Reservoir Drive Mechanisms Review

Spectrum of Reservoir Energies

Primary Production (internal energies)
- Pressure Depletion (Fluid Expansion, PV compaction) – Case Study Gloyd Mitchell
- Water Encroachment – Case Study Wilcox
- Gas Cap Expansion (Oil Reservoirs Only) – Problem Gas Cap Expansion – Section 5
- Gravity Drainage (Oil Reservoirs Only)

Improved Recovery (Secondary Depletion)

Water Injection (Pressure Maintenance/Waterflood)
- Gas Injection (Pressure Maintenance/Gasflood)
- “Cheap” Fluids

External Energies (Added – Injection)

Miscible Hydrocarbon/CO₂ Injection
- Chemical
- Thermal
- “Expensive” Fluids

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Material Balance – IT’S THE LAW!

- **Gas Cap**
  - Original Oil Volume
- **Aquifer**
- Reservoir Contents at Initial Reservoir Conditions

Production /Injection

- **Gas Cap**
  - Gas Expansion
  - Remaining Oil Volume
- **Aquifer**
- Water Influx

Reservoir Contents after Some Production

Recovery Factor – Drive Mechanism is key!

- **Up**
  - Producing Well
  - Cap Rock
  - Non-Reservoir Rock

What is *driving* the hydrocarbon fluids towards the well?
Recovery Factor – How Much Can We Get to Surface?

Water Drive Reservoir with Gas Cap

Water drives may or may not be sufficient to maintain reservoir pressure above "bubble point" (the pressure below which gas breaks out of solution).

When water drives cannot keep up with production, they are called "partial water drives".

The relative rates of water drive, reservoir fluid production and gas cap expansion affect ultimate recovery of hydrocarbons.
**Recovery Factor – How Much Can We get to Surface?**

*Solution Gas* Drive (also known as *Depletion Drive* or *Pressure Depletion*)

Hydrocarbons become gaseous as the pressure in the reservoir depletes due to production (i.e. removal of hydrocarbons by well)

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**Solution Gas Drive Reservoir Above Bubble Point Pressure**

Producing Wells
Solution Gas Drive Reservoir Below Bubble Point Pressure

Producing Wells

Gas Breaking out in Reservoir

Gas Cap Drive Reservoir

Crestal Well will "gas out", and either be abandoned or converted to "gas injector" or "gas producer with reservoir ultimately "blown down"."
Economic limit reached when reservoir pressure falls below level needed to move gas through surface facilities into a pipeline.

Compression is an alternative when economically feasible. Water injection may have a higher incremental recovery than compression and may be more economically feasible.

Incremental Recovery from Waterflooding vs. Compression:

Depletion → Waterflooding → Compression → G = OGIP

\[ \frac{P}{z} \]

\[ \Delta G_p \]

\[ G_p \]
**Economics**

NPV_{Waterflooding Reserves} > NPV_{Compression}

1. Compressor requires significant capital investment and complicated compressor design and unloading of wells
2. Injecting of water is not a major cost component and could be eliminated altogether by downhole commingling of a high pressure large aquifer with the depleted gas reservoir

**Waterflooding Recovery**

Determined by displacement efficiency:

\[ E_D = \frac{S_w - S_g}{S_g} \]

Where:

- \( S_w \) = gas saturation at start of waterflood
- \( S_g \) = bypassed gas saturation

- Typical bypassed gas saturations 30–35%
- Typical recovery factors around 60%
Duck Lake D-1 Reservoir

- Water Injected for 10 years
- Increased Recovery by 25 Bscf or 3.6% of OGIP

Range of Recovery Factors – RULES OF THUMB!
Conventional Reservoirs

<table>
<thead>
<tr>
<th>Gas Reservoirs</th>
<th>% OGIP</th>
<th>Key Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Permeability, Volumetric</td>
<td>70–90%</td>
<td>Abandonment pressure</td>
</tr>
<tr>
<td>Low Permeability, Volumetric</td>
<td>40–60%</td>
<td>Well spacing</td>
</tr>
<tr>
<td>Water Drive</td>
<td>50–70%</td>
<td>Aquifer strength; Producing rate</td>
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<table>
<thead>
<tr>
<th>Gas Condensate Reservoirs</th>
<th>% OGIP</th>
<th>% STOIP</th>
<th>Key Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Depletion</td>
<td>70–90%</td>
<td>30–70%</td>
<td>Condensate yield; API gravity</td>
</tr>
<tr>
<td>Water Drive</td>
<td>50–70%</td>
<td>40–65%</td>
<td>Aquifer strength; Producing rate</td>
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Note: Recovery can be referred to in various ways. The term “estimated ultimate recovery” (EUR) is often used to describe the ultimate amount of resource to be economically produced from the reservoir available to a specific well or for a field.
Range of Recovery Efficiencies – Conventional Reservoirs

<table>
<thead>
<tr>
<th>Oil Reserves</th>
<th>% STOIPP</th>
<th>Key Variables</th>
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</thead>
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<tr>
<td>Undersaturated Expansion</td>
<td>3–5%</td>
<td>Cf; solution GOR</td>
</tr>
<tr>
<td>Solution Gas Drive</td>
<td>10–17%</td>
<td>Gas-oil Kr; solution GOR</td>
</tr>
<tr>
<td>Water Drive</td>
<td>40–60%</td>
<td>Aquifer strength; water-oil mobility ratio; Sorw</td>
</tr>
<tr>
<td>Gas Cap Expansion</td>
<td>40–60%</td>
<td>Gas cap / Oil Zone ratio; Gas-oil Kr; Sorg</td>
</tr>
<tr>
<td>Gravity Drainage</td>
<td>60+%</td>
<td>Formation dip; permeability; Sorg</td>
</tr>
<tr>
<td>Volatile Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Oil</td>
<td>17–25%</td>
<td>Solution GOR;</td>
</tr>
<tr>
<td>- Gas</td>
<td>60–80%</td>
<td></td>
</tr>
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Performance of an Undersaturated Oil Reservoir

Case Study:
The Gloyd-Mitchell Zone
Rodessa Field, Louisiana

John M. Campbell
The Gloyd-Mitchell Zone (volumetric reservoir) in Rodessa Field in Louisiana was produced under primary depletion. This figure shows the daily oil production rate, the daily gas-oil ratio, reservoir pressure, and the number of producers for this reservoir.

This figure shows the production history plotted against the cumulative oil production. Features that are typical of a depletion (solution) gas drive are annotated.
Performance of a Partial Water Drive Reservoir

Case Study: Wilcox Field
Observations and Questions

- Oil was initially under-saturated
- Pressure is partially supported by aquifer influx

Why?
- Did GOR increase during 1944 and 1945 and decrease in 1946
- Did the oil production rate decrease in 1946
- Did pressure increase in 1949 and stabilize in 1950

What would you have done to improve economics of this project?