismic monitoring

Top reservoir

1 km

1994

1999

2001

Injection point

 Courtesy CO2STORE Project
Seismic monitoring (4-D)

2001  2004  2006
Basic Rule - RE - pressure distribution

- The pressure in any part of the subsurface is equal to the weight of the overburden column.
Basic Rule - RE - pressure distribution

- The pressure in any part of the subsurface is equal to the weight of the overburden column.
Pressure Status

• Result: Hydrostatic in the whole formation

Vertical Equilibrium
Carbon Dioxide

- Density

![Graph showing CO2 density in kg/m³ vs. pressure in bar]

- **Critical Point:**
  - Pressure: 73.773 bar
  - Temperature: 30.98 °C
  - Density: 467.6 kg/m³

- **Triple Point:**
  - Pressure: 5.18 bar
  - Temperature: -58.56 °C
  - Density: 1178.5 kg/m³

- **Reference:**
  - NIST generated data, based upon:
Carbon Dioxide

- Critical phases and density

**CO₂ density**

- **Triple point:**
  - -56.6 °C
  - 5.18 bar
  - 1135.8 kg/m³

- **Critical point:**
  - 73.8 bar
  - 30.98 °C
  - 467.6 kg/m³

- **CO₂ density**
  - [1 bar, 0 °C] = 1.9783 [kg/m³]
  - [1 atm, 15 °C] = 1.8684 [kg/m³]

**Phases:**

- **Liquid phase**
  - T < 30.98 °C

- **Liquid - vapor phase**
  - Temperature lower

- **Vapor phase**
  - Temperature higher

- **Supercritical fluid phase**
  - P > 73.8 bar
  - T > 30.98 °C

**Graph:**

- CO₂ density in kg/m³
- Temperature lower
- Temperature higher

**Axes:**
- Pressure in bar
- CO₂ density in kg/m³
Carbon Dioxide

- Solubility in water


<table>
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<th>water salinity in NaCl percentage</th>
<th>solubility fraction compared with pure water</th>
<th>standard deviation due to P-T-variation</th>
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Reduction of solubility of CO₂ into saline water
Archimedes principle

- Buoyancy = weight of displaced fluid

\[ F_d = 500 \text{ Kg/m}^3 \times 1 \text{ m}^3 \]

Resulting UPWARDS force is 500 kg

\[ F_u = 1000 \text{ Kg/m}^3 \times 1 \text{ m}^3 \]
Archimedes principle

- Total effect =

Gravity segregation

Natural Gas

CO2

Oil

Water
Carbon Dioxide

(from: IPCC, 2005: Special Report on Carbon Dioxide Capture and Storage.)
Carbon Dioxide in Sleipner

- Store deeper than 800 m (>80 bar, ~35 °C, Density ~700 Kg/m³)
- CO₂ super-critical (as a gas with a liquid density)
- Lighter than formation water (strong buoyancy forces)
  - Sleipner clearly upwards movement of CO₂
- CO₂ soluble in water
- Water soluble in CO₂
Sleipner CO₂ Storage Result

- Plume of free CO₂
- Contours of estimated CO₂ solubility

Time = 1827.00000 days
Questions